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Advances in Construction Management

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Advances in Construction Management

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Preface

We would like to present, with great pleasure, the selected proceedings of ACMM 2021, Advances In Construction Management. This work is published in the book series Lecture Notes in Civil Engineering, and is devoted to the gamut of sustainable construction issues, from theoretical aspects to application-dependent studies and the validation of emerging sustainable construction materials.

This new book work was envisioned and founded to represent the growing needs of sustainable construction of buildings by using novel materials as an emerging and increasingly vital field. Its mission is to become a voice of the civil engineering community, addressing researchers and practitioners presenting new construction materials, findings, and solutions.

This book comprises 49 contributions, connected by a unifying theme: Advances In Construction Management. Specifically, the presented contributory articles can be categorized into the following parts:

- Architecture Management
- Town Planning
- Project Management
- Building Automation
- Analytical Case Study

Many researchers and academicians have contributed to the creation and the success of this book compilation. We are very thankful to everybody who supported the idea of creating a new LNCE contributory book subline—Sustainable Construction Materials. We are certain that this very first issue will be followed by many others, reporting new developments in the civil engineering field. This issue would not have been possible without the great support of the Editorial Board members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the LNCE editorial staff of Springer, in particular Daniel Joseph Glarance and Priya Vyas, who supported us at every stage of the work. It is

our hope that this fine collection of articles will be a valuable resource for Sustainable Construction Materials readers and will stimulate further research.

Chennai, India
July 2021

K. Gunasekaran

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Architecture Management

Planning, Analysis, and Design of Smog-Free Tower with Louvers in Kolkata

Sija Arun, Rukhsar, Utkarsh Anand, and Pathikrit Bhattacharjee

Abstract Pollution in our environment is one of the most primary issues with which everyone have been dealing with. Among all the types of pollution, pollution in air is of utmost importance. It is the leading cause of the rise of different lung diseases and various other diseases in human beings and other problems in plants and vegetation. Formation of smog plays a huge part in causing air pollution. Smog is formed due to many reasons, some of them being natural and others being man made. In order to curb this form of pollution, lot of preventive measures have been taken and introduced. So, the idea of constructing an eco-friendly smog-free tower was taken. A lot of historical places in India have been losing their beauty because of smog, affecting the white marbles, which were used to build it. In order to enhance the economic and tourist activities near to the Victoria Memorial in Kolkata constructing smog tower is an attractive solution.

Keywords Air Quality Index · Air pollution control · Smog · Smog-free tower · Particulate matter

1 Introduction

Smog is a composite mixture of harmful solid particles and gases in air [1]. The harmful particles include emission from automobiles, chemicals released from factories and other suspended particles. Bad air quality is the reason of death of a huge number of people. According to WHO (World Health Organization), 4.2 million

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people lost their lives due to decreasing quality of air worldwide, especially in second and third world countries [2–4]. Smoke forming inside the house from burning of coal, biogas and cigarette is an ongoing cause of all the major lung problems in these countries [5, 6]. Air pollution has been the leading cause of numerous health diseases from cancer to micro-cardial infection affecting over 40% of the population all over the world [7]. Although the working principle of tower is simple but it is expensive, but not as expensive as human life [8]. The need of clean air has led to a stage where in upcoming decade installing average of one tower in one metro city will be necessary [9].

2 Literature Study

2.1 Air Quality Index

The AQI is the index which is used to determine the quality of air on daily basis and is used by government agencies to tell common people the extent of pollutant present in air. The comparison of acceptable value and observed value of pollutant is shown in (Table 1) from the references [10, 11].

To calculate AIQ of the desired location, Eq. (1) is used. AIQ at Victoria Memorial was calculated as 252.

$$AIQ = \left[\frac{(PM_{obs} - PM_{min}) \times (AQI_{max} - AQI_{MIN})}{PM_{max} - PM_{min}}\right] + AQI_{min} \tag{1}$$

where;
PM_{obs} = Observed 24-h average concentration in μg/m^3.
PM_{max} = Maximum concentration of AQI color category that contains PM_{obs}.
PM_{min} = Minimum concentration of AQI color category that contains PM_{obs}.
AQI_{max} = Maximum AQI value for color category that corresponds to PM_{obs}.

Table 1 Comparison of acceptable value and observed value of pollutants

Pollutants in smog	Acceptable value of pollutant in atmosphere (μg/m^3)	Observed value of pollutant in atmosphere (μg/m^3)
Particulate matters (PM) 2.5	40–60	107.6
Particulate matters (PM) 10	60–100	184.5
Carbon mono oxide	204	320
Nitrogen di oxide	4080	176.29
Ground level ozone	100–180	6.33
Sulfur di oxide	50–80	5.28

Source Central Pollution Control Board (CPCB)

Table 2 Classification of air quality index value

Air quality index value	Level of health concern	Health effects
0–50	Good	Little or no risk
50–100	Moderate	Acceptable Quality
100–150	Unhealthy for sensitive groups	General public not likely affected
150–200	Unhealthy	All may experience some effects
200–250	Very unhealthy	All may experience more serious effects
250–300	Hazardous	Emergency condition

Source Central Pollution Control Board (CPCB)

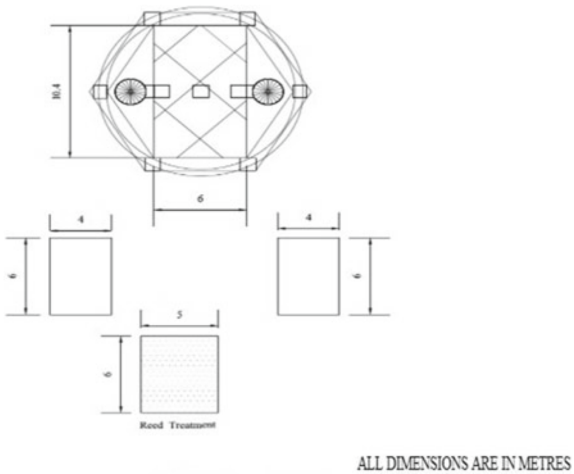
AQI_{min} = Minimum AQI value for color category that corresponds to PM_{obs}.

AQI around Victoria Memorial Hall 1, Queens Way, Kolkata, West Bengal dated on 27th January 2020 is 252 (Poor). By the reference of below Table 2, it is determined that the site has very unhealthy levels of health concerns, and the health effects that may be experienced by all age group of people have more serious effects.

2.2 *Working Principle of Smog-Free Tower*

In smog-free tower, wet scrubbers are installed inside the tower to clean the air. These scrubbers clean the air by introducing the polluted air stream with a scrubbing liquid (mostly water). Air from the environment is siphoned by the louvered sides of the tower. The air is trapped inside a wet scrubber. Wet Scrubbers are efficient air pollution control devices used for removing particles and gases from industrial exhausts smog. Wet Scrubber removes dust particles by capturing them in liquid droplets, then these pollutants are collected in the scrubbing liquid. The purified air is released from each levels of the smog-free tower through the top of the tower into air. The water used as scrubbing liquid must be treated before reusing or disposing away as it contains harmful pollutants which should be treated or else can cause harmful side effects. Reed treatment bed is used for treating the polluted water. The polluted water is allowed to pass through the bed and clean water is collected in a water tank. This treated water is used again in the scrubbers. Its efficiency depends upon the power supply provided, low energy scrubbers can collect particles larger than 5 micro-meter, while devices with more power supply can collect 1 micro-meter or less-sized particles. They are also known as absorbers, they require a good gas to liquid contact to attain higher removal efficiency.

Fig. 1 Plan of smog-free tower RCC underground water tank and reed treatment bed



3 Result and Discussion

3.1 Planning and Dimensioning of Tower and Reed Water Treatment Bed

The detailed plan with dimensions of smog-free tower and reed water treatment bed was prepared using Auto CADD software. The top view, front view and section view of the SFT are prepared. The plan of SFT, RCC UWT and RTB is shown in (Fig. 1), elevation and sectional view of SFT is shown in (Figs. 2 and 3), respectively.

3.2 Analysis

The structural analysis of SFT was done using STAAD Pro software. Various loading conditions were used to analyze the SFT which are acting on it. The analysis result was found to be safe, and the maximum shear force, bending moment and deflection are used to design the beams and columns of SFT manually (Fig. 4 and Tables 3, 4).

Different types of load acting on smog-free tower [10, 11]:

- Dead loads
- Live loads
- Seismic loads
- 1.5 × (Dead load + Live load)
- 1.2 × (Dead load + Live load + Seismic loads along X-direction)
- 1.2 × (Dead load + Live load + Seismic loads along Z-direction)

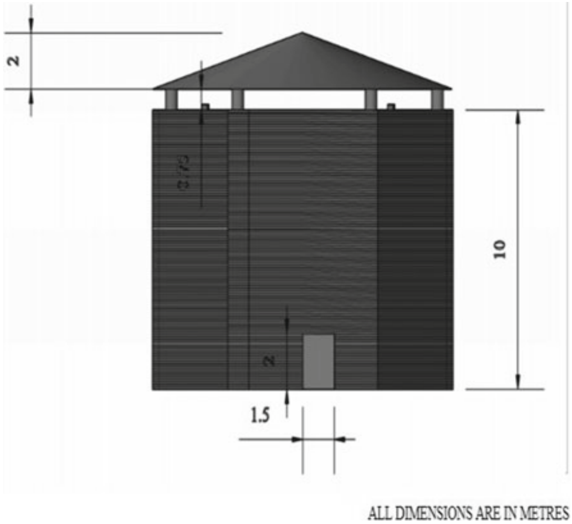


Fig. 2 Elevation of smog-free tower with louvers

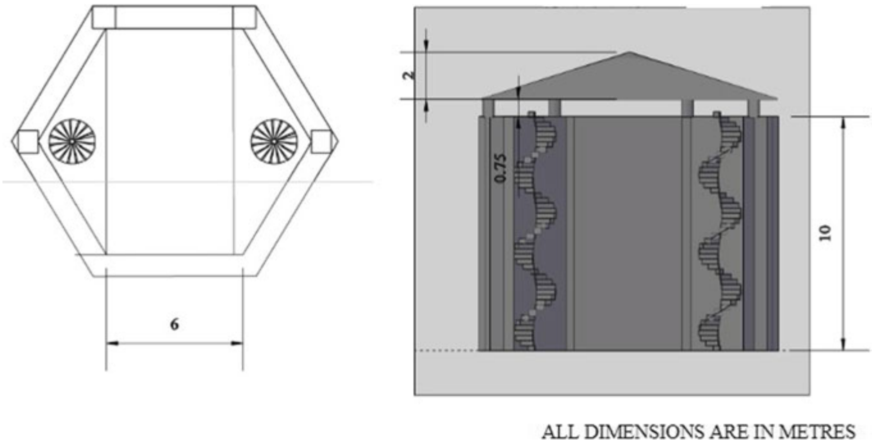


Fig. 3 Sectional view of smog-free tower

3.3 Artificial Reed Treatment Bed

Reed beds are naturally formed habitats found in flooded, waterlogged areas and estuaries. Artificial reed beds are employed to treat polluted water containing pollutants. Reed beds are only used to treat liquids; if they contain any solid pollutants, they need to be first settled in a sedimentation tank and the liquid effluents will discharge to the reed treatment bed and the solids effluents will be treated in sewage treatment plant, or composition of that solid effluent will occur. Reed beds consists of the aquatic

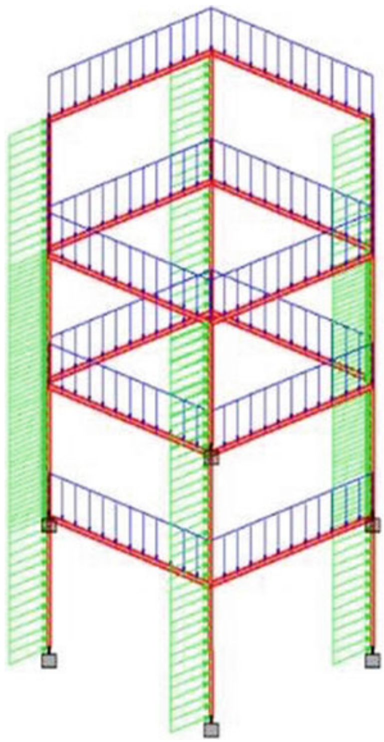


Fig. 4 Various loads acting on Smog-Free Tower

Table 3 Critical Bending Moment Values

Direction of B.M	Maximum positive B.M (kN-m)	Maximum negative B.M (kN-m)	Load Combination
M_y	9.401	9.401	1.5 × (D.L + L.L)
M_Z	36.73	16.78	1.5 × (D.L + L.L)

Table 4 Critical Shear Force Values

Direction of S.F	Maximum positive S.F (kN)	Maximum negative S.F (kN)	Load Combination
F_y	22.78	9.41	1.5 × (D.L + L.L)
F_Z	5.424	5.424	1.5 × (D.L + L.L)

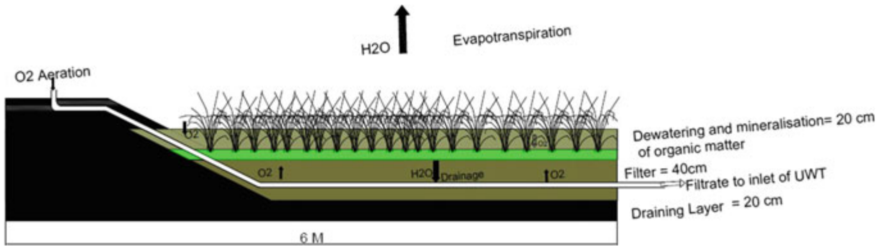


Fig. 5 Artificial reed treatment bed

plants that helps bacteria, fungi and algae to clean the sewage by digesting it in the treatment beds [4]. The diagrammatic representation of artificial reed treatment bed is shown below in (Fig. 5).

3.4 Louvers Selection

- A louver is a blind or shutter window with horizontal slats designed to admit light and air, but to keep away rain and direct sunlight. The angle of the slats can be adjustable or fixed, usually in blinds and windows.
- Modern louvers also consist of steel, metal, wood or glass. Through a metal handle, pulleys or by motorized operators, they can be opened and closed.
- Factors to be considered when choosing louvers: air volume, speed, free area, drop pressure and penetration of water.
- The louver size chosen for use is 3.5 inches or 88.9 mm.
- The type of louvers selected and arranged is shown in (Figs. 6 and 7).

Fig. 6 Louvers

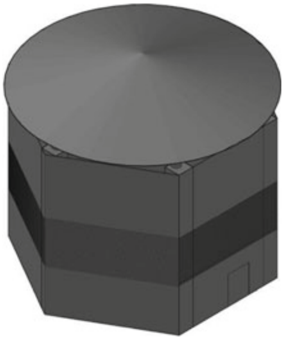


Fig. 7 Louvers in middle section of SFT

3.5 Volume of Air Purified

The tower is divided into three sections; each section consists of two wet scrubbers, and on an average, one wet scrubber can clean 50 m^3/h.

Therefore, volume of air purified $= 3 \times 2 \times 50 = 300$ m^3/h

4 Conclusion

The outdoor Air Pollution is among the top ten health risks in India, with an estimated 695,000 annual premature deaths from respiratory illnesses, compromised immune systems and cardiovascular conditions (IHME). To control this, a smog-free tower is very necessary at the high pollutants emitting zones of the country. Wet scrubbers are used in treatment of smog. Wet scrubbers use water as scrubbing liquid to collect the pollutants and release cleaned air. By constructing a tower of 10 m height and 100 m^2, volume of purified air is 300 m^3/h. It can clean up to 75% of the air [1]. In addition to this, the air purification is also helpful for reducing global warming and acid rain. The power requirement in the tower is low, therefore less energy is wasted. The water used in the tower is reused by treating in reed beds, therefore less wastage of water and no harmful pollutants are released in the surroundings. Tower has low initial cost and low running cost. Some other benefits that are also provided to the government is the attractive tourist spot that will help in strengthening the country's economy. Reed treatment bed will help to reuse water which is used in wet scrubber as scrubbing liquid. All together by reducing pollution, we can achieve a balanced ecosystem and great future.

References

1. Andre R, & Recentre, R. (2016). The Smog Free Tower « Solution » of Daan Roosegaarde *. https://doi.org/10.13140/RG.2.1.1328.8168. (August 2015).
2. Malik, J., Singh, R., & Bhardwaj, S. (2016). Combating air pollution: Exploring the solutions and analysis of the challenges. *Journal of Basic and Applied Engineering*, *3*(1).
3. Laxmipriya, S., AjayKumar, A., Aravinthan, S., & Arunachalam, N. (2018). Smog-free-tower a review paper. *International Research Journal of Engineering and Technology, 4*(2), 3251–3255.
4. Schönerklee, M., Koch, F., Perfler, R., Haberl, R., & Laber, J. (1997). Tertiary treatment in a vertical flow reed bed system-A full scale pilot plant for 200–600 P.E. *Water Science and Technology*; *35*(5), 223–230. https://doi.org/10.1016/S0273-1223(97)00072-3.
5. IHME. (2013). The Global Burden of Disease 2010: Generating Evidence and Guiding Policy. Institute for Health Metrics and Evaluation, Seattle, USA.
6. https://www.Kickstarter.Com/projects/1777606920/the-smog-freetower Retrieved January 27, 2020, at 11.50 am IST.
7. http://www.Aventurine.Com/smog-free-towers-pollution-killer. Retrieved January 27, 2020, at 01.20 pm IST.
8. https://www.Wte-ltd.Co.Uk/reed_bed_sewage_treatment.Html. Retrieved February 13, 2020, at 11.50 am IST.
9. https://www.Cleanindiajournal.Com/smog-free-tower/. Retrieved February 09, 2020, at 02.50 pm IST.
10. IS 456. (2000). Indian Standard Plain and reinforced concrete-code of practice (fourth revision), Bureau of Indian Standards, New Delhi.IS 3370(Part 1):2009 Indian Standard, Concrete structures for storage of liquids: Part 1 General requirements-Code of practice (first revision), Bureau of Indian Standards, New Delhi.
11. IS 3370(Part 2). (2009). Indian Standard, Concrete structures for storage of liquids: Part 2 Reinforced concrete structures-Code of practice (first revision), Bureau of Indian Standards, New Delhi. IS 800:2007 Indian Standard, General construction in steel-Code of practice (third revision), Bureau of Indian Standards, New Delhi.

Assessing the Role of Nature-Based Solutions in Urban Resilience and Climate Change Adaptation

Kiranmayi Raparthi and Ranee Vedamuthu

Abstract Cities are rapidly urbanizing and face immense social, economic and environmental challenges. These challenges amplify the climate change impacts, thereby posing a serious threat to urban and social resilience. With regard to climate change, ecological researchers globally advocate that nature-based solutions integrate with various ecosystems based approaches, provide biodiversity benefits and address societal challenges. However, the potential of nature-based solutions to build urban resilience and address climate change through urban planning has remained research rhetoric. This research puts forth an effort to assess the ability of nature-based solutions in building urban resilience and addressing climate change. This research incorporates a quantitative research methodology by undertaking a technical and scientific literature review about nature-based solutions, urban resilience and climate change adaptation. Accordingly, the characteristics, dimensions, areas of application, the challenges and opportunities are highlighted. The key research gap between urban resilience and nature-based solutions is identified by developing a socio-spatial framework that focuses on nature-based solutions tradeoffs and its response to urban resilience. This renewed approach highlights that nature-based solutions are cost-effective multifunctional ecosystem services and offer inclusive benefits, ranging from regenerating urban spaces to improving quality of life and reducing pollution. However, this research limits the application of nature-based solutions for urban resilience to local level urban planning and does not focus on master level urban planning. This research emphasizes nature-based solutions as an effective urban policy tool and reinforces its inclusion in local level urban planning for building climate change and urban resilience.

Keywords Nature-based solutions · Cities · Urban resilience · Climate change Adaptation · Policy perspectives

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1 Introduction

Climate change is a multidimensional observable fact and is regarded as one of the greatest challenge human society is facing in the twenty-first century. Cities are rapidly urbanizing and they face immense environmental, social and economic challenges. These challenges are further amplified by the impacts of climate change, thereby posing a serious threat to social and urban resilience [1]. Ecological researchers globally advocate that Nature-based Solutions through the integration of various Ecosystems based Approaches, provide biodiversity benefits and address societal challenges. However, the potential of nature-based solutions in building urban resilience and addressing climate change adaptation through urban planning has remained research rhetoric [2].

This research puts forth an effort to assess the ability of nature-based solutions in building urban resilience and addressing climate change adaptation. Accordingly, the paper first reviews the existing literature on nature-based solutions, urban resilience and climate change adaptation. Later, through the lens of urban resilience and climate change adaptation, the complexity and multifunctional aspects of nature-based solutions is highlighted. Following this, the ability of nature-based solutions in building urban resilience and climate change adaptation is discussed.

Accordingly, the research gap between urban resilience and nature-based solutions is identified by developing a socio-spatial framework that focuses on nature-based solutions tradeoffs and its response to urban resilience. This research emphasizes nature-based solutions as an effective urban policy tool and reinforces its inclusion in local level urban planning for building climate change and urban resilience. This research implies that it is necessary to mainstream nature-based solutions in local level urban planning.

2 Nature-Based Solutions and Urban Resilience

Nature-based solution is an emerging concept that integrates various ecosystem services and management strategies to address the societal challenges related to climate change, food and water security, quality of life and human wellbeing. Ecosystem services refer to the benefits provided by nature to people [3]. According to the Millennium Ecosystem Assessment report 2005, ecosystem services are classified into four categories based on the services they provide to the surroundings. They are, namely, provisioning, regulating, cultural and supporting. Accordingly, nature-based solutions have the ability to improve the quality of life and increase urban resilience through the delivery of ecosystem services [4].

Resilience of urban areas is mainly dependent upon the ability of urban areas to adapt and adjust to the change [5]. Urban resilience embraces the city's ability to respond to the chronic stresses, abrupt socioeconomic change and acute shocks due to natural disasters [6]. Accordingly, urban resilience is not only related to rebuilding or recovering. It relates to the ability of an urban area to thrive during normalcy and adapt, reorganize and grow in response to a disruption or change [7].

One of the most important aspects of urban policy is urban resilience. It is necessary to increase urban resilience by integrating long-term approaches, mechanisms and disciplines that have an ability to explore feasible transition paths in urban planning and development [8]. Literature regarding implementation of urban resilience highlights the necessity to understand the issues and relationship between new practices and policies related to resilience [9]. Moreover, governance plays a major role and it is necessary to incorporate proactive and anticipatory approaches to mainstream urban resilience in urban planning and development [10].

3 Multifunctional Aspects of Nature-Based Solutions and Climate Change Adaptation

In this section, the benefits and multifunctional aspects of nature-based solutions towards building urban resilience and responding to climate adaptation with regard to the three aspects of climate change vulnerability is highlighted. First aspect relates to exposure and highlights the extent of a community, region or resource exposure to the vulnerability. The second is sensitivity and relates to the degree to which community, region or resource is either responsive or affected to the effect. The third dimension is the adaptive capacity. It highlights the ability of the community, region or resource to either innovate or adjust to the changing conditions.

Within the human settlements context, nature-based solutions by protecting, restoring natural wetlands, there is a possibility of reducing flood risk, soil erosion and ground water recharge, and through constructed wetlands, contribute towards flood reduction and decrease surface flooding.

Urban green spaces, bioretention areas, green infrastructure and permeable areas have the ability to enhance the extent of social interaction, cohesion building and thereby contribute positively to the social, physical wellbeing and quality of life. Moreover, nature-based solutions' adaptive capacity is highlighted by its ability in empowering marginalized groups through efficient management of common pool resources and development of urban green spaces, green roofs and practising home gardening [11].

As such, nature-based solutions either through natural processes or hybrid approaches by integrating natural process with technical-based solutions have the ability to foster climate change adaptation and urban resilience.

4 Nature-Based Solutions Trade Offs

Nature-based solutions literature highlights that nature-based solutions are context-oriented and site-specific. Moreover, due to the multifunctional benefits, tradeoffs exists amongst various aspects in terms of the priorities of each solutions. Tradeoffs with regard to nature-based solutions and urban planning refer to the land use choices that are made to increase or gain from the delivery of one or more nature-based solutions at the expense of losing or diminishing the delivery of the other nature-based solution [12].

This research has categorized nature-based solutions tradeoffs as time-based tradeoffs, spatial tradeoffs, functional tradeoffs, normative ethical (social equity) tradeoffs and species tradeoffs. Time-based tradeoffs highlights that a specific nature-based solution for a specific time has the ability to affect or alter the opportunities in the future. These tradeoffs have both short-term as well as long-term outcomes. For instance, planning for an increase in sea-level through restoration of wetlands has short-term outcome which involves provision of retention space for storm surge flows. On the other hand, alleviating the rate of erosion by increasing the elevation with coastal sediments and growing organic matter is a long-term outcome.

Spatial tradeoffs are related to both scales and cross scales. These tradeoffs occur at various geographical locations and highlight that a nature-based solution for a specific area may cause either a positive or a negative impact in another area. For instance, an urban green space may have a positive impact at one scale by contributing to the inhabitants' quality of life but it may have a contrary effect at another scale by displacing the lower-income households due to the increase in housing costs because of the urban green space [13].

Functional tradeoffs highlight the function of one or many nature-based solution. As such, based on the function, the solution needs to be prioritized. For example, coastal landscapes can function to support recreation and also reduce sea-level rise. Supporting recreation can be carried out through improved walkways and park development but this function may lead to the loss of coastal wetlands and mangroves which may lead to sea-level rise. Normative ethical tradeoffs are associated with the proximity and provision of ecosystem services. Species tradeoffs emphasize that certain solutions support certain types and ignore others [14].

5 Research Gaps and Challenges Governing Nature-Based Solutions

Emerging evidence highlights that nature-based solutions deliver low-cost solutions to most of the climate change impacts through the delivery of ecosystem services. Thereby, provide advantages over grey engineered solutions in building urban resilience. However, it has been identified that there are several knowledge gaps, and limited research has been undertaken till date in addressing nature-based solutions tradeoffs and its integration in urban planning [15]. This research focuses on the fact that rather than highlighting nature-based solutions as an alternative to the hard-core engineering solutions, it is necessary to identify synergies among different solutions and the possibilities of its integration in urban planning [16].

One main research gap that was identified in the research is the difficulty in identifying indicators for nature-based solutions social–ecological effectiveness. For instance, the effectiveness of nature-based solutions in reducing the flood impact due to increased precipitation is inclined towards various contextual and socioeconomic factors (intensity and frequency of the rainfall, institutional capacity and financial capital to respond to the interventions and the ability to deliver the ecosystem services due to spatial changes) that change over a period of time. As such, the social–ecological effectiveness of NbS varies across various scales and so it is necessary to formulate context-specific strategies at the local level.

The other research gap is the lack of an appropriate framework to estimate the cost-effectiveness of NbS. As a result, the economic benefit of nature is usually underestimated, especially during the long term [17]. This research highlights that due to the multifunctional aspects of NbS, it is often difficult to predict the cost and monetize due to the non-market value of the ecosystem services (such as flood control, water security, urban agriculture and green roofs).

Moreover, nature-based solutions are flexible and also offer long-term solutions with benefits that might not be obtained instantly unlike the grey infrastructure and engineering services. In view of the multifunctional aspects of nature-based solutions, there is a growing consensus among landscape architects, urban planners, engineers and ecologists, that rather than viewing nature-based solutions and engineered solutions in isolation, a synthesis of both the nature-based and engineered solutions may be a viable alternative in many contexts.

6 Socio-Spatial Framework for Addressing the Nature-Based Solutions Tradeoffs

The above sections have described the ability of nature-based solutions to enhance urban resilience and climate change adaptation. This research highlights that lack of a socio-spatial framework addressing the evidence-based practical nature-based solutions tradeoffs might have halted its integration in urban planning. In this regard, it is necessary to bridge the gap between theory (benefits of nature-based solutions) and practise (nature-based solutions tradeoffs) and highlight strategies to deal with nature-based solutions tradeoffs and its response to urban resilience. This research puts forth an effort to synergize urban planning and nature-based solutions. Accordingly, this research proposes a socio-spatial framework that guides the implementation of nature-based solutions, emphasizes nature-based solutions as an effective policy tool and reinforces its inclusion in urban planning for urban resilience and climate change adaptation. Table 1 highlights the Socio-spatial framework for addressing the nature-based solutions tradeoffs.

Table 1 Socio-spatial framework for addressing the nature-based solutions tradeoffs

Tradeoffs	Characteristics of the tradeoffs	Addressing the trade off through urban planning	Examples
Time-based tradeoffs	Short-term actions and long-term actions	Understand the short- and long-term outcomes and how the function, form and scale change over a period of time Conduct stakeholders meeting and evaluate the policies frequently	Planning for sea-level rise through wetlands and mangroves and reefs have various short-term, medium-term and long-term benefits ranging from institutional to community and protection of coastal areas
Spatial tradeoffs	Place-based approaches operational at various scales [18]	Collection of socioeconomic, data and information related to demographics and geological services	Planning for sea-level rise through offshore breakwaters can have adverse impacts in another area
Functional tradeoffs	Prioritization of the outcomes and develop a balance amongst the preferred solutions [19]	Creating overlay land use map, land use land cover map over a period of time	Coastal landscapes can function to support recreation and also reduce sea-level rise
Normative ethical tradeoffs	Providing a utilitarian approach for acknowledging the conflict between the economic efficiency and the social aspect [20]	Conducting potential stakeholder meetings for dialogue on which Nbs provides maximum social equity to the identified issue	Green gentrification, urban renewal and regeneration projects have incorporated green and blue infrastructure and services as elements of upgrading over the general provision of the green and blue services
Species tradeoffs	Providing a utilitarian approach for acknowledging the conflict between the economic efficiency and the ecological aspect of the proposed solution [21]	Understand the type of native that are inherent to the area and collect data regarding the biodiversity and land use land cover	Ecosystem management actions tend to favour certain species and ignore others

Source Developed by the author

7 Discussions

The socio-spatial framework for addressing the nature-based solutions tradeoffs (Table 1) highlights ability of nature-based solutions in addressing urban resilience and emphasizes its integration in urban planning for urban resilience and climate change adaptation. However, the challenge perseveres in the accessibility and availability of the required information and data. The required information and data may not be available at all, or the data may not be reliable and validated. The data may not be site- and context-specific and local decision-making may be difficult [22]. Moreover, the stakeholders may not be aware of the cobenefits and the tradeoffs to support decision-making.

Moreover, given the multifunctional aspects of nature-based solutions, there may be certain challenges related to understanding in-depth the strategy and the function technically too. In this regard, it is necessary for inter- and transdisciplinary collaborations amongst planners, engineers, landscape architects, urban designers, environmental scientists and ecologists in identifying the nature-based solutions based on its benefits and trade offs, and implementing the nature-based solutions [23].

This research has highlighted various examples illustrating the trade-offs and cobenefits and how planning can address the tradeoffs. The examples used were mostly related to sea-level rise to emphasize that, in practical situations the multiple tradeoffs and benefits of nature-based solution may either exacerbate or amplify their selection. The complexity of nature-based solutions reinforces the need and importance of urban planning as a response to enable equitable and effective decision-making and management of nature-based solutions.

8 Conclusions

This paper demonstrates the role of nature-based solutions in building urban resilience and climate change adaptation. The paper highlights the strategies to and its implementation through urban planning. The research puts forth various mechanisms and strategies to address the nature-based solution tradeoffs and comprehensively implement in urban areas. Accordingly, by strategically understanding the tradeoffs, identifying the necessary urban planning and management approaches to address the trade off and by categorizing the vulnerabilities through implementation, evaluation and monitoring of the existing urban master plans, nature-based solutions can respond towards urban resilience and adapt to climate change.

The key research gap between urban resilience and nature-based solutions is identified by developing a socio-spatial framework that focuses on nature-based solutions tradoffs and its response to urban resilience. The research highlights that for nature-based solutions to effectively support its implementation, contemporary multidisciplinary practices of research are required. This renewed approach highlights that nature-based solutions are cost-effective multifunctional ecosystem services and offer inclusive benefits, ranging from regenerating urban spaces to improving quality of life and reducing pollution.

However, this research limits the application of nature-based solutions for urban resilience to local level urban planning and does not focus on master level urban planning. This research emphasizes nature-based solutions as an effective urban policy tool and reinforces its inclusion in local level urban planning for building climate change and urban resilience. This research implies that it is necessary to mainstream nature-based solutions in local level urban planning.

References

1. Raparthi, K. (2018). Assessing the role of urban planning policies in meeting climate change mitigation goals in Indian cities. *Journal of Urban Planning and Development, ASCE*, *144*(4), pp. 1–16. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000440. (Paper ID: 05018005).
2. Raparth, K. (2020). Ability of nature based solutions through urban green space management in building urban resilience. *International Journal of Urban Design, 3*(2), 45–55p.
3. Bolund, P., & Hunhammar, S. (1999) Ecosystem services in urban areas. *Ecological Economics*, *29*(2), 293–301.
4. Ainscough, J., de Vries Lentsch, A., Metzger, M., Rounsevell, M., Schröter, M., Delbaere, B., & Staes, J. (2019). Navigating pluralism: Understanding perceptions of the eco- system services concept. *Ecosystem Services*, *36*. https://doi.org/10.1016/j.ecoser.2019.01.004.
5. Albrechts, L., Balducci, A., & Hillier, J. (Eds.). (2017). Situated practices of strategic planning: An international perspective (pp. 1–12). London, UK: Routledge.
6. Campanella, T. J. (2006). Urban resilience and the recovery of New Orleans. *Journal of the American Planning Association*, *72*(2), 141–146. https://doi.org/10.1080/01944360608976734.
7. Gardner, J. (2019). The inclusive healthy places framework: A new tool for social resilience and public infrastructure. *Biophilic Cities Journal, 2*(2), 10–15.
8. Bush, J., Doyon, A. (2019) Building urban resilience with nature-based solutions: How can urban planning contribute?, *Cities.*
9. Coaffee, J. (2013). Towards next-generation urban resilience in planning practice: From securitization to integrated place making. *Planning Practice and Research*, *28*(3), 323–339. https://doi.org/10.1080/02697459.2013.787693.
10. McDonough, K., Hutchinson, S., Moore, T., & Hutchinson, J. M. S. (2017) Analysis of publication trends in ecosystem services research. *Ecosystem Services*, *25*, 82–88. https://doi.org/10.1016/j.ecoser.2017.03.022.
11. Raparthi, K. (2021) Assessing the relationship between urban planning policies, gender and climate change mitigation: Regression model evaluation of Indian cities. *Journal of Urban Planning and Development. ASCE*, *147*(2). https://doi.org/10.1061/(ASCE)UP.1943-5444.0000677
12. Raparthi, K. (2015). Assessing smart-growth strategies in Indian cities: A grounded theory approach to planning practice. *Journal of Urban Planning and Development, 141*(4), 05014031. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000267
13. Collier, M. J., Nedović-Budić, Z., Aerts, J., Connop, S., Foley, D., Foley, K., & Verburg, P. (2013). Transitioning to resilience and sustainability in urban communities. *Cities, 32*, S21–S28. https://doi.org/10.1016/j.cities.2013.03.010
14. Parris, K. M., Amati, M., Bekessy, S. A., Dagenais, D., Fryd, O., Hahs, A. K., & Williams, N. S. G. (2018). The seven lamps of planning for biodiversity in the city. *Cities, 83*, 44–53. https://doi.org/10.1016/j.cities.2018.06.007

15. Healey, P. (2009). In search of the "strategic" in spatial strategy making. *Planning Theory & Practice, 10*(4), 439–457. https://doi.org/10.1080/14649350903417191
16. Turkelboom, F., Leone, M., Jacobs, S., Kelemen, E., García-Llorente, M., Baró, F., & Rusch, V. (2018). When, "we cannot have it all: Ecosystem services trade-offs in the context of spatial planning." *Ecosystem Services, 29*, 566–578. https://doi.org/10.1016/j.ecoser.2017.10.011
17. Rudd, H., Vala, J., & Schaefer, V. (2002). Importance of backyard habitat in a comprehensive biodiversity conservation strategy: A connectivity analysis of urban green spaces. *Restoration Ecology, 10*(2), 368–375.
18. Healey, P. (1998). Building institutional capacity through collaborative approaches to urban planning. *Environment & Planning A, 30*(9), 1531–1546. https://doi.org/10.1068/a301531
19. Turkelboom, F., Leone, M., Jacobs, S., Kelemen, E., García-Llorente, M., Baró, F., & Rusch, V. (2018). When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. *Ecosystem Services, 29*, 566–578. https://doi.org/10.1016/j.ecoser.2017.10.011
20. Corburn, J. (2003). Bringing local knowledge into environmental decision making: Improving urban planning for communities at risk. *Journal of Planning Education and Research, 22*(4), 420–433. https://doi.org/10.1177/0739456X03022004008
21. Albrechts, L. (2017). Some ontological and epistemological challenges. In L. Albrechts, A. Balducci, & J. Hillier (Eds.). Situated practices of strategic planning: An international perspective (pp. 1–12). London, UK: Routledge.
22. Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147*, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011
23. Jennings, V., & Bamkole, O. (2019). The relationship between social cohesion and urban green space: An avenue for health promotion. *International Journal of Environmental Research and Public Health*, *16*(3). https://doi.org/10.3390/ijerph16030452.

Spatiotemporal Patterns of Urbanization in Chennai City, Tamil Nadu, India Using Remote Sensing Data

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Abstract Rapid urbanization in developing countries is leading to urban sprawl along the fringes of the cities. The land use of the regions surrounding the Chennai metropolitan area is changing drastically. It is vital to monitor and quantify the land-use change and the urban expansion process to achieve cities with proper planning, efficiency and sustainability. This paper aims to determine the land-use change in the study area for the years 1998, 2009 and 2019 using remote sensing data. Shannon's entropy was utilized to assess the nature of urban growth happening in the study area. The study region was divided into 50 zones of concentric circles drawn from the central business district point. The rate of urbanization in each zone shows gradual increasing trend from 2009 to 2019, moving outwards with a maximum value of 36.9% in the last zone. Whereas from 1998 to 2009, the rate of urbanization increases rapidly to attain a maximum value of 85.6% in the 31st zone and thereafter the value got decreased. Relative Shannon's entropy asserted that the city displayed a dispersed development from a distance of 12, 14 and 18 km from the city centre for the years 1998, 2009 and 2019, respectively.

Keywords Urbanization · Shannon's entropy · Relative Shannon entropy · Urban sprawl

1 Introduction

There is a large-scale shifting of rural population to urban population worldwide. Especially in developing countries, the shift is profound. The urban cities are expanding beyond their geographical limits. Rapid urbanization has caused radical changes in the landscapes [1]. Historically, urbanization is the biggest driver of land

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use land cover changes [2]. Changes in land cover and rapid urbanization results in food and water scarcity, environmental deterioration, loss of farming lands, demolition of forests, encroachment of waterways and surface water bodies, changes in biotic diversity. These changes cannot be well understood without the knowledge of urbanization that causes them.

The development of a scattered and isolated piece of land surrounded by vacant lands is considered urban sprawl [3]. Ewing et al. [4] state sprawl as strip development along highways and leapfrog includes low density urban developments. Remote sensing has been extensively used to facilitate the studies related to land use land cover changes, urban growth and sprawl identification [5]. Thematic images from satellite data are availed to understand the land use land cover changes occurring over time [6–8]. While classifying the images, impervious land surfaces such as buildings, pavements and other infrastructure facilities are mapped as urban areas [9]. The extent of urban land cover change over the decadal period was determined using land cover analysis. Many metrics were proposed to differentiate, identify and quantify the nature of urbanization. Urbanization can be either of compact nature or sprawling nature. Compact development is considered sustainable and a desired way of urbanization, whereas sprawling is considered as an undesired way of urbanization. The lack of consensus in the definition of sprawl has made its quantitative measurement a problematic task. The relative comparison of the quantified sprawl values among different cities have also been hindered by the lack of consensus and definitive technologies [10]. Spatial metrics such as percentage of landscape, largest patch index, patch density, edge density, patch cohesion index and landscape shape index are being utilized to evaluate the nature of the urbanization [11–13].

Shannon's Entropy is a spatial metric widely used to measure urban sprawl [1, 14–17]. It is used to measure the degree of dispersion among the variables. Shannon's entropy value helps to understand better the nature of urbanization, viz., compact or dispersed (sprawl).

In this study, Shannon's entropy is utilized to study the nature of urbanization happening in the Chennai city, Tamil Nadu, India for a decadal period (1998–2009). Relative Shannon entropy is used to determine the zone in which the transition of urban development from compact to sprawl happened for each decade.

2 Study

Chennai is the capital of the state of Tamil Nadu in India. It is situated on the east coast of India at a latitude and longitude of 13.0827° N, 80.2707° E. Established as Madras corporation in 1688, Chennai is the oldest municipal body in India. As per the 2011 census, the Chennai district covered an area of 178.2 km^2 and a population of 4.64 million. (Fig. 1) shows the shapefile of Chennai administrative boundary as per census 2011 along with the 50 km radial buffer. The study area considered covers an area of 4088 km^2.

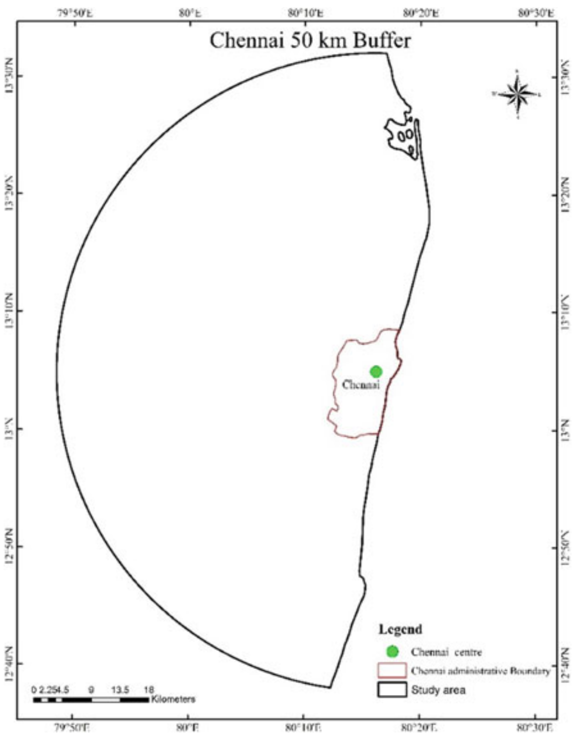

Fig.1 Study region for Chennai

3 Methodology

The satellite images were projected to UTM (WGS-84) coordinate system. The satellite images were enhanced by edge enhancement. The study region is extracted from the enhanced satellite images. A combined classification technique is utilized to classify land use land cover into five categories, viz., water bodies, urban, vegetation, agriculture and barren. Unsupervised classification is performed to divide the satellite images into 100 bands. Each band is then manually evaluated with the ground truth data and it is recoded into one of the mentioned classes. This method of classification has produced higher user's accuracy.

3.1 Shannon's Entropy

The study region was divided into 50 zones of concentric circles with a 1 km incremental radius. The concentric circles are drawn from the centre of Chennai at a latitude and longitude of 13.0827° N, 80.2707° E. Each circle is clipped with the study area shapefile so that only a portion of the concentric circles that cover the

Fig. 2 50 zones of the study region

land area is retained for the study purpose. The 50 zones which are considered for this study are given in (Fig. 2).

Shannon's entropy gives the measure of variability among the variables possible outcomes [18].

$$H_n = \sum\nolimits_{i=1}^{n} \mathrm{P_i}\log(\mathrm{P_i})$$

P_i is the proportion of the build-up area in the ith zone, n represents the number of zones. P_i is the ratio between the urban area in the ith zone to overall urban area. The value of Shannon's entropy varies from 0 to log n. The values closer to 0 indicates compact development and the values closer to log n indicate dispersed development. As the number of zones considered for this study is 50, the log n value corresponding to log 50 is 1.69897.

3.2 Relative Shannon Entropy

Relative Shannon entropy is calculated using the formulae [10]

$$H'_n = \frac{H_n}{\log_e(n)}$$

H_n is the Shannon entropy value and n represents the number of zones. The value of relative Shannon entropy varies between 0 and 1. 0.5 is considered as the threshold that differentiates compact development and urban development. The zone at which this threshold point is reached is generally measured to identify the location after which sprawl occurs.

4 Results and Discussions

4.1 Land Use Land Cover (LULC) Classification

The land use land cover classification for the years 1998, 2009 and 2019 is depicted in the (Figs. 3, 4 and 5). It is observed that the urban area has increased by 71.77% between 1998 and 2009 and 36.91% between 2009 and 2019. There is a reduction in the land areas covered by water bodies, vegetation, agriculture and barren land over the last 20 years. Table 1 illustrates the area of various LULC for the years 1998, 2009 and 2019.

Fig. 3 LULC of 1998

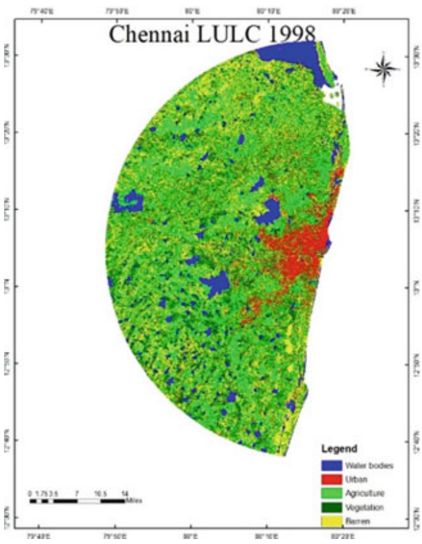

Fig. 4 LULC of 2009

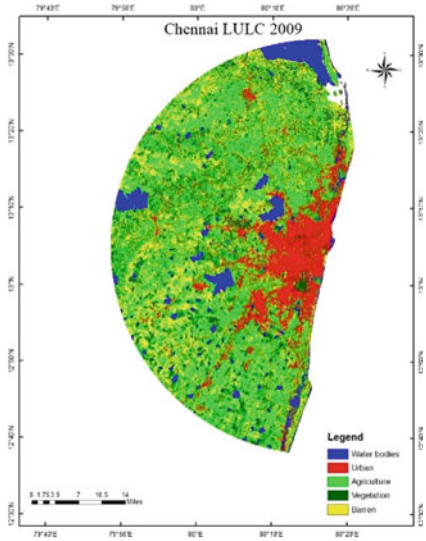

Fig. 5 LULC of 2019

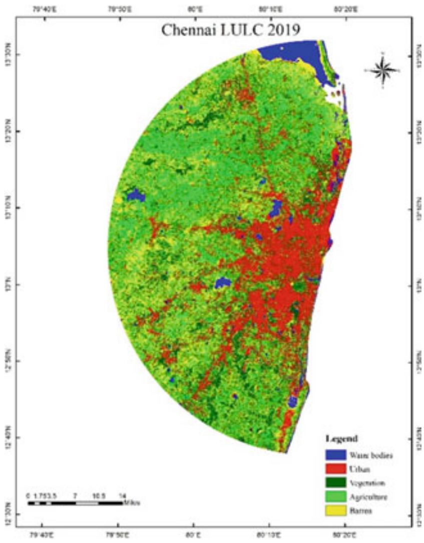

Table 1 Results of land use land cover analysis

Land class\year	1998 (km^2)	2009 (km^2)	2019 (km^2)
Water bodies	357.319	295.478	161.345
Urban	363.632	624.619	855.180
Agriculture	1323.660	1543.035	1189.660
Vegetation	976.088	617.224	862.838
Barren	1067.950	1008.294	1019.627
Total	4088.65	4088.65	4088.65

4.2 Urban Area

The land use land cover image is cropped for each zone and each year separately. The urban area is determined for all the 50 zones of each year. The difference between the urban areas for 1998 and 2009 for the first eight zones was less than 10%. There was a profound difference in the urban areas of 1998 and 2009 from zone 9 onwards. The urban area difference, which was 12% in zone 9, steadily increased to a difference of 85% in zone 26. The minimum difference in the early years is because the central core areas have already been urbanized to the maximum extent. Most of the urbanization between 1998 and 2009 has happened from zone 9 to zone 26. In other words, maximum urban development was witnessed between 9 and 26 km from the centre of the city. In contrast, the urban difference between 2009 and 2019 is evenly spread among all the zones. The urban difference has gradually increased and reached a maximum of 36% in the last designated zone. The nature of urban growth also gradually increases from the centre zones to the peripheral zones. This highlights that the outer edges of the city are getting urbanized at a rapid phase. The comparison of the urban area in each zone for the three different years is represented in (Fig. 6).

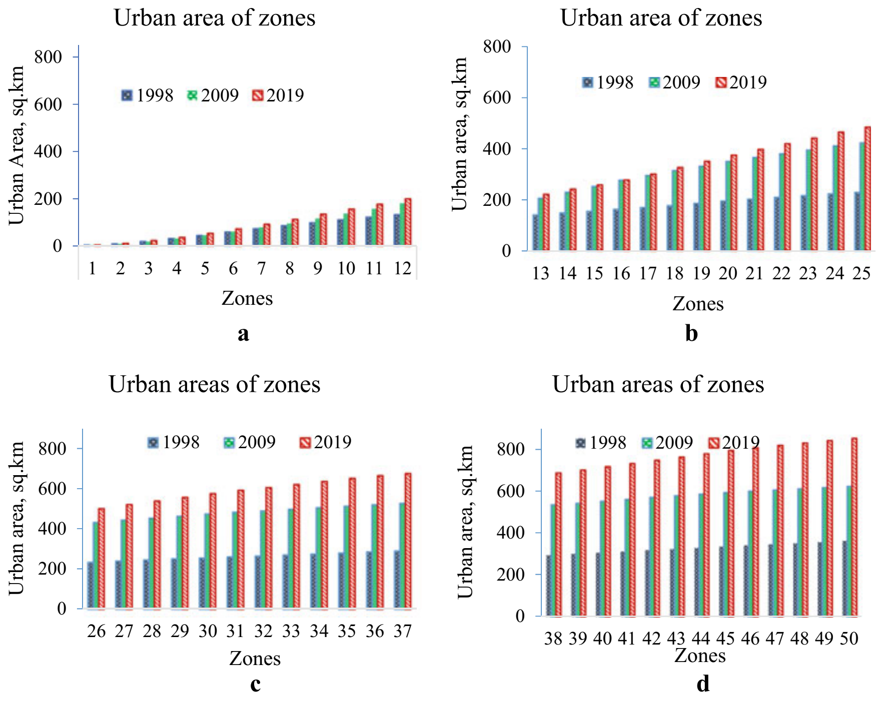

Fig. 6 **a** Urban area comparison, 1–12 zones, **b** Urban area comparison, 13–25 zones, **c** Urban area comparison, 26–37 zones, **d** Urban area comparison, 38–50 zones

4.3 Shannon Entropy

The Shannon entropy value up to each zone for the three different years (1998, 2009 and 2019) is given in (Table 2). The Shannon entropy values for the entire region are 1.668, 1.650, 1.680 for the years 1998, 2009 and 2019, respectively. The study region being huge, the direct interpretation of the Shannon entropy value would not convey the necessary understanding. The values of 1.668, 1.650 and 1.680 are very near to the maximum possible value of log n (1.69), which interprets the likelihood of maximum sprawl for all three years.

The Shannon's entropy value of the three years for different zones is depicted in (Fig. 7). It is evident the Shannon entropy value got reduced in the year 2019 when compared to 1998 and 2009, which envisages that urban development has become more compact from 2009 to 2019.

4.4 Relative Shannon Entropy

Relative Shannon entropy is adopted to find the pattern of growth. Generally, 0.5 is considered as the threshold relative Shannon entropy value. If the entropy value is less than 0.5, it is considered as compact development. If the value of entropy is more than 0.5, it is considered as disperse [19]. Table 3 gives the zones at which the threshold value had reached for the examining years. In 1998, sprawling development happened after zone 12; in 2009 and 2019, it had happened beyond zone 14 and zone 18, respectively.

From this, it is evident that the distance from the city centre to the point where the compact urban development happened had also increased over the years. In 1998, the compact urban development was witnessed till 12 km radius, and in 2009 and 2019, it was witnessed upto 14 km and 18 km radius, respectively, from the city centre. The important location names are represented along the threshold boundaries in (Fig. 8).

5 Conclusion

This study investigated the nature of urbanization happening in the city of Chennai. Remote sensing data combined with Shannon's entropy facilitates the measurement of spatial extents of urbanization pattern. The calculated land cover analysis indicated that the rate of urbanization during the years 1998 to 2009 was 71.77%, whereas it was 36.91% for the years between 2009 and 2019. Further, the study region was divided into 50 zones of concentric circles with a 1 km incremental radius to determine the zonal urbanization. Urbanization during the years 1998 to 2009 had increased more than 50% for each zone from zone 14 onwards, and for the years 2009 to 2019, a gradual increase in urbanization was witnessed for each zone, with a maximum of

Table 2 Shannon entropy and relative Shannon entropy value for 50 zones

Zones	Shannon entropy (H_n)			Relative Shannon entropy (H'_n)		
	1998	2009	2019	1998	2009	2019
1	0.012	0.008	0.008	–	–	–
2	0.043	0.029	0.026	0.142	0.095	0.086
3	0.085	0.058	0.052	0.178	0.122	0.109
4	0.134	0.091	0.081	0.223	0.151	0.134
5	0.187	0.128	0.114	0.268	0.183	0.163
6	0.244	0.168	0.150	0.313	0.216	0.193
7	0.297	0.211	0.188	0.352	0.249	0.223
8	0.348	0.255	0.227	0.386	0.282	0.251
9	0.400	0.303	0.268	0.419	0.317	0.280
10	0.449	0.353	0.309	0.449	0.353	0.309
11	0.494	0.401	0.347	0.474	0.385	0.333
12	0.539	0.455	0.389	0.499	0.422	0.361
13	0.578	0.510	0.430	0.519	0.458	0.386
14	0.614	0.564	0.469	0.536	0.492	0.409
15	0.645	0.616	0.502	0.548	0.524	0.427
16	0.681	0.671	0.539	0.566	0.557	0.447
17	0.714	0.717	0.581	0.580	0.583	0.472
18	0.748	0.763	0.627	0.596	0.608	0.500
19	0.787	0.806	0.671	0.615	0.630	0.525
20	0.826	0.851	0.715	0.635	0.654	0.550
21	0.862	0.892	0.756	0.652	0.674	0.572
22	0.895	0.930	0.798	0.667	0.693	0.594
23	0.927	0.968	0.839	0.681	0.711	0.616
24	0.960	1.009	0.881	0.695	0.731	0.639
25	0.989	1.041	0.919	0.707	0.745	0.657
26	1.017	1.072	0.955	0.719	0.758	0.675
27	1.048	1.104	0.994	0.732	0.771	0.694
28	1.076	1.132	1.028	0.744	0.782	0.710
29	1.103	1.160	1.063	0.754	0.793	0.727
30	1.128	1.192	1.100	0.764	0.807	0.745
31	1.152	1.218	1.133	0.773	0.817	0.760
32	1.176	1.240	1.163	0.781	0.824	0.772
33	1.201	1.264	1.193	0.791	0.832	0.786
34	1.228	1.287	1.225	0.802	0.840	0.800
35	1.254	1.311	1.256	0.812	0.849	0.813

(continued)

Table 2 (continued)

Zones	Shannon entropy (H_n)			Relative Shannon entropy (H'_n)		
	1998	2009	2019	1998	2009	2019
36	1.279	1.333	1.284	0.822	0.857	0.825
37	1.304	1.354	1.308	0.832	0.863	0.834
38	1.329	1.378	1.333	0.841	0.873	0.844
39	1.356	1.401	1.362	0.852	0.880	0.856
40	1.384	1.429	1.395	0.864	0.892	0.871
41	1.415	1.455	1.425	0.877	0.902	0.884
42	1.445	1.483	1.458	0.890	0.914	0.898
43	1.473	1.508	1.490	0.902	0.923	0.912
44	1.500	1.531	1.521	0.913	0.932	0.926
45	1.529	1.554	1.554	0.925	0.940	0.940
46	1.558	1.575	1.582	0.937	0.947	0.951
47	1.585	1.594	1.606	0.948	0.953	0.960
48	1.610	1.612	1.630	0.957	0.959	0.970
49	1.638	1.632	1.656	0.969	0.965	0.980
50	1.668	1.650	1.680	0.982	0.971	0.989
Overall	1.668	1.650	1.650			

Fig. 7 Shannon entropy for the various zones in 1998, 2009 and 2019

Table 3 Threshold distance

Years	The distance at which threshold is reached (km)
1998	12
2009	14
2019	18

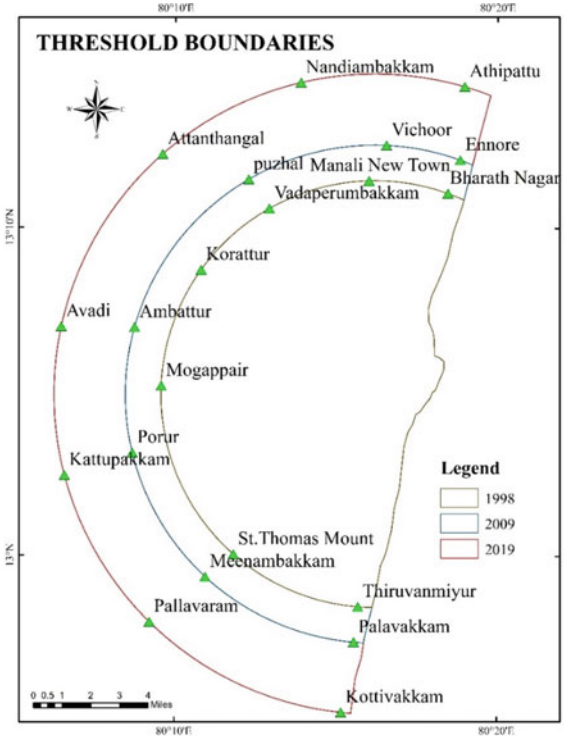

Fig. 8 Threshold boundaries for years 1998, 2009 and 2019

36% in the 50th zone. From the threshold Shannon entropy value, it was observed during the year 1998 the Chennai city has undergone compact development up to 12 km radius from the city centre and sprawl development beyond that. Similarly, in the year 2009, there was a compact development up to 14 km radius, and for 2019, the compact development was up to 18 km radius from the city centre. The exterior regions of the city beyond the administrative district boundary are undergoing rapid urbanization, which requires proper planning and regulation of urban development. Comparing the Shannon entropy values for the three years, it was observed that the urban development had become more compact during 2019.

References

1. Yeh, A. G. O., & Li, X. (2001). Measurement and monitoring of urban sprawl in a rapidly growing region using entropy. *Photogrammetric Engineering and Remote Sensing, 67*(1), 83–90.
2. Weng, Q. (2001). A remote sensing?GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China. *International Journal of Remote Sensing, 22*(10), 1999–2014.
3. Ottensmann, J. R. (1977). Urban sprawl, land values and the density of development. *Land Economics, 53*(4), 389.
4. Ewing, R., Pendall, R., & Chen, D. (2007). Measuring sprawl and its transportation impacts. *Transportation Research Record: Journal of the Transportation Research Board, 1831*(1), 175–183.
5. Sahana, M., Hong, H., & Sajjad, H. (2018). Science of the total environment analyzing urban spatial patterns and trend of urban growth using urban sprawl matrix : A study on Kolkata urban agglomeration, India. *Science of the Total Environment, 628–629*, 1557–1566.
6. Tian, L., et al. (2008). Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. *Journal of Urban Planning and Development, 2*(1), 50–58.
7. Shukla, A. (2019). Modeling urban growth trajectories and spatiotemporal pattern: A case study of Lucknow city, India. *Journal of the Indian Society of Remote Sensing, 47*(1), 139–152.
8. Pandian, M., Sakthivel, G., & Amrutha, D. (2014) Land use and land cover change detection using remote sensing and Gis in parts of coimbatore and Tiruppur Districts, Tamil Nadu, India. *International Journal of Remote Sensing and Geosciences*. (no. September, 2014).
9. Sudhira, H. S., Ramachandra, T. V., Raj, K. S., & Jagadish, K. S. (2003). Urban growth analysis using spatial and temporal data. *Journal of the Indian Society of Remote Sensing, 31*(4), 299–311.
10. Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography, 30*(4), 731–740.
11. Jat, M. K., Garg, P. K., & Khare, D. (2008). Modelling of urban growth using spatial analysis techniques: A case study of Ajmer city (India). *International Journal of Remote Sensing, 29*(2), 543–567.
12. Xu, C., Liu, M., Zhang, C., An, S., Yu, W., & Chen, J. M. (2007). The spatiotemporal dynamics of rapid urban growth in the Nanjing metropolitan region of China. *Landscape Ecology, 22*(6), 925–937.
13. Aithal, B. H., & Ramachandra, T. V. (2016) Visualization of urban growth pattern in Chennai using geoinformatics and spatial metrics.
14. Bhatta, B. (2009). Modelling of urban growth boundary using geoinformatics. *International Journal of Digital Earth, 2*(4), 359–381.
15. Sudhira, H. S., Ramachandra, T. V., & Jagadish, K. S. (2004). Urban sprawl: Metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation, 5*(1), 29–39.
16. Ramachandra, T. V., Aithal, B. H., & Sowmyashree, M. V. (2014). Urban structure in Kolkata: Metrics and modelling through geo-informatics. *Applied Geomatics, 6*(4), 229–244.
17. Sridhar, M. B., Sathyanathan, R., & Shaji, S. A. (2019). Spatio-temporal urban sprawl analysis and evaluation using gis for Lucknow City. *International Journal of Innovative Technology and Exploring Engineering, 8*(6), 894–899.
18. Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, 27(379), 623.
19. Alsharif, A. A. A., Pradhan, B., Mansor, S., & Shafri, H. Z. M. (2015). Urban expansion assessment by using remotely sensed data and the relative Shannon entropy model in GIS: A case study of Tripoli, Libya. *Theoretical and Empirical Researches in Urban Management, 10*(1), 55–71.

Evaluation of Operational BRTS System in Bangalore

Smitha Krishna, S. Sathvik, and S. Suchith

Abstract Bengaluru, Karnataka, India is known as the “City of Two Wheelers” because of its large two-wheeler population; additionally, during rush hour the city’s traffic is notoriously congested, resulting in traffic jams and lengthy travel times. To address this issue, the Bengaluru Municipal Corporation devised a plan to implement the BRTS in December 2006, and it was successfully implemented on a 16-km stretch, making Bengaluru the first city in India to do so. This system has dedicated bus lanes and signaling, and is thus independent of on-road traffic, to encourage Bengaluru motorists to take the BRTS instead of driving, with the goal of reducing traffic congestion and pollution. Currently, with a total system length of 66 km, and some more which is proposed, and 92 stations, sanctioned under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), BRTS is now one of the most significant transportation systems in Bengaluru. BRTS compares the cost, length, stations across each route, etc. between them. Each line of BRTS has different lengths, different corridor widths, and different number of stations. This study is for comparing these key factors through graphs, and then analyzing them.

Keywords BRTS routes · Transportation systems · Operational system · Quantitative scores · Qualitative scores

1 Introduction

The Bus Rapid Transit System (BRTS) is a mass rapid transit system that has been implemented with great success in many developed countries [1, 2]. While providing the speed and dependability of rail systems, it also provides the convenience and adaptability of bus systems. A total of Rs.521.22 billion has been allocated to urban transportation in the twelfth five-year plan. From this, about 57 percent, or Rs.296.03 billion, is the estimated investment for BRTS projects in India’s cities [3]. The construction of bus infrastructure, which includes bus bays, depots, terminals, and

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workshops, has been estimated to cost an additional 17% (Rs. 87.6 billion) [4, 5]. In the next 10 years, it is expected that an additional Rs. 69.65 crore will be invested in the BRTS systems across 14 cities. In India, the Twelfth Five-Year Plan estimates that about 1,480 km of BRTS networks will be needed.

Additionally, there is also a requirement for the construction of 5,230 depots, 2,360 terminals, and 74 workshops. Within the next decade, it is estimated that approximately 1,243 km of BRTS road networks will be built across 14 cities [6, 7]. This covers six expansions and eight new projects, resulting in the construction of 922 bus stations. In addition, support infrastructure is being planned in a number of cities. As part of the BRTS projects in these cities, three terminals are being built in Ahmedabad, Surat, Pimpri-Chinchwad, and Visakhapatnam. In addition, two depots and workshops in Hosur and Hubli's Gokul Road, as well as one in Dharwad, are being proposed [9, 10]. When completed, these depots will have a capacity of 120 regular buses and 30 BRTS buses, as well as a terminal in Naya Raipur.

Further, a major study is conducted for evaluation of Operational system consisting of 21 minor factors under three broad categories, namely, BRTS bus ways, bus stations, and buses. A visual observation study has been carried out by visiting various BRTS routes across various places in Bengaluru city [11]. Field survey was conducted for each BRTS lane, and all the factors were keenly verified by means of a prepared checklist to check whether the BRTS routes are provided with all necessary service elements across the categories. Following the physical observations around routes, points were assigned to various facilities based on availability of the prescribed service parameters [12, 13]. Thus quantitative scores are determined, and based on the total scores, the routes were ranked for operational performance the best BRTS routes, moderate and poor performing routes were identified within the system. Fig. 1 shows the typical cross section.

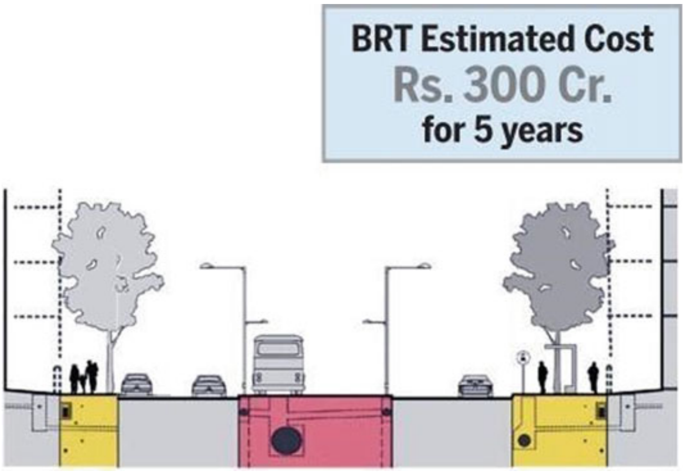

Fig. 1 Typical cross section for BRT on 30 m wide road

Fig. 2 BRTS route map

Bengaluru is India's eighth-largest city and the state of Karnataka's second-largest city after Mumbai. In this area, the automotive industry is particularly prominent [14]. Figure 2 shows the BRTS route map. All aspects of the automotive industry are represented, resulting in Bengaluru's designation as India's "Motor City," or India's Detroit. Bengaluru also has a thriving software industry, with massive development center run by multinational corporations. With over a hundred educational institutes and nine universities, Bengaluru has earned the moniker "SJB Institute of Science and Technology," with students studying in the University of Bengaluru's colleges from all over the world. Bengaluru has the greatest number of schools, colleges, and universities of any city on the planet.

Bengaluru's BRTS system: Bengaluru is a city with a total area of 470.79 square kilometer (Metropolitan). As of June 2009, the population was estimated to be around 73,250,000. According to records, there were 16,47,364 vehicles on the road in February 2007, with 11,23,898 two-wheelers. This number is increasing at a rate of 60,000 units per year. Within Metropolitan Bengaluru, travelling a distance of 5 km could take up to 3 h at certain times of the day. With all of these pressing reasons in mind, as well as the city's desire to decongest its roads and make it easier for the local public to commute, it was clear that the new bus system would win people's confidence at first [15, 16]. After Ahmedabad, which opened the country's first BRTS in 2010, and for which the BBMP began plying pilot routes in December 2006, Bengaluru is the second city in India to experiment with a fully operational Bus Rapid Transit system. In May 2006, the Bengaluru Municipality devised a plan to implement the BRTS, and after completing the design and planning stages, it was implemented on the vital Banashankari section, which spans 13.5 km, in 2008 [16]. The bus rapid transit system known as Rainbow BRTS serves the twin cities of Bengaluru and Mandya in Karnataka, India.

The Bruhat Bengaluru Mahanagara Palike (BBMP) manages the system. The Bengaluru Municipal Corporation is in charge of the highways (BMC). Currently, the project envisions 113 kms of dedicated bus corridors, as well as the necessary number of buses, bus stations, terminals, and an intelligent transit management system. The Rainbow BRTS project is funded by the Government of India's Jawaharlal Nehru National Urban Renewal Mission (JNNURM) [17, 18]. Additionally, some of the project's unique components in Mysore Road are being financed through the Ministry of Urban Development's "Sustainable Urban Transport Project," which is sponsored by the World Bank, UNDP, and the Global Environment Facility.

The features of Rainbow BRT include.

- Buses—Over 800 special Rainbow BRT buses with doors on both sides, and more standing space, that ply smoothly, and rapidly in reserved lanes.
- Bus stations in the BRTS Lanes are covered, and protected from rain and sun, they are well lit, have a ramp at the entrance, and signage boards with information about the BRTS corridors.
- Tickets at stations—The ticket required to travel is to be bought at the ticket counter inside the station before boarding the bus itself. Smart Cards are also proposed in the next phase.
- Level Boarding—The height of the bus platform, and the BRTS station platform are kept at the same level. So that the passengers do not have to climb steps to board the bus, a feature similar to metro rail.
- Automatic Doors—Automatic doors are also installed on BRT stations such that bus doors open only when the bus is properly docked at the station.
- The crossings from the footpath to the BRT stations have been installed with many signals at different locations or they have speed tables so that vehicles have to slow down to allow passengers to cross safely.
- Bus Numbers, Bus Arrival, and Station Information—Information of bus arrivals is displayed on screens at the bus stations. Display screens, and audio announcements in buses give information about the next stop. Route numbers appear on LED displays on the front, back, and the sides of buses.
- Intelligent Transit Management System—All BRT Buses have GPS, and stations are linked with the BRTS control room at Sawar gate which tracks bus movement and gives feedback to the drivers to improve their service.
- Security and Traffic Management—Security persons are present at each BRT bus station. A survey form is prepared including various features of above factors across BRTS Routes in Bengaluru, and the data is collected through site visits. The scores are assigned to various routes based on the operational element's availability, non-availability, and the ranking is given to various routes based on the total score of the operational performance.

2 Methodology

BRTS Bengaluru has six Corridors, the survey was conducted by site visits around BRTS corridors. The major components such as BRTS route, Bus stations, Buses are surveyed, and empirical data was collected in the pre-prepared format/checklist. The initial survey was started from Banashankari to Whitefield route as a sample for the initial study of how BRTS Bengaluru operates. Sirsi Circle to Mysore road lengths for 8 km with 25 bus stations, the BRTS corridors which were of 8 km stretch was divided into two parts. The factors for the study were selected from the literature review and observation of the corridor [19, 20]. Surveying of bus stations for the selected factors and rating them on the scale of one to five, one being the least rated, and five being best rated. The survey was conducted for the RAINBOW BRTS buses, and the whole route in the same process.

Once the survey of the sample route was completed, and the further process was continued, the survey was conducted for the remaining five corridors.

- Jayanagar to Whitefield road route is lane 2 of the BRTS corridor with length 10.25 km with 20 stations.
- Banashankari to Jayanagar route is lane 3 of the BRTS corridor with length 14 km with 17 stations.
- Jayanagar to Koramangala route is lane 4 of the BRTS corridor with length 12 km with 18 stations.
- Jayanagar to Banaswadi is lane 5 of the BRTS corridor with length 14 km with 13 stations.
- Banashankari to Koramangala is lane 6 of the BRTS corridor with length 8 km with 9 stations.

2.1 Data Collection

BRTS is divided into six lanes. For the study, each lane was divided into two parts; accordingly, in each part, two random stops were studied based on the above factors mentioned in Sect. 2.1. The final checklist was prepared after doing keen observation and studying the literature review [21]. By site visits, the components such as BRTS routes, Bus stations, Buses are surveyed, and empirical data was collected in the pre-prepared format/checklist. During this verification, some factors were available; these available factors were rated as 1, and the factors which were not available were rated 0. Further, the factors rated as 1 (available with the system) were checked for their highest quality of services on a Likert scale of rating 1 to 5, 5 for best services provided, and 1 for least services provided. This process was continued for all the lanes, and final scores were obtained; these were then compared to an ideal situation where all the factors being present, and the services being provided.

3 Data Analysis and Interpretation

The routes which are selected for the study were surveyed based on the three main factors that are Roadway, Bus way, and Bus stations.

3.1 Stretch Between Banashankari and Banaswadi

The corresponding level of service was marked for the factors from the scale 1–5, 1 being poor condition, and 5 being excellent. In this stretch, the factors are divided among three groups such as Roadway, Bus stations, and Buses. In the Roadway, the boom barrier was available being excellent in condition, bus boarding level being very good in condition, signpost display, advertisement, and passenger information system were available in good condition [22]. While there was a lack of underway or skyway for the passengers to reach the bus station, where the passengers find it difficult to cross the road.

The bus stations are in the middle of the right way, and security personnel were available at the station. Passenger information system, and Ramps for the disabled people were available in good condition. Patrols of BRTS stations were available, being average. The bus station was missing a CCTV camera which sometimes maybe difficult for the passengers to travel at night due to security reasons [23]. There was no problem with boarding as the passengers had to follow the queue to board the bus. The BRTS lanes, which were supposed to be specifically made for the BRTS buses, were also used by the local vehicles, which lead to delay in buses, and also sometimes the accidents occurred between the bus, and the other vehicles.

The BRTS Buses have a comfortable seating arrangement with low floor boarding being good in condition. The average speed of the bus is more than 30 km per hour more than that. The buses were missing an air conditioning system, due to which the passengers may feel tiring during the journey. There was non-availability of bus parking at the stations. Frequency of buses in Peak and Non-peak hours is very less. In Roadway, out of 6 factors, 5 factors were available which are quantitative. While the qualitative score is 21 out of 30. In Bus stations, out of 8 factors, 5 factors were available which are quantitative. While the qualitative score is 23 out of 40. In Buses, out of 7 factors, 3 factors were available which are quantitative. While the qualitative score is 9 out of 35. As shown in (Table 1), therefore, the total score of Lane 6 is 13 out of 21 for quantitative, and for qualitative 53 out of 105.

4 Conclusions

This study is mainly focused on analyzing the operational factors of the Bengaluru BRTS which were extracted by conducting site visits and studying literature review. Here, we study all the six BRTS corridors which is in current operation. The factors

Table 1 Ranking of lanes

BRTS stretch	RANK
Lane 1 (Indiranagar to Whitefield)	1
Lane 6 (Banashankari to Koramangala)	2
Lane 5 (Jayanagar to Banaswadi)	3
Lane 3 (Banashankari to Jayanagar)	4
Lane 2 (Jayanagar to Whitefield road)	5
Lane 4 (Jayanagar to Koramangala)	6

were mainly categorized under three categories, i.e., BRTS station, BRTS roadways, BRTS buses consisting of a total 21 factors.

Each lane was divided into two parts, in each part two random segments were studied, and rated accordingly by the use of Likert scale. Similarly, all the other lanes were studied, and total score was calculated; this total score included both quantitative, and qualitative scores. Ranking was done based on the total score and were evaluated against the ideal score. Lane 1 (Indiranagar to Whitefield) was found to be the best among all the 6 lanes, which got a quantitative score of 15 out of 21, and a qualitative score of 53 out of 105. Lane 4 (Jayanagar to Koramangala) was found to be the last among all the 6 lanes with a quantitative score of 10 out of 21, and qualitative of 38 out of 105. There was a huge difference in the frequency of buses, and advertising on the roadways from the highest ranked lane, i.e., lane 1(Indiranagar to Whitefield) to the other lanes. Lane 6 (Banashankari to Koramangala), and lane 5 (Jayanagar to Banaswadi) can be slightly improved in the areas of maintenance, and advertisement. Boom barriers being the best facility should be maintained in the same way in all the corridors, and skyway or underpass to reach the BRTS station [8], the worst factor among all the lanes, must be improved. Provisions of skyways or underpasses to reach the BRTS stations should be constructed at all stations.

These scores were individually interpreted and justified for their value, based on this final conclusion. From the literature review, and the suggestions from the experts, the factor chart is prepared, and each factor is rated based on their quality. Each lane was ranked according to the scores. Following is the Factors:

- Signpost display, an advertisement
- Entry path to the bus station, and the boarding level
- Passenger information system, and CCTV surveillance
- Separate lane for BRTS buses
- Ramps for disabled people
- Patrol of BRTS stations, and availability of security personnel at station
- Comfortable seating arrangements for communities
- Bus parking system
- Average bus speed
- Bus frequency at station (Peak hours, and Non-peak hours).

5 Recommendation

- BRTS stations and buses must be maintained in a clean and proper manner.
- Advertising in stations and along the bus ways must be encouraged, as they are a source of revenue generation.
- Awareness must be created among the road users to avoid usage of BRTS corridors.
- Automatic doors and passenger information system must be duly maintained in a proper way.
- The passenger information system can be modified such that it also shows the real-time bus tracking.
- During the non-peak hours, school buses can be allowed to use the corridors.
- Implementation of ticket counter in the stations rather than providing in the bus.
- Providing security to the users by installation of CCTV for real-time surveillance.
- Extending the connectivity further.
- This study can be used for further implementation of further corridors.

6 Scope for the Future Work

- During the study, some of the corridors were not in use due to construction of the metro, so there might be change in results if the study is conducted later.
- Cost benefit analysis can be conducted on these lanes based on usage. Further study can be conducted once Bengaluru metro becomes fully operational.
- Comparative study of Bengaluru BRTS and Bengaluru metro can be carried out. This study was conducted using Excel, but it can also be done using other softwares.
- The questionnaires can be done online, and this can be shared with experts for their rating. This study includes only 21 factors, so more factors can be added, and study can be conducted.
- This study was conducted using a random sampling method; this can be improvised by taking more samples for better accuracy of results.

References

1. Afolabi Oluwaseyi, J., & Fashola Olawunmi, K. (2016) Assessment of bus rapid transit in efficient movement of commuters in lagos state. *European Journal Humanities, and Social Sciences*, *35*(1), 1951–1963.
2. Agarwal, P. K., Anupama, S., & Singh, A. P. (2010) An overview on bus rapid transit system. *Journal of Engineering Research, and Studies*, *I*, 195–205.
3. Rangarajan, A. (2010). BRTS-bus rapid transit system in Bengaluru: Modelling, simulation, and feasibility analysis. In *International Conference on Industrial Engineering, and Operations Management Dhaka*, Bangladesh, January 9–10 (pp.781–785).

4. Dron, C., & Hajiani, N. D. (2014). Traffic impact analysis BRTS-a case study of Ahmedabad BRTS. *IJEDR, 2*(2), 1956–1959.
5. Kumavat, C., Sonawane, H., Patel, T., & Sakhalkar, X. (2016). Effective learning from Delhi BRTS–a case study of Bengaluru BRTS. *International Journal of Research in Engineering, and Technology, 05*(04), 149–154.
6. Venter, C. (2016). Assessing the potential of bus rapid transit-led network restructuring for enhancing affordable access to employment. *Research in transportation economics*, 1–9.
7. Chaurasia, D., Sankat, S., & Solanki, S. K. (2017). Bus rapid transit system (BRTS): A case study to investigate its use by persons with disabilities. *Advances in Human Aspects of Transportation*, 799–809.
8. Chaurasia, D. (2013). Bus rapid transit system (BRTS): A sustainable way of city transport (Case Study of Bhopal BRTS). *International Journal of Engineering, and Advanced Technology (IJEAT)*, *3*(4), 55–63.
9. Patel, D., & Shukla, R. (2017). Effect of bus rapid transit system on urban corridor. In *ICRISET2017*, (Vol. 1, pp. 279–284).
10. Chengula, D., & Kombe, K. (2017) Assessment of the effectiveness of Dar Es Salaam bus rapid transit (DBRT) system in Tanzania. *International Journal of Sciences: Basic, and Applied Research (IJSBAR)*, *36*, 10–30.
11. Maeso González, E., & Pérez-Cerón, P. (2013). State of art of bus rapid transit transportation.
12. Gupta, K., Singh, A., Dwivedi, V., & Tandon, M. (2014). BRTS: an effective mode of public transport. *International Journal of Innovative Engineering Research (IJIER), 1*(1), 7–11.
13. Kumar K. H., & Jain, R. (2015). Bus rapid transit system in Bhopal City.
14. Galicia, L. D., & Chu, R. L. (2009). Bus rapid transit features, and deployment phases for U.S. cities. *Journal of Public Transportation*, *12*(2), 23–38.
15. Boulle, M., & van Ryneveld, P. (2015). The case of the MyCiTi bus rapid transit in cape town. Unpacking implementations.
16. Balwadkar, N. P., Kamble, A., Meyani, D. G., Pawar, A., & Pawar, K. S. (2018). Increasing efficiency of BRTS from Nigdi to Dapodi. *International Journal of Research Engineering, Science, and Management*, *1*(5): 111–113.
17. Satiennam, T., Fukuda, A., & Oshima, R. (2006). A study on the introduction of bus rapid transit system in Asian developing cities.
18. https://timesofindia.indiatimes.com/city/Bengaluru/satara-rd-brts-lane-swings-between-now-on-now-off/articleshow/73195966.cms.
19. https://www.google.com/amp/s/m.hindustantimes.com/Bengaluru-news/allvehicles-now-welcome-on-brts-lanes-in-Bengaluru/storyaAgkGiRtKb0shrgp8lbCAI_amp.html.
20. https://timesofindia.indiatimes.com/city/Bengaluru/Bengaluru-police-make-brts-corridors-free-for-all-vehicles-till-metro-chugs-in/articleshow/71002060.cms.
21. https://timesofindia.indiatimes.com/city/Bengaluru/brts-corridorconfusion-continues/articleshow/71055800.cms.
22. https://timesofindia.indiatimes.com/city/hubballi/lack-of-sufficient-parking-facility-at-brts-bus-stops-irks-passengers/articleshow/73393397.cms.
23. https://timesofindia.indiatimes.com/city/jaipur/commuters-say-bus-corridors-didnt-serve-purpose/articleshow/73453223.cms.

Town Planning

A Study on the Assessment of Risk Management in High-Rise Buildings

J. S. Raamkumar and B. Indhu

Abstract Construction activities in general, high-rise building construction in particular, come with a variety of risks. The reason for the enhanced risk factors could be attributed to the complexity and dynamic nature of the construction work involving high-rise buildings. Construction activities in high-rise buildings accounts for the majority of the accidents every year. In this work, an effort is taken to accurately assess and analyze different risk management factors like Physical Factors (PF), Organizational Factor (OF), Work Environment (WE), Safety Environment (SE), Design Factors (DF), Safety Protection (SP), Safety Behavior (SB), and Quality Factor (QF) in the construction of high-rise buildings in Chennai, Tamil Nadu. The study used quantitative survey method to collect the data from the key stakeholders. To study the influence of different risk management factors, 250 responses from construction personnel, clients, contractors and consultants were collected and analyzed using statistical tools. The reliability analysis show that all the risk management factors have Cronbach's Value above 0.7, indicating that the factors are reliably measuring the underlying constructs. The results of the empirical analysis show that work environment is the most dominant factor affecting the risk management in construction projects based on the mean value. Based on the CFA-SEM analysis, it is inferred that all the factors like Work Environment (WE), Physical Factors (PF), Organizational Factor (OF), Safety Environment (SE), Design Factors (DF), Safety Behavior (SB), Quality Factor (QF), and Safety Protection (SP) contributes significantly to the Risk Management Factors at 0.01 level. CFA Analysis shows that Design Factors ($B = 0.880$), Physical Factors ($B = 0.866$) and Safety Environment ($B = 0.847$) have significant contribution toward Risk Management Factors at 0.01 level. The findings of the study have several implications for managing risk factors in the high-rise building construction projects. The findings enrich the existing body of literature on risk management factors in the construction of high-rise buildings.

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Keywords Construction safety · High-rise building projects · Risk management factors

1 Introduction

The construction activities continues to remain as one of the most dangerous industrial sectors in the world, accounting for about 30 to 40% of fatal accidents despite employing just over 7% of the total workforce [1]. The highest percentage of workplace casualties (around 25.3%) occur in construction sites in Korea [2]. The construction site accidents account for the third-highest number of fatalities in the United States [3], and the fourth-highest fatalities in Australia occur in construction projects [4]. Construction industry is riskier next only to coal mining industry in China [5]. Tall buildings are becoming increasingly prevalent around the world. With high-altitude operation and excavation of deep foundation pits, high-rise building construction poses a major safety problem, resulting in far higher accident rates and severe incidents than medium- and low-rise buildings. Falls and the impact of falling objects are a continuous danger, resulting in injuries and deaths. Fast developing economy like India with massive progress in urbanization is witnessing increased volume of construction projects involving development of high-rise buildings and structures.

Risk management has become an indispensable process in the construction projects. Risk assessment, contingency planning, and risk control are all part of the risk management process. In general, different qualitative and quantitative methods are used to quantify risk factors. Risk management is a systemic approach to detecting, evaluating, and reacting to project risk, which involves optimizing the probability and consequences of positive attributes while decreasing the probability and consequences of negative attributes.

2 Review of Literature

Li et al. [8] have determined the key success factors (CSFs) in safety management for high-rise building construction projects. They also investigated relationships between these CSFs. The study identified six CSFs that are critical in high-rise construction projects, namely, management measures, management organization, technical and management plan, worker safety behavior, safety climate, and worker safety quality. Management organization was identified as the most important factor influencing construction safety management and it directly influenced worker safety behavior. Goh et al. [6] have identified and assessed different risk factors in construction projects in Egypt. The study found that delay, cost overrun, schedule overrun are the main risk factors in construction projects. Hair et al. [7] have identified different risk management factors in construction like design changes, environmental factors, management factors, resources, etc. Li et al. [8] identified different risk management factors in building construction like climate conditions, safety environment, financial factors, design factors, etc. Nunnally [9] discovered that critical risk factors have a broad impact on overall productivity in the construction of high-rise buildings. The study identified primary factors affecting the construction of high-rise building that included technological risk (44.2%), followed by environmental risk (48.2%), physical risks (48.8%), financial risks (49.2%), socio-political risks (51.2%), and constructional hazards (52.8%). Rezakhani [10] has conducted a quantitative study and collected responses from project manager, onsite project engineer, and other site engineers to identify the major risk factors. The study identified important factors affecting the high-rise construction that included technical hazards, financial risks, physical risks, and constructional hazards.

From the synthesis of the review of literature, eight factors were identified and hypothesized. These factors have significant impact on the risk management in high-rise construction projects. The factors identified were Physical Factors (PF), Organizational Factor (OF), Work Environment (WE), Safety Environment (SE), Design Factors (DF), Safety Protection (SP), Safety Behavior (SB), and Quality Factor (QF).

3 Methodology

3.1 Research Design

The study used quantitative research design method [11, 12] and a survey instrument developed by the researcher was used to collect data from the key stakeholders like Contractors, Employees, Consultants, and Clients. The survey instrument included 40 items to measure each of the eight factors. Thus, five items were used to each factor. The study adopted Likert scale type of instrument in which the respondents were asked to rate on a scale of one to five (Strongly Disagree to Strongly Agree).

3.2 Population and Sample

The population of the study consisted of key stakeholders involved in the construction of high-rise buildings in the Chennai region, [13] Tamil Nadu. Using a simple random sampling, 300 respondents representing the five different regions of Chennai, Tamil Nadu were identified for data collection. The entire Chennai region was divided into five zones as North, South, Central, East, and West. Data was collected from 60 samples from each of the four zones. However, only 250 responses were considered for final analysis, as few response sheets were not obtained and few had incomplete details. The response rate was 83.3%. Thus, the total number of sample of respondents was limited to 250.

Table 1 Profile of the respondents

Variable	Category	Frequency	Percent
Gender	Male	207	82.8
	Female	43	17.2
Age	18–28	150	60.0
	28–38	67	26.8
	38–48	33	13.2
Qualification	Higher Secondary and Below	20	8.00
	Under Graduate	102	40.80
	Post Graduate	75	30.00
	Diploma and Certification	53	21.20
Stakeholder type	Contractors	36	14.4
	Employees	101	40.4
	Consultants	68	27.2
	Clients	45	18.0

4 Data Analysis and Discussion

4.1 Profile of the Respondents

The demographic profile and professional affiliation are presented in (Table 1).

Majority of the study respondents were male (82.8%) and female constituted only 17.2%. The study included majority of the respondents (60%) from young age group of 18–28 years. 26.8% of the respondents were from the age group of 28–38 years and 13.2% were from 38–48 years. With respect to the qualification of the respondents, majority were Under Graduates (40.8%) and Post Graduates (30.0%). The study also included respondents with Diploma and Certification (21.20%) and Higher Secondary and Below qualification (8.00%). The study collected the details of professional affiliations of the respondents. 40.4% of the respondents were Employees and engineers of the construction companies, 27.2% of respondents were Consultants, and 14.4% were Contractors. The study also included client respondents of 18.0%.

4.2 Descriptive Statistics

The study identified that eight factors viz. Physical Factors (PF), Organizational Factor (OF), Work Environment (WE), Safety Environment (SE), Design Factors (DF), Safety Protection (SP), Safety Behavior (SB), and Quality Factor (QF) were

Table 2 Descriptive statistics (N = 200)

Safety management factors	Minimum	Maximum	Mean	Std. deviation	Skewness	Kurtosis
Physical Factors (PF)	3.40	5.00	4.29	0.45	0.34	−0.70
Organizational Factor (OF)	3.20	5.00	4.04	0.38	1.02	1.16
Work Environment (WE)	3.80	5.00	4.30	0.40	0.75	−0.74
Safety Environment (SE)	3.40	5.00	3.99	0.50	1.13	0.01
Design Factors (DF)	3.00	5.00	3.84	0.61	1.07	−0.26
Safety Protection (SP)	2.80	4.60	3.68	0.54	0.11	−0.96
Safety Behavior (SB)	2.60	5.00	3.80	0.48	0.17	0.89
Quality Factor (QF)	2.00	5.00	3.70	0.60	0.48	−0.06

mainly influencing the risk management process in high construction projects. The descriptive statistics of the study is shown in (Table 2).

From the (Table 2), it is inferred from the mean rating of the respondents that Work Environment (WE) is the top-rated factor with mean value (M) of 4.30 and standard deviation (SD) of 0.40. This was followed by Physical Factors (PF) (M = 4.29, SD = 0.45) and Organizational Factor (OF) (M = 4.04, SD = 0.38). All the factors were rated above mean rating of 3.5. The least rated factor was Safety Protection (SP) (M = 3.68, SD = 0.54). The values of Skewness and Kurtosis were below the prescribed limits of ± 2 for all the factors signifying that the data are normal and suitable for further statistical analyses.

4.3 Reliability Analysis

The statistical measure, namely, "Cronbach's Alpha" coefficient was used to measure the reliability of the survey instrument. The value of Cronbach's Alpha above 0.7 indicates that the instrument is reliable [14]. The results of reliability analysis as shown in (Table 3) indicates that the Cronbach's Alpha values for all the factors exceeds the threshold limit of 0.7. Thus, the survey instrument is reliable and can be conveniently used in the study.

Table 3 Reliability analysis

Smart city factors	No. of items	Cronbach's alpha
Work Environment (WE)	5	0.803
Physical Factors (PF)	5	0.883
Organizational Factor (OF)	5	0.953
Safety Environment (SE)	5	0.933
Design Factors (DF)	5	0.901
Safety Behavior (SB)	5	0.751
Quality Factor (QF)	5	0.801
Safety Protection (SP)	5	0.851

4.4 Structural Equation Model (SEM) Analysis

AMOS 21.0 was used to develop confirmatory factor analysis (CFA) model of SEM using various risk management factors in the construction of high-rise buildings. The variables used in the model were Work Environment (WE), Physical Factors (PF), Organizational Factor (OF), Safety Environment (SE), Design Factors (DF), Safety Behavior (SB), Quality Factor (QF), and Safety Protection (SP). Figure 1 shows the standardized estimates for the model on risk management factors. From the above CFA model of SEM, it is clear that the loading value of each variable exceeds 0.4 indicating that the model is valid.

The regression weights (both unstandardized and standardized) of the CFA-SEM Model are shown in (Table 4). The contribution of the individual variables like Work Environment (WE), Physical Factors (PF), Organizational Factor (OF), Safety Environment (SE), Design Factors (DF), Safety Behavior (SB), Quality Factor (QF), and Safety Protection (SP) toward Risk Management Factors was found to be significant as the p-value is less than 0.05.

From the above Table 4, it is inferred that Design Factors (DF) has the highest contribution towards Risk Management Factors with standardized factor loading of 0.880, followed by Physical Factors (PF) with a standardized factor loading of 0.866, and Safety Environment (SE) with a standardized factor loading of 0.847. The significant of the all the loading was 0.01. Work Environment (WE) with a standardized factor loading of 0.543, Organizational Factor (OF) with a standardized factor loading of 0.523, and Safety Behavior (SB) with a standardized factor loading of 0.415 have lower contribution toward Risk Management Factors.

4.5 Model Fit Summary

The goodness of fit of the model is shown in (Table 5). Hence, the model is considered as a good fit model. The values obtained for the indices like CFI (Comparative Fit Index), GFI (Goodness of Fit Index), AGFI (Adjusted Goodness of Fit Index), TLI

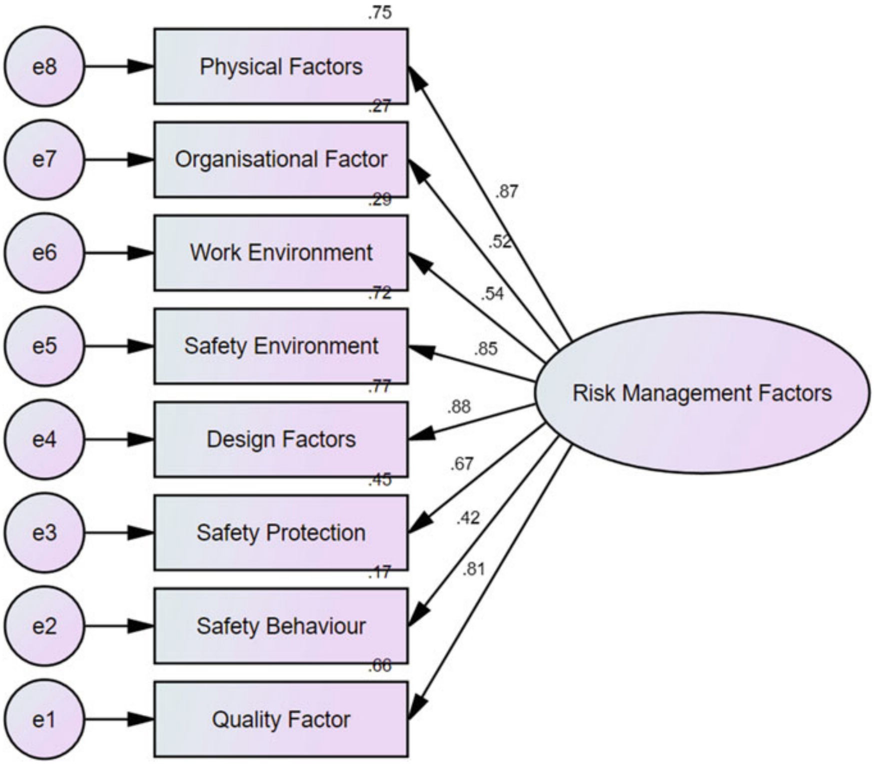

Fig. 1 Standardized regression coefficient

(Tucker-Lewis Index), NFI (Normed Fit Index), and RFI (Relative Fit Index) are better than the recommended value of 0.9 indicating that the model is perfectly fit (Daire et al. 2008). Similarly, RMSEA (Root Mean Square Error of Approximation) value was less near the recommended value of 0.2 [7], which again proves that the model is fit. Overall results of the analysis of fit indices values indicate that the generated values of the model are in conformance with standard values. Thus, the values for measurement variables are conforming to the recommended values. It is concluded that the CFA model is valid. The selected factors contribute significantly to the Risk Management Factors.

5 Conclusion

The design and construction of high-rise buildings is a complicated process that is affected by a variety of factors. Identification of risk management factors is critical to the success and sustenance of high-rise construction projects. This study has

Table 4 Regression weights of the SEM model

Observed variable		Latent variable	Standardized estimate	Unstandardized estimate	S.E	C.R	P
Quality Factor (QF)	<––	Risk management factors	0.811	1.000			
Safety Behavior (SB)	<––	Risk management factors	0.415	0.413	0.063	6.566	***
Safety Protection (SP)	<––	Risk management factors	0.668	0.742	0.065	11.359	***
Design Factors (DF)	<––	Risk management factors	0.880	1.113	0.068	16.441	***
Safety Environment (SE)	<––	Risk management factors	0.847	0.875	0.056	15.576	***
Work Environment (WE)	<––	Risk management factors	0.543	0.444	0.050	8.860	***
Organizational Factor (OF)	<––	Risk management factors	0.523	0.414	0.049	8.489	***
Physical Factors (PF)	<––	Risk Management factors	0.866	0.805	0.050	16.074	***

Table 5 Goodness of FIT–AMOS model (Industry)

Variable	Recommended value	Obtained value
Chi-square value	–	90.911
P value	p > 0.05	0.000
RMSEA	<0.2	0.128
RMR	<0.08	0.014
GFI	>0.90	0.942
AGFI	>0.90	0.905
CFI	>0.90	0.924
TLI	>0.90	0.902
RFI	>0.90	0.914
NFI	>0.90	0.908
Chisq/df	<5.0	4.54

successfully identified the eight factors like Physical Factors (PF), Organizational Factor (OF), Work Environment (WE), Safety Environment (SE), Design Factors (DF), Safety Protection (SP), Safety Behavior (SB), and Quality Factor (QF) that have significant impact in the construction of high-rise buildings.

The data for the study was collected from key stakeholders like contractors, employees, consultants, and clients using a quantitative survey. Based on the mean rating, the study found that Work Environment, Physical Factors, and Organizational Factors are the top-rated risk management factors in high-rise construction projects. These factors play a crucial role in the performance of projects; hence, it is important that that these risk factors should be managed by adequate risk assessment techniques. However, the validity of the study findings has to be evaluated in future with larger sample size involving larger number of projects.

The findings of the study have both theoretical as well as practical implications. In terms of theoretical contributions, the findings add to the vast body of literature on safety and risk management in high-rise construction projects. The significance of the different risk factors was measured by CFA-SEM analysis. Design factors has the highest loading of 0.88 on the risk management factors, followed by Physical Factors (PF) and Safety Environment (SE). Safety Behavior (SB) has the lowest contribution toward Risk Management Factors. In terms of practical contributions, the findings suggest that risk management in high-rise construction projects can be greatly enhanced if the Design factors, Physical Factors, and Safety Environment are given proper consideration in the high-rise construction projects.

References

1. Abd El-Karim, M. S. B. A., Mosa El Nawawy, O. A., & Abdel-Alim A. M. (2017). Identification and assessment of risk factors affecting construction projects. *HBRC Journal*, *13*(2), 202–216.
2. Bureau of Labor Statistics (BLS). (2013). *Fatal Occupational Injuries by Industry and Event or Exposure, All United States 2014*. Retrieved from https://www.bls.gov/iif/oshwc/cfoi/cftb0286.pdf.
3. Chougule, A., & Waghmare, A. (2015). Risk management in high-rise building construction. *International Journal for Scientific Research and Development, 3*(6), 601–602.
4. Creswell, J. W., & Creswell, J. (2003). *Research design*. Thousand Oaks, CA: Sage Publications.
5. Daire, H., Joseph, C., & Michael, R. M. (2008). Structural Equation Modeling: Guidelines for Determining Model Fit. *The Electronic Journal of Bussiness Research Methods, 6*(1), 53–60.
6. Goh, C. S., Abdul-Rahman, H., & Abdul Samad, Z. (2013) Applying risk management workshop for a public construction project: Case study. *Journal of Construction Engineering and Management*, *139*(5), 572–580.
7. Hair, J. F., Anderson, R. E., Tatham, R. L., Black, W. C. & Babin, B. J. (2006). *Multivariate data analysis* (pp. 734–735). New Delhi: Pearson Education.
8. Li, Y., Ning, Y., & Chen, W. T. (2018). Critical success factors for safety management of high-rise building construction projects in China. *Advances in Civil Engineering*.
9. Nunnally, J. C. (1975). Psychometric theory—25 years ago and now. *Educational Researcher, 4*(10), 7–21.
10. Rezakhani, P. (2012). Classifying key risk factors in construction projects. *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura*, *58*(2), 27.

11. Safe Work Australia. (2013). *Work-Related Traumatic Injury Fatalities Australia 2012*. Retrieved from http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/811/Traumatic-Injury-Fatalities-2012.pdf.
12. Sakthiniveditha, V., & Pradeep, T. (2015) A study on risk assessment in the construction of high-rise buildings. *International Journal of Science and Engineering Research (IJOSER)*, 3(2), 0–4.
13. Sunindijo, R. Y., & Zou, P. X. W. (2012) Political skill for developing construction safety climate. *Journal of Construction Engineering and Management*, *138*(5), 605–612.
14. Yi, J., et al. (2012) A suggested color scheme for reducing perception-related accidents on construction work sites. *Accident Analysis & Prevention*, *48*, 185–192.

Analysis of Duplex House with Underground Parking

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Abstract A Duplex House is one of the type of dwellings that has apartments with separate entrances (main doors) for two different families. In simple words, it has two separate flats within the same structure. Apartments of this type are more economical to build. Underground Parking is a structured parking built below the ground level. The vehicle is prevented from heat, rain and other external forces. On the other hand, the space that is saved on the ground can be used for garden, lawns and other purposes. The plan, section and elevation of the building have been made in the AutoCAD; keeping in mind the NBC norms. The 3D structure of the building has been analyzed in the STAAD. Pro; and shear force and bending moment diagrams have been studied. After considering financial and economic factors, it was found that the duplex house is more economical for metropolitan cities like Chennai, Mumbai, Kolkata, New Delhi, Bangalore and Hyderabad; where population density is very high. Preservation of the prime real estate is one of the long-term benefits of underground parking; that offers convenient parking and removing parking structures from street frontage (thus enhancing the facade of the structure).

Keywords Duplex house · Underground parking · Retaining wall · Lateral earth pressure · Safebearing capacity of soil

1 Introduction

To provide affordable lifestyle in limited area of land in the metropolitan cities, duplex houses are being constructed on larger scale these days. The analysis was done using the STAAD. Pro software. The building (duplex house) is subjected to

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both the vertical load as well as horizontal load. Dead loads of the structural members (beams, columns, slabs) and live loads are the two types of vertical loads. The lateral earth pressure is the horizontal load. Wind load has negligible effect on this structure. The structural members were designed and analyzed using Limit State Design. The total area of the plot is 90 m^2 (963 square feet). Setback distance of 0.5 m has been provided on all the four sides of the building. Nine main columns of square cross-section (0.3 m × 0.3 m) have been designed and one additional column has also been provided inside. A short straight ramp lets the cars enter the underground parking area, where two cars and two bikes can be easily parked. Parapet wall of height 0.5 m has been erected on the terrace. Multi-storey car parking and underground car parking have become very essential in the modern apartments' culture. Raft Foundation has been provided throughout the area of the plot. The maximum and minimum values of bending moment and shear force have been tabulated.

2 Literature Review

Retaining wall has been analyzed under static and seismic conditions. This wall has to face the lateral pressure of soil and has various applications in hydraulic structures, railways, highways and tunnels. Only the retained soil mass exerts the lateral earth pressure (in the static condition); and therefore, the deformation due to static loading may be negligibly small. The force that is seismically induced has greater influence on lateral earth pressure in earthquake prone areas. In the recent decades, permanent deformations have been caused to so many retaining wall type structures [1, 2]. In some cases, during earthquake, retaining walls have been collapsed with disastrous physical and economic consequences; so the dynamic earth pressure has to be evaluated accurately.

Active earth pressure (for cohesion-less soil) has been evaluated under different boundary conditions. To determine the impact of active earth pressure on the retaining structures, various soil parameters like φ, α, β and height of the retaining structure (H) have to be studied in detail. When ground elevation has the desired change, which exceeds the angle of repose (or to retain the backfill), retaining structures are constructed to resist the lateral pressure of backfill material. Therefore, all the factors that influence the magnitude of lateral earth pressure must be thoroughly studied and examined. Using Graphical Solution of Culmann, the magnitudes (positive as well as negative values) of pressure under various cases were analyzed graphically and were compared with those obtained using Elastic Theory; that clearly shows the decrease in active earth pressure with the increase in load distance (0.3H, 0.5H, 0.7H) from the face of the retaining wall [3–5].

3 Planning

The plan for the duplex house has been prepared in AutoCAD, keeping in mind the NBC norms. The location plan is shown in (Fig. 1).

The area of the plot is 90 m^2. The selected site lies in Anna Nagar, Chennai, which falls under Seismic Zone III (moderate intensity), and the soil is clayey (generally brick red in color) with a small amount of Titanium in it. The plan of underground floor is shown in (Fig. 2).

A short straight ramp lets the vehicles enter the underground parking area, where two cars and two bikes can be easily parked. The dimension of the slot for car parking is 4 m × 3 m. The plan of the ground floor is shown in (Fig. 3).

The entrance gate for the first floor has been provided next to the staircase of ground floor. Both of the rooms and kitchen of the ground floor are directly connected to the Hall. The staircase can be accessed from the hall too.

The plans of the ground and first floors shown in (Fig. 4) are quite similar. Balcony has been provided on the first floor that faces the roads on both sides. Sunlight can enter inside the flat from all the four sides.

This is the front view of the building shown in (Fig. 5). The parapet wall of 0.5 m has been provided at the terrace on all the four sides.

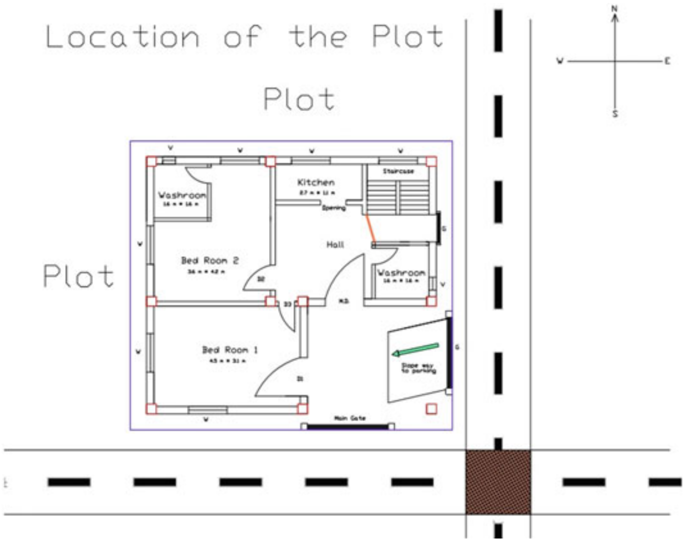


Fig. 1 Location of the plot

Fig. 2 Plan of the underground floor

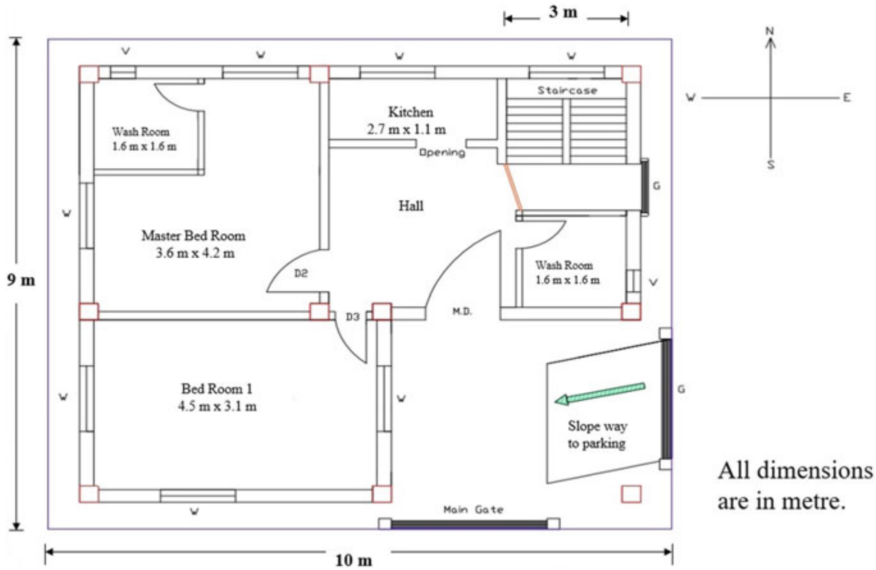


Fig. 3 Plan of the ground floor

4 Analysis

The structure was analyzed using STAAD.Pro software, and Shear Force Diagram and Bending Moment Diagram were studied as shown in (Fig. 6).

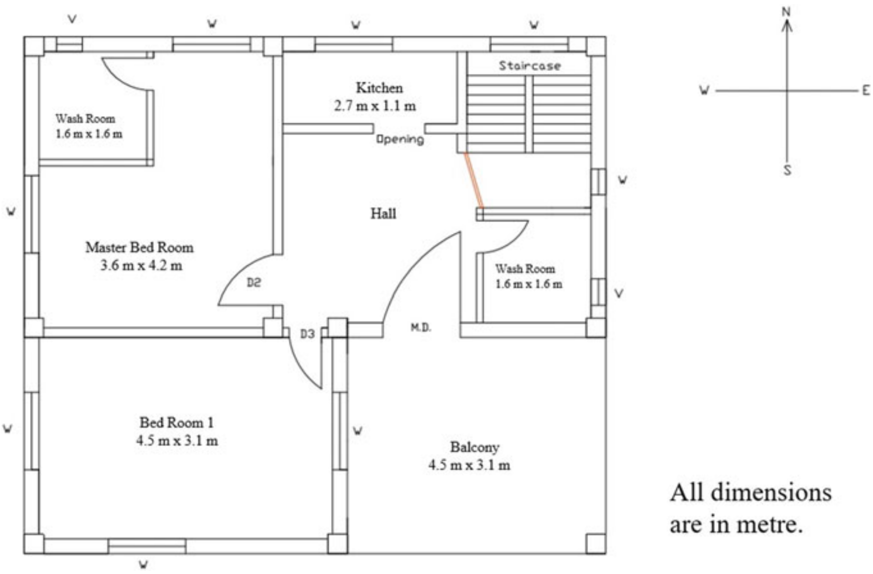


Fig. 4 Plan of the first floor

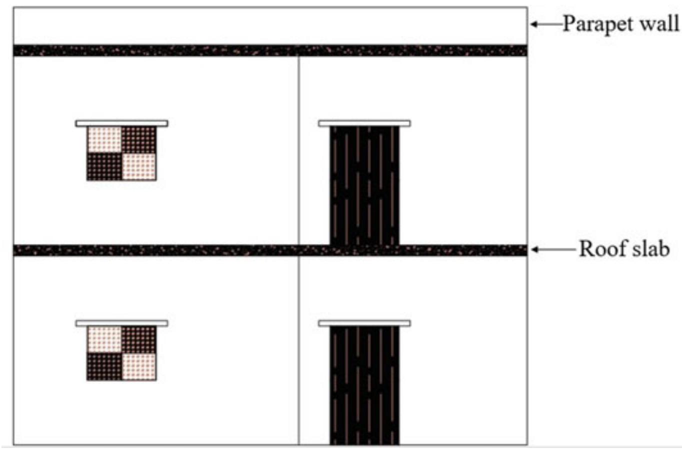


Fig. 5 Elevation

For structural members, M25 grade of concrete and Fe415 grade of reinforcement (HYSD bars) have to be used. External walls are 230 mm thick with 12 mm plaster (including both sides of wall). The value of Ec is 2,500 N/mm^2. Height of each storey is 3.3 m and magnitude of various loads are given below in the (Figs. 7, 8, 9, 10, 11, 12, 13, 14 and 15).

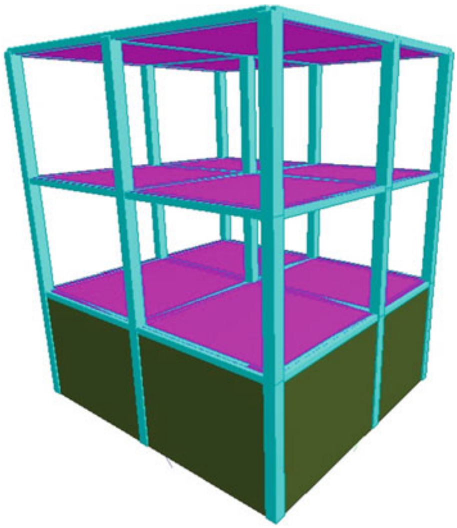


Fig. 6 3D diagram of the structure along with the retaining walls

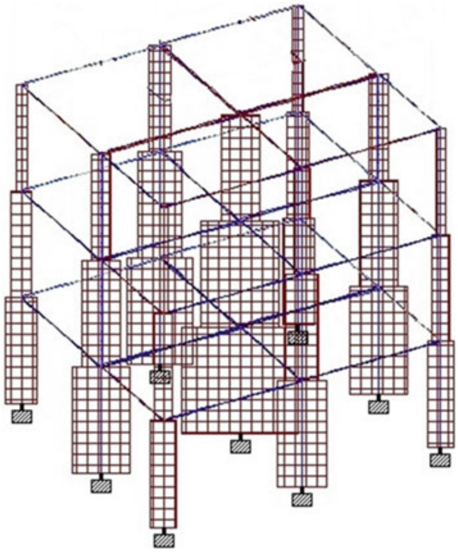


Fig. 7 Axial Force diagram

1. Live load: 4.0 kN/m^2.
2. Floor finish: 1.0 kN/m^2.
3. Terrace finish: 1.0 kN/m^2.
4. Water proofing: 2.0 kN/m^2.

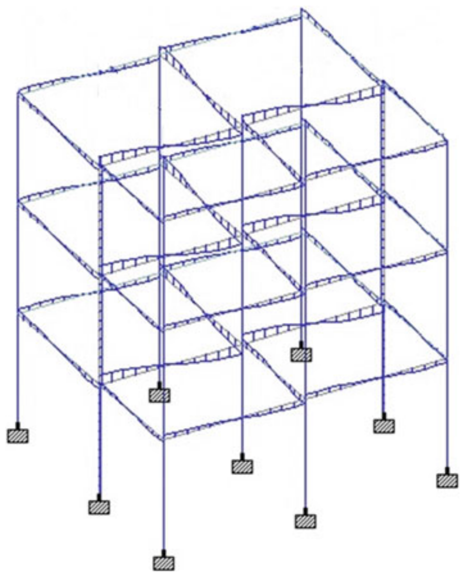


Fig. 8 Shear Force diagram along Y-axis

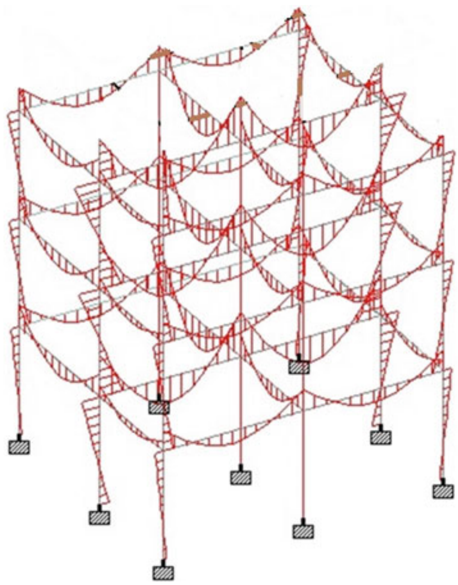


Fig. 9 Bending Moment diagram along Z-axis

5 Results

Below, the details of Axial Force, Shear Force Torsion and Bending Moment have been shown in Table 1.

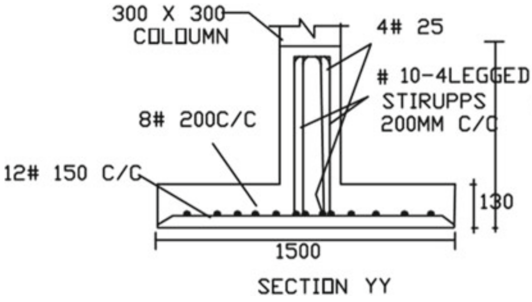
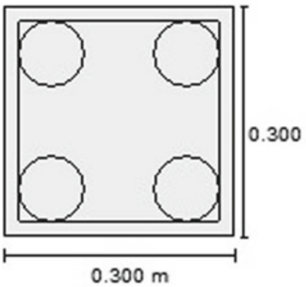


Fig. 10 Reinforcement details of the footing



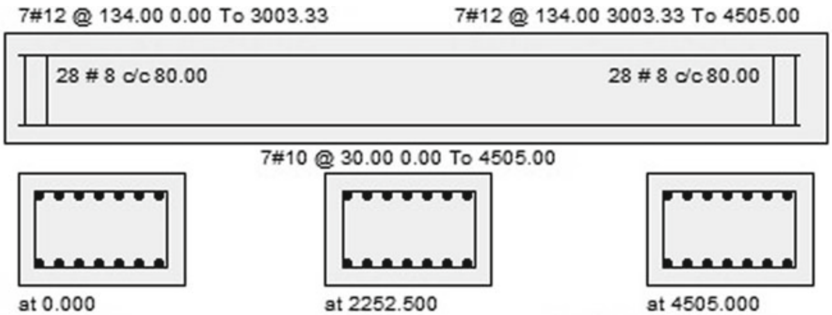
Design Load

Load	1
Location	End 1
Pu(Kns)	324.51
Mz(Kns-Mt)	0.21
My(Kns-Mt)	0.19

Design Parameter

Fy(Mpa)	550
Fc(Mpa)	30
As Reqd(mm²)	194
As (%)	0.50
Bar Size	12
Bar No	4

Fig. 11 Reinforcement details of the column



Design Load

Mz Kn Met	Dist. Met	Load
-6.36	0.4	2
-10.62	0	2
-10.54	4.5	2

Design Parameter

Fy(Mpa)	550
Fc(Mpa)	30
Depth(m)	0.165000006
Width(m)	0.25
Length(m)	4.505000114

Fig. 12 Reinforcement details of the beam

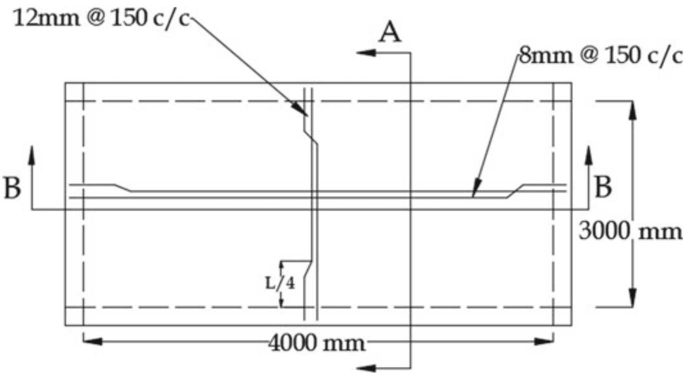


Fig. 13 Reinforcement details of the two-way slab

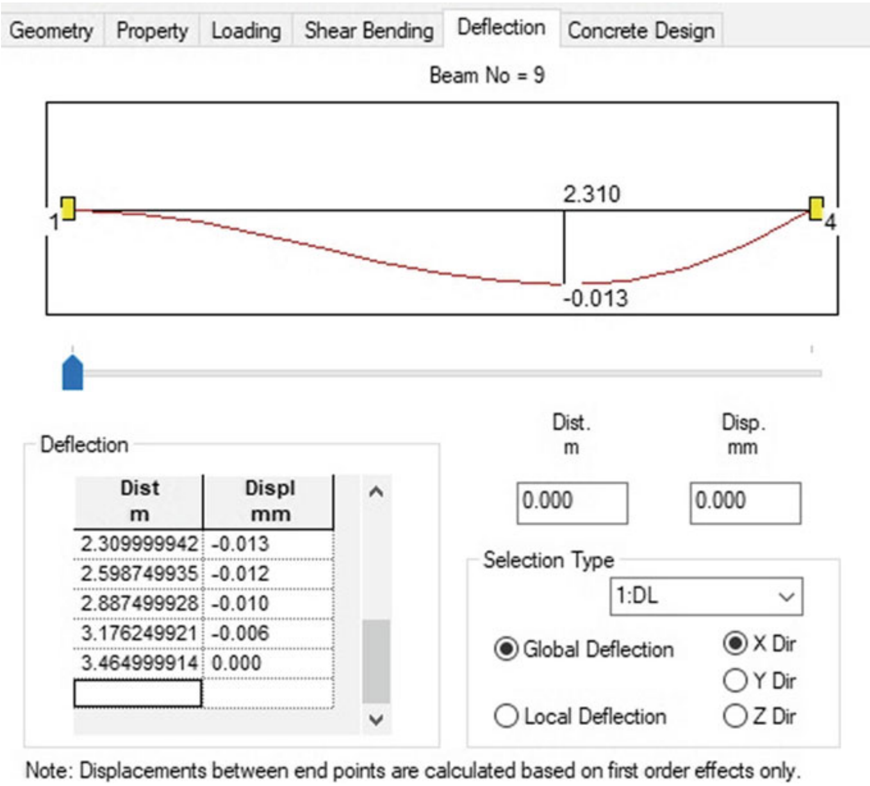


Fig. 14 Deflection diagram of the column

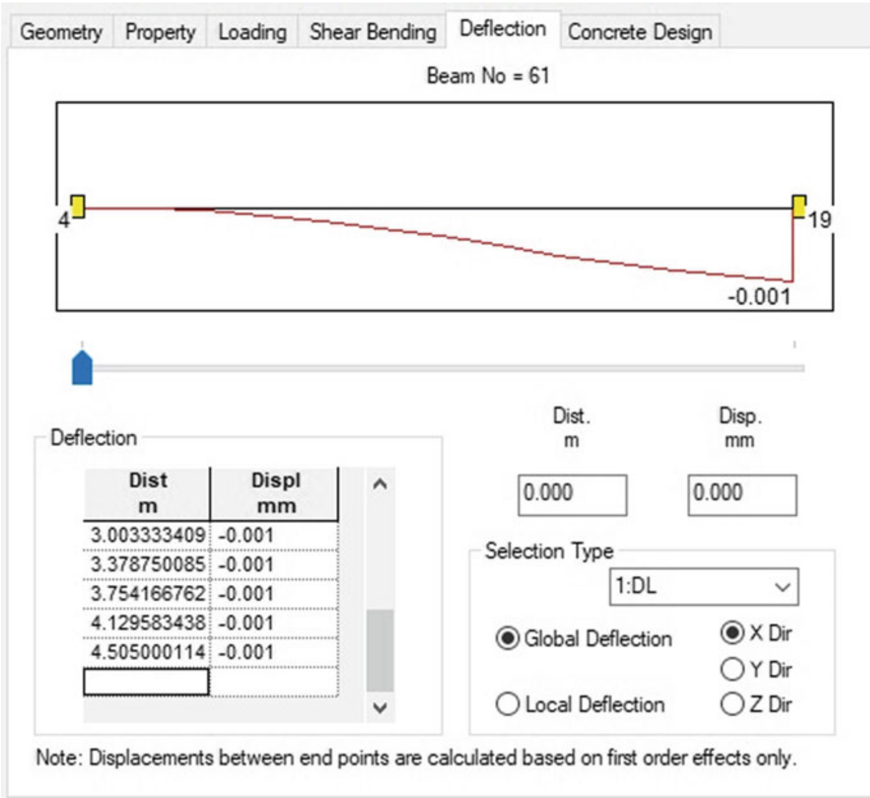


Fig. 15 Deflection diagram of the beam

Table 1 Table showing the values of Axial Force, Shear Force, Torsion and Bending Moment

		Axial	Shear	Shear	Torsion	Bending	Bending
		Max Fx (kN)	Max Fy (kN)	Max Fz (kN)	Max Mx (kN m)	Max My (kN m)	Max Mz (kN m)
Column 0.30 × 0.30	Max + ve	324.507	6.453	6.752	0.009	12.662	12.088
	Max − ve	− 1.129	− 6.453	− 3.455	− 0.009	− 11.786	− 12.088
Beam 0.17 × 0.25	Max + ve	3.997	22.457	0.043	0.173	0.096	21.068
	Max − ve	− 2.387	− 22.457	− 0.043	− 0.173	− 0.097	− 12.497
Beam 0.17 × 0.25	Max + ve	4.119	22.846	0.019	0.193	0.049	21.275
	Max − ve	− 2.497	− 22.908	− 0.019	− 0.193	− 0.049	− 13.225

6 Conclusions

The duplex house (a type of residential building) is suitable for metropolitan cities like Chennai and Delhi, where affordable lifestyle in limited area of land can be experienced. By providing underground parking, the space on the ground which is saved can be used for other purposes such as gardens and lawns. Underground parking space can also be utilized for storing the items.

Retaining walls are compulsory for the underground floor to withstand the lateral pressure of the soil and backfill (brick masonry walls cannot withstand such loads), and to protect the building from seismic forces upto some extent.

References

1. Thakur, A., & Chattopadhyay, B. C., et al. (2017). Active earth pressure on cohesion-less soil: theoretical and graphical considerations. *International Journal of Engineering Trends and Technology*, *49*(6), 394–397.
2. Chetan, V., KeerthiGowda, B. S., et al. (2014). Analysis of underground parking structure. *International Journal of Emerging Trends in Engineering and Development*, *3*(4), 838–843.
3. IS 456. (2000). Plain and Reinforced Concrete Code of Practice (Fourth Revision), Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-110002.
4. IS 875 (Part 1). (1987). Code of Practice for Design loads (other than earthquake) for buildings and Structures (Dead Loads), Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi-110002.
5. Jongo, J. S., Tesha, D., & Luvara, V. G. M., et al. (2018). Fire safety preparedness in building construction sites in Dar-Es-Salaam, Tanzania. *International Journal of Engineering Trends and Technology*, *66*(3), 154–169.

Behaviour of Pre-engineered Building with Reduced Beam Section

Karthikeyan Rajendiran, R. Deby Linsha, and S. Pradeep

Abstract Pre-Engineered buildings are being widely used as industrial structures due to their light weight, column free spaces and various other benefits. The incorporation of reduced beam Section in industrial moment resistant frames is not presented in India. Using Reduced Beam Section connection, the seismic performance of industrial structures which have high importance factor is enhanced. This led to the analysis of Pre-Engineered building with reduced beam section for different spans. The parameter s in this study is RBS profile dimension. The dimensions of reduced section are varied for each span and analysed using the computer program, STAAD.Pro. The analysis observed that stress concentration at beam column joint is less in models with reduced beam section. Maximum response of the structure is at the reduced sections which ensure ductile behaviour under seismic excitations.

Keywords Ductile · Pre-engineered building · Reduced beam section · Seismic performance

1 Introduction

One of the prequalified moment connections suggested by investigators post the Northridge and Kobe earthquakes is the Reduced Beam Section (RBS) connection. It was developed as an alternative to the conventional connections in steel moment frames which have poor seismic performance. It is a weakening strategy wherein a portion of beam flanges are cut down at appropriate distance from column face as shown in the Fig. 1. This forces the plastic hinge formation at the reduced section and promotes stable yielding. Stress concentrations occur at these weaker zones still allowing large rotations at plastic hinges necessary for ductile behaviour. Thus, the

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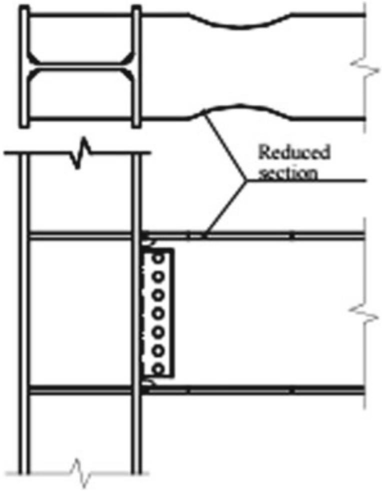


Fig. 1 Reduced beam section

beam column joint remains intact under seismic loads preventing the collapse of entire structure.

The performance of RBS moment connection has been analysed and experimentally verified by various researchers. The study of such a connection for Indian profiles is in initial stages [1]. Different flange cut geometries were studied and radius cut reduced section was found to be more adequate [2].

A brief explanation on the various parameters affecting the response of RBS connection such as connection strength, RBS profiles, use of deep columns have been presented [3]. Further research works have been carried out on connection strength and deep columns [4] but not on RBS dimensions. Moderately strong panel zone is selected for appropriate performance as it is a major influencing factor in the cyclic performance of RBS connection [5]. Welded connection is used widely as experimental results show bolted connection perform poorly due to premature brittle fracture of beam flange [6]. Requirements of plastic joint rotation were met without the use of continuity plates [7].

With the many favourable benefits of pre-engineered buildings (PEB) they find applications in warehouses, factories, aircraft hangers, railway platform shelters, etc. The advantages of RBS moment connection have not been used for Indian Profiles. The fabrication of radius cut reduced section is relatively simple and can be done at the factory along with PEB. Thus, in this paper the applicability of such a connection is being studied for industrial moment resistant frames.

Table 1 Adequate section for different spans of PEB

Span (m)	Adequate section
15	WPB 550 × 300
20	WPB 700 × 300
25	WPB 900 × 500
30	WPB 900 × 500

Table 2 Section properties

Section	Area (cm^2)	Depth (mm)	Width (mm)	Web thickness (mm)	Flange thickness (mm)	Inertia about X-axis (cm^4)	Inertia about Y-axis (cm^4)
WPB 300	149.1	300	300	11	19	25,166	8562.8
WPB 500	238.6	500	300	14.5	28	107,176	12,623.9
WPB 550	254.1	550	300	15	29	136,691	13,076.9
WPB 700	240.51	700	300	17	32	256,888	14,440.8
WPB 900	371.3	900	300	18.5	35	494,065	15,815.9

2 Modelling

2.1 Analysis and Design of PEB

Pre-engineered buildings satisfy the requirement of large column free spaces. The typical span ranges from 15 to 80 m. In this paper, 2D portal frames of span 15, 20, 25 and 30 m are selected for analysis. Ideal eave height of PEB as 6 m with roof slope of 1:10 is chosen. Wind force as per IS 875 (Part III) [8] and seismic forces as per IS 1893 (Part I) [9] was considered and analysed for each span. Using the Stiffness Analysis Program (SAP), the adequate section for each span is determined by trial and error. The sections are chosen from Indian Standards IS 12778 [10] having yield stress of 415 MPa. Hot rolled wide parallel flange (WPB) I beam sections are widely used for steel structures in India. The suitable section for each span and their properties are listed in Table 1 and Table 2, respectively.

2.2 RBS Geometry/Profile

Generally, the RBS connection implements radius cut to minimise stress concentration preventing fracture of the reduced section. The beam flange reduction parameters include the distance from column face ‘a’, the length of reduced section ‘b’ and the depth of reduction ‘c’ as shown in Fig. 2. The length of reduced section is dependent on the depth of the member.

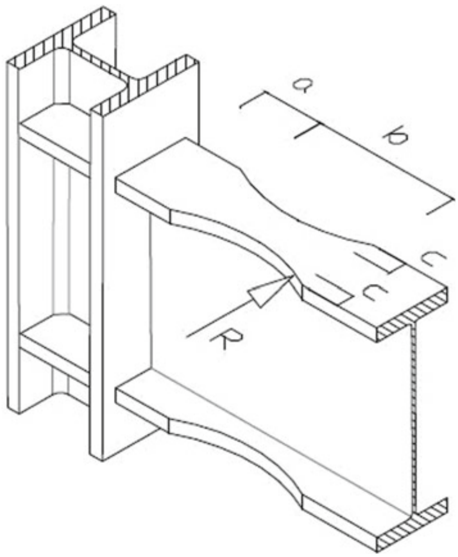


Fig. 2 Reduced beam section profile

According to ANSI/AISC 385-10, the limits of RBS dimension a, b and c is:

$0.5b_f \leq a \leq 0.75b_f$
$0.65d \leq b \leq 0.85d$
$0.1b_f \leq c \leq 0.25b_f$

where b_f and d are the breadth and depth of section, respectively.

2.3 RBS Parameters

The panel zone strength, connection type, use of deep columns, continuity plates are some of the parameters studied earlier by researchers. Much of the research work has been concentrated in these areas while the RBS sizing has been left unattended. Hence, in this paper, the RBS dimensions distance from column face, length of reduced section and depth of cut are considered. The dimensions are chosen within the limits specified by ANSI/AISC 385-10. The reduced sections are designated as RBS 1, RBS 2 and RBS 3 and without reduced beam section as WRBS. Table 3 shows the Flange reduction parameters.

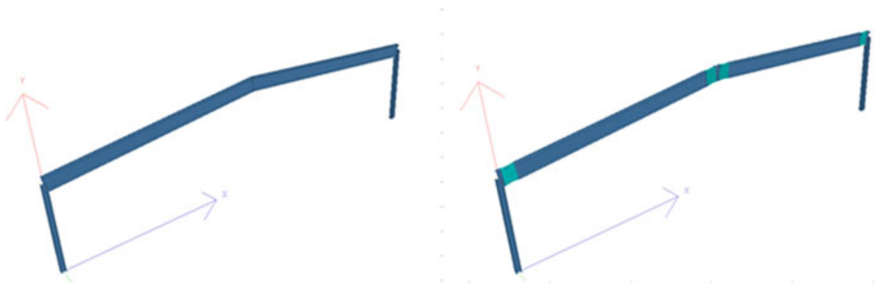
Table 3 Flange reduction parameters

Span/section (m/mm)	Model	Distance from column face 'a' (mm)	Length of RBS 'b' (mm)	Depth of cut 'c' (mm)	Radius of cut 'R' (mm)
15 WPB 550 × 300	RBS 1	150	357.5	30	547.52
	RBS 2	195	412.5	45	495.15
	RBS 3	225	467.5	75	401.76
20 WPB 700 × 300	RBS 1	150	455	30	877.6
	RBS 2	195	525	45	788.12
	RBS 3	225	595	75	627.54
25 WPB 900 × 300	RBS 1	150	585	30	1440.94
	RBS 2	195	675	45	1228.12
	RBS 3	225	765	75	1012.87
30 WPB 900 × 300	RBS 1	150	585	30	1440.94
	RBS 2	195	675	45	1228.12
	RBS 3	225	765	75	1012.87

3 Analytical Study

3.1 STAAD.Pro Model

For PEB analysis, STAAD.Pro software is a very useful tool. For each span of PEB, four models are analysed. One conventional without reduced beam section WRBS model and other three reduced beam section models RBS 1, RBS 2 and RBS 3 of different dimensions. The modulus of elasticity considered is equal to 210 kN/mm^2 and Poisson ratio is 0.3. The member properties are user defined as per IS 12778 [10] having yield stress of 415 MPa. The supports are pinned. The Fig. 3a shows the conventional moment connection PEB WRBS. The RBS connections are modelled



(a) (b)

Fig. 3 Model of **a** PEB WRBS **b** PEB RBS

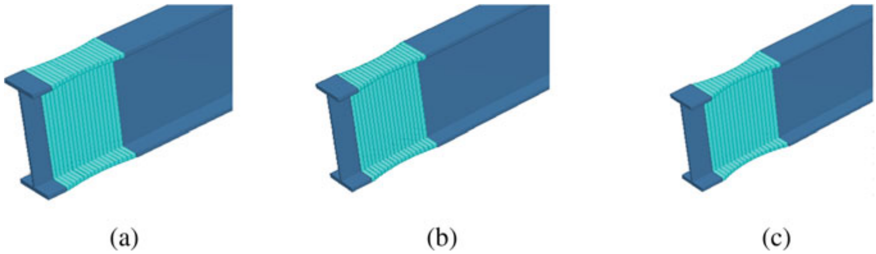


Fig. 4 Model of PEB **a** RBS 1 **b** RBS 2 **c** RBS 3

by dividing the length of reduced section into equal sections. Tapered beam sections are assigned to each element. For a portal frame, plastic hinge is formed at the beam column joints and ridge. So, the RBS connections are located at a distance from column near the joints and from apex of the structure as shown in Fig. 3b. A detailed view of the three reduced sections for 30 m span is seen in Fig. 4a–c. In this work, response spectrum analysis has been done on all 16 models using the computer programme STAAD.Pro.

4 Analysis Results

4.1 Base Shear

Base shear is an estimate of the maximum expected lateral force on a structure due to seismic ground motion. It depends on the soil conditions, ductility, weight of structure and natural time period. In RBS connection, the beam flange area is reduced. This reduces base shear which implies an equivalent reduction in forces applied to the foundation. The base shear values of the four models for each span is plotted and shown in Figs. 5a, b and 6a, b.

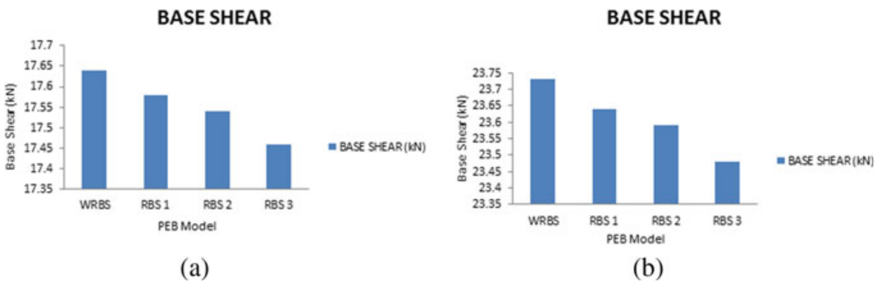


Fig. 5 Base shear comparison graph **a** 15 m **b** 20 m

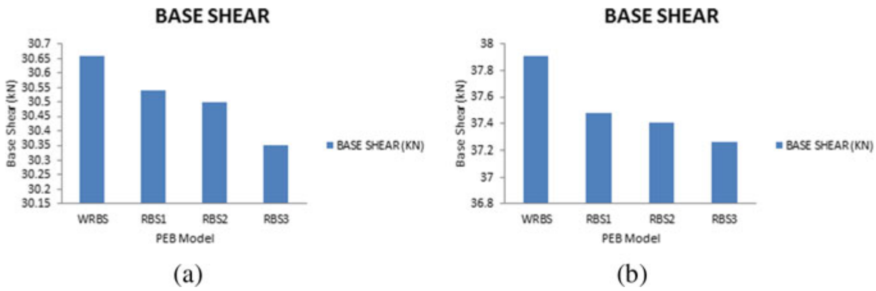


Fig. 6 Base shear comparison graph **a** 25 m **b** 30 m

4.2 Time Period

The fundamental natural period is an inherent property of a building. In RBS connection, there is a reduction in area hence the time period is shorter (less than 0.4 s). The time period values of first six modes for spans 15, 20, 25 and 30 m are plotted in Figs. 7a, b and 8a, b. For all spans in the first mode time period decreases for RBS connections.

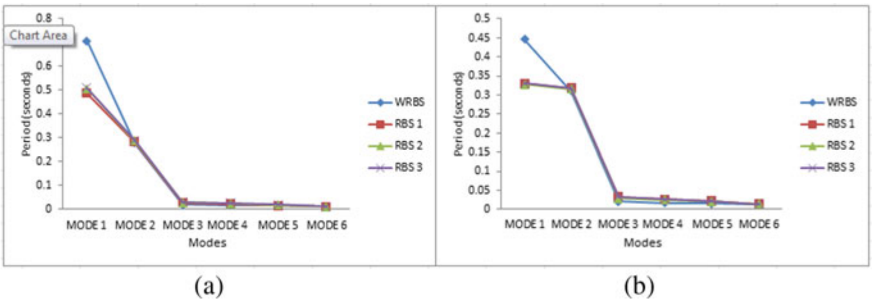


Fig. 7 Time period graph **a** 15 m **b** 20 m

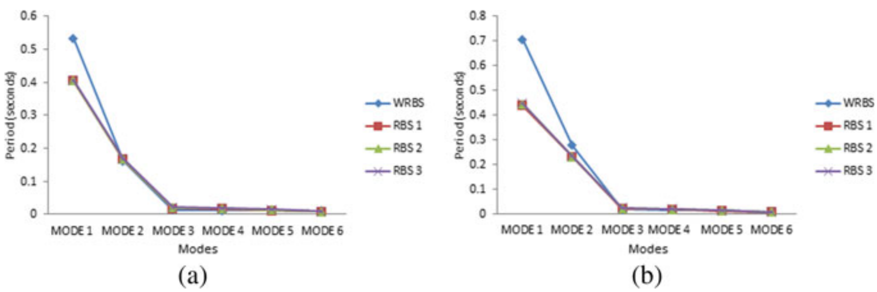


Fig. 8 Time period graph **a** 25 m **b** 30 m

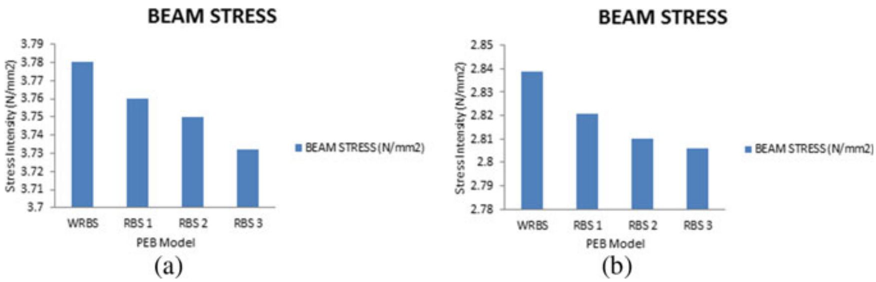


Fig. 9 Stress intensity at beam column joint for **a** 15 m **b** 20 m

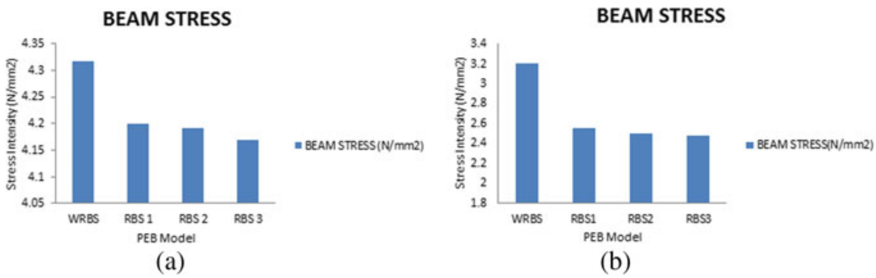


Fig. 10 Stress intensity at beam column joint for **a** 25 m **b** 30 m

4.3 Stress Concentration

From the analysis results, it is clear that the stress concentration at the reduced sections is more with a considerable reduction in stress at the beam column interface. As seen from earlier studies, the stress concentration will be uniformly distributed in radius cut RBS unlike other straight and taper cut reduced sections. So, there is less probability of fracture in radius cut reduced section. The stress intensity at beam column joint of all the four models of each span are plotted and shown in Figs. 9a, b and 10a, b.

4.4 Maximum Response

The beam elements are interconnected at points called nodes. The response spectrum analysis gives the displacement at these nodes which are quite small and are shown in millimetre (mm). From analysis results it is seen that displacement is less for PEB with reduced sections as shown in Figs. 11a, b and 12a, b. The maximum displacements occur at the reduced sections for RBS connections, while for WRBS, it occurs at the peak.

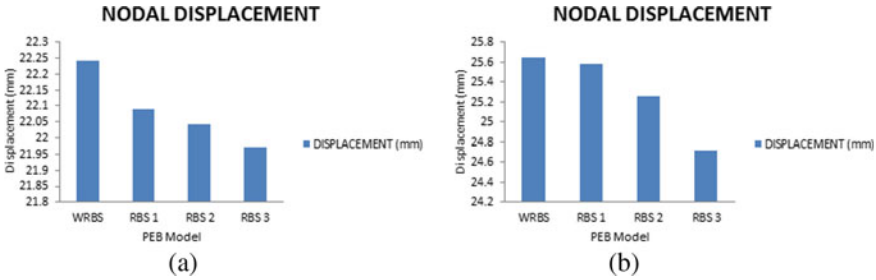


Fig. 11 Displacement graph **a** 15 m **b** 20 m

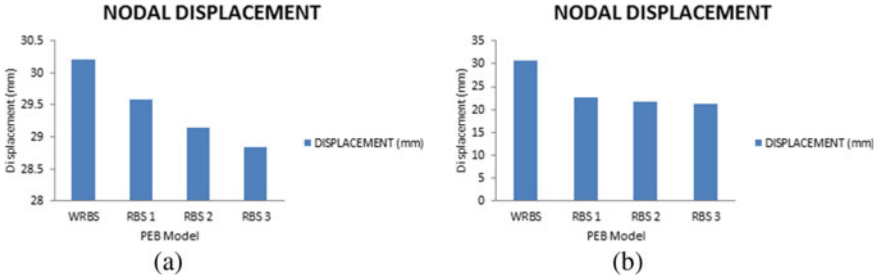


Fig. 12 Displacement graph **a** 25 m **b** 30 m

5 Conclusion

The analytical studies reveal that the PEB with reduced beam section connection was much superior to connection without reduced section under seismic excitation. The maximum lateral force on the industrial structure with reduced section is less due to reduction in self-weight. The sections are chosen from Indian Standards IS 12778 [10] having yield stress of 415 MPa. The reduced beam section dimensions are chosen within the limits specified by ANSI/AISC 385-10. The sections are not available according to our Indian codes but can be used from ANSI/AISC 385-10 code of practise. The use of RBS is very less in India hence can be used to enhance the seismic performance of the structure. The stress concentration at beam column joint of structure with RBS moment connection is less than conventional moment connection. Using RBS, the stress concentration at beam column joint is reduced by about 25% approximately. This implies that under seismic loads the connection is protected against early fracture. The nodal displacement values are about two times less in PEB with reduced sections. From mode shapes, it is clear that in PEB with RBS maximum displacement occurs at the beam span and column remains relatively stiff. Thus, PEB with reduced section can be used for Indian profiles in high seismic zones.

References

1. Swati, A. K., & Gaurang, V. (2014). Study of steel moment connection with and without reduced beam section. *Case Studies in Structural Engineering*, *1*(1), 26–31
2. Swati Ajay, K., & Gaurang, V. (2013). A study of reduced beam section profiles using finite element analysis. *IOSR Journal of Mechanical and Civil Engineering*, 01–06.
3. Sophianopoulos, D. S., & Deri, A. E. (2011). Parameters affecting response and design of steel moment frame reduced beam section connections: An overview. *International Journal of Steel Structures*, 133–144.
4. Shen, J.-H. J., Astaneh-Asl, A., & McCallen, D. B. (2002). Use of deep columns in special steel moment frames. *AISC*.
5. Lee, C.-H., Jeon, S.-W., Kim, J.-H., Kim, J.-H., & Uang, C.-M. (2004). Seismic performance of reduced beam section steel moment connection: Effects of panel zone strength and beam web connection method (p. 3449).
6. Jones, S. L., Fry, G. T., & Engelhardtc, M. D. (2000). Reduced beam section welded steel moment frames. In *12 WCEE*.
7. Adan, S. M., & Reaveley, L. D. (2004). The reduced beam section moment connection without continuity plates (p. 1504).
8. IS 875 (Part III). (1987). Indian standard code of practice for design loads for buildings and structures. In *Bureau of Indian standard*, New Delhi.
9. IS 1893 (Part-I). (2002). Indian standard code of practice for criteria for earthquake resistant design of structures. In *Bureau of Indian standard,* New Delhi.
10. IS 12778. (2004). Hot rolled parallel flange steel sections for beam, column and bearing piles-dimensions and section properties. In *Bureau of Indian standards*, New Delhi.
11. ANSI/AISC 358-10. (2010). Prequalified connections for special and intermediate steel moment frames for seismic applications. In *American Institute of Steel Construction*, Chicago.

Comparative Study on Framed Tube System and Diagrid Tube System Subjected to Seismic Load

Karthikeyan Rajendiran, B. Vijayashanthi, and S. Pradeep

Abstract Most significant modern development in construction methods, materials, structural system and analytical methods for analysis and design aided the growth of high-rise structures. In recent times, various structural systems like shear wall system, braced frame system, framed tube system and Diagrid structural system are used in high-rise structures for resisting lateral loads, structural performance and aestheticism. Framed tube system consists of closely spaced exterior column in outer perimeter which forms a tube-like structure which resists lateral load and the inner core resists gravity loads. In Framed tube system, there is a problem of shear lag in the exterior column that can be reduced by replacing the Diagrid elements. In Diagrid tube system, the outer perimeter consists of inclined diagonal elements, which resists both gravity and lateral loads. Diagrid structure involves simple construction techniques. The paper presents the seismic behaviour of the Diagrid tube system comparing with framed tube system with various parameters such as displacement, drift, stiffness, etc., using analytical software ETABS.

Keywords Diagrid · Framed tube system · Gravity loads · Lateral loads · Seismic

1 Introduction

The speedy growth of population and increasing demand for business and residential space leads to development of tall buildings. As the building height increases, the lateral load acting on it also increases. As a result, the lateral load resisting mechanism takes precedence over gravity load. Moment resisting frames, shear wall systems, braced frame systems, framed tube systems and Diagrid systems are some of the most commonly used lateral load resisting systems. One of the most important advances in tall building technology is the framed tube system. The tube system consists of

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(a) (b)

Fig. 1 **a** A on centre, **b** capital gate

2–4 m from centre-to-centre columns in the outer perimeter, which are linked at each floor by spandrel beams. The lateral loads acting on the framed tube framework are countered by a very stiff moment-resisting force that creates a tube around the structure's perimeter. This structural shape is suitable for buildings with 60–100 storeys. The tube and the inner columns are also subjected to gravity loading. When the lateral load is acting, the perimeter frame aligned in the loading direction acts as web, and those aligned in the opposite direction act as flange. The most notable example of framed tube system is Aon centre and the world trade tower as in Fig. 1a.

The vertical columns are removed in Diagrid systems. Because of their triangulated arrangement, the diagonal members in Diagrid systems can bear both gravity and lateral force, while the diagonal in a standard braced framework can only carry lateral loads. As compared to traditional tubular frame structures without diagonals. Diagrid structures are efficient in reducing shear deformation because shear is carried by the axial motion of the diagonal members, while shear is carried by the bending of vertical columns in traditional framed tubular structures. The number of structural elements needed on the building's facade is reduced as a result of this structural configuration [1].

Diagrid has good aesthetic appearance and structural efficiency as in Fig. 1b. This also eliminates the need for corner columns, allowing for greater versatility. As compared to traditional construction, Perimeter Diagrid saves 20% of structural steel [2].

The diagrid system has diagonal elements which resist the lateral load from the seismic forces, the diagonal element reduces the shear acting in the structure thereby enhancing the stability of the structure under lateral loads [3]. The diagrid system has more lateral stiffness compared to the braced structure to resist the lateral loads from the earthquakes. The stiffness of the diagrid elements is much greater than braced structure [4].

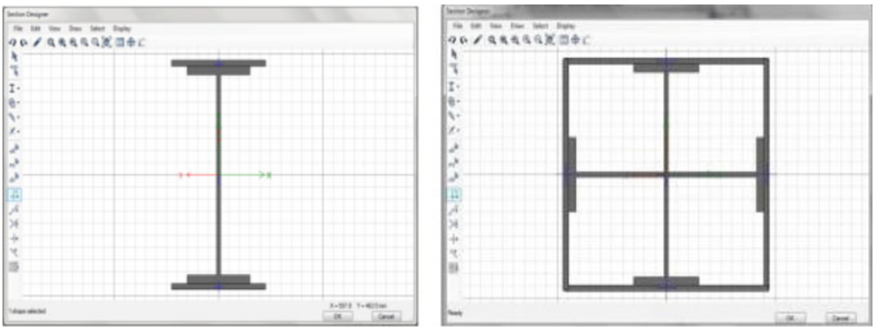
The number of structural elements needed on the building's facade is reduced as a result of this structural configuration. This also eliminates the need for corner columns, allowing for greater versatility. Diagrid structures' behaviour is influenced by their diagonal angle. For a 60-storey house, the ideal angle for the Diagrid structure is 65° to 75°. The building has a 7-aspect ratio [5]. The majority of the loads are resisted by peripheral diagonal columns, while gravity is resisted by both internal and peripheral columns. As a result, the internal column must be configured solely for vertical loads [6].

In Framed tube system, there is a problem of shear lag due to closely spaced column in the outer perimeter. So, the vertical columns are replaced by the diagonal elements to reduce the shear lag and to improve the structural efficiency of the structure. A 60-storey steel building of framed tube system and Diagrid tube system subjected to seismic load is analysed using ETABS. The seismic analysis of Diagrid tube system is compared with the framed tube system with the various parameters such as displacement, drift, stiffness, etc.

2 Material Specification

A Framed tube system and Diagrid Tube System are designed with steel framing members. This includes the beam and column sections. The wide flange parallel beam sections are used for designing the systems. The sections are selected from IS 800 [7] and IS 12778 [8]. Structural steel's properties are determined by its chemical composition as well as its manufacturing system, which includes prefabrication production. Product specifications specify the composition, quality and output boundaries, which designers use or assume.

For modelling of Framed tube system, the built-up sections of WPB 900X300 with plate of 450 mm width and 25 mm thickness on top and bottom flange of I sections have been used for all the beam in the structure. The built-up sections of WPB900X300 with plate of width 900 mm and thickness of 25 mm on four sides of intersected I section has been used for all the column of the structures. The built-up



(a) (b)

Fig. 2 **a** Built-up beam section, **b** built-up column section

Table 1 Properties of Steel section

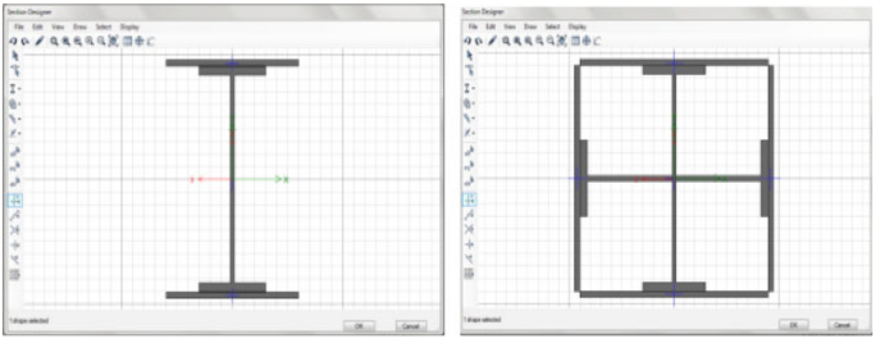
Sl. No	Properties	Built up beam	Built up column
1	Area of the section	585.6 cm^2	1619.2 cm^2
2	Inertia about major axis	955,480.9 cm^4	1,755,267.3 cm^4
3	Inertia about minor axis	53,537.5 cm^4	1,758,186.1 cm^4

Table 2 Properties of Steel section

Sl. No	Properties	Built up beam	Built up column/diagrid
1	Area of the section	663.6 cm^2	1961.2 cm^2
2	Inertia about major axis	1,130,014.2 cm^4	2,254,065.7 cm^4
3	Inertia about minor axis	105,793.8 cm^4	2,268,546.7 cm^4

section is as shown in Fig. 2a, b. The properties of steel sections which are used for framing the structure are given in Tables 1, 2.

For modelling of Diagrid tube system, the built-up sections of WPB 900X300 with plate of 600 mm width and 25 mm thickness on top and bottom flange of I sections have been used for all the beam in structure. The built-up sections of WPB900X300 with plate of width 900 mm and thickness of 35 mm on four sides of intersected I section has been used for all the interior column and exterior Diagrid of the structures. The built-up sections are as shown in Fig. 3a, b.



(a) (b)

Fig. 3 **a** Built-up beam section, **b** built-up column section

3 Modelling and Analysis

The modelling of Framed Tube system has been stimulated as shown in Fig. 4c. The system consists of 60 storeys with a plan dimension of 36 m × 36 m as per aspect ratio (H/L) is 6. The system consists of inner core and outer perimeter column. The outer perimeter consists of closely spaced column at 3 m centre to centre forms a tube. The inner core consists of closely spaced columns. The inner core has a dimension of 12 m × 12 m, which resists the gravity loading while the outer perimeter column resists the lateral loading. The columns are fixed at base (see Fig. 4).

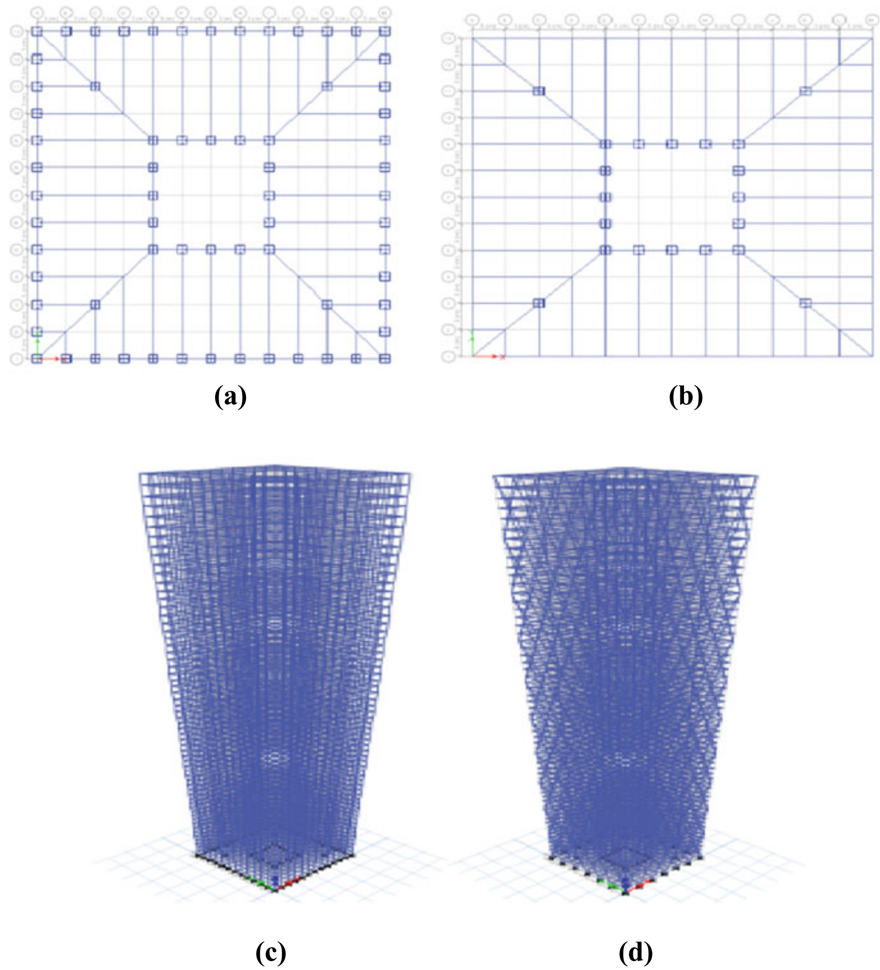


Fig. 4 **a** Plan of Framed tube system, **b** plan of Diagrid tube system, **c** Model of framed tube system, **d** model of Diagrid tube system

The modelling of Diagrid Tube system has been stimulated as shown in Fig. 4d. The system consists of 60 storeys with a plan dimension of 36 m × 36 m as per aspect ratio (H/L) is 6. The system consists of inner core and outer diagonal element. The outer perimeter consists of Diagrid element of angle 74° at 6 m spacing along the perimeter for entire structure. The inner core consists of closely spaced columns. The inner core has a dimension of 12 m × 12 m, which resists the gravity loading while the outer Diagrid resists the lateral loading. The columns and Diagrid are fixed at base.

ETABS software is used for modelling and analysis. And IS 875 [9, 10] (Part 1) are used to calculate the dead and live loads (Part 2). Two models were subjected to response spectrum analysis. The input values are in compliance with the IS1893 (part 1) [11] Indian standard. With a zone factor of 0.16, the configuration is classified as Zone III. The value of Importance Factor I is 1.5. For special moment-resisting frames, the response reduction factor R is 5. The medium soil type 2 is chosen. Because of internal friction and absorbed energy, the amplitude of the structure's vibrations decreases. For steel structures, this damping is assumed to be 5%. The SRSS (square root of sum of squares) modal combination approach is chosen.

4 Result and Discussion

The results of the study are described here in terms of storey displacement, storey drift, storey stiffness and time span.

4.1 Storey Displacement

The storey displacement of 60-storey Diagrid tube system and framed tube system is shown in Fig. 5. The top storey displacement for framed tube system is 421.4 mm and Diagrid tube system is 278.4 mm. It is observed that the displacement of Diagrid tube system is 1.5 times lesser than framed tube system. This Fig. 5) represents that the Diagrid tube system has the higher resistance to seismic loading than the framed tube system.

4.2 Storey Drift

The storey drift of 60-storey Diagrid tube system and framed tube system is shown in Fig. 6. It is observed that the inter storey drift of Diagrid tube system is less compared to framed tube system. Table 4 represents the storey drift for the framed tube system.

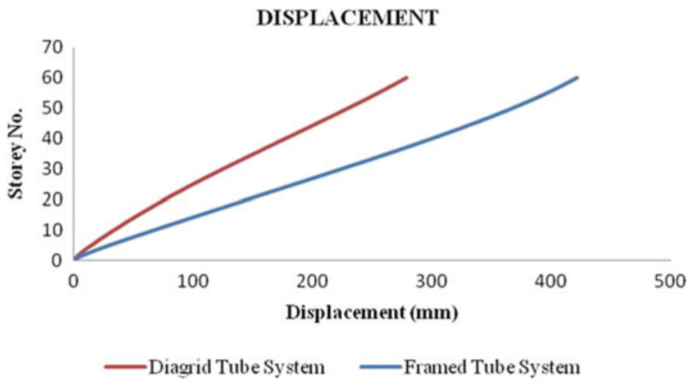


Fig. 5 Storey displacement

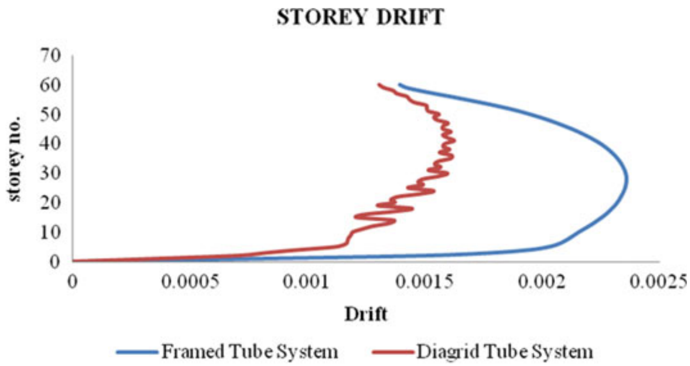


Fig. 6 Storey drift

It is observed that the maximum drift has occurred between 24 and 30 Storeys. The maximum drift for framed tube system is 0.00236, which is within the permissible limit (H/250).

4.3 Storey Stiffness

The storey stiffness of 60 storeys Diagrid tube system and framed tube system is shown in Fig. 7. The storey stiffness of Diagrid tube system is two times higher than the framed tube system. So, Diagrid tube system has 22 times the higher stiffness than framed tube system. The maximum stiffness has occurred between base and sixth storey as shown in Fig. 7.

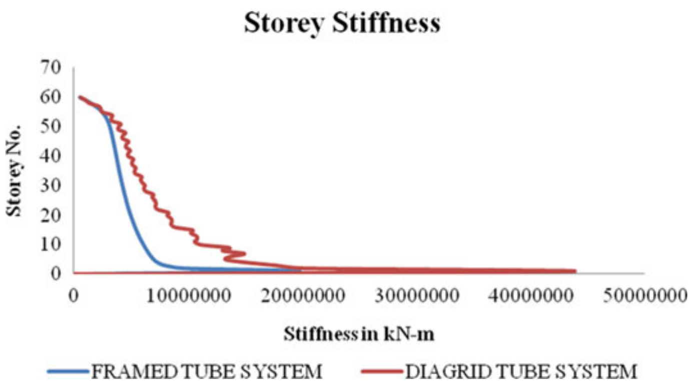


Fig. 7 Storey stiffness

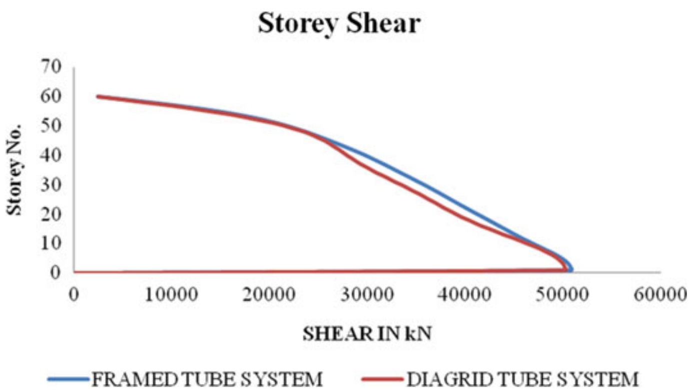


Fig. 8 Storey shear

4.4 Storey Shear

The storey shear for the 60-storey Diagrid tube system and framed tube system is presented in Fig. 8. The storey shear of Diagrid tube system is 50180 kN and for framed tube system is 50891 kN. Hence, base shear of Diagrid tube system is 1.015 times less than framed tube system.

4.5 Time Period

The time period for the 60-storey Diagrid tube system and framed tube system is shown in Fig. 9. The first mode period for Diagrid tube system is 3.847 s.

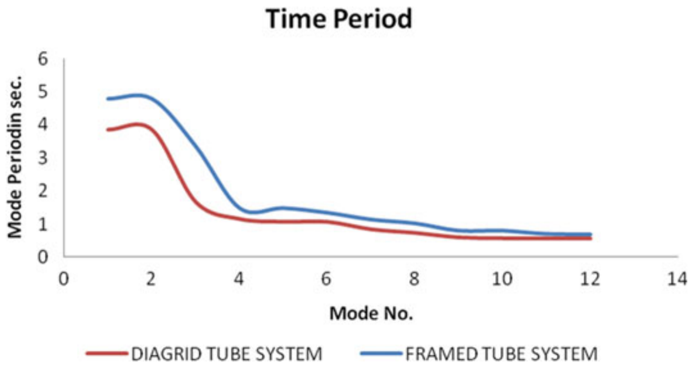


Fig. 9 Time period

4.6 Shear Lag

Consider the case of a bending thin wall beam. Shear stresses and strains in thin-walled beams are much higher than in solid beams, resulting in significant shearing deformations. The plane of bending distorts as a result of the large shear strains. The bending stresses would not be equal to the distance from the section's neutral axis due to this distortion. Since the wall panel lacks shear stiffness, the stress at the centre of the Flange's lags behind the stress near the web. Shear lag is a phenomenon that affects the uniformity of the flange's compressive and tensile stresses.

These stresses must differ linearly along every panel (flange or web). In contrast to the column in the middle panel, the magnitude of axial stress at the corner side of the flange panel is high. As a result, axial tension in the flange panel middle columns lags behind that of the corner columns. Shear lag refers to the non-linear distribution of axial stress along the flange plates.

The shear lag for the ground storey of framed tube system has occurred in flange panel due to the lateral loads acting on the structure as shown in Fig. 10.

5 Conclusion

The seismic analysis of 60-storey Diagrid tube system and framed tube system has been completed. From this result, it is clear that from both the structures modelled, from this study, it is observed that Diagrid tube system possesses maximum stiffness of 43,570,632 kN-m and has minimum value of lateral displacement of 278.4 mm. The storey drift and base shear are less for Diagrid tube system compared to Framed tube system. Better resistance to lateral loading, due to the diagonal columns on its periphery, makes the system effective. Shear lag effect that occurred in frame tube system is eliminated by replacing Diagrid (inclined diagonal) member in the exterior perimeter. The structural stability of Diagrid tube system is more compared to the

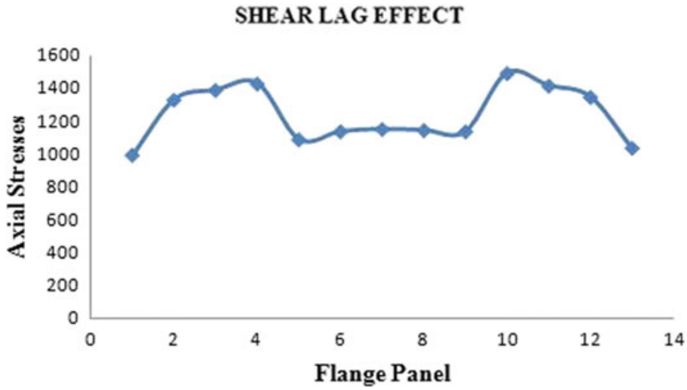


Fig. 10 Shear lag effect in flange panel

frame tubed system, this is due to the diagonal element present in the periphery of the structure that resists the lateral load from the seismic forces. This can be seen from the response spectrum analysis carried on both the system which shows the displacement and base shear of the diagrid frame system is less compared to the frame tube system. Also, the stiffness of the diagrid frame system is more compared to the frame tube system which shows that lateral stiffness to resist the lateral load is high for diagrid tube system. Diagrid tube system has increased the structural efficiency, and the seismic performance of the structure has improved.

References

1. Lee, K.-K., Loo, Y.-C., & Guan, H. (2011). Simple analysis of framed–tubed structures with multiple internal tubes. *Journal of Structural Engineering*, *127*, , 450–460.
2. Moon, K. S. (2007). Diagrid structural system for tall buildings: Characteristics and methodology for preliminary design. *Wiley Interscience*, *16*, 205–230.
3. Moon, K. S. (2011). Diagrid structures for complex-shaped tall buildings. *Proceedia Engineering, 14*, 1343–1350
4. Rafey, M. A., & Azeem, M. A. (2018). Comparative analysis of a diagrid structure and a conventional structure with chevron bracing. *International Journal of Applied Engineering Research*, 12311–12317.
5. Leonard, J. (2008). Investigation of shear lag effect in tall buildings. In *CTBUH 8th world congress*, Dubai.
6. Jani, K., & Patel, P. V. (2013). Analysis and design of diagrid structural system for high rise steel buildings. *Procedia Engineering, 51*, 92–100.
7. IS: 800. (2007). General construction in steel–code of practice. In *Bureau of Indian standards*, New Delhi (pp. 1–144).
8. IS: 12778. (2004). Hot parallel flange steel sections for beams, columns and bearing piles–dimensions and section properties. In *Bureau of Indian standards*, New Delhi (pp. 1–15).
9. IS: 875. (1987). Code of practice for design loads (Other than Earthquake) for buildings and structures, Part 1: Dead loads. In *Bureau of Indian standards*, New Delhi (pp. 1–38).

10. IS: 875. (1987). Code of practice for design loads (Other than Earthquake) for buildings and structures, Part 2: Imposed loads. In *Bureau of Indian standards*, New Delhi (pp. 1–18).
11. IS: 1893. (2002). Criteria for earthquake resistant design of structures-general provisions and buildings Part-1. In *Bureau of Indian standards*, New Delhi (pp. 1–39).

Static and Dynamic Analysis of Corrugated Beam with Restrained Boundary Conditions

Sunny Mathur, M. SenthilPandian, and K. Karthikeyan

Abstract Implementation of corrugated steel beam have increased in the past few years in all types of structures utilizing the new fabrication techniques. Corrugated beams are a type of I section with thin corrugated web and wide thick plate flanges. Stress distribution in corrugated beam is different from that of an I section both in case of flexure and shear. Due to the accordion effect, the participation of web in bending moment resistance is neglected. The advantage of corrugated web beams is the increased resistance to shear buckling without the need of web stiffeners. In this study, the main focus is to do static and dynamic analysis of corrugated beams with trapezoidal corrugation profile and varying different parameters beam like aspect ratio and corrugation angle. This paper tries to find the best possible combination of the parameters which performs best in the analysis. The analysis is done on ANSYS 18. The corrugation beam would be having an aspect ratio of (0.8, 0.9, 1.0, 1.1, 1.2) and corrugation angles as (35°, 40°, 45°, 50°, 55°). The results show that aspect ratio and corrugation angle have a major effect on deflection and amplitude of the beam, further various comparisons are provided to help engineers design an efficient corrugated beam.

Keywords Finite element analysis · Corrugated beams · Aspect ratio · Corrugation angle · I-section

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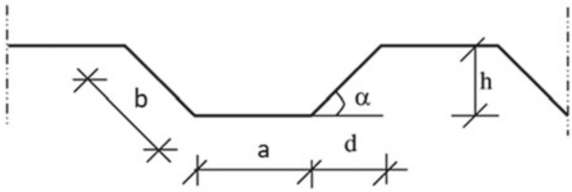


Fig. 1 Top view of corrugation

1 Introduction

Research on corrugated beams started in 1956 as a replacement for airplane wings [1]. After this, only they gained importance in civil engineering, especially in bridges. Corrugated beams undergo the accordion effect [2], which is conventionally assumed to make the web unable to resist the longitudinal normal stresses. As, a consequence the bending resistance is to be provided by flanges, due to which they are thicker compared to I section beam [3]. The major advantage of corrugated beam is increase in resistance to shear buckling that too without the use of weld stiffeners [4]. This helps with the management of beam weight without a compromise in strength. In bridge construction, composite bridges of different cross section is made possible due to corrugated beam. Corrugated beams can be of different profiles, e.g., sinusoidal, trapezoidal, square; for this study, we have chosen trapezoidal.

Although corrugated beams are used extensively around the world no proper code is available for design, this leaves the end open for researcher. In this study, we are going to take corrugated beam with trapezoidal profile and varying aspect ratios and corrugation angles. The material of the beam will be S355 steel [5–7]. Our basic work is to analyze and find out which aspect ratio and corrugation angle give the best result in stress distribution, Deformation, shear stress, natural frequency, ultimate load, and amplitude. The length of the beam is going to be 5 m and dimensions are going to be similar as ISMB 300 section. We are going to take aspect ratio (a/b) as 0.8, 0.9, 1.0, 1.1, 1.2, where "a" and "b" is shown in Fig. 1, while the corrugation angle(α) will be 35°, 40°, 45°, 50°, 55°.

2 Procedure

2.1 Preparation of Model

A three-dimensional finite element model is developed to study the behavior of the beams in ANSYS 18 [8]. A uniformly distributed load of 1 MPa has been applied over the complete span of the beam which is 5000mm. As the span of the beam is on larger side, the boundary conditions are taken as fixed at both ends, which means all translation and rotations are restrained. Static analysis is performed to determine the deflection, stress distribution, and shear stress. Dimension provided on Table 1 and the clear

Table 1 Dimensions of beam

Properties	Value (mm)
Length of beam	5000
Breadth of flange	140
Thickness of flange	12.4
Height of web	275.2
Thickness of web	7.5
Total height	300

view of dimensions in Fig. 2, material properties are mentioned in Table 2. Dynamic analysis is performed to determine natural frequency, ultimate load, and amplitude.

Aspect ratio which is a/b has been kept as 0.8, 0.9, 1.0, 1.1, and 1.2, where the length of "b" was fixed at 100 and the length 'a' was changed from 80 to 120. Corrugation angles were 35°, 40°, 45°, 50°, and 55°.

A total of 25 models will be generated and analysis of the same would be carried out.

Fig. 2 Dimensions

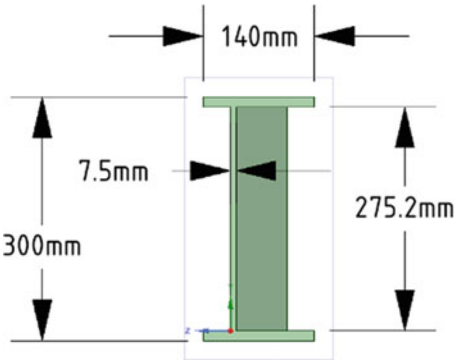


Table 2 Material properties

Engineering properties	Value
Young's modulus	2.1×10^5 MPa
Poisson's ratio	0.3
Yield strength	355 MPa
Ultimate strength	490 MPa
Bulk modulus	1.75×10^5 MPa
Shear modulus	8.0769×10^4 MPa
Density of steel	7850 kg/m^3

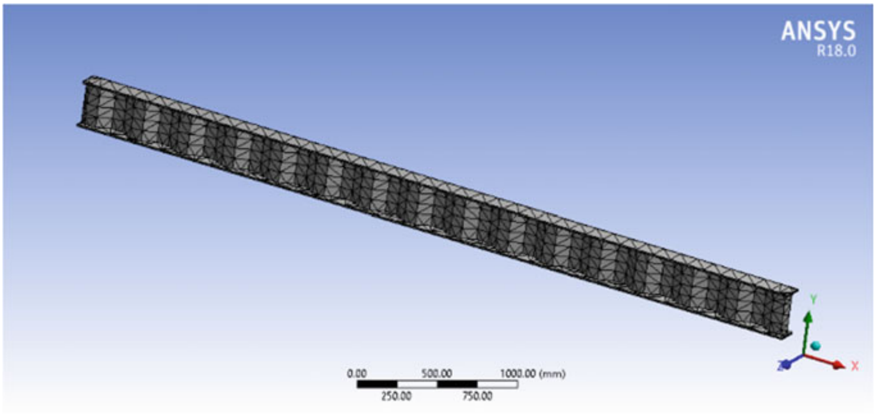


Fig. 3 Typical meshed beam

2.2 Static Analysis

After modeling was completed, analysis is carried out using ANSYS18 software, and results are obtained for values of deformation, stress distribution, and shear stress. From these results, graphs are prepared and analyzed for comparison.

Tetrahedral meshing was done using ANSYS18 and default element size of element was kept and loading is applied as pressure to determine the uniformly distributed load. The support condition was applied as per Fig. 3. The static results are provided in Table 3.

Following is a table containing the output values for deflection, stress, and shear.

2.3 Results from ANSYS

Figure 4 gives the typical idea of the meshed shape of the beam; the Fig. 5 shows the boundary condition applied to the model at the preprocessing stage. Figures 6, 7, 8, 9, 10, 11, 12, 13 and 14 shows stress, shear stress, and deflection obtained from ANSYS workbench postprocessing mode.

2.4 Compilation of Results

Following are graphs for similar aspect ratio but different corrugation angles (Figs. 14, 15, 16, 17 and 18).

Following are graphs with similar corrugation angle but different aspect ratios (Figs. 19, 20, 21, 22 and 23).

Table 3 Static results

Specimen	Deflection (mm)	Stress (MPa)	Shear (MPa)
a80b100c35	36.236	378.07	191.59
a80b100c40	52.637	405.34	179.71
a80b100c45	45.7	392.56	182.87
a80b100c50	49.348	395.66	201.88
a80b100c55	50.543	402.54	196.65
a90b100c35	33.299	382.08	190.73
a90b100c40	48.831	400.45	179.82
a90b100c45	39.195	387.59	187.95
a90b100c50	46.359	397.09	196.26
a90b100c55	53.677	408.34	191.19
a100b100c35	23.786	419.35	189.41
a100b100c40	44.613	390.71	178.36
a100b100c45	24.332	365.33	187.79
a100b100c50	39.37	385.46	182.58
a100b100c55	32.849	368.64	168.9
a110b100c35	58.088	415.53	203.62
a110b100c40	33.798	377.63	194.95
a110b100c45	48.013	404.43	183.01
a110b100c50	39.719	382.38	186.7
a110b100c55	53.237	432.22	191.51
a120b100c35	30.057	373.64	193.28
a120b100c40	40.28	389.87	176.85
a120b100c45	45.706	396.41	196.51
a120b100c50	47.318	387.73	169.82
a120b100c55	48.219	397	195.01

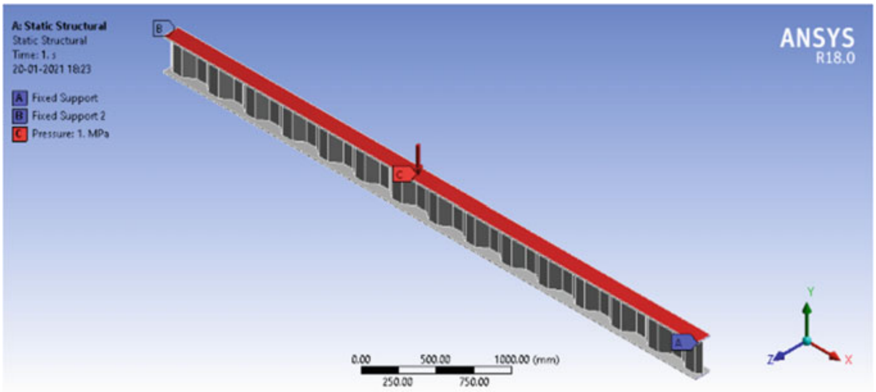


Fig. 4 Loading and support conditions

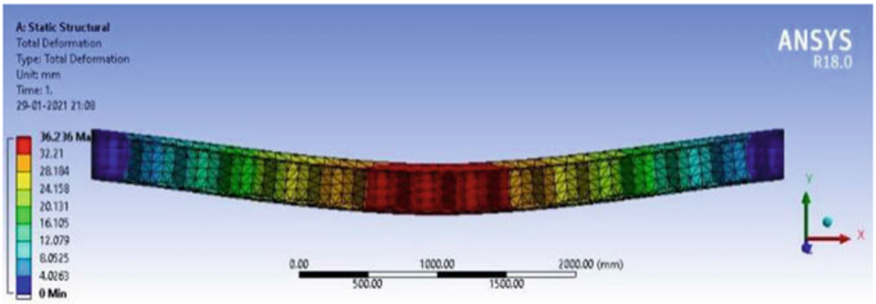


Fig. 5 Deflection a80b100c35

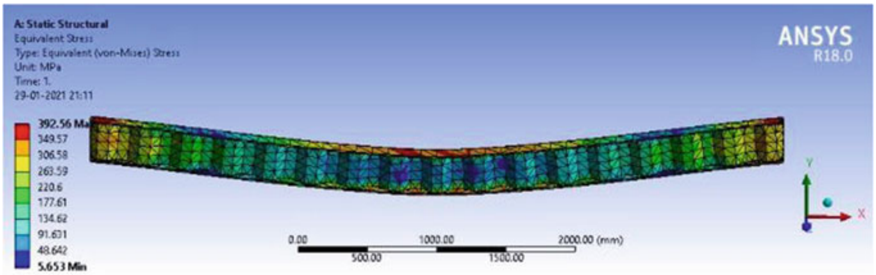


Fig. 6 Stress a80b100c45

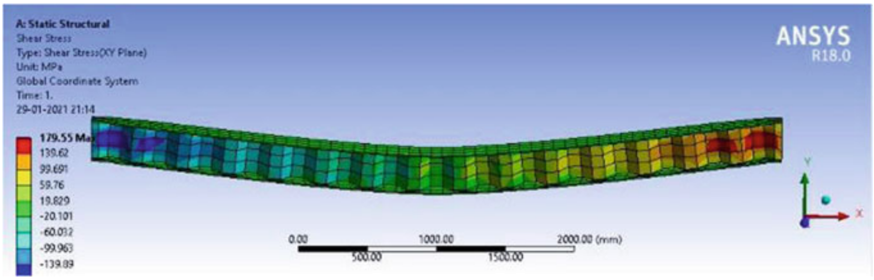


Fig. 7 Shear a90b100c40

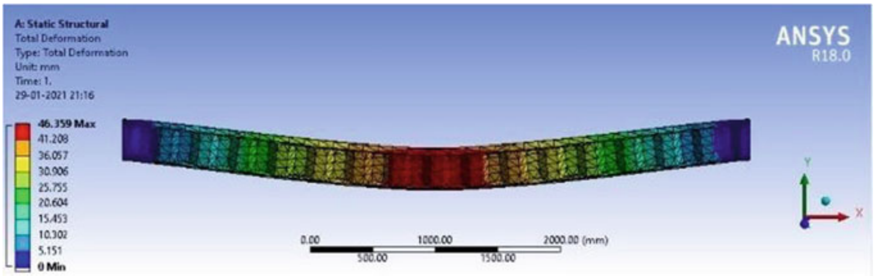


Fig. 8 Deflection a90b100c50

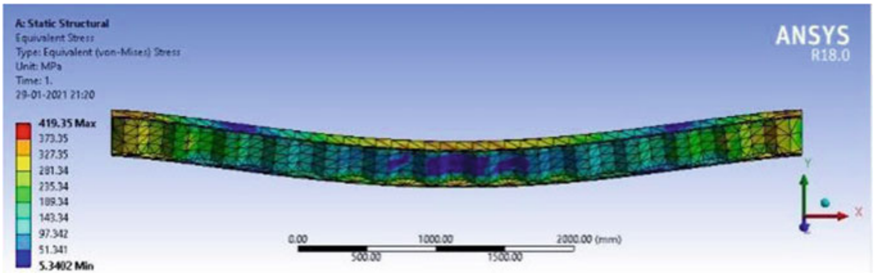


Fig. 9 Stress a100b100c35

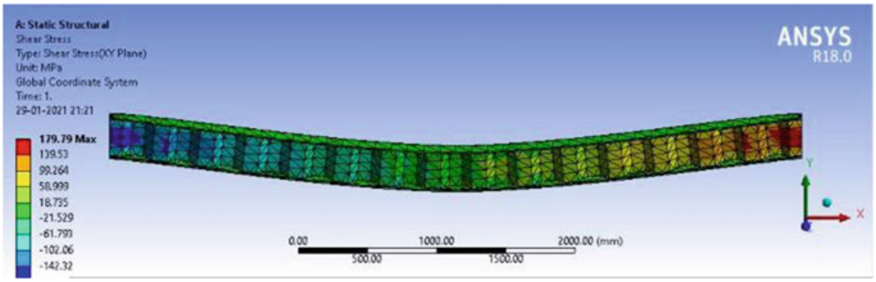


Fig. 10 Shear a100b100c50

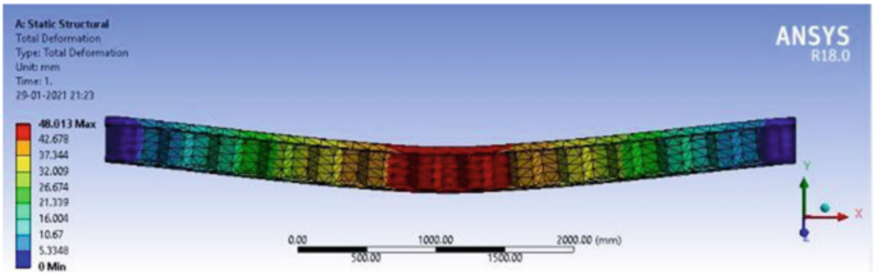


Fig. 11 Deflection a110b100c45

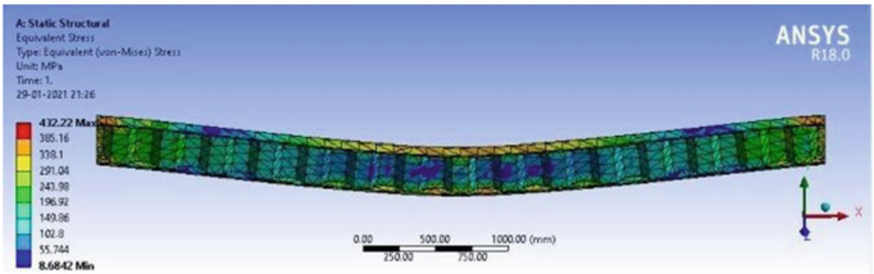


Fig. 12 Stress a110b100c55

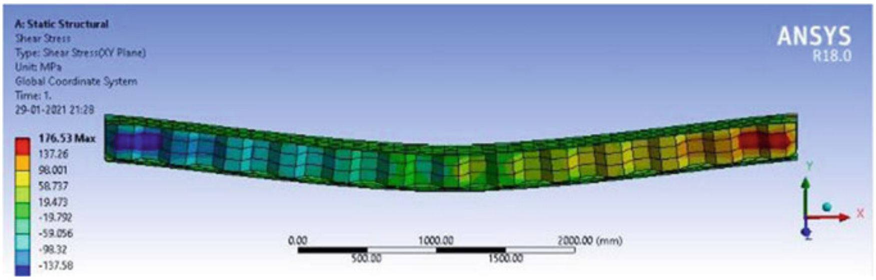


Fig. 13 Shear a120b100c40

Fig. 14 Aspect ratio of 0.8

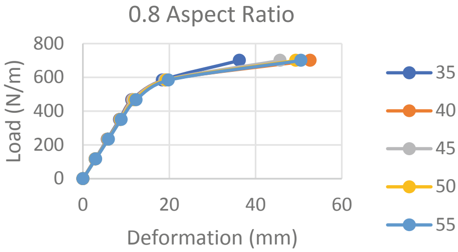


Fig. 15 Aspect ratio of 0.9

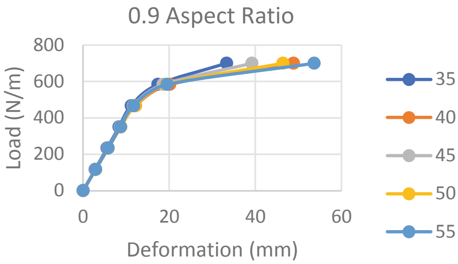


Fig. 16 Aspect ratio of 1

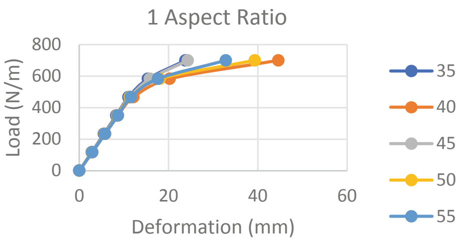


Fig. 17 Aspect ratio of 1.1

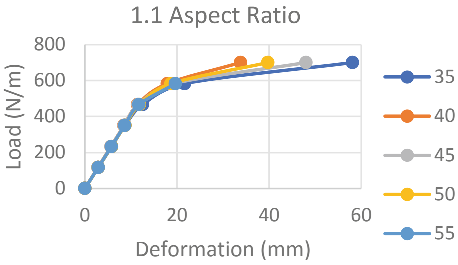


Fig. 18 Aspect ratio of 1.2

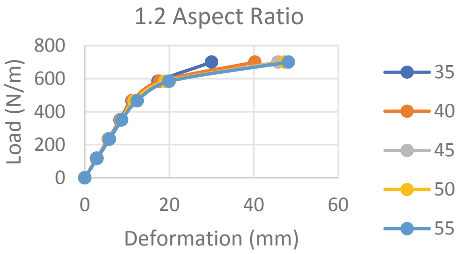


Fig. 19 Corrugation angle of 35°

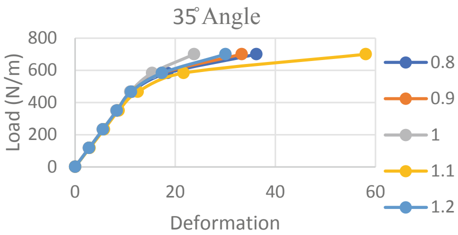


Fig. 20 Corrugation angle of 40°

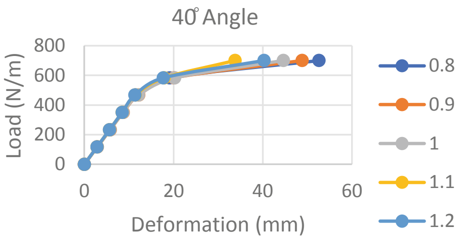
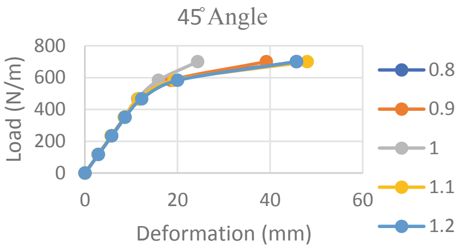


Fig. 21 Corrugation angle of 45°



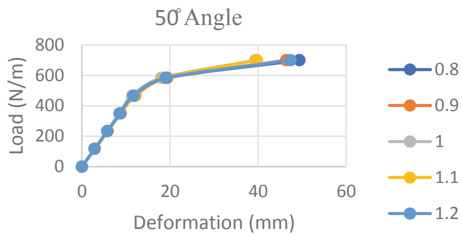


Fig. 22 Corrugation angle of 50°

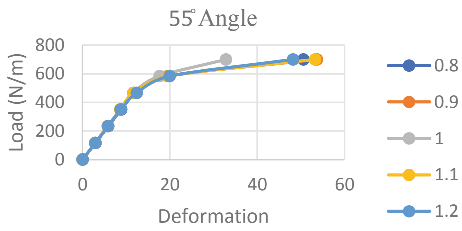


Fig. 23 Corrugation angle of 55°

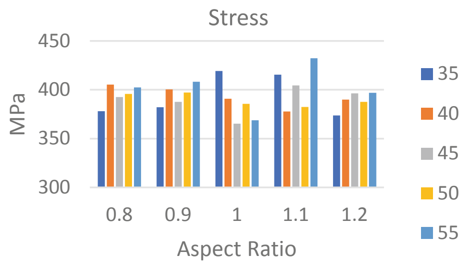


Fig. 24 Maximum stress

The Figs. 24 and 25 shows the maximum stress and maximum shear.

2.5 *Dynamic Analysis*

The analytical model investigated the natural frequency and harmonic response, the maximum values of natural frequencies are tabulated (Table 4).

2.6 *Results from ANSYS*

Figures 26, 27, 28, 29, 30, 31 and 32 show the different mode shapes of different corrugated beams.

Fig. 25 Maximum shear

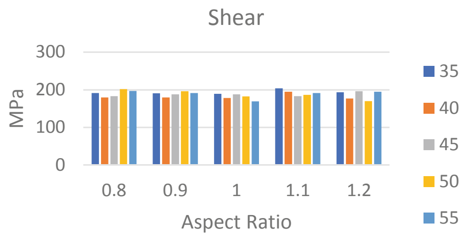


Table 4 Dynamic results

Specimen	Frequency (Hz)
a80b100c35	124.9
a80b100c40	123.75
a80b100c45	123.59
a80b100c50	123.29
a80b100c55	122.35
a90b100c35	125.1
a90b100c40	124.39
a90b100c45	124.07
a90b100c50	123.89
a90b100c55	122.79
a100b100c35	125.86
a100b100c40	124.87
a100b100c45	125.14
a100b100c50	124.45
a100b100c55	123.86
a110b100c35	125.19
a110b100c40	125.59
a110b100c45	124.85
a110b100c50	125.09
a110b100c55	123.97
a120b100c35	126.23
a120b100c40	125.45
a120b100c45	125.62
a120b100c50	124.8
a120b100c55	124.83

2.7 Compilation of Results

Following are amplitude graphs for similar aspect ratio but different corrugation angles Figs. 32, 33, 34, 35, and 36).

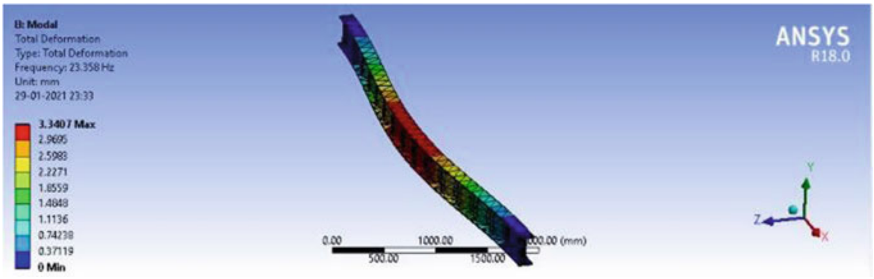


Fig. 26 Mode shape 1 of a80b100c35

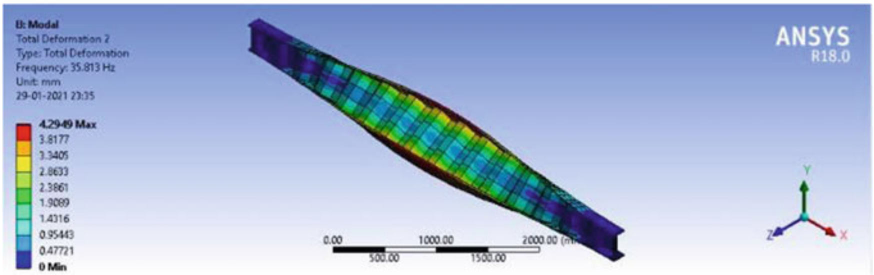


Fig. 27 Mode shape 2 of a90b100c40

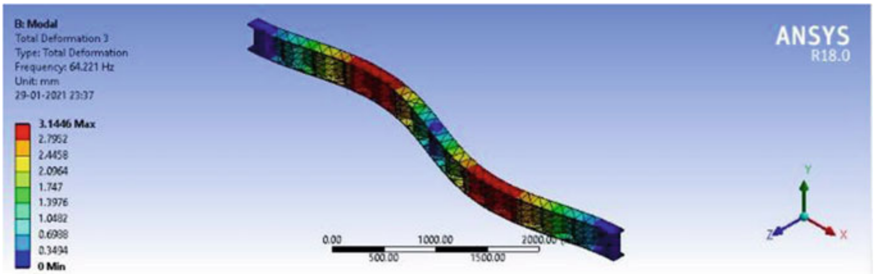


Fig. 28 Mode shape 3 of a100b100c45

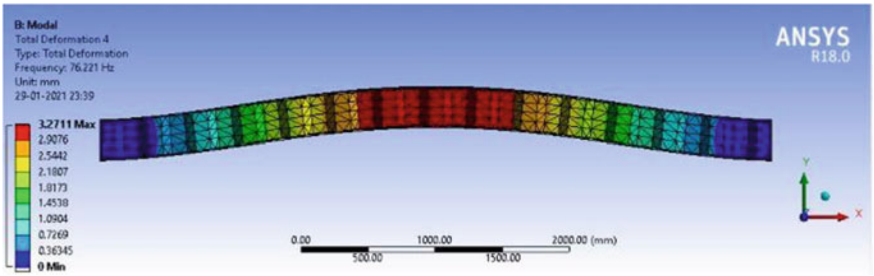


Fig. 29 Mode shape 4 of a110b100c50

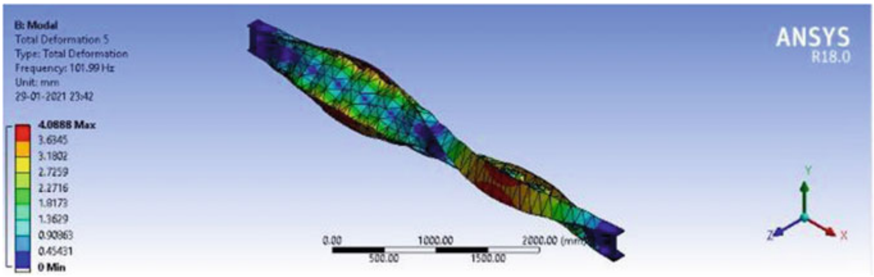


Fig. 30 Mode shape 5 of a120b100c55

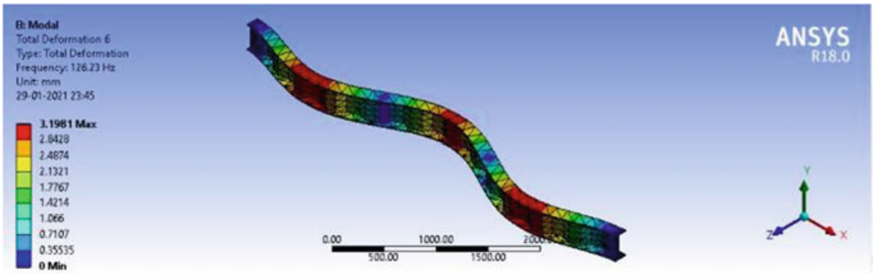


Fig. 31 Mode shape 6 of a120b100c35

Fig. 32 Aspect ratio of 0.8

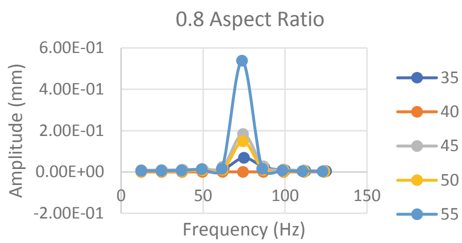
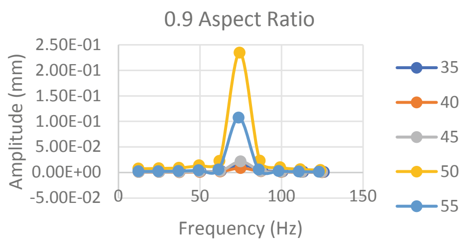


Fig. 33 Aspect ratio of 0.9



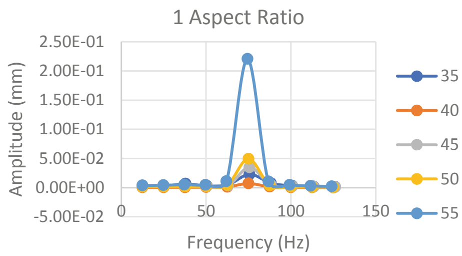


Fig. 34 Aspect ratio of 1

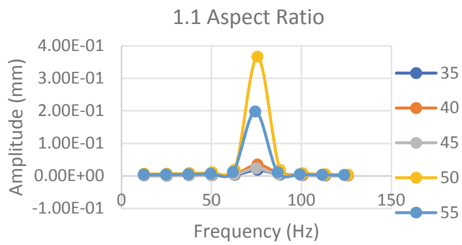


Fig. 35 Aspect ratio of 1.1

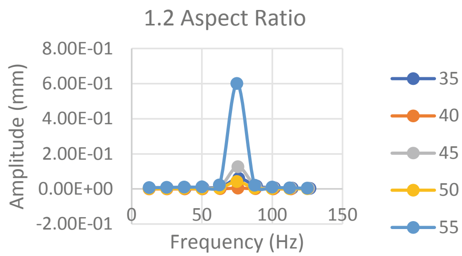


Fig. 36 Aspect ratio of 1.2

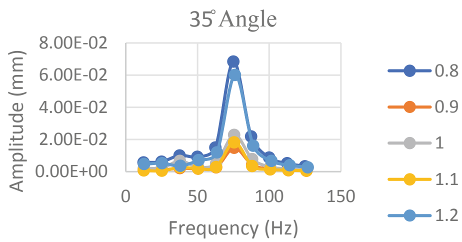


Fig. 37 Corrugation angle of 35°

Following are amplitude graphs with similar corrugation angle but different aspect ratios (Fig. 37, 38, 39, 40 and 41).

This is a bar chart of maximum natural frequency (Fig. 42).

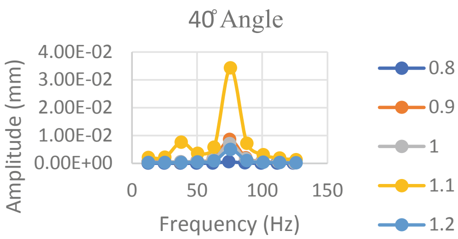


Fig. 38 Corrugation angle of 40°

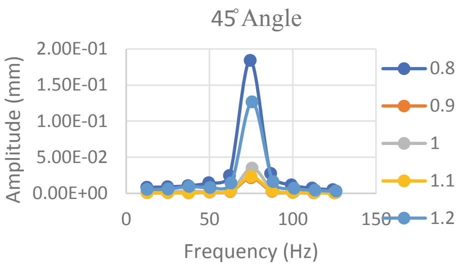


Fig. 39 Corrugation angle of 45°

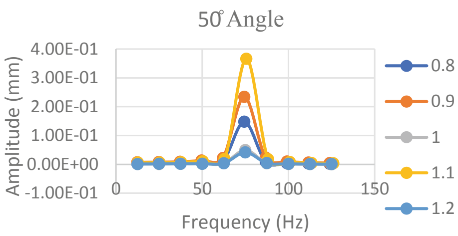


Fig. 40 Corrugation angle 50°

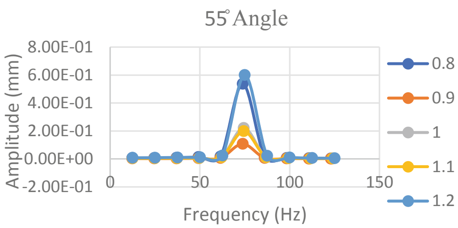


Fig. 41 Corrugation angle of 55°

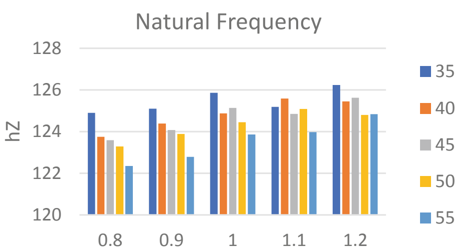


Fig. 42 Maximum natural frequency

3 Discussions

A parametric study on corrugated beam was conducted and aspect ratio and corrugation angle were the varying parameters. In this study, much models were made and lot of comparisons were done depending on various parameters. These comparisons and graphs can be summed up in the following points:

- Highest deflection of 58.088 mm is shown by a110b100c35 model, while lowest deflection of 23.786 mm is shown by a100b100c35 model.
- Highest stress of 432.22 MPa is shown by a110b100c55 model, while lowest stress of 365.33 MPa is shown by a100b100c45 model.
- Highest shear of 203.62 MPa is shown by a110b100c35 model, while lowest shear of 168.9 MPa is shown by a100b100c55 model.
- Highest frequency of 126.23 Hz is shown by a120b100c35 model, while lowest frequency of 122.35 Hz is shown by a80b100c55 model.
- Highest amplitude of 0.6001 mm is shown by a120b100c55 model, while lowest amplitude of 0.000574 mm is shown by a80b100c40 model.
- Constant aspect ratio models with higher corrugation angle mostly show higher deflection.
- With constant corrugation angle, aspect ratio of 1 constantly showed least deflection, whereas aspect ratios of 0.8 and 1.2 constantly showing high deflection values, which implies to higher the difference in values of 'a' and 'b' higher the value of deflection.
- With aspect ratio as constant, the value of von Mises stress mostly increases with increase in corrugation angle.
- With corrugation angle as constant, von Mises stress is least with aspect ratio as 1 and keeps on increasing as aspect ratio moves away from 1.
- The trend which is shown by shear stress is very much like that of von Mises stress.
- Aspect ratio as constant amplitude of beam increases with increasing corrugation angle.
- With constant corrugation angle, aspect ratio of 0.8 and 1.2 shows highest amplitude most of the times.
- With constant aspect ratio, lower corrugation angles give higher natural frequency and as corrugation angle is increased natural frequency decreases.
- Constant corrugation angle natural frequency increases with increase in aspect ratio.

4 Conclusions

The analysis of corrugated steel web beams for stresses, shear, deflection, natural frequency and amplitude was carried out using ANSYS18 software, and the modeling was also done on the same. The purpose of this study was to compare different corrugation angles in web at different aspect ratios and find the best for different use case scenario. Therefore, a number of analysis were performed to find the same and conclusions made from this study are as follows:

- Compiling the results, it shows that Aspect Ratio of '1' is constantly performing better in all parameters and as the difference in values of 'a' and 'b' increases results become worse for all the parameters of study.
- Corrugation angle of '45' is best, lower values of angle perform good in static analysis but natural frequency being more for the same it is concluded angle of '45' is best to use due to its load dispersion.
- The percentage increase from the model with least value to the model with highest value for each parameter is as follows:
  - Deflection—144.21%
  - Stress—18.3%
  - Shear—20.55%
  - Natural Frequency—3.17%
  - Amplitude—104,447.03%
- This shows that amplitude and deflection should be a major deciding factor while choosing the dimensions of beam for use in project.

References

1. Mathur, S., Senthilpandian, M., & Karthikeyan, K. (2021). Static and dynamic analysis of steel beams with web openings. *Journal of Physics: Conference Series*, *1716*, 012016.
2. Manoj Kumar, U., Pradeep Reddy, D., Patel, R. R., Pandian, S., & Kothandapani, K. (2018). A study on flexural capacity of steel beams with corrugated web. *International Journal of Civil Engineering and Technology*, *9*(4), 679–689.
3. Inaam, Q., & Upadhyay, A. (2020). *Flexural behaviour of steel I-girder having corrugated webs and slender flanges*. *Structures*, *27*, 12–21.
4. Jáger, B., Dunai, L., & Kövesdi, B. (2017). Flange buckling behaviour of girders with corrugated web Part I: Experimental study. *Thin-Walled Structures, 118*, 181–195.
5. Shao, Y.-B., Zhang, Y.-M., Hassanein, M. F. (2020). Strength and behaviour of laterally-unrestrained S690 high-strength steel hybrid girders with corrugated webs. *Thin–Walled Structures*, *150*, 106688.
6. Aggarwal, K., Wu, S., Papangelis, J. (2018). Finite element analysis of local shear buckling in corrugated web beams. *Engineering Structures*, *162*, 37–50.
7. Chen, D. H. (2012). The collapse mechanism of corrugated cross section beams subjected to three-point bending. *Thin-Walled Structures*, *51*, 82–86.
8. Lopes, G. C., Couto, C., Real, P. V., Lopes, N. (2017). Elastic critical moment of beams with sinusoidally corrugated webs. *Journal of Constructional Steel Research*, *129*, 185–194.

Experimental Investigation on Torsional Behaviour of Coconut/Steel Fiber Using Reinforced Concrete Beam

Rajesh Mocharla and R. Ramasubramani

Abstract This study examines and investigates the outcomes for coconut fiber/steel fiber concrete beams As compared to traditional concrete beams, which are applied to torsion. Four beams, two of them with coconut fiber/steel fiber concrete and another two of them with traditional concrete with manufactured sand were developed and tested. The research contains specific cracking features, pre-cracking performance including analysis, post cracking performance and evaluation, limited torsional reinforcing, torsional reinforcing, ductility, crack width and stiffness. These were noted that coconut shell concrete's torsional activity is compared with that of traditional concrete. Compared with ACI projection, Macgregor's proposed method is more cautious in measuring torsional resistance to deformation. And for calculating the ultimate torque force ACI projection are more moderate Contrasted to the Macgregor proposed formula. In this respect, Indian standard is also progressive, but it has been undervalued in comparison with ACI and the Macgregor constants. Reasonable torsional reinforcement for beams is required to ensure the beam does not failure to crack. The influence of 5, 10, 15, 20% fiber contents by mass of cement and fibers length of 13 mm is researched.

Keywords Coconut fiber · Steel fiber · Reinforcement · Torsion · Ductility · Concrete · Cracks

1 Introduction

1.1 General

The experimental investigation of introduction of coconut/steel fiber in the normal reinforced concrete beams to enhances its torsional strength. Fibers are randomly throughout the matrices and are generally discontinuous [1, 8]. The research has

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concluded that adding of coconut fibers to concrete mix leads to improves concrete mechanical performance. In comparison of behaviour of torsion for coconut/steel fiber reinforced concrete beams has been carried over normal reinforced concrete beams. In the present work the behaviour of torsion for coconut/steel fiber compared with conventional reinforced concrete beams under pure torsion. The various percentage of reinforcement to be consider for torsional behavior [9, 11].

1.2 Torsional Importance

Torsional importance has been an important and interesting aspect in structural behaviour. The study of torsional behaviour in structural member is important [6]. In a conventional concrete where independent theories have been developed based on loading situations such as axial load, flexural, shear and torsion and these loading situations are established in combinations of basic effects. Torsion has been considered as second importance in reinforced concrete structural systems [4].

2 Coconut Fiber

Concrete is used for construction material, most widely all over the world. In a construction industry with science and technology, the structural material of concrete has widened. Adding of various types of fibers to concrete makes strong, durable, and economical. Use of coconut fiber in cement concrete leads to improvement and this study comprise with traditional concrete and coconut fiber concrete. The influence of 2.5, 5, 7.5, 10% fiber contents by mass of cement and fiber of length 5 cm is investigated. Table 1 shows the results of compressive and split tensile strength of cubes and Table 2 shows the results of compressive strength of cylinders. Figure 1a sample of coconut fibre (Fig. 1b) steel fibre.

Table 1 Results for compressive strength of cubes

% of coconut/steel fiber (%)	The average compressive strength (N/mm^2) of cubes for 3 days	The average compressive strength (N/mm^2) of cubes for 7 days	The average compressive strength (N/mm^2) of cubes for 28 days
0	16.9	24.8	34.4
5	17.23	25.26	36.65
10	21.38	28.23	39.38
15	19.26	26.12	34.68
20	13.7	19.85	25.73

Table 2 Results for split tensile strength of cylinders

% of coconut/steel fiber (%)	The average split tensile strength (N/mm^2) of cylinders for 3 days	The average split tensile strength (N/mm^2) of cylinders for 7 days	The average split tensile strength (N/mm^2) of cylinders for 28 days
0	0.951	1.44	2.12
5	1.09	1.66	2.22
10	1.23	1.92	2.48
15	1.11	1.72	2.31
20	0.94	1.47	2.01

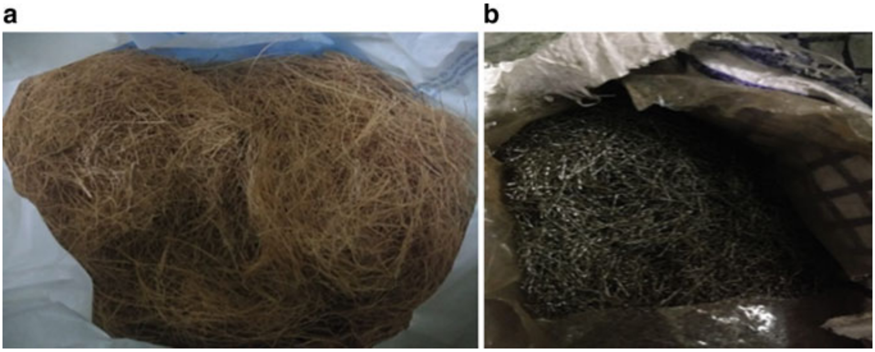


Fig. 1 **a** Coconut fiber **b** steel fiber

3 Steel Fiber

Steel fibers are strengthen concrete by resisting tensile cracking. Steel fibers can be used as reinforcing for industrial concrete for floor slabs and it's considered for structural purpose in reinforcement slabs on tunnels, piles and shear reinforcement in prestressed elements. Steel fiber mechanical properties are influenced by type of fiber, size and shape of fiber, amount of fiber and size of aggregate. It exhibits better crack resistance, higher resistance to spalling, higher first crack strength and higher post crack flexural strength. The influence of 2.5, 5, 7.5, 10% of steel fiber by mass of cement and fiber length of 1.3 cm is investigated.

4 Experimental Program

4.1 Testing Program

Totally four beams, two with normal CC (CC1-CC2) and two with CF/SF (CF/SF 3-CF/SF 4) were tested. The research covers basic cracking features, pre-cracking activity and analysis, post-cracking activity and analysis, limited torsional reinforcement, stiffness, torsional reinforcement, cracking breadthand ductility.

4.2 Reinforcement Details for Specimen

The cross-sectional size of the beam was defined as 200 × 275 mm and the beam length too was take as 1200 mm Center-to-center both to CC and CF/SF beams [4, 5]. For both cases, the concrete grade was considered to be M30. Table 1 shows the results of compressive and split tensile strength of cubes and Table 2 shows the results of compressive strength of cylinders and Table 3 shows the diameter and number of bars utilized in longitudinal reinforcing, Diameter as well as space between bars used in transverse reinforcement and also the percentage of total volumetric torsional reinforcement, accordingly. The diagram and top view of the specimen with loading points was shown in Fig. 2. In order to prevent failure of the portion, the cantilever of the beam must be strong, especially at joints between cantilever portion and beam. Figure 3 shows the cross-sectional reinforcement details and cantilevered portion.

4.3 Instrumentation for Testing

The 40 tones of frame capacity the testing was done. The 25 tones of load was applied using hydraulic jack. The 20 tones capacity of proving ring was used for measuring the load. By using of dial gauges, the twists meter was fixed at both sides of beam, and least count of 0.001 mm.

Table 3 Reinforcement ratio

Beams	Reinforcement of longitudinal	Reinforcement of transverse
CC1 and CF/SF 1	2–8 mm Ø at top 2–12 mm Ø at bottom	8 mm at 150 mm c/c
CC2 and CF/SF 2	2–12 mm Ø at top 2–12 mm Ø at bottom	8 mm at 90 mm c/c

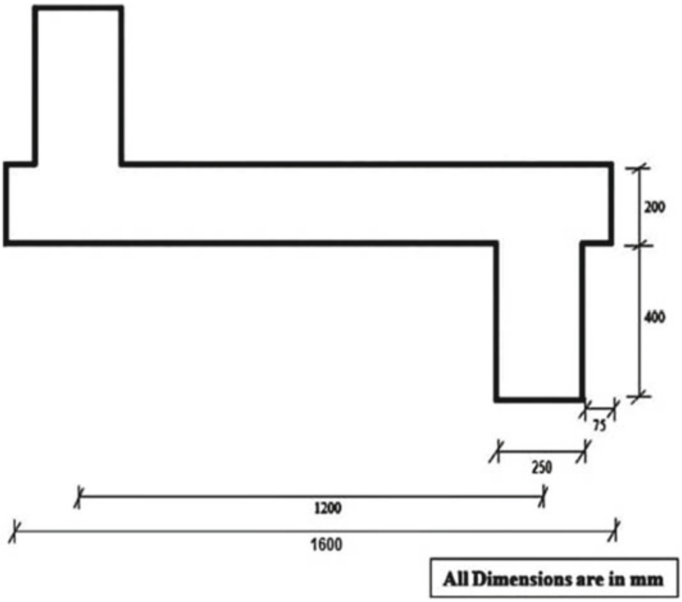


Fig. 2 Plan view of the beam specimen

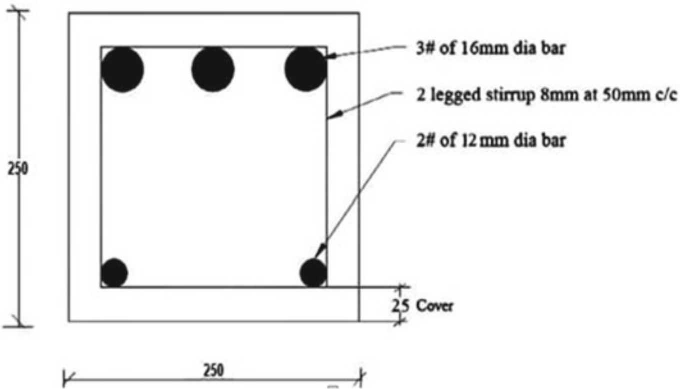


Fig. 3 Cantilever beam of cross section

4.4 Conduct of Experiments

The diagram of the loading frame was conducted and explained here in detailed manner was shown in Fig. 4. The beam is placed inside the frame and steel saddles is ready to hold the beams and to be tested on either ends for twist where torque is applied on it.

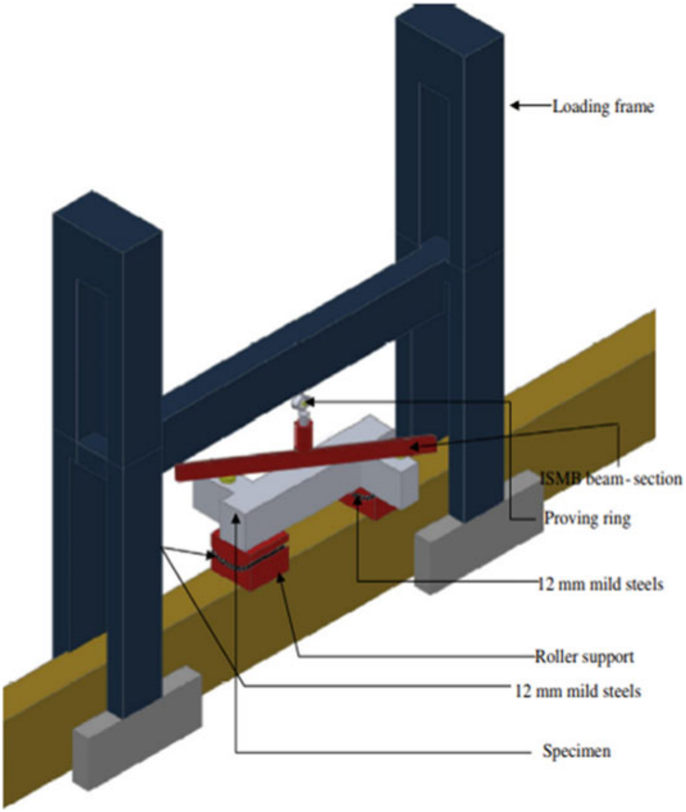


Fig. 4 Schematic diagram for loading frame

The research was conducted out over a 40 ton load—carrying device. The load was distributed using a hydraulic jack of 25 tonnes. The load was assessed utilized a proving ring of 20 tonnes. The beam twisting were tracked using dial gages, these are attached to the twist meter on either side. The beam to also be evaluated was raised and placed within the charging frame where steel saddles were fitted. To hold the beams at both ends to allow torsion when the torque is applied. Mild steel rods of 12 mm diameter were used to develop twists between the steel saddles. Hydraulic jack with a capacity of 25 T were positioned over ISMB I75 of use with the 20 T ability test ring is Placed in the middle of the hydraulic jack above. The beam was so balanced that is the center of the testing ring then the beams used the plumb bob was in the same position [5]. Twist meter was positioned 15 cm away from one of support. In the vertical position, two dial gauges was fixed to the opposite ends of the twist meter to calculate the angle of twist. Now that the arrangement was prepared for the experiment and the dial gages had already been set to zero before the experiments began. Torque was often distributed via a hydraulic jack. The ISMB used transmitted the load to its edges similarly. Beams were allowed and continuously increased in applied load until the maximum torque was achieved. A compact microscope with only an optical magnification of 40X and a tolerance of 0.01 mm was used to examine crack widths. Figure 5 shows the Arrangements for the specimen, Fig. 6 shows the Testing of the specimen in side view, Fig. 7 shows the Specimen during testing (Spiral Crack), Figs. 8, 9, 10 and 11 shows the Torque versus Twist for conventional beam and CF/SF beams.

Fig. 5 Arrangements for the specimen

Fig. 6 Testing of the specimen in side view

Fig. 7 Specimen during testing (Spiral Crack)

Fig. 8 Torque versus Twist for CC1 beam

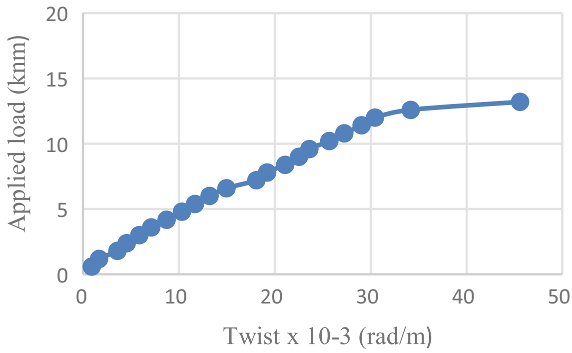
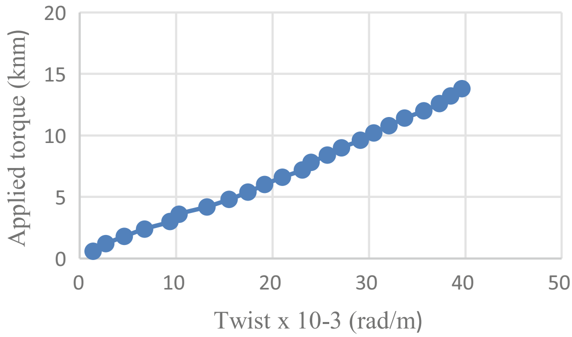


Fig. 9 Torque versus Twist for CC2 beam



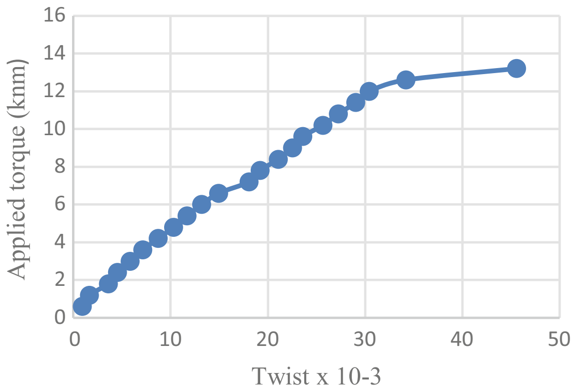


Fig. 10 Torque versus Twist for CF/SF 1 beam

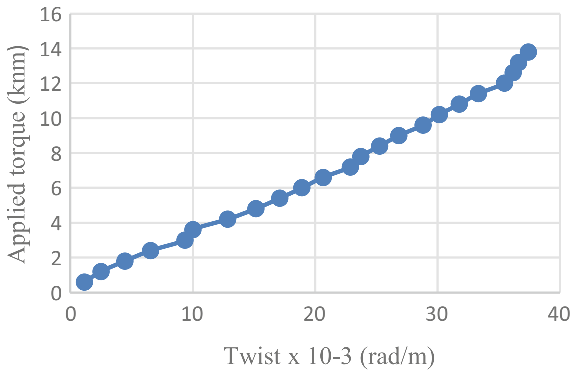


Fig. 11 Torque versus Twist for CF/SF 2 beam

5 Results and Discussion

Prior discussing the study, the researcher believes the tradition of torsion theories known elsewhere needs to be refreshed. They were two theories i.e.; space truss analogy and skew bending which helps in torsional problems. When comparison to ACI 318-1989 torsional provisions with ACI 318-1985 were substantially improved [2]. ACI 318-95 has introduced new torsion guidelines is idealized as a tube were beam cross sectional is more rational [3]. The space truss analogy and thin wall tube is a new method which is helpful in both reinforcement and prestressed structures.

Table 4 Torsional strength at initial cracking and at ultimate

S.NO	Beam details	Total volumetric reinforcement ratio (%)	Cracking at initial		Ultimate	
			Torque kNm applied	Twist (rad/m)	Torque kNm applied	Twist (rad/m)
1	CC1	1.367	7.8	19.198	13.2	45.593
2	CC2	1.517	8.4	25.69434	13.8	39.62924
3	CF/SF 1	1.367	7.8	19.198	13.2	45.593
4	CF/SF 2	1.517	8.4	25.26926	13.8	37.43251

5.1 General Characteristics for Cracking

The first crack was appeared where the beam with shorter face was failed. The cracks with spiral were at 45° as the applied torque increases and spread in the test area where the beam is strengthened.

5.2 Minimum Torsional Reinforcements

The beam does not fail during cracking where the minimum torsional reinforcement is necessary. To prevent such a sudden loss, the torsional reinforcement for the minimum should be increased by 1% and specimen fail at 1.2 times more than of cracking load suggested by Hsu and Hwang and shown in Table 4. The reason that due to the lack of reinforcement. It is provided 1% greater for all the beams expect CC1 and CF/SF 1. To avoid sudden failure this study suggested that torsional reinforcement of minimum should be provided 1% greater suggested by Hsu and Hwang.

5.3 Ductility

The imminent failure of a structure, before it fails it receives a warning for important parameter is knows as ductility. That ductility of a torsional beam shall be called the deformable ability that could be used as the torsional angle of 90 percent of the final torque Torsion is subjected to ductility of the beam. Ductility improves as torsional strengthening ratios increase for both CC and CF/SF beams. The calculation of ACI method is moderate in maximum twist and Macgregor method of maximum twist of calculation is miscalculated [10].

Table 5 Stiffness comparison

S. No.	Beam details	Ultimate		Exp stiffness kNm	Stiffness using Park and Paulay method
		Applied torque kNm	Twist (rad/m) × 10^{-3}		
1	CC1	13.2	45.593	289.51	172.71
2	CC 2	13.8	39.629	348.22	172.71
3	CF/SF 1	13.2	45.593	289.51	172.71
4	CF/SF 2	13.8	37.43251	368.663	172.71

5.4 Stiffness

The stiffness is calculated in both CC and CF/SF specimen as thewas computed as for the ratio of an ultimate torque to a angle of rotation of a specific experimental data [7]. The theoretical stiffness was measured using the concept of Park and Paulay indicated (Table 5) indicates the experimental rigidity and theoretical rigidity measured for comparison. The experimental rigidity of the CC and CF/SF specimens' samples was about equivalentand the theoretical rigidity measured as Park and Paulay had indicated was moderate.

6 Conclusion

Fourbeams (two in coconut fiber/steel fiber and the next two using conventional concrete aggregate) with the reinforcement ratios were tested in torsion. The results were made based on conclusions. In general, it is similar when subjected to torsion CC beams is similar to CF/SF beams. The cracking torque strength is to calculate for both CC and CF/SF beams as Macgregor's ACI calculation and equation are conservative. In the event that the equation by Macgregor is more conservative when compared to ACI prediction. The coconut fibers are more ductility than conventional aggregate. Similarly, equation suggested by Macgregor and ACI calculation is more cautious to calculate the strength of ultimate torque. To prevent sudden failure, the torsional reinforcement should be increased by 1%. Conventional specimens compared with CF/SF specimens have more ductility. This is due to the reason of natural fibers present in coconut fiber. Crack width of CF/SF beams is somewhat higher than Conventional beams. Experimental stiffness of Conventional and CF/SF specimens are almost equal and theoretical stiffness suggested by park and paulay is moderate. The results of coconut/steel fiber in a beam is subjected to torsion. Hence in this study only two beams of conventional and CF/SF are studied.

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References

1. Jain, A. K. (1995). *Reinforced concrete, limit state design.* New Chand & Bros, Roorkee, © 1993, reprinted 1995 (p. 305).
2. ACI Committee 318. (1989). *Building code requirements for reinforced concrete and commentary*. Farmington Hills, United States of America: American Concrete Institute.
3. ACI Committee 318. (1995). *Building code requirements for structural concrete and commentary*. Farmington Hills, United States of America: American Concrete Institute.
4. Gunasekaran, K., Ramasubramani, R., Annadurai, R., & Prakash Chandar, S. (2014). Study on reinforced lightweight coconut shell concrete beam behavior under torsion. *Materials and Design, 57*, 374–382.
5. Hsu, T. T. C., & Hwang, C. S. (1977). Torsional limit design of spandrel beams. *ACI Structural Journal, 74*(2), 71–79.
6. IS: 2386 (Part 1). (1963). Indian standard for methods of test for aggregates for concrete (part 1) of particle size and shape.
7. IS 456. (2000). *Indian standard plain and reinforced concrete–code of practice*. New Delhi: BIS.
8. Park, R., & Paulay, T. (1994). *Reinforced concrete structures.* A Wiley-Interscience Publication.
9. Macgregor, J. G., & Ghoneim, M. G. (1995). Design for torsion'. *ACI structural Journal, 92*(2), 211–218.
10. Purushothaman, P. (1986). Reinforced concrete structural elements, behavior, analysis and design. Tata McGraw Hill Publishing Company Limited, New Delhi, © 1984, reprinted 1986 (p. 169).
11. Punmia, B. C., Jain, A. K., & Jain, A. K. (2011). *Limit state design of reinforced concrete.* Laxmi Publications (P) Ltd.: New Delhi, © 2007, reprinted 2011 (p. 194).

Analysis of "Integrated Exhibition-Cum-Convention Centre, Pragati Maidan, New Delhi", Using ETABS

Kanuj Thenua and M. Shanmuga Sundaram

Abstract Analysis is done to intuit the response of erection under various load combinations. Principle purpose of this work is to examine the "Redevelopment of ITPO Complex into Integrated Exhibition-cum-Convention Centre at Pragati Maidan, New Delhi", consisting of long column, deck slab, RCC slab, truss, shear walls, etc. The out-turn of seismic push on structure with various units have been studied using ETABS. Load combinations is done as per norms. Grade of concrete and steel is taken as per need. There are several factors affecting the performance of erection in which storey drift, base shear and storey displacement have a major part in finding the response of erection against the seismic loads in various regions.

Keywords Analysis · Truss · Storey displacement · ETABS

1 Introduction

The vibrations produced by earth tremor are grouped by volatility, as the loam pulsate in the prone zones in all routes, which lead san alterable ground easing and affecting the ground of origin sited in the earth tremor zone because of which the units of the erection vibrates and causes internal forces according to acceleration caused by the earth tremor and also by the mass of these units [1]. There are two main categories in seismic analysis they are 'static analysis' and 'dynamic analysis'. This study examines the "Redevelopment of ITPO Complex into Integrated Exhibition-cum-Convention Centre at Pragati Maidan, New Delhi", consisting of long column, deck slab, RCC slab, truss, shear walls, etc. The modelling is done using ETABS and for reinforcement Fe500, Fe415, M35 and M50 grades of concrete and UC and UB is adapted for steel members. The effect of seismic forces is calculated and load combinations are done according to code book. The layout of the conventional centre has been shown in the 'Fig. 1'.

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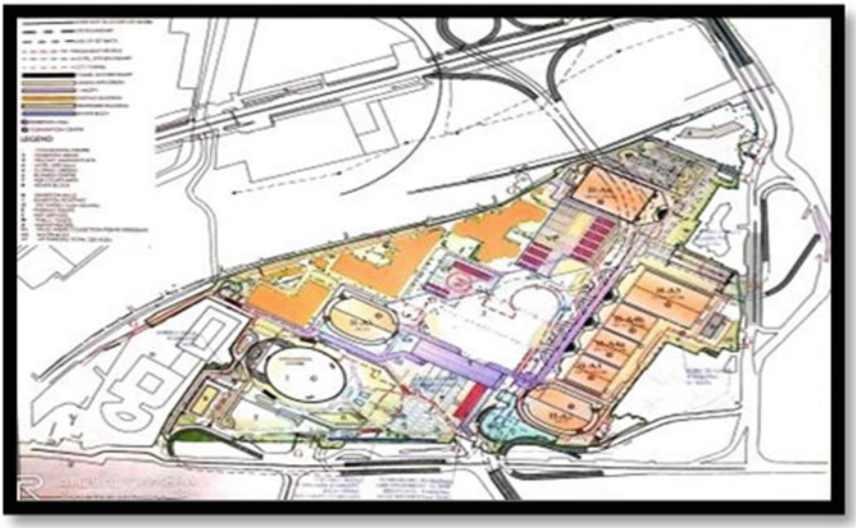

Fig. 1 Integrated Exhibition-cum-Convention Centre, Pragati Maidan, New Delhi

2 Objective

To carry out analysis and study the behaviour of structure under seismic zones, soil type, and other factors, the 'Fig. 2' shows the front view of the conventional centre.

- Storey displacement
- Storey drift
- Storey shear

3 Redevelopment of ITPO Complex into Integrated Exhibition-Cum-Convention Centre at Pragati Maidan, New Delhi

The conventional centre is located at the Pragati Maidan, New Delhi, which is to be reengineered to a world-class Integrated Exhibition-cum-Convention Centre. The budget of the project is Rs. 2254 crore, 'Fig. 3' shows a tri column. This centre will be of 32.4 m tall with a capacity of 7000 people and also has an amphitheatre with capacity of 3000 people. It also includes 22 conference rooms, special areas for international dignitaries and has a rooftop helipad. 'Fig. 4' shows the slab Truss members.

Fig. 2 Front View of Convention Centre

Fig. 3 Long column (Tri column)

Fig. 4 Truss member

Fig. 5 Load combinations

1) $1.2\,[\mathrm{DL} + \mathrm{IL} \pm (EL_X \pm 0.3\,EL_Y \pm 0.3\,EL_Z)]$ and

$1.2\,[\mathrm{DL} + \mathrm{IL} \pm (EL_Y \pm 0.3\,EL_X \pm 0.3\,EL_Z)]$;

2) $1.5\,[\mathrm{DL} \pm (EL_X \pm 0.3\,EL_Y \pm 0.3\,EL_Z)]$ and

$1.5\,[\mathrm{DL} \pm (EL_Y \pm 0.3\,EL_X \pm 0.3\,EL_Z)]$; and

3) $0.9\,\mathrm{DL} \pm 1.5\,(EL_X \pm 0.3\,EL_Y \pm 0.3\,EL_Z)$ and

$0.9\,\mathrm{DL} \pm 1.5\,(EL_Y \pm 0.3\,EL_X \pm 0.3\,EL_Z)$.

4 Methodology

The grade used for reinforcement is Fe500 and Fe415, in case of concrete M35 and M50 and for steel members UC and UB are used. ‘Figure 8’ shows basement plan, the preliminary details of the conventional centre are given in Table 1.

- IS456:2000–Plain and Reinforced concrete
- IS226:1975, IS808:1964, IS801:1975, IS2062:1984-Structural Steel Codes
- IS875-Part 1 for Dead load

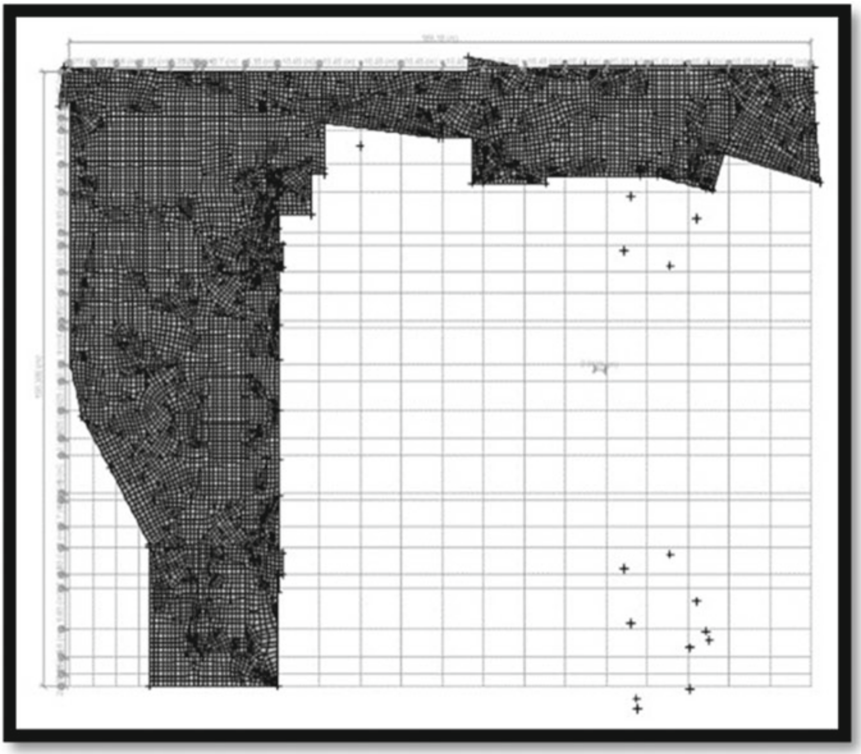

Fig. 6 Basement plan

- IS875 -Part 2 for Live load
- IS875 -Part 3 for Earthquake load
- IS 1893: 2016—Part 1 Criteria for Earthquake Resistant Design of Structures Some load and load combination applied are:

1. Dead Load
2. Live Load
3. EQinx direction
4. EQiny direction
5. Load combinations as shown in 'Fig. 5'.

Following figures show the plan of the structure at various levels (Figs. 6–12).

Fig. 7 Ground-level plan

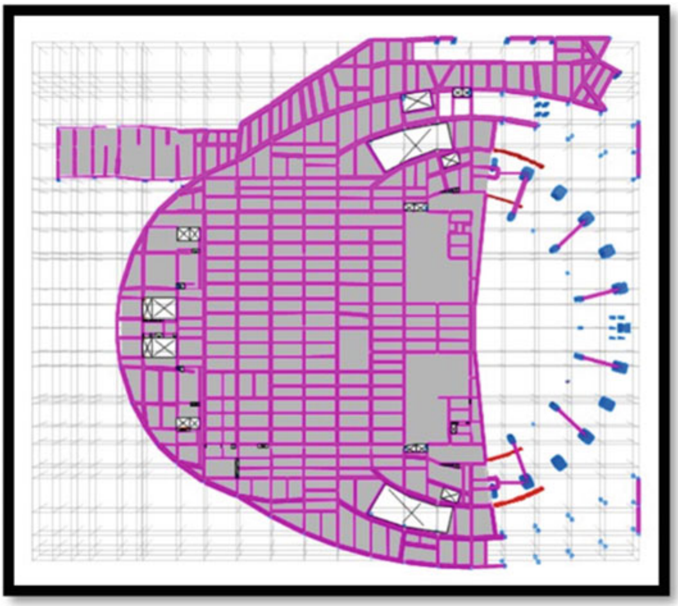

Fig. 8 Level 2 plan

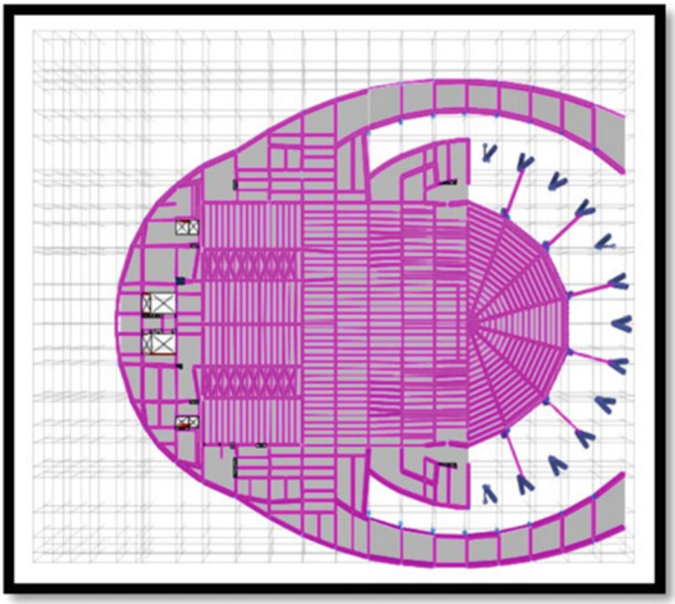

Fig. 9 Level 3 plan

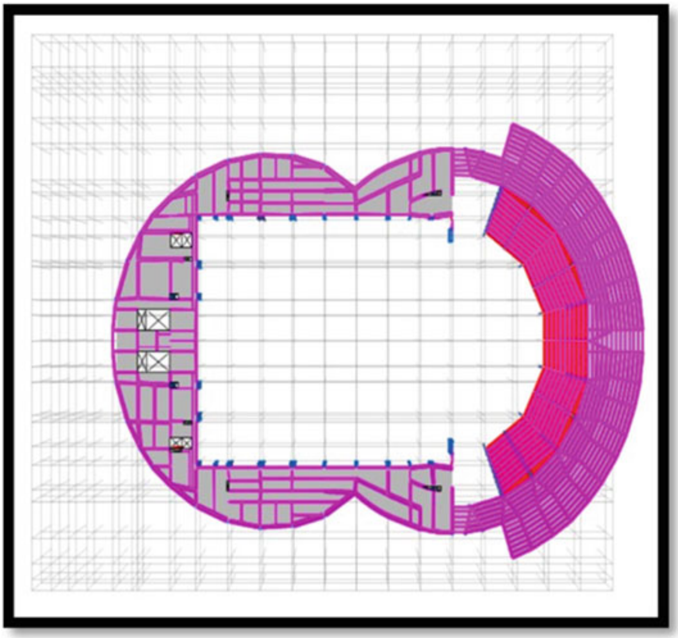

Fig. 10 Level 4 Plan

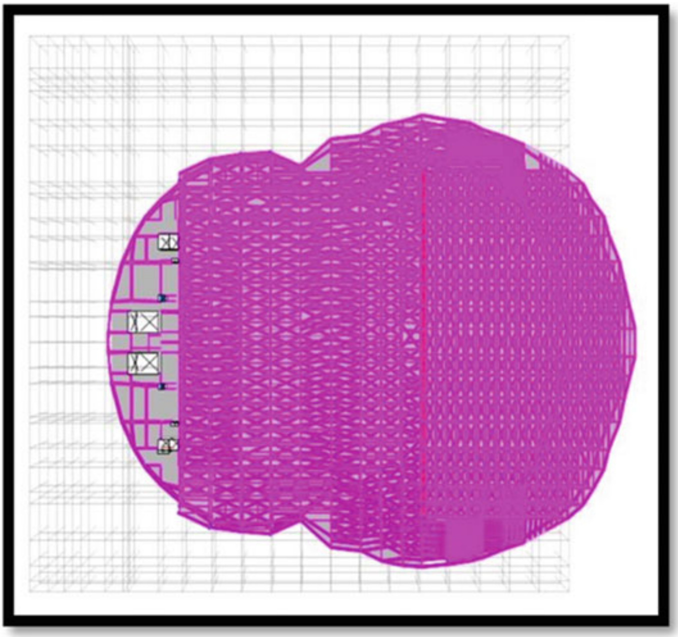

Fig. 11 Roof level plan

Table 1 Preliminary details of convention Centre

S. no	Name	Dimension
1	Length	189.18 m
2	Breadth	150.335 m
3	Height above GL	34.35 m
4	Basement (Level 0)	-5.75
5	GL (Level 1)	+ 0.00
6	Level 2	+ 6.4
7	Level 3	+ 15.4
8	Level 4	+ 22.3
9	Terrace level	+ 30.19

5 Results and Discussion

Following analysis considerations are assumed as per code given below, Tables 2 and 3 give the various results obtained in analysis.

- Seismic zone (Z): II, III, IV, V
- Soil Type: I, II, III

Table 2 Maximum and minimum displacements

Levels	Storeyheight	Z(V) S(III)	Z(V) S(III)	Z(V) S(III)	Z(V) S(III)
		MaxX (mm)	MinX (mm)	MaxY (mm)	MinY (mm)
Roof Level (30.19)	35.54	158.169	21.693	123.139	27.648
Level 4 (22.3)	27.65	88.258	12.775	76.142	11.725
Level 3 (15.4)	20.75	45.878	16.24	52.782	23.871
Level 2 (6.4)	11.75	26.102	7.83	24.122	19.991
Ground level	6.35	7.235	2.2	22.115	15.925
Basement	0	0	0	0	0

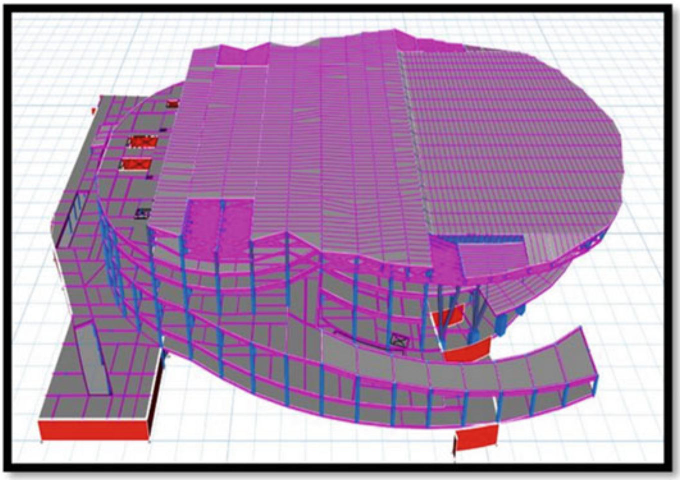

Fig. 12 3D model (Front view)

- Importance factor (I):1.2
- Response Reduction Factor (R):5

5.1 Graphs

The following graphs are obtained after analysing the structure, (Figs. 13–18) are given below.

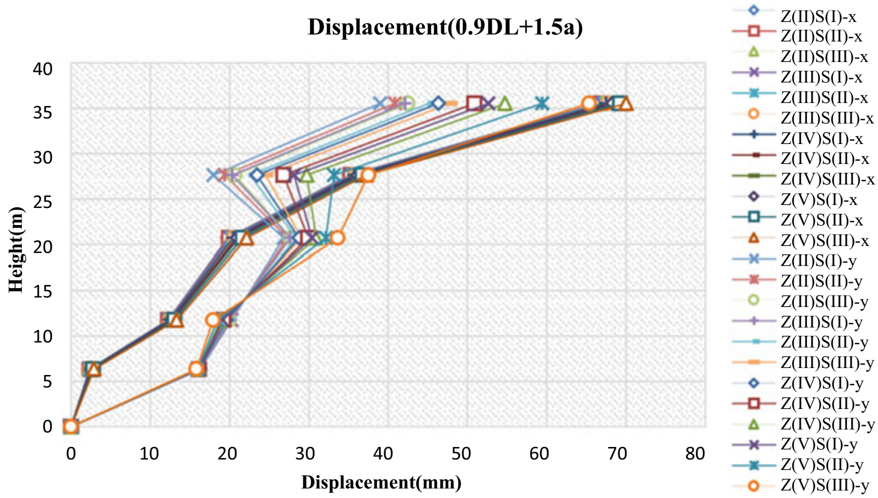

Fig. 13 Displacement (0.9DL + 1.5a)

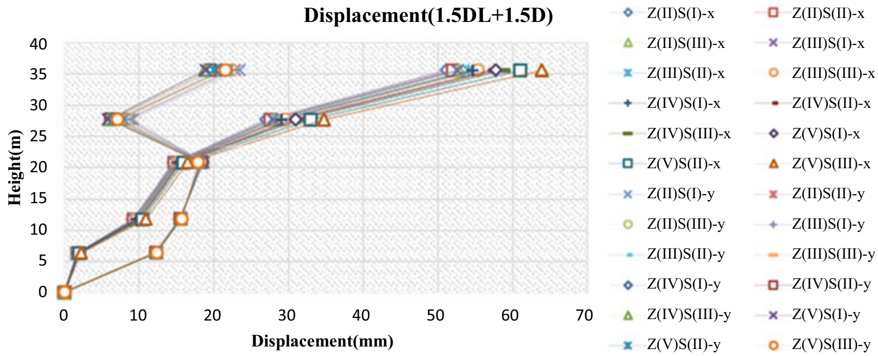

Fig. 14 Displacement (1.5DL + 1.5D)

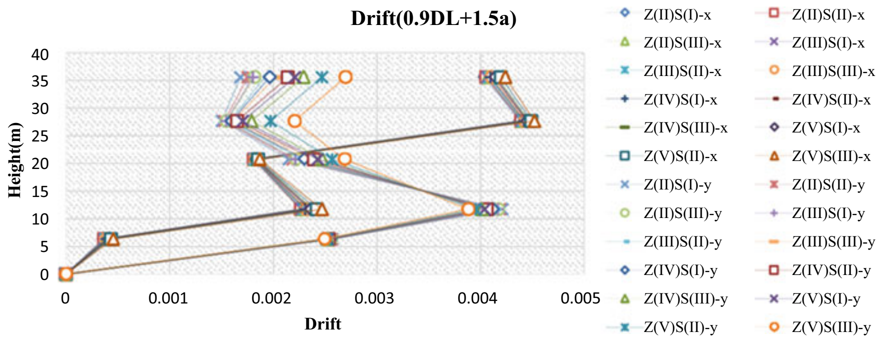

Fig. 15 Drift (0.9DL + 1.5a)

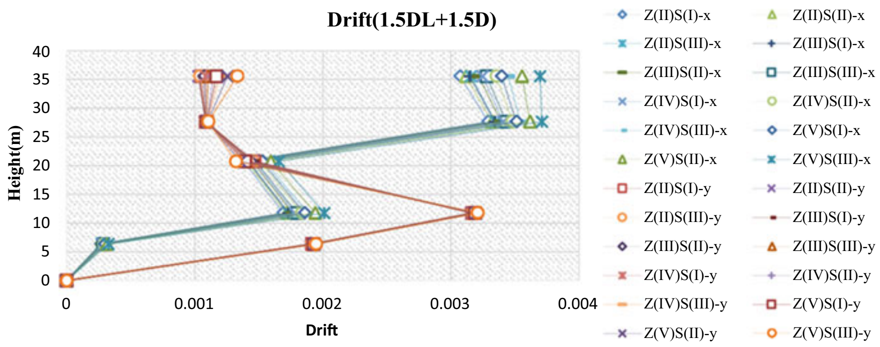

Fig. 16 Drift (1.5DL + 1.5D)

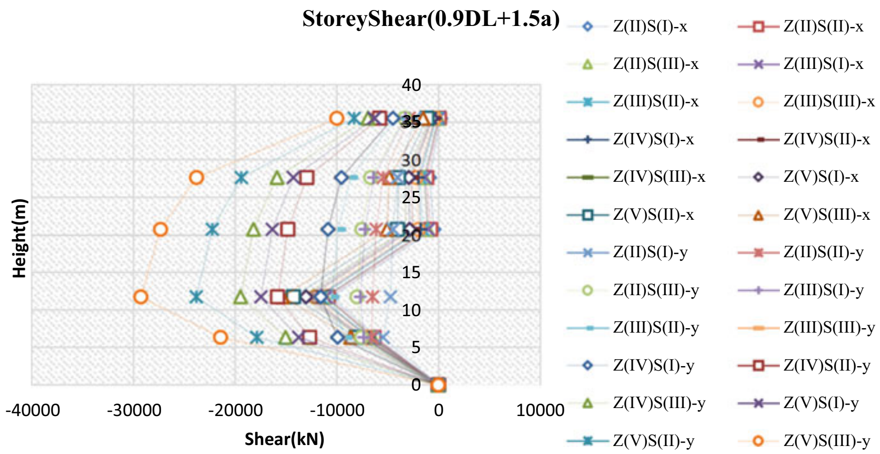

Fig. 17 Storey shear (0.9DL + 1.5a)

6 Conclusion

The analysis of the convention centre is performed in ETABS to study the behaviour of structure under different seismic zones and soil types which gives the data including displacement, drift and shear. The obtained results are studied and the following is concluded:

- Maximum displacement is observed in load combination (0.9DL + 1.5a) in Z(V)S(III) in x and y directions in comparison to other seismic zones and soil types at Roof Level.
- Minimum displacement is observed in load combination (0.9DL + 1.5a) in Z(V)S(III) in x and y directions in comparison to other seismic zones and soil types at Ground Level.

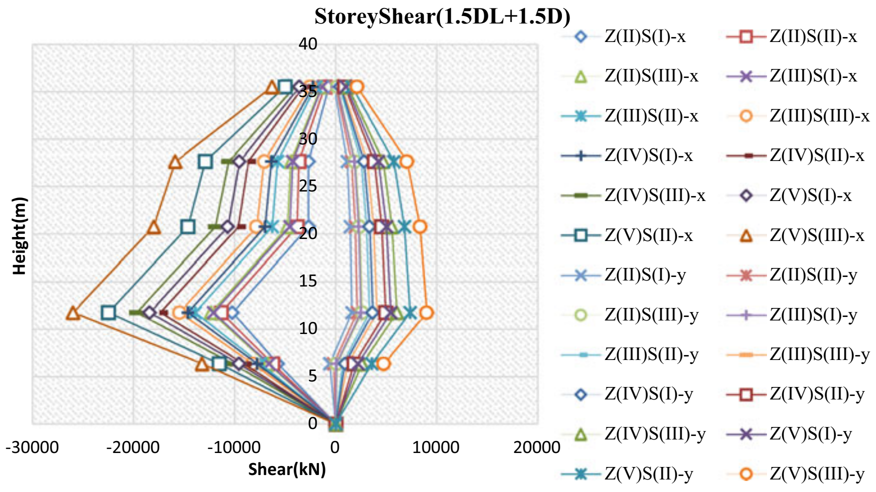

Fig. 18 Storey shear (1.5DL + 1.5D)

- Maximum drift is observed in load combination (0.9DL + 1.5a) in Z(V)S(III) in comparison to other seismic zones and soil types at Level 4 in x direction and at Level 2 in y direction.
- Minimum drift is observed in load combination (0.9DL + 1.5a) in Z(V)S(III) in comparison to other seismic zones and soil types at Level 4 in x direction and at Ground Level in y direction.
- Maximum store y shear is observed in load combination (0.9DL + 1.5a) in Z(V) S(III) in x and y directions in comparison to other seismic zones and soil types at Level 2.
- As zone and soil type increase, there is a simultaneous increase in the values of displacement, drift and shear.

References

1. Pellicane, P. J. (2000). Comparison of ASD and LRFD codes for wood members. III: connections. *Practice Periodical on Structural Design and Construction, ASCE*, *5*(2), 66–69.
2. Roeder, C. W. (1990). Comparison of LRFD and allowable stress design methods for steel structures. In *5th Seminariode Ingenieria E structural*, *San Jose, Costa Rica.*
3. Shahawy, M. A., & Batchelor, B. D. (1996). Shear behaviour of full-scale prestressed concrete girders: Comparison between AASHTO specifications and LRFD code. *PCI Journal, 41*(3), 48–62.
4. Malhas, F. A., & Rahman, A. (2003). A comparative investigation of the provisions of the ACI and EC2 for flexural deflection. In *ACI special publication*,s SP-210 (pp. 93–114). American Concrete Institute.

5. Miller, L. J., & Durham, S. (2008). Comparison of standard load and load and resistance factor bridge design specifications forburied concrete structures. *Transportation Research Record*, *2050*, TRB.
6. Washington, D. C., Nielsen, R. J., & Schmeckpeper, E. R. (2002). Single-spanprestressed girder bridge: LRFD design and comparison. *Journal of Bridge Engineering*, *7*(1), 22–30.

Project Management

Greenhouse Gases Emission from Municipal Solid Waste in Thanjavur

D. Deepa, P. Sharmila, and S. Mary Rebekah Sharmila

Abstract The topic of greenhouse gas (GHG) emissions from municipal solid waste (MSW) is important in the sense of climate change. In all of India's megacities, population growth is outpacing municipal solid waste production. With a population of 2.56 lakhs in 2019, Thanjavur is one of Tamil Nadu's oldest and fastest growing cities, with an 8.5% growth rate over the last decade. Every day, approximately 105 tonnes of urban solid waste are produced. In the existing scheme, there are no scientific techniques for treating and disposing of solid waste. The solid waste collected will be transported to the Srinivasapuram disposal site without discrimination (5 kms from the city). This endangers people's health and degrades the urban climate. Inventory of Thanjavur site-specific emission factors using IPCC and LandGEM models and site-specific measurements based on appropriate activity data. These models are used to measure the emissions of methane, total landfilll gas, non-methane organic compounds, carbon dioxide, and other MSW air contaminants.

Keywords IPCC model · LandGem model · Greenhouse gases (GHG) · Municipal solid waste (MSW)

The original version of this chapter was revised: An affiliation correction for the author "S. M. R. Sharmila" has been incorporated. The correction to this chapter is available at https://doi.org/10.1007/978-981-16-5839-6_49

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1 Introduction

The anaerobic waste oxidation produces greenhouse gases as a result of microbial activity [12]. These deposition sites are one of the largest anthropogenic sources of greenhouse gases, in particular methane gases, with 21 times the global carbon dioxide heating capacity [9]. CH_4 is generated due to poor CO_2 management. The municipal solid waste is 3–4% annually responsible for worldwide anti-growth emissions of greenhouse gases. With increasing population and GDP, solid waste disposal emissions are projected to grow [10]. Weather and climate variability have already adapted human communities to some extent. Consequently, it is important to identify places where residents cannot cope with current and severe climate variations, such as floods, droughts, and thermal waves [11]. This highlights the need for urgent action. Improving one's ability to deal with current climate variability would almost definitely boost one's ability to deal with long-term climate change. The bulk of methane produced by landfills and dumps is directly released into the atmosphere [9, 2]. Mismanagement of urban waste management is undeniably related to greenhouse gas emissions [6, 5]. Methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) are the main elements of greenhouse gases. The GHG emissions were calculated based on data obtained in 2009. In order to find a way to reduce both GHG emissions and waste volume in sites of waste disposal, two scenarios were also developed [7–13].

2 Study Area

Thanjavur is a city located 315 km south of Chennai. This city's population and density have increased dramatically, resulting in increased solid waste production and exerting immense pressure on local authorities in terms of best solid waste management practices. Around 105 tons of solid urban waste are being made every day in this town. Increased development of solid waste, notably Municipal Solid Waste (MSW), is a significant concern, particularly in urban areas, which is exacerbated due to poor waste disposal plans. Corresponds to the collection and disposal of solid waste by the local municipalities [1–11]. The bulk of solid waste produced in Thanjavur is residential and commercial waste. Thanjavur Municipal Corporation (TMC) faces a major challenge in disposing of rising volumes of urban solid waste. The city's new solid waste disposal system does not meet scientific standards, posing a danger to the environment and sanitation.

3 Methodology

3.1 Present Scenario

Thanjavur is a town 315 km south of Chennai. The population and density of this town have grown significantly, resulting in increased volume of solid waste and great pressure on local authorities as regards best practices for managing solid waste. Around 105 tons of municipal solid waste is generated every day. Increased production of solid waste, in particular the MSW, is a grave concern, particularly in urban areas, and the problem has been worsened by poor disposal plans. The collection and waste management should be properly carried out by urban local authorities [7, 8]. In Thanjavur, the majority of solid waste is generated from residential and commercial areas. Thanjavur Municipal Corporation (TMC) faces a major challenge in disposing of rising volumes of urban solid waste. The city's new solid waste disposal system does not meet scientific standards, posing a danger to the environment and sanitation. TMC has a population of around 2.40 lakhs, according to the 2011 census, with an annual decadal growth rate of 8.59%. The selected plan for Srinivasapuram dump-yard is 36 years long, based on a detailed waste management plan in Thanjavur. TMC is a local government in Thanjavur, Tamil Nadu. Table 1 shows the population and waste generation rate. Thanjavur has been a special grade municipality since 1983, and it is responsible for solid waste management. Thanjavur's main dump yard is in Srinivasapuram, and it has been in service for the past 36 years. Push carts and tricycles are used to transport waste to the dumping site in Srinivasapuram, but there is no decentralized system in place. The overall length of roads is approximately 754 km, with 276 km of tar roads and 35 km of cement roads being swept every day. There are 51 wards that make up the municipal corporation.

The sanitary supervisor and sanitary inspectors oversee each ward, which is managed by conservancy staff. The garbage is being delivered to the city's land-fill ground. Table 2 shows the facilities in TMC for MSW transportation. In order for LandGem software to calculate the amount of methane emissions, the weight of waste produced during planned period needs to be carefully evaluated, and LandGem specifies the quantity of methane released dependent on the quantity of waste and methane power generation [6].

Table 1 Shows the population size and waste generation rate

S. no	Year	Pop (in lakhs)	Generation rates	Quantity of waste generation
1	1981	1.84	300 g/p/day	552tpd
2	1991	2.05	320 g/p/day	656tpd
3	2001	2.21	350 g/p/day	773.5tpd
4	2011	2.40	400 g/p/day	960tpd
5	2021 (Estimated)	2.59	400 g/p/day	1036tpd

Table 2 Solid waste collection and transportation Infrastructure in Thanjavur Municipal Corporation

S. no	Type of vehicles	No of vehicles
1	Auto	25
2	Lorry	2
3	Tractor	1
4	Mini Lorry	3
5	Tipper	5
6	Dumper placer	3

3.2 LandGEM Model

The LandGEM model is based on a first-order decomposition rate equation for the quantification of emissions from decomposition of landfilled waste in MSW deposits. The application provides an easy way to measure emissions of waste pumps. LandGEM uses the first decomposition rate equation below to estimate annual emission over a time frame of your choice. This decomposition Eq. (1) defines model parameters k and Lo further [3, 4, 12, 14].

$$Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \tag{1}$$

where

I mean an increase in time for one year.

n = (year calculated)—–year calculated) (initial year of waste acceptance).

j is a 0.1-year time increase.

k = production rate of methane (year-1).

(m^3 /Mg) = capacity to produce potential methane.

Mi refers to last year's acceptance of waste (Mg).

tij is the age of the jth waste section Mi accepted during the last year (decimal years, e.g., 3.2 years).

3.3 IPCC Model

In this case the mass of degradable organic carbon, decomposable in anaerobic conditions, is proportional to the amount of reactant remaining in the first order decline reaction (DDOCm). DOC decomposable from waste disposing data can be measured using the below Eq. (2) [7, 8, 15].

$$\text{DDOCm} = \text{W} * \text{DOC} * \text{DOCf} * \text{MCF} \tag{2}$$

where

DDOCm is the deposited mass of decomposable DOC, Gg.
W is the quantity of urban waste.
DOC is the decomposable organic carbon, Gg.
DOC.f = DOC fraction decomposable (fraction).
MCF = element of degradation CH4 for the year of deposition (fraction).

4 Results and Discussion

4.1 LandGEM Model

In the current situation, the default values used by the US Environmental Protection Agency were used Table 3 lists the constant value terms used in the model. The

Table 3 Emission of Greenhouse gases based on LandGEM model

Year	Total landfill gas	Methane	Carbon dioxide	Year	Total landfill gas	Methane	Carbon dioxide
	Mg/Year	Mg/Year	Mg/Year		Mg/Year	Mg/Year	Mg/Year
2011	0	0	0	2021	6.06E + 04	1.62E + 04	4.44E + 04
2012	7.27E + 03	1.94E + 03	5.33E + 03	2022	6.54E + 04	1.75E + 04	4.79E + 04
2013	1.42E + 04	3.80E + 03	1.04E + 04	2023	7.00E + 04	1.87E + 04	5.13E + 04
2014	2.09E + 04	5.59E + 03	1.53E + 04	2024	7.44E + 04	1.98E + 04	5.45E + 04
2015	2.73E + 04	7.29E + 03	2.00E + 04	2025	7.86E + 04	2.10E + 04	5.76E + 04
2016	3.34E + 04	8.92E + 03	2.45E + 04	2026	8.26E + 04	2.21E + 04	6.05E + 04
2017	3.93E + 04	1.05E + 04	2.88E + 04	2027	8.63E + 04	2.31E + 04	6.33E + 04
2018	4.49E + 04	1.20E + 04	3.29E + 04	2028	8.99E + 04	2.40E + 04	6.59E + 04
2019	5.03E + 04	1.34E + 04	3.69E + 04	2029	9.33 + 04	2.49E + 04	6.84E + 04
2020	5.55E + 04	1.48E + 04	4.07E + 04	2030	9.66E + 04	2.58E + 04	7.08E + 04
				2031	9.97E + 04	2.66E + 04	7.31E + 04

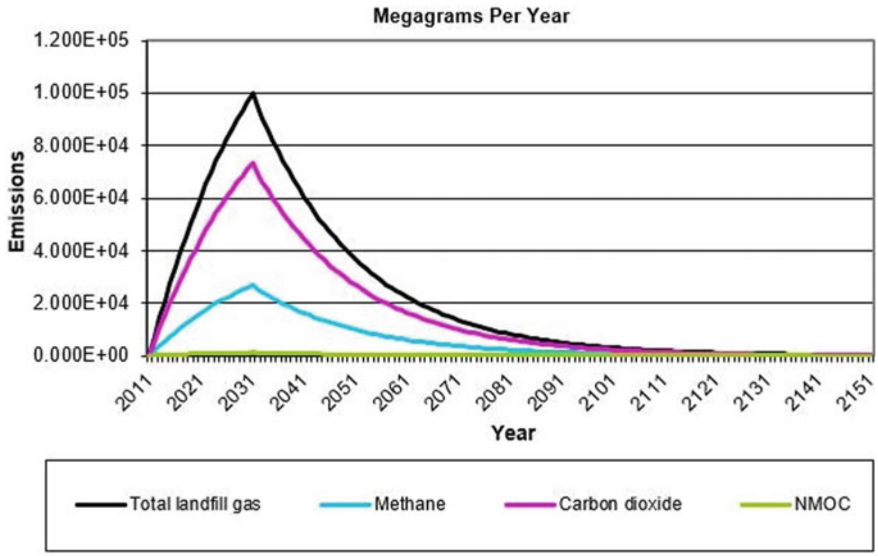

Fig. 1 Gas emission from Srinivasapuram dump yard using LandGem model

annual methane production from the disposed site is shown in the table. In 2012, methane production was 1.94E + 03 Mg/year, and by 2031, it had risen to 2.66E + 0 Mg/year. Figure 1 depicts the pattern of total gas emission, methane, and carbon dioxide emissions at the dump site over the course of the project. The annual methane, Nonmethane Organic Compound (NMOC) and CO_2 production from the disposed site is shown in the (Fig. 1).

4.2 IPCC Model

India was given as the nation, and Asia-South Central was given as the region. The climate was dry tropical, meaning it was hot and the average annual rainfall was less than 1000 mm. Table 4 displays the constant value terms used in the following model. The annual methane production from the disposed site is shown in the (Fig. 2). In 2012, methane production was 3 Gg/year, but by 2031, it had risen to 36 Gg/year.

5 Conclusion

It has been observed that the existing facilities for solid waste management in Thanjavur are inadequate to cope with the city's rising population and waste generation. From the LandGEM model, it was found that the annual methane production from

Table 4 Emission of greenhouse gases based on IPCC model

Year	Methane (Gg/year)	Year	Methane (Gg/year)	Year	Methane (Gg/year)
2011	0	2018	20	2025	30
2012	3	2019	22	2026	31
2013	6	2020	24	2027	32
2014	9	2021	26	2028	33
2015	11	2022	27	2029	34
2016	14	2023	28	2030	35
2017	17	2024	29	2031	36

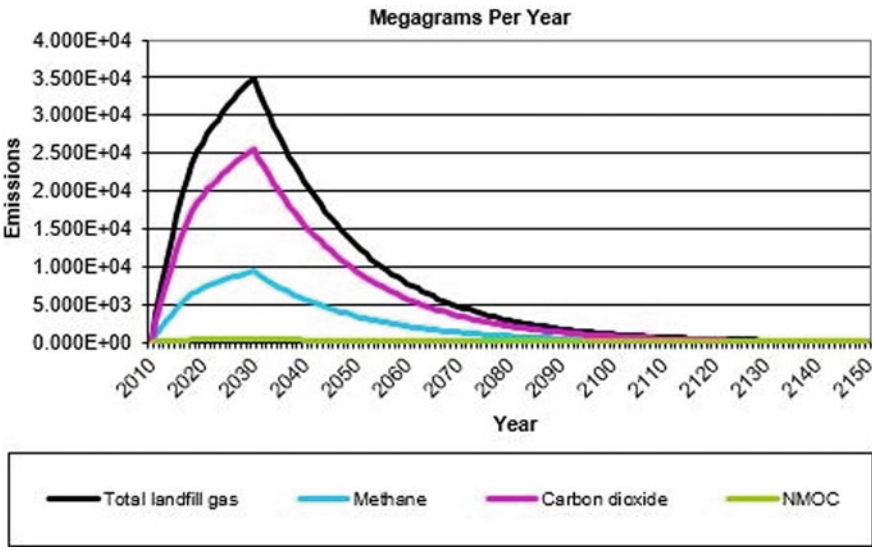

Fig. 2 Gas emission from Srinivasapuram dump yard using IPCC model

the disposed site is shown in the table. In 2012, methane production was 1.94E + 03 Mg/year, and by 2031, it had risen to 2.66E + 0 Mg/year, whereas from the IPCC model, in 2012, methane production was 3Gg/year, but by 2031, it had risen to 36 Gg/year. This is due to temperature has a smaller impact on LFG generation than precipitation and should not be assigned equal weight in assigning climate categories and Potential Evapotranspiration Data (PET) data are usually not available and should not be a basis for assigning climate in temperate regions even if they are scientifically more valid. To reduce waste load on the compost yard, the site's waste segregation should be strengthened in terms of biodegradable and non-biodegradable waste. New methods can be used to enhance existing facilities for solid waste collection, segregation, and transportation. It is also evident that lack of understanding, technological expertise, and enforcement of the legal framework for an integrated SWM system are major impediments to proper solid waste management.

References

1. Abichou, T., Clark, J., Tan, S., & Chanton, J. (2011). Reporting central tendencies of chamber measured surface emission and oxidation. *Waste Management, 31*(5), 1002–1008.
2. Andriani, D., & Atmaja, T. D. (2019). The potentials of landfill gas production: A review on municipal solid waste management in Indonesia. *Journal of Material Cycles and Waste Management, 21*(6), 1572–1586.
3. Bhailall, S., Bogner, J., Lee, C. P., et al. (2016). Site specific landfill gas emissions: model comparisons to actual LFG yields and measured methane and carbon dioxide fluxes at six landfill sites in South Africa. In *Proceedings of the 23rd WasteCon conference* (pp. 17–21).
4. Cho, H. S., Moon, H. S., & Kim, J. Y. (2012). Effect of quantity and composition of waste on the prediction of annual methane potential from landfills. *Bioresource Technology, 109*, 86–92.
5. Das, D., Majhi, B. K., Pal, S., & Jash, T. (2015). Estimation of land-fill gas generation from municipal solid waste in Indian cities, energy. *Procedia, 90, 50–56.*
6. Deepa, D., Dhivya, K. S., Sasireka, K. (2019). Evaluation of MSW management in the pursuit of climate change mitigation by LandGEM model in Chidambaram town. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *8*(11), 2893–2897. ISSN: 2278-3075.
7. Intergovernmental Panel on Climate Change (IPCC). (1996). *Report of the twelfth season of the intergovernmental panel on climate change, Mexico city* (pp. 11–13).
8. NEERI. (2002). Uncertainty reduction in methane emission factor from municipal solid waste landfills. In *NEERI report*, (pp. 8–19).
9. Palogos, I., Chourdakis, I., Tsafantakis, K., & Gikas, P. (2017). Simulation of landfill gas production rate and methane concentration: modelling and verification through field measurements. *IASTEM International Conference, Los Angeles, USA.*
10. Plocoste, T., Jacoby-Koaly, S., Petit, R.-H., & Roussas, A. (2016). Estimation of methane emission from a waste dome in a tropical insular area. *International Journal of Waste Resources, 6*(2), 1–7.
11. Prashanthi, R., & Pavithra, R. (2017). Environmental and health risk assessment for municipal solid waste dump-Yard in Chidambaram. *International Conference on "Recent Trends in Environmental Science and Engineering, 6*(1), 35– 38.
12. Sil, A., Kumar, S., & Kumar, R. (2014). Formulating LandGEM model for estimation of landfill gas under Indian scenario. *International Journal of Environmental Technology and Management*, *17*, 2/3/4, 293–299.
13. Spokas, K., Bogner, J., Chanton, J. P., Morcet, M., Aran, C., Graff, C., Moreau-Le Goluan, Y., & Hebe, I. (2006). Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems? *Waste Management, 26*(5), 516–525.
14. Talyan, V., Dahiya, R. P., Anand, S., & Sreekrishnan, T. R. (2007). Quantification of methane emission from municipal solid waste disposal in Delhi. *Resources, Conservation and Recycling, 50*(3), 240–259.
15. Thompson, S., Sawyer, J., Bonam, R., & Valdivia, J. E. (2009). Building a better methane generation model: Validating models with methane recovery rates from 35 Canadian landfills. *Waste Management*, *29*(7), 2085–2091.

Evaluation of Meteorological Drought Impact Using Drought Indices

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Abstract Drought is said to occur when there is a lack of water or when there is less precipitation than usual. Drought is typically triggered by changes in environment and human activities; its severity can vary from place to place and this intensity will be measured using drought indices. This study used rainfall data from the last 100 years of five districts in Andhra Pradesh, namely, Kadapa, Prakasam, Krishna, East Godawari and Visakhapatnam, and drought severity is measured using indices such as the Standardized Precipitation Index (SPI), China Z Index (CZI) and Statistical Z-score (SZ Score). The SPI is known to be the world's standard drought measurement index, but the calculation of the SPI is very complex compared to other indices. Thus, by using all these three indices, drought is measured, and comparative analysis is done to find the best alternative for the five districts to find drought severity. The implementation of each index is compared in this analysis, and the findings indicate that CZI and SZ score can provide similar results in East Godawari and Visakapatnam districts, whereas SZ score can provide similar results in Krishna, Prakasam and Kadapa districts, and shows slight deviation to the SPI for all time scales.

Keywords Precipitation · Drought · Standard Precipitation Index · China Z Index · Statistical Z-score

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1 Introduction

In a developing country like India, the majority of the population lives in rural areas, with agriculture as their primary source of income. Seasonal variations affect agricultural yield. But, now-a-days, seasonal changes do not occur properly, leading to shortages of water. This water shortage phenomenon is known as drought. Drought is a period of time in which an area experiences rainfall below its usual value. Drought is one of the most critical problems to be tackled. Droughts are known as meteorological droughts, hydrological droughts, agricultural droughts and socioeconomic droughts. Based on the rainfall data of an area, meteorological drought is assessed. Many drought indices are available for evaluating drought characteristics, including the Standard Precipitation Index (SPI), China Z Index (CZI), Statistical Z-score, Standard Precipitation Evaporation Index (SPEI) and Palmer Drought Severity Index (PDSI) [1] .

The authors assessed dry and wet periods for Thanjavur city using Standard precipitation index (SPI), statistical Z-score and China Z index (CZI) and compared these indicators in different time scales; from this study, it is concluded that the results of CZI and Z-score are close to each other for annual and seasonal rainfall data and they are different from SPI in Thanjavur city [2]. The study explains each and every basic detail of drought like types of droughts, how to study drought, different types of drought indices, deciles [3, 4]. This study compared SPI, EDI, SZI, CZI, Reclamation Drought Index (RDI) and RDDI for their suitability in drought-prone districts of ken river basin. Multiple steps are applied to compute the severity for the five-time steps of 1,3,6,9 and 12 months and compared with each other. The process of calculation of drought index with all different indices is also explained [5–7]. The author has taken the monthly rainfall data (from June to October for 39 years) of two districts in Andhra Pradesh, namely, Ananthapur and Khammam as they were found to be low and high rainfall areas, respectively. They also found that SPI showed moderate dryness instead of extreme dryness and moderate wet instead of extreme wet, when the SPI values are compared with the actual rainfall of the two districts. They also concluded that SPI as a stand-alone indicator needs to be interpreted with caution to assess intensity of drought [8, 9]. The author states that calculation of SPI is not much easier when compared to other indices. In this paper, CZI and Z-score were used to assess drought impact along with SPI and final results were compared. The main aim of this paper is to find better alternative for SPI in their area for assessing drought.

2 Study Area

Andhra Pradesh is a state in India's south-east coastal region. Andhra Pradesh is made up of two principal regions: the southern region of Rayalaseema in the south-west, and the coastal region that is bordered on the east and north by the Bay of Bengal.

There are nine districts in Coastal Andhra and four in Rayalaseema that make up the entire state. The current study utilizes four districts from Coastal Andhra (Prakasam, Krishna, East Godawari and Visakhapatnam) plus one district from Rayalaseema (Kadapa) for its research.

The climate of Kadapa is semi-arid. It has a tradition of getting up to a temperature of over 46 degrees. Living in a hot and humid environment can be extremely unpleasant in the summer. Temperatures range from a minimum of 24 °C to a maximum of 43 °C during this period. It is not unusual for temperatures to exceed 43 degrees Celsius during heat waves. Daytime temperatures vary, with highs in the low to mid-thirties. 75% of the time, humidity is between 75 and 80% during the season. During the monsoon season, the region gets a great deal of rain. The city of Prakasam, with an average temperature of 24.5 degrees Celsius and an average rainfall of 975 mm by the monsoons arriving from the north-east and south-west, has an average temperature of 24.5 degrees Celsius. It is 44 °C hot. The dry winter months are normal (Fig. 1).

Because of its exceptionally hot summers and moderately hot winters, Krishna is known as tropical. The months of April to June have the hottest temperatures.

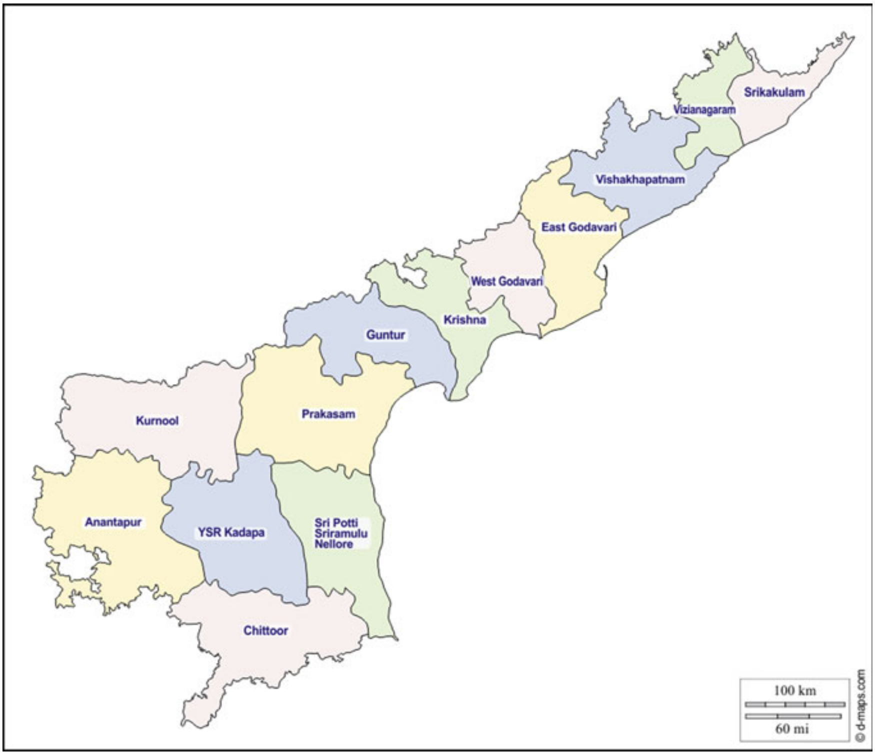

Fig. 1 Location of Study Area. *Source* https://i.pinimg.com/originals/cf/6c/e7/cf6ce7c4f5221d22a4dbe956366b10f3.gif

The south-west monsoon contributes to rainfall, with an annual rainfall of about 1030 mm in the country. East Godawari has a 144-km coastline. As it is situated in the coastal belt, the temperature remains humid for the majority of the year. Andhra Pradesh's green belt is situated in this district. It is covered with deciduous forests. Visakhapatnam has a tropical climate with both wet and dry seasons. The average mean temperature is between 24 and 30 degrees Celsius. The months of May and January have the highest and lowest temperatures, respectively. The highest and lowest temperatures ever recorded were 42 °C in 1978 and 20 °C in 1904. Rainfall comes from the south-west and north-east monsoons, with an annual rainfall of 1118.8 mm.

3 Methodology

Monthly Rainfall data of past 100 years, i.e. from year 1901 to year 2000 is collected from India water portal for all the five districts, i.e. Kadapa, Prakasam, Krishna, East Godawari and Visakapatnam. Drought intensity is measured by using indices like SPI, CZI and Z-score. The detailed procedure for calculation of each index is shown in Fig. 2.

3.1 Standard Precipitation Index (Spi)

The SPI is used as a standard measure for assessing dry and wet times. As a result, SPI is the most commonly used measure for estimating and characterizing meteorological drought around the world. It compares measured total precipitation amounts for an accumulation period of interest with the long-term historic rainfall record for that period to assess precipitation anomalies at a given location.

$$A = lnln\left(\underline{x}\right) - \frac{\sum lnln\,(x)}{n} \tag{1}$$

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{2}$$

$$\beta = \frac{\underline{x}}{\alpha} \tag{3}$$

$$g_x = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \tag{4}$$

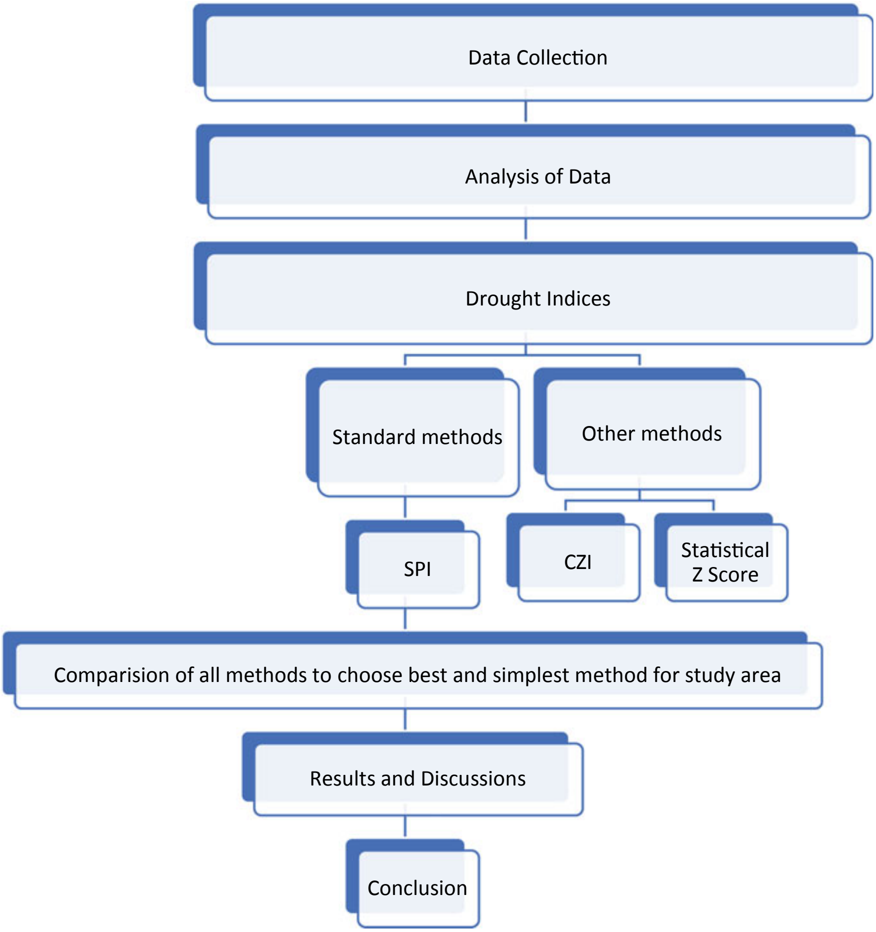

Fig. 2 Flow chart of methodology

$$G_x = \int_0^x g_x dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \tag{5}$$

where $\underline{x}$ = Mean precipitation.
n = Number of precipitation observations.
α (shape factor) parameter of the gamma probability density function.
β (scale factor) parameter of the gamma probability density function.
g_x = gamma probability distribution function.
G_x = cumulative probability distribution function.

3.2 Z-score

This index is determined by subtracting the long-term mean from a single rainfall value and then dividing the result by the standard deviation. The data does not need to be modified by fitting it to the Gamma or Pearson Form III distributions while using the Z-score. Z-score has been used in many drought studies due to its ease of measurement and effectiveness.

$$\varphi_{ij} = \frac{x_{ij} - \underline{x}_i}{\sigma_i} \tag{6}$$

$$\sigma_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(x_{ij} - \underline{x}_i\right)^2} \tag{7}$$

$$\underline{x}_i = \frac{1}{n}\sum_{j=1}^{n} x_{ij} \tag{8}$$

where φ_{ij} = Z-score.
x_{ij} = Precipitation of jth month for period i.
σ_i = Standard deviation.

3.3 China Z Index

The CZI is related to the Wilson-Hilferty cube-root transformation. Assuming that precipitation data obey the Pearson type-III distribution. After calculating values of each indices, moisture categories have to be assessed using Table 1.

$$Z_{ij} = \frac{6}{C_{si}}\left(\frac{C_{si}}{2}\varphi_{ij} + 1\right)^{\frac{1}{3}} - \frac{6}{C_{si}} + \frac{C_{si}}{6} \tag{9}$$

Table 1 Ranges of SPI, China Z index and statistical Z-score for drought categorization

Index	Moisture category
> 2.0	Extremely wet (EW)
1.50 to 1.99	Very wet (VW)
1.00 to 1.49	Moderately wet (MW)
−0.99 to 0.99	Normal (N)
−1.49 to −1.00	Moderately dry (MD)
−1.99 to −1.50	Severely dry (SD)
<−2.0	Extremely dry (ED)

$$C_{si} = \frac{\sum_{j=1}^{n} \left(x_{ij} - \underline{x}\right)^3}{n * \sigma_i^3} \tag{10}$$

where Z_{ij} – CZI.
φ_{ij} = z score.
X_{ij} = precipitation of j month for period i.
C_{si} =Coefficient of skewness.
σ_i =Standard deviation.

4 Results and Discussions

Using SPI, all five districts' measured moisture categories were determined. In the Kadapa district, normal moisture levels have only occurred in 68 of the past 100 years. In 10 and 6 years, respectively, there are mild dry and wet periods. In the last 6 and 5 years, there have been exceptionally dry and rainy phases. In 1 and 4 years, respectively, extreme dry and wet cycles are observed. In the Prakasam district, normal moisture levels have only occurred in 68 of the past 100 years. In 9 and 9 years, respectively, mild dry and wet cycles are observed. In the last 5 years, there have been particularly dry and rainy periods. Extremely dry and rainy cycles occur every 2 years and every 2 years, respectively. In the Krishna district, normal moisture levels have only occurred in 63 of the past 100 years. In 5 and 10 years, respectively, mild dry and wet cycles are observed. In 9 and 5 years, respectively, there have been exceptionally dry and rainy phases. In 0 and 3 years, there are extreme dry and wet periods, respectively.

In the East Godawari district, normal moisture levels have only occurred in 59 of the past 100 years. In 18 and 12 years, mild dry and wet cycles are observed, respectively. In the last 5 and 4 years, there have been exceptionally dry and rainy phases. In 2 and 0 years, respectively, extreme dry and wet cycles are observed. In the Visakapatnam district, normal moisture levels have only occurred in 66 of the past 100 years. In 11 and 12 years, respectively, mild dry and wet periods are observed. In 1 and 5 years, respectively, exceptionally dry and rainy cycles have occurred. In 4 and 1 years, respectively, extreme dry and wet cycles are observed. Drought indices are compared using graphs with historic years on the x-axis and drought indices values on the y-axis. Different coloured lines are drawn here, such as red for SPI, yellow for Z-score and green for CZI. Annual trends of SPI, CZI and Z-score values for Kadapa and East Godawari are depicted in Figs. 3 and 4, respectively.

In Fig. 3, SPI and Z-score are barely differentiated but CZI shows more deviations from SPI. SPI and Z-score exposed very few number of extreme dry condition when compared to CZI. Prakasam and Krishna districts followed the same pattern as of Kadapa district.

In Fig. 0.4, all three indices, i.e. SPI, CZI and Z-score curves are in same pattern. Visakapatnam district followed the same pattern as of East Godawari district. Z-score

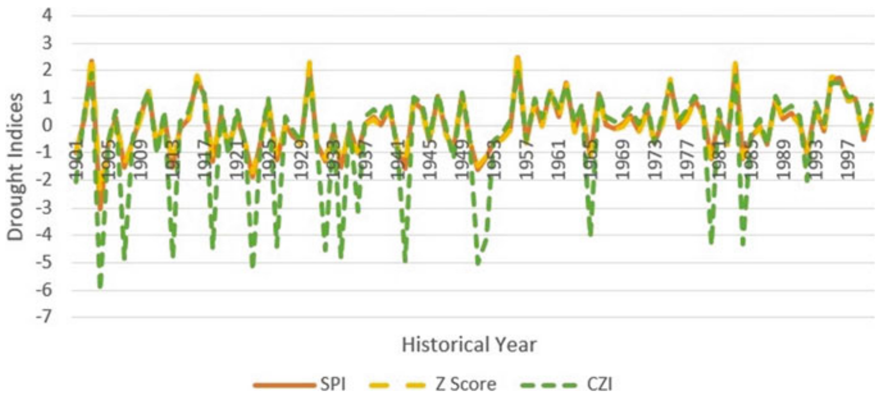

Fig. 3 Annual Pattern of three drought indices of Kadapa District

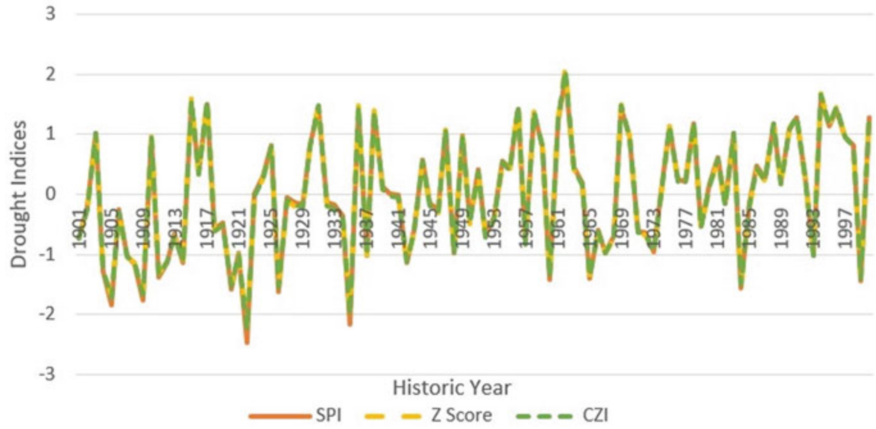

Fig. 4 Annual Pattern of three drought indices of East Godawari District

is showing more normal values when compared to CZI and SPI as its calculation is based on standard deviation. In some months, the rainfall may be heavy and in some low. Finally, it is giving average values coming to SPI, it shows more EW, VW, ED and VD. Even if the rainfall of the place is moderately wet, it shows EW and VW. China Z index shows more Normal, MW and MD categories.

4.1 Regression Analysis

Figures 5 and 6 depict the regression analysis of SPI vs Z-score and SPI vs CZI of Kadapa district, respectively. Regression coefficient of SPI vs Z-score is 0.9912

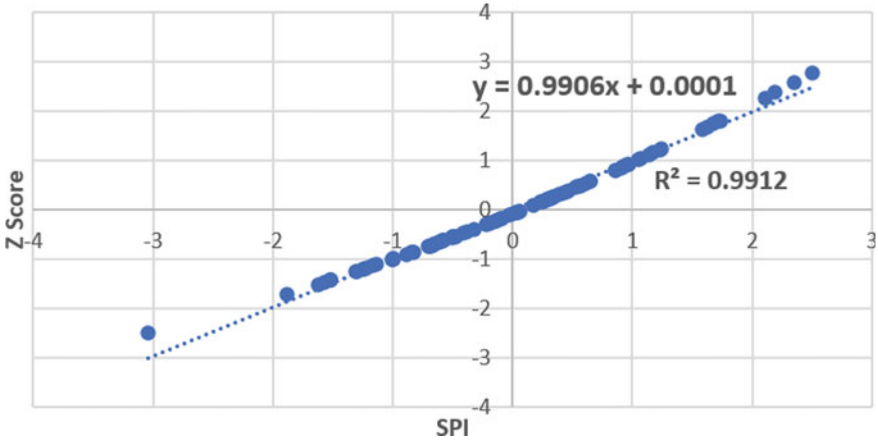

Fig. 5 Linear regression analysis of SPI versus Z-Score of Kadapa

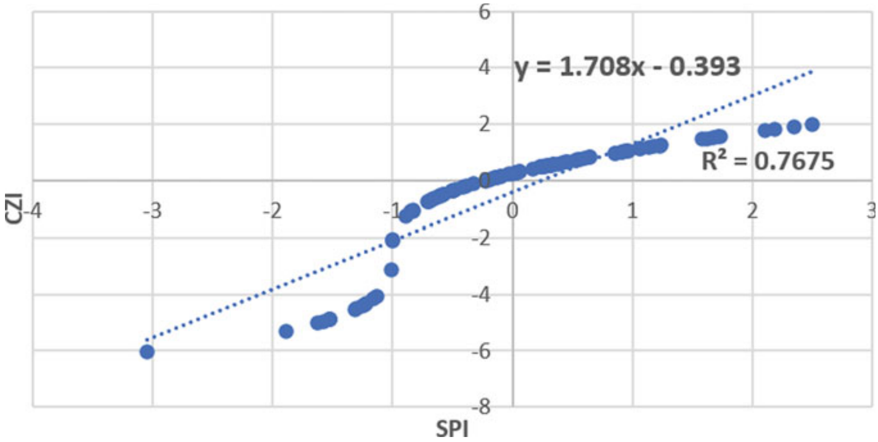

Fig. 6 Linear regression analysis of SPI versus CZI of Kadapa

whereas that of SPI vs CZI is 0.7675. This shows that Z-score depicts the same values of SPI with precision of 0.0088.

From the regression analysis of SPI vs Z-score and SPI vs CZI of Prakasam district, regression coefficient of SPI vs Z-score is 0.9898 whereas that of SPI vs CZI is 0.8056. This shows that Z-score depicts the same values of SPI with precision of 0.0101.

From the regression analysis of SPI vs Z-score and SPI vs CZI of Krishna district, regression coefficient of SPI vs Z-score is 0.9937 whereas that of SPI vs CZI is 0.7475. This shows that Z-score depicts the same values of SPI with precision of 0.0063.

Figures 7 and 8 depict the regression analysis of SPI vs Z-score and SPI versus CZI of East Godavari district, respectively. Regression coefficient of SPI vs Z-score is 0.996 whereas that of SPI vs CZI is 0.9977. This shows that Z-score and CZI depict the same values of SPI with precision of 0.004 and 0.0023, respectively.

From the regression analysis of SPI vs Z-score and SPI vs CZI of Visakhapatnam district, regression coefficient of SPI vs Z-score is 0.9941 whereas that of SPI vs CZI is 0.9993. This shows that Z-score and CZI depict the same values of SPI with precision of 0.0059 and 0.0007, respectively.

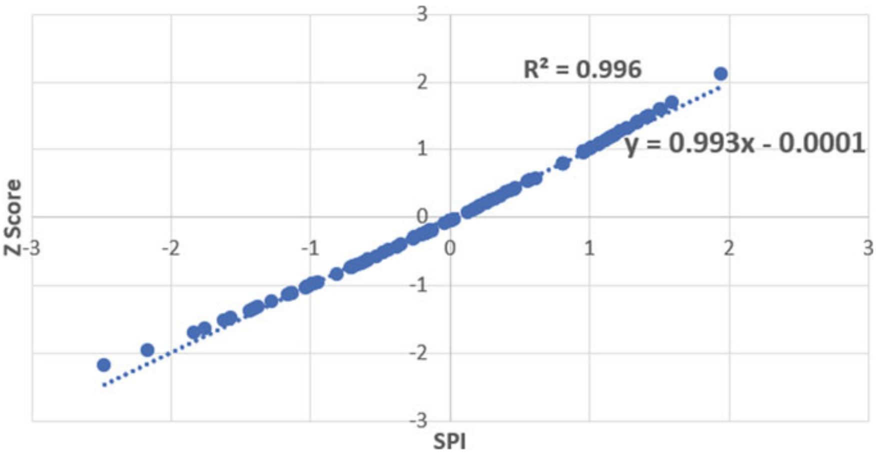

Fig. 7 Linear regression analysis of SPI versus Z-score of East Godawari

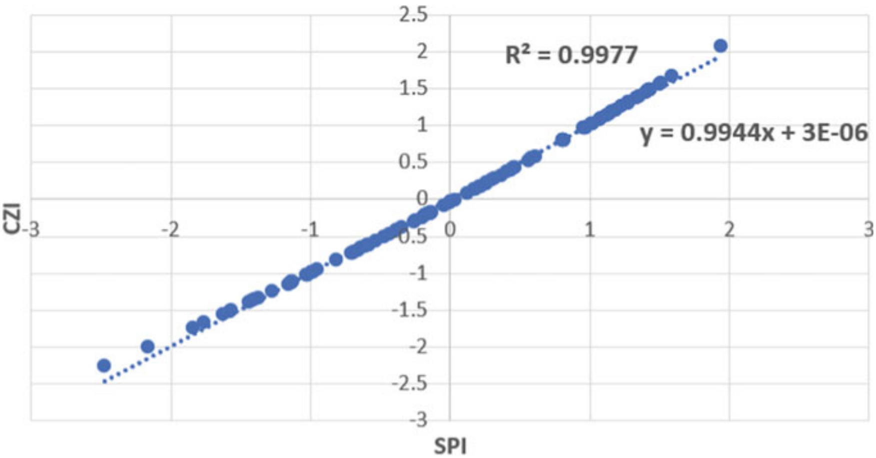

Fig. 8 Linear regression analysis of SPI versus CZI of East Godawari

5 Conclusions

The drought intensities of the five districts have been assessed with the help of three drought indices, i.e. SPI, CZI and Z-score. Different moisture categories are assessed for each of the five districts under study area by considering the time period of 1, 3, 4 and 12 months. Based upon drought indices values, moisture categories are classified as Extreme Dry (ED), Very Dry (VD), Moderate Dry (MD), Normal (N), Moderate Wet (MW), Very Wet (VW) and Extreme wet (EW).

SPI is a standard method but it is very complex and laborious to calculate. So, for assessing an easier and simpler method which shows similar values as SPI, Annual values of CZI and Z-score are compared with that of SPI for each district in our study area. There are so many methods available to compare these indices. In our present study, simple graphical comparison of indices and linear regression analysis are taken. From graphical analysis, it is evident that the graphs of Kadapa, Prakasam and Krishna have similar pattern and graphs of East Godawari and Visakapatnam are similar. In the graphs of Kadapa, Prakasam and Krishna, SPI and Z-score curves coincided, whereas CZI showed more deviations at extremes. In the graphs of East Godawari and Visakapatnam, all the three indices curves coincided, i.e. all indices show similar behaviour.

From regression analysis graphs, it is evident that for Visakhapatnam and East Godawari Districts, regression coefficients are around 1 for both CZI vs SPI graph and Z-score vs SPI graph. So, we can rely on both CZI and Z-score for evaluating drought characteristics instead of SPI for Visakapatnam and East Godawari. For Krishna, Prakasam and Kadapa Districts, regression coefficient of SPI vs Z-score graph is around 1, whereas regression coefficient of SPI vs CZI graphs are 0.74, 0.80 and 0.76, respectively. This implies Z-score values are very nearer to SPI, whereas CZI values show more deviation from SPI. So, we can rely on Z-score rather than CZI for Krishna, Prakasam and Kadapa. So, Z-score can be used for evaluation of drought instead of laborious and complex SPI for the five districts.

References

1. Suribabu, C. R., & Neelakantan, T. R. (2018). Assessment of dry and wet periods using selected rainfall-based drought indicators–a case study. *ISH J Hydraulic Engg, 1*, 1–8.
2. Eslamian, S., Ostad-Ali-Askari, K., Singh, V. P., Dalezios, N. R., Ghane, M., Yihdego, Y., Mohammed, M. (2017). A review of drought indices. *International Journal of Constructive Research in Civil Engineering (IJCRCE) 3*(4), 48–66.
3. World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2016) Handbook of drought indicators and indices. Svoboda, M., Fuchs, B. A (ed) integrated drought management programme (IDMP), integrated drought management tools and guidelines series 2, Geneva.
4. Jain, V. K., Pandey, R. P., Jain, M. K., & Byun, H.-R. (2015). Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. *Weather and Climate Extremes, 8*, 1–11.

5. Dogan, S., Berktay, A., & Singh, V. P. (2012). Comparison of multi-monthly rainfall-based drought severity indices, with application to semi-arid Konya closed basin, Turkey. *Journal of Hydrology, 470*, 255–268.
6. Pai, D. S., Sridhar, L., Guhathakurta, P., Hatwar, H. R. (2011). District-wide drought climatology of the South-West monsoon season over India based on Standardized precipitation index. Nat Hazards.
7. Naresh Kumar, M., Murthy, C. S., Sesha Sai M. V. R., Roy, P. S. (2009). On the use of standardized precipitation index (SPI) for drought intensity assessment. *Meteorologist Application*, 16 381–389
8. Husak, G. J., Michaelsen, J., & Funk, C. (2007). Use of the gamma distribution to represent monthly rainfall in africa for drought monitoring applications. *International Journal of Climatology, 27*(7), 935–944.
9. Hong wu, Hayes MJ, Weiss A, Qi Hu (2001) An evaluation of the standardized precipitation index, the china-z index and the statistical z-score. *International Journal of Climatology,* 21(6), 745–758

The Freezing Point of Soils and the Factors Affecting its Depression

Rufaidah Shah and Bashir Ahmed Mir

Abstract Determination of freezing point is the prerequisite for any laboratory or field study on the freeze–thaw behaviour of soils. Depression in the freezing point of soil pore water as compared to pure water (which freezes at 0 °C) in a two-phase or a three-phase soil system is associated with several factors such as water content, mineralogical composition, salinity of pore water, pore size, plasticity of soil, etc. An experimental study was conducted on three types of soils of different plasticity and gradation to study the effects of water content, salinity of pore water and plasticity of soil on the freezing point depression. The results showed that the freezing point significantly depresses only when water content decreases beyond a certain value. The freezing point also showed depression with increasing soil plasticity and a linear depression with increasing salinity of pore water. The study is a part of extensive laboratory investigation on frost susceptibility of soils in Kashmir.

Keywords Seasonally frozen grounds · Freezing point depression · Salinity · Plasticity · Freeze–thaw test

1 Introduction

Soils and rocks present in cold regions of the world that experience seasonal frost are required to be tested for freeze–thaw susceptibility. In such regions, the ground freezes in the coldest month of the year and remains in an unfrozen state for the rest. This seasonal freezing and thawing of soils prove detrimental to engineering structures, particularly pavements [1]. This, therefore, demands freeze–thaw testing of soils to device proper measures and modifications for a particular site.

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Determination of freezing point is the prerequisite for any laboratory or field study on freeze thaw behaviour of soils [2, 3]. It helps the recognition of the freezing front and determination of total frost penetration in a laboratory freeze–thaw setup. It is also an important design parameter for constructions which involve artificial freezing of grounds like construction of frozen earth walls for deep excavation and for management of ground water seepage at the construction site [4].

Before actual freezing of soil, it is necessary for the temperature to go down below the freezing point of soil pore water (T_f) to a temperature T_{sc}, where the super-cooled pore water exists in a metastable state until triggered to turn into ice in a process called nucleation (Fig. 1). Accumulations of water molecules or soil particles may act as nucleation centres that trigger water to ice transformation [5]. The crystallization results in the release of latent heat that raises the temperature of soil to T_f, the actual freezing point of soil. All the free pore water then freezes at this temperature, T_f. The temperature then starts decreasing further depending on the ambient temperature [6, 7].

Unfrozen soil, whether saturated or not, usually freezes at a temperature below 0°C. The depression in the freezing point of soil pore water as compared to pure water in a two-phase or three-phase soil system is primarily because of soil grain matrix effect and osmotic effect [8]. This is associated with the number of factors such as water content, mineralogical composition, salinity of pore water, plasticity of soil, etc. [7, 9, 10].

An experimental study was conducted on three types of soils of different plasticity and gradation to determine the freezing point of soils under different conditions of water contents and pore water salinity. The objective of the study was to recognize the role of water content, salinity of pore water and plasticity on depressing the freezing point of soil. This paper presents the details of the testing procedure, the results obtained and the conclusions drawn therein from the study.

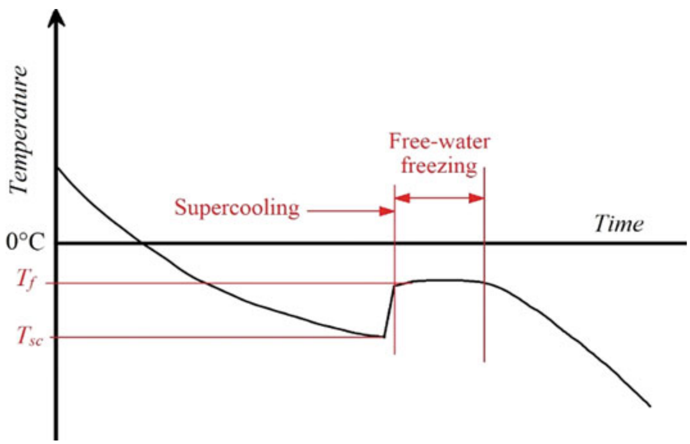

Fig. 1 Typical cooling curve of soil

2 Materials and Methodology

For achieving the objectives of the study, three different soils were used of distinctly different composition in terms of their particle size and plasticity. The basic properties of the three soils used in this experiment are shown in Table 1.

The soil S-1 has 42% sand content and is of least plasticity while S-2 and S-3 have <1% coarse-grained fraction with S-3 having the highest plasticity of the three samples. After obtaining the basic properties required for classification of the soils as per Indian system of soil classification, the maximum dry density and the optimum moisture content using light compaction test as per Indian standard code [11] were obtained. The compaction curves of the three soils are shown in Fig. 2. The maximum dry density decreased while the optimum moisture content increased with increasing plasticity of the soil.

Table 1 Basic soil properties of the three soils used in this study

	S-1	S-2	S-3
Specific gravity (G)	2.67	2.61	2.60
Sand %	41.8	0.9	0
Silt %	54.2	92.1	73
Clay %	4	7	27
Liquid limit (w_l)	25	35	57
Plastic limit (w_p)	20	25	30
Plasticity index (I_P)	5	10	27
IS classification	CL-ML	ML-MI	MH
Max. dry unit weight*, kN/m^3	18.25	16.4	14.6
Optimum moisture content*, %	15.5	19	23.8

*obtained using Light Compaction Test (IS: 2720 Part VII-1980)

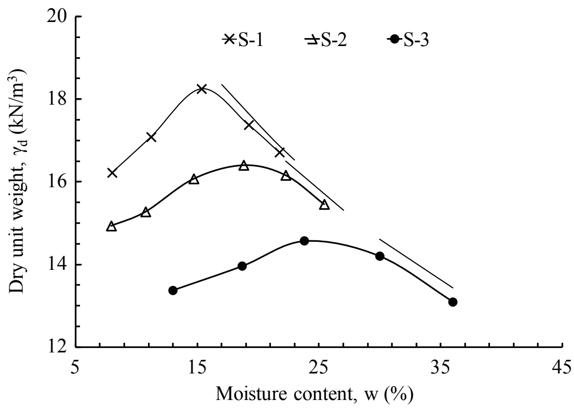

Fig. 2 Compaction curves (and corresponding ZAV lines) of the soils used in this study

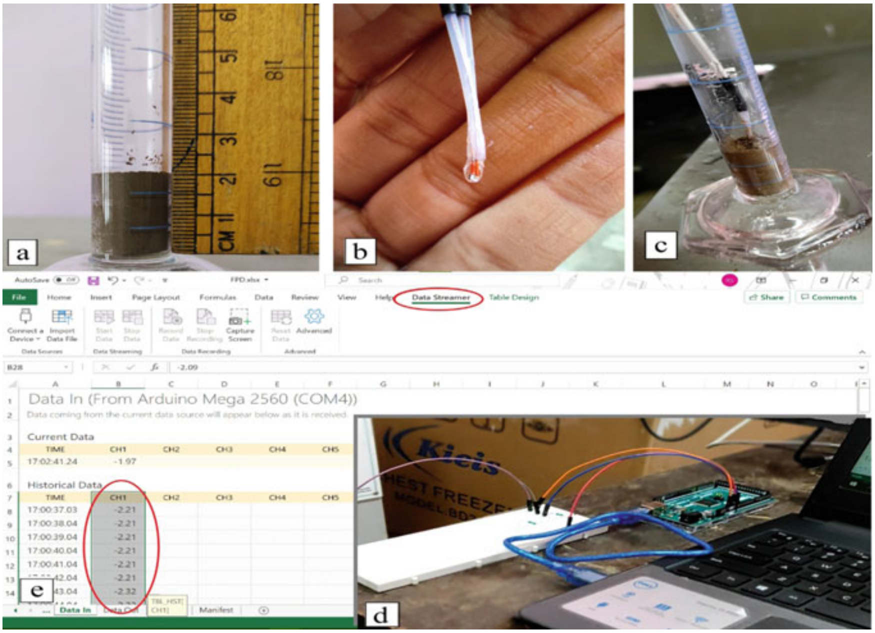

Fig. 3 Sample preparation. **a** sample compacted in a test tube upto 20 mm height; **b** an NTC thermistor; **c** thermistor inserted in the test tube containing soil; **d** Arduino mega 2560 connected to PC; **e** streaming data in MS excel using data streamer add-in

2.1 Sample Preparation and Determination of Freezing Point

For the determination of freezing point, a weighed amount of oven dry soil sample was mixed with pre-determined quantity of water as per the desired moisture content and dry density. It was then compacted in a test tube up to a height of 20 mm (Fig. 3).

For obtaining continuous temperature change within this soil sample, a negative temperature coefficient (NTC) thermistor (Fig. 3b) was used. The thermistor was carefully inserted through 10 mm into the soil placed in the test tube (Fig. 3c). For soils prepared on dry side of optimum, a small hole, 10 mm deep, was made using a nail prior to the insertion of thermistor. The thermistor was connected through Arduino Mega 2560 to obtain temperature change directly into Microsoft Excel using Data Streamer Add-in (Fig. 3).

The test tube containing the soil sample and the temperature sensor was then placed in a water bath at 0 °C until the temperature of soil stabilized. The test tube was then placed in the water bath at −3 °C (in some cases at −5 to −7 °C). This resulted in the lowering of soil temperature beyond the actual freezing point. In some cases, the super-cooled state did not exist for long, and the temperature jumped up to the actual freezing point without any external instigation, while in most cases the nucleation was initiated by striking the test tube with the wall of water bath while keeping it immersed in the water bath coolant. The freezing point of the soil was obtained from the graph of temperature sensor readings (in °C) with time (t) as shown in Fig. 4.

The different combinations of water contents and solute concentrations tested are shown in Table 2. The test Series 1 covers the tests performed on the soils at different moisture contents without any solute added to the water. Series 2 tests were conducted on the three samples at moisture content specified in Table 2 with solute (NaCl) concentration of 0.5%, 1%, 2% and 5%. For these tests, the salt solution of desired concentration was first prepared, and then the dry sample of soil was mixed with the pre-determined quantity of this solution to obtain desired moisture content.

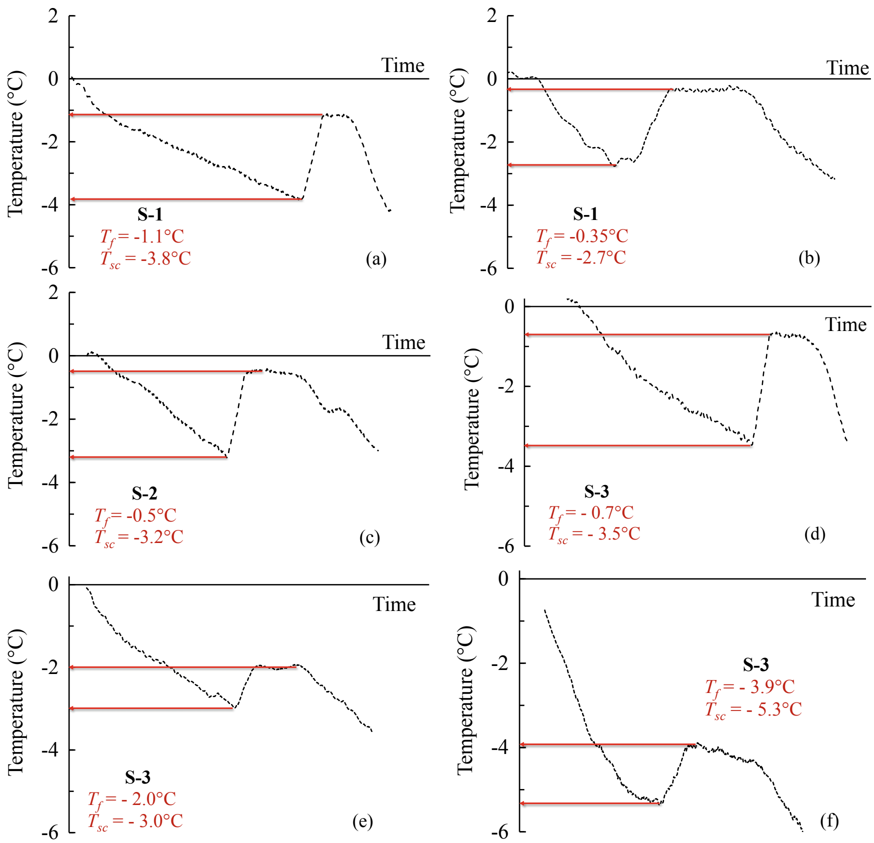

Fig. 4 Cooling curves of soils obtained at specific water and solute content; **a** S-1, $w_c = 5\%$, $S = 0\%$; **b** S-1, $w_c = 20\%$, $S = 0\%$; **c** S-2, $w_c = 20\%$, $S = 0\%$; **d** S-3, $w_c = 20\%$, $S = 0\%$; **e** S-3, $w_c = 20\%$, $S = 2\%$; **f** S-3, $w_c = 20\%$, $S = 5\%$

Table 2 Description of tests performed

	Water content, w_c (%)	Solute concentration, S%
Series 1		
S-1	5, 10, 20, 30	–
S-2	5, 10, 20, 30	–
S-3	10, 20, 30	–
Series 2		
S-1	5%, 10%, 20%	0.5, 1, 2, 5
S-2	20%	0.5, 1, 2, 5
S-3	20%	0.5, 2, 5

3 Results and Discussions

Some selected graphs showing variation of temperature, in °C, within the sample as recorded using the NTC thermistor at different water contents and solute concentrations is shown in Fig. 4. Similar graphs were observed for the other combinations (Table 2) considered in this study.

From the graphs in Fig. 4, one can observe the jump in the temperature of the soil sample as the sample is super-cooled to a temperature T_{sc}. As the spontaneous nucleation takes place at T_{sc}, the latent heat of crystallization is released, resulting in abrupt rise in temperature to T_f. The latent heat slows down the cooling till most of the free water is frozen [7]. The degree of neutralization between the latent heat release and the effect of outside cooling rate is the deciding factor for the length of equilibrium temperature stage at T_f. Thus, the temperature will not rise to T_f spontaneously until the latent heat is enough to increase the system temperature to T_f [10]. Thus, the supercooling, defined as ($T_f - T_{sc}$) has been correlated to cooling rates, in addition to pore water solution [12], plastic limit, mass and water content of the soil [9]. It is important, however, to note here that T_{sc}, and not T_f, is a function of the cooling rate.

Figure 5 shows the variation of freezing point, in °C, with water content for the three soils. It can be observed that the freezing point for all the three soils showed significant decrease when the water content decreased beyond a certain value, which was close to the optimum moisture content of that soil. It can be inferred that the soils prepared on the wet-side of optimum had no influence of water content on their freezing points.

However, the freezing points of S-1 (having the least plasticity and more than 40% coarse-grained fraction) were higher than S-2 and S-3 for all water contents observed. While S-3, which is of highest plasticity of the three, showed greater depression in freezing point compared to other two soils for the same values of water content.

The reason for lower freezing points in S-3 compared to S-2 and S-1 can be explained by the specific surface area of the soil particles. The nucleation of super-cooled water is a function of water activity [13]. More the specific surface area, greater is the adsorption of water and thicker is the water film (bound water) on

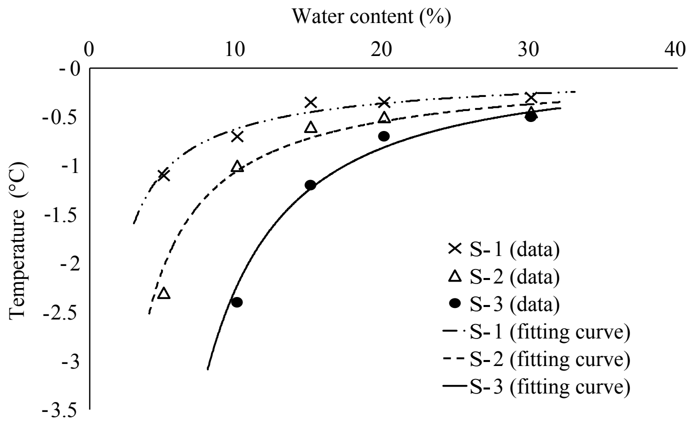

Fig. 5 The variation of freezing point with water content for the three soils

the surface of soil particle which results in lower freezing point as amount of free water decreases. As the grain size increases, the adsorption and the bound water film decreases and the soil freezes at a higher temperature. Thus, at the same water content, S-1 showed highest freezing point followed by S-2 and S-3.

The fitting curve for the variation of freezing point with water content is a power function of the form:

$$T_f = -A \times \mathrm{w}_o{}^B \tag{1}$$

where, T_f = the freezing point in degree Celsius and
w_o = the percentage of initial water content.

The values of the fitting curve parameters A and B for the three soils are given in Table 3.

Figure 6 shows the variation of freezing point with the solute concentration of the three soils, each having 20% water content. A linear decrease in T_f can be observed with increasing solute concentration (S%). From the values of the slope, m, and the intercept, c, for the three linear fitting curves, it can be inferred that for the same water and solute content, the freezing point is slightly higher for low plastic soil, but this difference decreases with increasing solute concentration.

Using theoretical analysis to understand the effect of pore diameter on freezing point, Xiao et al. [13] demonstrated that the freezing point decreased with decreasing

Table 3 Values of parameters A and B of Eq. 1 for the three soils

	A	B	R^2 value
S-1	3.7526	−0.782	0.9205
S-2	9.4458	−0.952	0.9477
S-3	63.787	−1.456	0.9719

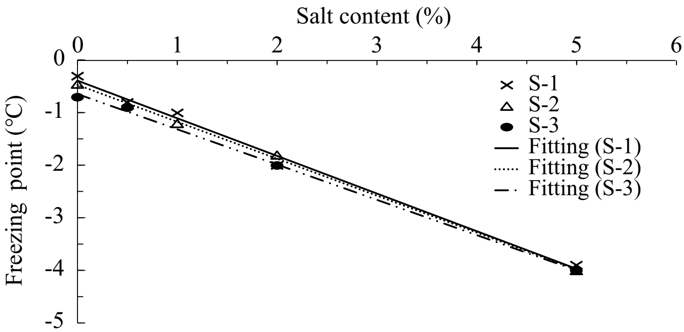

Fig. 6 The variation of freezing point with solute concentration for the three soils at $w_c = 20\%$

pore diameter as interfacial forces came into play. For the same water content in a soil, the freezing point is influenced by concentration and type of salt [14].

The variation of freezing points, in °C, with solute concentration, S%, for the soil S-1 is shown in Fig. 7. At a particular salt content, the reduction in water content increases the salt concentration thereby reducing the freezing point further. It can be observed from Fig. 7 that for lower water content, the depression in freezing point with increasing salinity was greater compared to that for higher water content. Also, as the water content decreases, water is retained easily in smaller pores than larger pores and the effect of pore size [14] increases, thus reducing the freezing point.

Also, from Figs. 5 and 7, it can be deduced that for higher values of water content, the freezing point is more influenced by solute concentration in pore water than the initial water content of the soil, which almost had no influence when the water content is above the critical water content.

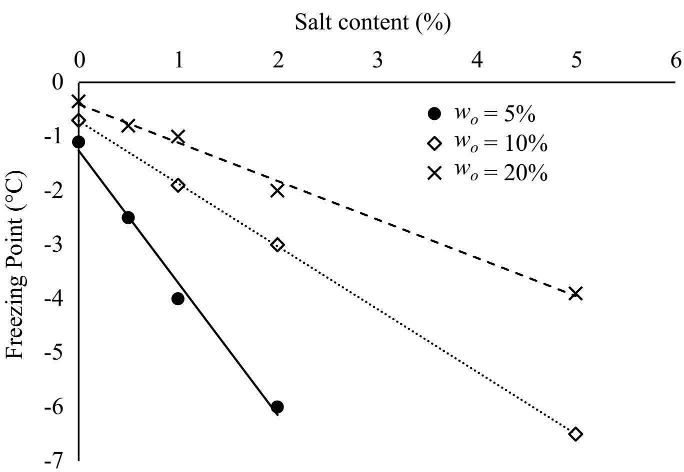

Fig. 7 The variation of freezing points with solute concentration for soil S-1

4 Conclusions

An experimental investigation was carried out on three types of soils for the assessment of effects of water content and solute concentration in pore water of the soils on freezing point depression. The following conclusions can be drawn from the results obtained.

1. The freezing points *(T_f)* of the three soils at their optimum moisture contents *(w_{opt})*, i.e. 15.5, 19 and 23.8% is −0.35, −0.50 and −0.70 °C, respectively. When water content increased beyond w_{opt}, there was no significant change in the freezing points of the three soils. However, a decrease in water content beyond optimum resulted in a rapid decrease in freezing points of the soils. For S-3, there was approximately 9 times decrease in the freezing point when water content was lowered to 5%. Similarly, T_f was about 3 times and 5 times lower for S-1 and S-2 at 5% water content compared to that at their respective w_{opt}. It can therefore be concluded that the effect of water content is significant on the depression of freezing point of soils only when the value of water content is less than the w_{opt} of that soil. Increasing the water content beyond this critical value for a particular soil, does not influence the freezing point of that soil.
2. By increasing the solute concentration *(S)* in pore water, there is a linear decrease in T_f of the three soils. However, the rate of depression *($\Delta T_f / \Delta S$)* increased with decreasing w_o of the soil. For S-1, the rate of depression ranges from 0.82–2.5 °C/% with higher value for lower water content ($w_o = 5\%$), that means, 1 °C depression in freezing point was caused by almost 1.5% increase in solute concentration at higher water content (20%), but the same level of depression was caused by only 0.4% solute concentration at lower water content (5%).
3. For the similar moisture and solute concentrations, the freezing point was lower for fine-grained, high plastic soil compared to low plastic and coarse-grained soils. This is due to presence of more bounded water in fine-grained soil with higher specific surface area resulting in greater adsorption compared to coarse-grained soils having lesser specific surface and lower adsorption. Lesser adsorption of water results in thinner water film (bounded water) around the soil particle. As the amount of free water is more in a coarse-grained soil, it freezes at a higher temperature. The effect of plasticity and grain size on the freezing point of soil, however, decreased with increasing water content.

References

1. Simonsen, E., & Isacsson, U. (1999). Thaw weakening of pavement structures in cold regions. *Cold RegNs Sci Technol, 29*(2), 135–151.
2. Arenson, L. U., & Sego, D. C. (2006). The effect of salinity on the freezing of coarse-grained sands. *Canadian Geotechnical Journal, 43*(3), 325–337.
3. ASTM (2006) International, standard test methods for frost heave and thaw weakening susceptibility of soils D5918. Annual Book of ASTM Standard.
4. Bell, F. (1993). *Grounf freezing*. CRC Press.
5. Andersland OB, Ladanyi B (2013) An introduction to frozen ground engineering. Springer Science & Business Media
6. Ming F et al. (2020) Investigation into freezing point depression in soil caused by NaCl solution. Water 12(8):2232
7. Wan, X., Liu, E., & Qiu, E. (2021). Study on ice nucleation temperature and water freezing in saline soils. *Permafrost and Periglacial Processes, 32*(1), 119–138.
8. Liyang W et al. (2021) A simplified model for the phase composition curve of saline soils considering the second phase transition. Water Resour Res 57(1) e2020WR028556.
9. Kozlowski, T. (2009). Some factors affecting supercooling and the equilibrium freezing point in soil–water systems. *Cold RegNs Sci Technol, 59*(1), 25–33.
10. Bing, H., & Ma, W. (2011). Laboratory investigation of the freezing point of saline soil. *Cold RegNs Sci Technol, 67*(1–2), 79–88.
11. Indian standard (2011) Methods of test for soils. determination of water content—dry density relation using light compaction, 2720 (Part VII). 1980. fifth reprint: Aug 1997
12. Liu, Z. (1986). Freezing point of wet soil and its measurement. *J China Min Technol Chin, 3*, 24–31.
13. Koop T et al. (2000) Water activity as the determinant for homogeneous ice nucleation in aqueous solutions. Nature 406(6796):611–614
14. Xiao, Z., Lai, Y., & Zhang, M. (2018). Study on the freezing temperature of saline soil. *Acta Geotechnica, 13*(1), 195–205.

Blast Loads and Their Effects on Structures

George Vincent Jasmine, Markandeya Raju Ponnada, and Siba Prasad Mishra

Abstract The main objective is to investigate the present proceedings on the blast loads on the civil structures as an act of terrorism, industrialization or mining actions. Explosives are detonating materials that explode with high pressure on ignition. The blast explosion inside or at a proximity distance of a structure damages the structure physically, incurring trauma/death to the inmates or people in the surrounding. During the present Anthropogenic epoch, the act of terrorism has surged targeting mainly the commercial units, high-rise buildings, 5-star hotels and crowded places. The bombing action is done through a small packet bomb to suicidal trucks or even aeroplanes. Customarily while designing the imposed loads on a structure, the structural engineers consider the dead, live, lateral and seismic loads but do not consider the blast load. In designing important and high rising structures, it has become pertinent to consider blast loads (dynamic loads) along with other loads. Since it was not warranted, there was no code provision for the blast load in the design of structures. The present research is an attempt to review all the old literature available and to find the research gap before proceeding with the calculation of blast loads in the design of a structure. The conclusions derived from the research gap shall be helpful to understand the behaviour of blast loads on structures and can be useful in designing the important structures.

Keywords Blast load · Impact load · Dynamic loads · Collapse analysis

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1 Introduction

Blast loads are dynamic in nature and they cause catastrophic damage to the structures. An explosion releases a lot of energy in the form of light, heat, sound and shock waves. These waves can propagate through the structure in a very short duration and lead to the collapse of the structure. So, there is a significant need to design the structure as a blast-resistant structure. Structural irregularities also play a prominent role in designing blast-resistant structures. Therefore, it is important to understand these factors before designing. In this paper, we gathered the available literature on the blast loads on the structures and explained the special problems while defining the loads.

Terrorists attack by explosive loading along border territory by targeting both government buildings and also civilian houses. On the safety issue, the vulnerability of structures to blast loads must be protected. The explosives during a blast release huge kinetic energy and also produce heavy blast waves comprising of the pressure of about 3–5 kPa or even more [1].

1.1 *Aims of the Study*

The myth of blast is catastrophic causing loss of life and permanent structures. The residuals left after a blast pose threat to the environment for a long period. Increasing blast loads of the twenty-first century like the Beirut explosion and WTC blasts are the burning examples. India had to suffer from Improvised Explosive Device (IED) blasts in 337 numbers (2017), 268 (2015), 190 (2014), 283 (2013) and 365 (2012), respectively, as per NBDC data (National Bomb Data Centre, India). Therefore, it is high time that either we have to think of dissolution methods, or we shall have controlled blasting. For terrorist blast loads, structures must be blast-resistant (The Economic Times news, S. K. Gurung, Jul 12, 2018, 10:34 PM).

1.2 *The Objective of the Present Paper*

The following are the objectives of the present paper:

- To review the studies done by the various researchers on blast load effects on different RC and Steel-framed structures.
- To review various works done on blast effect on framed structures with different irregularities, viz., Geometric, Stiffness, Mass irregularities, etc.
- To review the blast loads and blast-affected structures.

2 Literature Review

Terrorism is one of the major threats to humanity and its property. Gradually, the Naxal/terrorist groups are becoming unstructured and hostile to use blast loads to attack the public and their structural possessions like bridges, towers and structures.

The summary of timeline key inferences obtained from the various literature survey done from 1995 to 2018 is shown in Table 1.

2.1 *Recent Studies on Blast Loads*

Kumar et al. [41, 43] studied the performance of symmetric RC space framed buildings subjected to seismic and impact loads. They used time history analysis to study the response of the considered building. From their study, it has been observed that the maximum lateral displacement for a surface blast of 2500 kg TNT and seismic load were comparable at all storey levels. This maximum lateral displacement was obtained at 5 s in buildings subjected to the Northridge earthquake, while it was obtained at 0.5 s in the same building subjected to a surface blast of 2500 kg TNT. Applied Element Method-based software was used for their study.

Vangipuram et al. [44] observed that Blast loads do not act uniformly and may be symmetrical or skew. While designing for blast loads the reflected peak pressure and temperature varies at different points in a structure with diminution of the standoff distance.

Megha and Ramya [45] studied the impact of the blast load on buildings. A six-storey building is considered for the study. The building is modelled using ETABS 2016. The building is subjected to different charge weights of 200 g, 400 and 600 kg with a standoff distance of 20, 40 and 60 m. Blast parameters are determined as per the guidelines of IS:4991–1968. The time history analysis is carried out and the response of the structure is determined in terms of displacement versus time, velocity versus time and acceleration versus time. To make the building more resistible against blast load, shear walls and steel bracings were implemented. The results conclude that the storey displacement, storey drift and column forces are high when the blast is at a distance of 20 m from the building. The displacement and drift are more when the charge weight and distance are less.

Sunita and Bharati [46] have studied the effects of surface blasts on multi-storey buildings. Four seismically designed RC structures with 3, 6, 9 and 12 heights were considered. The parameters considered are standoff distance and charge weight. The non-linear time history analysis is used to obtain the response of the building. For analysis, SAP2000 software has been used. Charge weights of 500 kg TNT and 1000 kg TNT at a standoff distance of 5, 10, 15, 30, 40 and 60 m were considered for analysis. The results conclude that base shear produced by ground shock is greater than the base shear produced by air pressure for all the standoff distances in both

Table 1 Chronological inferences derived from the literature survey

Timeline	Reference	Progress during investigation	Key Inference
1995	Dharaneepathy et al. [2]	Critical ground zero distance was established.	Critical blast load demand.
1998	Hatem et al. [3] Corley et al. [4]	A new discrete element tool was established to model separation of materials. Recommendations were made such as jacketing of columns & in compartments.	Appropriate numerical tool. General protection for blasts.
1999	Krauthammer et al. [5]	Explosion wave's negative phase studied and the vulnerability of glass panels.	Impact on cladding systems.
2002	Krauthammer [6] Meguro et al. [7]	Developed progressive collapse and damage assessment methodology. AEM was used to model blast loads on structures.	AEM could be a suitable tool for collapse analysis.
.2003	Alexander et al. [8]	Studied different numerical methods to predict explosion effects on buildings.	A numerical application of blast demand.
2004	Elkholy and Meguro [9] Luccioni et al. [10]	AEM improved with larger element sizes making it possible to analyze large buildings. Collapse analysis is modelled using AUTODYN.	AEM becomes faster and efficient. Blast demand.
2005	Kirk and Farid [11] Alex and Timothy [12]	Studied general science of blast loading and reviewed general blasts. Blast loads on buildings and the effects of it on adjacent buildings were studied	
2006	Pandey et al. [13]	Effects of external blast loads on the concrete shell of a nuclear reactor.	External blast is more critical.
2007	Khadid et al. [14] Ngo et al. [15] Zhu and Lu [16]	Used FEM/ CDM for modelling blasts on plates. Several buildings and blasts have been studied under extreme conditions. Characteristics of explosion loads on buildings with different constitutive relations	Numerical modelling, the study of different buildings and material models involved.

(continued)

Table 1 (continued)

Timeline	Reference	Progress during investigation	Key Inference
2008	Van der Meer [17] & Nitesh et al. [18] Zeynep et al. [19] Henera et al. [20] Koccaz et al. [21]	MDOF modelling of BLEVE blast load achieved. The design aspect of the blast-resistant structures. Worked on structural plan irregularities Architectural Blast resistant building theories.	The incapability of SDOF systems and design theories to prevent collapse due to blast. Buildings in symmetry are stable against blast effects.
2010	Nassret et al. [22] Hussein [23] Assal [24] Jayasilake et al. [25]	Blast wave characters of typical charge weight and standoff distances were examined Studied analytical/ SDOF methods for blast loads Non-linear dynamic response of high rise Buildings was studied (SDOF method of the blast) Blast and earthquake loads were compared for Six storied building	Blast demand.
2011	Raparla et al. [26] Khalil et al. [27]	Progressive collapse due to EQ loads in 2D AEM.	Proving AEM a better tool over FEM for collapse modelling.
2012	Helmy et al. [28] In 2013 [30] Mohammed et al. [29]	A comparative study of AEM and FEM AEM is proved to be the most effective tool for collapse analysis. Studied the response of SIFCON and RCC frames against blast.	AEM could be an effective tool for collapse analysis. Dynamic response of SIFCON frame better than RCC frame.
2013	Subin et al. [31] Jayashree et al. [32]	Using FEM, the explosion effects and earthquake loading was studied. Compared the blast wave parameters at various charge weights at different ranges.	Blast and earthquake demand on buildings. Reduced +ve phase duration with an increase of intensity of blast depends on the height.
2014	Amy Coffield et al. [33] Kulkarni et al. [34] Shallan et al. [35]	Earthquake designed framing systems subjected to blast loads using AEM. Dynamic response of high rise building with irregularities subjected to blast load	Blast and earthquake loads using AEM. Studied about the vulnerability of irregular high-rise buildings.

(continued)

Table 1 (continued)

Timeline	Reference	Progress during investigation	Key Inference
2015	Amy Coffield and Hojjatadeli [36]	Studied different steel frame with bracings subjected to blast loadings	Recommendation of structural systems for blast loads
2016	Madonna et al. [37] Chiranjeevi et al. [38] Swathi [39] Habib and Alam [40]	Used alternative path method for design to prevent the structure from damage from the blast. Studied the effect of plan irregularity (L,T and U shape) on RC buildings	Dampers or stiffeners can be used to resist impact loads. L-shaped structure has max base shear & overturning moment.
2017	Kumar and Rambabu [41]	Studied behaviour of RC space framed building with vertical irregularity to seismic and impact loading using AEM	Blast and earthquake loads applied on irregular buildings using AEM.
2018	Kumar and Rambabu [42] Singh [43]	Studied the performance of symmetric RC Space framed building subjected to seismic and impact loads using AEM Studied the behaviour of vertical irregular buildings under blast load	Blast and EQ loads applied on regular buildings using AEM The resistance of regular buildings are higher than irregular buildings

high-rise and low-rise buildings. With the increase in charge weight, the effect of the ground shock increases more than air pressure.

2.2 *Models Developed*

Models are developed for finding the parameters of the shock waves generated by the blast loads based upon the scaled distance, and they are compartmentalized as Airburst (free air) and Surface burst models. The different burst models are the Brode mode (Brode [48]), Henrych and Major mode (Henrych et al. [49]), Held's Model (Held [50]), Mill's mode (Mills [51]), Sadovskiy mode (Sadovskiy et al. [52]), Bajie model (Bajie [53]) and Kinny & Graham model (Kinny et al. [54]) which is the development of the US Army TM5-855–1 model [55].

Similarly, the surface burst models developed by different researchers are Newmark & Hansen model (Newmark et al. [56]), Swisdak model (Swisdak [57]), Wu and Hao model (Wu and Hao [58]), Siddiqui and Ahmad model (Siddiqui et al. [59]), Iqbal and Ahmad model (Iqbal et al. [60]) and Badshah model (Badshah [61]).

2.3 Lapses and Research Gap

Investigating the past works, it is ascertained that a large number of works have been done on blast loads on regular and irregular structures, standoff distances and charge weight variations and behaviour on different types of buildings (SIMCON or SIFCON) than RCC structures. However, it is found that the impact on blast loads on the framed structure was meagre.

3 Preface to Blast Loads

3.1 Blast Materials

The blast materials (explosives) are a solid or liquid base that should have the properties as follows: The material is normal at ground state but undergoes a chemical change when stimulated, mainly Tri-nitro Toluene main base structure. This reaction may yield a very high temperature, huge amount of gases and produces explosion and undergoes exothermic reaction. The controlled explosions are intended during quarry blasting, demolition of structures, shaping foundation and tunnel excavation within a mountainous base.

The health issues (trauma/death) associated with improvised explosive device (IED) spasm are overpressure damage (heart, lungs, abdomen and other sensitive organs); fragmentation injuries from flying debris; thermal injuries, impact injuries, fall injuries and toxic exposure injuries (John Pichtel [62]).

3.2 Field Test Results

To have experimented on blast loads, it is difficult to conduct and generally military laboratories are preferred. Field tests are conducted by various researchers for different blast materials and the results are summarized in Table 2.

Regarding Table 2, the notation followed is as follows:

RCC: Reinforced cement concrete;

RC + ACJ: Reinforced concrete with advanced composite jackets;

ALFC: Reinforced cement concrete with aluminium foam claddings;

FRC: Fibre-reinforced concrete;

SFRC: Steel fibre-reinforced concrete;

LCFRC: Long carbon fibre-reinforced concrete.

Table 2 Field tests for different specimens, explosives and standoff distance researches in the past

S. No.	Specimen type	Material made of	Mix ratio/size (m)	Blast type	Charge wt. (kg)	Standoff distance (m)	Reference
1	Columns	RC and RC + ACJ	1:01	AFNO	558	4.36	Rodriguez-Nikl [63]
2	Slabs	RC	1.22 × 1.22	TNT	1.16 and 1.71	Contact	Wei et al. [64]
3	Slabs	RC and FRC	1:01	TNT	1000	20	Schenker et al. [65]
4	Panels	RC and SFRC	0.6 × 0.6	N/A	1	0.6	Yusof et al. [66]
5	Slabs	RC	1:1, 1:1.25 & 1:1.67	TNT	0.19–0.94 0.3,	0.4 and 0.5	Wang et al. [67]
6	Panels	RCC and LCFRC	1.83 × 1.83	AFNO	38.5	1.065,1.37 and 1.675	Tabatabaei et al. [68]
7	Slabs	RCC	1 × 1	TNT	0.2, 0.31 and 0.46	0.4	Zhao et al. [69]
8	Panels	RCC and FRC	6 × 1.5	TNT	25	0.45	Foglar et al.
9	Columns	RCC	1:01	Gelamon	12.3 0.6	1.5	Codina et al.
10	Slabs	RCC and RCC + ALFC	2 × 0.8	TNT	6, 8 and 12	1.5	Wu and Hao [58] Rigby et al. [70]

3.3 Discussion

Structures could not be completely safe and riskless. It is always against a distinct risk level. The distresses occurred to the building by an earthquake, blast loads and hurricane loads can be at a reduced level, and the distresses caused to the building shall be less. The mitigation strategies for the reduction of the threat level from blast loadings are strict surveillance through diligent intelligence, well vigilant security system, enhancing standoff distance between the approach to the target, constructing blast walls for attenuation of shocks, proper landscaping with the optimized alignment of the structure and constructing structural elements, to absorb the blast load impact.

4 Conclusions

After studying the above literature, the following conclusions have been drawn:

1. As the standoff distance increases, the blast pressure decreases and vice versa.
2. As the charge weight increases, the blast pressure increases.
3. The regular structure has higher resistance than the irregular structure.
4. The dynamic behaviour of SIMCON buildings is better than RCC buildings.
5. Dampers or stiffeners can be used to resist such heavy loads, and also joints should be designed to resist such heavy moments.
6. The dynamic behaviour of the SIFCON frame is better than that of the RCC frame.

From the literature review, it has been observed that no studies are made on the performance of Reinforced Concrete Framed structures subjected to blast loads by considering Soil-Structure Interaction.

References

1. Chiquito, M., Santos, A. P., López, L. M., & Castedo., R. (2019). *Blast effects on structural elements*. Open access peer-reviewed chapter 257. https://doi.org/10.5772/intechopen.88721.
2. Dharaneepathy, M. V., Keshava Rao, M. N., Santhakumar, A. R. (1995). Critical distance for blast resistance design. *Computer and Structure, 54*(4), 587–595. ISSN: 0045–7949.
3. Tagel-Din., Hatem. (1998). *A new efficient method for nonlinear, large deformation and collapse analysis of structures*. PhD thesis, Civil Engineering Department The University of Tokyo.
4. Corely, W. G., Mlakar, P., Sozen, M., Thornton, C. (1998). The Oklahoma city bombing: summary and recommendations for multihazard mitigation. *Journal of Performance of Constructed Facilities 12*(3), 100–112. ISSN: 0887–3828/eISSN: 1943–5509.
5. Krauthammer, T., Altenberg, A. (2000). Negative phase blast effects on glass panels. *International Journal of Impact Engineering, 24*(1), 1–17. ISSN: 0734–743X.
6. Kauthammer, T. (2002). *Development of progressive collapse analysis procedure and condition assessment for structures*. paper published by the Pennsylvania State University, US Army Engineer Research and development Centre, Defence Threat Reduction Agency.
7. Meguro, K., Tagel-Din, H. S. (2002). Applied element method used for large displacement structural analysis. *Journal of Natural Disaster Science 24*(1), 25–34. ISSN: 0388–4090/e ISSN: 2434–6705.
8. Remennikov, A. M. (2003). A review of methods for predicting bomb blast effects on buildings. *Journal of Battlefield Technology 6*(3) 5–10. ISSN: 1440–5113.
9. Elkholy, S., Meguro, K. (2004). Numerical modelling of steel structures in fire conditions using improved applied element method. *Proceedings of the 3rd international symposium on new technologies for urban safety of mega cities in Asia*, Kanpur, India.
10. Luccioni, B. M., Ambrosini, R. D., Danesi, R. F. (2004). Analysis of building collapse under blast loads. *ELSEVIER Engineering Structures* 63–71.
11. March, K. A., Farid Al Fawakhiri. (2005). *Blast and progressive collapse*. fact for Steel Buildings, USA.
12. Remennikov, A. M., Rose, T. A. (2005). Modelling blast loads on buildings in complex city geometries. *Computers and Structures 83*(27), 2197–2205. ISSN: 0045–7949.
13. Pandey, A. K., Kumar, R., Paul, D. K, Trikha, D. N. (2016). Non-linear response of reinforced concrete containment structure under blast loading. *Nuclear Engineering and Design 236*(9), 993–1002. ISSN: 0029–5493.
14. Kadid, A., Lahbari, N., Fourar, A. (2007). Blast loaded stiffened plates. *Journal of Engineering and Applied Sciences 2*(2): 456–461, ISSN: 1816–949x/eISSN: 1818–7803.

15. Ngo, T., Mendis, P., Gupta. A, Ramsay, J. (2007). Blast loading and blast effects on structures–an overview. *EJSE Special Issue: Loading on Structures,* 76–91 http://www.ejse.org/Archives/Fulltext/2007/Special/200707.pdf.
16. Zhu, F., Lu, G. (2007). A review of blast and impact of metallic and sandwich structures. *EJSE Special Issue: Loading on Structures,* ISSN: 1443–9255.
17. Van der meer, L. J. (2008). Dynamic response of high rise building structures to blast loading. research report, Eindhoven University of Technology, A-2008.3, O-2008.8.
18. Moon, N. N. (2009). *Prediction of blast loading and its impact on buildings.* M. Tech. thesis, National institute of technology, Roukema.
19. Pichtel, J. (2012). Distribution and fate of military explosives and propellants in soil: a review. *Applied Environmental Soil Science.* https://doi.org/10.1155/2012/617236
20. Herrera RG, Soberon, CG (2008) Influence of plan irregularity of buildings. In: 14th World conference on earthquake engineering, China, 53–60.
21. Koccaz, Z., Sutcu, F. (2008). Architectural and structural design for blast resistant buildings. *The 14th world conference on earthquake engineering.*
22. Nasser, A. A., Razaqpur, A. G., Tait, M. J., Campidelli, M., Foo, S. (2010). Evaluation of nonlinear response of steel members under blast loading. *2nd specialty conference on disaster mitigation*, Winnipeg, Manitoba.
23. Hussein, A. T. (2010). Non-linear analysis of SDOF system under blast load. *European Journal of Scientific Research,* (3), 430–437.
24. Jayatilake, I. N., Jayasinghe, M. T. R., Thambiratnam, D. P. (2010). Response of tall buildings with symmetric setbacks under blast loading. *Journal of the National Science Foundation of Sri Lanka,* 115–123.
25. Raparla, H. B., Bodige, N., Kumar, R. P. (2011). 2D Numerical modeling of progressive collapse during earthquakes: a case study on RC bare frame. *Proceedings of international conference on advances in civil engineering*, 21–23, INV 1–25, Department of civil engineering, K L University, Guntur Dist., A.P., India.
26. Khalil, A. (2012). Enhanced modeling of steel structures for progressive collapse analysis using applied element method. *Journal of Performance of Constructed Facilities 26*(6), 766–779. ISSN: 0887–3828/eISSN: 1943–5509.
27. Helmy, H., Hamed, S., Sherif, M. (2012). Progressive collapse assessment of framed reinforced concrete structures according to UFC guidelines for alternative path method. *Engineering Structures, 42*, 127–141. ISSN: 0141–0296.
28. Al-Ansari, M. S. (2012). Building Response to Blast and Earthquake Loading. *International Journal Civil Engineeering Technolnogy (IJCIET),* (2), 327–346.
29. Helmy, H., Hamed, S., Sherif, M. (2013). Computer-aided assessment of progressive collapse of reinforced concrete structures according to GSA code. *Journal of Performance of Constructed Facilities, 27*(5), 529–539. ISSN: 0887–3828/eISSN: 1943–5509.
30. Subin, S. J. (2013). Analysis of building under blast. research report, M A college of engineering kothamangalam.
31. Jayashree, S. M. (2013). Dynamic response of a spaced framed structure subjected to blast load. *Journal of Civil and Structural Engineering 4*(1).
32. Coffield, A., Adeli, H. (2014). An investigation of the effectiveness of the framing systems in steel structures subjected to blast loading. *Journal of Civil Engineering and Management 20*(6), 767–777. ISSN: 1392–3730/eISSN: 1822–3605.
33. Kulkarni, A. V., Sambireddy, G. (2014). Analysis of blast loading effect on high rise buildings. *Civil and Environmental Research* 6.
34. Osman, S., Atef Eraky., Tharwat Sakr., Shimaa Emad. (2014). Response of building structures to blast effects. *International Journal of Engineering and Innovative Technology (IJEIT) 4*(2).
35. Coffield, A., Hojjat Adeli. (2016). Irregular steel building structures subjected to blast loading. *Journal of Civil Engineering and Management*, *22*(1), 17–25. ISSN: 1392–3730/eISSN: 1822–3605.
36. Madonna, J., Vijaya, G. S., Er. Kiran Kumar, K. L. (2016). Analysis of high rise RCC buildings subjected to blast loads. *International Research Journal of Engineering and Technology 3*(8).

37. Chiranjeevi, D., Simon, J. (2016). Analysis of reinforced concrete 3D frame under blast loading and check for progressive collapse. *Indian Journal of Science and Technology* 9.
38. Habib, M. Z., Alam, M. A., Barua, S., & Islam, M. (2016). Effect of plan irregularity on RC buildings due to BNBC-(2006) earthquake load. *International Journal of Scientific and Engineering Research, 7*(1), 761–765.
39. Ratna SK (2016) Analysis of RCC and SIMCON buildings subjected to blast effects. *International Journal of Civil Engineering and Technology (IJCIET) 7*(4), 223–233.
40. Kumar,M. P., Rambabu, K. (2017). Performance of RC space frame with vertical setback subjected to seismic and blast load using applied element method.*Disaster Advances 10*(5), 1–13. ISSN: 0974262X.
41. Kumar, M. P., Rambabu, K. (2018). Response of regular RC space frame subjected to seismic and blast load using applied element method. *Disaster Advances 11*(7), ISSN: 0974262X.
42. Singh, P. (2018). Analysis of vertical irregular building under blast loading. *International Journal of Civil Engineering and Technology 9*(8).
43. Kumar, M. P., Krishna, C., Rambabu, K. (2019). Collapse analysis of RC buildings subjected to blast load using AEM. *Proceedings of The 18th international symposium on new technologies for urban safety of mega cities in Asia (USMCA–2019)*, Yangon Technological University, Yangon, Myanmar.
44. Vangipuram, B., Sharief Md, A. J., Sandeep, B. B., Baraik, S. (2019). Behaviour of reinforced concrete structural members under the influence of implicit blast loading *International Journal of Civil Engineering and Technology 10*(7), 349–358.
45. Megha, S. M., Ramya, K. (2019). Analysis of multi-storey RC building subjected to blast load using time history method. *International Journal of Innovative Science and Research Technology 4*(6)
46. Sunita, T., Bharati, S. D. (2020). Effect of surface blast on multistory buildings. *Journal of Performance of Constructed Facilities 34*(2).
47. Pichtel, J. Distribution and fate of military explosives and propellants in soil: a review. *Applied Environmental Soil Science*, https://doi.org/10.1155/2012/617236
48. Brode, H. L. (1955). Numerical solutions of spherical blast waves. *Journal of Applied Physics,* (6), 766–775.
49. Henrych, J., Major, R. (1979). The dynamics of explosion and its use. Elsevier, Amsterdam, Netherlands.
50. Held, M. (1983). Blast waves in free air. *Propellants, Explosives, Pyrotechnics,* (1), 1–7.
51. Mills, C. A. (1987). The design of concrete structure to resist explosions and weapon effects. *Proceedings of the 1st International conference on concrete for hazard protections*, 61–73.
52. Sadovskiy, M. (2004). *A Mechanical effects of air shockwaves from explosions according to experiments Sadovskiy MA Selected Works: Geophysics and Physics of Explosion.* Nauka Press.
53. Bajić, Z. (2007). *Determination of TNT equivalent for various explosives.* MS. thesis, University of Belgrade, Belgrade, Serbia.
54. Kinney, G. F., Graham, K. J. (2013). *Explosive shocks in air*. Springer Science Business Media.
55. US Army. (1965). *Fundamentals of protective design (non-nuclear).* Department of Army Technical Manual, TM5–855–1, US Army, Washington, DC, USA.
56. Newmark, N. M., Hansen, R. J. (1961). *Design of blast resistant structures.* Shock and vibration handbook 3.
57. Swisdak, M. M. Jr. (1994) *Simplified Kingery Air blast Calculations.* Naval Surface Warfare Center, Indian Head, Md, USA.
58. Wu, C., & Hao, H. (2005). Modeling of simultaneous ground shock and air blast pressure on nearby structures from surface explosions. *International Journal of Impact Engineering,* (6), 699–717.
59. Siddiqui, J. I., & Ahmad, S. (2007). Impulsive loading on a concrete structure. *Proceedings of the Institution of Civil Engineers: Structures and Buildings,* (4), 231–241.
60. Ahmad, S., Elahi, A., Iqbal, J., Keyani, M. A., & Rahman, A. G. A. (2013). Impulsive loading on reinforced concrete wall. *Proceedings of the Institution of Civil Engineers: Structures and Buildings,* (3), 153–162.

61. Badshah, E. (2017). *Performance evaluation of clay brick masonry against blast loading*. PhD. thesis, University of Engineering Technology (UET) Peshawar Pakistan.
62. Pichtel, J. (2012). Distribution and fate of military explosives and propellants in soil: a review applied and environmental soil science (2012). *Article ID, 617236*, 33. https://doi.org/10.1155/2012/617236.
63. Rodriguez- NiklT., Lee, C. S., Hegemier, G. A, Frieder, H., Seible, F. Experimental performance of concrete columns with composite jackets under blast loading. *Journal of Structural Engineering*, *138*(1), 81–89. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000444.
64. Wei, J., Quintero, R., Galati, N., Nanni. (2007). A failure modelling of bridge components subjected to blast loading part I: strain rate-dependent damage model for concrete. *International Journal of Concrete Structures and Materials (IJCSM)*, *1*(1), 19–28.
65. Schenker, A., Anteby, I., & Gal, E. (2008). Full-scale field tests of concrete slabs subjected to blast loads. *International Journal of Impact Engineering,* (3), 184–198.
66. Yusof, M. A., Norazman, N., Ariffin, A., Mohd Zain, F., Risby, R., Nag, C. (2011). Normal strength steel fiber reinforced concrete subjected to explosive loading. *International Journal Sustainable Construction Engineering and Technology, 1*, 127–136.
67. Wang, W., Zhang, D., LuF., Wang, S. C., Tang, F. (2012). Experimental study on scaling the explosion resistance of a one-way square reinforced concrete slab under a close-in blast loading. *International Journal of Impact Engineering 49*, 158–164.
68. Tabatabaei, Z. S., Volz, J. S., Baird, J., Gliha, B. P., Keener, D. I. (2013). Experimental and numerical analyses of long carbon fiber reinforced concrete panels exposed to blast loading. *International Journal of Impact Engineering 57*, 70–80.
69. Zhao, C. F., & Chen, J. Y. (2013). Damage mechanism and mode of square reinforced concrete slab subjected to blast loading. *Theoretical and Applied Fracture Mechanics, 63–64*, 54–62.
70. Rigby, S. E., Tyas, A., Curry, R. J, Langdon GS Experimental measurement of specific impulse distribution and transient deformation of plates subjected to near-field explosive blasts. *Experimental Mechanics, 59*(2), 163–178.
71. Makovika, D., & Makovika, D., Jr. (2014). Blast load of building structure. *Mechanical Engineering,* (21), 11–18.
72. Makovicka Jr, D., Makovicka, D. Dynamic response of structure under blast load. https://doi.org/10.17265/1934-7359/2016.04.004.
73. IS 4991: 1968 .(reaffirmed 2003). Indian standard criteria for blast resistant design of structures for explosions above ground, bureau of indian standards, Manak Bhavan. 9 Bahadur Shah Zafar Marg, New Delhi, India, 110002.

Study on Irregular Tall RC Structure and Composite Structure by Pushover Analysis

N. Pannirselvam and M. Sreelekshmi

Abstract Irregular systems make up a significant portion of urban infrastructure. As a result, irregular structures, especially those in seismic zones, become a matter of concern. Buildings with irregular shapes are more likely to be designed than buildings with regular shapes, as the architectural element of a building has become more important than the structural safety of the building in recent years. According to studies, irregularity plays a significant role in seismic behaviour, forcing a comprehensive investigation in structural design. The present research addresses the study and behaviour of structures with composite columns–concrete-filled steel tube columns (CFST) having irregularities in plan and elevation, subjected to ground motion. In this paper, a study on how composite column–concrete-filled steel column meets seismic demands in five irregular structures and its advantages over RCC has been carried out by pushover analysis in ETABS.

Keywords CFST columns · Irregular buildings · Pushover analysis · Seismic

1 Introduction

The structural configuration of a multi-storey building has a significant impact on its behaviour during a strong earthquake. As a result, irregular structures, especially those in seismic zones, are a cause of concern. The irregularity in structures can be created by an irregular distribution of mass, weight, and stiffness across the height of the structure [1]. The design and examination of such structures becomes more complicated when they are built in high seismic zones. The two types of irregularity are plan irregularity and vertical irregularity, with vertical irregularities being one of the most significant causes of failure. However, it is unavoidable due to the

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recent demand for aesthetically distinguished building structures in terms of plan, configuration, and other geometrical features [2, 3]. Reinforced concrete structures are commonly used in India because they are the most convenient and cost-effective structure for low-rise building. However, due to increase in dead load, less stiffness, span limitations, and other factors, this type of structure is no longer economically viable for medium- to high-rise buildings.

Steel and concrete have been used to construct composite member beams and columns. Multi-storey commercial structures often use steel and concrete structures. Composite structures are becoming more prominent and preferred by structural engineers as the disadvantages of using solely steel or purely concrete structures are reduced. As a result, the drawbacks of using solely steel or concrete structures can be reduced. Concrete filled steel tube columns, a composite construction that combines the benefits of steel and concrete, are widely used in high-rise and multi-storey buildings [4].

Long-term seismic design will be influenced by the development of specialized nonlinear techniques for large critical structures, which will impact seismic design. As a result, pushover analysis will help identify members that are more critical during an earthquake, requiring serious consideration in design and detailing.

Modelling of an irregular reinforced cement concrete structure as well as an irregular composite structure with CFST columns will be carried out in this article, accompanied by seismic and pushover analyses on both structures. A comparison of the effects and results was conducted.

1.1 Reinforced Concrete Structure

Reinforced concrete is a durable composite material which is one of the most widely used in modern construction. Reinforced concrete structures are made up of concrete and steel members such as columns, beams, and slabs. Concrete resists compression in the members, while steel resists tension, resulting in a joint action. This type of construction, on the other hand, is ideally suited to medium- to high-rise structures and not cost-effective [5]. Following the achievement of such structures for safety factors and design requirements in accordance with international standards, the most important consideration in the design of structures is the economic cost of engineering projects. There are many types of structural systems such as earthquake resistance, and structural systems that were typically referred to as systems used in the design of public and private structures, but in the design of RC high-rise buildings, we use those structural systems regardless of the number of floors, type of foundation soil, or other factors. The cracking behaviour of concrete does affect the load capacity of concrete structures. Concrete belongs to the category of brittle materials since its tensile strength is much smaller than its compressive strength, but it is not entirely brittle. Since concrete is known as a semi-brittle material, it is important to consider not only tensile strength but also tensile toughness when studying its cracking behaviour [6].

Disadvantages of reinforced concrete structures

- Increased dead load for structures
- Imparts lesser stiffness for higher structures
- Large span restriction
- Uneconomical for high-rise structures
- Slower construction procedures

1.2 Composite Structure

In composite structures, beams and columns are constructed of two different materials, such as steel and concrete. In the construction of multi-storey commercial buildings, steel and concrete structures have a wider range of applications. Composite structures are becoming more popular and preferred by structural engineers as the disadvantages of using purely steel or purely concrete structures are reduced. Steel composite columns like CFT (Concrete Filled Tubular) columns proved to be efficient in terms of seismic performances [4]. When it comes to sustaining load during a fire, CFT columns outperform normal columns. It has also been stated that CFT columns made of ultra-high strength concrete can withstand high static loads at high temperatures. The post-yield axial ductility of circular steel tubes is much higher than that of square or rectangular tube sections. Smaller D/t ratios provide a large improvement in yield load and more desirable post-yield behaviour for small dimensional CFT columns [7]. Because of their excellent strength, ductility, and constructional flexibility, structures with concrete-filled steel tubular (CFST) columns have been commonly used for decades. The beam-column connection is the most integral component of a CFST frame structure. The seismic activity of connections has a significant impact on a building's reliability.

Advantages of composite structures

- Increased stiffness
- Enables speedy construction
- Economic in structural system with durability
- Rapid erection and its seismic performance
- Enables lesser deflections and longer span
- Good fire-resistant capacity.

1.3 Irregular Structure

Irregular structures have become an important part of modern urban development. Such structures are often built for both functional as well as for aesthetic purposes. Irregular structures have an irregular distribution of mass, weight, and stiffness over the building's height. When such structures are built in high seismic zones, their design and analysis become more difficult. Plan irregularity and vertical irregularity are the two forms of irregularity, with vertical irregularities being one of the leading causes of structural collapse during earthquakes [7, 8]. The structures considered for study are L-shaped, T-shaped, plus-shaped, and two vertically irregular setback buildings as shown in Figs. 1, 2, 3, 4, and 5.

Fig. 1 L-shape

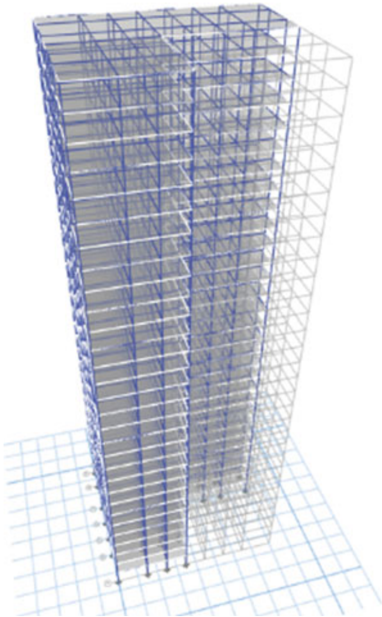


Fig. 2 Plus-shape

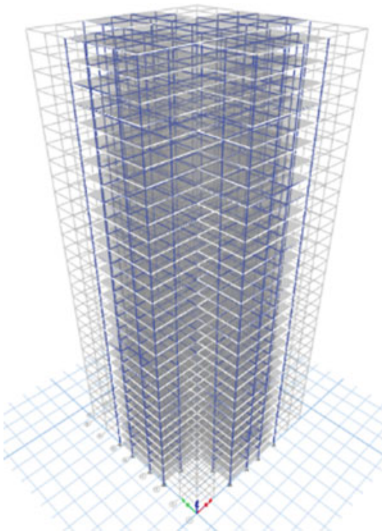


Fig. 3 T-shape

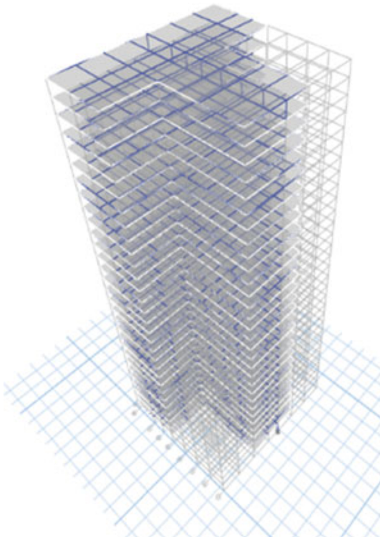
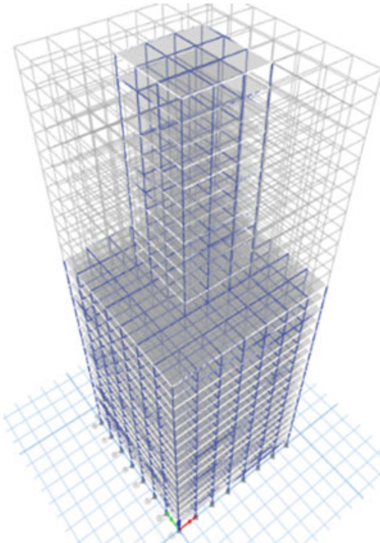


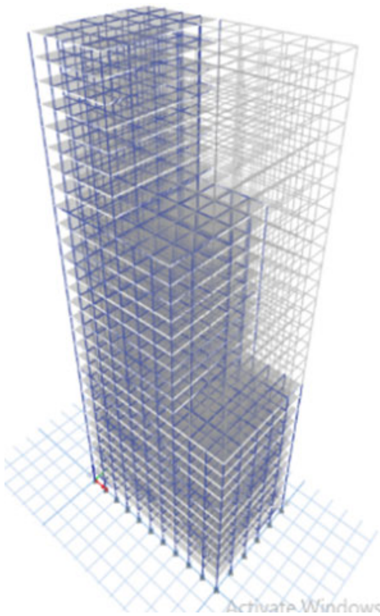
Fig. 4 Setback 1



2 Objective of the Work

The project's main objective is to investigate the seismic response of irregular structures with composite columns and to compare irregular reinforced cement concrete structures with composite structures, as well as to examine the feasibility of concrete-filled steel columns in irregular structures. The current research focuses on the action of structures subjected to ground motion that have irregularly formed composite

Fig. 5 Setback 2



columns. Vertical geometric irregularity and stiffness were among the vertical irregularities investigated. The horizontal irregularity that is being considered is the re-entrant corner. The re-entrant corner is the horizontal irregularity that is being considered. Difference in the pushover curves of the irregular reinforced concrete structures and composite structures with CFT columns, estimate of force and displacement, and identification of failure mechanisms and critical regions are to be determined.

3 Methodology

This research work is aimed at irregular structures with plan irregularity and vertical irregularity. Models of G + 30 structures have been developed. Framed components include beams and columns, which are restrained in all six degrees of freedom. Membrane thin elements are referred to as slabs. Initially, response spectrum analysis and linear static analysis were performed and the results were compared to IS code. Each structure was subjected to a pushover analysis, and the results were compared. Tables 1, 2, and 3 show the material properties, geometrical details, and structural details, respectively.

Table 1 Material properties

Specimen	Material
Column	M 60
Beam	M 40
Slab	M 40
Rebar	Fe500
Steel	F 345

Table 2 Geometric details

Number of stories	30
Storey height	3.2 m

Table 3 Details of structures

Type	Dimension "m"	Columns in mm		Beams in mm		Slabs in mm	
		RCC	Composite	RCC	Composite	RCC	Composite
L-shape	35 × 25	600 × 600 mm	300 mm, t = 8 mm	350 × 650	ISMB350, ISMB250	160 mm	120 mm
T-shape	40 × 35	800 × 800 mm	600 mm, t = 0 mm	350 × 650	ISMB350, ISMB250	200 mm	150 mm
Plus-shape	35 × 35	1000 × 1000 mm	800 mm, t = 10 mm	350 × 650	ISMB350, ISMB250	200 mm	150 mm
Setback 1	35 × 35	800 × 800 mm	600 mm, t = 10 mm	350 × 650	ISMB350, ISMB250	200 mm	150 mm
Setback 2	40 × 25	800 × 800 mm	600 mm, t = 10 mm	350 × 650	ISMB350, ISMB250	200 mm	150 mm

4 Modelling

All the 30 storey structures were modelled using ETABS 18. Three buildings were having irregularity in plan with re-entrant corner L-shape, T-shape, plus-shape, and two buildings were vertically irregular with setbacks—setback 1 and setback 2. Grade of concrete assigned for slabs and beams was M40 and M60 for columns. Rebars were assigned with Fe 500. Composite structures were modelled with circular CFT columns and secondary beams were provided for all composite buildings. Structures have been modelled in accordance with IS codes and Eurocode.

4.1 Linear Static Analysis

Linear static analysis, also known as equivalent static analysis, is a type of static analysis that uses formulas from code of practise. The procedure begins with the calculation of base shear and is then spread across the building's height. Base shear

Table 4 Seismic Definition

Zone factor	0.36
Response reduction factor	5
Importance factor	1
Site type	II

Fig. 6 Displacement

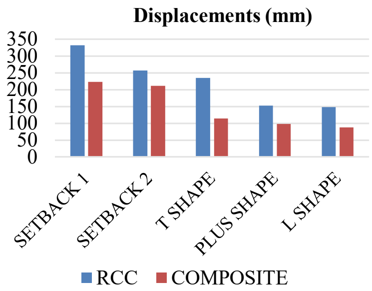
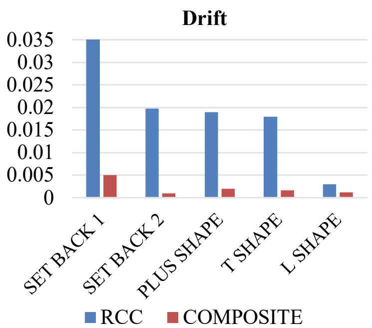


Fig. 7 Drift



Vb, seismic coefficient Ah, response reduction factor R, zone factor Z, importance factor I, response acceleration coefficient Sa/g, and undamped natural time period T are all important parameters for the study and can be found in IS: 1893. The structure is believed to be in fundamental mode of vibration in this study. As a result, drift storey, storey shear, overturning moment, and storey displacement were discovered. Table 4 shows the seismic data considered. Results obtained are shown in Figs. 6, 7, 8, and 9.

4.2 *Response Spectrum Analysis*

Since multiple mode shapes of buildings are taken into account, response spectrum analysis, which is a linear dynamic analysis, is also known as the modal approach. The

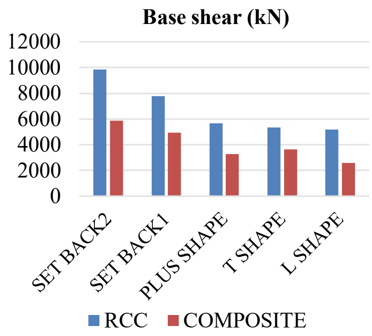


Fig. 8 Base shear

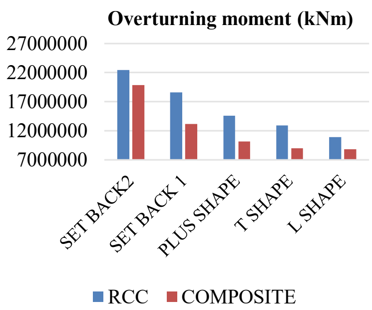


Fig. 9 Overturning moment

undamped natural time and damping values are plotted against the response which is maximum [9]. Relative velocity, absolute acceleration, and relative displacement which are maximum are used to show the results. The results obtained are shown below from Figs. 10, 11, 12, and 13.

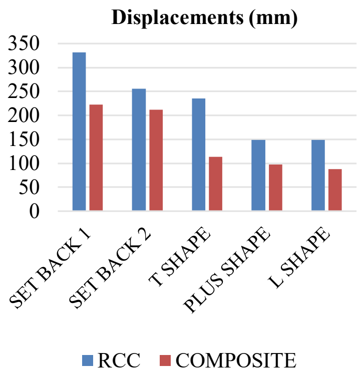


Fig. 10 Displacement

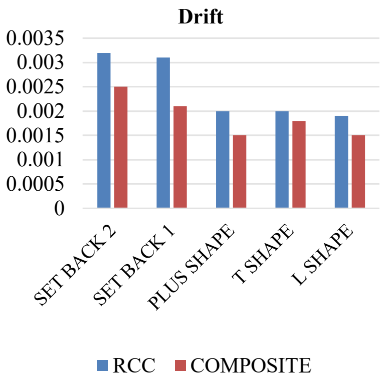


Fig. 11 Drift

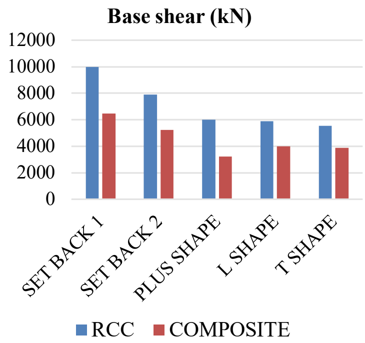


Fig. 12 Base shear

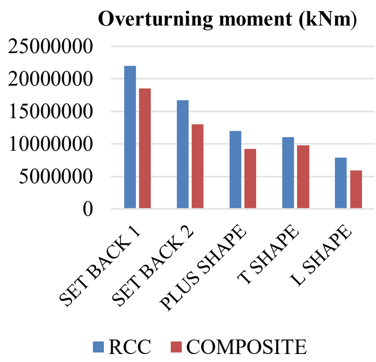


Fig. 13 Overturning moment

5 Pushover Analysis

Pushover analysis is a nonlinear static analysis that allows structures to behave in-elastically. It is used to calculate demand distribution, strength, drift capability, seismic demand, and the adequacy of new structural design for existing buildings. It is

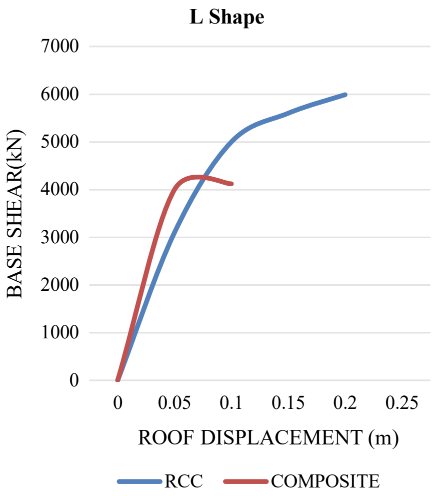


Fig. 14 L-shape

possible to obtain response characteristics such as force and displacement estimates, failure sequence, structural stability, and critical area identification. The results of the modelled structures of RCC and Steel composite structures have been compared. According to most engineers, the importance and use of nonlinear static analysis approaches in the structural analysis are unavoidable to minimize dynamic analysis problems [8, 10]. This form of analysis is more accurate than conventional static analysis, and its results are much easier to interpret than nonlinear dynamic analysis. If the structure's performance objective results in a large non-elastic strain–stress curve, linear approaches are ineffective due to uncertainty enhancement, and a nonlinear analysis should be used to achieve higher accuracy. This form of analysis is more accurate than conventional static analysis, and its results are much easier to interpret than nonlinear dynamic analysis [11]. If the structure's performance objective results in a large non-elastic strain–stress curve, linear approaches are ineffective due to uncertainty enhancement, and a nonlinear analysis should be used to achieve higher accuracy. From the Figs. 14, 15, 16, 17, and 18, it is seen that the lateral displacement is reduced for composite structure than the RCC structure (Table 5).

5.1 Results and Discussions

See (Figs. 19, 20, and 21).

Fig. 15 T-shape

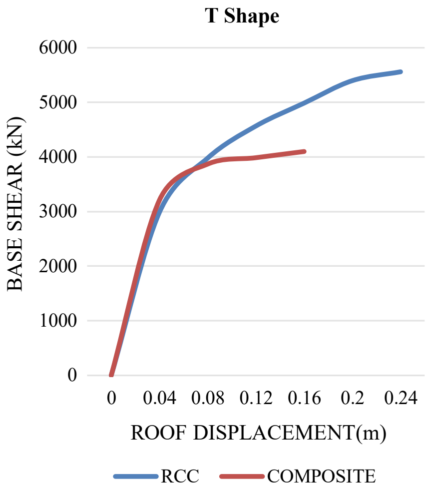
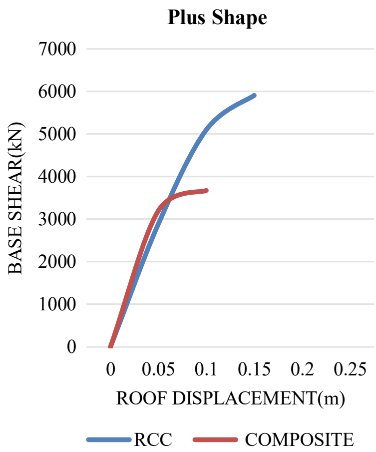


Fig. 16 Plus-shape



6 Conclusions

1. Response spectrum analysis shows lower base shear and storey displacements than linear static analysis.
2. Pushover analysis yields a higher base shear than response spectrum analysis or linear static analysis.
3. Compared to the RCC, the structural weight of steel composites is found less.
4. As compared to RCC, the composite structure has a higher stiffness. As a result, the composite structure's storey stiffness has been decreased, and the storey drift obtained is within the acceptable range of 5. Base shear values

Fig. 17 Setback 1

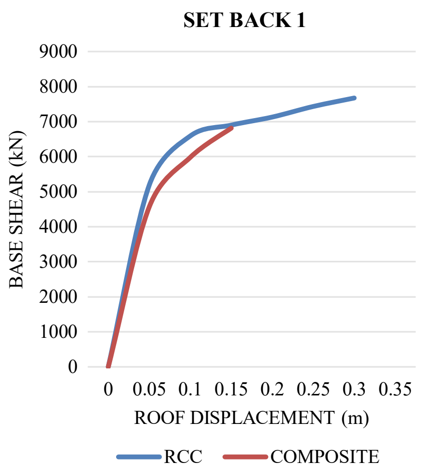


Fig. 18 Setback 2

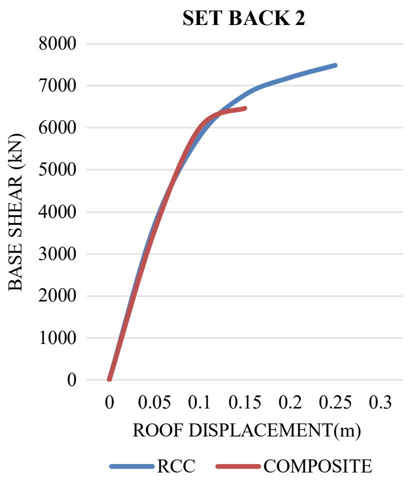


Table 5 Yield deflection and yield base shear

Type of structure	Yield displacement, mm		Yield base shear, kN	
	RCC	Composite	RCC	Composite
L-shape	176	99	5560	4120
T-shape	224.3	184.22	5988	4100
Plus-shape	158	100.35	5910	3675.43
Setback 1	337	226.90	7673.5	6813.50
Setback 2	256	167.30	7490	6467.34

Fig. 19 Base shear

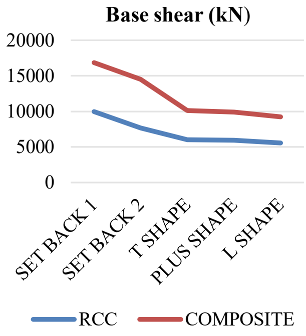


Fig. 20 Time period

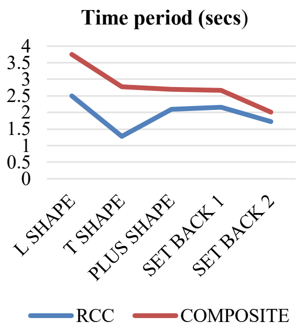
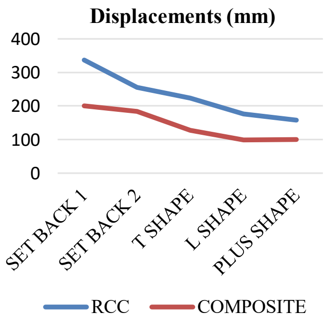


Fig. 21 Displacement



obtained is higher in RCC than the composite structures because composite structures are light in weight.

5. In composite structure, the dead weight is found to be lower than that of an RCC structure, resulting in lower seismic forces.
6. The secondary beams produced just below the composite slab also provide more stiffness than the structure with RCC. As the stiffness of a composite structure is increased, the lateral displacement is reduced.

7. Since composite structures are more flexible than reinforced concrete structures, it takes longer for them to start oscillating back and forth after lateral forces are applied.
8. The lateral displacement of the composite structure is found to be lower than that of the RCC structure.
9. RCC has more structural weight than composite structure, therefore overturning moment is higher for RCC.
10. For both RCC and composite structures, linear static analysis results such as storey drift, storey shear, storey displacement, and overturning moment were found to be higher in vertically irregular setback building 1. Out of the five structures, the L-shaped plan irregular building had the lowest values.
11. In composite structure, yielding started at displacement lesser than yielding started in RCC structure.
12. Due to the lower ductility of RCC, plastic hinges were formed earlier in the stages than in composite structures. In composite structures, the number of plastic hinges formed was less.
13. From the results and comparison, for irregular structures, composite structure exhibits better performance in higher seismic zones.
14. It is possible to enhance the behaviour of structures by adding bracings, shear wall along with the composite structures.

References

1. Naveen ES, Abraham NM, Kumari SA (2019) Analysis of irregular structures under earthquake loads. Procedia Struct Integr 14 806–819
2. Das PK, Dutta SC (2020) Seismic behavior of plan and vertically irregular structures: state of art and future challenges. Nat Hazards Rev-ASCE 1527–6988
3. Pena LA, Carvalho (2015) Influence of the concrete structural configuration in the seismic response. IBRACON Struct Mater J 8:800–826
4. Denavit MD, SM, Hajjar JF (2012) Nonlinear seismic analysis of circular concrete-filled steel tube members and frames. J Struct Eng 138:1089–1098
5. Katkhoda, A., & Knaa, R. (2012). Optimization in the selection of structural systems for the design of reinforced concrete high-rise buildings in resisting seismic forces. *Energy Procedia, 19*, 269–275.
6. Lu X, Li Y, Guan H (2017) Progressive collapse analysis of a typical super-tall reinforced concrete frame-core tube building exposed to extreme fires. FireTechnol 53:107–133
7. Patel, V. I., Liang, Q. Q., & Hadi, M. N. S. (2014). Nonlinear analysis of axially loaded circular concrete-filled stainless steel tubular short columns. *ELSEVIER J Constr Steel Res, 101*, 9–18.
8. Mohod, M. V. (2015). Pushover analysis of structures with plan irregularity. *J Mech Civ Eng, 12*(4), 46–55.
9. Lewandowski, R., & Pawlak, Z. (2018). Response spectrum method for building structures with viscoelastic dampers described by fractional derivatives. *Engineering Structures, 171*, 1017–1026.

10. Mahmoud, S., Abdallah, W., Hanna, N., & Abdelaa, A. (2016). Seismic response evaluation of connected super-tall structures. *Proceedings of the institution of civil engineers-structures and building, 169*(11), 840–852.
11. Cimellaro GP, ASCE AM, Giovine T, Lopez-Garcia D (2014) Bidirectional pushover analysis of irregular structures. J Struct Eng ASCE 140(9)

Feasibility Study on Subgrade Stabilization of Pavement Using Lime and Fly Ash as Admixtures

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Abstract The nature of the underlying layers of the pavement determines its life. Among these layers, the subgrade plays a very crucial role in aiding the load transfer mechanism as well as facilitates the drainage mechanism. India, being a developing nation, has focused a lot on infrastructure development of which highways are a huge part. Being an agriculturally driven nation, the available land for development of these pavements is agricultural in nature with soils of poor mechanical properties. Thus, in order to keep up with this pace, there's a need for an innovative solution and such solution is the soil stabilization technique. The work is focused on identifying the impact of lime and fly ash-induced admixture's impact on the various parameters of soil including the CBR, Maximum Dry Density (MDD), Liquid Limit (L.L), Plastic Limit (P.L), etc..,. black cotton soil was blended by varying lime at 2% for three trials by keeping the fly ash constant at 7% of the total weight of the soil sample. The percentage increase in moisture content is 9.09% from soil to blended soil. MDD decreased with a percentage of 8.43% from soil to that of blended mixture. CBR increased by a steeping 92.83% from soil to blended soil i.e., from 1.59 to 22.19. The trend stayed the same for both lime and fly ash in the determination of the above properties. The results show that both lime and fly ash are suitable for enhancing the properties of soils that are clayey in nature.

Keywords Flexible pavement · Black cotton soil · Lime · Fly ash · CBR

1 Introduction

In India, currently, most of the highway widening and expansion projects were green-field projects and the land turns out to be of agricultural in nature. The quality and the life of pavement are greatly affected by the type of filling materials used as subgrade, subbase, and base course [1]. Among these layers, the subgrade rather plays a very important role as the load from the top layers gets transferred to this layer, which,

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in addition, also needs to facilitate the drainage mechanism of the road. With rapid industrialization and increasing demand for infrastructure due to population growth, roads turned out to be the network connecting the important places in the country. As a result of this, most of the expansion and new age projects required a vast amount of area, and agricultural land is to be occupied as India is an agricultural-based economy. But the problem arises due to the low bearing capacity of these soft strata clayey soils [2].

Soil replacement technique is one of the most practiced indemnification measures used to treat the problems that arise due to soils with lower mechanical properties. The existing soil is replaced by an equivalent but a stable mechanized feature. But this cannot be an ample solution as it can increase the project cost by a huge value as the highway projects expand to kilometers and thus it was not promoted in many projects [3]. Another method used to overcome this problem is the institution of soil stabilization methods, in which the mechanical and geotechnical properties of the soil were improved as a result of the same and this was widely adapted in case of highly expansive soils [4, 5]. Several methods of soil stabilization were employed in the field and in the literatures [6–9]. But the most common and most beneficially used soil stabilization is by the use of waste materials that are derived from the processing industries [10, 11], and the waste product used here in this experimental study is the fly ash produced from the thermal power plant alongside lime [12, 13].

The current scope of work focuses on conducting experimental procedures on such soft clay, i.e., black cotton soil. In evaluating the shrinkage and the FSI of the expansive soil, the microstructure always plays a very key role as it directly gives us an opportunity in enhancing the mechanical properties of the soil in stabilization projects as it aids in the selection of a more suitable and reliable material for stabilization. Other properties such as heat of hydration and other possible chemical reactions are to be taken into consideration while the selection of the same [14]. The most difficult type of soil to stabilize is the highly organic soils even for a chemical stabilizer due to their rapid interaction with water. Cement has a higher reaction rate with water, which is rapid whereas lime has a slower reaction with the same. Alongside lime, polymer can also be one of those soil stabilization techniques to be adopted [15]. The impact of addition of lime and fly ash [16, 17] on the mechanical properties of the soil is determined in this research. Lime has many applications. Stabilization of soil in foundation and for the strength improvement of highways and runways, lime is used in the construction industry. Around 1.6 million metric tonnes of lime were used for stabilization purposes in the United States in 2003 [18].

Greater the CBR value, the lesser will be the thickness of the pavement, and our focus is glued in achieving the same. Indian Standard [19, 20] had been referred in regards to the adoption of the procedure of testing. In India, highways count is constantly increasing, and the length of the highways has been increasing every year in an exponential manner, pavement design being the major component. It contributes to nearly one third to one half of the total cost of construction [21]. A consolidated subgrade layer supposedly acts as a load transfer belt, received from the top surface to the bottom layers. For better road conditions, good pavement is used, which can easily bear the load as well easily transmit it. As a part of the green field approach, part of agricultural land is also being taken for the sole purpose of highway construction. Since the soil is fertile, there arises a problem with the pavement thickness as mainly black cotton soil is present, which has a very low CBR strength [22]. As the thickness of the pavement increases, scope of the problem also increases as failure due to load is going to play a major role. We aim at increasing the bearing capacity of soil, viz., CBR, which, in the end, helps in reducing the thickness of the pavement [23].

2 Methodology

Fig. 1 depicts the detailed methodology followed for the project.

Initially, geotechnical properties such as dry density, liquid limit, plastic limit, specific gravity, and OMC are analyzed. CBR test is conducted on the soil sample in soaked and condition at different OMCs. We clearly know that the governing factor for both strength and thickness of the pavement is CBR. For finding CBR, Optimum Moisture Content (OMC) is to be calculated by Standard Proctor Test. After finding OMC, using it Compaction is done and the mould is kept soaked under water for 3 days in order to find the soaked CBR value. At 2.5 mm and 5 mm penetration, load is taken and thus CBR @ 2.5 mm and @5mm is found out by the formula and higher value is taken into consideration:

CBR @ 2.5 mm penetration = {(Load @ 2.5 mm penetration) × 100}/1370 @ 5 mm penetration = {(Load @ 5 mm penetration) × 100}/2055

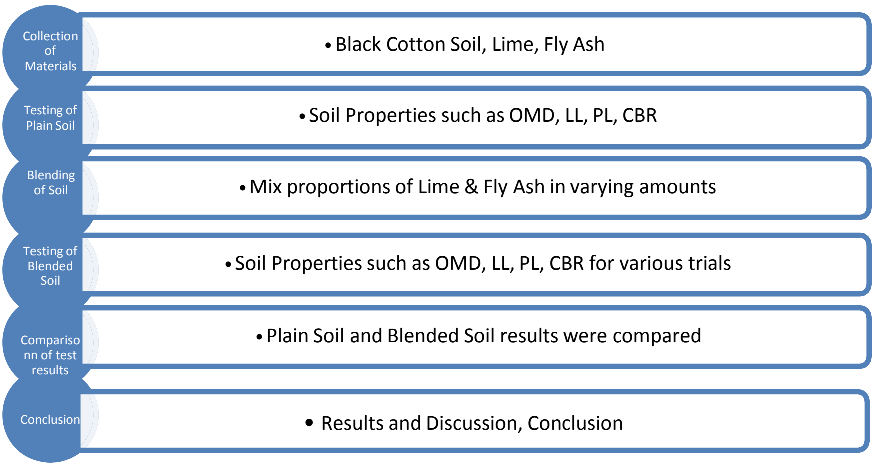

Fig. 1 Methodology

3 Results and Discussion

In order to figure out the soil strata and their subsequent mechanical properties, the following tests were conducted, and the results were interpreted as below:

Free Swell Index, Grain Size Distribution, Plastic Limit, Liquid Limit, Maximum Dry Density, California Bearing Ratio were to name a few. Initially, the Free Swell Index (FSI) is found out to be 87%. This FSI value shows that the water absorption capacity is relatively higher placing it in the clayey soil category, with high plasticity, which is to be confirmed by further experimentation. The FSI was used only to get an idea about the nature of the soil. This was followed by the Grain Size Distribution Curve test where the graph below is plotted (Table 1).

Wet Sieve Analysis is carried out in order to find the percentage finer in the soil sample taken for the experiment, and the particle size distribution curve is plotted as shown in Fig. 2. The amount of soil passing through the 4.75 mm sized sieve is 95.2% out of which 40.5% have passed through the 0.075 mm or 75micron sieve. It can be inferred from this that the percentage finer is relatively higher. Further properties of the soil such as, the Liquid Limit (L.L), Plastic Limit (P.L), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Specific Gravity, and California Bearing Ratio (CBR) were determined. The results were tabulated below,

Table 1 Grain Size Distribution data

IS Sieve size (mm)	% Finer
4.75	95.2
2.36	93.4
1.18	88.4
0.600	80.1
0.300	61.4
0.150	43.8
0.075	40.5

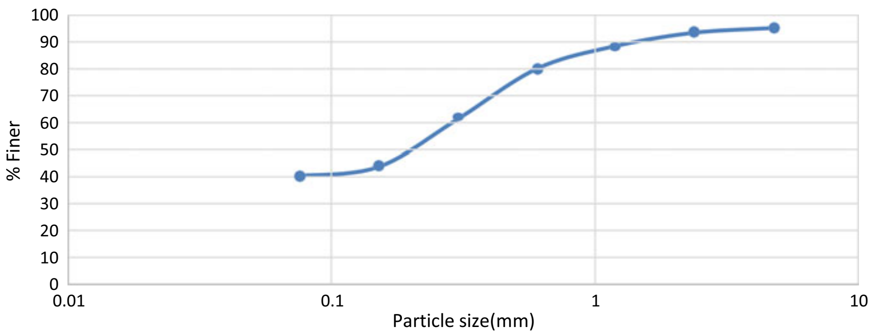

Fig. 2 Particle size distribution curve

and respective graphs are also plotted. Shown below are the compaction curves and CBR of the soil followed by those of the blended soil mixture.

It was observed that the soil had a moisture content of 20% and the dry density at 20% moisture is 1.59 kg/m^3, which was the highest among all the tested samples. This is nothing but the Maximum Dry Density (MDD) and the corresponding moisture content are known as Optimum Moisture Content (OMC). The same can be noted from the graph above titled Fig. 3.

It can be observed from the graph above, i.e., Fig. 4, the maximum load borne by the soil was 46.12 kg, which is very less when compared with the traffic load that is to be received on the roads. The load at 2.5 mm penetration was 21.72 kg whereas the load at 5 mm penetration was 29.86Kg. The CBR value at 2.5 mm penetration is 1.59, whereas at 5 mm penetration is 1.45. The CBR value at 2.5 mm penetration is considered as it is higher.

The compaction curves for the blended soil of proportions—(2% lime + 7% fly ash), (4% lime. + 7% fly ash), and (6% lime + 7% fly ash) are drawn as shown in Fig. 5. We can see a shift toward the right in Fig. 5. This is because of the addition to the soil we can observe an increase in the moisture content from 20 to 22%,

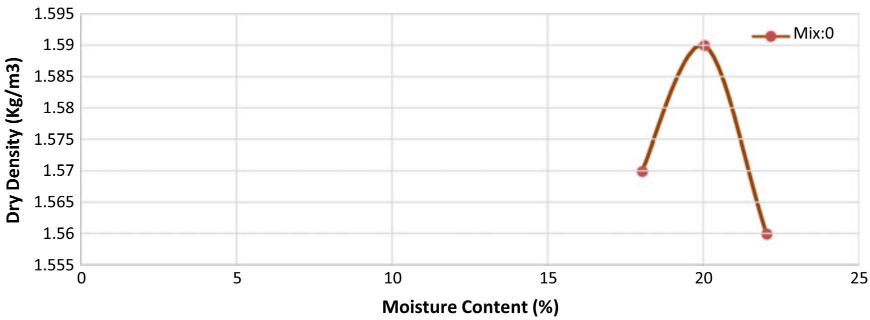

Fig. 3 Compaction curve of soil

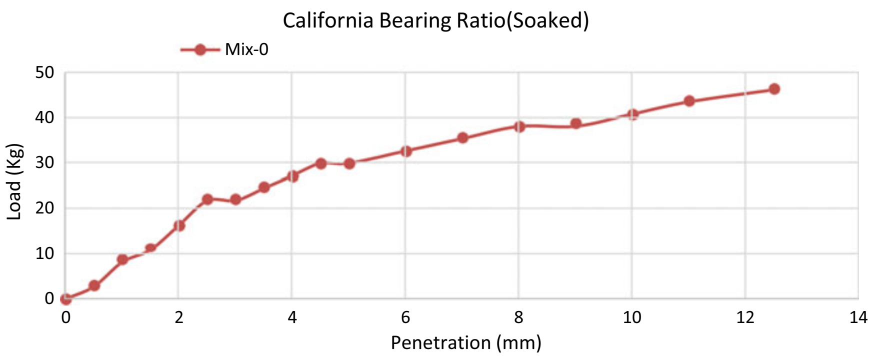

Fig. 4 CBR of soil

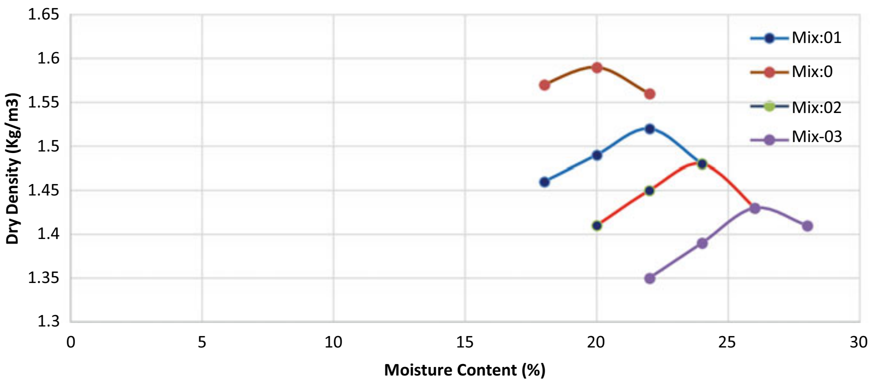

Fig. 5 Compaction curves of blended soil in comparison with soil

24%, and 26%, respectively, for soil and blended soils, which confirms the reaction between water and lime, thus making the soil require more water for compaction, hence the rise in OMC. The MDD also decreased from 1.59 kg/m^3 to 1.520 kg/m^3, 1.456 kg/m^3, and 1.423 kg/m^3.

From Table 2, it is observed that the Plasticity Index (PI) of the soil to blended soil varies from 17.6, 3.07, 2.86, and 2.3 respectively. The Liquid Limit of the plain soil was found to be 54.38, which is very high, and it conclusively affirms from the fact that a 40% finer soil passing through the 75 micron sieve and 87% FSI followed by this level of L. L puts the soil in the highly plastic and clayey soils. Thus, the soil can be classified as CH (fat clay). Specific gravity isn't changing much and it's staying around 2.73.

From the CBR curves shown in Fig. 6, the maximum load-bearing capacity of the soil started to increase gradually in response to the blended soil, which clearly

Table 2 Properties of soil and blended soil

S.No	Property	Mix-0 (pure sample)	Mix-01 (Lime = 2%, Fly ash = 7%)	Mix-02 (Lime = 4%, Fly ash = 7%)	Mix-03 (Lime = 6%, Fly ash = 7%)
1	Dry density (Kg/m3)	1.590	1.520	1.456	1.423
2	Liquid limit (L.L)	54.38	37.64	35.45	32.98
3	Plastic limit (P.L)	36.78	34.57	32.59	30.68
4	Specific gravity	2.75	2.73	2.73	2.73
5	OMC	20	22	24	26
6	CBR (soaked)	1.59	22.19	23.81	18.23

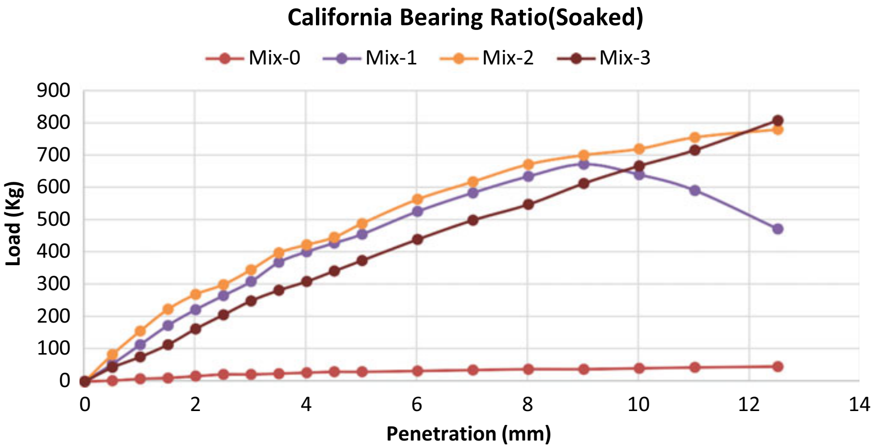

Fig. 6 CBR comparison of all mixes

confirms the effect of lime and fly ash on the weaker or expansive nature of the soil. It can also be observed that the L.L, P.L readings have dropped from 54.38 to 32.98 and 36.78 to 30.78, respectively, which shows a significant drop, thus reducing the water clogging capacity as well as the expansive swell, i.e., the plasticity of the soil, which, in turn, enhances the bearing capacity of the soil. The loads at 2.5 and 5 mm were (21.72,29.86), (266.07,456.12), (300.29,489.36), and (206.34,374.67) Kg, and, thus, it is safe to say that the load-bearing capacity of the soil has hugely increased from a mere 21.72 to 206.34 kg for 2.5 mm penetration and from 29.86 to 374.67 kg for 5 mm. Greater the load bearing capacity of the soil, higher the CBR. The value of CBR of the pure sample is 1.59, which is nearly 93% lesser than the blended soil's value of 22.19 in the Mix-01 of the blended soil.

4 Conclusion

The following conclusions were drawn based on the experimental studies carried out in this investigation.

Based on the Grain sieve analysis and the plasticity index value, the soil can be classified as CH (Clay of high plasticity). Now for the blended soil, the PI came down to 3.07 from 17.60 with a percentage decrease of 82.56%. The percentage increase in Moisture Content is 9.09% from soil to blended soil. The trend stayed the same for both lime and fly ash. MDD decreased with a percentage of 8.43% from soil to that of blended mixture. The trend stayed the same for both lime and fly ash. CBR increased by a steeping 92.83% from soil to blended soil, i.e., from 1.59 to 22.19. The trend stayed the same for both lime and fly ash. The results show that both lime and fly ash are suitable for enhancing the properties of soils that are clayey in nature.

References

1. Singh DV, Murty AVSR (1998) Fly ash in India—problems and possibilities. In: Proceedings of experience sharing meet on use of fly ash in roads and embankments. CRRI, New Delhi 1–9.
2. Anadurai, R., Kamalanandhini, M., Sudarsan, J. S., & Golda, P. V. P. (2018). Feasibility study of marine clay treated with lime for construction purpose. *J Adv Res Dyn Control Syst, 10*, 616–619.
3. Gobinath R, Ganapathy GP, Akinwumi II, Kovendiran S, Hema S, Thangaraj M (2016) Plasticity, strenth, permeability and compressibility characterisitcs of black cotton soil stabilized with precipitated silica. J CentL South Univ 2688–2694
4. Dang, L. C., Fatahi, B., & Khabbaz, H. (2016). Behaviour of expansive soils stabilized with hydrated lime and bagasse fibres. *Proc. Eng., 143*, 658–665.
5. Estabragh AR, Naseh M, Beytolahpour I, Javadi AA (2012) Strength of a cly soil and soil-cement mixture with resin. proceedings of institution civil engineers. Ground Improv 108–114
6. Arora, K. R. (2003). *Soil mechanics and founation engineering* (pp. 94–109). Standard Publishers Distributors.
7. Mutaz E, Dafalla M (2014) Utilizing chemical treatment in improving bearing capacity of highly expansive clays. In: International conference on sustainable civil infrastructure, Hubei, China, 62–66
8. Mirzababaei M (2009) Effect of polymers on swelling potential of expansive soils.proceedings of institution civil engineers. Ground Improv 162(3):111–119
9. Moghai AA, Chittiiri BC, Basha BM (2018) Effect of fibre reinforcement on CBR of lime-blended expansive soils: reliability approach. Road Mater Pavement Des 690–70
10. Cokca E (2001) Use of class C fly ashes for the stabilization of an expansive clay. J Geotech. Geoenviron Eng 127(7): 568–573
11. Kate M (2005) Strength and volume change behaviour of expansive soils trated with fly ash. geo-frontriers congress, Austin, TX, USA, 94–100
12. Seda JH, Lee JC, Carraro AH (2007) Benefial use of waste tire rubber for swelling potential mitigation in expansive soils. Geo-denver 2007 new peaks in geotechnics Denver, CO, USA, 55–58
13. Sridharan, A., Prashanth, J. P., & Sivapullaiah, P. V. (1997). Effect of fly ash on the unconfined compressive strength of black cotton soil. *Ground Improv, 1*(3), 169–175.
14. Fazal EJ, Yongfu X, Babak J, Shazim AM (2020) On the recent trends in expansive soil stabilization using calcium-based stabilizer materials (CSMs): a comprehensive review. Adv Mater Sciemce Eng 1–23
15. Tan EH, Zarhran EMM, Tan SJ (2020) A review of chemical stabilisation in road construction. In: IOP Conference series: materials science and engineering, 1–10
16. Irene S (2005) Proc Uses of Coal Fly ash—Benefits and Barriers. INSB, Australia, 411–416
17. Kumar A, Prasad G (2009) Use of lime cement stabilized pavement construction. Indian Journa1 Eng Mater Sci. JNTU Kakinada 18 269–276
18. M. Miller (2004) Lime U.S. geological survey minerals yearbook USGS, 12–18
19. 2. IS (1983) Part-5 Method of test for soil determination of liquid limit and plastic limit
20. IS 2720 (1983) Part-8 Method of test for soil determination of water content. Dry density relation using a heavy Compaction & light compaction
21. Brown, F. S. (1996). Soil mechanics in pavement engineering. *Geo Technique, Canada, 46*, 383–426.
22. Boominathan A, Hari S (1998) Behavour of Fly ash under static and cyclic loading. Proceedings of IGC-99, Calcutta, 324–326
23. Mallela J, Harold VQ, Smth KL, Consultants E (2004) Consideration of lime- stabilized layers in mechanistic-empirical pavement design. The National Lime Association, Arlington, Virginia, USA, 45–48

Treatment of Seawater Using Electrochemical Mediated Desalination

V. M. V. Sai Krishna and K. Prasanna

Abstract One of the most vulnerable resources in nature is WATER. Due to global warming, the water gets evaporated from different sources drastically. The availability of fresh water sources is polluted by anthropogenic activities. So, the scarcity of drinking water also increases and the heavy metals, organic pollutant influence are very high in drinking water. Hence this requires high technological treatment to remove the pollutants before it is used for drinking purpose. The best way to overcome the scarcity of water is converting the seawater into drinking water, as of now so many methods are there for converting the seawater. Among all the existing methods, membrane process (desalination process) is most commonly used for converting the seawater into the drinking water due to its flexibility and easy operational process. But, the major drawback of this method is membrane cost, membrane lifetime, membrane clogging and electricity cost. To overcome these drawbacks, a new, emerging and effective technology to treat the seawater is Electrochemical Mediated Desalination (EMD). In this method, to treat the seawater with the help of graphite electrodes with 9 V DC supply were used. Here, achieve the maximum efficiency of this method with two different trails are 10.55% (trail—1) and 15.33% (trail—2) on the basis of reduction of chloride content present in the solution.

Keywords Desalination · EMD process · Graphite electrodes · Chlorides · Seawater

1 Background

In this globe, freshwater is needed for biotic components for their sustain life. But nowadays we are facing a lot of problems due to the scarcity of freshwater sources. The reason behind that day by day increasing global warming due to drastically increasing the industrial activities for meeting the present demands of people who want to live with extravagant things. Even the small amounts of available freshwater

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Table 1 Global water distribution. Adopted from Ref. [5]

Sources	Percentage (%)
Saltwater	97.5
Freshwater	2.5
(a) Glaciers & permanent snow cover	68.9
(b) Fresh ground water	29.9
(c) Others [including soil moisture, swamp water & permafrost]	0.9
(d) Freshwater lakes & river storages [only this portion is renewable]	0.3

sources are also contaminated due to anthropogenic activities [1, 2]. The recent studies on the status of water distributed globally by the United Nations conclude one-third of world's population is living in water-stressed regions [3]. Even more, they are estimated from the above range by 2025 it will become as two-thirds of world's population and not only for arid and developing regions, the countries are which are living in water rich environments [4] now, also takes place on this list, this type of situation continues (Table 1).

The above table clearly shows the way to provide or supply a huge amount of freshwater while converting the seawater into the freshwater for various purposes of domestic and industrial purposes. The available ground water also reached down due to over sucking. At the same time so many technologies are found for treating the wastewater but, the only conversion of contaminated water for reusing not sufficient to the meet the demand due to the growth of population. For treating the seawater also many technologies are find like thermal desalination, ion exchange [6], Nano filtration [6], pervaporation [7], reverse osmosis [8] (membrane technology) etc., among all the existing technologies now a day's most commonly used method is membrane technology due to its wide range of applications and its flexibility for operation and maintenance. But, the major drawback is membrane cost, membrane lifetime, frequent clogging and the most important one is electricity and pre-treatment cost.

2 Introduction

A new emerging and effective method Electrochemical Mediated Desalination (EMD) is used for treating the seawater. [9] have reported that EMD provides a number of benefits relative to existing desalination technologies. Since EMD is membraneless technology, it reduces capital cost and consumption of energy [9]. The schematic representation of ionic reduction near Y-intersection is shown in below Fig. 1.

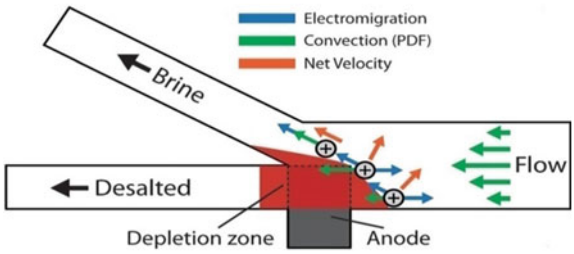

Fig. 1 Schematic representation of ionic redirection near Y-intersection of A desalination device. adapted from Ref. [10]

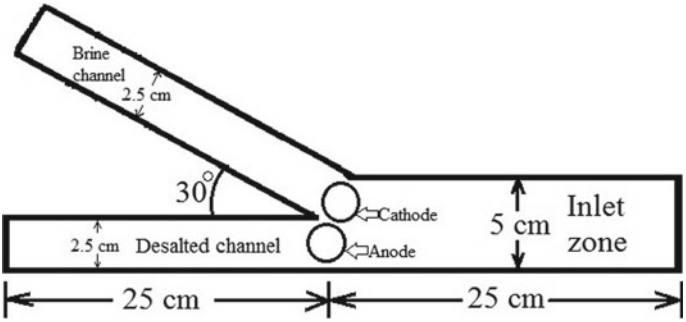

Fig. 2 Layout of desalination device

3 Materials and Methodology

3.1 Experimental Setup

The desalination device which is used for this technique is made up of plexiglass or acrylic sheet. Figure 2 shows the experimental setup of the scale up model of lengthwise 1:100 and widthwise of 1:500 (inlet, desalted and brine channels). The graphite rods of height 6 cm and diameter 1.5 cm are used as anode and cathode respectively. Both inlet and outlet channels having same height from the base.

3.2 Procedure

Keep the barriers near the Y-intersection at outlets with a 1 mm gap at the bottom to let the water to the out and given the head in inlet zone is maintained the gravimetrical velocity 0.016 m/s. Fill the inlet zone with seawater solution. Insert the graphite electrodes near the Y-intersection and pass 9 V DC supply through the electrodes. The chloride ions present in the solution are oxidized and it diverted the brine channel which is 30° inclined to the desalted channel. Collect the desalted and brine through separate channels. Find the chlorides present in the desalted water. Compare the result with initial one to find the efficiency of the device.

4 Results and Discussion

To initiate desalination, 9 V DC supply voltage is applied between the electrodes. This voltage results in the oxidation of Cl^- [9]

$$2Cl^- - 2e^- \leftrightarrow Cl_2 \quad (1)$$

Two types of trails are used for the experiment. As shown in Figs. 3 and 4.

The results of the trail—I are shown in below Table 2.
The results of the trail—II are shown in below Table 3.

The Pictorial Representation for better understanding for comparing the trails used for experiment among the samples of seawater shown in below Fig. 5.

In the time of the process is going on we clearly inhale the smell of HOCl near the intersection and the treated water also contains this HOCl odor. The following reaction shows the hydrolysis process for producing HOCl.

$$NaCl + H_2O \rightarrow HOCl + Na^+(ion) + H^+(ion) \quad (2)$$

Fig. 3 Trail—I

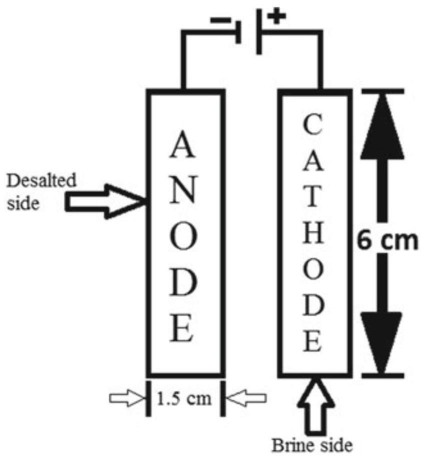

Fig. 4 Trail—II

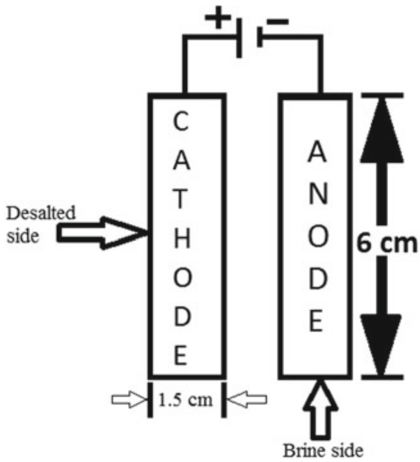

Table 2 Results of seawater treated with trail—I

S.No	Initial chloride (mg/L)	Final chloride (mg/L)	Efficiency (%)	Energy consumed (V)
1	2,377.63	2,126.76	10.55	1.53
2	10,969.09	10,618.33	3.20	1.64
3	12,441.14	12,073.23	2.96	1.92
4	13,627.27	13,229.40	2.92	1.83
5	4,675.05	4,326.91	7.45	1.44

Table 3 Results of seawater treated with trail—II

S.No	Initial chloride (mg/L)	Final chloride (mg/L)	Efficiency (%)	Energy consumed (V)
1	2,377.63	2,076.82	12.65	1.35
2	10,969.09	9,303.76	15.18	1.32
3	12,441.14	10,540.33	15.28	1.62
4	13,627.27	11,538.42	15.33	1.23
5	4,675.05	4,078.24	12.77	1.24

5 Conclusions

In summary, we conclude that EMD is the most common method for treating the seawater in future. The reasons are mentioned below:

- From the above tables, we clearly observe trail—2 gives the maximum efficiency when compared to the trail—1. There is a decrease in energy consumption for the trail—2.

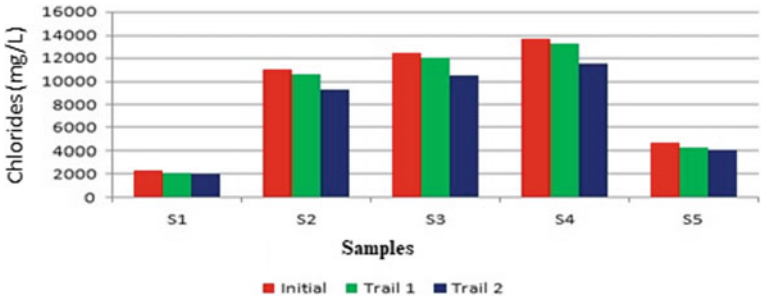

Fig. 5 Graphical representation of difference between initial and final chloride content treated with trail—I and trail—II

- Importantly, the only pre-treatment is enough to perform EMD is sedimentation of silt and sand particles for avoiding the obstruction in the channel near the electrodes.
- Another important notable point is Cl^- oxidation Eq. (1) results in a Cl_2 generation, which subsequently undergoes hydrolysis to produce hypochlorous acid (HOCl), a common water disinfectant [11].

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References

1. Schwarzenbach, R. P., Escher, B. I., Fenner, K., Hofstetter, T. B., Johnson, C. A., Von Gunten, U., & Wehrli, B. (2006). *Science, 313*, 1072–1077.
2. J.F. Kenny, N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace, M.A. Maupin, Estimated Use of Water in the United States in 2005, U.S. Geological Survey, (2005).
3. United Nations, World Water Development Report **2**, (2006).
4. The World's Water: The Biennial Report on Freshwater Resources, Vol.**7** (Ed.: P.H. Gleick), Island Press, (2012).
5. Gleick, P. H. (2013). *Water in Crisis: A Guide to the World's Freshwater Resources*. University Press.
6. Rodrigo Bo´rquez, Javier Ferrer, Desalination and water Treatment, (2016).
7. Nick Wynn, Pervaporation comes of age, www.cepmagazine.org, Oct. (2001).
8. Public Health and the Environmental World Health Organization, Geneva (2007).
9. R.M. Crooks, K.N. Knust, M.R. Stanley, F.J. Carrillo, D. Hlushkou and U. Tallarek, 18^{th} Int. Conference on Miniaturized Systems for Chemistry and Life Sciences, Oct. 26–30, (2014).
10. Kyle, N. (2014). Knust, DzmitryHlushkou, Ulrich Tallarek, and Richard M. *Crooks, ChemElectroChem, 1*, 850–857.
11. Geise, G. M., Lee, H. S., Miller, D. J., Freeman, B. D., McGrath, J. E., & Paul, D. R. (2010). *J. Polym. Sci. part B, 48*, 1685–1718.

Assessment of Energy Dissipation Capacity of Steel Moment Resisting Frames Under the Effect of Earthquake

Bethapudi Suvarna Susan and A. Arun Kumar

Abstract In recent years, earthquake engineering was introduced and showed the path for energy concepts, these concepts have applications in evaluating the vulnerability of the structures under earthquake vibrations and also in optimization design. Now-a-days, energy dissipation capacity is estimated by either empirical equations or experimental way which are not sufficient and considered effective for the study and also numerical analysis which is considered difficult to use in practice. In the present study, nonlinear dynamic analysis is obtained to investigate the distribution of damage and dissipation capacity in the structure and also to find out the maximum storey drift and storey displacement. The main aim of this study is to evaluate the energy dissipation capacity of steel moment resisting frames under earthquake motions. The more the structure height increases, the dissipation capacity increases. The stress levels at top stories are high which are controlled by potential and kinetic energy and balanced with damping.

Keywords Moment resisting frames · Seismic design · Response spectrum analysis · Nonlinear dynamic analysis · Energy dissipation capacity

1 Introduction

Assessing the structural behavior at times of earthquake, plays an important role in earthquake engineering. One of the concepts found by researchers in recent years was Energy Concept. This concept was introduced by Housner [1] in which he proposed energy method based on limit design. His affirmation is that the absorption of energy against earthquake was said to be the safety factor of its own building, and the Energy input during the earthquake will lead to some parameters like kinetic and potential energies. Energy dissipation is mostly considered in seismic and dynamic analysis in

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which hysteric behavior was represented by viscous damping and global damping of the structure. Gerami and Abdollahzadeh [2] carried out a research on energy dissipation for steel frames at near- and far-fault regions and concluded that damping plays powerful role in energy dissipation for high-rise structures. In seismic design methods, the parameters are earthquake duration and frequency, some of the structural requirements are hysteresis behavior, damping and ductility. Abdollahzadeh [3], concluded that hysteric energy at lower stories will be higher when compared to higher stories. Hysteric energy shows the level of damage in a structure but cannot specify the damage at different locations or parts of the structure, where this energy is wasted when the structural members reach its beyond yielding point. The whole behavior is said to be inelastic behavior, which is to be taken care when structure is subjected to Nonlinear dynamic analysis. Benavent [4] defined a model to show the damage level of the structural members and hysteresis behavior at different earthquake records, where he concluded that the damage occurs due to inter story drift and hysteric energy. Storey drift is one the causes for waste of energy. Idels and Taiyari [5, 6] defined about the Steel Moment resisting frames (SMRF), in their study they said that SMRF have a great capacity on holding the dissipated energy and have resistance against the lateral forces (earthquake forces). This study is to focus on energy dissipation capacity of steel structures using seismic design of nonlinear dynamic analysis, which shows the energy wasted through inelastic behavior and the damping forces that are balanced when the input energy is absorbed into the structure at times of earthquake. The main objective of this paper is to find out the maximum story drift, maximum story displacements and the cumulative energy dissipation capacity for both the structures.

2 Modelling

The selected plan and models for research are five and ten storey steel structures. They were analyzed and designed by using ETABS software on the basis of Indian Standard codes. All the material, section properties and loads of the selected structures were taken under IS code and are mentioned below. The modelled structures used for this study were taken from the observation of many traditional buildings and constructions in and around India. The layout of the created plan and models was based on the assumptions which are suitable for seismic regions as shown in Figs. 1, 2 and 3.

The grid lines taken for X- and Y-direction are 9 and 6. The grid spacings taken were 8 in X-direction including stair case and 5 in Y-direction as shown in Fig. 1.

2.0.1 X-Direction

- Spacings for A–B and H-I are 4 m and Spacing for B-C was taken as 4.2 m
- Spacing for C-D was taken as 3.5 m and Spacing for D-E was taken as 4.8 m
- Spacing for E–F was 3 m—stair case
- Spacing for F-G was 5 m and Spacing for G-H was 5.5 m

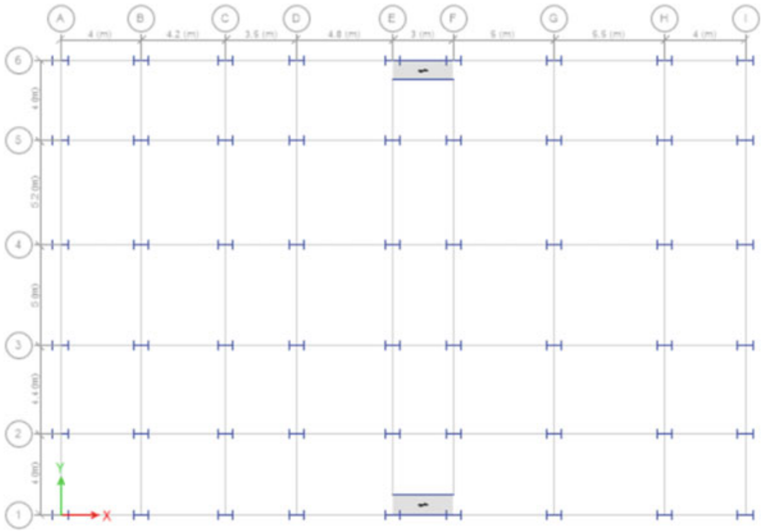
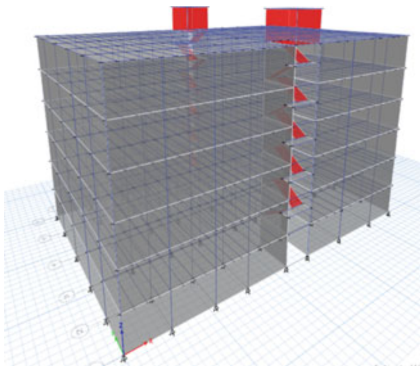


Fig. 1 Plan of steel structures

Fig. 2 3D model of five storey building



All the spacings taken in X-direction were based on codes, while the variations in spacing is due to different trail methods the appropriate values have been chosen.

2.0.2 Y-Direction

- Spacing between 1–2 and 5–6 is 4 m and Spacing for 2–3 is 4.4 m
- Spacing for 3–4 is 5 m and Spacing for 4–5 is 5.2 m

Spacing in Y-direction was taken as shown above, the variation in spacing is due to plan adopted, and due to many trails, these dimensions were chosen. Structural detailing has been considered on the basis of IS code. The storey heights for both five and ten story steel structures were 3 m.

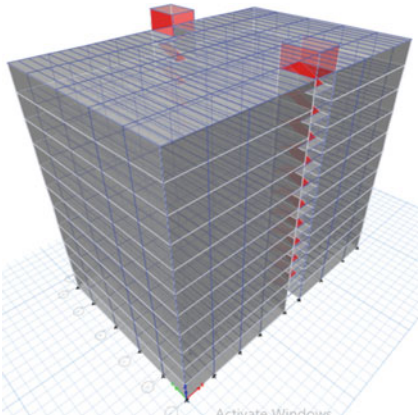


Fig. 3 3D model of ten storey building

2.1 Details of Preliminary Data

- For steel Fe250
- Reinforcement HYSD 415

2.2 Structural Detailing

2.2.1 For G + 5 Storey

- For Beam—ISLB 300
- For column—ISLB 600

All the dimensions were taken according to the Codal provisions [7] and steel book.

2.2.2 For G + 10 Storey

- For Beam—ISLB 350
- For column—ISMB 600

The approximate dimensions are given in the table.

3 Analysis and Design of Steel Models in ETABS

For analyzing the selected steel structures, time history and non-linear dynamic analysis were considered.

3.1 Parameters Considered for Building

For this design,

- Zone selected was II with zone factor 0.1, Type of soil selected was 2
- Reduction factor as 5, Damping as 5% and Importance factor 1 and 1.2.
- Dead load and Live load are given as per IS 875 (Part I) and (Part II) 1987 [8, 9], respectively. Seismic Loading is taken as per IS 1893:2016 [10]
- Earthquake loads (EQ X, EQ–X, EQ Y, EQ-Y) were considered under the basis of Indian Standard codes (IS). Other loads like snow and wind were not considered in the seismic design.

Plastic hinges play an important role in Energy dissipation, they help in finding out whether the structure can withstand or not when effected by heavy lateral forces. In this paper, the structures were analyzed for El Centro time history function as mentioned by Rathod [11]. All the members in the steel structure were passed for all the applied loads, material and section properties given.

3.2 Deformed Shape of Five and Ten Storey Building

The below shown models were deformed models obtained after the load application (Figs. 4 and 5).

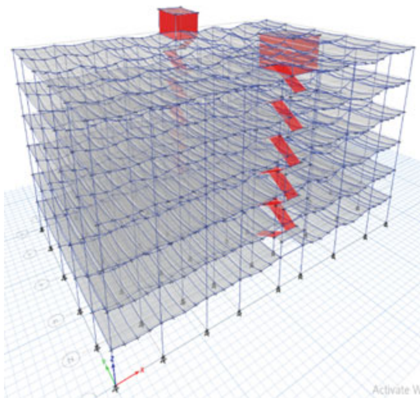


Fig. 4 Deformed G + 5 building

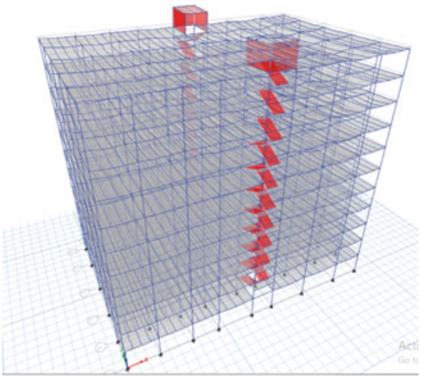


Fig. 5 Deformed G + 10 building

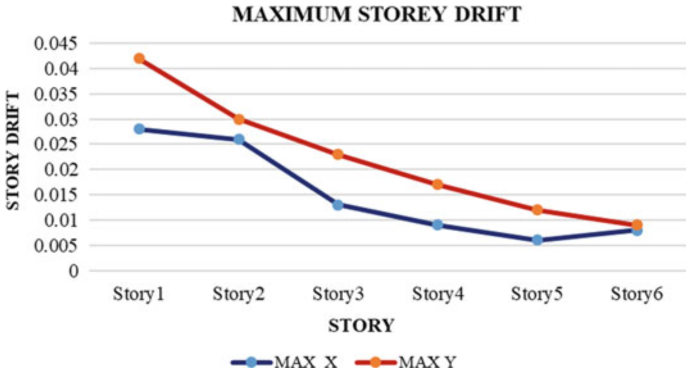


Fig. 6 Storey Drift for five storey building

4 Results and Discussion

4.1 Maximum Storey Drift for Time History in X and Y Directions

4.1.1 For Five Storey Building

Maximum Story drift for time history analysis in X and Y directions were under the limit. According to the IS code limit check is done using the formula (0.004h), "h" is the height of the story.

Fig. 7 Storey Drift for ten storey building

4.1.2 For G + 10 Storey Building

Maximum Storey drift shown in Figs. 6 and 7 for time history analysis in X and Y directions were under the limit by using the formula (0.004 h), "h" is the height of the storey.

4.2 Maximum Displacement for Time History in X and Y Directions (mm)

4.2.1 For G + 5 Building

Displacement obtained were checked by H/500 from codal provision (IS 1893:2016), where H is height of the building. And both the graphs were linearly increasing from the base to the top stories.

4.2.2 For G + 10 Building

Displacement obtained were checked by H/500 from codal provision (IS 1893:2016), where H is height of the building. And both the graphs were linearly increasing from the base to the top stories.

See Figs. 8 and 9.

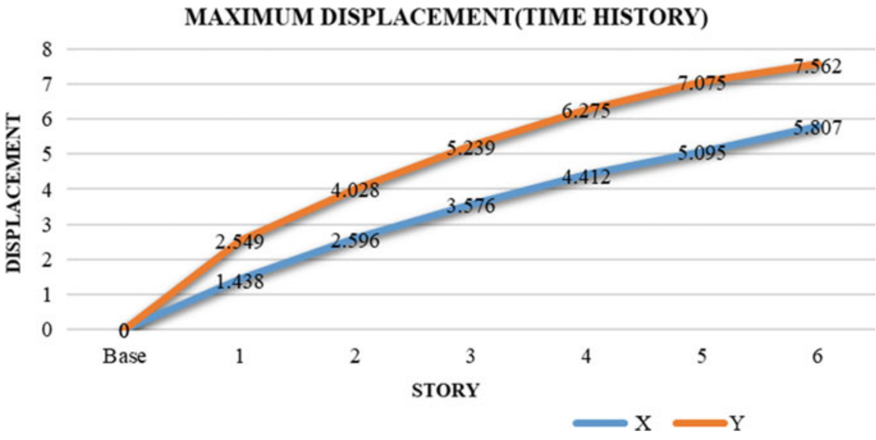


Fig. 8 Displacement (mm) for G + 5 building

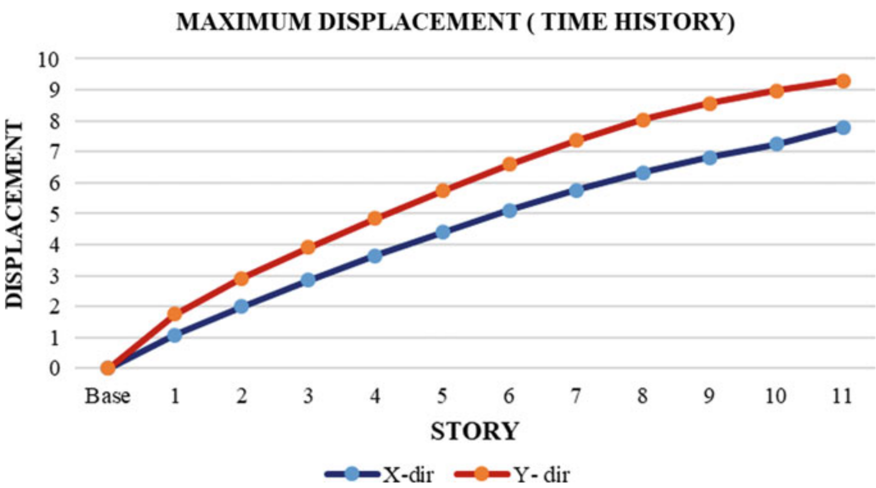


Fig. 9 Displacement (mm) of G + 10 building

4.3 Cumulative Energy Dissipation in X and Y Directions

4.3.1 For G + 5 Building

Cumulative Energy dissipations (KN-m/sec) in X and Y directions are shown in Figs. 10, 11, 12 and 13, where the blue color area is potential energy and the pink color area is global damping of the structure. Whenever the building is effected by earthquake, stresses increase in structure and cause local failures; these stresses can be balanced by maximizing the global damping in order to decrease the potential

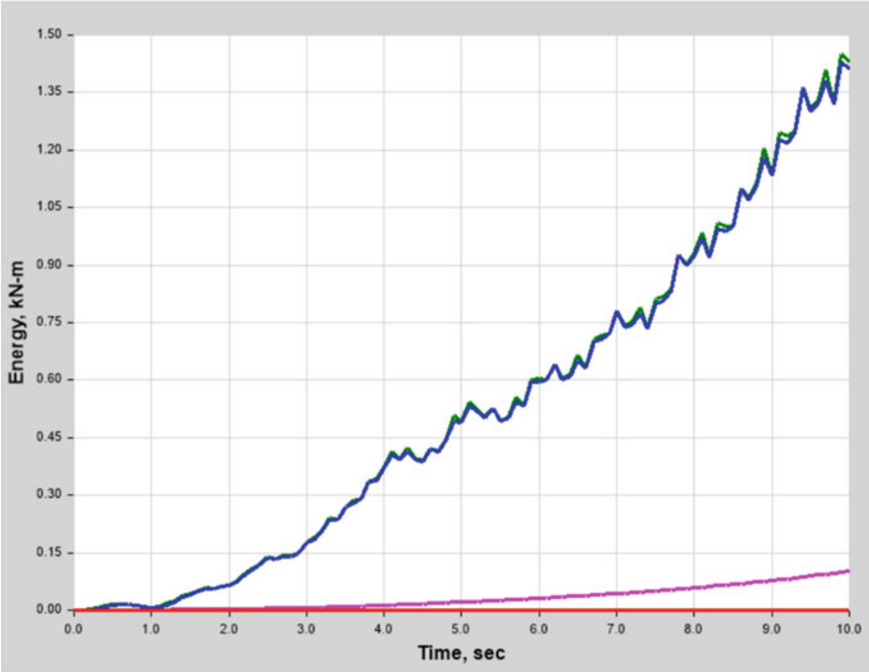


Fig. 10 Energy Dissipation TH-X direction

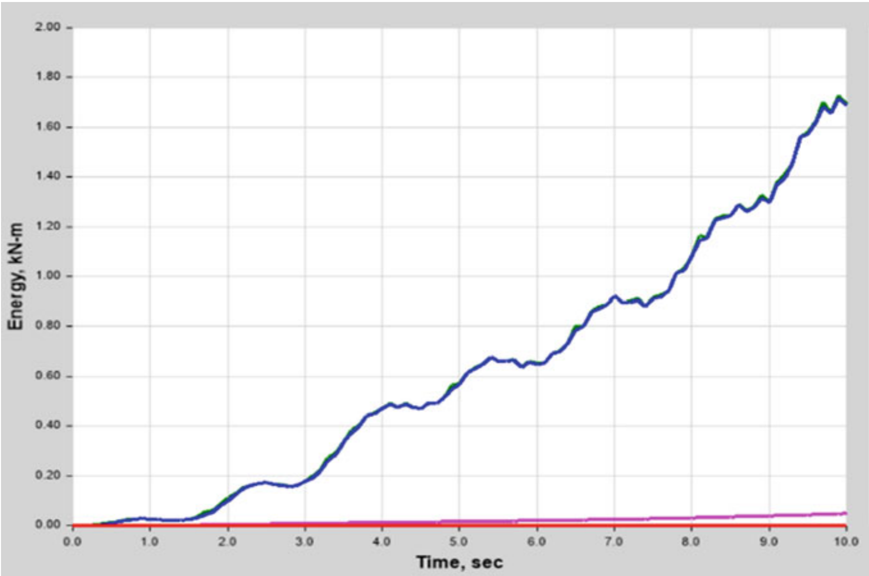


Fig. 11 Energy Dissipation TH-Y direction

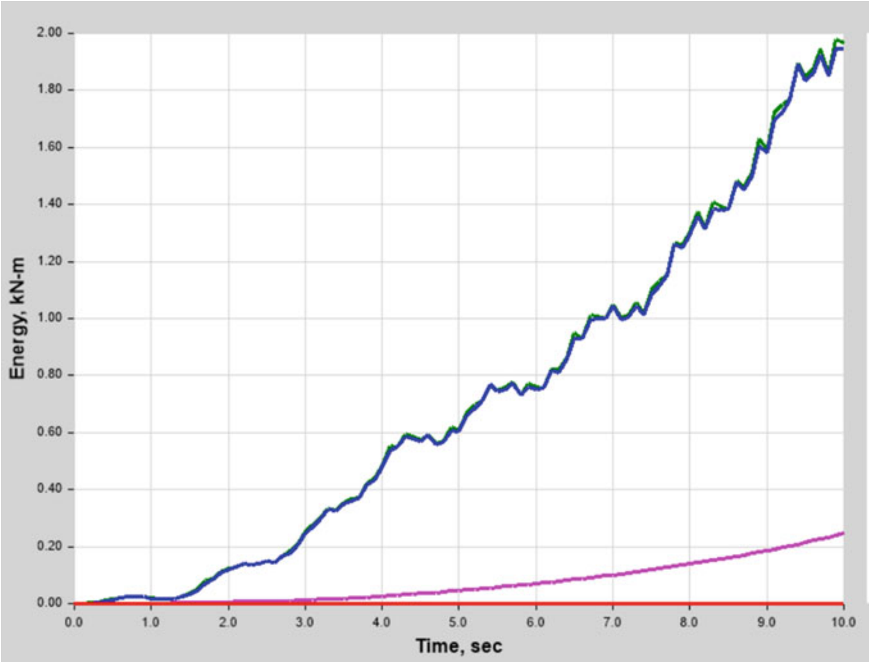


Fig. 12 Energy dissipation TH-X direction

energy or kinetic energy. Then energy dissipation will be maximum and structure will be safe from total collapse. Damping energy helps in balancing the building when the input energy is absorbed from the lateral forces.

4.4 Cumulative Energy Dissipation in X and Y Directions

4.4.1 For G + 10 Building

Cumulative Energy Dissipations in both X & Y directions were quite impressing, they have shown the damping nature of G+10 storey Structure at times of earthquake.

See Figs. 12 and 13.

4.5 Discussion

Storey drift and story displacements were checked using the formulas based on code book. 0.004 h and H/500, where "h" is height of story and "H" is height of building.

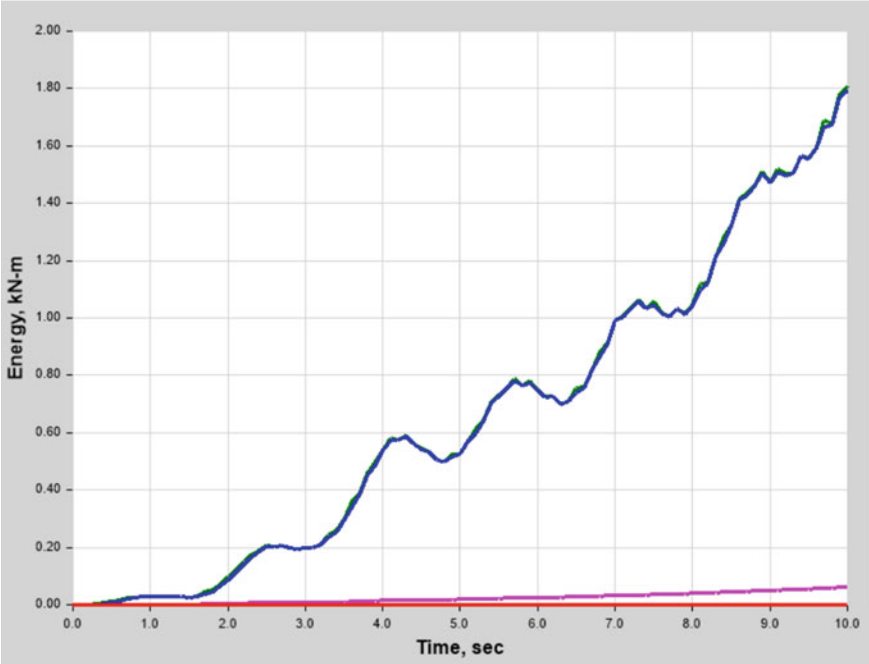


Fig. 13 Energy dissipation TH-Y direction

Storey drift at lower stories (1st stories) was observed as 0.042 and 0.022 where the limit was exceeded, but remaining all the stories were under the limit. This was due to the effect of heavy depth of beams and also due to seismic loads application. Which can be decreased by reducing the depth of beams.

When the structure is subjected to the lateral forces like earthquake, dissipation occurs. The more the structure height increases, the more the dissipation capacity increases. For every structure, kinetic energy, potential energy, damping force and viscous damping is present. Whenever the building is effected by earthquake, stresses increase in structure and cause local failures; these stresses can be balanced by maximizing the global damping in order to decrease the potential energy or kinetic energy. Then energy dissipation will be maximum and structure will be safe from total collapse. Damping energy helps in balancing the building when the input energy is absorbed from the lateral forces. In the above Figs. 5 and 7, the percentage increase was 10%. Here from the observation, maximum the damping area increases, the stresses in the structure decrease, safety of the structure increases and resist toward the external forces.

5 Conclusion

From the time history, non-linear dynamic analysis for the selected steel structures five and ten stories, maximum story drift, maximum story displacement (mm) and cumulative energy dissipation were studied. In this analytical study, the following results were obtained.

- Maximum story drift for five story building was 0.042 and Maximum story drift for ten story building was 0.022, where at lower stories, drift has been exceeded the limit and can be reduced by reducing the depth of beams. Storey drift is unitless as it is relative displacement from one level to the other level.
- Maximum story displacements (mm) obtained were acceptable but also can be reduced by providing shear wall to the buildings.
- Energy dissipations in the buildings are balanced by damping, whereas for five story building it was 8% in X-direction and even less in Y-direction.
- For ten story building, the global damping was 18% in X-direction and even less in Y-direction.
- One thing which was observed was the cumulative energy dissipation capacity was less in five story building when compared to ten stories, it can be increased by reducing the stresses which are in the form of potential energy and kinetic energy.
- Further study can be done by extending the research by providing the bracings and infills in the buildings, which improves the stiffness during seismic excitations.

References

1. Housner, G. (1956). Limit design of structures to resist earthquake. In *First World Conference on Earthquake Engineering*, California
2. Gerami, M. (2014). *Numerical study on energy dissipation of steel moment resisting frames under effect of earthquake vibrations* (p. 13). Hindawi Publishing Corporation.
3. Abdollahzadeh, G. (2016). Comparing hysteretic energy and inter-story drift in steel frames with V-shaped brace under near and far fault earthquakes. *Alexandria Engineering Journal*, 8.
4. Benavent-Climent. (2007). An energy-based damage model for seismic response of steel structures. *Wiley InterScience*, 16.
5. Idels, O. (2020). Performance based formal optimized seismic design of steel moment resisting frames. *Computers and Structures*, 13.
6. Taiyari, F. (2019). Seismic behaviour assessment of steel moment resisting frames under near-field earthquakes. *International Journal of Steel Structures*, 10.
7. IS 800:2007. (2007). *General construction in steel*. New Delhi: Bureau of Indian standards.
8. IS 875:1987 part 1. (1987). *Dead load unit weight of materials*. New Delhi: Bureau of Indian standards.
9. IS 875:1987 part 2. (1987). Design loads (other than earthquake) for buildings and structures, imposed load. New Delhi: Bureau of Indian standards.
10. IS 1893:2016 part 1. (2016). *Criteria for earthquake resistant design*. New Delhi: Bureau of Indian standards.
11. Rathod, K. V. (2020) A nonlinear time history analysis of ten storey RCC building. *International Research Journal of Engineering and Technology*, 8.

Assessment of Ground Water Quality in Industrial Area of Thiruvallur, Tamil Nadu

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Abstract Water is an important resource for the survival of human on the earth. Of all the sources of water available on the earth, groundwater plays a vital role for domestic water supply. Rapid urbanisation and industrialisation are the two important reasons for the diminishing of water quality. The chemicals and heavy metals which are released from the industries leads to severe water pollution. So, the present study focuses on analysing the different physiochemical parameter of groundwater in Thiruvallur. From the study area, ten water samples were collected and analysed for different water quality parameters such as pH, Total Hardness, Calcium, Total alkalinity, Chloride, Magnesium, Total Dissolved solids, Turbidity, Sulphate, Iron and Manganese. The test results are compared with Bureau of Indian Standards (BIS: 10,500:2012). The major pollutants in the groundwater sample are Total hardness, Chlorides and Total dissolved solids and its value is in the range of 1041 mg/l, 1625 mg/l and 3644 mg/l. The results of analysis shows that except sample 4 for all other samples the concentration was within the permissible limit suggested.

Keywords Bureau of Indian Standards · Ground water · Industrialisation · Heavy metals · Water quality

1 Introduction

Groundwater is the natural form of fresh water, but the availability of groundwater on earth is limited which complicates the decision-makers in order to allocate the water among different users of groundwater such as irrigation, drinking and Industries [1, 2]. This limited availability of groundwater also requires sustainable management of groundwater for long-term use [3, 4]. The various influencing factors in the formation of groundwater are type of soil, geological formation, lithology and type of land use available in that area. The purification of the ground water is done by natural filtration

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process through the different soil layers which makes the water free from impurities [5, 6].

Many researchers carried out water quality analysis study in various parts of India. Contamination of groundwater has crossed permissible limits in urban areas and metropolitan zones. The major factors influencing the contamination of groundwater are rapid increase in human populace, industrialisation, utilisation of composts in agribusiness and various man-made activities [7, 8]. The specific issue on account of water quality checking is the intricacy related with examining the enormous number of estimated factors and high inconstancy because of anthropogenic and natural influences [9–11]. The various techniques available to investigate and classify the quality of water are Water Quality Index (WQI), statistical analysis, and spatial analysis in GIS platform [12, 13]. The selection of particular method is based upon data objectives, the sort of tests and the size of the examining study area [14, 15].

2 Materials and Methods

2.1 Study Area

Thiruvallur is a town in Thiruvallur district of Tamil Nadu. The latitude and longitude of the study area are 13.2544° N, 80.0088° E. The city is located near to Chennai city and it is one of the fast developing district in Tamil Nadu. Since, the district is near to Chennai city, the town is having special industrial and commercial importance. The district has 11 industrial estates. The major industries in the study area are steel, fertiliser, motors and chemical industries. Figure 1 shows the study area map and

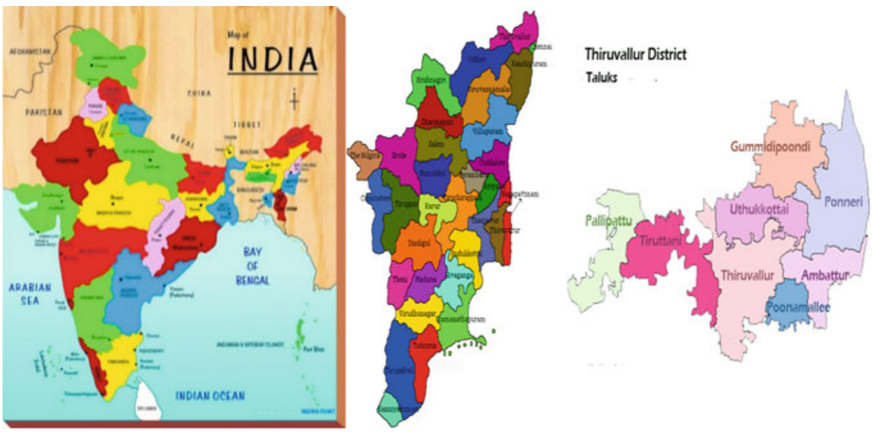


Fig. 1 Study area map

Fig. 2 the map sampling location. The details about sampling locations have been given in Table 1.

Fig. 2 Sampling locations

Table 1 Details of sampling locations

S. No	Locations	Sample no	Latitude	Longitude	Source	Month and year
1	Kakulur Avadi bypass	Sample 1	13.1370	79.9198	Borewell	Feb 2021
2	Chinna Kaadu	Sample 2	13.1441	79.9187	Borewell	Feb 2021
3	Mahalakshmi Nagar	Sample 3	13.1441	79.9180	Borewell	Feb 2021
4	Kakulur sipcot	Sample 4	13.1310	79.9312	Borewell	Feb 2021
5	Ramapuram main road	Sample 5	13.7582	79.5641	Borewell	Feb 2021
6	Ikadu kakulur	Sample 6	13.1384	79.9291	Borewell	Feb 2021
7	Ikadu kakulur	Sample 7	13.1383	79.9287	Borewell	Feb 2021
8	Poonga Nagar	Sample 8	13.1201	79.9227	Borewell	Feb 2021
9	Nggo colony	Sample 9	13.1202	79.9230	Borewell	Feb 2021
10	Maruthi new town	Sample 10	13.1251	79.9259	Borewell	Feb 2021

2.2 Water Sample Collection and Testing

The water samples were collected using cleaned polyethylene bottle from the study area. The collected samples were tested for different physiochemical parameters immediately after the sampling as per APHA [16]. The parameters are pH, Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{2-}, Cl^{-}, TDS, Total Hardness (TA), Turbidity, Total Alkalinity (TA), Manganese (Mn) and Iron (Fe). Table 2 shows physiochemical parameter of collected water samples, Table 3 shows drinking water standards given by BIS and Table 4 gives methods used to test various water quality parameters.

3 Results and Discussion

pH

The pH value represents the concentration of hydrogen ion in water. The required amount of pH in drinking water controls the metabolic process in human body. The Bureau of Indian standards describe the range of pH value should lie between 6.5 and 8.5 for drinking water. The test results show the pH values to be within the permissible limit for all the ten samples. Figure 3 shows the comparison of pH values for all the ten samples. Sample 10 shows the highest pH concentration among all the collected samples.

Total hardness

From Fig. 4, the total hardness value of sample 4 is 1041 mg/l which is beyond the maximum limit; for all other samples, the hardness value is less than the permissible limit. The important health effect of excess amount of hardness in water is skin irritation and food becomes poor in quality.

Calcium

From Fig. 5, the concentration of Calcium in the collected water sample was in the range of 36 to 165 mg/l. The lowest concentration was observed in sample 1 and highest concentration was in sample 4. From the water quality analysis, it is evident that except sample 1, for all other sample the concentration was within the limit, and for sample 1, the concentration of calcium was well below the desirable limit.

Total Alkalinity

From Fig. 6, the concentration of Alkalinity for the collected water samples varies between 130 and 462 mg/l, and the highest concentration of total Alkalinity was present in sample 3 and lowest concentration was in sample 1. The acceptable limit of alkalinity is 200 mg/l and permissible limit is 600 mg/l. The test result shows that for all the collected samples, the total Alkalinity value was within the permissible limit.

Table 2 Physiochemical parameter

S. No.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
pH	7.4	7	7.2	7.2	7.3	6.9	6.7	7.2	7.5	7.6
Total hardness (CaCO3) mg/l	131	363	420	1041	449	350	300	501	440	539
Calcium (Ca) mg/l	36	106	145	165	137	106	117	82	125	137
Total alkalinity mg/l	130	273	462	315	357	189	180	410	330	284
Chloried (Cl-) mg/l	81	314	223	1625	333	228	218	1012	320	318
Magnsium (Mg)-mg/l	10	24	14	153	26	21	20	72	22	48
Total Dissolved Solids-mg/l	348	1116	1148	3644	1358	952	980	2518	1400	998
Turbidity (NTU)	2	8	<1	<1	1	<1	1	1	1	<1
Sulphate (SO_4)-mg/l	39.6	168	98.6	262	203	209	207	216	200	52.1
Iron (Fe) -mg/l	0.24	0.53	0.06	0.10	0.12	0.06	0.09	0.13	0.1	0.05
Manganese (Mn)- mg/l	0.02	0.11	BDL	0.05	BDL	BDL	0.06	0.14	0.12	0.05

BDL—Below Detection Level

Table 3 Bureau of Indian Standards

S. No.	Parameter	Permissible limit (mg/l)	Acceptable limit (mg/l)
1.	pH (no units)	6.5-8.5(no unit)	No relaxation
2.	Total hardness ($CaCO_3$)	200	600
3.	Calcium (Ca)	75	200
4.	Total alkalinity	200	600
5.	Chloried (Cl-)	250	1000
6.	Magnesium (Mg)	30	100
7.	Total Dissolved solids	500	2000
8.	Turbidity	1	5
9.	Sulphate (SO_4)	200	400
10.	Iron (Fe)	0.3	No relaxation
11.	Manganese (Mn)	0.1	0.3
	Turbidity unit-NTU-	Nephelometric turbidity unit	

Source Bureau of Indian Standards [5]

Table 4 Methods used for analysis of quality parameters for the water samples

S. No	Parameter	Methods used
1.	pH	pH meter
2.	Total hardness	Atomic absorption spectrometry
3.	Calcium	Atomic absorption spectrometry
4.	Total alkalinity	Neutralising with standard HCl
5.	Chloride	Mohr's method
6.	Magnesium	Atomic absorption spectrometry
7.	Total dissolved solids	Evaporation method
8.	Turbidity	Turbidity meter
9.	Sulphate	Spectrophotometry
10.	Iron	Atomic absorption spectrometry
11.	Manganese	Atomic absorption spectrometry

Fig. 3 Concentration of pH

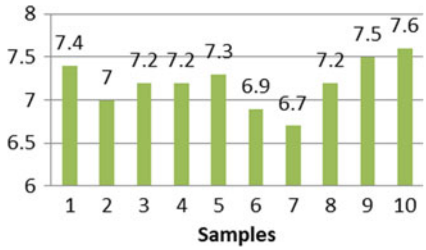


Fig. 4 Concentration of total hardness

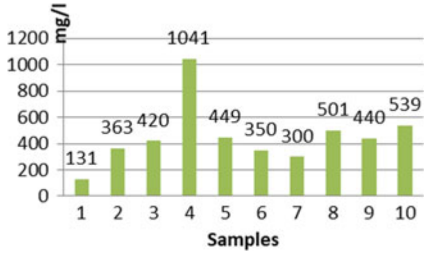


Fig. 5 Concentration of calcium

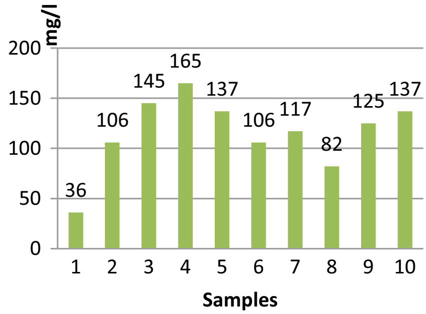
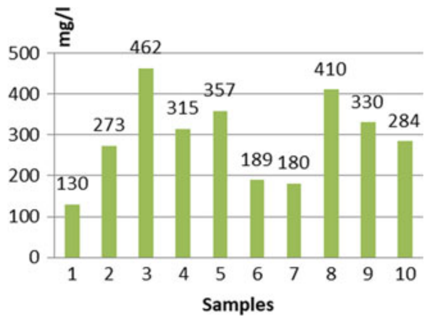


Fig. 6 Concentration of total alkalinity



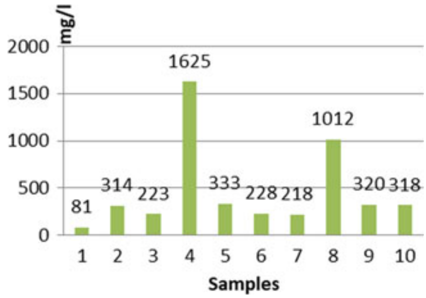


Fig. 7 Concentration of chloride

Chloride

The acceptable and permissible range of chloride was in the range of 250–1000 mg/l. Figure 7 shows that for sample 2, sample 4, sample 5, sample 8, sample 9 and sample 10, the chloride concentration was more than the permissible limit, and sample 1, sample 2, sample 6 and sample 7 show lowest chloride content. The increase in chloride content of water will affect the taste of drinking water.

Magnesium

From Fig. 8, the highest Magnesium concentration was observed in sample 4 and the least concentration was observed in sample 1. The permissible limit of Magnesium is 100 mg/l and from the test result, the concentration of Magnesium in sample 4 is 153 mg/l.

Total Dissolved Solids (TDS)

Total dissolved solids includes salts such as carbonates, bicarbonates, nitrates of calcium, Magnesium and small amount of inorganic matter and dissolved gases. From Fig. 9, except for sample 1, in all other samples the concentration is not within the desirable limit. The maximum concentration of TDS in the collected water sample is 3644 mg/l present in sample 4.

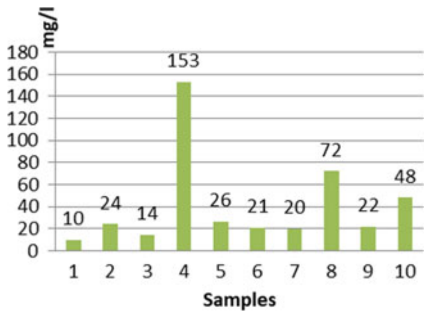


Fig. 8 Concentration of magnesium

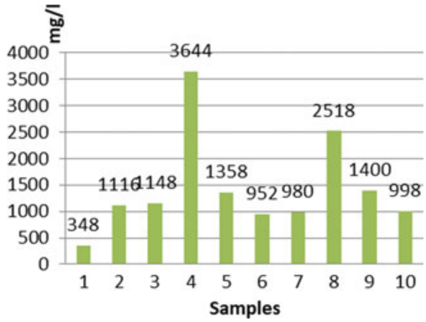


Fig. 9 Concentration of TDS

Turbidity

Turbidity is the presence of suspended and dissolved particles in the water. The turbidity value above the desirable limit makes the drinking water unsuitable for drinking. The desirable limit of Turbidity in drinking water is 1 NTU. Figure 10 shows the variation of turbidity in all the collected samples. From Fig. 6, it is sample 1 and sample 2 that have more turbidity value which needs more water treatment before drinking. The high concentration of Turbidity was due to the presence of steel industry near to sample 2.

Sulphate

The variation of Sulphate concentration for the ten samples is shown in Fig. 11. The maximum value of Sulphate in sample 4 is 262 mg/l and lowest value 39.6 mg/l was present in sample 1. The permissible limit of Sulphate in drinking water is 400 mg/l. The comparison of water sample with BIS standard shows the Sulphate concentration was within the range for all the collected samples.

Heavy Metals

The presence of heavy metal in drinking water beyond the desirable limit is toxic. The essential heavy metals which are required for human body are cobalt, copper, Zinc and Manganese. The heavy metals are also called as trace elements. The analysis

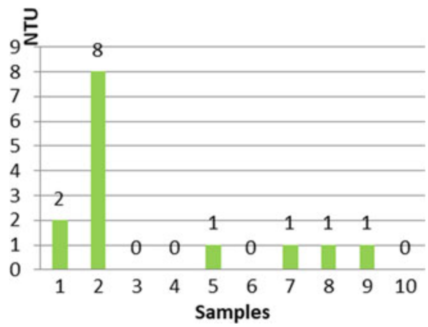


Fig. 10 Concentration of turbidity

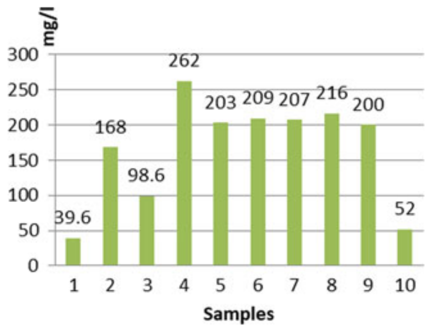


Fig. 11 Concentration of sulphate

of water sample shows the presence of only two heavy metals, namely, Iron and Manganese, and concentrations of all other elements are Below Detection Level. The permissible limit of iron and Manganese is 0.3 mg/l. From Figs. 12 and 13, except for sample 2, in all other samples the Iron concentration is less than the permissible limit, and the concentration of manganese was within the permissible limit for all the collected water samples.

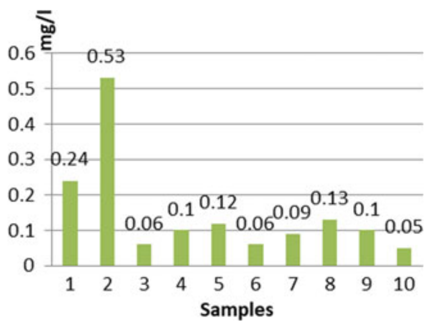


Fig. 12 Concentration of iron

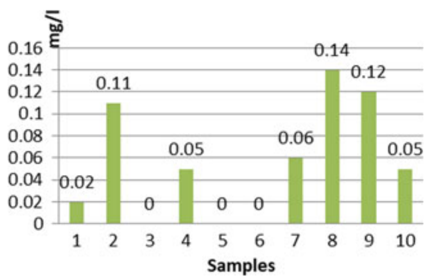


Fig. 13 Concentration of manganese

4 Conclusion

The analysis of the result shows that the concentration of Calcium, Chloride, Manganese, Total dissolved solids, Total hardness and Sulphate in sample 4 was above the permissible limit by Bureau of Indian Standards. Sample 4 located very near to the steel industry was the main reason for high concentration of various parameters. The concentration level can be reduced in the study area by adopting secondary treatment of water in the industry before discharging it. The significant pollutants in the groundwater sample in the study area are Total hardness, Chlorides and Total dissolved solids. The concentrations of these parameters are 1041 mg/l, 1625 mg/l and 3644 mg/l. The pH range was within the standard limit, and in most of the samples, the chloride concentration was more than the permissible limit. The test on heavy metal concentration in the collected sample shows the presence of small quantity of manganese and Iron in water; all other heavy metal concentration was below detection level. Even though the concentration was within the permissible limit, the concentration was more than acceptable levels given by Bureau of Indian Standards. So, necessary steps have to be taken to protect further contamination of ground water and maintain the concentration of different parameters within the permissible limit.

References

1. Jafar, A. A., & Loganathan, K. (2012). Assessment and correlation analysis of surface and ground water of Amaravathi river basin-Karur, Tamilnadu India. *Journal of Chemical and Pharmaceutical Research, 4*(8),3972–3983.
2. Asadi, S.S., Vuppala, P., & Reddy, M. A. (2007). Remote sensing and GIS techniques for evaluation of groundwater quality in Municipal Corporation of Hyderabad (Zone-V), India. *International Journal of Environmental Research Public Health, 4*(1), 45–52.
3. Balakrishnan, P., Saleem, A., & Mallikarjun, N. D. (2011). Groundwater quality mapping using geographic information system (GIS): A case study of Gulbarga City, Karnataka, India. *African Journal of Environmental Science and Technology, 5*(12), 1069–1084.
4. Balathandayutham, K., Mayilswami, C., & Tamilmani, D. (2015). Assessment of groundwater quality using gis: a case study of walayar watershed, parambikulam-aliyar-palar basin, Tamilnadu, India. *Current World Environment, 10*(2), 602–609.
5. BIS. (2012). Indian Standard Drinking Water Specifications IS: 10500, Bureau of Indian Standards, New Delhi.
6. Boyacioglu. (2007). Surface water quality assessment by environmental methods. *Environmental Monitoring and Assessment, 131*(1–3), 371–376.
7. Engel, B. A., & Navulur, K. C. S. (1999). The role of geographical information systems in groundwater engineering. In: Delleur, J. W. (Ed.), *The handbook of groundwater engineering* (Vol. 13, No. 2, pp. 703–718). CRC, Boca Raton.
8. Sekar, M., Praveenkumar, T. R., & Eshanthini, P. (2021). Combined analysis of heavy crude oil viscosity and stress acting on the buried oil pipelines. *Journal of Pipeline Systems Engineering and Practice, 12*(1), 04020059.
9. Krishnaraj, S., Kumar, S., Elango, K. P. (2015). Spatial analysis of groundwater quality using geographicinformation system—A case study. *Journal of Environmental Science, Toxicology and Food Technology*, 01–06

10. Ketata-Rokbani, M., Gueddari, M., & Bouhlila, R. (2011). Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer (Enfidha, Tunisian Sahel). *Iranica Journal of Energy & Environment, 2*(2), 133–144.
11. Priyadharshini, B., Abraham, M., & Parvathy (2020). Treatment of contaminated water using eco friendly material. In *IOP Conference Series: Materials Science and Engineering*, Vol. 993, No. 1, 012168.
12. Parameswari, K., & Karunakaran, K. (2010). ground water issues and community awareness in perungudi dumpsite, chennai, India. *Journal of environmental research and development, 5*(2), 404–412.
13. Priyadharshini,B., Abraham, M., VarshaLakshmi & Kavisri, M. (2020). Experimental investigation on removal of chromium metal using coconut shell. *International Journal of advanced science and technology, 29*(6),103–109.
14. Suramani, T., Krishnan, S., & Kumaresan, P. K. (2012). Study of ground water quality with GIS application for Coonoor Taluk in Nilgiri District. *International Journal of Modern Engineering Research, 2,* 586–592.
15. WHO. (1997). Guideline for Drinking Water Quality Vol.2 Health criteria and other supporting Inforamtion,2nd edition. Geneva: World Health Organizaton, 940–949
16. APHA Standard methods for examination of water and wastewater, 20th edition. (1999).

Ground Water Modelling of Poondi Micro-Watershed, Thiruvallur, Tamil Nadu

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Abstract Ground water is one of the major source of water for drinking and agriculture in rural areas. Due to rapid increase in population, urbanization and industrialization, the consumption of ground water has been increased which leads to the over exploitation of available groundwater sources. The present study focuses on simulating the discharge groundwater pattern for Poondi micro-watershed, Tamil Nadu, India using Visual MODFLOW. United States Geological survey developed a finite difference discharge model named Visual MODFLOW. The ground water flow equations are represented in terms of computer codes. The steady and transit state conditions were calibrated using the Visual Modular Three-Dimensional Finite-Difference Groundwater Flow Model (Visual MODFLOW). The calibration and validation was done for the period 2012–2018. The optimization of the model for spatial distribution of hydraulic conductivity and storage properties was done using trial and error technique. The model output show that ground water level mainly depends on precipitation and recharge rate. Due to the presence of river and the water level contours, prediction using the model showed high ground water level in Poondi.

Keywords Visual MODFLOW · Ground water level · Calibration · Prediction

1 Introduction

Water is an important source in the development of any activity in the world. The water is used in developing domestic water supply for communities, for irrigation and agriculture, for industrial and many other activities. The sustainable use of groundwater resource is possible only after the complete analysis of quantity and quality of ground water. The postulated equation was used for unconfined flow to a well [1].

Visual MODFLOW software in groundwater modelling has been universally accepted and well documented in research journals [2, 3]. The hydrological and geological parameters which are involved in the groundwater flow can be calculated

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approximately with the help of ground water models. The ground water models are considered as the important asset for policy makers for allocation of water among different users as well as sustainable utilization of this valuable resource [4]. There are many numerical models available in ground water research totally based on extraordinary strategies [5, 6]. Incorporation of Soil Water Assessment Tool SWAT and MODFLOW, Conceptualization, characterization and numerical modelling have been done using ARC/INFO, MODFLOW and MODPATH for hydrodynamic simulation Processing [7, 8]. MODFLOW is one of the most extensively used software in the field of ground water engineering studied due to its easy strategies and giving solutions for special hydro-geologic problems using its modular programme structure [9]. GMS, Visual MODFLOW and PMWIN are some of the ground water modelling software that evolved from MODFLOW. The integration of MODFLOW with GIS provided an efficient tool for visualizing the ground water flow [10]. Nowadays, the quantity and quality analysis of ground water was carried out by 2-D and 3-D groundwater modelling packages which will give a solution for groundwater flow problems [11, 12].

The area selected for the study is Poondi Micro watershed in Tiruvallur district and the watershed number is 4C2C4b1. The study area lies between longitude 79°42' and 79°54′36″ and latitude 13°1′40.8″ and 13°12′50.4″. Poondi is the major source of drinking water supply to the Chennai city and covers an area of 528.93 Sq.km. Average rainfall in the study area is 604 mm. The depth of rock strata is 45 m below ground level. The water level in the study area ranges from 7 to 11 m. The study area is composed of sedimentary rock. The major lithology in the study area is sand, silt, silty sand, sandstone, laterite and conglomerates. The depth of rock is 11 to 45 m below ground level. In sedimentary formation, the occurrence and movement of ground water is based on coarse gravelly sand and connected media. Alternate layers of clay and silty sand occurred in the study area.

Groundwater flow is a complex, three-dimensional heterogeneous unit. The description of such a complex system can be done only through hydrological practice on various factors influencing ground water flow. Principle of conservation of mass of fluid will be the governing equation of mathematical model. A universal equation for conservation of mass of volume can be expressed as.

Rate of inflow –Rate of Outflow = change in storage.

Ground water flow equation in Cartesian form is as follows:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) \pm Q = C \frac{\partial h}{\partial t} \tag{1}$$

where,

h = piezometric head, m(L).

K_x, K_y, K_z = x, y and z axis hydraulic conductivity.

C = storage constant.

Q = Uniform discharge representing source of flow.

t = Duration in secs.

2 Materials and Methods

Ground water models describe complex ground water flow in simple mathematical equations. In this study, the groundwater flow has been done for Poondi micro-watershed using visual Modflow. In this boundary map, slope, rainfall, recharge, hydraulic properties like specific storage, specific yield and effective porosity were used to construct the model. The major aquifer characteristics like soil type, bore-hole details of wells, Hydraulic conductivity and porosity are collected from central ground water board (CGWB). Lithology of bore wells and water level data of well for different years are collected from Institute of water studies (IWS), Taramani, Chennai, and PWD, Thiruvallur. Table 1 shows the aquifer properties of the study area. In this study, seven wells are considered for finding out flow direction. The base map of the study area was prepared using ArcGIS 10.3. The shape file from the ArcGIS environment is directly imported into MODFLOW. Based on the geology and lithology of the study area, the model was conceptualized as single layer and the elevation is imported through grid menu in the model screen.

The total study area was split up into 40 columns and 40 rows. Figure 1 shows gridded base map of study area. Based on water level data collected from district profile report of groundwater division, PWD, the well locations and water level of observation wells are imported into the model. The water level in the seven observation wells are used to find the hydraulic head.

General head, recharge, constant head, river and no flux were considered to be visual MODFLOW boundary conditions. The boundary of the Poondi micro-watershed is no flow boundary was selected for north because of less impact of water table.

Table 1 Aquifer properties

Model properties	Hydraulic conductivity (Kx in m/day)	Model properties	Hydraulic conductivity (Kx in m/day)
Longitudinal direction Hydraulic conductivity (Kx m/s)	0.00015	Specific yield (Sy)(l/S)	0.20
Lateral direction Hydraulic conductivity (Ky m/s)	0.00014	Effective porosity	0.15
Vertical direction Hydraulic conductivity (Kz m/s)	0.00012	Total porosity	0.30
		Specific storage (l/S)	1e-4

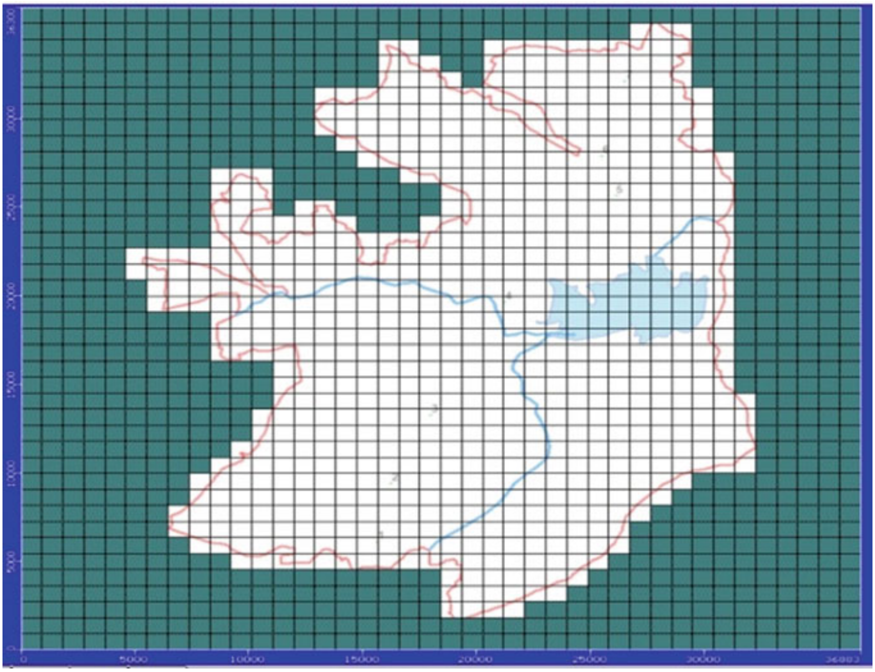

Fig. 1 Grid map of study area

3 Results and Discussion

After ensuring the incorporation input datum, the model was run through by selecting run in the main menu in the dialogue box. During the period between 2012 and 2018, the current visual flow model was validated and calibrated. The model was calibrated by changing the model input parameters like hydraulic conductivity and recharge values using trial and error method. The model was validated with observed and estimated water level in all seven inspection wells. The following Fig. 2 shows observed and predicted water head in the well from the year 2012 to 2018 (2544 days).

4 Model Prediction

The model prediction was done for the year 2025. Figure 3 shows the contour of head difference, Velocity of flow and drawdown. The velocity of flow is higher towards river flow direction.

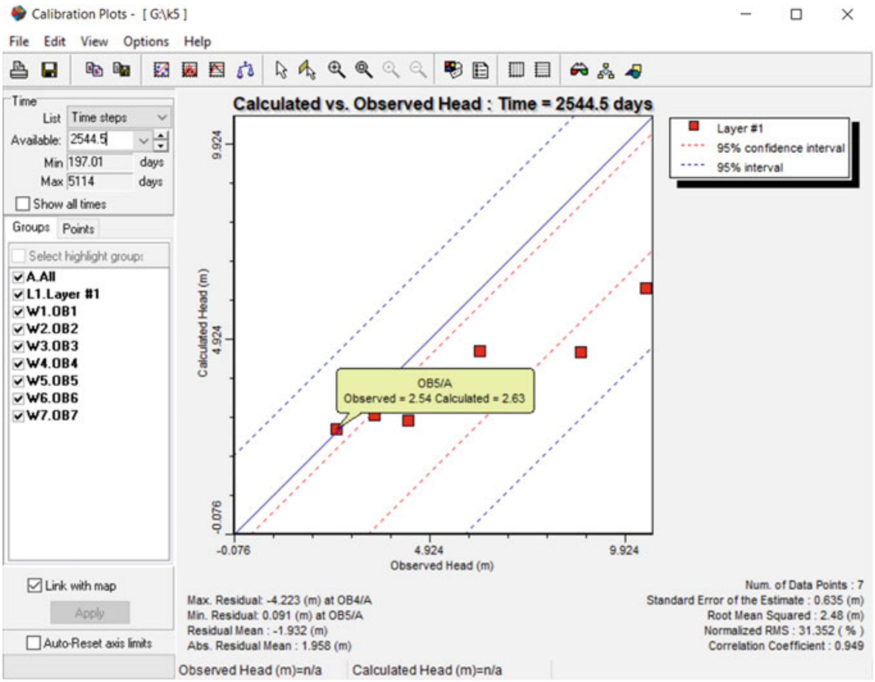

Fig. 2 Observed head values and calculated model values for 2544 Days

5 Conclusion

Visual MODFLOW is the important ground water modelling software used in various works like modelling ground water flow, velocity of flow and solute transport. The input datum for the model used in the current study was water level data and the aquifer characteristics. The version used in the study was visual MODFLOW version 2.8 to analyse the directions of ground water flow. Calibrated model was validated and values were observed from the period between 2012 and 2018. The future ground water level contour in the year 2025 was predicted using the validated model. Since the predicted water measurement correlates with the water level change in the field, the recharge in the Poondi micro-watershed is found to be sufficient.

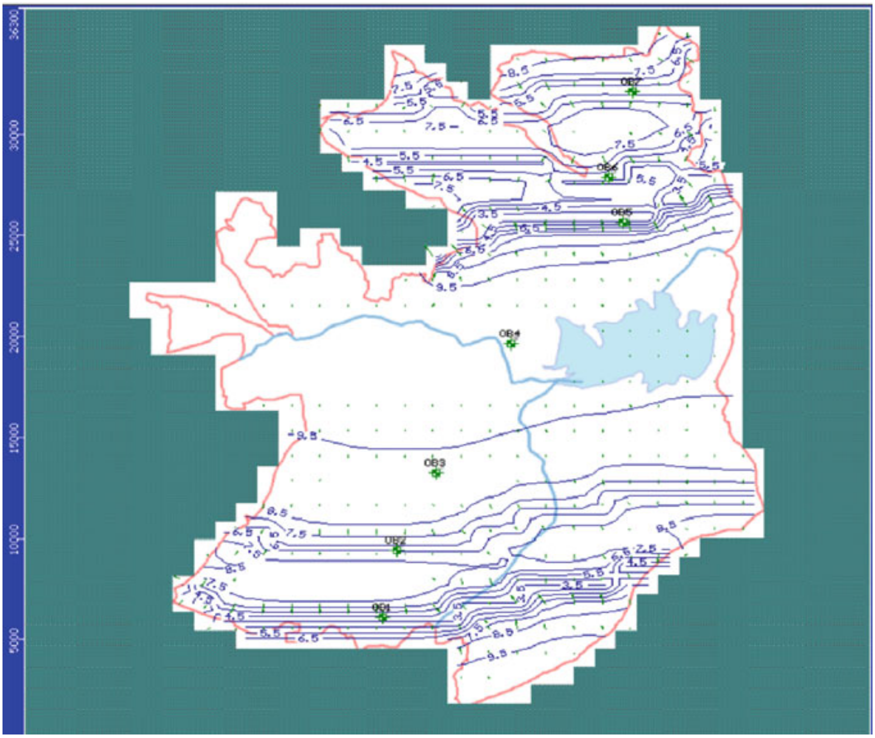

Fig.3 Predicted water level contour (2025)

References

1. Boulton, N. S. (1954). Unsteady radial flow to a pumped well allowing for delayed yield from storage. International association of science Hydrology publication.
2. Juan, C. S., & Kolm, K. E. (1996). Conceptualization, characterization and numerical modeling of the Jackson Hole alluvial aquifer using ARC/INFO and MODFLOW. *Engineering Geology, 42,* 119–137.
3. Aliyari, F., Bailey, R. T., Tasdighi, A., Dozier, A., Arabi, M., & Zeiler, K. (2019). Coupled SWAT-MODFLOW model for large-scale mixed agro-urban river basins Fatemeh. *Environmental Modelling & Software, 115,* 200–210.
4. HosseinDehghanipour, A., Zahabiyoun, B., Schoups, G., & Babazade, H. (2019). AWEAP-MODFLOW surface water-ground water model for the irrigated Miyandoab plain, Urmia lake basin, Iran: Multi-objective calibration and quantification of historical drought impacts. *Agricultural water management, 223,* 105704.
5. Mosasea, E., Ahiablameb, L., Parkc, S., & Baileyc, R. (2019). Modelling potential groundwater recharge in the Limpopo River Basin with SWAT-MODFLOW. *Groundwater for Sustainable Development, 9,* 100260.
6. Guzman, D. N., Moriasi, P. H., Gowda, J. L., Steiner, P. J., Starks, J. G., & Arnold, R. (2015). Srinivasan, A model integration framework for linking SWAT and MODFLOW. *Environmental modelling and software, 73*, 103–116.
7. Lia, F., Liua, Y., Zhaob, Y., Dengc, X., & Jiangd, R. (2019). Regulation of shallow groundwater based on MODFLOW. *Appliedgeography, 110,* 102049.

8. Rossettoa, R., De Filippis, G., Trianaa, F., Ghetta, M., Borsi, I., & Schmid, W. (2019). Software tools for management of conjunctive use of surface- and ground-water in the rural environment: Integration of the farm process and the crop growth module in the FREEWAT platform. *Agricultural Water Management, 223,* 105717.
9. Jaxa-Rozen, M., Kwakkel, J. H., & Bloemendal, M. (2019). A coupled simulation architecture for agent-based/geohydrological modelling with Net Logo and MODFLOW. *Environmental Modelling & Software, 115,* 19–37.
10. Sith, R., Watanabe, A., Nakamur, T., Yamamotoa, T., & Kazuonadaoka (2019). Assessment of water quality and evaluation of best management practices in a small agricultural water shed adjacent to coral reef area in Japan. *Agricultural Water Management, 213,* 659–673.
11. Chen, M., Izady, A., Abdalla, O. A., & Amerjeed, M. (2018). A surrogate-based sensitivity quantification and Bayesian inversion of a regional groundwater flow model. *Journal of Hydrology , 557,*826–837.
12. Batu, V. (2015). A generalized analytical solution for an inclined well in a vertically and horizontally anisotropic confined aquifer and comparisons with MODFLOW. *Journal of Hydrology* (520), 168–179.

Analysing the Effect of Enzyme-Induced Stabilization (EIS) in Improving the Strength Characteristics of Weak Soils

Nehaun, K. Prasanna, Nihit Omprakash Prajapathi, Maaz Rafi Ashraf, and V. M. V. Sai Krishna

Abstract In later days, Civil Engineers frequently confront issues for developing structures on or with soils, which own inadequate strength to sustain the loads thrusted on them amid development or the benefit life of the structure. Soil engineers have been forced to develop cost-effective and environmentally sustainable methods for soil stabilization due to the poor engineering performance of the soil. Bio-enzyme is a, non harmful, non combustible, non-corrosive liquid enzyme composition fermented from vegetable extracts that enhances soil qualities, is eco friendly, and is cost effective. It decreases water assimilation inside the soil and lowers gaps between the soil particles, allowing for the most extreme compaction possible. Protein is a natural biodegradable fluid, which does not have any harmful impact on environment. The bio protein which we utilized is known as TerraZyme. The Gurti soil sample from Southern Srinagar was treated with TerraZyme, and the treated soil was cured for 7 days. The effects of different protein blends (0.05 ml/kg, 0.1 ml/kg, and 0.15 ml/kg) used for soil stabilization on the geotechnical qualities of soils are investigated. Geotechnical features such as the California bearing proportion (CBR) and unconfined compression quality (UCS) are taken into account and discussed. These studies were carried out to determine the appropriate TerraZyme extent at various curing times.

Keywords TerraZyme · Stabilization · CBR · Unconfined compression

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1 Introduction

Ground stabilization is a process of increasing soil strength and endurance. The main goal of stabilization is to reduce the cost and make better use of locally available materials. Soil stabilization is mostly used in the construction of roads and airport runways.

There are numerous methods for soil stabilization, such as soil grouting (more suitable for increasing foundation-bearing capacity), using cement, fly ash and lime; electrical stabilization; and chemical soil stabilization. It should be replaced with high-quality soil etc. The selection of a specific technique is primarily determined by the type of soil to be progressed and its characteristics. It moreover depends on the sort and degree of enhancement craved in a specific application. Lime is also used to stabilize the soil. An ideal soil stabilizer should be easily available. It should also be economical and eco-friendly.

TerraZyme is a good alternative to all the traditional soil stabilizers like lime, fly ash, cement etc. TerraZyme is a bio-catalyst used as a soil stabilizer. It improves the soil properties. It is non-toxic and natural substance. It is prepared from plants, veggies and fruit extract. Therefore, it is also eco-friendly. TerraZyme advances the engineering features of soil and strength of soil. CBR value and UCS are increased. TerraZyme strengthens the chemical bonds between soil particles, resulting in a long-lasting structure that is resistant to damage, weathering, and infiltration. It also eliminates the need for granular and sub-base.

2 Summary of Literature Review

Soil stabilization is an advanced technique, which has showed excellent performance for the construction of roadways and geotechnical applications. The enzyme (TerraZyme) being a non-poisonous, non-corrosive, and non-inflammable natural material alters the characteristics of the virgin soil which enhances the strength and durability of the soil sample. Various tests like CBR, UCS, and Compaction were performed for different dosages given for the period of 0, 7, 14, 28 days and the values are noted. Soil stabilization is an eco-friendly, cost-effective, easy handling, and low maintenance cost technique.

The study aims to find out the outcome of varying doses of TerraZyme on strength and other features of known soil. In addition to that, to identify the optimum TerraZyme required for selected soils for comparison of the results obtained from soil before and after adding TerraZyme.

Rintu Renjith et al. (2017) surveyed the problems in Australia's road network and concluded that chemical stabilization is an effective solution to these problems. CBR tests were performed on samples from the road before and after stabilization, which revealed an increase in the strength of the road from before to after stabilization, and inspection on the model revealed that the stabilized road exceeded the minimum description required. Their work will help the industry of construction to execute the road infrastructure with a less and effective budget [1].

Ali Akbar Firoozi et al. (2017) studied that in order to increase soil strength, durability stiffness, and reduction in soil plasticity, soil stabilization is very beneficial. The strengthened soil can be used for road surface and geotechnical uses. We can strengthen the native soils by stabilizing it with cement which will lessen the volume changes in the native soil, by stabilizing it with lime which will increase the volume of soil, by stabilizing it with fly ash which will increase the content of the native soil and is considered to be the best method because strength of the soil is also increased, and by stabilizing it with fibres. TerraZyme stabilization not only increases the strength of the soil but also improves the quality of the native soil which is very beneficial in the future [2].

Athira et al. (2017) analysed the requirement of new eco friendly methods which will help the development of roads, geotechnical applications and for the construction projects from the old conventional methods. Soil stabilization is one such method for the future use. On the native sample, initial tests were conducted to determine dry density, particle size, liquid limit. Unconfined test was initiated for different dosages for the duration of 0, 7, 14, 28 days. A standard proctor test for light compaction was performed with a 2.6 kg rammer and a 310 mm free fall over a period of 0, 7, 14, and 28 days. The mechanical strength of the base course and sub grade was determined using the California bearing ratio for curing times of 0, 7, 14, and 28 days. The value in the UCC was increased to 281.5% in 28 days, according to the data. CBR value increased by approximately 139.32%. Soil stabilization will stabilize the native soil at a low cost [3].

Anjali Gupta et al. (2017) Soil stabilization is a method of increasing the strength and durability of soil by modifying some changes in the soil. Unconfined Compressive Strength, California Bearing Ratio, and Shear Strength in-situ soil tests were carried out on the native sample. The sample is surrounded by a negatively layered environment and combined with positive charge to neutralize. TerraZyme reduces the charge, and particles come closer to attain greater compaction, and the strength of the soil also increases. TerraZyme also decreases the voids present in sample. Nowadays, TerraZyme is widely used because of its cost-effective and eco-friendly behaviour [4].

Pradeep Singh Sodhi et al. (2018) studied about the process of soil stabilization which will help to improve the construction of road. The sample was collected from a site and tests like Atterberg's limit, California bearing ratio, Unconfined Compressive Strength were conducted on the native soil. The results obtained showed an increase in dosage of TerraZyme, decreased liquid limit and plastic index from 0.06 ml/kg. There was also an increase in Unconfined Compressive Strength value by 375% and also in the California Bearing Ratio by 185.32% when mixing it with TerraZyme of 0.2 ml/kg. TerraZyme, a non-toxic, biodegradable liquid, improves the soil's strength and durability [5].

Priyanka Shaka et al. (2016) describe the study that was carried out to check the improvements in the properties of black cotton soils and red soil treated with TerraZyme stabilizer and concluded that the best results were observed with the application of TerraZyme at a curing period of 21 days. Unconfined compressive strength (UCS) test was carried out on four different soil samples and observations were noted after 7, 14, 21 days, respectively, for each soil sample. Significant amount of increase in UCS and decrease in liquid limit were observed after 21 days. This study examines the changes in physical and strength properties caused by TerraZyme stabilization, as well as the effect of various parameters such as curing period on stabilized soil [6].

Joydeep Sen et al. (2015) In order to use this technology for low volume roads, researchers studied the properties of soil modified with a bio-enzyme and concluded that the amount of clay content plays a significant role in the variation of consistency limits. Black cotton soil with varying index properties was tested for stabilization in this study, and the strength of the stabilized soil was evaluated after curing periods of 0 days, 14 days, 21 days, and 28 days for various enzyme dosages 200 ml/3m^3, 200 ml/2.5m^3, 200 ml/2m^3, and 200 ml/1.5m^3. The soil specimen was subjected to the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests. The results of the tests show that bio-enzyme stabilization improves the strength of Black Cotton soil, indicating that the bearing capacity and resistance to deformation increase in stabilized soil [7].

Puneet Agarwal et al. (2014) The importance of bio-enzymes in improving the soil quality of black cotton soil in India was investigated, and it was concluded that the duration of soil treatment with TerraZyme played a critical role in improving strength. The Unconfined Compressive Strength was measured after 1 and 7 days of curing with different enzyme dosages (0.0, 0.25 ml, 0.5 ml, 0.75 ml, 1.0 ml, 2.0 ml, 3.0 ml, and 4.0 ml/per 5 kg of soil). The use of TerraZyme to strengthen the soil resulted in an increase of up to 200% in the Unconfined Compressive Strength of the Black Cotton Soil [8].

Venika Saini et al. (2015) studied the significance of new methods such as bio-enzyme and how beneficial it can be for soil geotechnical properties when compared to traditional methods. Bio-enzymes are cost-effective, and it changes the properties of soil drastically, and the changes are permanent. Tests like specific gravity test, standard proctor test, consistency limit test, and California bearing ratio were carried and results were compared. Local soil (from Ballupur Road) and TerraZyme were used in the experiment (bio-enzyme). After a two-week curing period, the third enzyme dosage is the best because the consistency limits are reduced and the soaked CBR is increased [9].

Sandeep Panchal et al. (2017) TerraZyme, a bio-enzyme, was studied for improving the California bearing ratio (CBR) value in road construction. They concluded that TerraZyme can be a useful approach for ground improvement and soil stabilization in construction of roads. California bearing ratio, Atterberg's limit test, and standard proctor test were carried out and results were analysed on the basis of dosages and different curing periods. Local soil samples were tested with and without enzyme. The best CBR value was obtained with the third dosage after a two-week curing period, with a percentage increase of 131.49% when compared to a local soil sample without TerraZyme [10].

Elsa Jacob Joseph et al. (2017) studied the importance of improving the poor conditions of subgrade soil prior to construction work of roads. Tests were performed on Kaolinitic clay taken from Thonnakkal region, Thiruvananthapuram district, Kerala, and the results were taken after different curing periods. The Dynamic Cone Penetration Tests were done and the Dynamic Cone Penetration Index was found to decrease with the use of TerraZyme. TerraZyme dosage of 0.1 ml/kg dry samples were found to be ideal. The CBR value increased by 25-fold and UCS increased by 3-fold for the sample stabilized with 0.1 ml/kg of TerraZyme after 28 days curing. The DPI value decreased by 59% for the soil stabilized with 0.1 ml/kg dosage of TerraZyme after 28 days curing [11].

Sanjeet Saho et al. (2018) studied the importance of soil stabilization for construction and analysed the sample of TerraZyme stabilizer with the other sample and concluded that TerraZyme stabilizer can effectively be used to stabilize the soil.

The increase in the unconfined compressive strength from 120 KN/m2 to 122.5KN/m2 was found for the indigenous soil. The CBR values for unsoaked sample with indigenous soil was about 3.79% at 2.5 mm, when it is soaked for the period of 4 days the values are 2.286% at 2.5 mm. TerraZyme execution is a substitute for lowering roadwork expenses [12].

3 Materials and Methodology

3.1 Materials

TerraZyme could be a great elective to all the customary soil stabilizers like fly fiery remains, cement, etc. TerraZyme may be a bio-enzyme utilized as a soil stabilizer. It moves forward the soil properties. It is a non-harmful and natural substance. It is defined as the extraction of plants, vegetables, and natural products. Subsequently, it is additionally eco-friendly.

It is necessary to dilute it before using it. When it's mixed with soil and added to water, it changes the properties of soil depending on the type of soil and the amount of TerraZyme used. It may be a fluid added substance, which diminishes voids and minimizes water retention for most extreme compaction of soil. It responds with sticky matter in soil and shapes cementitious fabric, which diminishes swelling capacity of soil and diminishes penetrability.

It increases soil load-bearing capacity and improves climate resistance. TerraZyme's reaction with soil is permanent, and the substance is biodegradable. Properties of TerraZyme are listed in Table 1 (Fig. 1).

Table 1 Properties of TerraZyme. *Source* https://www.irjet.net/archives/V6/i3/IRJET-V6I3156.pdf

Identity (as it appears on the label)	Enzyme
Hazardous component	None
Boiling point	100 °C / 212° F
Specific gravity	1.05
Melting point	Liquid
Evaporating rate	Same as water
Solubility in water	Same as water
Vapour density	1
pH value	3.50
Appearance/odour	Brown liquid/non-obnoxious

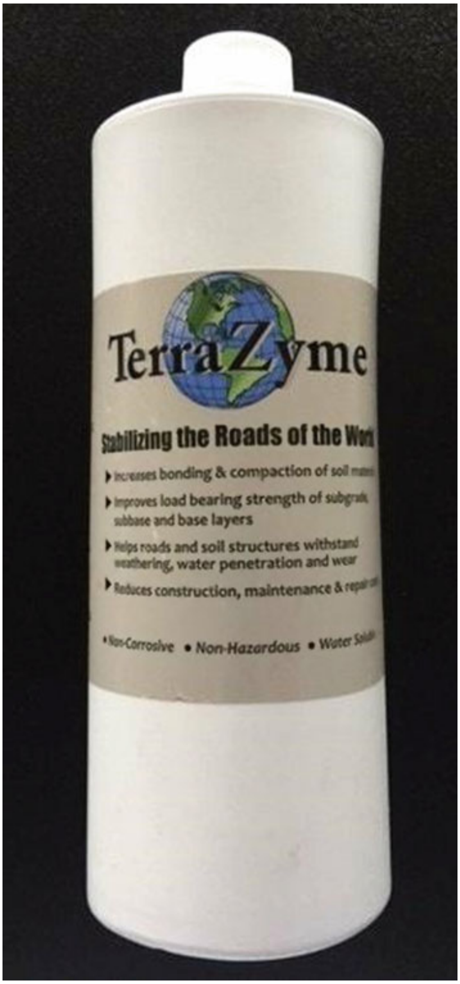

Fig. 1 TerraZyme. *Source* https://www.l-q-international.com/store/p2/TerraZyme.html

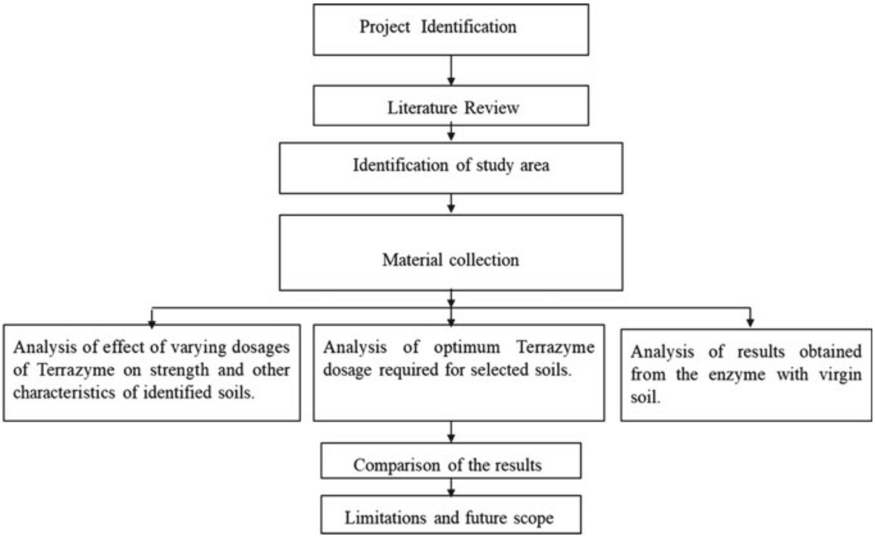

Fig. 2 Methodology

3.2 Methodology

The Gurti soil sample was collected from Southern Srinagar, treated with TerraZyme, and cured for 7 days. The effect of the dosage (0.05 ml/kg, 0.1 ml/kg, and 0.15 ml/kg) used for soil stabilization on the geotechnical properties of soils is investigated. Geotechnical properties such as the California bearing proportion (CBR) and unconfined compression quality (UCS) are investigated. Soil CBR and UCS were found to be 4.68% and 196.33kN/m^2, respectively [13–20]. The methodology adopted for the soil stabilization is shown in the Fig. 2.

4 Results and Discussion

4.1 Results

Experimental results obtained on effect of varying dosages of TerraZyme on CBR and UCS are listed in the following Tables 2 and 3.

Table 2 Experimental results obtained on effect of varying dosages of TerraZyme on CBR

Dosage (ml/kg)	CBR (%)	
	Period of curing (0 days)	Period of curing (7 days)
0.05	4.68	12.16
0.1	9.79	30.17
0.15	4.53	14.9

Table 3 Experimental results obtained on effect of varying dosages of TerraZyme on UCS

Dosage (ml/kg)	UCS (kN/m^2)	
	Period of curing (0 days)	Period of curing (7 days)
0.05	196.33	234.65
0.1	217.26	273.72
0.15	204.68	249.71

4.2 Discussion

4.2.1 CBR TEST

The CBR value for the respective soil samples is determined by CBR test. Three different mix proportions of TerraZyme (0.05 ml/kg, 0.1 ml/kg, and 0.15 ml/kg) were added, and CBR test was done after 0 and 7 days of curing. The CBR esteem for test stabilized with 0.05 ml/kg TerraZyme 4.68%, for test stabilized with 0.1 ml/kg TerraZyme is 9.79%, and for test stabilized with 0.15 ml/kg TerraZyme is 4.53% after curing time. After 7 days curing period, the CBR esteem for test stabilized with 0.05 ml/kg TerraZyme is 12.16%, for test stabilized with 0.1 ml/kg TerraZyme is 30.17%, and for test stabilized with 0.15 ml/kg TerraZyme is 14.9%. From the outcomes, CBR esteem for test stabilized with 0.1 ml/kg TerraZyme after 7 days of curing is the ideal dose of TerraZyme. The graphical representation of CBR is shown in Fig. 3.

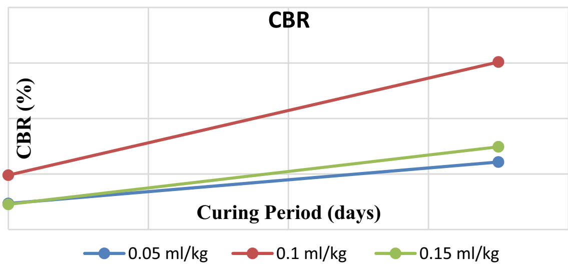

Fig. 3 Graphical representation of CBR results

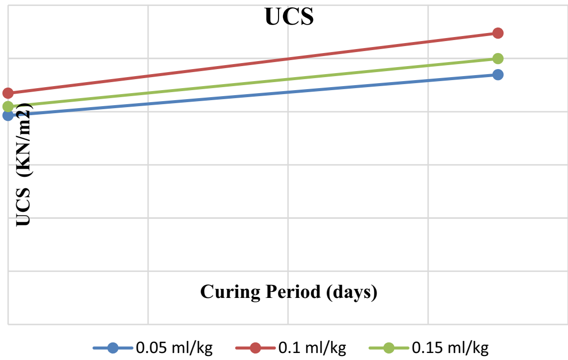

Fig. 4 Graphical representation of UCS results

4.2.2 UCS TEST

The shear strength parameters were determined by unconfined compressive test using disturbed soil sample. Three different mix proportions of TerraZyme (0.05 ml/kg, 0.1 ml/kg, and 0.15 ml/kg) were added and UCC strength was found after 0 and 7 days of curing period. The value of ucc strength for soil sample stabilization with 0.05 ml/kg TerraZyme is 196.33 KN/m^2, for sample which is stabilized with 0.1 ml/kg TerraZyme is 217.26 KN/m^2, and for sample which is stabilized with 0.15 ml/kg TerraZyme is 204.68 KN/m^2 after 0 days of curing. After a 7-day curing period, the ucc strength for sample which is stabilized with 0.05 ml/kg TerraZyme is 234.65 KN/m^2, for sample which is stabilized with 0.1 ml/kg TerraZyme is 273.72 KN/m^2, and for sample which is stabilized with 0.15 ml/kg TerraZyme is 249.71 KN/m^2. From the results, the UCC strength for sample which is stabilized with 0.1 ml/kg TerraZyme after 7 days of curing is the best TerraZyme dosage. The graphical representation of UCC is shown in Fig. 4.

5 Conclusions

TerraZyme is a good alternative to all the traditional soil stabilizers like fly ash, cement, lime, etc. TerraZyme is a bio-catalyst used as a soil stabilizer. It improves the soil properties. It is a non-toxic and natural substance. It is prepared from plants, veggies, and fruit extract. Therefore, it is also eco-friendly. TerraZyme enhances the engineering features of soil and strength of soil. CBR value and UCS gets increased. TerraZyme strengthens the chemical bonds between soil particles, resulting in a long-lasting structure that is resistant to damage, weathering, and infiltration. It also eliminates the need for granular and sub-base.

The addition of TerraZyme improved the engineering properties of the soil sample. Various tests were performed before and after mixing TerraZyme with sample. After combining different TerraZyme dosages with different curing periods, the UCS and

CBR values increased. The maximum amount of TerraZyme used to improve the UCS and CBR value of Gurti soil was discovered to be 0.1 ml/kg.

The duration of TerraZyme treatment of soil plays an important role in increasing the strength of treated soil (7 days gives highest strength). TerraZyme, an environmentally friendly enzyme, can be effectively used to increase the UCS and CBR value of Gurti soil. Other TerraZyme dosages were also tested. Even though it was not the optimum dosage, TerraZyme dosages of 0.05 ml/kg and 0.15 ml/kg significantly improved the engineering properties of an untreated soil sample. As a result, it can also be used in the field, taking into account the balance between the performance of stabilized soil and the total cost involved.

Future Scope in India: TerraZyme has a tremendous opportunity in India due to its profitable results. It is a progressive method that can be effectively chosen as a top strategy for soil stabilization. Because of its adequacy and higher quality, particularly in the case of interstates, it is now used in India in Maharashtra, Kerala, and Karnataka. However, because different types of soil necessitate different measurements, there is a need for research to be conducted in this field.

References

1. Renjith, R., Robert, D., & Fuller, A. (2017). Enzyme based soil stabilization for unpaved road construction. In: MATEC Web of Conferences 138.
2. Firoozi, A. A. (2017). Fundamentals of soil stabilization. *International Journal of Geo-Engineering, 08*(26), 1–16.
3. Athira, S. (2017). Soil stabilization using TerraZyme for road construction. *International Journal of Engineering Research and Technology, 06*(03), 547–549.
4. Gupta, A., Saxena, V., & Saxena, A. (2017). Stabilization of Soil using TerraZyme. *International Journal of Engineering Research and Application, 07*(04), 54–57.
5. Sodhi, P. S., Ocean, & Kumar, Y. (2018). Stabilization of soil using acidic bio-enzyme (TerraZyme). *International Journal of Innovative Research in Science, Engineering and Technology, 07*(08), 9172–9177.
6. Shaka, P., & Rakaraddi, P. G. (2016). Experimental study on the effect of bio-enzyme stabilization on black cotton soils and red soil. *International Journal of Innovative Research in Science, Engineering and Technology, 05,*(08), 15378–15386.
7. Sen, J., & Prasad Singh, J. (2015). Stabilization of black cotton soil using bio-enzyme for a highway material. *International Journal of Innovative Research in Science, Engineering and Technology, 04*(05), 12453–12459.
8. Agarwal, P., & Kaur, S. (2017). Effect of bio-enzyme stabilization on the unconfined compressive strength of expansive soil. *International Journal of Research in Engineering & Technology, 03*(05), 9172–9177.
9. Saini, V., & Vaishnava, P. (2015). Soil stabilization by using TerraZyme. *International Journal of Advances in Engineering & Technology, 08*(01), 566–573.
10. Sandeep Panchal, Md., Khan, M., & Sharma, A. (2017). Stabilization of soil using bio-enzyme. *International Journal of Civil Engineering and Technology, 08*(01), 234–237.
11. Joseph, E. J., & Saiyada, M. K. (2017). Stabilization of Kaolinite clay by using TerraZyme. Indian Geotechnical Conference.
12. Sahoo, S., & Sridevi, G. (2018). Soil stabilization using bio-enzyme. *International Journal of Pure and Applied Mathematics, 118*(24), 1–10.

13. IS 2720-Part 5. (1985). *Determination of liquid limit and plastic limit of soils*. New Delhi: Bureau of Indian Standards.
14. IS 2720-Part 13. (1986). *Methods of direct shear test for soils*. New Delhi: Bureau of Indian Standards.
15. IS 2720-Part 16. (2002). *Laboratory determination of CBR*. New Delhi: Bureau of Indian Standards.
16. IS 2720-Part 7. (1980). *Determination of water content dry density relation using light compaction*. New Delhi: Bureau of Indian Standards.
17. IS 2720-Part 10. (1991). *Determination of unconfined compressive strength of soils*. New Delhi: Bureau of Indian Standards.
18. IS 2720-Part 3. (1980). *Determination of specific gravity*. New Delhi: Bureau of Indian Standards.
19. IS 2720-Part 4. (1985). *Grain size analysis*. New Delhi: Bureau of Indian Standards.
20. IS 1498. (1970). *Classification and identification of soils for general engineering purposes*. New Delhi: Bureau of Indian Standards.

Building Automation

Constructed Wetland (CW) Technique as an Effective Sustainable Treatment for Wastewater: A Review

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Abstract Wetland's concept are becoming a popular alternative to traditional technologies for processing wastewater from domestic as well as industrial, especially for tertiary treatment of wastewater. Constructed Wetland (CW) is the assemblage which performs the treatment of wastewater by the process of unit operation techniques using natural process. It helps in achieving effective treatment efficiency in a sustainable manner. Due to an increase in wastewater loading, insufficient arrangement of sterilization and sewage treatment prompts in ecological impact and contamination of water bodies. It leads to water stress and depletion of good quality of ground water. Therefore, wastewater and reusing techniques will be essential in the coming days to overcome the crisis. CW is an effective alternative to overcome this situation. CW systems seem to be viable alternative in treating predominantly domestic wastewater and some type of industrial wastewater. In this method, the readied wet soil is successful for eliminating natural and suspended solids, while the evacuation of nitrogen is moderately low, however, can be improved by utilizing a combination of various sorts of wet soil arranged to satisfy water system reusing guidelines. In this research study, feasibility analysis has been carried out with domestic wastewater and industrial wastewater to ascertain the efficiency of CW in treating the wastewater and also the problems and limitations in handling the same was also assessed. General instruction regarding CW operation built for the treatment of specific wastewater types also ascertained in this research study. The important points that should always include suggestions about the pre-treatment stage, plants, and permeable media and built wetland operation strategies, etc., are discussed in this research paper. CW with integrated/hybrid model by linking both horizontal and vertical flow units was fabricated in a lab-scale hybrid wetland unit for treating the wastewater. Based on several trail study, it was observed that CW are very effective in treating organic wastewater. The treatment efficiency of some of the common parameter like Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) was around 70–80%. Several researchers have also proved that this one of the viable alternative technique for urban environment and semi-urban environment were availability of space for developing the CW unit is not a problem. It was evident from the study that CW is effective

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sustainable technology for the near future to solve the water crisis and to implement 3R concept in wastewater treatment.

Keywords Wetlands · Constructed wetlands · Wastewater · Hybrid wetland · Organic wastewater

1 Introduction

Construct Wetlands (CW) can also be called as artificial wetland It can be used as portion of a decentralized waste water treatment system and is a strong and "low tech" technology by low operating requirements, whereas artificial wetland is type of wetland which is mimic of natural wetland which is created artificially. But constructed wetland are artificial type which are created according to the requirements and based on design criteria of quantity and quality of wastewater. CW can be used to treat a wide variety of waste water and plays a vital role in many environmental hygiene concepts. CWs are designed to remove water pollutants using natural extraction systems provided by plant, soil, and related microbial populations. The treatment of CWs based on many biological and physical method such as absorption, precipitation, filtration or methods, nitration, decomposition, etc. The most significant method is the process of biological filtration by a biofilm made by aerobic and fascistic bacteria. CWs has traditionally been used to treat municipal waste, but over the last two decades, the use of this technology to treat various industrial effluents has increased significantly [6]. The CW is of many types like submerged flow and subsurface flow types in which horizontal and vertical flow pattern was followed to achieve the objective. In this research study, a setup has been fabricated by considering subsurface flow pattern integrating both horizontal and vertical flow types by providing intermediate baffle with impregnated holes in it as represented in the following Fig. 1.

The functional process of the hybrid CW was depicted in Figs. 1 and 2 it is clear that CW consist of three units, namely inlet zone, wetland zone or treatment zone, and outlet zone. The inlet zone is the main unit where the entire functioning of the treatment happening. It is influenced by several factors like vegetation, filter media, and other external environmental and climatic factors. It is a natural process; the efficiency of the treatment and functioning unit depends on the quantity and quantity of wastewater, and also the size and type of vegetation selected for treatment. Wetland plants are used to treat sewage as a result of cold, chemical, and biological processes in soils and aquatic environments (macrophytes). In this process, unlike conventional biological reactors, it does not produce huge amount secondary sludge and also CW system is resistance to uneven and variable flow of sewage. The efficiency of the CW unit can be improved by proper design, well-maintained hydraulic loading rate (HLR), and hydraulic retention time (HRT). The functioning process, working, benefits, and limitations are discussed in this following chapters.

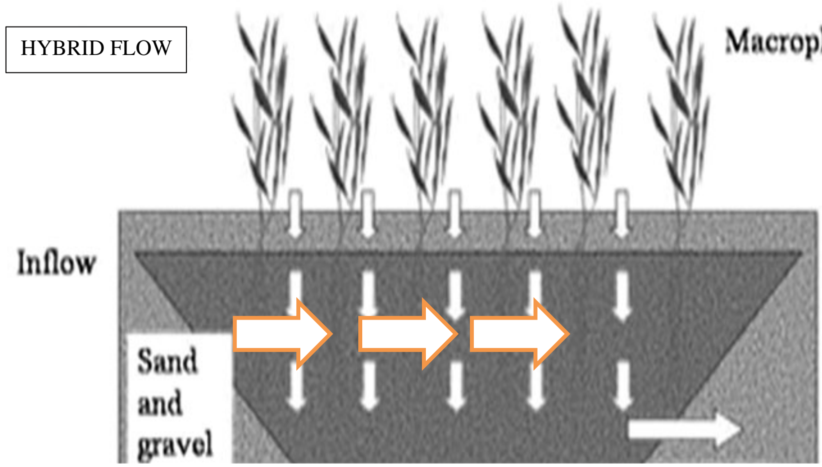

Fig. 1 Schematic diagram of Integrated/Hybrid Wetland Unit

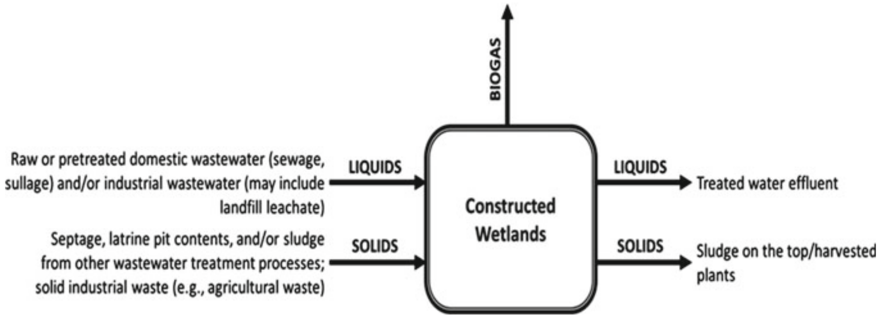

Fig. 2 Typical inputs for CWs

Several waste water domestic and industrial wastewaters are found to be appropriate for the treatment in CW. In this research, several study on domestic and industrial wastewater such as dairy, pulp and paper, tannery, and petrochemical has been considered for trail study and the processing for wastewater generation in following.

1.1 Domestic Wastewater Treatment

Domestic sources are the main source of wastewater in treatment plants. It contains about 0.1% solids, which include food particles, oil, feces, soap, sand and grit, toilet paper, and detergents. Most of the domestic water in urban areas is discharge into drains and taken to wastewater treatment plants, while in some areas, it is discharged directly into water bodies, which is usually considered in rural areas where there is no treatment facility available. Disposal of this water in the aquifer causes disturbance in the water and affects the aquatic life. In addition to the traditional method of water treatment, artificial wetlands can also be extremely economical and efficient for wastewater treatment. Experiments have shown that in some cases wetland efficiency can be around 78%–91% as shown in Fig 3 [2]. It taken that the treatment process was easier and resulted in less economy. It is taken to be effective in removing BOD from significant amounts of water.

This is a simple method of water reduction and can be used efficiently in rural areas where domestic sewage is not high. As this is an easy process, it is not difficult to run in rural areas where more funds are not available. Various aspects of domestic wastewater can be treated in artificial humid areas such as BOD, COD, pH, water turbidity, and Total Dissolved Solids (TDS). However, this method cannot be used where the discharge of muddy water is high because it is submerged in domestic water [19].

1.2 Industrial Wastewater Treatment

Initially, CW is used to treat domestic sewage. However, both surface and sub-surface hybrid CW are used to treat industrial wastewater for past two decades. Industrial effects such as diary, petrochemical, waste from pulp and paper factories, abattoir and meat processing were first to be handled by CW [13]. Wastewater system from tanneries, olive mills, and brewery have recently been applied to CW applications [11]. As a result, a variety of industrial wastewater, including mine wastewater, which has landfill leachate and low organic matter, are treated using CW as represented in Fig 4 [20]. However, there are no rules for choosing the most suitable type of CW for a particular industrial wastewater or even urban wastewater. Each case should be studied, especially because of the number of conditions: sewage type, soil availability, contaminant load and flow rate, outlet discharge limit, etc. [9]. Depending on operating conditions, system design features, and sewage characteristics, performance can vary greatly. In this research study, an initiative was carried out to treat the dairy, pulp and paper, tannery and petrochemical wastewaters was taken for trail study.

1.2.1 CW for Dairy Wastewater

The usage of acid and alkaline kernel cleaner and disinfectant in a dairy industry produces strong waste characterized by a wide range of high organic matter (BOD, COD) and pH values between 3.5 and 11.0 [14]. The production of wastewater varies as stated by the types of invention, and expertise used, as the dairy industry produce a variety of products such as yogurt, milk, ice cream, and cheese. In the most recent trial of CW treatment of milk wastewater, the pre-treatment stage was primarily used to extract suspended solid that were required before the creamy wastewater reached the CW bed to prevent porous media reduction and reduce the organic load. Simple setting basins are popular pre-treatment processes [10–12]. Since hybrid-constructed wetland system also has HSSF beds, these wetland beds are only needed to treat the dairy wastewater [16]. Integrated building wetlands systems were found to achieve high-amount removal bulk of organic matter from the VSSF system, despite contaminant superficial loads typically greater than those applied to the CW scheme [3]. The HSSF system appears to be more efficient in the treatment of milk wastewater [22]. In this trail study, wastewater from dairy processing unit near Chennai was used for trail in CW and output efficiency was recorded for different trails.

1.2.2 CWs for Pulp and Paper Wastewater

The pulp and paper industry generates significant volume of wastewater. Waste water treatment in the pulp and paper industry depends on the type of processing, wood material type, method of controlling, processing technology, internal recycling of the wastewater for recovery, and the specific quantity of water [1]. Extremely volatile organic compounds, fatty acids, AOX, lignin and its derivatives, and resins usually contain high amount of organics (BOD and COD) and suspended solids. Some of these contaminants are present naturally in wood extracts, while others are xenobiotic compounds produced in processes of pulping and paper making (Chlorinated lignin, resins, seeds, and phenols, dioxane). The result of the 1-month operation showed that the extraction efficiency for the phenols changed but reached an average of 77% on day hydraulic retention time (HTR). Prolonged retention can lead to a lack of oxygen and nutrients, which can lead to reduced drainage efficiency [15]. In this trail study wastewater from pulp and paper industry from Tamil nadu was collected and processed in for trail in CW and output efficiency was recorded for different trails.

1.2.3 CWs for Tannery Wastewater

CWs are used for secondary or tertiary treatment as environmentally friendly and cost-effective technology, on tannery Wastewater. When using CW as part of a treatment system, it is important to have strong pre-treatment, primary treatment, and precious treatment in place before sending wastewater to the CW [4]. The treatments of tannery wastewater CW that have been documented are active sludge as a primary and secondary treatment. The BOD/COD level of water effluent differ depending on the form of treatment used, varying from 0.23 to 0.66 for primary treatment and 0.0 to 0.55 for secondary treatment [16]. CWs accounts for up to 10% of traditional secondary biological treatment costs and current costs are approximately 10%, although they can differ based on venue, and the method is to be implemented with pre-treatment involving, are equal to a conventional treatment; however, the installation and maintenance costs are equivalent to a conventional treatment. In this trail study wastewater from Chrome tannery from Chennai was collected and processed in for trail in CW and output efficiency was recorded for different trails.

1.2.4 Petrochemical Industry

Petrochemical industries transform fresh oil and additional hydro-carbon bearing sources like natural gas and oil sands into a range of final product of intermediary materials. And generating waste water from cracking, lube oil, topping, cooling tower blow down, water and sludge drainage from tanks and strom water drainage and runoff. Efficiency of treatment process within one year was better for compost wetlana as comparison with gravel wetland. Whereas the removal efficiencies are 51% and 49% for chemical oxygen demand, 55% and 47% for biological oxygen demand5 as well as 51% and 42% for total suspended solids. The gravel-based wetland is less efficient as compared to compost-based wetlands for removing heavy metals from wastewater [21]. In this trail study wastewater from petrochemical processing industry from the outskirt of Chennai was collected and processed in for trail in CW and output efficiency was recorded for different trails.

2 Methodologies

Increase in population results in more water demand. Nowadays huge quantity of wastewater discharge into the water bodies and drainage without proper treatment and it leads to several impact on environment and also it affects the ecology. Acknowledging several researches outcome, it is necessary to adopt the methodologies for executing proto type research trails. A lab scale proto type unit as represented in Fig. 1 and 2 was fabricated as per design criteria in vogue. The proto type wetland unit fabricated and planted with wetland plants and it was seasoned with normal water so that plant attained the growth. Once plant attained the growth the trail was started initially with domestic waste water continue with industrial waste water. Each waste water trail was carried for one month it continued till three consecutive trails got over and this process is continued for around one year. During each trail treated sample was collected for every 24 h. In each trail and the samples were analyzed in laboratory as per APHA guide lines for basic common parameter like BOD, COD, TSS /TDS and TN/TP and the output of different trails are interpreted and average results are documented and discussed in result and discussion.

3 Result and Discussion

CW can remove the organic compounds and nutrients from wastewater, where as they expeditiously eliminate biodegradable organic waste, pathogenic microorganisms and total solids. Separate of nitrogen depends on the design of system, process configuration and loading rate. From above study, it is observed that wetland is efficient for domestic waste water treatment (70%) compare to industry wastewater, especially organic wastewater, pH, temperature, feeding mode, hydraulic retention

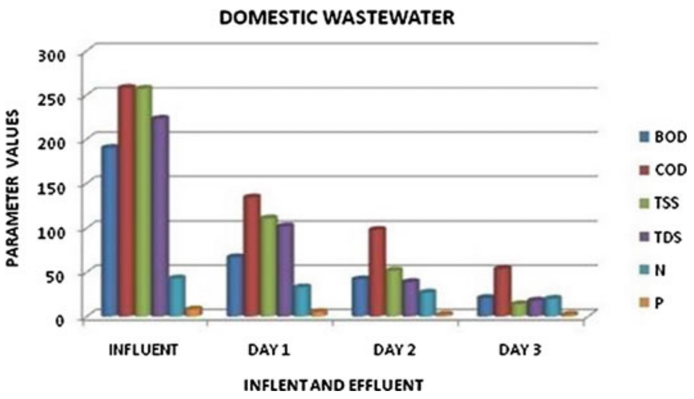

Fig. 3 Raw influent and treated effluent at HRT of domestic water (mg/l)

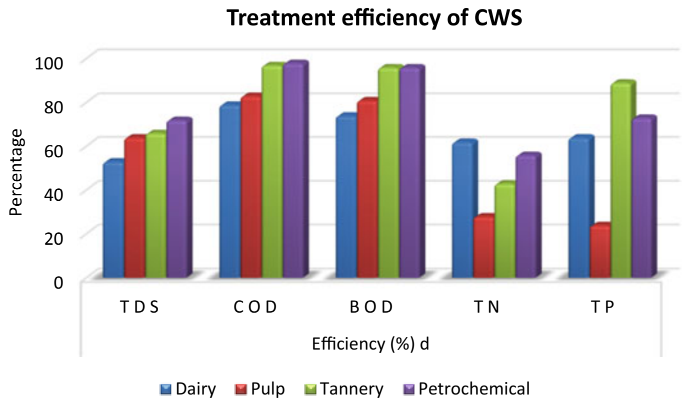

Fig. 4 Treatment Efficiency of CWs with different industries (mg/l)

time (HRT), hydraulic loading (HL), dissolve oxygen, bed depth, harvesting and species of plant all effect the removal of organic compounds. Some of them form a bond with one another. Various types of flow (horizontal or vertical flow, sporadic, HRT, HL and wastewater loading pollutant) and dissolved oxygen and convey to CW are depending on the plant species, various types of flow. HRT simulates the time needed for wastewater to pass through wetland system; a longer HRT in a built wetland increases pollutant removal because of the longer contact time between microorganism and contaminants. Physical relative than biological method can be credited to the removal of substances which is sediment and filtrated [19].

In terms of conditions of environment, CW has ability to work in wide range of temperature, from the coldest to the hottest. Natural processes, such as CW, tend to be capable of treating industrial wastewater; for example, wastewater from

Table 1 Main Characteristics of various industrial effluent

Wastewater	Main Characteristics
Dairy wastewater	Wide range of high organic matter (BOD, COD) and pH values between 3.5 and 11.0
Pulp and paper mill	Highly intense color, chlorophenoilc compounds
Tannery	High organic loadings, high salt content (up to 80 g. dm-3NaCl)
Petrochemical	Low biodegradability, including salt, oil, phenolics, metals, and various hydrocarbons

Table 2 Comparison of treatment efficiency of CWS with industrial wastewater

Types of wastewater	Types of CW	HLR	Efficiency (%) d				
	(n) c	(d)	T D S	C O D	B O D	T N	T P
Dairy	Hybrid	0.8- 9.8	39–91	71–95	56–91	41–91	31–87
Pulp	HSSF	2.0- 15	56–67	60–70	28–91	28–60	15–30
Tannery	Hybrid	3–10	56–72	70–98	80–90	50–80	82–96
Petrochemical	Hybrid	2–13	44–95	30–50	50–98	48–80	50–60

refineries, pulp and paper mills, tanneries and textile mills contains few biodegradable compounds. CW can perform secondary or tertiary treatment as well as excellent efficiency in wastewater with high BOD/COD ratio, with strong pre-treatment that can minimize organic loads [7]. The amount of wastewater from different industries handled by CW is high and this is more likely in the latest research in the field. Following table 1 shows main characteristics of different industrial waste water and table 2 shows treatment efficiency of constructed wetlands [6].

From the above results as represented in Figs 3 and 4 it is clear that all parameters are reduced by a considerable percentage after treatment in the wetland unit. The BOD is still not within discharge limits but an increase in the hydraulic retention time (HRT) will help in achieving the BOD reduction.

Constructed wetlands have been used extensively to treat several types of wastewater and runoff. The dairy wastewater tested in this study, contained high levels of BOD, COD, total solids, total dissolved solids, total suspended solids, nitrogen and phosphorus. The result indicates that the treatment efficiency significantly improved within 3 days of HRT for organic wastewater. The results also suggest that wetland plant species and soil play a significant role in the treatment of wastewater. HRT should be given special attention in the design of future full scale facilities. From the highlighted study, we can summaries that the technique is efficient for small scale group treatment of community domestic wastewater, as the installation, operation and maintenance cost is very low. In case of industrial effluents, there are serious treatment limitations in the industrial effluents due to their specific characteristics but more efficient for organic wastewater. Based on the analysis, it was observed that wetland showed greater efficiency in removal of parameters such as COD, BOD, and Phenolic compound. Change in the design criteria is very important for treatment of different kind of industrial effluent and its filter media has a major role in the removal of pollutants Constructed Wetland should be taken into account in the treatment of industrial effluent as Constructed Wetlands are used from past time to remove the organic pollutant, but the selective wetland species would made it very useful in removal of inorganic pollutant too. The following initiatives as discussed in following paragraph will help in improving the efficiency of CW units.

3.1 Improve Water Quality in CWs

Several factors like Water, strata, plants (vascular and algae), waste (mostly fallen plant material), and invertebrates make up wetlands (mainly insect larvae and worms). Furthermore, a number of microorganisms (most importantly bacteria) helps in improvising the water quality in the wetland unit5. Water quality improvement can be further achieved by adopting these [8]. Mechanisms it comprised of:

- Disposal of suspended particulate material
- Filtration or chemical precipitation from contact with substrate and waste-containing water
- Chemical change
- On the surface of plants, layers, silt, and debris, absorption and ion exchange occur
- Pollutant decomposition and transformation by microorganisms and plants
- Nutrient enhancement and transformation by microorganisms and plants.

3.2 Systems Lifetime

CWs were used for wastewater treatment with a fixed lifespan, which will be calculated based on the amount of wastewater, the capability of the wetland to remove and maintain pollutants and the amount of waste generated. If the effect is slight, several systems have been in use for more than 20 years [17]. Long-term data on the performance of constructed wetlands being procure, as more systems are being monitor over a longer period. Data from some of the manufactured wetland systems that have provided long-term data show that loading is reasonable for organic pollutants, such as BOD, dissolved suspended solids and nitrogen unless the treatment efficiency is reduced. Moreover, the wetland system design plays an important role and deciding factor and it must be carefully Prepared and maintained. The ability of moisture to remove and store pollutants that persist in humid environments, such as phosphorus and metal, can decrease over time. To improvise the life time and efficiency of CW unit, the composition of these substances must be tracked on a regular basis. Wetland sludge, debris can be removed when needed, and the wetland can be recreated with new substrate if required [20].

3.3 Limitations of CWs

There are some limitations regarding the usage of built-up wetlands: They usually need a larger area than traditional waste water treatment system. Wetland treatment can be economical compared to other option if solitary the land is not available and reasonable. Performance may be less reliable than traditional treatments. In the face of changing climatic conditions, such as rainfall and drought, the efficacy of wetland treatment can vary 'seasonally.' Where the year's average output is reasonable, but wetland treatment is not based on required quality or strict discharge limits. Biological elements are toxic chemicals, like ammonia and pesticides. If the flushing of contaminants or increased water flow can temporarily reduce the efficiency of treatment, they require less water if they survive [5]. Although the humidity tolerates a temporary drop, they cannot tolerate a complete drought. In addition, the use of wet land built for sewage treatment and storm water control is a very recent development. The optimal design of wetland systems is not yet agree upon is known about their long-term performance [18] (Tables 1 and 2).

4 Conclusion

The review study highlighted the provocation of global water shortage, which shows that by 2020; nearly half of the global population to experience water scarcity and global need of water is to improve 55% by 2050. This is the result of population growth, industrial growth and agricultural jobs, global warming, and weather change, which has making water scarcity globally. As a result, this study explores unconventional water supplies in order to detect the increasing demand for freshwater. Recycling wastewater is a systematic option for tackling global water scarcity. Inadequate sanitation and wastewater treatment facilities are creating a concern for the environment and public health. As a result, in order to provide enough fresh water in the future, wastewater treatment and recycling would be taken seriously. While more than 70% of the world's water is used for irrigation, the potential to use wastewater for agricultural irrigation is greater, particularly when nutrients like nitrogen and phosphorous are necessary for plant development. Among the newer technologies for reprocessing urban wastewater for irrigation, CW has a high potential for eliminating pollutants, as well as low maintenance costs and energy requirements. Water level, macrophyte, and water movement management were used to identify the generated cross-spaces. Sewage makes an odd appearance on the purification wetland pattern. In terms of wastewater treatment, macrophytes, substrate, hydrology, surface loading rate, efficient intake process, microbial optimality, and environment conditions play a role.

References

1. Abira, M. A., VanBruggen, J. J. A., & Denny, P. (2005). Potential of a tropical subsurface constructed wetland to remove phenol from pre-treated pulp and papermill wastewater. *Water Science and Technology, 51*(9), 173–176.
2. Arroyo, P., la Anso, G., & de Luis, E. (2010). Effectiveness of a full-scale constructed wetland for the removal of metals from domestic wastewater. *Water, Air, and Soil Pollution, 210*(1–4), 473–481.
3. Badkoubi, A., Ganjidoust, H., Ghaderi, A., & Rajaba, A., (1998) Performance of a subsurface constructed wetland in Iran. *Water Science and Technology, 38*(1), pt 1. International Association on Water Quality, 345–350
4. Calheiros, C. S. C., Rangel, A. O. S. S., & Castro, P. M. L. (2007). Constructed wetland systems vegetated with different plants applied to the treatment of tannery wastewater. *Water Research, 41*(8), 1790–1798.
5. Carballeira, T., Ruiz, I., & Soto, M. (2016) Effect of plants and surface loading rate on the treatment efficiency of shallow subsurface constructed wetlands. *Ecological Engineering* (Vol. 90, pp. 203–214). Elsevier B.V.
6. Chang, Y., Wu, S., Zhang, T., Mazur, R., Pang, C., & Dong, R (2014). Dynamics of nitrogen transformation depending on different operational strategies in laboratory-scale tidal flow constructed wetlands. *Science of the Total Environment, 487*(1), 49–56. Elsevier B.V.
7. de la Varga, D., Soto, M., van Oirschot, D., Kilian, R., & Pascual, A. (2016). Constructed wetlands for industrial wastewater treatment and removal of nutrients. *Technologies for the Treatment and Recovery of Nutrients from Industrial Wastewater*.
8. Garner, E., et al. (2021). Next generation sequencing approaches to evaluate water and wastewater quality. *Water Research, 194*, 116907.
9. Hu, J., et al. (2017). Study on treatment of electroplating wastewater using construction wetland. In *IOP conference series: Earth and environmental science* (Vol. 61).
10. Kadlag, V. (2016). Study of dairy wastewater treatment by using constructed wetland. *ICRTESM-16*, 238–252.
11. Minakshi, D., Sharma, P. K., Rani, A., & Singh, N. (2018). Treatment of dairy farm effluent using recirculating constructed wetland units, pp. 57–66.
12. Pachpute, A. A., Kankal, S. B., & Jadhav, M. V. (2014). Use of artificial wetland for treatment of dairy industry waste water for Analysis of BOD and COD. *6*, 38–41
13. Deeptha, V. T., Prathap, M. G, Deepak, M., & Sudarsan, J. S. (2014). Performance study of constructed wetlands for industrial waste water. *International conference on innovatiove technologies and management for water security*
14. Sudarsan, J. S., Thattai, D., & Das, A. (2012). Phyto-remediation of dairy-waste water using constructed wetland. *International Journal of Pharma and Bio Sciences, 3*(3), 745–755.
15. Prasanna, K., Sudarsan, J. S., & Nithiyanantham, S. (2017). Wastewater treatment using combined biological and constructed wetlands technique in paper mills. *Sustainable Water Resources Management, 3*(4), 431–439. Springer International Publishing.
16. Prathap, M. G., Sudarsan, J. S., Annadurai, R., Nithiyanantham, S., & Sudharson, G. (2021). Treatment of wastewater with modified constructed wetland system as a tertiary treatment unit. *International Journal of Environment and Sustainable Development, 20*(2), 189.
17. Siracusa, G., & La Rosa, A. D. (2006). Design of a constructed wetland for wastewater treatment in a sicilian town and environmental evaluation using the emergy analysis. *Ecological Modelling, 197*(3–4), 490–497.
18. Stottmeister, U., Weibner, A., Kuschk, P., & Kappelmeyer. (2003). Effects of plants and microorganisms in constructed wetlands for wastewater treatment. *Biotechnology Advances, 22*(1–2), 93–117.
19. Sudarsan, J. S., Roy, R. L., Baskar, G., Deeptha. V. T., & Nithyanantham, S. (2015). Domestic wastewater treatment performance using constructed Wetland. *Sustainable Water Resources Management, 1*(2), 89–96. Springer International Publishing.

20. Sudarsan, J. S., & Vaishampayan, S. et al. (2021). Grey water recycling as a tangible solution to water crisis: A case study in Thiruvananthapuram, India. *International Journal of Energy and Water Resources, 0123456789*. Springer International Publishing
21. Sudarsan, J. S., Annadurai, R., Subramani, S., & George, R. B. (2016). Petrochemical wastewater treatment using constructed wetland technique. *Pollution Research, 35*(4), 727–732.
22. Tanner, C. C., Clayton, J. S., & Upsdell, M. P. (1995). Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands-I. Removal of oxygen demand, suspended solids and faecal coliforms. *Water Research, 29*, 17–26.

Comparative Statistical Analysis to Determine the Impact of COVID-19 Lockdown on $PM_{2.5}$ Concentration in Chennai City, India

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Abstract The COVID-19 pandemic has jolted India as it has with the world, and the death toll has crossed the 1.5 lakh mark as of February 2021. To curb this wildfire like the spread of the virus, the Government of India has imposed a nationwide phased lockdown from 25 March 2020 to 31 May 2020. Studies have shown that more than 22 cities in India recorded a drastic decrease in $PM_{2.5}$ during this lockdown period. This research aims to study the impact of this phased lockdown on Particulate Matter ($PM_{2.5}$) by means of statistical analyses. The $PM_{2.5}$ concentration for Pre-COVID years up to the end of Phase-IV of the lockdown is acquired via the continuous air quality monitoring stations of the Central Pollution Control Board in three locations; namely, Velachery, Alandur and Manali. Graphical analysis provides insight into the efficiency of lockdown showing April 2020 achieved the highest reduction in $PM_{2.5}$ concentration in all three locations. Manali being an industrial area notices a significant increase as evidenced by the one-way ANVOA in May 2020 when the Government sanctioned relaxations on the logistical and industrial front. Analysis of Summer 2020 $PM_{2.5}$ levels with previous years shows an overall decrease through the years and a significant decrease specifically in 2020. Comparison of air quality during the lockdown period with the previous years provides a distinctive perspective to understand the extent of anthropogenic influence on the air quality of Chennai, which can in turn act as a tool to identify suitable mitigation measures to vastly improve quality of life.

Keywords COVID-19 · Lockdown · Pollution · $PM_{2.5}$ · ANOVA

1 Introduction

Air pollution is always an issue of pressing concern in developing countries like India especially considering its large population. In the urban areas and metropolitan cities, due to good economic development and growth of industries, there has been

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a decrease in air quality [1]. Particularly, it has been noticed that particulate matter is at the forefront of major pollutants in major parts of India and has been shown to be originating from industrial, vehicular and dust emissions [2, 3]. The Central Pollution Control Board (CPCB) in its annual report has reported that in the study of the ambient air quality for cities with a population over a million, with respect to PM_{10}, 98% of the cities studied did not comply with the National Ambient Air Quality Standards (NAAQS) and with respect to $PM_{2.5}$; 95% of the cities under study exceeded the NAAQ limits [4]. Chennai city, in particular, is vital to focus upon, as it has undergone rapid demographic growth over the last four decades, and this resulted in industrialization-driven urbanization [5]. The Tamil Nadu Pollution Control Board (TNPCB) in its annual report for the year 2018–2019 has reported that respirable suspended particulate matter levels exceeded the standard in Chennai in certain monitoring locations. The reason for exceedance has been stated to be due to the metro rail works, telephone/electric cable laying, resuspension of traffic dust, etc. The Care Air Center established in Chennai is a real-time emission-monitoring system, which pertains to highly polluting industries, incinerators, etc. During the exceedance of emission levels from the norms, the inbuilt system alerts the concerned industry and the District Environmental Engineer to take immediate action. This is indicative of the TNPCB's objective to sustain the ambient air quality especially in Chennai [6].

The COVID-19 (Corona Virus Disease-2019) pandemic is caused due to severe acute respiratory syndrome coronavirus 2 or SARS-CoV-2 that was originally identified in Wuhan, China in December 2019 [7]. In India, the first COVID-19-positive case was reported on 30 January 2020 in Kerala [8]. As per the WHO Coronavirus Disease Dashboard, on 11 November 2020, there are over 50.8 Million cases worldwide with over 1.2 million deaths. The USA has the most number of cases (9.8 Million), India currently has the second largest number of cases (8.6 Million) and its transmission is classified as a cluster of cases. In India, the death toll has currently reached 1.27 Lakh people. In order to combat the spread of this pandemic, the Indian Government implemented a stringent nationwide lockdown from 25 March to 14 April (Phase-I), which was later further extended from 15 April to 3 May (Phase-II), 4 May to 17 May (Phase-III) and finally up to 31 May 2020 (Phase-IV) This lockdown curbed the logistical movement and industrial activities. As a result, there was definitive progress in the air quality, particularly during the various lockdown phases [9, 10]. It was noticed that in 22 cities in India, the PM_{10}, $PM_{2.5}$, CO and NO_2 levels drastically reduced by 43, 31, 10 and 18%, respectively, during the lockdown period compared with the previous years [11]. Chennai seems to show a positive trend in reduction during the lockdown period in comparison to 2019 [12]. Among the various pollutants studied, it was noticed that Particulate Matter ($PM_{2.5}$) observed a greater reduction in various regions [11]. This could be attributed to the Nitrogen Oxide (NO_x) levels that are particularly important for secondary particulate matter formation [13]. Hence, this study delves further into the statistical analysis of the variation of $PM_{2.5}$ concentration during the lockdown phases in Chennai city and its comparison to the pre-lockdown period.

Table 1 Details of CPCB CAAQM stations

Station name	Address	Coordinates (Decimal degrees)
Velachery	Sardar Patel Road, Opposite of C.L.R.I, Near Adyar Cancer Institute, Chennai-600036	Latitude: 13.0052189 N Longitude: 80.2398125 E
Alandur bus depot	MKN Rd, St. Thomas Mount, Chennai-600016	Latitude: 12.9099161 N Longitude: 80.1076538 E
Manali	Government School, Periya Thoppu Manali	Latitude: 13.164544 N Longitude: 80.26285 E

2 Materials and Methods

2.1 Study Area

Chennai city is one of the major metropolitan cities in India and is the capital of Tamilnadu, India. It is stated to be the fourth largest city in the country. The entire district is classified as urban. The district extends an area of 174 sq. km and has a coastal line of 22 km. Its coastline stretches vastly along the Bay of Bengal, and for that reason, most of the localities in Chennai are at sea level. The coordinates of Chennai are 12° 59’ and 13° 9’of the northern latitude and between 80° 12’ and 80° 19’of the eastern longitude. The Bay of Bengal is on the western side of Chennai, while Kancheepuram and Thiruvallur districts are located on the western and northwestern side, respectively.

Under the guidance of the Central Pollution Control Board (CPCB), there are about 200 continuous air quality monitoring stations across 20 states and 116 districts. Out of this, in Chennai, Tamil Nadu, three locations, namely, Velachery, Manali and Alandur are considered (Table 1). All three locations are contrastingly different in the sense that they are different categories. The area selected in Velechary is a prominent residential area. Alandur bus depot can be considered as a commercial (traffic intersection) area and Manali is an industrial area.

2.2 Timeframe

To understand the impact of the COVID-19 lockdown on $PM_{2.5}$ concentrations in the above-mentioned locations, data analysis is carried out for the concentrations of Particulate Matter $PM_{2.5}$, for the following time periods as provided in Table 2:

Table 2 Details of time period of data analysis considered

Details	Type of data	Period of data collected
COVID-19 lockdown period	Monthly average	January–May 2020
	Weekly average	March Week-1 to May Week-4
Past 5-year period	Yearly average	2016–2019
	Summer season average	March–May 2016–2020

2.3 *Methodology*

The $PM_{2.5}$ concentration for the study locations mentioned in Table 1 and the time frame mentioned in Table 2 are obtained from the 'Central Control Room for Air Quality Management—All India', a website managed by the Central Pollution Control Board. Preliminary graphical analysis is carried out for the COVID-19 lockdown period and the 5-year period. Subsequently, one-way Analysis of Variance (ANOVA) coupled with Tukey's post hoc test and independent samples T-Test is used to determine the significant changes in air quality based on these statistical tools.

3 Results and Discussions

3.1 *Determining the Status of $PM_{2.5}$ Concentration in Velachery, Alandur and Manali During the COVID-19 Lockdown Period*

3.1.1 Monthly Average

The monthly average of $PM_{2.5}$ concentration is plotted on a graph against the months of January–May 2020 and is depicted in Fig. 1. It is observed that April 2020 achieves

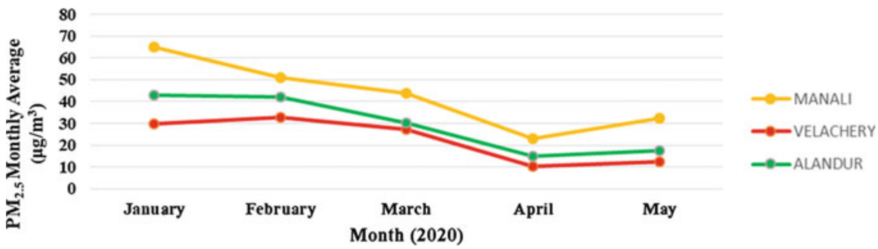

Fig. 1 Monthly Average of $PM_{2.5}$ Concentration in 2020

Table 3 One-Way ANOVA coupled with Tukey HSD post hoc test for monthly average $PM_{2.5}$ concentration in 2020—Velachery

Dependent variable: $PM_{2.5}$ concentration							
	(I) Month	(J) Month	Mean difference (I-J)	Standard error	Sig	95% Confidence interval	
						Lower bound	Upper bound
Tukey HSD	March	April	16.71224[a]	2.00551	0.000	11.9320	21.4925
		May	14.57387[a]	1.98900	0.000	9.8330	19.3148
	April	March	–16.71224[a]	2.00551	0.000	–21.4925	–11.9320
		May	–2.13837	2.00551	0.537	–6.9186	2.6419
	May	March	–14.57387[a]	1.98900	0.000	–19.3148	–9.8330
		April	2.13837	2.00551	0.537	–2.6419	6.9186

[a] The mean difference is significant at 0.05 level

the best reduction in concentration by 65.2% in Velachery, 65.06% in Alandur and 64.7% in Manali. Contrastingly, there is an increase in the $PM_{2.5}$ concentration in May month in comparison to April, which may be attributed to the relaxations sanctioned by the government on logistical and industrial aspects. The highest increase is observed in Manali with about 41.37% and the least is noticed in Alandur with 14.87%. In Velachery, there was a 20.68% increase in $PM_{2.5}$ concentration in May 2020.

A significant difference between the concentrations in the 3 months is observed as determined by one-way ANOVA (Velachery: $F(2,89) = 41.489$, Alandur: $F(2,89) = 16.598$ and Manali: $F(2,89) = 15.717$ where $p = 0.000$ for all 3 locations). Tukey HSD post hoc test reveals that there is no statistically significant difference between April and May for 2 locations with $p = 0.537$, $p = 0.718$ for Velachery, Alandur. However, in the instance of Manali, $p = 0.032$, indicating a significant increase in $PM_{2.5}$ levels in the month of May compared with April. This is in line with the earlier finding regarding concentration rise due to government relaxations. Considering that based on graphical analysis, Velachery observed the best reduction, it is seen that in that particular case as shown in Table 3, the mean $PM_{2.5}$ concentration of April ($10.3 \pm 8.2\ \mu g/m^3$, $p = 0.00$) is significantly lower than May ($12.48 \pm 5.82\ \mu g/m^3$, $p = 0.000$) in comparison with March ($27.05 \pm 9.10\ \mu g/m^3$).

3.1.2 Weekly Average

The weekly average $PM_{2.5}$ concentration from the first week of March to the last week of April is plotted in Fig. 2 to understand the variations over the four phases of the lockdown. It was noticed that all three locations observe a decrease in the Phase-I of the lockdown. Phase-II and Phase-III of the lockdown are quite stable and of a lower range of values, wherein the average $PM_{2.5}$ concentrations were ranging

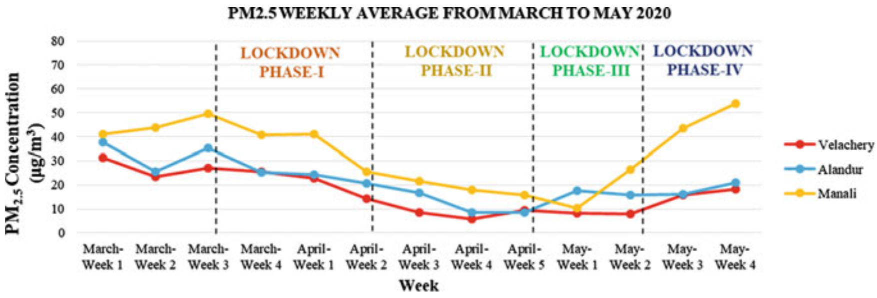

Fig. 2 Weekly average of $PM_{2.5}$ concentration—March to May 2020

between 7.74 and 7.92 µg/m^3 in Velachery and 16.7 and 19.3 µg/m^3 in Manali. From the second week of May, all three locations observe a rise in concentration. Manali observes the most significant rise in the month of May owing to restarting of industries, in comparison with the other two locations.

One-way ANOVA is carried out for the four phases of lockdown in Manali as shown in Table 4 and a significant difference is observed ($F(3,65) = 30.974$, $p = 0.000$). To understand the implications of the individual phases, Tukey HSD post hoc test is performed, wherein it is clear that Phase IV of the lockdown was significantly

Table 4 One-way ANOVA coupled with Tukey HSD post hoc test for weekly average $PM_{2.5}$ concentration in 2020—Manali

Dependent variable: $PM_{2.5}$ concentration

	(I) Lockdown phase	(J) Lockdown phase	Mean difference (I-J)	Standard error	Sig	95% Confidence interval	
						Lower bound	Upper bound
Tukey HSD	Phase I	Phase II	17.65000[a]	3.34805	0.000	8.8220	26.4780
		Phase III	15.10857[a]	3.69730	0.001	5.3597	24.8575
		Phase IV	–14.84929[a]	3.69730	0.001	–24.5982	–5.1004
	Phase II	Phase I	–17.65000[a]	3.34805	0.000	–26.4780	–8.8220
		Phase III	–2.54143	3.73409	0.904	–12.3873	7.3045
		Phase IV	–32.49929[a]	3.73409	0.000	–42.3452	–22.6534
	Phase III	Phase I	–15.10857[a]	3.69730	0.001	–24.8575	–5.3597
		Phase II	2.54143	3.73409	0.904	–7.3045	12.3873
		Phase IV	–29.95786[a]	4.05019	0.000	–40.6372	–19.2785
	Phase IV	Phase I	14.84929[a]	3.69730	0.001	5.1004	24.5982
		Phase II	32.49929[a]	3.73409	0.000	22.6534	42.3452
		Phase III	29.95786[a]	4.05019	0.000	19.2785	40.6372

[a] The mean difference is significant at 0.05 level

higher (49.26 ± 9.58 $\mu g/m^3$, p = 0.00) in comparison to all other phases, which is in line with the observations of the graphical study.

3.2 *Comparison of $PM_{2.5}$ Concentration from 2016 to 2020 to Understand the Effect of COVID-19 Lockdown*

The annual $PM_{2.5}$ concentration obtained from the Central Control Room for Air Quality Management—All India for the three locations from 2016 to 2020 was studied to observe the variations and trends in $PM_{2.5}$ levels over the years and also with special emphasis on seasonal trends.

3.2.1 Annual Average

Based on the data of yearly averages provided in Table 5, it is seen that Manali follows a steady decline in $PM_{2.5}$ concentration over the years from 2016 to 2019, whereas Velachery and Alandur do not. The yearly average $PM_{2.5}$ concentration for all the 3 locations has been listed below.

To delve further into the findings that Velachery and Alandur not following a steady decline through the years, exceedance factor (EF) method provided by CPCB was carried out. It is the ratio of the yearly average concentration of the pollutant to the yearly standard of that particular pollutant. Based on this above-stated equation, air pollution is classified into four distinct criteria as shown in Table 6. Location-wise and year-wise EF analysis is provided in Tables 7, 8 and 9 and the same is plotted in Fig. 3.

Table 5 Yearly average $PM_{2.5}$ concentration from 2016 to 2019

Year	Annual average $PM_{2.5}$ concentration ($\mu g/m^3$)		
	Velachery	Alandur	Manali
2016	40.49	70.82	72.92
2017	32.30	54.52	63.87
2018	39.95	59.32	62.36
2019	35.50	43.23	60.03

Table 6 Exceedance factor criteria

E.F	Criteria
Above 1.5	Critical pollution (C)
Between 1.0 and 1.5	High pollution (H)
Between 0.5 and 1.0	Moderate pollution (M)
Below 0.5	Low Pollution L

Table 7 Exceedance factor analysis—Velachery

Year	E.F	Criteria of classification
2016	0.99	Moderate pollution (M)
2017	0.77	Moderate pollution (M)
2018	1.00	High pollution (H)
2019	0.89	Moderate pollution (M)

Table 8 Exceedance factor analysis—Alandur

Year	E.F	Criteria of classification
2016	1.76	Critical pollution (C)
2017	1.36	High pollution (H)
2018	1.44	High pollution (H)
2019	1.07	High pollution (H)

Table 9 Exceedance factor analysis—Manali

Year	E.F	Criteria of classification
2016	1.86	Critical pollution (C)
2017	1.6	Critical pollution (C)
2018	1.56	High pollution (H)
2019	1.51	High pollution (H)

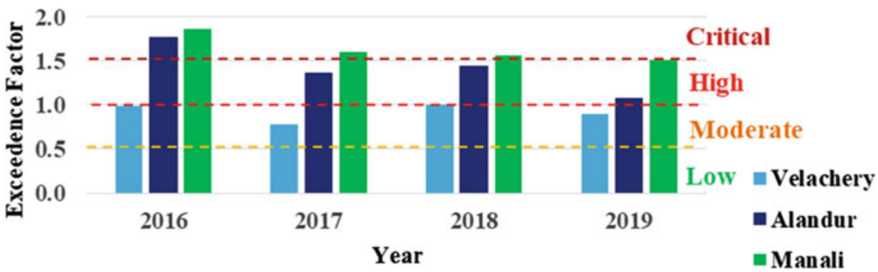

Fig. 3 Comparison of exceedance factors for the three locations from 2016 to 2020

From the exceedance factor analysis, it is deduced that the EF of Velachery in 2018 had risen to 1.00 (High Pollution) compared with the previous year, where it was 0.77 (Moderate Pollution) and the EF of Alandur had risen to 1.44 in 2018 from 1.36 in 2017. This increase is in line with the findings provided in Table 5.

3.2.2 Seasonal Average

In addition to the Annual Average $PM_{2.5}$ concentrations in the three locations from 2016 to 2019, the seasonal average concentration was also studied to understand the

Table 10 Seasonal variations in $PM_{2.5}$ concentrations (values in $\mu g/m^3$)

Year	Winter	Summer	Monsoon	Post monsoon
Velachery				
2016	58.39	41.47	25.49	44.76
2017	38.36	34.37	24.10	30.57
2018	45.86	36.64	39.31	40.14
2019	32.70	37.68	34.80	36.50
Alandur				
2016	100.02	79.52	52.45	65.36
2017	65.65	57.69	44.79	56.37
2018	63.84	34.38	67.06	63.85
2019	77.50	31.59	28.96	48.98
Manali				
2016	53.09	94.53	43.29	110.07
2017	74.57	79.13	58.26	49.10
2018	90.07	48.89	54.61	67.65
2019	71.05	56.65	50.76	69.53

variations in levels across different seasons and is provided below in Table 10. It is seen that in all three locations, the winter season has the highest concentration of $PM_{2.5}$ in comparison to the other seasons. This finding of the winter season having a higher concentration of pollutants has also been reported for other parameters such as SO2, NOx and SPM earlier in a study [14]. The seasonal concentrations observed for the three locations are provided in the tables.

Considering that the COVID-19 lockdown period in 2020 falls in the summer months of 2020, the average $PM_{2.5}$ concentration during the summer season during the previous years was considered for the comparative study. It is evident to consider that earlier studies have reported that pollutant concentrations tend to decrease during the progression into summer owing to greater surface heating caused by the increased PBLH height [15].

The average $PM_{2.5}$ concentration observed in all the three locations during the summer season of 2016–2020 is provided in Table 11. From the table, it is observed that in all three locations, there is a reduction in average $PM_{2.5}$ concentration in the year 2020 in comparison with the other years. The average $PM_{2.5}$ concentration in the summer season from the year 2016 to 2020 is provided in Fig. 4.

A significant difference is observed between the average $PM_{2.5}$ concentration in summer in the years 2016 to 2020 as seen using the one-way ANOVA(Velachery: $F(4,455) = 6.295$, Alandur: $F(4,407) = 9.866$ and Manali: $F(4,447) = 61.832$ where $p = 0.000$ for all the three locations.) Tukey HSD Post Hoc Test shows that there is a statistically significant difference in the summer of 2020 when compared with all other years, wherein $p < 0.05$ in Velachery and Manali. However, in Alandur, it is deduced that there the difference is not significant when compared with 2018

Table 11 Average $PM_{2.5}$ concentration during summer season

Year	Summer season average $PM_{2.5}$ concentration ($\mu g/m^3$)		
	Velachery	Alandur	Manali
2016	41.37	78.74	94.51
2017	34.25	57.95	79.09
2018	36.75	40.21	49.45
2019	37.66	38.32	55.76
2020	16.69	20.89	33.16

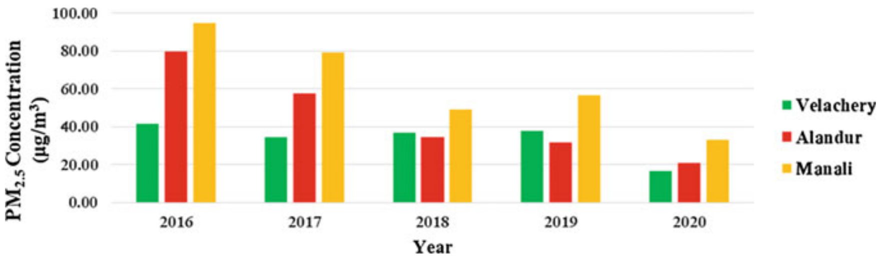

Fig. 4 Average $PM_{2.5}$ concentration in summer season (2016–20)

and 2019, wherein p = 0.453 and = 0.398, respectively. Manali witnesses the best reduction in average $PM_{2.5}$ concentration in the summer of 2020 when compared with the other locations as evidenced in Table 12.

4 Conclusions

The study of ambient air quality in a bustling urban setting such as Chennai city during the COVID-19 pandemic nationwide lockdown considering the complete cessation of anthropogenic activities is an ideal avenue to understand the impact and implications of human interference in the environment. From the study of $PM_{2.5}$ concentration during the COVID-19 lockdown period, it is seen that April 2020 achieved the best reduction overall in all three locations with the highest achieved in Velachery (65.2%), Manali being an industrial area, due to relaxations sanctioned by the government on logistical and industrial front during the Phase-IV of the lockdown, sees a significant increase in May 2020 compared with the previous month, which is corroborated by the one-way ANOVA coupled with Tukey HSD post hoc test. Besides, when comparing the $PM_{2.5}$ levels of 2020 with the previous years, it is seen that Manali follows a steady decline over the years up to 2019, whereas Velachery and Alandur show an increase in the year 2018. Exceedance Factor analysis study further validates this finding by providing the result that the EF of Velachery had risen

Table 12 One-way ANOVA coupled with Tukey HSD post hoc test for average $PM_{2.5}$ concentration in summer season—Manali

Dependent variable:PM2.5 concentration							
	(I) Year	(J) Year	Mean difference (I-J)	Standard error	Sig	95% Confidence interval	
						Lower bound	Upper bound
Tukey HSD	2016	2017	15.41741[a]	4.39956	0.005	3.3672	27.4676
		2018	45.06109[a]	4.37532	0.000	33.0773	57.0449
		2019	38.75060[a]	4.45098	0.000	26.5596	50.9416
		2020	61.34630[a]	4.37532	0.000	49.3625	73.3301
	2017	2016	–15.41741[a]	4.39956	0.005	–27.4676	–3.3672
		2018	29.64367[a]	4.39956	0.000	17.5935	41.6938
		2019	23.33319[a]	4.47481	0.000	11.0769	35.5895
		2020	45.92889[a]	4.39956	0.000	33.8787	57.9791
	2018	2016	–45.06109[a]	4.37532	0.000	–57.0449	–33.0773
		2017	–29.64367[a]	4.39956	0.000	–41.6938	–17.5935
		2019	–6.31049	4.45098	0.617	–18.5015	5.8805
		2020	16.28522[a]	4.37532	0.002	4.3014	28.2690
	2019	2016	–38.75060[a]	4.45098	0.000	–50.9416	–26.5596
		2017	–23.33319[a]	4.47481	0.000	–35.5895	–11.0769
		2018	6.31049	4.45098	0.617	–5.8805	18.5015
		2020	22.59571[a]	4.45098	0.000	10.4047	34.7867
	2020	2016	–61.34630[a]	4.37532	0.000	–73.3301	–49.3625
		2017	–45.92889[a]	4.39956	0.000	–57.9791	–33.8787
		2018	–16.28522[a]	4.37532	0.002	–28.2690	–4.3014
		2019	–22.59571[a]	4.45098	0.000	–34.7867	–10.4047

[a] The mean difference is significant at 0.05 level

from 0.77 to 1.00 in 2018 and Alandur from 1.36 to 1.44. Besides, as the COVID-19 lockdown period falls in the summer season, a comparison between the average $PM_{2.5}$ concentrations during the summer season of other years was considered. It was seen that there is a visible reduction in 2020 compared with other years in all three locations, and the most significant decrease is witnessed in Manali, wherein $p = 0.000$ when 2020 was compared with all other years in one-way ANOVA with Tukey HSD post hoc test. These results authenticate the claims of the COVID-19 pandemic lockdown in 2020 particularly in Chennai being a boon with regards to reduction in particulate matter concentrations, especially $PM_{2.5}$ as seen from this study due to a decrease in anthropogenic influences.

Acknowledgements The authors are thankful to the Central Pollution Control Board for facilitating the provision of $PM_{2.5}$ concentrations for Velachery, Alandur and Manali for various time periods in this study through the 'Central Control Room for Air Quality Management—All India' website.

References

1. Raju, H. P., Partheeban, P., & Hemamalini, R. R. (2012). Urban mobile air quality monitoring using GIS, GPS, sensors and internet. *International Journal of Environmental Science and Development*, *3*(4), 323–327.s https://doi.org/10.7763/ijesd.2012.v3.240.
2. Guo, H., Kota, S. H., Sahu, S. K., & Zhang. H. (2019). Contributions of local and regional sources to PM2.5 and its health effects in north India. *Atmospheric Environment*, *214*, 116867. https://doi.org/10.1016/j.atmosenv.2019.116867.
3. Guo, H. et al. (2017). Source apportionment of PM2.5 in North India using source-oriented air quality models. *Environmental Pollution*, *231*, 426–436. https://doi.org/10.1016/j.envpol.2017.08.016.
4. CPCB. (2019). Annual report (2018–19).
5. Dahiya, B. (2003). Peri-urban environments and community driven development: Chennai, India. *Cities*, *20*(5), 341–352. https://doi.org/10.1016/S0264-2751(03)00051-9.
6. Tamil Nadu Pollution Control Board. (2019). Annual reports and accounts.
7. World Health Organization. (2020). Novel Coronavirus (2019-nCoV) situation report-1.
8. World Health Organization-India. (2020). Coronavirus disease 2019 (COVID-19), Global situation update-situation report-1.
9. Masum, M. H., & Pal, S. K. (2020). Statistical evaluation of selected air quality parameters influenced by COVID-19 lockdown. *Global Journal of Environmental Science and Management*, *6*, 85–94. https://doi.org/10.22034/GJESM.2019.06.SI.08.
10. Mandal, I., & Pal, S. (2020). COVID-19 pandemic persuaded lockdown effects on environment over stone quarrying and crushing areas. *Science of the Total Environment*, *732*, 139281. https://doi.org/10.1016/j.scitotenv.2020.139281.
11. Sharma, S., Zhang, M., Gao, J., Zhang, H., & Kota, S. H. (2020). Effect of restricted emissions during COVID-19 on air quality in India. *Science of the Total Environment*, *728*, 138878. https://doi.org/10.1016/j.scitotenv.2020.138878.
12. Singh, R. P., & Chauhan, A. (2020). Impact of lockdown on air quality in India during COVID-19 pandemic. *Air Quality, Atmosphere, and Health*, *13*(8), 921–928. https://doi.org/10.1007/s11869-020-00863-1.
13. Sharma, M., Jain, S., & Lamba, B. Y. (2020). Epigrammatic study on the effect of lockdown amid Covid-19 pandemic on air quality of most polluted cities of Rajasthan (India). *Air Quality, Atmosphere, and Health*, *13*(10), 1157–1165. https://doi.org/10.1007/s11869-020-00879-7.
14. Chauhan, A., Pawar, M., Kumar, R., & Joshi, P. C. (2010). Ambient air quality status in Uttarakhand (India): A case study of Haridwar And Dehradun using air quality index. *Journal of American Science*, *6*(9), 565–568.
15. Singh, V., Singh, S., & Biswal, A. (2021). Exceedances and trends of particulate matter (PM2.5) in five Indian megacities. *Science of the Total Environment*, *750*, 141461. https://doi.org/10.1016/j.scitotenv.2020.141461.

Comparison of Nutrient Removal Efficiency, Growth Characteristic and Biomass Cultivation of Two Microalgal Strains Provided with Optimal Conditions in Agricultural Wastewater

R. V. Anusha Gowri, S. Dhanasekar, and R. Sathyanathan

Abstract Agricultural wastewaters can contain a lot of pollutants, so they can't be disposed of properly unless they're treated. Agricultural wastewaters, if improperly disposed of, can cause eutrophication of surface and ground waters, as well as impose substantial trade waste charges. Water scarcity in agricultural sector can be reduced by proper ground water recharge with treated agricultural wastewater. An ideal, economic and passive technology biological treatment facility is effective to replace chemical and physical treatment methods which would result in ground water contamination and are expensive. Microalgae are photosynthetic microorganisms that thrive in wastewater because of their rapid growth and adaptability [22]. Use of microalgae to remove nitrogen has many advantages. First, nitrogen is digested by microalgal cells which is used for biomass production as an essential nutrient factor. Biofuel production from microalgae could be more effective, with a smaller environmental footprint and no competition for arable land or biodiverse ecosystems. Present algae cultivation systems and lipid induction methods, on the other hand, need to be greatly enhanced. Optimal conditions to enhance the biomass production can be achieved with the help of photobioreactors in which the temperature, aeration, agitation and light intensities can be controlled. Thus, cultivation of *Chlorella vulgaris* and *Scenedesmus obliquus* in agricultural wastewater will serve as an integrated wastewater treatment option since it serves as an effective media for algal biomass production as well as the pollutants such as ammonia and phosphate can be effectively removed by selected microalgal strains. Wastewater as an alternative media has a number of advantages, including wastewater cleaning, recycling, lowering emissions levels, and providing economic growth media [23]. To realize

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the full potential of *Chlorella vulgaris* and *Scenedesmus obliquus*, comprehensive studies of using wastewater as an economic growth medium.

Keywords Microalgae · Photo bioreactor · Wastewater treatment · Nutrients · Biological treatment

1 Introduction

1.1 Background

At the moment, all modern energy storage strategies must be developed with the global effect and economy in mind. Due to the application of fertilizers and pesticides, a broad range of chemicals, especially nitrates and phosphates compounds, as well as some heavy metals, are present in agricultural wastewater, posing a major environmental pollution concern [1]. Heavy metals in wastewater are typically non-biodegradable compounds that accumulate within living organisms, resulting in bioaccumulation and a variety of environmental effects. Owing to higher energy use, the use of chemical additives, and contaminated air, the water and wastewater treatment plant (WWIP), which is marketed as an effective treatment facility, raises environmental issues.

1.2 Specification

The specifications are the integrated water treatment and comparative study of nutrient removal efficiencies with two microalgal species in a photo bioreactor.

1.3 Agricultural Wastewater

Water is essential for food production, and climate change puts this most valuable resource in jeopardy. Agriculture currently accounts for 70% of global freshwater withdrawals and more than 90% of its consumptive consumption [2, 3]. Freshwater supplies are under tremendous strain as a result of population and economic growth. Because, of the advantages that can be gained from the reuse of wastewater as well as the valuable by-products such as biogas, biofertilizers, biomass, and others, the effectiveness of Integrated Systems for agricultural wastewater treatment has been found to be suitable for developing countries [4, 16]. Microalgae cultivation using wastewater achieves the highest biomass efficiency among all terrestrial bio-remediators for contaminant pollutant removal by 80–90% (40–50% higher than terrestrial crops) [5]. An important quantity of pollutants can be removed by integrated systems. The construction and set-up of such systems prove the importance of treating agricultural wastewater to obtain by-products and avoid environmental pollution.

1.4 Algal Biomass

The microalgae culture may use the biogas provided during the biological treatment as a source of CO_2. Micro algae generally are thought to contain up to 70%, 60% and 65% of lipids, carbohydrates, and proteins and essential amino acids respectively.[6] When compared to traditional crops, microalgae cultivation for biomass production has a higher environmental impact such as energy use, greenhouse gas emissions, and water use. Only by using wastewater and flue gas as a nutrient and carbon source can the environmental impact be minimized [7, 18]. Microalgal biomass is an alternative to traditional feedstocks because it has a shorter growth period than terrestrial plants or energy crops, higher biomass productivity, and a higher harvesting index. Because of its protein content, algal biomass can be used as a proteinic animal supplement (40–70%). It should be noted that algal biomass can be fed to all of the animals that provide waste to the plant, substituting for a portion of the protein they need (10%). Second, under aerobic conditions, microalgae can extract both ammonium and nitrate in a single reactor [8]. The use of microalgae to remove pollutants has many advantages. Algae has the ability to grow under harsh environmental stress conditions such as higher nitrogen and phosphate concentrations. Additionally they reduce eutrophication and remove harmful pollutants with increase in biomass concentrations [9]. First, nitrogen is assimilated by microalgal cells for biomass production as an essential nutrient factor [10]. Second, phosphorous removal from the wastewater results in phosphate starvation stress which may accumulate higher concentrations of lipids with reduction in chlorophyll a,b and nucleic acids.

1.4.1 Microalgal Strains Selection

The aims of this study are to investigate the growth characteristics of two widely used green algal species, *Chlorella vulgaris* and *Scenedesmus obliquus*, as well as nitrogen and phosphate removal from agricultural wastewater with high ammonium and phosphate as nutrient sources [11]. *Scenedesmus sp.* demonstrated higher utilisation efficiency of textile desizing wastewater when cultivated [12, 19]. Butyrate, propionate, and acetate yields were 98.2%, 97.1%, and 95.2%, respectively, with a growth rate of 0.53 gd^{-1}, biomass productivity of 74 $gm^{-2}d^{-1}$, and lipid yield of 20%.

1.5 Photo Bioreactor

Closed structures, also known as photobioreactors (PBR), are more complex and expensive when compared to open raceway ponds. Each design has its own advantages and disadvantages [13, 20]. The culture is agitated in PBRs, which are typically made of glass or plastic. *Chlorella*, *Spirulina*, *Scenedesmus*, and other algae have been grown in these photobioreactors. Another concept designed in Chile up to a scale of 110 m^2 of solar irradiation area is a pond made of cement lined with epoxy resin and covered with a polyethylene dome [14]. Algae are often grown in processes similar to traditional agriculture due to their reliance on large areas and sunlight radiation; on the other hand, modern processing techniques include growth within PBR [15]. Since closed systems are less prone to contamination, they may be able to support the development of biomass. They also have a high surface-to-volume ratio and much higher biomass concentrations (2–5 g/L) than open ponds, which makes harvesting and dewatering much easier.

2 Materials and Methods

2.1 Strain Selection

Scenedesmus obliquus (FACHB-417) and *Chlorella vulgaris* (FACHB-1227) were obtained from the Algae Phycospectrum Environmental Research Centre (PERC) culture set. Before the experiment, the algae were pre-cultivated in flasks using BG-11 medium [21] and white, red, and blue LEDs operating at a light intensity of 115 mol/s/m^2 under a 16 h:8 h light/dark period. The optimum room temperature was set at 22 °C (Figs. 1, 2 and 3).

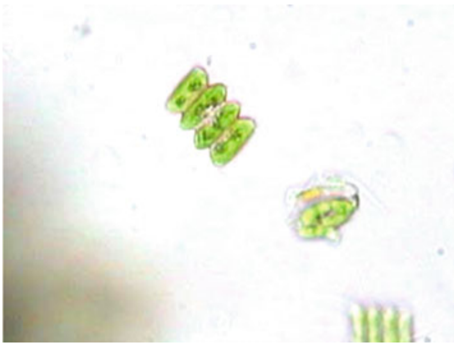

Fig. 1 Light Microscope image of a *Scenedesmus obliquus*

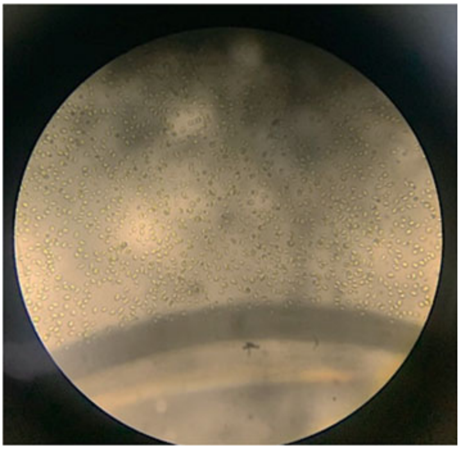

Fig. 2 Light Microscope image of b) *Chlorella vulgaris*

Fig. 3 Culture of *Chlorella vulgaris* cultivated in plate streaking

2.1.1 Synthetic Wastewater Preparation

The synthetic wastewater were prepared with slight modifications in the $(NH_4)H_2PO_4$ and P_2O_5 compositions. Higher concentrations of ammonia and phosphate was considered during the preparation since the agricultural wastewater will serve as a stress condition for maximum lipid accumulation the microalgal cells. The carbon source was provided by glucose and for macro and micronutrients the following chemicals such as NH_4Cl, $NaNO_3$, NaCl, $CuSO_4.5H_2O$ and Co $(NO_3)_2.6H_2O$ were added in following compositions with pH maintained at 7 as mentioned in Table 1.

Table 1 Composition of Synthetic agricultural wastewater

Composition	mg/L
Glucose	5600
NH_4Cl	300
$NaNO_3$	500
KH_2PO_4	45
NaCl	64
$CuSO_4.5H_2O$	1
$Co(NO_3)_2.6H_2O$	0.05
$(NH_4)H_2PO_4$	10
P_2O_5	5

2.1.2 Initial Characteristic Study of Prepared Wastewater

The initial characteristic studies such as COD, ammonium and phosphate were performed and found to be 6500 mg/L, 82 mg/L and 22 mg/L by Open reflux method and UV spectroscopy methods respectively.[(1)]

2.2 Cultivation of Micro Algae

Chlorella vulgaris and *Scenedesmus obliquus* were cultivated in traditional BG-11 media and was centrifuged at 1,957 × g for 5 min and the pellets were washed in deionized water which was again centrifuged at 1,957 × g for 5 min. Collected pellets were suspended in agricultural wastewater samples. The cultures were grown under optimal conditions at 16 h L:8 h D cycle of photoperiod while placed in shakers with 160 rpm speed.

2.3 Estimation of Biomass Concentration

The microalgal biomass grown in agricultural wastewater was filtered through 0.45 μm cellulose acetate filter membrane. Dry weight of the blank filter and the dry weight of filter with algal biomass after drying at 105 °C for 24 h were measured. The microalgal concentration mg/L were calculated using the formula:

$$\text{Biomass concentration mg/L} = \frac{\text{Dry weight of filter with algae (mg)} - \text{Dry weight of blank}}{\text{Volume of micro algae}}$$

2.4 Analysis of Nutrient Removal

The nutrients such as nitrogen and phosphate removal efficiencies of two microalgal stains such as the *Chlorella vulgaris* and *Scenedesmus obliquus* were monitored and studied. The samples were withdrawn from the reactor at daily basis and were centrifuged at 1975 × g to separate the algal biomass. NH_4–N and PO_4–P estimation were carried out in the harvested clear supernatant by Nesslerization method and Stannous chloride method in Vis UV-spectrophotometer.[(2)]

3 Results and Discussion

3.1 *Biomass Characteristic Study of* Chlorella Vulgaris *and* Scenedesmus Obliquus *in Agricultural Wastewater Samples Compared to BG-11 Media*

The growth media was the prepared wastewater samples and the estimation of biomass along with comparative study on *Chlorella vulgaris* and *Scenedesmus obliquus* were performed. Figure 5 Depicts the growth curve of *Chlorella vulgaris* with different concentrations of NH_4 and PO_4 as mentioned in Table 2. It was observed that the microalgal biomass concentration was higher on 4th and 5th days when compared to traditional BG-11 media[(1)]. There was nearly an increase of 2000 mg/L of biomass concentration at 5th day when compared to that of the growth phase of *Chlorella vulgaris* when cultivated in BG-11 media. It was grown in photoperiod of 16 h L: 8 h D cycle, with 115 μmol/s/m^2 of light intensity. The final average biomass yield when grown in wastewater samples s1, s2 and s3 were 1.9 g, 2.1 g and 2.8 g respectively at day five. And it was much higher when compared to the final biomass of algae grown in BG-11 media which was 0.9 g/L.

Figure 5, Depicts the growth curve of *Scenedesmus obliquus* grown in synthetic wastewater in varying concentrations of NH_4 and PO_4 as mentioned in Table 2[(1)]. When compared to microalgae grown in BG-11 media, during 5th day the biomass concentrations were much lower than the cultures grown in wastewater media. There was nearly an increase of 2500 mg/L of biomass concentration at 5th day when compared to that of the growth phase of Scenedesmus obliquus when cultivated in BG-11 media. It was grown in photoperiod of 16 h L: 8 h D cycle, with 115 μmol/s/m^2 of light intensity. When compared to *Chlorella vulgaris* strain, *Scenedesmus obliquus* showed much higher biomass concentrations, when it was cultivated in wastewater.

Table 2 Different initial concentrations of NH_4-N (mg/L) and PO_4-P (mg/L) in S1, S2 and S3

Samples	NH_4-N (mg/L)	PO_4-P (mg/L)	pH
S1	82 mg/L	22 mg/L	7
S2	76 mg/L	120 mg/L	7
S3	108 mg/L	26 mg/L	7

Fig. 4 Prepared synthetic wastewater sample

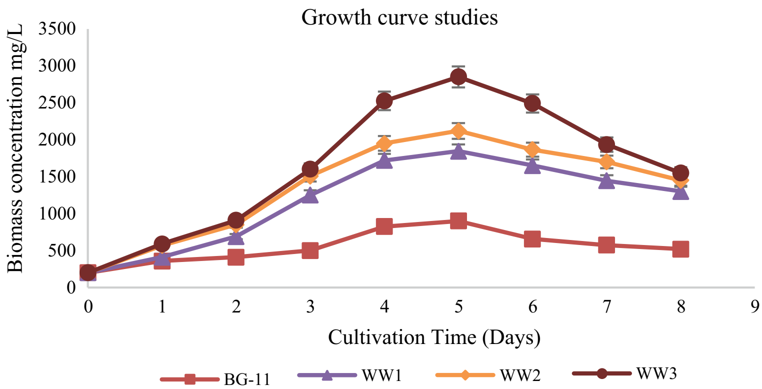

Fig. 5 The growth curve studies and biomass concentration analysis of *Chlorella vulgaris* cultivated in BG-11, WW1, WW2. (BG-11- Blue green medium, WW1- Waste water sample 1, WW2-Waste water sample 2, WW3- Waste water sample 3) and WW3 medias, (WW1- Waste water sample 1, WW2-Waste water sample 2, WW3- Waste water sample 3)

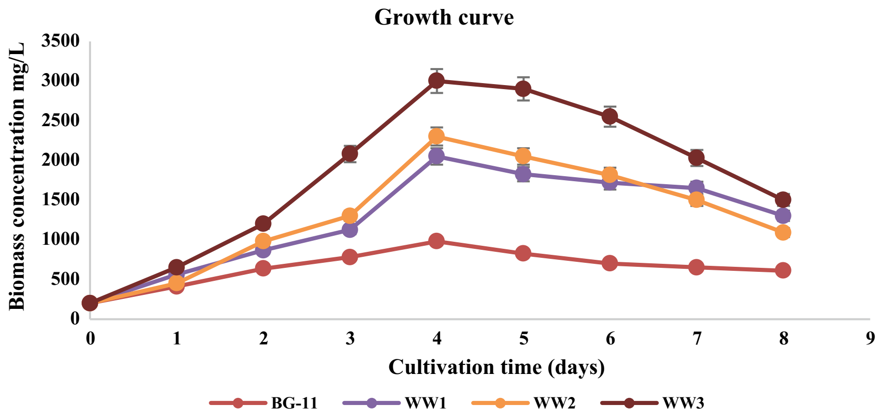

Fig. 6 The growth curve studies and biomass concentration analysis of *Scenedesmus obliquus* cultivated in BG-11, WW1, WW2 and WW3 medias. (BG-11- Blue green medium, WW1- Waste water sample 1, WW2-Waste water sample 2, WW3- Waste water sample 3)

The final average biomass yield when grown in wastewater samples s1, s2 and s3 were 2 g, 2.3 g, 3 g respectively at day 4. And it was much higher when compared to the final biomass of *Chlorella vulgaris* and *Scenedesmus obliquus* grown in BG-11 media which was 0.82 g/L (Fig. 6).

3.2 Optimal Conditions for Algal Growth

See Fig. 7.

3.3 Nutrient Removal

3.3.1 NH_4-N Removal Efficiency of *Chlorella Vulgaris* and *Scenedesmus Obliquus* in S1, S2 and S3

The efficiency in NH_4-N removal with different initial concentrations as mentioned in the Table 2, from the wastewater samples by *Chlorella vulgaris* is highly effective and obtained maximum removal. After 3 days there was drastic improvement in the reduction of NH_4-N and the pattern was very steep[(1)]. During the log phase the reduction was much higher, which shows that the removal efficiency increases with the increase in biomass concentration. There was 95–97% removal efficiency in case of *Chlorella vulgaris* with respect to wastewater treatment.

The algal culture was extraordinarily efficient enough to remove and consume almost 96% of the initial ammonia concentration (Figs. 8 and 9).

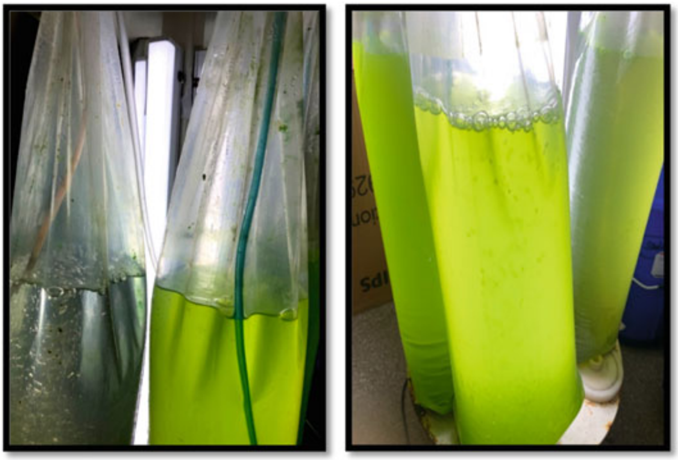

Fig. 7 Shows the experimental setup of microalgal growth in photo bioreactors and the comparison between Day1 of inoculation in WW1, WW2 and WW3 with Day 3. Day3 shows much greener and dense *Chlorella vulgaris and Scenedesmus obliquus* cultures when physical appearances were compared to day 1 (WW1- Waste water sample 1, WW2-Waste water sample 2, WW3- Waste water sample 3).**(1)**

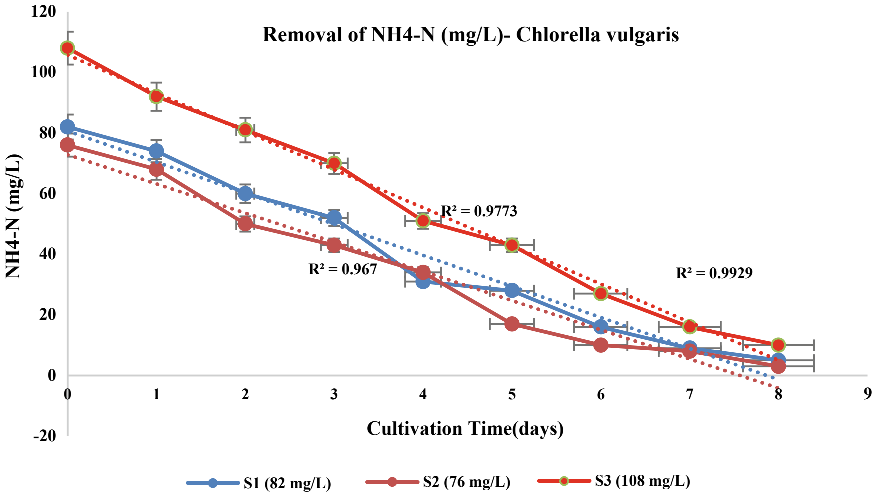

Fig. 8 The comparative study of the NH_4-N removal efficiency of *Chlorella vulgaris* in S1, S2 and S3 with different initial concentrations of NH_4-N as mentioned in Table 2. (S1- Waste water sample 1, S2- Waste water sample 2, S3- Waste water sample 3)

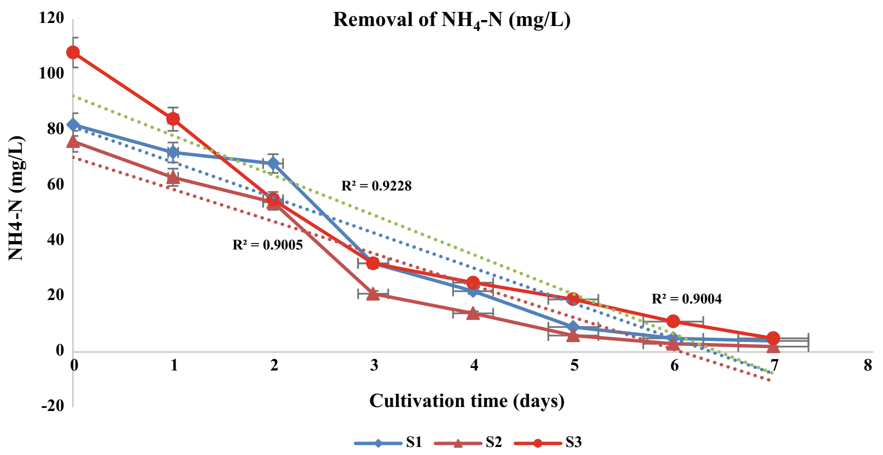

Fig. 9 The comparative study of the NH_4-N removal efficiency of *Scenedesmus obliquus* in S1, S2 and S3 with different initial concentrations of NH_4-N as mentioned in Table 2. (S1- Waste water sample 1, S2- Waste water sample 2, S3- Waste water sample 3)

In case of *Scenedesmus sp.* the NH_4-N was much more effective since from day 1 there was a steep reduction of ammonia when compared to initial concentrations. NH_4-N uptake was nearly 98% and almost complete reduction rate was achieved. Thus, the performance of *Scenedesmus obliquus* was spiffing when compared to *Chlorella vulga*ris in case of NH_4-N removal.

The influence of photoperiod with higher light intensity of 115 μmol/s/m^2, temperature and aeration provided in the photo bioreactor has enhanced the removal rates when compared to conical flask cultivation of algal without optimal conditions and monitoring.

3.3.2 PO_4-P Removal Efficiency of *Chlorella Vulgaris* and *Scenedesmus Obliquus* in S1, S2 and S3

The efficiency in PO_4-P removal with different initial concentrations as mentioned in the Table 2, from the wastewater samples by *Chlorella vulgaris* is highly effective and obtained maximum removal. Before being added to the wastewater, our cultures were not starving[(1)]. As a result, it's likely that starved cultures would accumulate more phosphate than seen in this analysis. Higher PO_4–P removal was amplified after 3 days, and it was found that there was 99–100% removal efficiency when compared to the initial concentration. With the higher light period provided we have achieved the best removal rates in case of PO_4-P when compared to NH_4–N. In case of *Scenedesmus obliquus* species the removal efficiencies were better than *Chlorella vulgaris* and there was much significant removal after day 2. When comparing the initial and final nutrient concentrations that were present in the wastewater samples, the trend of removal of nutrients were similar by both the species. Differences in the

NH_4–N and PO_4–P depletion rates that were observed was not much higher when *Scenedesmus obliquus* was compared to *Chlorella vulgaris*, yet the performance of the Scenedesmus obliquus was better. For both the nutrient removal studies in *Chlorella vulgaris* and *Scenedesmus obliquus* the magnitude has been enhanced with higher light period and light intensity.[3] There was also a getter correlation of growth curve and nutrient removal efficiencies, and it was observed that the NH_4-N and PO_4-P depletion increases with increase in the algal biomass. The peak removal of the nutrient was between day 2 and day 4 when the biomass concentration was much higher (Figs. 10 and 11).

In this work, it can be concluded that than *Chlorella vulgaris*, *Scenedesmus obliquus* strain of microalgae has better ammonia and phosphate removal efficiencies

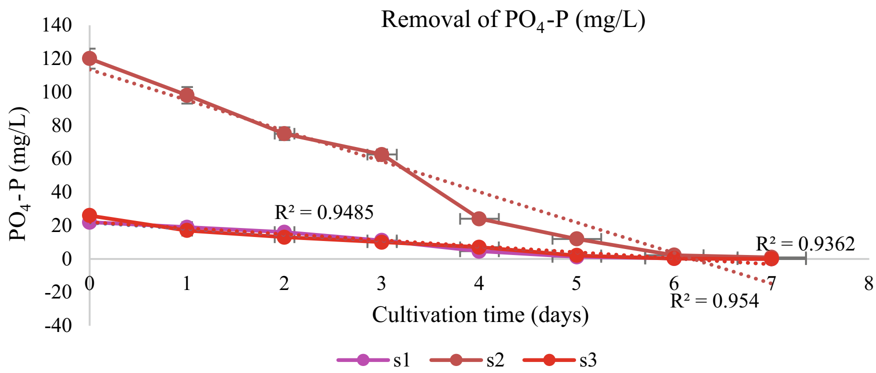

Fig. 10 The comparative study of the PO_4-P removal efficiency of *Chlorella vulgaris* in S1, S2 and S3 with different initial concentrations of PO_4-P as mentioned in Table 2. (S1- Waste water sample 1, S2- Waste water sample 2, S3- Waste water sample 3)

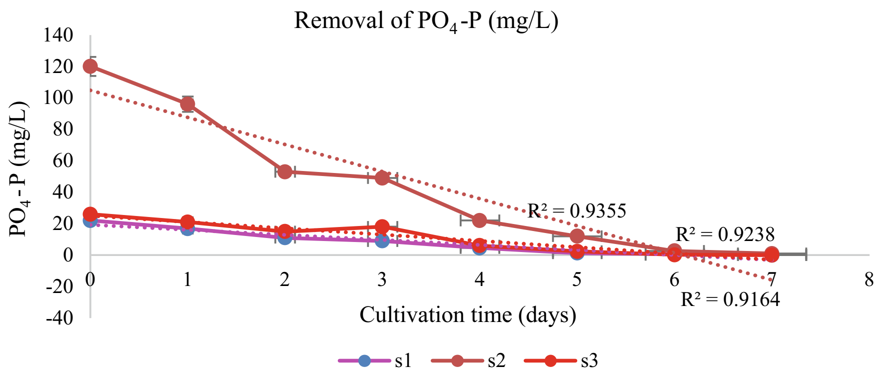

Fig. 11 The comparative study of the PO_4-P removal efficiency of *Scenedesmus obliquus* in S1, S2 and S3 with different initial concentrations of PO_4-P as mentioned in Table 2. (S1- Waste water sample 1, S2- Waste water sample 2, S3- Waste water sample 3)

Table 3 Reported ammonia and phosphate removal efficiencies by *Chlorella vulgaris* and *Scenedesmus obliquus* with a comparison to present study. (3)

S. NO	Species	Medium	Removal efficiency of NH_4-N (%)	Phosphate removal(%)	Reference
1	*Chlorella vulgaris*	Synthetic wastewater enriched with Ammonium-Nitrogen	85	94%	Junping Lv et al. 2018
2	*Scenedesmus obliquus*	Synthetic wastewater enriched with Ammonium-Nitrogen	92	96%	Junping Lv et al. 2018
3	*Chlorella vulgaris*	Modified Bristol medium	53.12	–	Tam and Wong 1998
4	*Scenedesmus obliquus*	Domestic wastewater	95.03	–	Nayak et al. [17]
5	*Chlorella vulgaris*	Mixed wastewater of primary effluent and anaerobic digestion	50.60	–	Wang et al. 2014
6	*Chlorella vulgaris*	Concentrated municipal wastewater with waste glycerol	100	90%	Xiaochen Ma et al.2016
7	*Chlorella vulgaris*	Synthetic wastewater	92	99%	Present study
8	*Scenedesmus obliquus*	Synthetic wastewater	98	100%	Present study

when they are cultivated in agricultural wastewater which is rich in ammonia and phosphate. Similarly, total biomass concentration was higher in *Chlorella vulgaris* and *Scenedesmus obliquus* when they were cultivated in wastewater than in traditional BG-11 media. *Scenedesmus obliquus* has higher potential than *Chlorella vulgaris* in treating agricultural wastewater along with higher biomass production. Thus, when suitable microalgal strain is selected for wastewater treatment higher potential can be achieved in both nutrient removal as well as biomass production. High quality byproducts such as biodiesel, bioethanol and bio-fertilizers can be harvested from the produced biomass after wastewater treatment (Table 3).

4 Conclusion

In this work, the NH_4–N and PO_4–P removal efficiencies with different initial concentrations in S1, S2 and S3, by two micro algal species *Chlorella vulgaris* and *Scenedesmus obliquus* were studied. The optimal conditions such as temperature, light intensities and the photo period of 16L:8D were adopted to enhance the improvement biomass concentration during the algal cultivation in prepared wastewater media. High NH_4–N removal efficiency was observed in both *Chlorella vulgaris* and *Scenedesmus obliquus* and much higher PO_4–P removal efficiency was also observed. Day 2–Day 5 is chosen to be the ideal period for the peak nutrient removal efficiency when the biomass concentration was at its peak. Though there were only a little significant difference in the nutrient removal efficiency when both the algal strains were compared yet *Scenedesmus obliquus* showed better performance. PO_4–P was almost completely removed by both the microalgal species with different initial PO_4–P concentrations and there was 96% removal of NH_4–N. Higher the biomass productivity higher was the nutrient removal rate. For both NH_4–N and PO_4–P removal only moderate aeration was required which was provided by motor pump.

When compared to other physical and chemical treatment solutions, biological degradation of microalgal wastewater may be a more efficient and cost-effective solution. Advantage of using micro algae is the introduction of biomass production along with improved nutrient removal rates thus it serves as an integrated treatment option. There is also a possibility of preventing the ground water contamination in case of ammonia and phosphate rich agricultural wastewater and possible recycling of assimilated NH_4–N and PO_4–P as a fertilizer. The microalgal biomass will contain higher colossal lipid accumulation with phosphate reduction stress and can be harvested after the wastewater treatment for production of various bioproducts such as bioethanol and biodiesel.

Chlorella vulgaris and *Scenedesmus obliquus* have the ability to treat agricultural wastewater containing major pollutants such as ammonium and phosphorus and can also be used as a mixed microalgal culture.

References

1. Abe, K., Imamaki, A., & Hirano, M. (2002). Removal of nitrate, nitrite, ammo- nium and phosphate ions from water by the aerial microalga Trentepohlia aurea. *Journal* of *Applied Phycology, 14*, 129–134.
2. Aksu, Z., Sag, Y., & Kutsal, T. (1992). The biosorption of copper (II) by Chlorella vulgaris and Zoogloea ramigera. *Environment Technology, 13*, 579–86.
3. Aravantinou, A. F., Theodorakopoulos, M. A., & Manariotis, I. D. (2013). Selection of microalgae for wastewater treatment and potential lipids production. *Bioresource Technology, 147*, 130–134.
4. Ayre, J. M., Moheimani, N. R., & Borowitzka, M. A. (2017). Growth of microalgae on undiluted anaerobic digestate of piggery effluent with high ammonium concentrations. *Algal Research, 24*, 218–226.
5. Bohutskyi, P., Kligerman, D. C., Byers, N., Nasr, L. K., Cua, C., Chow, S., Su, C., Tang, Y., Betenbaugh, M. J., & Bouwer, E. J. (2016). Effects of inoculum size, light intensity, and dose of anaerobic digestion centrate on growth and productivity of Chlorella and Scenedesmus microalgae and their poly-culture in primary and secondary wastewater. *Algal Research, 19*, 278–290.

6. Craggs, R., Sutherland, D., & Campbell, H. (2012). Hectare-scale demonstration of high rate algal ponds for enhanced wastewater treatment and biofuel production. The *Journal* of *Phycology, 24*, 329–337.
7. Eroglu, E., Agarwal, V., Bradshaw, M., Chen, X., Smith, S. M., Raston, C. L., & Iyer, K. S. (2012). Nitrate removal from liquid effluents using microalgae immobilized on chitosan nanofiber mats. *Green Chemistry, 14*, 2682–2685.
8. Ge, S., Wang, S., Yang, X., Qiu, S., Li, B., & Peng, Y. (2015) Detection of nitrifiers and evaluation of partial nitrification for wastewater treatment: A review. *Chemosphere*, *140*, 85–98.
9. Ghafari, S., Hasan, M., & Aroua, M. K. (2008). Bio-electrochemical removal of nitrate from water and wastewater—a review. *Bioresource Technology, 99*, 3965–3974.
10. Gonzalez, L. E., Canizares, R. O., & Baena, S. (1997). Efficiency of ammonia and phophorus removal from Colombian agroindustrial wastewater by the microalgae Chorella vulgaris and Scenedesmus dimorphus. *Bioresource Technology , 60*, 259–62.
11. Han, L., Pei, H., Hu, W., Jiang, L., Ma, G., Zhang, S., & Han, F. (2015). Integrated campus sewage treatment and biomass production by Scenedesmus quadricauda SDEC-13. *Bioresource Technology, 175*, 262–268.
12. Kumar, M., & Lin, J. G. (2010). Co-existence of anammox and denitrification for simultaneous nitrogen and carbon removal-strategies and issues. *Journal Hazard Mater, 178*, 1–9.
13. Li, X., Hu, H. Y., Gan, K., & Yang, J. (2010). Growth and nutrient removal properties of a freshwater microalga Scenedesmus sp. LX1 under different kinds of nitrogen sources. *Ecological Engineering, 36*, 379–381.
14. Lin, Q., & Lin, J. (2011). Effects of nitrogen source and concentration on biomass and oil production of a Scenedesmus rubescens like microalga. *Bioresource Technology, 102*, 1615–1621.
15. Magalhaes, J. R., & Huber, D. M. (1991). Response of ammonium assimilation enzymes to nitrogen form treatments in different plant species. *Journal* of *Plant Nutrition*, *14*, 175–185.
16. Markou, G., Depraetere, O., & Muylaert, K. (2016). Effect of ammonia on the photosynthetic activity of Arthrospira and Chlorella: a study on chlorophyll fluorescence and electron transport. *Algal Research, 16*, 449–457.
17. Nayak, M., Karemore, A., & Sen, R. (2016) Performance evaluation of microalgae for concomitant wastewater bioremediation, CO_2 biofixation and lipid biosynthesis for biodiesel application. *Algal Research, 16*, 216–223.
18. Podevin, M., De Francisci, D., Holdt, S. L., & Angelidaki, I. (2015). Effect of nitrogen source and acclimatization on specific growth rates of microalgae determined by a high-throughput in vivo microplate autofluorescence method. The *Journal* of *Applied Phycology, 27*, 1415–1423.
19. Rasoul-Amini, S., Montazeri-Najafabady, N., Shaker, S., Safari, A., Kazemi, A., Mousavi, P., Mobasher, M. A., & Ghasemi, Y. (2014). Removal of nitrogen and phosphorus from wastewater using microalgae free cells in bath culture system. *Biocatal Agric Biotechnol, 3*, 126–131.
20. Raven, J. A., & Giodano, M. (2016). Combined nitrogen. In M. A. Borowitzka, J. Beardall, & J. A. Raven (eds.) *The Physiology of Microalgae*. Springer, Dordrecht, pp. 143–154.
21. Rippka, R., Deruelles, J., Waterbury, J. G., Herdman, M. & Stanier, R. Y. (1979). Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *The Journal of General Microbiology, 111*, 1–61.
22. Salama, E. S., Kurade, B. M., Shanab, R. A. I. A., Dalatony, M. M. E., Yang, I. S., Min, B., & Jeon, B. H. (2017). Recent progress in microalgal biomass production coupled with wastewater treatment for biofuel generation. *Renewable and Sustainable Energy Reviews, 79*, 1189–1211.
23. Yadav, M. K., Short, M. D., Gerber, C., van den Akker, B., Aryal, R., & Saint, C. P. (2019). Occurrence, removal and environmental risk of markers of five drugs of abuse in urban wastewater systems in South Australia. *Environmental Science and Pollution Research, 26*, 33816–33826.https://doi.org/10.1016/j.scitotenv.2019.05.068

Revealing the Design of Energy-Efficient Techniques to Enhance the Building Performance

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Abstract Building temperature conditioning requires a considerable amount of energy in extreme climatic conditions. There are many ways to reduce the climate control load, the most notable of which is proper design and selection of the building envelope and its components. There is an increasing need to forecast energy consumption and consider alternative energy management measures (ECM) and design requirements for more energy-efficient construction during the design phase. The various parameters and alternatives are taken for the study. The results were gathered after the alternative scenarios were analyzed. Each case study compares annual energy consumption and costs. Both traditional and automated methods were used in the analysis, and validation work was performed. The findings show that integrating Autodesk Revit and the Green Building Studio, as well as integrated energy analysis and design choices, results in more energy-efficient buildings.

Keywords Energy · Sustainable · Annual cost · Green building studio · Orientation

1 Introduction

Development is the largest global electricity producer. Energy-efficient building architecture is expected to reduce CO_2 emissions. The location of the frame is one of the most significant elements of energy-efficient building architecture [1]. Significant reduction is a low-cost method of improving occupant satisfaction and cooling and heating system performance. A good building orientation allows the ideal winter

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sun to shine indoors while still allowing ventilation in the summer by facing the summer wind stream [2, 3]. The most important architecture parameters influencing indoor thermal comfort and energy efficiency at a building scale are the optical and thermos physical properties of the building envelope [4]. From the start of the design process, design engineers will think about the energy efficiency of their envelope models [5, 6]. For government agencies, architects, and engineers, reducing energy use, especially in office buildings, is a difficult task. To minimize the energy fee, it is essential to understand the architectural design features of existing high-rise office buildings in the hot tropics. Occupants are believed to have a significant impact on building efficiency [7–9]. The selection for the particular case of efficient modeling complexity is a critical problem when it comes to the implementation of people behavior models in building energy simulation (BES). A significant portion of the electricity produced by a building is usually attributed to its occupants [10]. Long-term use of building simulation is unavoidable as building design becomes more sophisticated and performance criteria become more stringent [11–13]. Orientation is also required to provide thermal comfort to occupants. It is important to consider climatic variables such as solar radiation and wind when evaluating the building's orientation [14]. Human–building interactions in office buildings are either designed or restricted, and occupancy data is easier to obtain than in residential buildings. As a consequence, occupancy data can be used in large building controls, especially when occupancy sensors are connected to the building management system [15, 16]. The direction of a system determines the amount of sunlight that reaches it. For greater energy quality, houses in the Northern Hemisphere should have southern exposure screens. When a passive solar system is faced south, the heat load is considerably decreased [17]. Owing to a lack of electricity availability and inadequate access to energy security, most tropical countries' energy demand is badly impacted. About the fact that energy depletion makes it difficult to use energy-intensive equipment such as air conditioners, successful structural architecture is the best way to achieve the desired thermal comfort [18–20]. New building framework designs, ironically, are being designed to meet the needs of consumers without regard for the environment or energy efficiency [21]. BIM implementation allows for better cooperation. This research paper used existing literature to explain the expectations and risks of BIM adoption, and then suggested risk-response strategies for implementing BIM, using a case study of a dynamic multipurpose building project facility [22]. A complex set of factors affect the thermal state of a building and, as a result, the amount of energy needed for mechanical indoor temperature control. Factors such as latitude, position, inclination, and building structure affect the amount of heat produced by solar energy [23–25]. Laptop computers, for example, are often wired to them. Portable machines used by the occupants move from room to room, absorbing energy or making heat gains. The bulk of tenant interaction patterns are affected by occupancy [26]. Building electricity usage accounts for much more than 70% of the total of all the other electricity used in urban areas, having a major impact on the functioning of the electric grid. The California smart house is an example of a building control system that is automated [27]. Low-energy building construction necessitates the use of advanced modeling techniques to measure heating and cooling loads. Such designs will provide residents with thermal comfort while still reducing energy usage over the building's lifespan. The key to planning for long-term sustainability is to have parameters that take into account thermal properties [28–30]. Since significant quantities of solar gain occur from exterior windows in tropical climates due to high solar radiation and average yearly temperature, the window-to-wall ratio (WWR) of a building is useful in predicting energy consumption [31]. Thermal comfort is needed in all types of lodging, including schools. A compatible indoor climate configuration is a change to the building's outdoor environment structure that is meant to supply warmth to the occupants. Many people agree that heat relief is an important factor to recognize in college design because it affects students' efficiency [32]. A huge amount of energy can be saved by the technology used. One of the most important green building goals is to reduce electricity use and greenhouse gas emissions. There is a lack of published literature on the project conducted on the orientation and lighting regulation of the area where the study was conducted with different choices, despite the emergence of multiple experimental and numerical science studies.

2 Model Development

Green Building Studio assists in the construction of high-performance buildings in a fraction of the time and expense required by traditional methods. The project's data is correctly obtained, as the quality of the analysis would have a direct effect on the final results. The aim is to construct a comprehensive model of a house, complete with atmosphere and materials. The school building chosen is located near Chennai, and the relevant information of the building is shown in Table 1, the data collected using the GBS software.

A 3D model of a school in Guduvencherry, Chennai, is shown in this image (Fig. 1). It was built in Revit Architecture and then exported to Green Building Studio for research, the gold standard in BIM energy analysis software.

Table 1 Basic information of building

Building type	Commercial building
Building	SRM school
Floors	G + 3
Situated	Guduvencherry
Area	2586.53 sqm
Dry bulb	99°F
Wet bulb	84°F

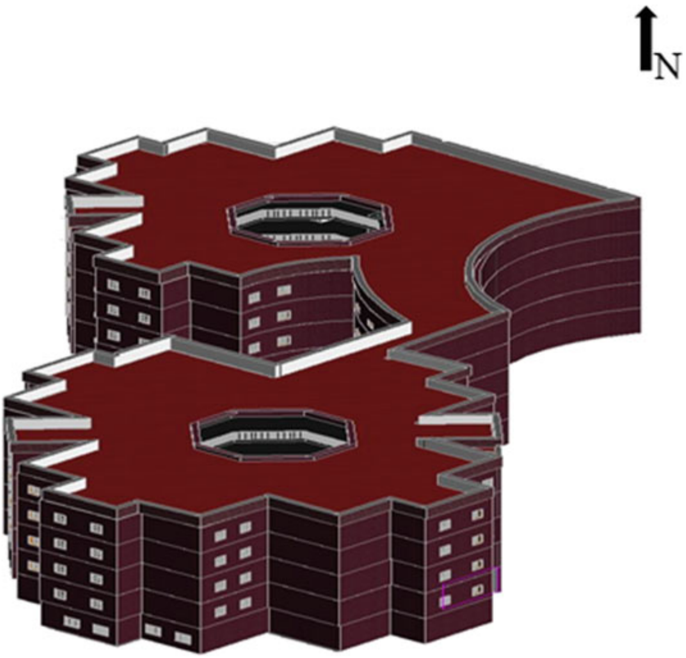

Fig. 1 3D model of a school building

3 Method

The energy used can be assessed using both conceptual and detailed knowledge-building models. Three simulation workflows of an Autodesk tool's main are building materials, conceptual mass, and gbXML exports. The data is then imported from Revit as a gbXML file and then sent to the Green Building Studio, where it would be further evaluated and design options for an energy-efficient structure are implemented.

For various orientations and lighting power, the investigation was carried out in both directions. The choices are made in the same way as they were in the Green Building Studio's energy simulation. Figure 2 depicts the process of creating alternatives.

Orientation and Lighting Control

The construction model is rotated in different ways to get the best effects. The direction of various places varies. Lighting management would help us save money on electricity because the construction of the building and the living occupants have a big impact on energy usage. Table 2 depicts a different simulation depending on the illumination and orientation.

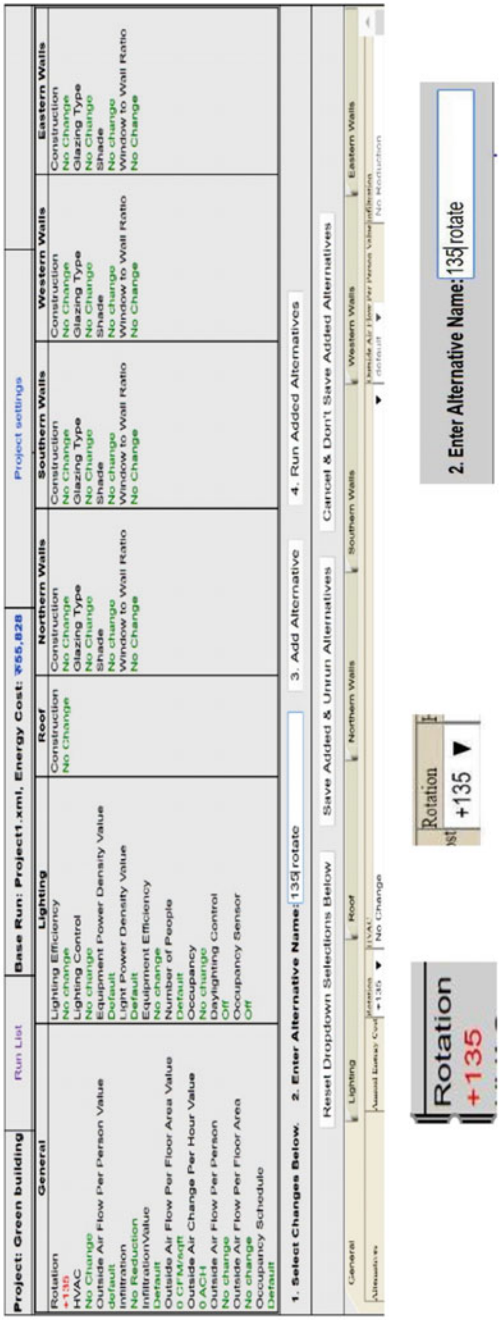

Fig. 2 Creating design alternatives

Table 2 Simulation alternatives for orientation and lighting control

S. no.	Orientation alternatives	Lighting control alternatives
1	+45°	Occupancy sensors
2	+90°	Daylighting sensors and controls
3	+135°	Occupancy/daylighting sensors and controls
4	+180°	
5	−135°	
6	−90°	
7	−45°	

4 Manual Method

For the city of Chennai, the energy cost per kWh and the fuel cost per MJ are 0.08 and 0.007, respectively. The following is a calculation for a 45° rotation using the conventional form. Table 3 lists 1–7 options for orientation and 8–10 options for lighting power.

Annual cost	Lifecycle cost
Electricity use = 667,172 kWh	Electricity use = 20,015,148 kWh
Cost = electricity use * actual cost	Cost = electricity use * actual cost
= 667,172kWh * 0.08/kWh	= 20,015,148kWh * 0.08/kWh
= 53,373.76	= 1,601,211.84
Fuel use = 314,269	Fuel use = 9,428,061
Cost = fuel use * actual cost	Cost = Fuel use * Actual cost
= 314,269 * 0.007/ MJ	= 9,428,061* 0.007/MJ
= 2199.883	= 65,996.427
Annual energy cost = 53,373.76 + 2199.883	Total lifecycle cost = 1,601,211.84 + 65,996.427
= 55,573.643	= 1,667,208.267

5 Results and Discussion

This chapter discusses the impact of modeling and data obtained from alternatives using a Green Building Studio.

Table 3 Annual energy cost and lifecycle cost using the traditional method

Alternatives	Annual energy use		Lifecycle use		Annual energy cost (Rs)	Lifecycle cost (Rs)
	Electricity use (kWh)	Fuel use (MJ)	Electricity use (kWh)	Fuel use (MJ)		
1	667,173	314,271	20,015,149	9,428,062	55,574	1,667,209
2	664,741	313,604	19,942,204	9,408,061	55,375	1,661,233
3	665,973	297,487	19,979,164	8,924,536	55,361	1,660,805
4	666,444	311,502	19,993,291	9,345,001	55,496	1,664,879
5	666,434	307,746	19,992,999	9,232,306	55,469	1,664,067
6	664,915	314,396	19,947,424	9,431,827	55,394	1,661,817
7	667,448	291,635	20,023,420	8,748,985	55,438	1,663,117
8	667,025	305,053	20,010,721	9,151,516	55,498	1,664,919
9	638,989	306,729	19,169,608	9,201,841	53,267	1,597,982
10	636,801	306,613	19,103,989	9,198,358	53,091	1,592,708

5.1 Orientation

This segment evaluates the effect of the building's orientation. Figures 3 and 4 show total annual energy costs and lifecycle costs for different orientation options (+45°, + 90°, +135°, +180°, −45°, −90°, −135). The 90° rotation configuration, according to the observations, lowers annual costs and total energy usage.

Figures 3 and 4 show the main differences between the orientation options. It is reasonable to believe that orienting a building at 135° will significantly decrease annual and lifecycle costs.

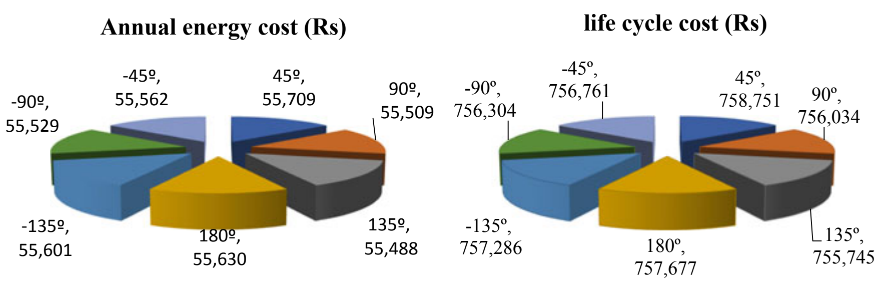

Fig. 3 Cost of different orientation alternatives

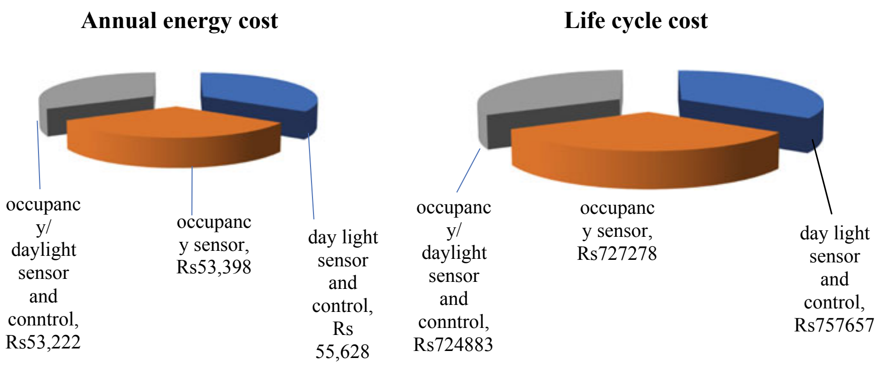

Fig. 4 Cost of different lighting control alternatives

5.2 Lighting Control

The findings of a comparison of different alternatives based on total annual energy expense and lifecycle cost are seen in Fig. 4. The building's cost can be decreased by using the lighting control as an occupancy/daylight sensor and control, making it more cost-efficient.

6 Comparison Using Software and Traditional Method

The research findings must be double-checked to back up the conclusions obtained using software and conventional approaches. The annual cost differential between conventional and software methods is minimal, but the lifecycle cost difference is larger, as seen in Table 4.

7 Summary of Recommendation

The proposed suggestion from the simulation results is summarized in Table 5.

Following the completion of the simulation, the best option for each parameter is selected, and the final simulation is run to demonstrate the differences between conventional and energy-efficient school buildings. The variations in results between the base run and the alternatives are shown in Fig. 5.

Table 4 Result using software and manual method

Alternatives	Manual method		Software method	
	Annual energy cost (Rs)	Lifecycle cost (Rs)	Annual energy cost (Rs)	Lifecycle cost (Rs)
45°	55,574	1,667,209	55,709	758,751
90°	55,375	1,661,233	55,509	756,034
135°	55,361	1,660,805	55,488	755,745
180°	55,496	1,664,879	55,630	757,677
(−135°)	55,469	1,664,067	55,601	757,286
(−90°)	55,394	1,661,817	55,529	756,304
(−45°)	55,438	1,663,117	55,562	756,761
Daylight sensor	55,498	1,664,919	55,628	757,657
Occupancy sensor	53,267	1,597,982	53,398	727,278
Occupancy/daylight sensor and control	53,091	1,592,708	53,222	724,883

Table 5 Simulation recommendation

Variables	Recommended alternative
Orientation	135°
Lighting control	Occupancy/daylight sensor and control

8 Conclusion

It can be inferred based on the study that

- Eventually, the project's various standards mean that modern buildings' thermal quality has increased, making the project more environmentally friendly.
- The thesis goal of performing simulation on energy conservation using Revit and Green Building Studio has been achieved with success. This can serve as a roadmap for aspiring designers to use BIM in their journey toward energy analysis.
- The difference in forecasting annual costs between the traditional method and the automatic method was less than 1%, but the difference in measuring lifecycle costs was more than 20%.
- The study's goal of conducting energy-saving simulations using Revit and Green Building Studio was accomplished.

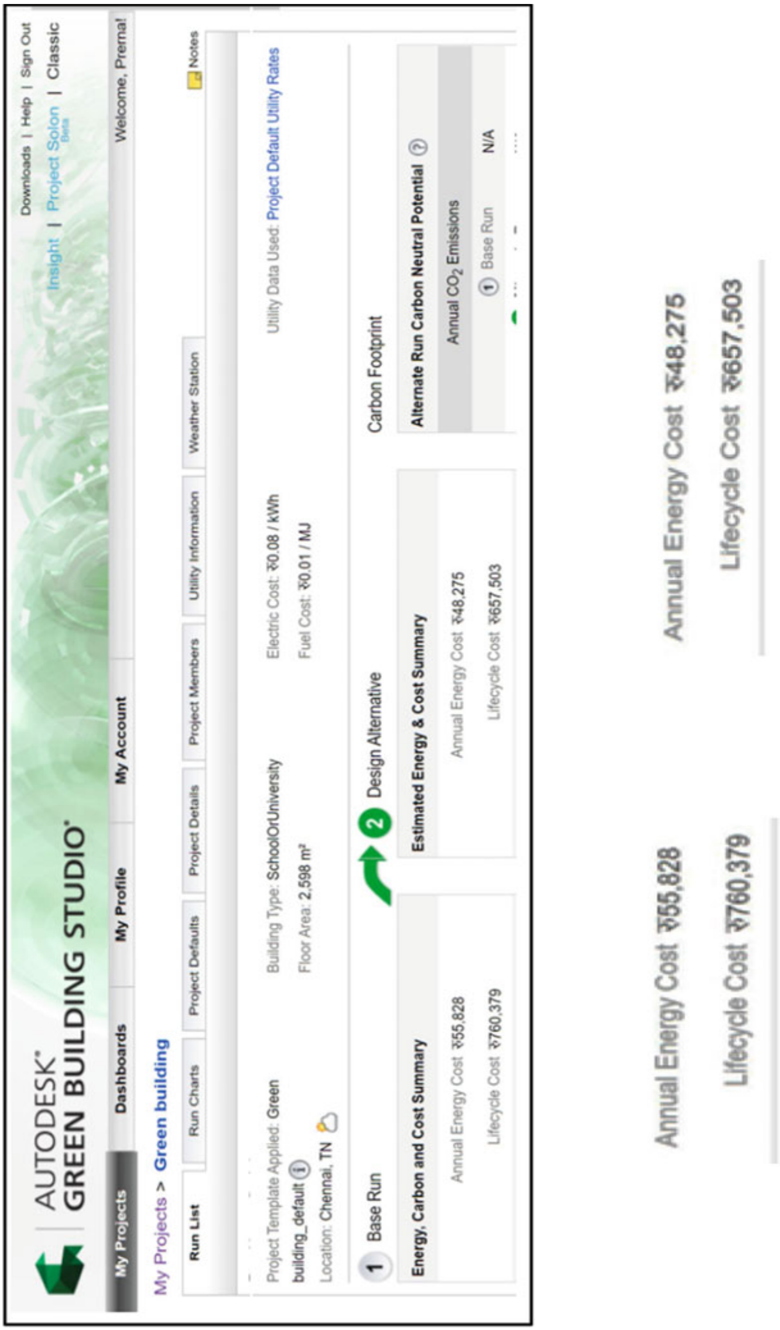

Fig. 5 Energy cost and lifecycle cost for base run and alternatives

References

1. Perez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Building,* 394–398.
2. Hedayati, A. (2016). BIM-based energy analysis of conventional residential buildings in hot-humid climate. *International Journal of Advances in Mechanical and Civil Engineering*, 64–68.
3. Vogiatzi, C., Gemenetzi, G., Massou, L., Poulopoulos, S., Papaefthimiou, S., & Zervas, E. (2018). Energy use and saving in residential sector and occupant behaviour: A case study in athens. *Energy & Buildings*, 1–24.
4. Ramesh Kannan, M. (2013). Whole building energy analysis using BIM. *International Conference on Advances in Civil Engineering*, 935–943.
5. Sharma, N., Kaur, B., & Goel, A. (2018). Green building based on BIM. *Indian Journal of Science and Technology*, 1–8.
6. BanihashemiNamini, S., Ding, G. K. C., & Wan, J. (2015). Developing a framework of artificial intelligence application for delivering energy efficient buildings through active BIM. *Research Gate*, 18–26.
7. Khan, R. J., Zubayer Hossain Bhuiyan, Md., & Hasan Ahmed, D. (2020). Investigation of heat transfer of a building wall in the presence of phase change material (PCM). *Energy and Built Environment*, 1–16.
8. Galadancia, A. S., Ianakiev, A., Kromanisa, R., & Robinson, J. (2020). Energy investigation framework: Understanding buildings from an energy perspective view. *Journal of Building Engineering*, 1–14.
9. Nalamwar, M. R., Parbat, D. K., & Singh, D. P. (2016). Optimum Building Orientation Study For Central India By Simulation, 25–27.
10. Behbood, K. T., Taleghani, M., & Heidari, S., Energy Efficient Architectural Design Strategies in HotDry Area of Iran: Kashan".
11. Al-Tamimi, N. A. M., & Syed Fadzilb, S. F. (2010). Experimental and simulation study for thermal performance analysis in residential buildings in hot-humid climate (Comparative Study). 15:17–25.
12. de Gracia, A., & Cabeza, L. F. (2015). Phase change materials and thermal energy storage for buildings. *Energy and Buildings*, 1–18.
13. Basack, S., & Sarkar, A. (2019). BIM framework for operational energy assessment in composite climate at early design stage. *Research Gate*, 2–26.
14. Moulana, A., & Abdul Rahman, S. (2017). Control strategies for efficiency of building. *International Journal of Civil Engineering and Technology*, 703–710.
15. Kim, D.-B., Kim, D. D., & Kim, T. (2019). Energy performance assessment of HVAC commissioning using long term monitoring data: A case study of the newly built office building in South Korea. *Energy & Buildings*, 1–9.
16. Shie, P., Tarantino, S., & Fischer, M. (2018). Parametric analysis of design stage building energy performance simulation models. *Energy & Buildings,* 1–24.
17. Reeves, T., Olbina, S., & Issa, R. R. A. (2015). Guidelines for using building information modelling for energy analysis of buildings, 1361–138.
18. Balali, A., Hakimelahi, A., & Valipou, A. (2020). Identification and prioritization of passive energy consumption optimization measures in the building industry: An Iranian case study. *Journal of Building Engineering*, 1–27.
19. Radziszewska-Zielina, E. (2014). A comparative analysis of selected parameters of roofing used in the Polish construction industry. *Journal of civil engineering,* 41–50.
20. Hatem, M., & Mostafa, E. (2015). Effect of roofing material type on microclimate in the sheep buildings. *Agricultural Engineering International Special Issue,* 52–56.
21. Saleh, N. J., Al-Saadi (2006). Envelope design for thermal comfort and reduced energy consumption in residential buildings. *Researchgate,* 42–49.
22. Shivsharan, A. S., Vaidya, D. R., & Shinde, R. D. (2017). 3D modelling and energy analysis of a residential building using BIM tools. *International Research Journal of Engineering and Technology (IRJET)*, 629–635.

23. Nalamwar, M. R., Parbat, D. K., & Singh, D. P. (2017). Study of effect of windows location on ventilation by CFD simulation. *International Journal of Civil Engineering and Technology (IJCET)*, 521–531.
24. Haldi, F., & Robinson, D. (2014). The impact of occupants behavior on building energy demand. *Journal of Building Performance Simulation*, 323–338.
25. Guerra Santin, O. (2013). Occupant behavior in energy efficient dwellings: evidence of a rebound effect. *Journal Hous and the Built Environment*, 311–327.
26. Gaetani, I., Hoes, P.-J., & Hensen, J. L. M. (2016). Occupant behavior in building energy simulation: Towards a fit- for- purpose modelling strategy. *Energy and buildings*, 1–16.
27. Anand, Y., Gupta, A., Maini, A., AviGupta, Sharma, A., Khajuria, A., Gupta, S., Sharma, S., Anand, S., & Tyagi, S. K. (2014). Comparative thermal analysis of different cool roof materials for minimizing building energy consumption. *Journal of Engineering*, 1–9.
28. Singh, S. P., & Sunayana. (2017).Cool roof technology. *IJSRD—International Journal for Scientific Research & Development,* 97–100.
29. Patil1, S. E., & Shinde, N. N. (2017). Analysis of new composite roof material and design in building envelope. *International Journal of Engineering Technology and Management*, 27–31.
30. Pedrosoa, M., de Britob, J., & Silvestreb, J. D. (2019). Characterization of walls with eco-efficient acoustic insulation materials (traditional and innovative). *Construction and Building Materials,* 892–902.
31. Hendry, E. A. W. (2001). Masonry walls: Materials and construction. *Construction and Building Materials,* 323–330.
32. Bhujbal Nitin, B., & Kumbhar, S. B. (2013). Optimization of wall thickness and material for minimum heat losses for induction furnace by Fea. *International Journal of Mechanical engineering and Technology,* 418–428.

Behaviour of Battered Pile Subjected to Lateral Load

Anmol Basnett, S. Sathvik, Prerna Sharma, V. R. Prasath Kumar, and L. Krishnaraj

Abstract The present investigation has been carried out to study the behaviour of battered piles and to evaluate the variation of stresses around these piles due to lateral loads and moment using subgrade reaction approach and finite difference method. In reality, uniform soil deposits are not found in nature and the piles are embedded in layered soils. The research was performed with the free headed pile in mind with its tip embedded in hard rock strata at the bottom. The effect of soil type, pile diameter, and pile length on pile response was examined, and the findings were presented. The formulation was programmed in MATLAB 2016a for the analysis. The validity of the presented solution was confirmed through available solutions in the literature. It has been discovered that soil layering has a significant effect on pile response and must be taken into account for proper study and design. When a pile is exposed to lateral loads, the deflection of the pile decreases as the thickness of the top stiff layer increases. However, it has negligible impact on the maximum moment.

Keywords Laterally loaded pile · Layered soil · Subgrade reaction approach

1 Introduction

In the design of a building, the structure will be analysed in two different parts as the substructure and a superstructure. Superstructure refers to the parts of a building that are above ground level, and substructure refers to the parts that are below ground

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level. The transfer of the load from the superstructure to the soil has more relevance in the design; hence, the design of the substructure is always critical [1, 2]. The piles are used to convey the lateral and vertical loads acting on the surrounding soil when a soft or loose soil extends to a significant depth.

In the past years, several analytical methods including the subgrade method, p–y curves method, and FEM method have been created to investigate pile response influenced by lateral loads. Most of these methods do not account for layered soil system. In reality, uniform soil deposits are not found in nature and piles are embedded in layered soils. Several authors have analysed battered piles subjected to lateral loads, considering various parameters to evaluate the behavioural characteristics of Battered pile and they have been briefly explained below.

For the study of the response of the batter pile subjected to pullout and lateral loads using three-dimensional finite analysis, the analysis was based on the Mohr–Coulomb criterion. From their studies they, have reported that the pullout capacity of a battered pile decreases up to 50% when the pile is inclined up to 10° [3]. The author have also reported that the inclination reduces both the lateral pile stiffness and pullout capacity. It was concluded that the reduction in pile stiffness due to the sliding of the soil-pile interface analysed the effect of lateral load on a single pile based on the Winkler's spring model, and the numerical solutions were obtained using MATLAB [4, 5]. It was concluded that the pile design wage was governed by serviceability aspects and ground improvement techniques. The soil stiffness had a big impact on pile deflections. It was reported that the bending moment decreases linearly (from 200 kNm to 110 kNm) as the subgrade modulus (constant throughout the pile length) varied from 2 kN/m^3 to 20 kN/m^3, and it was concluded that the results obtained from Indian code (IS 2911–2002) and the pile response that were modelled by the MATLAB software were in good agreement carried out studies on the using the Winkler elastic model, piles are subjected to lateral soil movement surrounded by the elastoplastic constitutive soil model considering the continuity and boundary condition [6].

The calculation procedures were coded into the MATLAB program and their accuracy reported was in good agreement with the equations suggested by Poulos (1980), and the pile deflections were 9.65 mm (proposed approach) and 12.57 mm (theoretical approach) for a pile with Poisson ratio of 0.35 and bending stiffness $EI = 1.7\ kNm^2$ [7, 8]. They studied the relationship of pile-soil-pile interaction in uniform soil for piles with different batter angles of 10º, 15º, and 25º and concluded that the analytical approach considering soil non-linearity and plastic yielding is capable of reflecting the actual output of the pile [9]. They solved the relationship between battered pile groups using analytical and numerical methods; they studied the relation of pile-soil-pile interaction in uniform soil for piles with different batter angles of 10º, 15º, and 25º.

The author has discovered that as the batter angle with respect to the vertical increases, the interaction between the pile and the soil pile decreases, and as the departure angle with the horizontal increases, the interaction between the pile and the soil pile decreases. It was found that vertical piles have more pullout capacity than 15o battered piles at all load inclinations, and 30º negative battered piles have more pullout capacity than vertical piles above 5º of load inclinations.

For the study of the behaviour of piles by carrying out Finite Element System seismic analysis of a laterally loaded pile under the impact of vertical loading, the analytical approach (finite element method) was used and MATLAB for the computation; it was found that for the l/d ratio of 40. As the lateral load coefficient is increased from 0.1 to 0.3, the normalized moment and displacement increase from 0.033 m to 0.042 m and 0.009 m to 0.035 m, respectively [10]. It is found that the magnitude of lateral load acting at the top of the pile increases as the lateral load coefficient increases, resulting in higher magnitudes of pile head displacement, and pile bending moment carried out a series of simulated analysis on the 3D battered piles that have been exposed to lateral loads in the sandy soils using the FlAC3D software [11, 12]. In this finite difference modelling of the battered pile, the lateral capability of piles was discovered to be battered forward which is not much affected compared to the vertical pile.

It was reported that the value of the ultimate load capacity of the piles obtained from the FE analysis was the same with the static load tests but the displacement was found to be slightly lower, approximately 8% with the experimental values. And they concluded that the bearing capacity of piles decreases with increasing negative battered angles, and the horizontal pile displacement was found to be more in the positive battered than that of the vertical or negative battered pile [13]. In this study the lateral load-carrying behaviour of inclined single and group micro piles of length 310 mm, Single (SMP) and community (GMP) micro piles were subjected to a series of model load tests with varying inclination angles, load directions, and micro pile spacing. This was due to the skin friction mobilized along micro pile surfaces which become larger with longer mobilized length for $\delta = 0°$, whereas upward skin friction was observed for $\delta = 180°$ [14, 15]. The Behaviour of Cyclic Laterally Loaded Pile Group in Soft Clay experiment showed that increasing the L/D ratio from 12 to 24 increased the ultimate lateral load capacity of the pile by 72.6% linearly.

2 Methodology

To explain the load-carrying mechanism of inclined micro piles, a finite element (FE) analysis was performed. They found that for = 0°, the inclined SMP's load-carrying capacity was greater than that of the vertical SMP and it increased with increasing values from 0° to 30°, while for 180°, in contrast, increasing values of angles 90° and 180° resulted in lower lateral load-carrying capability.

2.1 Finite Difference Method

To solve the differential equations, there are several methods. Whenever exact methods are not possible to use, numerical techniques are commonly used. Among this, FDM is a a commonly used methodology for the variation of soil properties. In this approach, all the derivatives were replaced with a differential operator.

2.2 Subgrade Reaction Approach

Subgrade reaction approach is also termed as beam-on-elastic-foundation strategy. In this approach, the beam was represented as foundation and the foundation was represented as soil mass. Commonly, the Winkler spring model is used for the research. The soil is represented by elastic springs in series such that the compression of the springs is directly proportional to the applied load. The spring constant reflects the stiffness of the ground against applied loads. Matlock and Reese analysed the piles subjected to horizontal loads and reported them in non-dimensional form, where they have assumed that the shear or Young's modulus increased with depth for which equations are provided for determining deflection, moment, shear, and slope along the pile.

The relative stiffness factor is calculated from Eq. 1.

For long piles, L > 5 T

$$\mathrm{T} = \sqrt[5]{\frac{EI}{Kh}} \tag{1}$$

The modulus of horizontal subgrade reaction K_h is given by Eq. 2:

$$Kh = \frac{p}{y} \tag{2}$$

where p = soil reaction per unit length of pile in N/mm^2,

y = pile deflection in mm,

E = Young's modulus of pile material,

I = moment of inertia of pile material,

T = relative stiffness factor.

The governing differential equations (Eq. 3) for the analytical solutions are used for different types of loads, position of loads, and load distribution to determine deformation, SF, and BM throughout the length. This approach is applicable only for long piles, as the pile length increasing the deflection of depth may be zero or negligible:

$$\mathrm{EI}\frac{d^4 y}{dx^4} + \mathrm{p} = 0 \tag{3}$$

In the subgrade reaction method, the pile is considered as a thin strip whose behaviour is governed by Eq. 4:

$$\mathrm{EI}\frac{d^4 y}{dx^4} + \mathrm{k_h y} = 0 \tag{4}$$

The solution for the above equations is obtained numerically as

$$\mathrm{EI}\frac{d^4 y}{dx^4} = -pd \tag{5}$$

The pile of length L is divided into n equal parts each of length δ. The above-mentioned basic differential equation is written in finite difference form for a typical point i from Fig. 1:

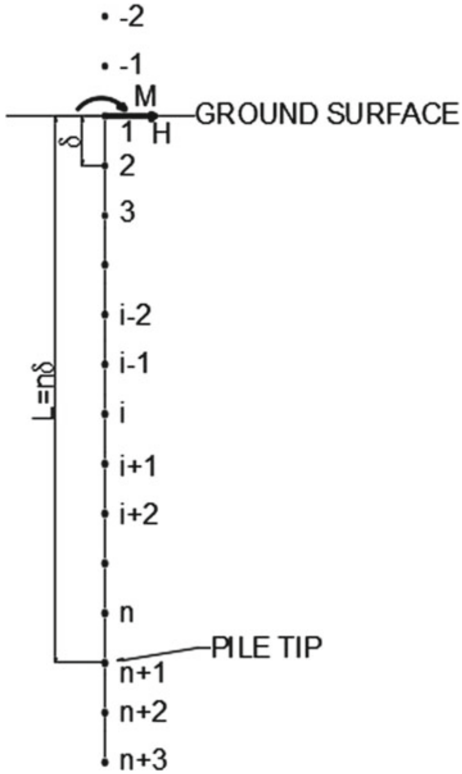

Fig. 1 Pile discretization

$$\frac{y_{i-2} - 4y_{i-1} + 6y_i - 4y_{i+1} + y_{i+2}}{\delta^4} = \frac{p_i d}{EI} \tag{6}$$

where
p = pressure,
y = deflection,
kh = modulus of subgrade reaction,
D = diameter or width of pile,
E = modulus of elasticity of pile,
I = MOI of pile.
WKT $\delta = \frac{L}{n}$
Rearranging the above equation:

$$y_{\mathrm{i}-2} - 4y_{\mathrm{i}-1} + 6y_{\mathrm{i}} - 4y_{\mathrm{i}+1} + y_{\mathrm{i}+2} = -\frac{p_{\mathrm{i}} d L^4}{n^4 EI} \tag{7}$$

Boundary condition.

1. Free head pile

$$\text{ShearEI}\frac{d^3 y}{dx^3} = H$$

$$\text{Moment EI } \frac{d^2 y}{dx^2} = \mathrm{M}$$

$$\mathrm{EI}\frac{y_i y - 2y_i + y_i{+}_1}{y^2} = \mathrm{M}$$

$$y_{\mathrm{i}-1} - 2y_{\mathrm{i}} + y_{\mathrm{i}}{+}_1 = \frac{ML^2}{n^2 EI}$$

At pile top, i = 1

$$\mathrm{y}_0 = 2\mathrm{y}_1 - \mathrm{y}_2 + \frac{ML^2}{n^2 EI} \tag{8}$$

At i = 2, Eq. (1)

$$\mathrm{y}_0 - 4\mathrm{y}_1 + 6\mathrm{y}_2 - 4\mathrm{y}_3 + \mathrm{y}_4 = -\frac{p_2 d L^4}{n^4 EI}$$

Substitute (2) in above equation

$$-2\mathrm{y}_1 + 5\mathrm{y}_2 - 4\mathrm{y}_3 + \mathrm{y}_4 + \frac{ML^2}{n^2 EI} = -\frac{p_2 d L^4}{n^4 EI} \tag{9}$$

Solving above equations, we get

$$\frac{\mathrm{E\,ln}^4}{dL^4}\begin{pmatrix} -2 & 5 & -4 & 1 & 0 & 0 & - & - & 0 & 0 \\ 1 & -4 & 6 & -4 & 1 & 0 & - & - & 0 & 0 \\ 0 & 1 & -4 & 6 & -4 & 1 & - & - & 0 & 0 \\ - & - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & - & - \\ 0 & 0 & 0 & 0 & 0 & 0 & - & - & 1 & -4 \\ 0 & 0 & 0 & 0 & 0 & 0 & - & - & 0 & 1 \end{pmatrix}\begin{pmatrix} y1 \\ y2 \\ - \\ - \\ - \\ - \\ - \\ - \\ - \end{pmatrix} + \frac{EI}{dL^4}\begin{pmatrix} \frac{ML^2}{n^2 El} \\ - \\ - \\ - \\ - \\ - \\ - \\ - \\ - \end{pmatrix} = -\begin{pmatrix} p1 \\ p2 \\ - \\ - \\ - \\ - \\ - \\ - \\ - \end{pmatrix}$$

$$-\{\mathbf{p}\} = \frac{EIn^4}{dL^4}[\mathrm{D}]\{\mathrm{p}\rho\} + \frac{EI}{dL^4}\{\mathrm{A}\} \tag{10}$$

$$\{\mathrm{s}\rho\} = \frac{d}{Es}[\mathrm{Is}]\{\mathrm{p}\} \tag{11}$$

Substitute (11) in (10), i.e., $\{_{\mathrm{S}}\ \rho\} = \{_{\mathrm{p}}\ \rho\}$

$$-\{\mathrm{p}\} = \frac{EIn^4}{dL^4}[\mathrm{D}]\frac{d}{Es}[\mathrm{Is}]\{\mathrm{p}\} + \frac{EI}{dL^4}\{\mathrm{A}\}$$

$$\{p\}\big[1 + K_R n^4[D][Is] = \{B\} \tag{12}$$

where $\mathrm{K_R} = \frac{EI}{EsL^4} =$ pile flexibility factor .
[Is] = (n + 1) × (n + 1), matrix of soil displacement influence factors;

$$\{\mathrm{s}\rho\} = \text{ horizontal soil displacement}$$

$$\{\mathrm{p}\} = \text{ horizontal loading between pile and soil}$$

Elements of Iij of [Is] are evaluated from Mindlin's equation.
Soil displacement

$$\{\mathrm{s}\rho\} = \frac{d}{Es}[\mathrm{Is}]\{\mathrm{p}\} \tag{13}$$

The lateral and shear stresses are calculated by integrating Mindlin's equation with respect to c. MATLAB is used to construct a computer programme that computes the pile answer for different L/D ratios using the above set of equations.

3 Results and Discussion

In determining the behaviour of the battered pile subjected to lateral loading, the equations as stated in the methodology (3.2.3) are used in order to compute the various parameters such as deflection, bending moment, normal, and shear stresses. The property of the soil is varied in a uniform layer of varying elastic modulus (Es), and the pile is battered at a positive inclined angle φ as 10, 15, and 20 and negative inclined angles of -10, -15, and -20 for the deflection-bending behaviour, and Poisson's ratio (v) is varied as 0.1, 0.25, and 0.4 in determining the normal and shear stresses for the same battered angles above.

3.1 Variation in the Battered Pile

To understand the behaviour of the battered piles subjected to a lateral load, the deflection and bending moment are evaluated for the following cases:

- Case 1: Length of the pile = 20 m, d1 = L/3(loose sand), d2 = L/3(soft clay), d3 = L/3(hard clay), and embedded layer of rock 0.5 m.
- Case 2: Length of the pile = 20 m, d1 = L/4(loose sand), d2 = L/2(soft clay), d3 = L/4(hard clay), and embedded layer of rock 0.5 m.
- Case 3: Length of the pile = 20 m, d1 = L/4(loose sand), d2 = L/4(soft clay), d3 = L/2(hard clay), and embedded layer of rock 0.5 m.

The variations of deflection and BM for the above cases are presented as follows: Case 1: For the soil layers of L/3, L/3, L/3.

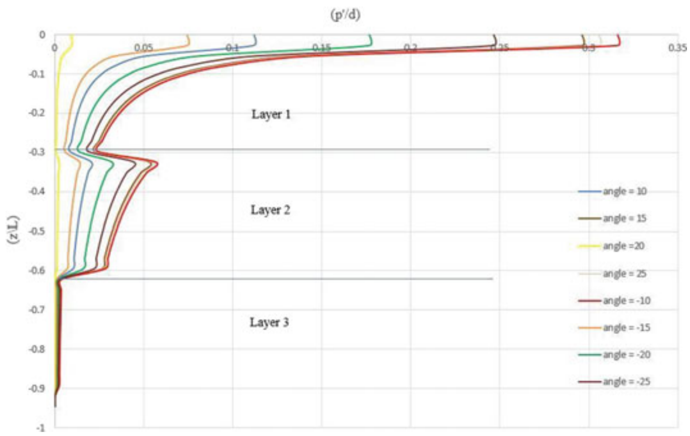

Fig. 2 Variation of ρ/d along z/L

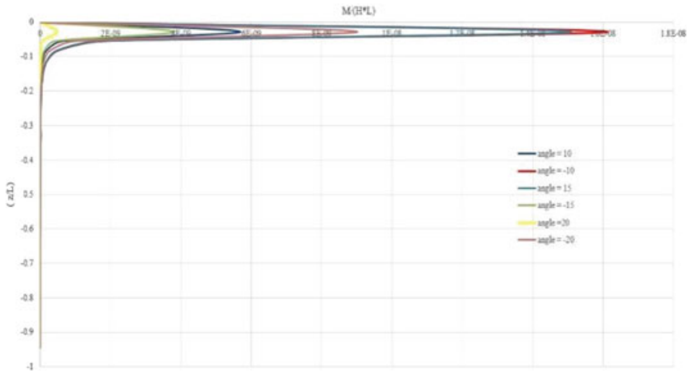

Fig. 3 Variation of M/H*L along z/L

From the above (Figs. 2 and 3), for the positive battering angles, when the inclination was increased from 10° to 15°, the percentage increase in the deflection and moment was found to be 62.26% but when there is an increase of angle from 15° to 20°, the values of deflection and moment was found to decrease to 97.09%. In the case of negative battering angle of −10° to −15°, it was observed that there is a percentage decrease in the deflection and moment to 76.38% and from 15° to 20° it was found to increase to 57.79%.

Case 2: For the soil layers of L/4, L/2, L/4.

From the above (Figs. 4. and 5), for the positive inclinations of angles, 10° to 15º, the percentage increase in the deflection and moment was found to be 60.96%, and again it was found to decrease rapidly to 94.61% when the angle is increased from 15° to 20°. In the negative battering angles, it is found that there is a decrease of values to 74.91% for −10° to −15° but from −15° to −20° it is found that there is an increase of 55.82%.

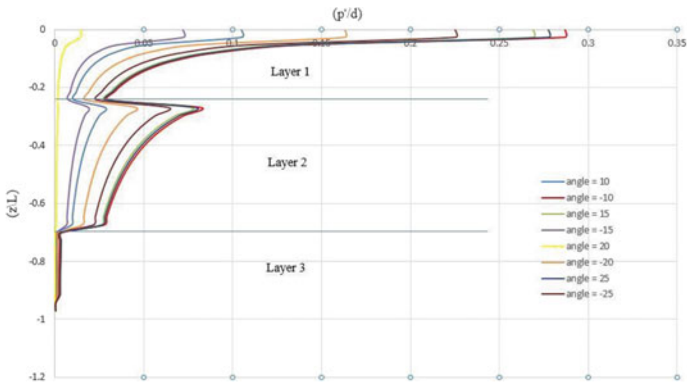

Fig. 4 Variation of ρ/d along z/L

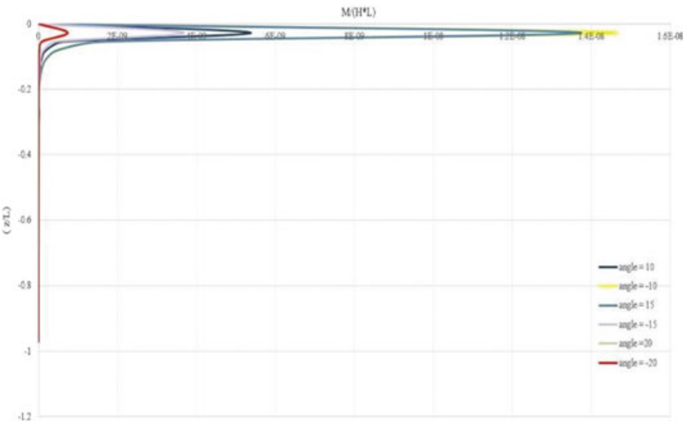

Fig. 5 Variation of M/H*L along z/L

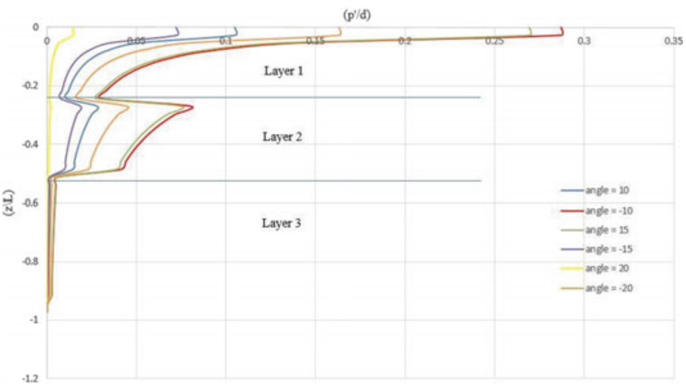

Fig. 6 Variation of ρ/d along z/L

Case 3: For the soil layers of L/4, L/4, L/2.

From the above (Figs. 6 and 7), the positive battering angle of 20 is lower by 94% compared to that of the highest value observed at the negative battering angle of 10 degrees.

3.2 *Variation of Stresses*

The lateral stresses, σ_x, and shear stresses, τ_{xz}, were calculated by integrating Mindlin's solution with respect to c for different pile lengths L = 10 m, 20 m, and 25 m by varying x/L values (0.1, 0.2, and 0.3) for Poisson's ratio $\vartheta = 0.25$ and $\vartheta = 0.5$, respectively. From the graphs, it is observed that when x/L raises from

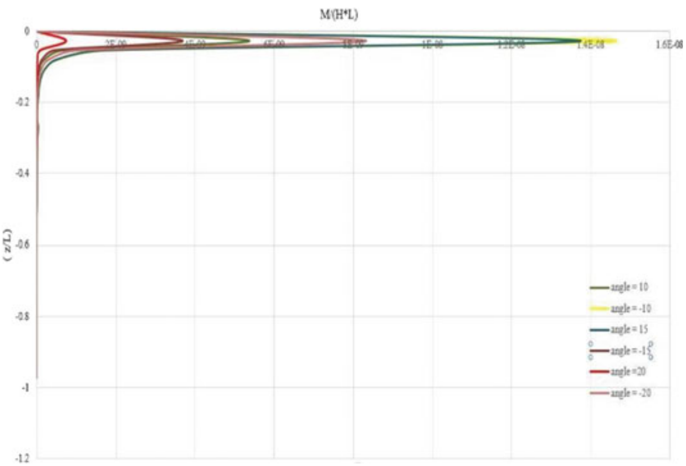

Fig. 7 Variation of M/H*L along z/L

Table 1 Lateral and shear stresses

x/L	0.1	0.2	0.3
Lateral stress	51.36	55.9	65.7
Shear stress	186.7	164.1	147.45

0.1 to 0.3, lateral stresses increase from 51.36 to 65.7% and shear stresses decrease from 186.7 to 147.45%. Shear stresses and lateral stresses increase with increase in length of pile from L = 10 m to 25 m. Lateral stresses increase by 0.19% and shear stresses increase by 148.9%.Table 1 shows the percentage variation of lateral stress and shear stress for x/L = 0.1, 0.2, and 0.3 for pile length L = 10 m, 20 m, and 25 m for Poisson's ratio 0.25 and 0.5 (Figs. 8 and Fig. 9).

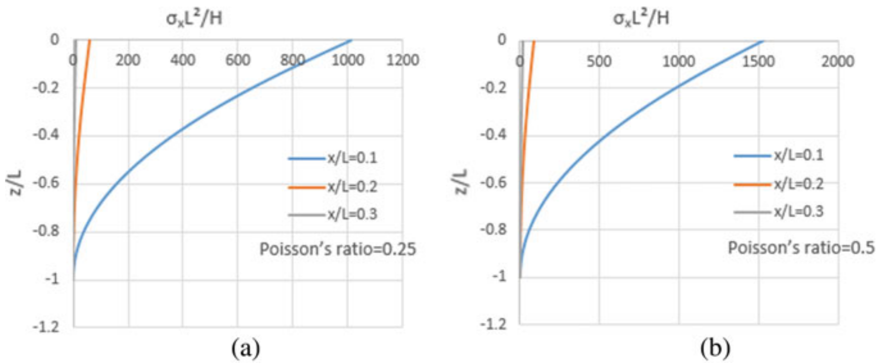

Fig. 8 Variation of $\sigma_x L^2/H$ with z/L for pile length L = 10 m and Poisson's ratio **a** $\vartheta = 0.25$ and **b** $\vartheta = 0.5$

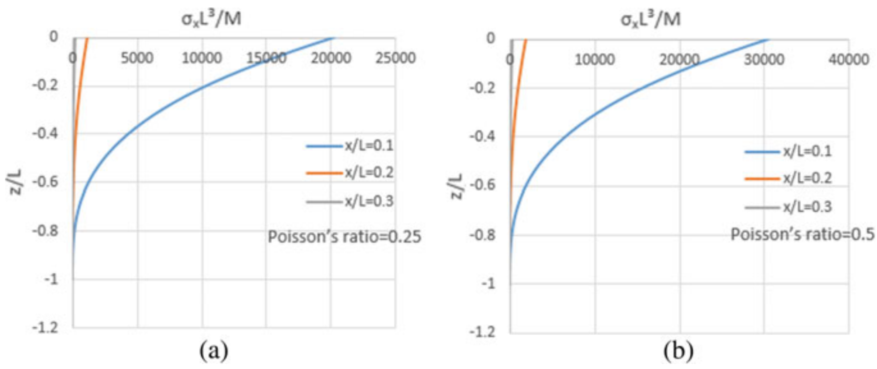

Fig. 9 Variation of $\sigma_x L^3/M$ with z/L for pile length L = 10 m and Poisson's ratio **a** $\vartheta = 0.25$ and **b** $\vartheta = 0.5$

4 Conclusion

- When a pile is exposed to horizontal load, the deflection of the pile decreases with rise in the depth of the top layer. An increase of 113.01% was observed in the deflection of pile tops. The soil layer thickness has negligible effect on bending moment.
- As Poisson's ratio rises from 0.25 to 0.5, the deformation and moment also raise.
  - For L = 10 m, the maximum deflection increases by 22.5% and maximum moment increases by 25.6%.
  - For L = 25 m, the maximum deflection increases by 17.9% and maximum moment increases by 44.09%.
- Large variations in stresses are induced in consolidated clay when Poisson's ratio is 0.5 as consolidated clay starts acting as a rock. Hence, deflection and moments increase.
- The normal stress σ_x is found to increase by 17.01% with increase in Poisson's ratio of 0.1–0.25 and 20.41% with increase in Poisson's ratio of 0.25–0.4. The shear stress is found to increase by 62.24% with the increase in Poisson's ratio of 0.1–0.25 and 48.28% with increase in Poisson's ratio of 0.25–0.4.
- The effect of battering angle on the normal and shear stresses is found to be decreasing to 14.71% with an increase in battering angle of 10°–15° and 18.31% for an increase in battering angle of 15°–20°. In case of negative battering angle, it was found that for the increase of batter angle from −10° to −15°, the normal and shear stresses were increased to 5.41% and 4.44% for increase in battering angles of −15° to −20°.

References

1. AsskarJanalizadeh, A. Z. (2015). Lateral response of pile foundations in liquefiable soils. *Journal of Rock Mechanics and Geotechnical Engineering, 7*(2015), 532–539.
2. Basu, D., Salgado, R., & Prezzi, M. (2009). A continuum based model for analysis of laterally loaded piles in layered soils. *Journal of Geotechnique*. https://doi.org/10.1680/geot.2007.0001.
3. Basu, D (2006). *Analysis of laterally loaded piles in layered soil*. Ph.D thesis, Purdue University, West Lafayette, Indiana.
4. Bipin, K., & Gupta, DipanjanBasu. (2017). Analysis of laterally loaded short and long piles in multilayered heterogeneous elastic soil. *Soils and Foundations, 57*(2017), 92–110.
5. Basu, D., & Salgado, R. (2007). Elastic analysis of laterally loaded pile in multi-layered soil. *Geomechanics and Geoengineering: An International Journal, 2*, 183–196.
6. Abdrabbo, F. M., & Gaaver, K. E. (2012). Simplified analysis of laterally loaded pile groups. *Alexandria Engineering Journal, 51*, 121–127.
7. Liang, F., Zhang, H., & Yang, K. (2015). A Variational solution for nonlinear response of laterally loaded piles with Elasto-plastic winkler spring model. *KSCE Journal of Civil Engineering*. https://doi.org/10.1007/s12205-014-0020-6.
8. Yu, G., Gong, W., Chen, M., Dai, G., & Liu, Y. (2019). Prediction and analysis of behaviour of laterally loaded single piles in improved gravel soil. *International Journal of Civil Engineering*. https://doi.org/10.1007/s40999-018-0372-2.
9. Madhusudan Reddy, K., & Ayothiraman, R. (2016). Experimental studies on behaviour of single pile under combined uplift and lateral loading. *Journal of geotechnical and geoenvironmental engineering*. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001314
10. Mallikarjuna Rao, K., & Suresh Kumar, V., Measured and predicted response of laterally loaded piles. Department of civil engineering, S.V.U. College of Engineering, Tirupati.
11. Chatterjee, K., Choudhury, D., & Poulos, H. G. (2015). Seismic analysis of laterally loaded pile Under influence of vertical loading using finite element method. *Computers and Geotechnics, 67*(2015), 172–186.
12. Zhang, L., Zhao, M., & Zou, X. (2013). Behavior of laterally loaded piles in multi-layered soils. *International Journal of Geomechanics*. https://doi.org/10.1016/(ASCE)GM.1943-5622.0000319
13. LassaadHazzar, M. N., & Hussien, M. K. (2017). Influence of vertical loads on response of pile foundations in sands and clays. *Journal of Rock Mechanics and Geotechnical Engineering, 9*(2017), 291–304.
14. Mu, L. L., Huang, M. S., Zhang, J., & Feng, C. M. (2015). *Influence of vertical loads on behaviour of laterally loaded large diameter pile in sand*. Tongji university, China.
15. Poulos, H. G., & Davis, E. H., *Pile foundation-analysis and design*. Willey, New York.

Modelling Residential House Pricing Using Regression Analysis

M. B. Sridhar and R. Sathyanathan

Abstract The paramount ingredient for the socio-economic development of any country is the land and buildings. An accurate appraisal of these land and buildings' value has a colossal effect on the state's economy. Still, the value of these buildings has been outrageous with realtors' emergence. Various computational techniques have been employed to resolve the issue of the appraisal of the value. The factor analysis, correlation analysis and linear regression analysis are employed in this paper in order to model the residential house prices. This study is to be carried out in the Chengalpattu neighbourhood, where the modelling of the residential house prices is considered. All the factors which account for house price were determined. The modelling is performed by taking the market prices and the various factors that account for the valuation using various software.

Keywords House pricing · Regression · Urban density

1 Introduction

Real estate is a class of real property that includes land and anything attached to it, whether human-made or natural. It was found that more than half the total value of the world's wealth is from the real estate industry [1]. This property's valuation is usually vital for the pledge, auction, acquisition, and levying taxes [2]. On such occasion, the terminal aim of the valuation communique final user is to consider the utmost definite property value, ultimately making the investment decisions [3,

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4]. Taffese identified that fiscal and prudent decisions are based on the observed appraisal of the property values.

Hedonic price model (HPM) is a prevailing and assertive method used for anticipating house price movements [5]. The neural network model has been used for prophecy, outline recognition, cataloguing, progression control, nonlinear plotting, and statistics scrutiny [6], making it apt for assets assessment. Sir Francis Galton first recommended the idea of linear regression in 1894. Linear regression is an objective test applied to an information collection to illustrate and portion the fixture flanked by the factors [7]. Regression, in general, is a statistical technique used to find the dependency of an independent and dependent variable. In comparison, correlation is a proportion of a monotonic association between two factors. A monotonic connection between two aspects is a one wherein either as the estimation of a variable increment, so does the supplementary variable's assessment; or as the analysis of a variable expands, the additional variable worth diminishes [8]. While correlation gives a quantitative way of estimating the degree or strength of a connection between two factors, regression analysis numerically depicts this relationship [9]. Pursued the inception of the neural networks acknowledging that neural networks can formulate logical arithmetic functions, the way the web works is based on neuronal information. It has been implied as a resolution to hail the criticisms such as linear relationship and dearth of accurateness [10, 11]. Dowell accounted for the spatial development of Chennai through land use, land value data [12]. Sampath Kumar and Shanthi examined the trend in land prices in Sowcarpet, Chennai. An article in The Hindu stated that Chennai registered a 6% increase in residential sales in the first six months of 2019 as per the Knight Frank India. In the second half of 2019, housing sales surged by 8%, with south Chennai bagging the most significant new launches. As per a report for July–September 2020, an average of 38% of the residential inventory and 66% of the buyer demand have the budget category under 40 lakhs, and it also stated that despite the discrepancy between the supply and demand, the northern and southwestern suburbs such as Guduvancheri, Avadi, and Urapakkam have a larger inventory in the affordable class with a price range of 3500–4500 per sq. ft.

The valuation can be performed by the approaches such as rent capitalization method or income capitalization method, profit method, depreciation method, development method, direct comparison or sales comparison, and land and building method. The valuation is done by performing the regression analysis, contemplating the various factors that account for the residential houses' monetary worth. The number of factors generally influence the prices of houses [13]. Rahadi categorized components into trio chief clusters such as physical condition, notion, and position [14]. Kauko enumerated a customary of facets that have been generally used in land assessment scrutiny, including convenience factors, neighbourhood-level aspects, precise undesirable externalities, community factors and compactness factors [15]. Tse and Love classified grades of facets, namely structural, corporal and conservational. The factors considered were the numeral of bedchambers [16, 17], the numeral of lavatories [18, 19], the possessions site [16, 20], the accessibility of civic passage [21, 22], the assets magnitude [21, 23] and the availability of security fence [22], which among other attributes have a sizable bearing on property values. Another facet that influences a house price or land is the urban density, which generally describes how a city's population or development is concentrated or compact [24]. Babawale said the number of bedrooms, numeral of bedchambers, the size of the bedchamber and the security fence suggestively impact the properties' value [25]. Ajide and Kareem endowed that the numeral of bedchambers and lavatories is the substantial property value determinant [26]. Bello determined that the assets oldness and the property's location make a significant contribution to property desirability [25]. Kareem found the accessibility of civic passage facilities to be an essential property value determining factor.

2 Study Area

The Chengalpattu district forms part of the 38 districts of Tamil Nadu, India. The Chengalpattu district came into being on November 29, 2019, when it was carved out of the Kanchipuram district after the district bifurcation was announced on July 18, 2019. This district's total area accounts for 2,945 km^2 with a population of about 2,556,423 with a density of 870 per km^2. This district has three revenue divisions: the Tambaram division, Chengalpattu division and Madurantakkam division. Chengalpattu district has 16 district panchayat wards, 8 Municipalities, 1 cantonment zone, 8 panchayat unions, 12 town panchayats, 359 rural panchayats and 6 state assembly constituencies. The shapefile of the Chengalpattu district created by ArcMap is shown in Fig. 1.

3 Methodology

3.1 Selection of Factors

A quantizable number of factors were found from the relevant papers [27–30], which in general would affect the price or value of a land or building. Then the factor analysis was performed using the SPSS software, and the normalization was done. The factors which were considered were distance to hospital, distance to Central Business District, distance to the MRTS, distance to the Chennai International Airport, distance to the nearest bus stop, distance to the Secondary City Centre, distance to National Highway, ratings to a building based on the amenities such as power backup, reserved parking, gated community, visitors parking, swimming pool, park, security, maintenance staff, gym, lift, intercom, furnished status and water treatment on a scale of 0–1, ratings based on the road nearby such as National Highway, State Highway, 100 ft road, 60 ft road, 20 ft road on a scale of 1–5 and urban density.

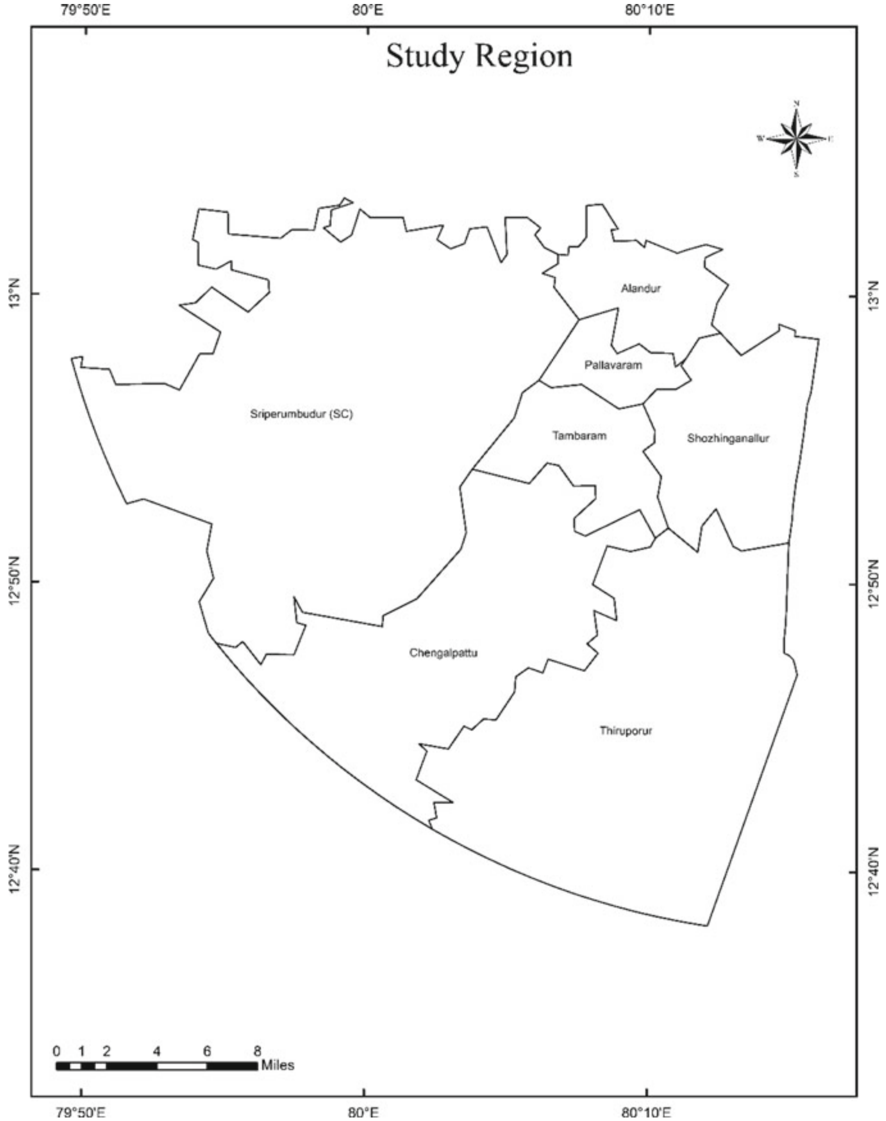

Fig. 1 Shape file of Chengalpattu

3.2 Urban Density

The Landsat 8 Satellite image of March 31, 2019 covering the study region was downloaded from the United States Geological Survey (USGS). The satellite image is clipped with the shapefile for further classification. A combined classification technique which is a combination of supervised and unsupervised classification is utilized to classify the landcovers. The study region is classified into five landcover classes such as waterbody, urban, vegetation, agriculture and barren land. The urban area present within 1 km radius is considered as the urban density. To determine the urban density a point shapefile within 1 km buffer radius is created for every location, where the residential price is considered. The urban area encompassed within the 1 km buffer of each point is determined.

3.3 Data Collection and Normalization

This study concerns the data gathered from the real estate internet, an electronic version of the real estate industry. The concept of this internet property is to publish housing domains for sale or lease and for the end-user who has been on the lookout to either buy or lease a property. Initially, around 600 data were collected from various domains, considering the factors mentioned earlier that these buildings would have in general. The data was compiled from multiple places in the Chengalpattu district. The total collected data had undergone the process of data cleaning, and data of about 200 were considered.

3.4 Factor Analysis

Factor analysis is a simple procedure for perceiving which essential components are assessed by the (much greater) number of factors. Factor examination is essential for the general straight model (GLM). Likewise, the technique accepts cons such as there is a direct relationship and there is no multicollinearity; it integrates noteworthy factors into the investigation, and there is an honest construction amongst factors. The default setting is for SPSS to utilize the Kaiser halting measure. You can set a more reasonable halting standard by requiring each factor to have a higher eigenvalue. Or then again, if you know precisely the number of components you think there will be, you can set the extraction strategy to a particular "Number of variables" and afterwards put the number into this crate.

3.5 Correlation

The Pearson association is else called the "product-moment correlation coefficient" or basically "correlations". Pearson correlations are fair apposite or quantitative features (counting amphibious elements). For idempotent factors, employ the Spearman connection or Kendall's tau. For apparent factors, use Cramer's V. A connection factor displays the mark to which specks in a scatterplot be on a straight line. This proposes that we can generally assess connections pretty precisely from just scatterplots. Correlations are not ever lesser than 1. A correlation of 1 proves that the statistics focuses on a disintegrate plot that lies exactly on a straight sliding line; the two factors are impeccably defiantly directly connected. A correlation of 0 suggests that dual elements do not have slightly direct linking at all. Nonetheless, some non-straight links might happen between the dual factors; relationship constants are seldom higher than 1. A correlation constant of 1 recommends that dual essentials are consummately decidedly directly associated; the spots in a disperse plot lie precisely on a straight ascending line. When deciphering correlations, we should refer to two central matters, and correlations could conceivably show contributing relationships. Contrarily, causal relationships from one factor to another variable could bring about correlations between the two factors. Relationships are gentle to omissions; an unsociable surprising insight might enormously affect a correlation. A fast assessment of a scatterplot effectively recognizes such exceptions.

3.6 Regression Analysis

Linear regression is the accompanying stage up after association. It is used when we need to expect the assessment of a variable subject to evaluate another variable. We need to expect the variable as the reliant variable (or, every so often, the outcome variable). The variable we are using to predict the other variable's worth is the free factor (or now and again, the marker variable). While dissecting the information in SPSS, the presumptions, for example, the two factors, ought to be estimated at the ceaseless level. There ought to be a direct connection between the factors; there ought to be no significant outliers which overall is a noticed information point that has a reliant variable worth which is different to esteem anticipated by the relapse condition. There ought to be freedom of perceptions, and info requests to show homoscedasticity, which is the room somewhere the variations along the line of unsurpassed fit. Lastly, we need to check the lingering blunder of the regression line.

4 Results and Discussion

4.1 Urban Density

The obtained urban density values from ArcMap were determined after creating a buffer zone of about 1 km, and the below sample values such as 0.8982, 0.3942, etc. were obtained. The above results show that the urban density is obtained from the LULC 2019, and then the data normalization was performed.

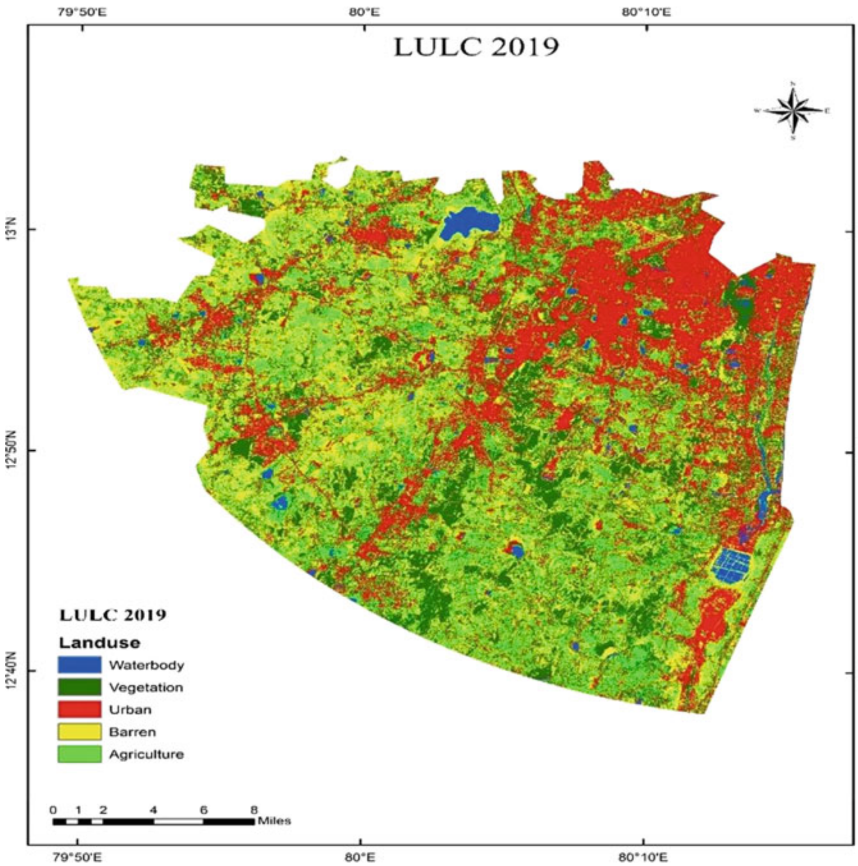

Fig. 2 LULC showing the land use

The model developed in this research will undergo factor analysis for all the 12 considered factors followed by correlation in order to determine the interdependency between dependent and independent variables and then the mean absolute percentage error (MAPE) would be determined by performing regression analysis in SPSS software (Fig. 2).

4.2 Factor Analysis

The factor analysis was performed using SPSS software, and the obtained results using the principal component analysis are shown in Table 1.

Component 1 indicates the distance to the central business district (CBD), component 2 indicates the distance to the hospital, component 3 indicates the distance to

Table 1 Factor analysis using SPSS

Overall variance						
Component	Preliminary eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.709	27.086	27.086	2.709	27.086	27.086
2	1.782	17.818	44.904	1.782	17.818	44.904
3	1.090	10.904	55.808	1.090	10.904	55.808
4	1.045	10.451	66.259	1.045	10.451	66.259
5	0.920	9.205	75.463	0.920	9.205	75.463
6	0.756	7.560	83.023	0.756	7.560	83.023
7	0.101	1.010	84.033	0.101	1.010	84.033
8	0.543	5.434	89.467	0.543	5.434	89.467
9	0.125	1.251	90.718	0.125	1.251	90.718
10	0.494	4.943	95.661	0.494	4.943	95.661
11	0.344	3.443	99.104			
12	0.090	0.896	100.000			

Extraction method: Principal component analysis

MRTS, component 4 indicates the distance to the airport, component 5 indicates the distance to bus stop, component 6 indicates the distance to the secondary city centre (SCC), component 7 indicates the distance to NH, component 8 indicates amenities rating, component 9 indicates road rating, component 10 indicates urban density, component 11 indicates lake view, component 12 indicates the distance to school. From the factor analysis, it is evident that the extracted 10 factors from the principal component analysis are accurate enough to undergo further correlation analysis. The above results show that the urban density is obtained from the LULC 2019, and then the data normalization was performed. After performing the data normalization, the factor analysis was performed, and it was found that the factors such as lakeview and school were not opted for among the 12 elements.

4.3 Correlation Analysis

The correlation analysis was performed in SPSS and the obtained results are shown in Table 2.

Positive correlation states that if there is a rise in one value the other dependent variable also increases, whereas negative correlation states that if there is a rise in one variable there would be a decrease in another dependent variable. From the obtained correlation analysis from the SPSS software, it is evident that the components 1–10 are significant at 0.05 significance level and the components 11 and 12 are non-significant at 0.05 significance level. The significance level is a percentage of the

Table 2 Correlation analysis using SPSS

S.no	Particulars	Correlations	Significance
1	CBD	−0.462	Significant
2	Hospital	−0.342	Significant
3	MRTS	−0.086	Significant
4	Airport	−0.277	Significant
5	Bus Stop	0.117	Significant
6	SCC	−0.045	Significant
7	NH	0.304	Significant
8	Rating	0.127	Significant
9	Road-rating	−0.083	Significant
10	UD	0.314	Significant
11	Lakeview	−0.074	Non-significant
12	School	−0.062	Non-significant

**Significant at 0.05 confidence level

forte of the proof that should be available in your example before you will terminate the unenforceable theory and deduce that the impact is unaffectedly huge. Then the correlation analysis was performed determining the significance of the factors and it is evident that these two factors were not significant at a confidence level of 0.05.

4.4 Regression Analysis

The regression analysis was performed with the normalized data in SPSS, and the results are obtained as in Table 3.

The obtained R-value was 0.547 and the R-square value is 0.299 and the standard error estimate which in general states that it is the absolute measure of the typical distance that the data points fall from the regression line is 0.859282119.

Table 3 Regression analysis using SPSS

Model summary				
Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.547[a]	0.299	0.262	0.859282119

[a]Predictors: (constant), UD, Bus stop, NH, Road Ratings, SCC, Hospital, Ratings, MRTS, Airport, CBD

5 Conclusion

In this paper, several tests such as factor analysis, correlation analysis, and regression analysis were performed using several factors that affect the residential house prices. A component of urban density was derived by ArcMap software. From the factor analysis, it is evident that 10 factors accounted to influence the price among the 12 factors. From the correlation analysis, it was observed that the lakeview and school components were not significant at 95% confidence level. From the regression analysis, the observed R^2 value was 0.299 and the value of R was 0.547. The value of R square is observed to be low in regression analysis or inaccuracy due to problems with heteroskedasticity and multicollinearity among the variables in the model [31].

References

1. Abidoye, R. B., & Chan, A. P. C. (2016). Research trend of the application of artificial neural network in property valuation. *33rd CIB W78 Conference 2016*, no. November, pp. 1–9.
2. Abidoye, R. B., & Chan, A. P. C. (2017). Modelling property values in Nigeria using artificial neural network. *Journal Property Research.* https://doi.org/10.1080/09599916.2017.1286366.
3. Frew, J., & Jud, G. D. (2014). "Buildings," no. February 2003, 2014. https://doi.org/10.1080/10835547.2003.12091101.
4. Taffese, W. Z. (2007). Case-based reasoning and neural networks for real estate valuation. *Proceedings IASTED International Conference Artificial Intelligent Application. AIA 2007*, pp. 84–89, 2007.
5. Limsombunc, V., Gan, C., & Lee, M. (2004). House price prediction: Hedonic price model vs. artificial neural network. *American Journal of Applied Sciences, 1*(3), 193–201. https://doi.org/10.3844/ajassp.2004.193.201.
6. Abiodun, O. I., Jantan, A., Omolara, A. E., Dada, K. V., Mohamed, N. A. E., & Arshad, H. (2018). State-of-the-art in artificial neural network applications: A survey. *Heliyon*, *4*(11), e00938.https://doi.org/10.1016/j.heliyon.2018.e00938
7. Kumari, K., & Yadav, S. (2018). Linear regression analysis study. *J. Pract. Cardiovasc. Sci., 4*(1), 33. https://doi.org/10.4103/jpcs.jpcs_8_18.
8. Schober, P., & Schwarte, L. A. (2018). Correlation coefficients: Appropriate use and interpretation. *Anesthesia and Analgesia, 126*(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864.
9. Lu, S., Li, Z., Qin, Z., Yang, X., & Goh, R. S. M. (2018). A hybrid regression technique for house prices prediction. *IEEE International Conference Industrial Engineering Management*, vol. 2017-Decem, no. December, pp. 319–323, 2018. https://doi.org/10.1109/IEEM.2017.8289904.
10. Tay, D. P. H., & Ho, D. K. H. (1992). Artificial intelligence and the mass appraisal of residential apartments. *Journal of Property Valuation and Investment, 10*(2), 525–540. https://doi.org/10.1108/14635789210031181.
11. Dowall, D., Monkkonen, P., & Angeles, L. (2008). Urban development and land markets in Chennai, India. *Int. Real Estate Rev., 11*(2), 142–165.
12. Sampathkumar, V., Santhi, M. H., & Vanjinathan, J. (2015). Forecasting the Land Price Using Statistical and Neural Network Software. https://doi.org/10.1016/j.procs.2015.07.377.
13. Rahadi, R. A., Wiryono, S. K., Koesrindartoto, D. P., & Syamwil, I. B. (2015). Factors influencing the price of housing in Indonesia. *International Journal of Housing Markets and Analysis, 8*(2), 169–188. https://doi.org/10.1108/IJHMA-04-2014-0008.

14. Kauko, T. (2003). Residential property value and locational externalities: On the complementarity and substitutability of approaches. *J. Prop. Invest. Financ., 21*(3), 250–270. https://doi.org/10.1108/14635780310481676.
15. Tse, R. Y. C., & Love, P. E. D. (2000). Measuring residential property values in Hong Kong. *Property Management, 18*(5), 366–374. https://doi.org/10.1108/02637470010360669.
16. Ge, X. J.,& Du, Y. (2007). Main variables influencing residential property values using the entropy method—The case of Auckland. *5th International Structural Engineering Construction Conference*, pp. 2–21, 2007, [Online]. Available: http://www.asres2007.umac.mo/papers/041-PAPER.pdf.
17. SELİM, S. (2008). Determinants of house prices in Turkey : A Hedonic regression model. *Doğuş Üniversitesi Derg.*, *1*(9), 65–76. https://doi.org/10.31671/dogus.2019.223.
18. Zietz, J., Zietz, E. N., & Sirmans, G. S. (2008). Determinants of house prices: A quantile regression approach. *Journal of Real Estate Finance and Economics, 37*(4), 317–333. https://doi.org/10.1007/s11146-007-9053-7.
19. Pozo, A. G. (2009). A nested housing market structure: Additional evidence. *Housing Studies, 24*(3), 373–395. https://doi.org/10.1080/02673030902875029.
20. Anim-Odame, W. K., Key, T., & Stevenson, S. (2009). Measures of real estate values from land registration and valuation systems in emerging economies: The case of Ghana. *Journal of Real Estate Literature, 17*(1), 63–84.
21. Choy, L. H. T., Mak, S. W. K., & Ho, W. K. O. (2007). Modeling Hong Kong real estate prices. *Journal Housing Built Environment, 22*(4), 359–368. https://doi.org/10.1007/s10901-007-9089-2.
22. Ferlan, N., Bastic, M., & Psunder, I. (2017). Influential factors on the market value of residential properties. *The Engineering Economist, 28*(2), 135–144. https://doi.org/10.5755/j01.ee.28.2.13777.
23. Sanjari, H. (2012). Estimation of the hedonic pricing function for housing units (A Case Study of Hashtgerd New Town, Iran). *International Business Management, 6*(6), 676–679. https://doi.org/10.3923/ibm.2012.676.679.
24. Babawale, G. K., Koleoso, H. A., & Otegbulu, C. A. (2012). A hedonic model for apartment rentals in ikeja area of Lagos metropolis. *Mediterranean Journal of Social Sciences, 3*(3), 109–120. https://doi.org/10.5901/mjss.2012.v3n3p109.
25. Ajide, B. K., & Kareem, I. O. (2010). Hedonic analysis of residential housing market in a third world city: A preliminary investigation. *Social Sciences, 5*(6), 520–524. https://doi.org/10.3923/sscience.2010.520.524.
26. Bello, M. O., & Bello, V. A. (2007). The influence of consumers behavior on the variables determining residential property values in Lagos, Nigeria. *American Journal of Applied Sciences, 4*(10), 774–778. https://doi.org/10.3844/ajassp.2007.774.778.
27. Hong, T., Wang, Z., Luo, X., & Zhang, W. (2020). State-of-the-art on research and applications of machine learning in the building life cycle. *Energy Building, 212*, 109831. https://doi.org/10.1016/j.enbuild.2020.109831.
28. Mhatre, M. S., Siddiqui, D., Dongre, M., & Thakur, P. (2017) A review paper on artificial neural networks: A prediction technique. *International Journal Science Engineering Research, 8*(3), 1–. Available: http://www.ijser.org.
29. Wittowsky, D., Hoekveld, J., Welsch, J., & Steier, M. (2020). "Residential housing prices: Impact of housing characteristics, accessibility and neighbouring apartments—a case study of Dortmund, Germany", *Urban. Plan. Transp. Res., 8*(1), 44–70. https://doi.org/10.1080/21650020.2019.1704429.
30. Selim, H. (2009). Determinants of house prices in Turkey: Hedonic regression versus artificial neural network. *Expert System Application, 36*(2) PART 2, 2843–2852. https://doi.org/10.1016/j.eswa.2008.01.044.
31. Rahman, S. N. A., Maimun, N. H. A., Razali, M. N., & Ismail, S. (2019). The artificial neural network model (ANN) for Malaysian housing market analysis. *Plan. Malaysia, 17*(1), 1–9. https://doi.org/10.21837/pmjournal.v17.i9.581.

An Ant Colony-Based Optimization Model for Resource-Leveling Problem

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Abstract Resource leveling, a resource management technique, plays an important role in developing a realistic schedule, aims to maintain a uniform resource profile, and avoids construction delays. Many researchers in the past have tried solving resource-leveling problems (RLPs) using various numerical, heuristic, metaheuristic approaches. RLP is a classic example of a combinatorial problem. It can be solved using a metaheuristic approach to obtain the optimal or near-global optimal solution. This study aims to solve RLP using ant colony optimization (ACO), a metaheuristic approach. MATLAB 2019 is used to implement the ACO model. A real-time project is used in this study to verify the efficiency of the proposed model. The results obtained from the ACO model are near-global optimum solutions that eliminate premature convergence.

Keywords Resource leveling · Ant colony optimization · Construction management · Optimal solution

1 Introduction

Project management plays a vital role in completing the project in the stipulated time, cost, and quality [1]. Resource management is a project management technique that ensures the planning and scheduling of resources. It helps to complete the project on time without causing any delay [2]. Resource leveling is one of the resource management techniques; it is performed to reduce peak fluctuations in the resource demand profile [3]. It is employed to reduce frequent hiring and firing of laborers and creates an efficient resource allocation schedule [4]. It significantly minimizes

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construction delays [5]. In resource leveling, shifting of the early start of the non-critical activities using the float days creates a realistic project schedule and better decision-making in the resource allocation process.

Researchers have used mathematical, heuristic, and metaheuristic approaches to solve resource-leveling problems (RLP). Mathematical techniques give a good quality solution, but it is only suitable for small projects [6]. Heuristic approaches can handle large project data, but it gives good or near-optimal solutions [7]. Metaheuristic approaches guarantee an optimal or global optimal solution and are suitable for large-sized projects [8]. Genetic algorithm, neural network, simulated annealing, Tabu search, and ant colony optimization are the frequently used metaheuristic approaches used by researchers to solve RLP.

In this study, the ant colony optimization (ACO) model is proposed to solve the resource-leveling problem (RLP). The proposed ACO model is simple, attempts to reduce the moment deviation, fluctuations in resource requirements, and eliminates the premature convergence that makes the proposed ACO model better than the other metaheuristic approaches.

2 Literature Review

A genetic algorithm-based resource-leveling approach was proposed to optimize multiple resource utilization with the decision support system architecture [9]. This method minimizes construction pollution by resource leveling using the genetic algorithm by considering construction pollution index and hazard magnitude [4]. A multi-objective technique using the genetic algorithm was developed to solve multi-resource-leveling problems [10]. Two innovative resource-leveling metrics to measure and minimize the negative impact of resource fluctuations on construction productivity and cost were developed and studied [11]. A genetic algorithm model considering the activity splitting was proposed with a novel local search heuristic and a repair mechanism. A path-relinking metaheuristic algorithm, which includes relinking method, repairing method, and improvement method, was developed to solve RLP [12]. A model to solve resource-leveling problems using the genetic algorithm was proposed that considered the precedence relationship between the activities [13]. Improved and adaptive harmony search was developed for the RLP with multiple resources considering the minimal time lag [8]. A modified scheduling method was proposed, which considered the start-to-start precedence relationship to solve RLP using the genetic algorithm [14]. An integrated approach by combining a serial schedule generation scheme with ant colony optimization was developed to solve RLP [6]. An activity-on-node-based directional ant colony optimization technique was developed to solve RLP [15]. A simple resource-leveling approach with multi-mode execution activities was considered to solve RLP [16]. In this study, the ACO model is proposed to reduce the moment deviation and the fluctuations in the resource profile.

3 Methodology

Ant colony optimization (ACO) is a swarm-intelligence-based metaheuristic approach to solve combinatorial problems. The ACO algorithm is developed based on the behavior of real ants. Real ants try to find out the shortest possible route between their nest and the food source. Initially, the ants from the nest travel randomly to reach the food source. On their way to the back to the nest from the food source, ants deposit pheromone, a chemical substance. The blind ants communicate with other ants with the help of pheromone. The following ant from the nest chooses the path with high pheromone concentration. As the time increases, pheromone tends to evaporate. It indicates that the higher the pheromone concentration, the shorter the route.

The proposed ACO model attempts to find the optimal shift of the non-critical activities to reduce the moment deviation and the maximum daily resource requirement. A real-time project data with 53 activities in G+1 residential villa located in Bangalore is used to validate the proposed model (Table 1). MS-Project 2016 application is used to schedule the activities and identify the non-critical activities and their float days.

The developed ant colony optimization (ACO) model is implemented in MATLAB 2019. The procedure to implement the model is as follows:

Step 1: ACO graph is created with the given input X, Y coordinates and the distance between the edges.

Step 2: ACO graph provides a path for ants to travel from the first node to the last node.

Step 3: The ACO parameters such as pheromone exponential parameter (α), desirability exponential parameter (β), evaporation rate (ρ), number of iterations, and number of ants are initialized.

Step 4: The parameters are initialized in the ant colony.

Step 5: Using the fitness function best tour graph is created.

Step 6: The best tour fitness function is updated for the next iteration, and the process continues till the specified number of iterations.

Step 7: The optimal shift of float days of each non-critical activity is identified from the best tour graph.

4 Results

The main objective of this study is to reduce the moment deviation and the maximum daily resource demand without extending the project duration. Using the ACO model, moment deviation was reduced by 9.8%. The other resource-leveling metrics, such as resource-leveling index, standard deviation, and square deviation was reduced by 9%, 14.6%, and 14.6%, respectively (Table 2).

Table 1 Activity details

S. no.	Task name	Duration	Precedence	Free slack	Total slack	Resource
1	Excavation	8		0 days	0 days	M72, H60
2	Footing shuttering	5	1	0 days	0 days	H88, C44
3	Footing reinforcement	6	2	0 days	0 days	H68, C68
4	Footing concrete	13	3	0 days	0 days	M11, H94, B56
5	Column above footing to GL shuttering	1	4	0 days	0 days	H61, C31
6	Column above footing to GL reinforcement	1	5	0 days	0 days	H15, F18
7	Column above footing to GL concrete	1	6	0 days	0 days	M6, H47, B28
8	Grade beam shuttering	5	7	0 days	0 days	H79, C39
9	Grade beam reinforcement	2	8	0 days	0 days	H72, C72
10	Grade beam concrete	6	9	0 days	0 days	M8, H73, B43
11	GF column shuttering	6	10	0 days	0 days	H92, C46
12	GF column reinforcement	3	11	0 days	0 days	H87, C87
13	GF column concrete	5	12	0 days	0 days	M10, H82, B48
14	GF beam shuttering	6	13	0 days	0 days	H82, C41
15	GF beam reinforcement	3	14	0 days	0 days	H82, C82
16	GF beam concrete	1	15	0 days	0 days	M10, H87, B51
17	GF slab shuttering	2	16	0 days	0 days	H82, C41
18	GF slab reinforcement	2	17	0 days	0 days	H87, F87
19	GF slab concrete	10	18	0 days	0 days	M9, H80, B47
20	GF de-shuttering	2	19	0 days	0 days	H82, C41

(continued)

Table 1 (continued)

S. no.	Task name	Duration	Precedence	Free slack	Total slack	Resource
21	FF column shuttering	6	20	0 days	0 days	H83, C41
22	FF column reinforcement	3	21	3 days	3 days	H59, F59
23	FF column concrete	5	22	0 days	0 days	M9, H75, B44
24	FF beam shuttering	6	23	0 days	0 days	H82, C41
25	FF beam reinforcement	4	24	0 days	0 days	H84, F84
26	FF beam concrete	5	25	0 days	0 days	M10, H88, B52
27	FF slab shuttering	6	26	0 days	0 days	H65, C33
28	FF slab reinforcement	4	27	0 days	0 days	H70, F70
29	FF slab concrete	1	28	0 days	0 days	M9, H81, B48
30	GF block work	7	29,20FS + 7 days	12 days	12 days	M56, H4
31	FF de-shuttering	6	29	0 days	0 days	H65, C33
32	Headroom column shuttering	4	31	0 days	0 days	H51, C26
33	Headroom column reinforcement	4	32SS + 2 days	0 days	0 days	H24, F24
34	Headroom column concrete	1	33	0 days	0 days	M6, H49, B29
35	Headroom beam shuttering	4	34	0 days	16 days	H51, C26
36	Headroom beam reinforcement	4	35	0 days	16 days	H38, F38
37	Headroom beam concrete	3	36	0 days	16 days	M8, H67, B39
38	Headroom slab shuttering	4	37	0 days	16 days	H33, C17

(continued)

Table 1 (continued)

S. no.	Task name	Duration	Precedence	Free slack	Total slack	Resource
39	Headroom slab reinforcement	2	38	16 days	16 days	H47, F47
40	Headroom slab concrete	3	39	2 days	2 days	M9, H73, B43
41	FF block work	1	31FS + 7 days	6 days	6 days	M56, H4
42	GF button work and plastering	15	30FS + 10 days,34SS + 3 days	0 days	0 days	M84, H92
43	FF button work and plastering	15	41,42SS + 5 days	0 days	0 days	M79, H86
44	Headroom button work and plastering	10	43SS + 4 days, 40	0 days	0 days	M70, H77
45	Outer plastering	16	44SS + 4 days	0 days	0 days	H99, B99
46	Water proofing GF	1	44SS + 2 days,45	0 days	0 days	M50, H56
47	Water proofing FF	1	44SS + 2 days,45	0 days	0 days	M50, H56
48	Water proofing Headroom	5	47SS	0 days	0 days	M63, H69
49	Door frame	3	45SS	0 days	1 day	H45, C23
50	Granite work	16	49	2 days	2 days	
51	Windows	5	45SS + 5 days	11 days	11 days	H28, C14
52	Grill	6	46SS + 3 days	8 days	8 days	H40, F40
53	Outer painting	18	49SS + 2 days	1 day	1 day	H89, P89

M- Mason, H-Helper, C-Carpenter, F-Fitter, B-Bhisthi, P-Painter

Table 2 Resource-leveling metrics

S. no.	Metrics	Before leveling	After leveling
1	Moment of histogram	14,980.4	13,359.5
2	Maximum resource demand	63	58
3	Minimum resource demand	0	1
4	Resource-leveling index	2940	2673
5	Standard deviation	225.4	192.8
6	Square deviation	50,805.16	37,171.84

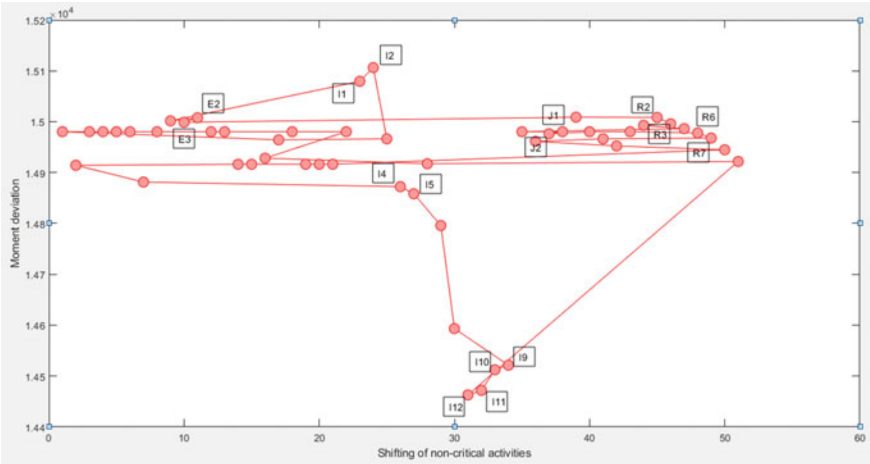

Fig. 1 Best tour graph

Ant colony optimization (ACO) inputs X, Y coordinates are determined from possible shifts of non-critical activities and their corresponding moment deviation value. The possible shifts of non-critical activities can be denoted as 1, 2, and 3 in X coordinates for simplicity and can be decoded to identify the optimal shift of the non-critical activities. More number of non-critical activities increases the search space (possible solutions) of the ACO algorithm that improves the optimal solution quality. Figure 1 presents the possible solution and the best tour graph. The optimal solution is obtained from the best tour graph. The negative slope from the graph (Fig. 1) with consecutive x-axis values is chosen to perform the shifting process in the non-critical activities. The decoded results are presented in Table 2. Figure 4 presents the convergence of the optimal solution obtained from the fitness value of each iteration (Figs. 2 and 3).

5 Discussion

Ant colony optimization (ACO) algorithm developed in this study attempts to reduce the moment deviation. Compared with other approaches, the proposed ACO model takes additional few seconds of computational time to obtain the result. The computational time taken by the ACO algorithm depends on the number of nodes and the specified number of iterations.

The optimal solution obtained from the best tour graph for the considered activity details can reduce the moment deviation. Figures 2 and 3 present the before leveling and after leveling resource requirements, respectively. Compared with Figs. 2 and 3 shows the reduction in the resource fluctuations. The other resource-leveling metrics such as resource-leveling index, standard deviation, and squared deviation show

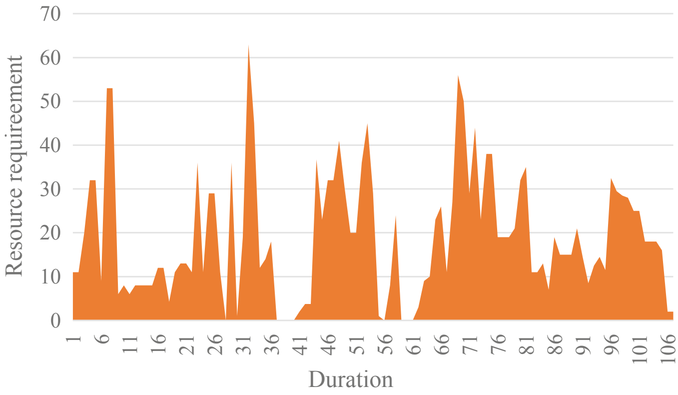

Fig. 2 Before leveling resource requirement

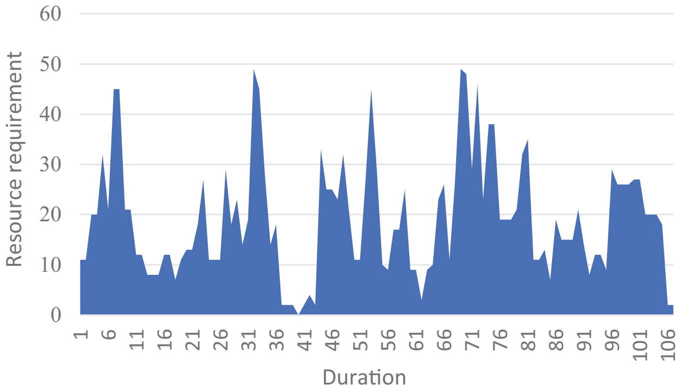

Fig. 3 After leveling resource requirement

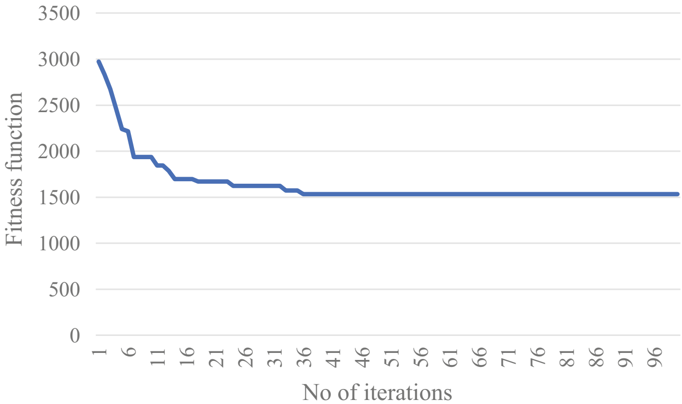

Fig. 4 Convergence curve

Table 3 Decoded ACO results

S. no.	Activity	Float	Optimal shift
1	FF column reinforcement—E	3	3
2	GF block work—I	12	12
3	Headroom slab concrete—J	2	2
4	Grill work—R	8	7

significant improvement after leveling (Table 2). The proposed model eliminates premature convergence as the fitness function increases with the number of iterations (Table 3).

6 Conclusion

The optimal shift of the early start of the non-critical activities to reduce the resource requirement is derived from the proposed ACO model. The moment deviation, maximum and minimum resource requirement, resource-leveling index, standard and square deviations were decreased by shifting the non-critical activities based on the float days obtained from the ACO best tour graph. Logical changes or combinations of precedence relationships can reduce the difference between the maximum and minimum resource demand. The proposed ACO model eliminates premature convergence.

7 Future Scope

The ACO model can be used to solve other combinatorial problems like resource-constrained project scheduling, traveling salesman problems, vehicle routing problems, and disaster relief operations. The impact of the visibility factor and statistical function in the proposed model can be the potential scope of future research.

References

1. Ponz-Tienda, J. L., Yepes, V., Pellicer, E., & Moreno-Flores, J. (2013). The Resource Leveling Problem with multiple resources using an adaptive genetic algorithm. *Automation in Construction, 29*, 161–172. https://doi.org/10.1016/j.autcon.2012.10.003.
2. Agarwal, A., Colak, S., & Erenguc, S. (2011). A Neurogenetic approach for the resource-constrained project scheduling problem. *Computers & Operations Research, 38*(1), 44–50. https://doi.org/10.1016/j.cor.2010.01.007.
3. Lafayette, W. (1999). “M a r l p c e : h a,” no. February, pp. 23–31.

4. Li, H., Chen, Z., Wong, C. T. C., & Love, P. E. D. (2002). A quantitative approach to construction pollution control based on resource levelling. *Construction Innovation, 2*(2), 71–81. https://doi.org/10.1191/1471417502ci029oa.
5. Sen Leu, S., Yang, C. H., & Huang, J. C. (2000). Resource leveling in construction by genetic algorithm-based optimization and its decision support system application. *Automation in Construction, 10*(1), 27–41. https://doi.org/10.1016/S0926-5805(99)00011-4.
6. Xiong, Y., & Kuang, Y. P. (2006)"ANT colony optimization algorithm for resource leveling problem of construction project. *Proceedings CRIOCM 2006 International Research Symposium Advances Construction Management Real Estate, 1*, 384–391, 2006.
7. Ranjbar, M. (2013). A path-relinking metaheuristic for the resource levelling problem. *The Journal of the Operational Research Society, 64*(7), 1071–1078. https://doi.org/10.1057/jors.2012.119.
8. Ponz-Tienda, J. L., Salcedo-Bernal, A., Pellicer, E., & Benlloch-Marco, J. (2017). Improved adaptive harmony search algorithm for the resource leveling problem with minimal lags. *Automation in Construction, 77*, 82–92. https://doi.org/10.1016/j.autcon.2017.01.018.
9. Leu, S.-S., Yang, C.-H., & Huang, J.-C. (2000). Resource leveling in construction by genetic algorithm-based optimization and its decision support system application.
10. Maloney, W. F., & Smith, G. R. (2004). Copyright ASCE 2004 Construction Research Congress Construction Research 2003, pp. 1–8.
11. Heon Jun, D., & El-Rayes, K. (2011). Multiobjective optimization of resource leveling and allocation during construction scheduling. *Journal Construction Engineering Management, 137*(12), 1080–1088. https://doi.org/10.1061/(asce)co.1943-7862.0000368.
12. Hossein Hashemi Doulabi, S., Seifi, A., & Shariat, S. Y. (2011). Efficient hybrid genetic algorithm for resource leveling via activity splitting. *Journal Construction Engineering Management, 137*(2), 137–146. https://doi.org/10.1061/(asce)co.1943-7862.0000261.
13. Benjaoran, V., Tabyang, W., & Sooksil, N. (2015). Precedence relationship options for the resource levelling problem using a genetic algorithm. *Construction Management and Economics, 33*(9), 711–723. https://doi.org/10.1080/01446193.2015.1100317.
14. Selvam, G., & Tadepalli, T. C. M. (2019). Genetic algorithm based optimization for resource leveling problem with precedence constrained scheduling. *International Journal Construction Management*, 1–10, 2019https://doi.org/10.1080/15623599.2019.1641891.
15. Geng, J. Q., Weng, L. P., & Liu, S. H. (2011). An improved ant colony optimization algorithm for nonlinear resource-leveling problems. *Computer Mathematic with Application, 61*(8), 2300–2305. https://doi.org/10.1016/j.camwa.2010.09.058.
16. Garmsiri, M., & Abassi, M. R. (2012). Resource leveling scheduling by an ant colony-based model. *Journal Industrial Engineering International, 8*(1), 1–9. https://doi.org/10.1186/2251-712X-8-7.

Impact of Genetic Algorithm Operators in Solving Resource-Leveling Problem

R. S. Gokula Krishnan and Gopinath Selvam

Abstract Resource leveling reduces the peak fluctuations in the resource requirement. Fluctuation in the resource requirement leads to construction delays, frequent hiring and firing of labors which affects labor productivity during the execution of the project. Resource-leveling problem (RLP) is a type of combinatorial problem that requires advanced problem-solving approaches to solve. Genetic algorithm (GA) is one of the well-adopted meta-heuristic approaches to solve combinatorial problems like RLP. The objective of this study is to determine the impact of different values of genetic algorithm operators from previous literature works to obtain the optimal values to perform genetic algorithm operations. A real-time construction project data is considered to study the relationship of genetic algorithm operators which leads to determining the optimal values.

Keywords Resource leveling · Genetic algorithm · Labor productivity · GA operators

1 Introduction

In the construction industry, project management plays a crucial role in handing over the project on time and this depends on handling the various resources efficiently [1]. Resource-leveling problem (RLP) is considered the most critical phase in managing the project [2]. Resource leveling focuses on utilizing the resources efficiently where the duration is a constraint, and it minimizes deviation in daily resource requirement to the possible extent [3]. When the variation in resource requirement reduces, automatically the resource demand and the cost of the project decreases [1].

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Resource leveling takes place after scheduling the project in which the objective is to minimize the fluctuation of the resource. The resource-leveling solution can be found by shifting the non-critical activity. The critical path method (CPM) is the technique that is generally used to schedule the project activities by considering the precedence relationship [4]. Traditional approaches give solutions when the number of activities is less; similarly, heuristic approaches give solutions for larger projects but the problem is that these approaches will not provide an optimal solution or near-optimal solution and when the number of activities increased these approaches take a long time to resolve [10].

Resource leveling is considered the most important factor in project management in which it defines the profit and success of the project [5]. Resource leveling was done in various approaches to minimize the project's peak resource requirement. These approaches gave a better solution, but a complex project to deal with it took a long time. In resource-leveling problem, duration is the constraint where the project duration is not extended at any cause. Resource leveling is done to reduce the variation in the resource requirement throughout the project duration. The process of resource leveling is done by shifting the early start of the non-critical activities [6].

2 Genetic Algorithm

Genetic algorithm was invented by John Henry Holland in the 1970s. It is purely based on Charles Darwin's theory of natural selection. It consists of six phases. They are initial population where it refers to the set of possible solutions, and the second phase is the fitness function where each possible solution has a fitness score. The third phase is the selection process. This process is done by Roulette wheel, based on the fitness score it moves to the recombination process. The fourth phase is recombination. During the process of recombination, chromosomes might face random changes in the gene. Genes are joined into a string to form a chromosome. Good characteristics of the population get transferred to the next generation [7]. The fifth phase is the mutation where at a random point changes take place in the gene. In this phase, the changes that take place in a positive manner move to the next generation; otherwise, the gene will not transfer to the next generation. Good genes and good features will be transferred from one generation to the next generation. The final process is elitism where the fittest individual guaranteed will not undergo mutation. These processes are repetitively done over the generation until we get the optimal solution.

3 Research Gap

Genetic algorithm optimization was the most preferred method to solve the resource-leveling problem (RLP) [8] since the nature of RLP and genetic algorithm (GA) is similar. GA is a meta-heuristic approach in which it consists of six stages, including four operators—initial population, selection, fitness function, recombination, mutation and elitism. Previously the authors who solved the RLP using GA had come across these operators. In the proposed study, the selection process is done by the Roulette wheel method and then the different values were assigned to the operators to obtain the optimal solution. This paper presents the variant values for each operator to know how the different values of each operator influence the determination of optimal solution.

4 Literature Review

An idea is proposed to use genetic algorithm in solving the resource-leveling problem in order to overcome the difficulties faced in traditional and heuristic approach, which were complex to solve larger data and it had a limitation on computation time [1]. Genetic-algorithm-based resource-leveling scheduling system is used to illustrate the approached problem [1]. An idea is stated to control the pollution caused due to the execution of construction by resource leveling [9]. Here, the author introduces new parameters such as construction pollution index (CPI) and hazard magnitude (h_i). These were considered pseudo-resource [9]. If the level of pollution increases the limit assigned by the government, then it is founded by the regulatory body; hence, resource leveling is done to distribute the pollution evenly [9]. Reference [10] A model was adopted to use a hybrid GA for scheduling the resources in construction projects in which it considers all precedence relationships; the presented algorithm showed good performance over the traditional critical path method (CPM) by reducing the cost, minimizing the project schedule.

This paper affirmed a new GA that enables the multi-objective technique to level multi-resource. In this GA model, each resource usage is founded by adaptive weights where it is generated from the previous generation [11]. In this process, the GA model and the method of moving asymptotes (MMA) approach were compared where GA showed better solutions as it can be used to optimize larger projects [11]. A new approach is proposed using GA and Monte Carlo simulation to level the resource by developing a model under uncertainty. The project networks were modeled by Monte Carlo simulation and the GA is used to level the multi-resource to get maximum usage of resource under minimum duration [12]. This paper proposed a new concept of RLP with relationship options and it provides an alternative relationship that offers more float time and allows new possibilities to arrange in an efficient pattern and minimizes the project resource demand. This model can be used directly to level multiple resources [4]. The model is verified with two project instances. From both instances, it was concluded that the RLP model with options gave better results than the model without relationship options [4]. The presentation of this paper involves an algorithm based on hyper-heuristic which is a tabu-based search for problems in resource leveling under the circumstances of resource constraints. By using the concept of “replace” and “swap” in the priorities of work, “hard core” has not been changed in the hyper-heuristic algorithm [13]. Therefore, the result proves that this algorithm will improve resource handling under resource constraints [13]. This paper deals with resource-leveling optimization problem met in modern project management and it is comparatively analyzed with three different intelligent meta-heuristics by hybrid nature-inspired intelligent approach, and a combination of ant colony optimization (ACO) and genetic algorithm here proves to be a more effective approach in making a special decision [14]. This paper proposed the development of two resource-leveling metrics to assess and mitigate the negative effects of resource volatility on construction efficiency and cost. This shows that the developed metrics are capable of reducing unfavorable resource fluctuation and resource idle time [15]. In previous research, authors have used different values for each operator and concluded the optimal solution for their approached problem. In this study, the different values of each operator are assigned and their results are compared and from that the optimal solution is obtained.

5 Methodology

Figure 1 shows the procedure for carrying out the proposed idea. The real-time construction project data was considered to solve the proposed idea. Then the activities were determined from which the resources were allocated to each activity and the resource profile was prepared. From the given activities, the non-critical activities were determined. The GA model is created in the MATLAB 2016a. The input data got from the resource profile is implemented in the GA model. The parameters are defined until an optimal solution is obtained. A real-time construction project data of G + 1 residential building located in Chennai, which consists of 18 activities is used to study the effectiveness of the optimal values. The resources were allocated according to the quantity of work to be done. The data was then implemented in the Microsoft project management (MSP) through which the critical, non-critical activity and total float days were calculated.

Once the data is collected, the quantity of the amount of work to be done should be calculated. The duration for each work was allocated according to the amount of work to be done and it depends on the amount of resource availability. The resources were allocated to each activity, and the activity predecessors are also mentioned. The critical, non-critical activity and float days were calculated by implementing the data in MSP. The daily resource requirement was then calculated by acquiring the data from the MSP and implementing it to MS-Excel. The acquired data is implemented into the MATLAB 2016a, and then using genetic algorithm optimization, resource leveling is done. Finally, the daily resource requirement after leveling is acquired (Table 1).

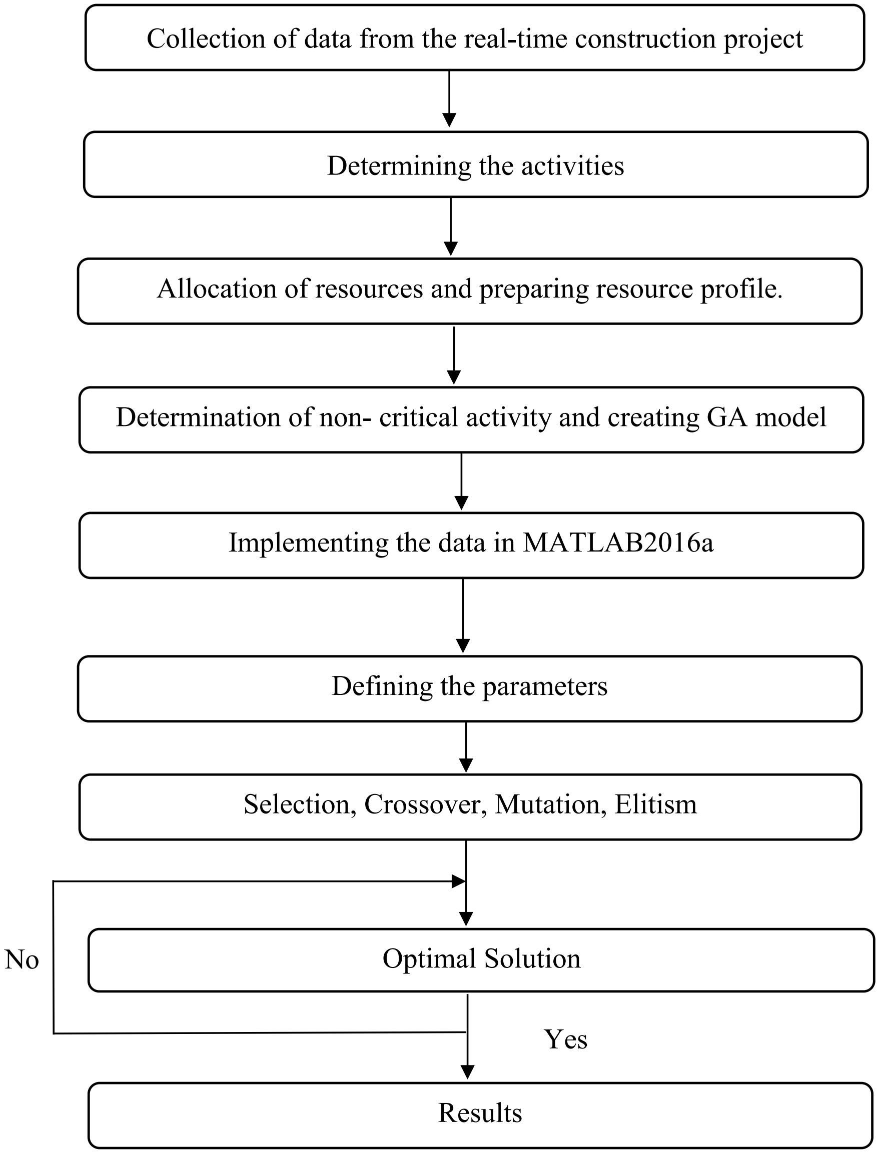

Fig. 1 Methodology

6 Results and Discussion

The parameters considered to obtain the solutions are the probability of crossover (P_{cr}), probability of mutation (P_m), and probability of elitism (P_{er}). The convergence curve shows the attainment of the optimal solution where the x-axis denotes the

Table 1 Activity details

S. no.	Task name	Precedence	Duration	Mason	Helper	Carpenter	Fitter	Bhisti
1	*Column casting*							
2	Reinforcement		14	–	15	–	10	–
3	Shuttering	2SS+1 days	8	–	8	15	–	–
4	Concreting	2,3	4	10	15	–	–	20
5	De-shuttering	4FS+1 days	2	–	15	17	–	–
6	*Beam casting*							
7	Reinforcement	5FS	13	–	8	–	4	–
8	Shuttering	7SS+2 days	6	–	10	13	–	–
9	Concreting	7,8	4	10	15	–	–	20
10	De-shuttering	9FS+1 days	1	–	10	13	–	–
11	*Floor slab*							
12	Shuttering	10FS	10	–	5	2	–	–
13	Reinforcement	12SS+2 days	14	–	6	–	10	–
14	Strand laying	13SS+1 days	4	–	10	–	13	–
15	Reinforcement	13SS	10	–	5	–	6	–
16	Concreting	13,14,15	4	15	90	–	–	55
17	Stressing of strands	16FS+18 days	4	–	30	–	30	–
18	De-shuttering	16FS+14 days	2	–	26	15	–	–

number of generations and the y-axis denotes the optimal solution The graph shows the number of iteration done for each trial and it shows the significant changes in obtaining the optimal solution (Z). Five trials were done to attain the optimal solution from the input data we got from the real-time construction project data. The objective is to keep the duration as the constraints we need to level the resource without affecting the project's even flow.

Table 2 shows the variant values of each operator and their optimal solution. Figure 3 shows their respective operator input values and their optimal solution. In Fig. 2, the optimal solution is attained at the ninth generation and in Fig. 3 the

Table 2 Different operator's values and its respective optimal solution

Trial no.	Pcr	Pm	Pel	Z
1	0.85	0.03	0.01	−351188
2	0.90	0.01	0.2	−352100
3	0.95	0.01	0.2	−351204
4	0.85	0.02	0.02	−351188
5	0.85	0.02	0.01	−351284

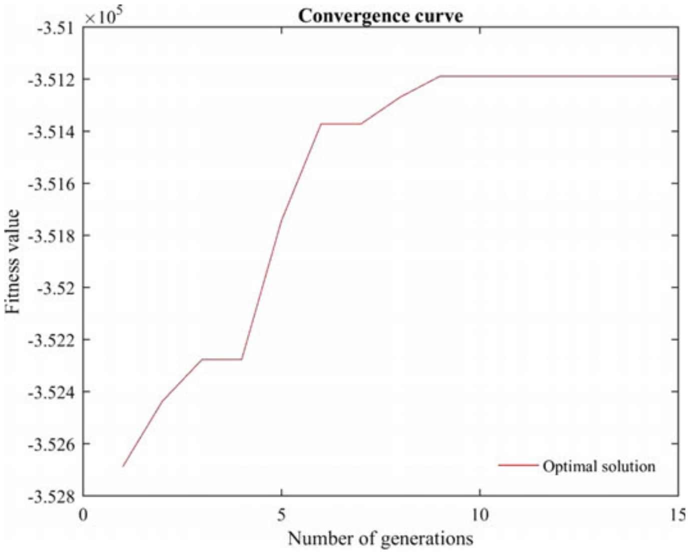

Fig. 2 Trial 1—$P_{cr} = 0.85$, $P_m = 0.03$, $P_{er} = 0.01$, $z = -351{,}188$

optimal solution is attained at the fifth generation. In Fig. 4, the optimal solution is attained at the seventh generation. In Fig. 5, the optimal solution is attained at the 12th generation. In Fig. 6, the optimal solution is attained at the 14th generation. The maximum iteration considered was 15 where we found the optimal solution by varying the values of the different operators. The bar chart shows the daily resource requirement of the schedule throughout the project.

The bar chart (Fig. 7) shows the resource histogram before leveling. Figs. 8, 9 and 10 show the after leveling profile of their respective trials and its significant changes occur in the resource requirements for each trial. The objective is to keep the duration as the constraints and we need to level the resource without affecting the project's even flow.

7 Conclusion

This study is done to determine the impact of different values of genetic algorithm operators to obtain the optimal solution. From the conducted trials, the optimal solution is $z = -352{,}100$ for which the value of the defined parameters is $P_{cr} = 0.90$, $P_m = 0.01$, $P_{el} = 0.2$. The optimal solution is obtained from the fifth iteration. The optimal solution is obtained in lesser iteration. It shows the relationship between the different GA operators from the conducted trials by their respective optimal solutions.

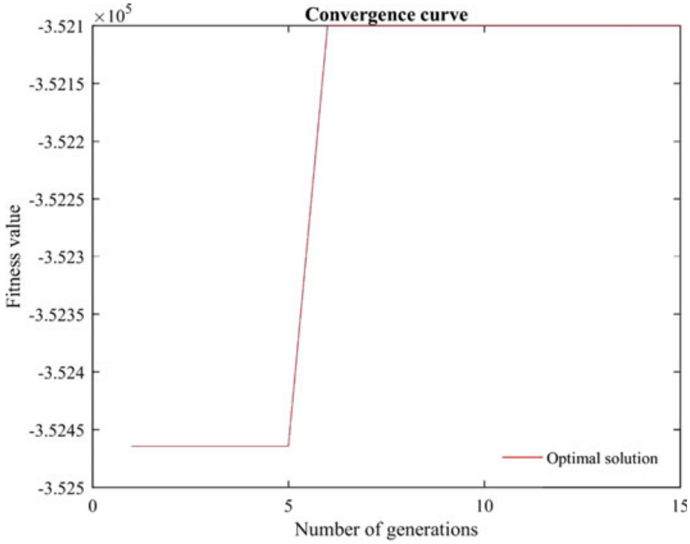

Fig. 3 Trial 2—$P_{cr} = 0.90$, $P_m = 0.01$, $P_{er} = 0.2$, $z = -352{,}100$

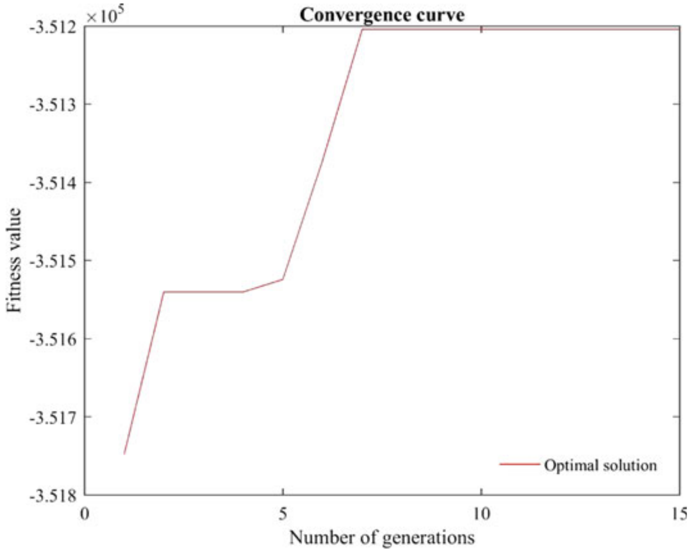

Fig. 4 Trial 3—$P_{cr} = 0.95$, $P_m = 0.01$, $P_{er} = 0.2$, $z = -351{,}204$

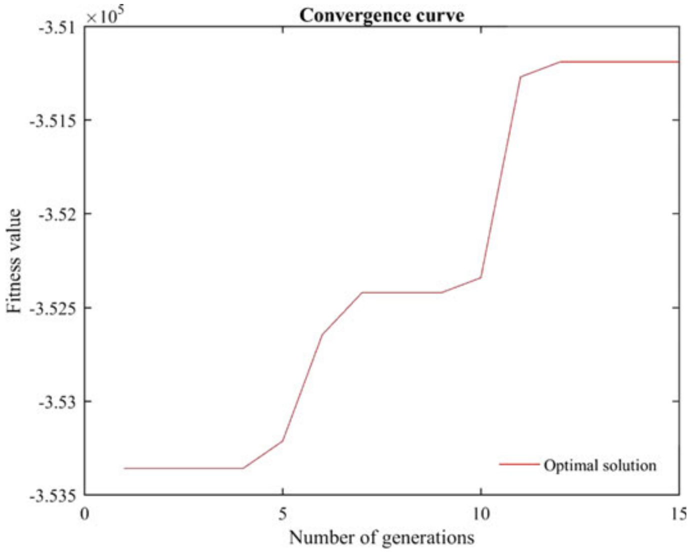

Fig. 5 Trial 4—$P_{cr} = 0.85$, $P_m = 0.02$, $P_{er} = 0.01$, $z = -351{,}188$

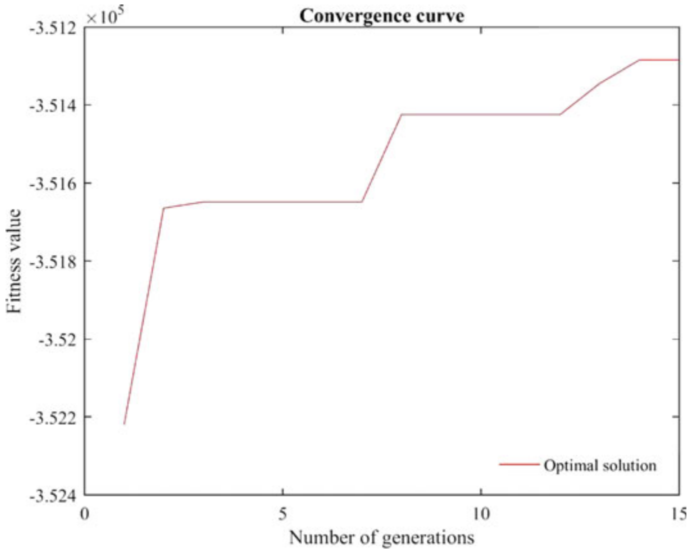

Fig. 6 Trial 5—$P_{cr} = 0.85$, $P_m = 0.02$, $P_{er} = 0.01$, $z = -351{,}284$

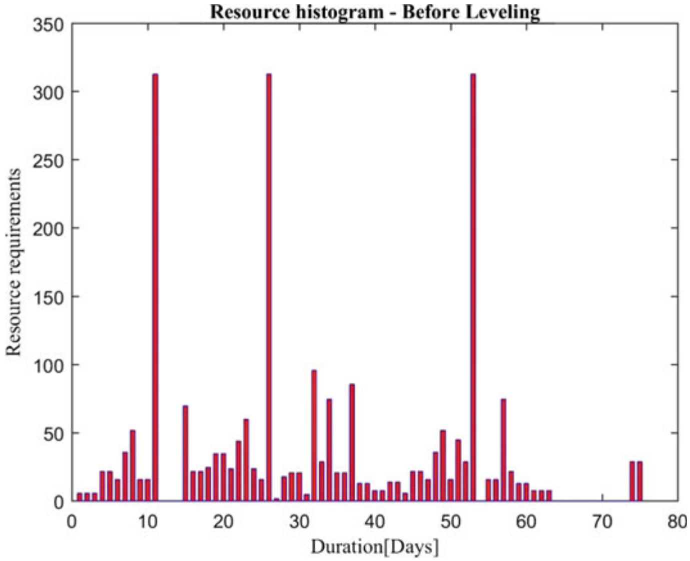

Fig. 7 Before leveling

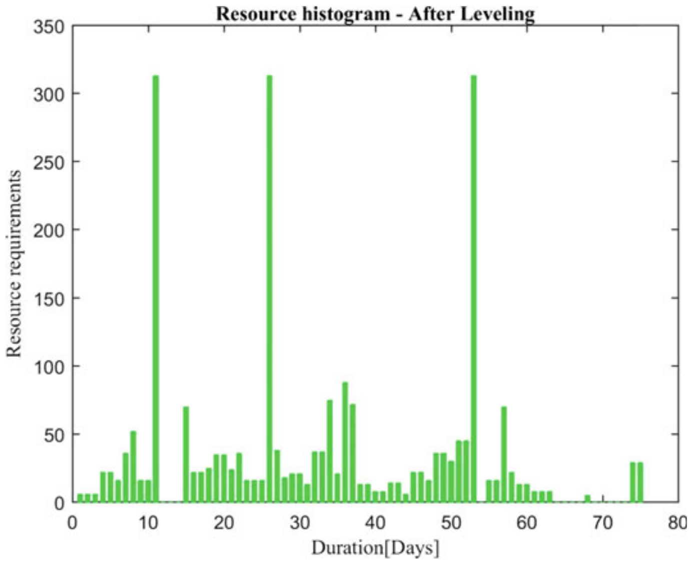

Fig. 8 Trial 1—After leveling

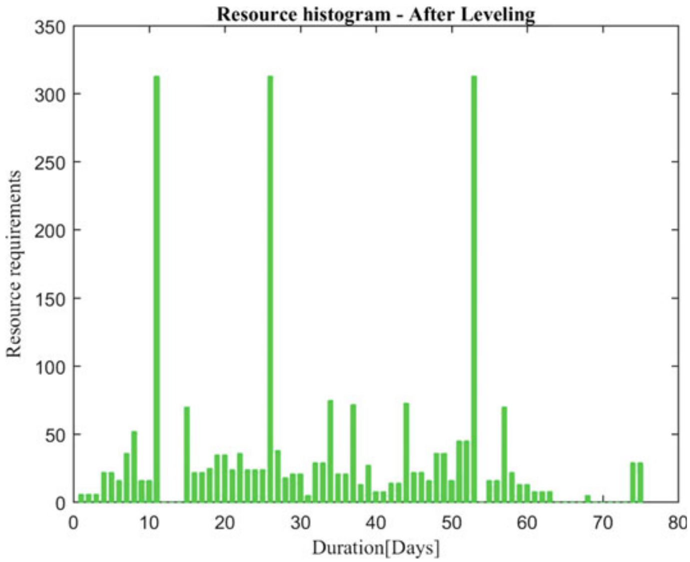

Fig. 9 Trial 2—After leveling

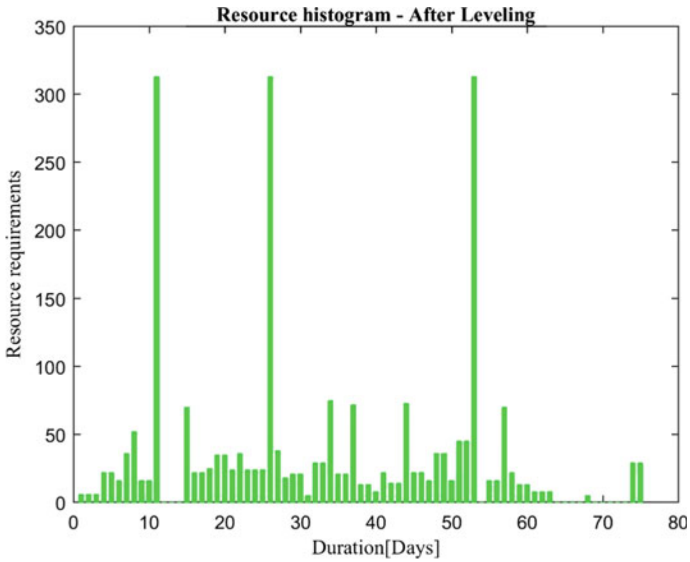

Fig. 10 Trial 3—After leveling

References

1. Leu, S.-S., Yang, C.-H., & Huang, J.-C. (2000). Resource leveling in construction by genetic algorithm-based optimization and its decision support system application. [Online]. Available: www.elsevier.comrlocaterautcon.
2. Li, H., & Demeulemeester, E. (Feb. 2016). A genetic algorithm for the robust resource leveling problem. *Journal of Scheduling, 19*(1), 43–60. https://doi.org/10.1007/s10951-015-0457-6
3. Damci, A., & Polat, G. (Jul. 2014). Impacts of different objective functions on resource leveling in construction projects: A case study. *Journal of Civil Engineering and Management, 20*(4), 537–547. https://doi.org/10.3846/13923730.2013.801909
4. Benjaoran, V., Tabyang, W., & Sooksil, N. (Sep. 2015). Precedence relationship options for the resource levelling problem using a genetic algorithm. *Construction Management and Economics, 33*(9), 711–723. https://doi.org/10.1080/01446193.2015.1100317
5. Ponz-Tienda, J. L., Yepes, V., Pellicer, E., & Moreno-Flores, J. (Jan. 2013). The resource leveling problem with multiple resources using an adaptive genetic algorithm. *Automation in Construction, 29*, 161–172. https://doi.org/10.1016/j.autcon.2012.10.003
6. Selvam, G., & Tadepalli, T. C. M. (2019). Genetic algorithm based optimization for resource leveling problem with precedence constrained scheduling. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2019.1641891
7. Ponz-Tienda, J. L., Salcedo-Bernal, A., Pellicer, E., & Benlloch-Marco, J. (2017). Improved adaptive harmony search algorithm for the resource leveling problem with minimal lags. *Automation in Construction, 77*, 82–92. https://doi.org/10.1016/j.autcon.2017.01.018
8. Georgy, M. E. (Jul. 2008). Evolutionary resource scheduler for linear projects. *Automation in Construction, 17*(5), 573–583. https://doi.org/10.1016/j.autcon.2007.10.005
9. Li, H., Chen, Z., Wong, C. T. C., & Love, P. E. D. (2002). A quantitative approach to construction pollution control based on resource levelling. *Construction Innovation, 2*(2), 71–81, Jun. 2002, doi: https://doi.org/10.1108/14714170210814694.
10. Senouci, A. B., & Eldin, N. N. (2004). Use of genetic algorithms in resource scheduling of construction projects. *Journal of Construction Engineering and Management, 130*(6), 869–877. https://doi.org/10.1061/(asce)0733-9364(2004)130:6(869)
11. Zheng, D. X. M., Ng, S. T., & Kumaraswamy, M. M. (2004). GA-Based Multiobjective technique for multi-resource leveling. *Construction Research Congress 2003*. https://doi.org/10.1061/40671(2003)29.
12. Sen Leu, S., & Hung, T. H. (2002). An optimal construction resource leveling scheduling simulation model. *Canadian Journal of Civil Engineering*, *29*(2), 267–275. https://doi.org/10.1139/l02-007.
13. Koulinas, G. K., & Anagnostopoulos, K. P. (2013). A new tabu search-based hyper-heuristic algorithm for solving construction leveling problems with limited resource availabilities. *Automation in Construction, 31*, 169–175. https://doi.org/10.1016/j.autcon.2012.11.002
14. Kyriklidis, C., Vassiliadis, V., Kirytopoulos, K., & Dounias, G. (Oct. 2014). Hybrid nature-inspired intelligence for the resource leveling problem. *Operations Research, 14*(3), 387–407. https://doi.org/10.1007/s12351-014-0145-x
15. Heon Jun, D., & El-Rayes, K. (2011). Multiobjective Optimization of resource leveling and allocation during construction scheduling. https://doi.org/10.1061/(ASCE)CO.

A Quantitative Study on Construction Job Safety Analysis and Occupational Safety and Health Management

M. G. Soundarya Priya, K. S. Anandh, and K. Prasanna

Abstract This paper aims to generate an extensive database to consolidate all the possible loss-of-control situations in construction sites using the job safety analysis (JSA) method, examine hazards, give remedial measures, and create a health and safety plan. The safety techniques of various organizations are studied from data collection questionnaire surveys conducted at 30 different construction sites in Tamil Nadu and Kerala. The questionnaire consists of 83 questions of dichotomous questions. Quantitative analysis is done using the Statistical Package for the Social Science (SPSS) software. Findings say that both the regions have their advantage and disadvantage. Both sites follow regulations and provide proper training to workers, but at the same time in opposite, both sites give improper provisions of facilities. Some sites do not maintain the record and most workers on site are not aware of the principles. Results show that the selected construction project struggles in safety and health management. The resulting findings may help the project managers in their future works in safety provisions at the construction site. Recommendations for construction safety are provided.

Keywords Construction safety · Job safety analysis · Construction accidents · Safe workplace · Occupational risk

1 Introduction: The Construction Industry

After agriculture, the construction industry is India's second-largest employer, trailing only road accidents. The construction industry in India has an annual turnover of about 4000 billion rupees. The amount of deaths in the construction sector is

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alarming, and falls from great heights and through openings are two of the most common causes of serious accidents.

Construction safety is still a top concern in almost every country because the construction industry is the leading cause of severe and fatal accidents among all other sectors. Whether calculated in absolute terms or in comparison to other industries, the construction industry has a disconcertingly low safety record. Variations in labor forces, changing economics, insurance rates, legal implications, and technological advancement all impact the level of construction safety in a region. The issue is global, and several approaches can be used in different countries to address it. Designing, preplanning, preparation, management engagement, and establishing a safety culture are all effective tools [1].

The current study assesses businesses based on building health and safety (H&S) practices, which are the foundation of H&S, workplace H&S facilities, transportation safety, electrical safety, fire resistance, manual handling and repetitive tasks safety, dangerous substances, and workplace H&S [2, 3].

1.1 Construction Job Safety Analysis

The process of identifying and evaluating hazards and threats is an essential part of safety management. A realistic approach for detecting, analyzing, and monitoring industrial procedure hazards is job safety analysis (JSA), also known as job hazard analysis (JHA).

The disparities among construction locations and industrial facilities, on the other hand, necessitate a unique construction process. Supervisors may use the findings of a job hazard analysis to identify and mitigate hazards in their workplaces. This would likely result in fewer occupational injuries and illnesses and safer, more efficient work procedures, lower workers' compensation rates, and increased staff productivity. The findings may also be used to teach new employees how to execute their jobs safely. A work hazard analysis must demonstrate the organization's dedication to H&S and follow-up on any unrestrained hazards found to be successful. Otherwise, management will mislay trust, and workers will not approach authority when they are at risk [4].

1.2 Major Causes of Accidents on a Construction Site

On a construction site, there are several causes of injuries. Many result from human error, such as dangerous working conditions, improper tool and equipment use, and let-down to use personal protective equipment (PPE). Following are eight of the most popular construction site mishaps: Unsafe working conditions, fall hazards, improper use of step ladders, roof construction falls, distorted excavation walls and ditches, electrical tool accidents, lifting/body straining, and truck accidents are all common causes of injury [5].

2 Literature Review

The following section deals with the summaries of the literature reviewed. Essential topics for this study are described below with the help of relevant literature.

2.1 Owner's Part in Safety

The research on the owner's role in construction safety was proposed [6]. Data was gathered through interviews conducted on significant construction projects. Project characteristics, safe contractor selection, contractual safety criteria, and the owner's position in project safety management during the execution were examined to determine the relationship between project safety performance and the owner's control. Direction on how owners directly disturb safety efficiency is offered by recognizing owners associated with successful project safety performances. Despite significant changes in recent years, the building industry remains to have one of the worst safety records in any industry. Owners, vendors, subcontractors, and designers have all worked together to make recent progress. While previous safety studies have looked into the roles of contractors, subcontractors, and builders, no study has ever looked into the impact of the owner on construction safety.

2.2 Safety in Construction

A survey of professional construction staff and first-line supervisors comprehensively detailing the preconditions and elements of high safety standards in the construction industry was published [7]. The findings provide a detailed description of the construction of high safety standards, including organizational, community, person, and technical aspects. High-quality interaction between different organizational positions and hierarchical levels stood out as essential aspects of security. The study aimed to collect data from experienced construction workers and first-line managers to define the preconditions and components of high safety standards in the construction industry.

Human factors are neglected in many construction sites that lead to vulnerable risk in construction safety [8, 9].

2.3 Job Load and Hazard Analysis

In this report, a simple, systematic workplace investigative approach for occupational health care was developed [10]. The stress–strain model, the hazard–danger model, and risk behavior theory are all part of the method's theoretical structure. Job load and hazard analysis are a modern approach with four stages: hazard detection, assessment, findings and proposals, and follow-up. Danger detection can be done in various ways. The process begins with a rough assessment of five factors: chemical hazards, physical hazards, physical load, mental stress, and the risk of an accident. An ordinal scale is used to rate hazards and stressors. If the analytical approach includes (1) detecting hazards at work by observations and interviews, as well as a questionnaire; (2) assessing findings as a team; and (3) evaluating the outcomes of these evaluations to produce conclusions and proposals by occupational health care workers, specialized approaches are used. For the storage and future use of data, a data processing system was built. In practice, the approach has improved the contents of occupational health care programs and created preventative measures. The method opens up a slew of new possibilities for reducing workplace hazards and researching the connection between working conditions and worker health.

2.4 Improve Performance in Modular Homebuilding

Low productivity and high accident rates in the construction industry [11] can be tackled simultaneously by incorporating lean manufacturing methods and conventional safety-analysis tools. In this case study, a modular housing manufacturing facility used Safety and Lean Integrated Kaizen (SLIK) by combining one lean development tool, Kaizen, a safety analysis tool, and work safety analysis (JSA). Lean manufacturing is a method of increasing manufacturing productivity and product quality. Five basic concepts underpin lean production: (1) Determine the customer's priorities; (2) define the value stream and question any moves that are wasting time; (3) deliver the product when the consumer requests it and keep it moving across the supply chain; (4) when continuous flow is complex, implement pull between all steps; and (5) manage toward perfection. In practice, Kaizen, an intense and oriented approach to process improvement, is used to put these ideas into practice. As a result, lean provides a comprehensive solution to transforming a homebuilder's community into constructive and efficient.

2.5 Characteristic Study of Workplace Accidents

Using descriptive statistics, correlation coefficient analysis, and ANOVA methodologies, the characteristics factors responsible for occupational accident occurrence in small construction enterprises in Taiwan were investigated [12]. According to the findings of this report, H&S management skills were among the factors affecting workplace accidents in small construction firms. Occupational accidents are more likely to occur on a worker's first day of work, the construction project has poor H&S management, and the employer does not provide PPE to the worker, according to the findings.

2.6 Creating Safer Workplaces

The safety climate was investigated [13]; from that we can say negligible attention has been paid to the factors that affect the safety system and the hypothesized mediating effect of safety climate in safety-related outcomes. A total of 2208 workers completed the survey from a large national retail chain in 21 different locations. After controlling for demographic factors, three factors accounted for 55% of the difference in perceived safety climate: environmental conditions, safety-related policies and programs, and general organizational climate. The organizational environment had a significant effect on the safety climate after improving the other more safety-relevant factors. According to partial correlations, security guidelines and services had the most critical observed link with safety environment, trailed by two dimensions of organizational climate. The main effects of numerous job situation influences on perceived workplace safety were direct, rather than being mediated by the safety environment. The perception of workplace safety was affected by the safety environment, but its position as a moderator was minimal. These outcomes are conferred in light of other latest findings on the workplace safety climate and the growing attention in administration and organizational factors in workplace safety.

2.7 Causative Reasons for Construction Catastrophes

Causative reasons for construction catastrophes were presented [14]. The accident investigations gathered qualitative data on the circumstances of each incident and the factors that contributed to it. Interviews with accident-involved staff and their supervisors or managers, a site assessment, and a review of relevant documents were part of the site-based data collection process. Off-site stakeholders, such as designers, vendors, and suppliers, were then contacted about concerns raised during the site investigation. Employee or work-team issues (70% injuries), workstation concerns (49%), equipment deficiencies (including PPE) (56%), glitches with fitness and state of materials (27%), and hazard controlling failures were the most common causes of incidents (84%). A model is proposed using an ergonomics systems approach, showing how initiating decision-making, design, and cultural influences affect workplace environments, resulting in actions and situations that, consecutively, cause injuries. For long-term progress in construction safety, it is contended that concentration on the initiating forces is needed.

2.8 Mitigating Construction Safety Risks

In this study, decisions taken before starting work on a construction site that can affect workman safety were demonstrated [15]. Most architects and structural engineers, on the other hand, are said to lack the necessary knowledge of construction safety and construction processes to conduct construction hazards prevention by design (CHPD) effectively. The quantitative technique aids designers by using a risk analysis-based approach to assess the safety-related performance of residential construction designs. The methodology compares the overall safety risk level of different construction designs and rates the importance of the various safety risks associated with each of these designs. Also, the approach compares the absolute value of specific safety risks across different building designs and significant risks are identified in advance. As a result, during on-site construction, various strategies for reducing safety risks may be introduced. Construction companies can enhance their on-site safety efficiency by using this approach.

The Just in Time concept can be adopted in construction to prevent the various categories of risks [16, 17]. Professionals working in construction sites can incorporate lean ideas, entailing assigning probabilities and outcomes to individual risks and determining risk exposure.

2.9 Work-Related Hazard of Construction

The quantification of workplace risk in a building construction project was discussed [18]. The occupational risk model (ORCA), developed in the Netherlands as part of the Workgroup Occupational Risk Model project (WORM), is used to assess risk. This model considers a worker's different duties, behaviors, and hazards when determining occupational danger. Three types of outcomes are considered when evaluating risk: curable wound, permanent wound, and casualty. The ORCA comprises 63 bowties that assess the risk of falling from ladders, scaffolds, or roofs, dropping objects, being struck by a moving vehicle, coming into contact with moving pieces, and so on. ORCA measures the risk profile of a building construction site, which consists of 38 employees in various employment positions, such as excavator operatives, loaders, compaction machine operators, workers in the excavation and framing processes, etc. All employee risk reports have been quantified, and jobs are ranked according to the level of risk they pose. Labors fitting timber formworks face the most significant risk of fatality, followed by laborers fixing reinforcement.

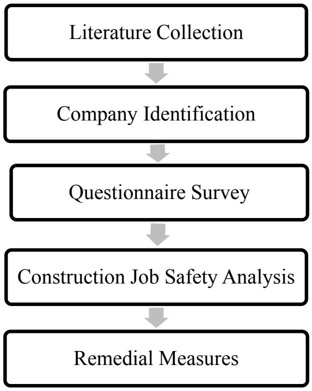

Fig. 1 Flowchart of the methodology

2.9.1 Scope of the Project

- To reduce accident rates replaced by toss-of-control events
- Good practices for all workplaces
- Awareness of safety in workplaces
- To make it clear, safety management in the construction industry

2.9.2 Objectives of the Project

- The Construction Job Safety Analysis (CJSA) approach creates a broad knowledge-based database that describes all potential construction loss-of-control incidents
- Analysis of hazards in construction industries
- Suggestions for remedial measures
- Create a health and safety plan.

2.9.3 Methodology

The following flowchart indicates the methodology adopted for the project (Fig. 1).

3 Work Process

Questionnaires are used as one tool for collecting data for quantitative analysis. The collected data from 30 construction sites (Tamil Nadu and Kerala) are analyzed with the help of SPSS software. The final questionnaire consists of 83 questions of dichotomous questions.

Fig. 2 Construction job safety factors

3.1 Parameters for Questionnaires

The factors identified are given in Fig. 2.

4 Results and Discussion

In the following section, the inferences gained by analyzing the data collected from various construction sites are discussed below with graphical representations and tabulations.

4.1 Data Analysis and Implication

SPSS version 17 was used to research this study. SPSS offers tools for analyzing and visualizing data using several methods.

4.2 SPSS Analysis Results

The various factors affecting site maintenance in Kerala and Tamil Nadu region sites are summarized in Table 1. Safety of workplace shows a mean value of 8.6 and 9.6 for Kerala and Tamil Nadu, respectively. Hence it can be inferred that Tamil Nadu construction sites are more secure when compared to Kerala. The mean value of 6.3 and 5.6 is for the free from obstruction parameter for Kerala and Tamil Nadu,

Table 1 Mean value table of factors affecting sites

Regions		Safety workplace	Free from obstruction	Temporary structure stable	Site tidy	Adequate lighting
Kerala	Mean	8.6667	6.3333	9.3333	10.000	6.6667
	N	15	15	15	15	15
	Std. deviation	2.28867	2.28867	1.75933	0.000	2.43975
Tamil Nadu	Mean	9.6667	5.6667	9.3333	10.000	6.0000
	N	15	15	15	15	15
	Std. deviation	1.29099	1.75933	1.75933	0.000	2.07020
Total	Mean	9.1667	6.0000	9.3333	10.000	6.3333
	N	30	30	30	30	30
	Std. deviation	1.89525	2.03419	1.72873	0.000	2.24888

respectively. It shows that Kerala sites are more obstruction-free than Tamil Nadu. Temporary structures stability and site tidiness parameters have a mean value of 9.3 and 10 for Kerala and Tamil Nadu, respectively. Thus it can be concluded that temporary structures are stable and that sites are maintained tidy. Adequate lighting facilities reports mean values of 6.6 and 6 for Kerala and Tamil Nadu regions, respectively. Hence Kerala site provides better lighting facilities.

The welfare of workers in both regions is shown in Fig. 3. Ease of welfare facility availability performance gives a mean value of 7.6 and 9.3, respectively, for Kerala

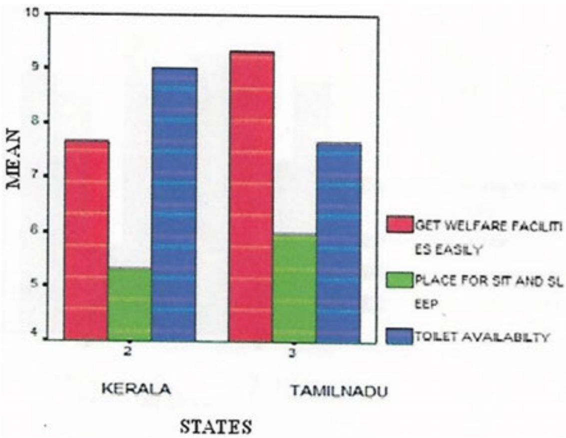

Fig. 3 Factors for worker welfare

and Tamil Nadu. Hence, Tamil Nadu workers get more welfare facilities like insurance claims, etc., when compared to those in Kerala. Most sites do not provide proper toilets and resting places for workers, as can be inferred from the mean value of 9, 8.3 and 5.3, 6, respectively, for Kerala and Tamil Nadu sites.

The various factors affecting the equipment are shown in Fig. 4. The operator training and competence give a mean value of 9 and 9.3 for Kerala and Tamil Nadu. It shows that in both regions equipment operators are well qualified. The mean value of warning notice performance and proper load marking comparison for Kerala and Tamil Nadu gives a value of 8.6, 9.3 and 9.6, 9, respectively. Hence it can be inferred that reasonable warning notice and load markings are issued on both sites. Inspection record maintenance in Tamil Nadu shows better performance over Kerala, as inferred from the mean value of 6.3 and 7.6 for Kerala and Tamil Nadu, respectively.

The excavation factor provision in construction sites of the regions is shown in Fig. 5. The mean value of the barrier to stop people parameters is 6.3 and 6.6 in

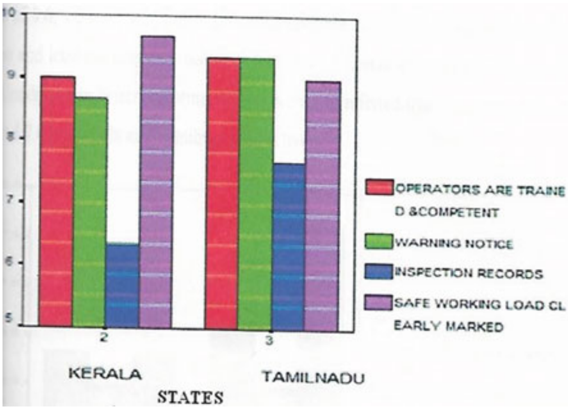

Fig. 4 Factors affecting the equipment

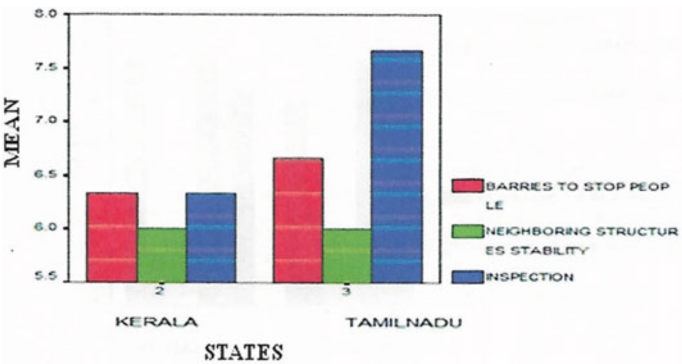

Fig. 5 Excavation factors

Kerala and Tamil Nadu. The inspection parameter gives a mean value of 6.3 and 7.6 for Kerala and Tamil Nadu, respectively. Hence it can be deduced that Tamil Nadu exhibits better inspection over Kerala. The neighboring structure stability reports a mean value of 6 for sites in both regions. However, the strength of neighboring structures for both parties cannot be ensured satisfactorily.

The result for PPE provisions in a site is given in Fig. 6. Motivation programs for laborers in Kerala report a mean value of 10, while only 9 for Tamil Nadu. The first aid provision parameter shows 9.3 and 9 for Kerala and Tamil Nadu, respectively. Fire extinguisher provision and proper storage of flammable materials parameters report an excellent mean value of 10 and 9 for both regions. The illumination and protection against noise parameter results show that most sites do not provide proper provisions for workers at a stretch. But according to the site requirements, these provisions are met.

The provision for workers' training is shown in Fig. 7. It can be seen that the training program and meetings held on-site for laborers of Kerala and Tamil Nadu

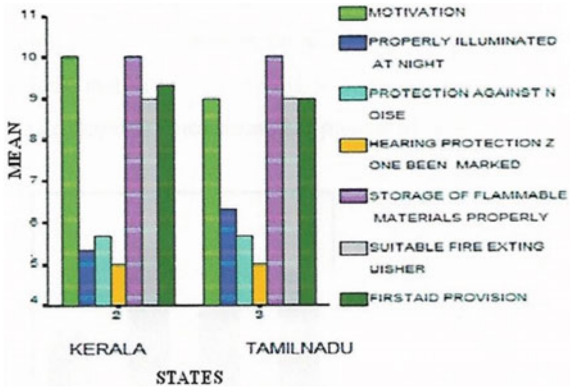

Fig. 6 Personal protective equipment factors

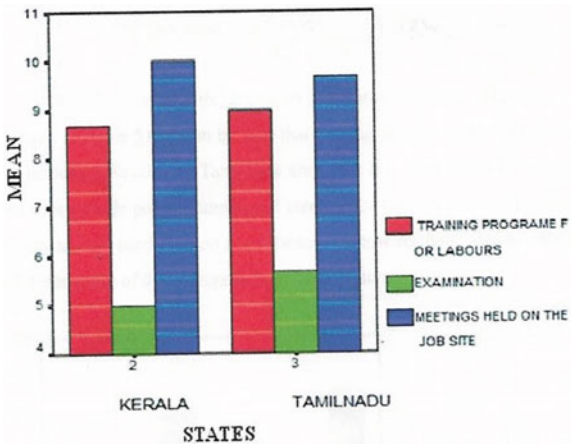

Fig. 7 Training factors

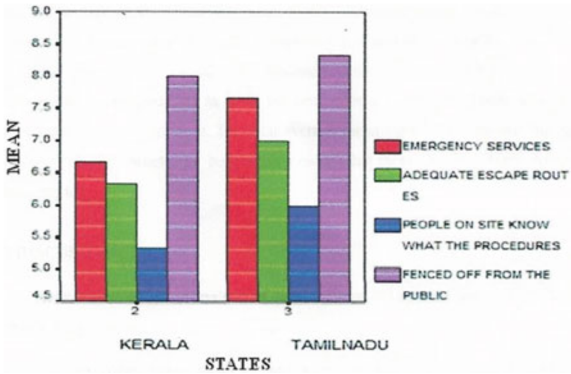

Fig. 8 General factors

are above 8.5. Thus, it can be inferred that most sites provide proper training and meeting for laborers. Further, exams are not conducted satisfactorily for both sites as only a total average mean value of 5.3 is reported for these regions.

The general factors affecting the sites are shown in Fig. 8. Emergency services report an average mean value of 6.6 and 7.6 for Kerala and Tamil Nadu, respectively. Good escape routes for these regions give a mean value of 6.3 and 7, respectively. Knowledge about the procedure by workers in Kerala and Tamil Nadu regions is 5.3 and 6, respectively. Thus it can be inferred that most of the people on site do not know what the procedures are going on there. The total average mean value of 8.2 for the fencing off from public parameter for both regions implies that these sites are fenced from the public.

4.3 Discussions

Discussions based on analysis of questionnaire survey done using SPSS 17 software are given below:

i. The mean value table of site access (Table 1) shows the various factors affecting Kerala and Tamil Nadu region sites. The average mean value of Kerala and Tamil Nadu sites are 8.16 and 8.1, respectively. Thus it can be ensured that in both the sites, the regulations have been followed.
ii. The graphical representation of site welfare (Fig. 3) shows that the average mean values in Kerala and Tamil Nadu are 7.6 and 7.5, respectively. This means that welfare facilities have not been given properly in both regions.
iii. Equipment (Fig. 4) analysis reports a total average mean value of 9 for both regions. So the equipment provided at these sites is satisfactory. But some sites do not maintain these records properly.
iv. The excavation graph (Fig. 5) results give a total average mean value of 6.5 for sites of both regions. Thus most of these sites do not provide a proper arrangement for excavation.

v. The graphical representation of PPE (Fig. 6) results reports an average mean value of 7.7. Hence it can be concluded that most of the sites do not provide proper PPE provisions for workers at a stretch. But according to the site requirements, the necessary conditions are met.
vi. The mean value analysis of the training program (Fig. 7) factors for Kerala and Tamil Nadu are 8.1 and 8.2, respectively. This means that the sites of both regions provide proper training for laborers.
vii. The general factors graph (Fig. 8) result reports an average mean value of 6.9. This means that general provisions are not provided correctly. Most of the workers on site are not aware of the underlying principle behind each construction work.

5 Conclusions

While achieving the work objectives, the education and training toward safety management in the construction site was provoked. The study explored seven facets of safety management: training, PPE program, machine safety, H&S advice tools and machinery, welfare, and environmental measures. From the work findings, it was observed that the sites in both the regions (Kerala and Tamil Nadu) have their own merits and demerits. It can be concluded that the construction sites of both the regions implement safety measures of about the same level. Survey results reveal that the selected construction projects are facing severe problems in H&S management. Many construction companies could benefit from the information obtained from this study, especially those in developing countries where construction safety awareness is low. Project managers and safety practitioners may find the findings helpful in making their workplaces safer.

5.1 Recommendations

1. Companies should ensure proper PPE provisions and safety training for all the workers. It should explain to the workers the hazardous nature of the work environment and how the safety equipment will protect them.
2. Work must be appropriately planned and then carried out to prevent accidents. Companies should treat their employees as though they were members of their families at home. It should ensure that each employee is aware of and respects his or her safety responsibilities.
3. The company should foresee the threats that can occur due to improvements in equipment or procedures and seek professional safety advice to help protect against any new dangers.

4. They should ultimately collaborate with organizations that are worried about workplace protection. Their true goal should be to keep staff completely capable and on the job and reduce the high personal cost of injuries.

References

1. Seetharaman, S. (2007). *Construction engineering and management*. Umesh Publications. Fourth edition.
2. Handbook of OSHA construction safety and health, Third edition, (2006).
3. Health and safety in construction, Third edition (2006), HSE books.
4. U.S. Department of Labor, OSHA 3071 Job Hazard Analysis, (Revised on 2002).
5. Causes of construction accident. (2019). https://www.amortech3d.com/9-common-causes-of-construction-accidents/. Accessed on 08 July 2019.
6. Xinyu, H., & Hinze, J. (2006). Owner's role in construction safety. *Journal of construction engineering and management, 132*(2), 164–173.
7. Marianne, T., & Pousette, A. (2009). Safety in construction–a comprehensive description of the characteristics of high safety standards in construction work, from the combined perspective of supervisors and experienced workers. *Journal of safety research, 40*(6), 399–409.
8. Anandh, K. S., Gunasekaran, K., & Mannan, M. A. (2020). Investigation on the factors affecting lifestyle of professionals in the construction industries (Kerala and Tamil Nadu). *International Journal of Integrated Engineering, 12*(9), 246–252.
9. Anandh, K. S., Gunasekaran, K., Senthamizh Sankar, S. (2020). An envisage on emotional intelligence among superior-subordinate in construction sector of Chennai City, India. *AIP Conference Proceedings*, Vol. 2277, p. 240012.
10. Mattila, M. K., Job load and hazard analysis, "A method for the analysis of workplace conditions for occupational health care,". *British Journal of Industrial Medicine*, 656–666.
11. Ikuma, L. H., Nahmens, I., & James, J. (2011). Use of safety and lean integrated kaizen to improve performance in modular homebuilding. *Journal of Construction Engineering and Management*, 551–560.
12. Ching-wu & Cheng, S.-S. L. (2010). Characteristic analysis of occupational accidents at small construction enterprises. *Journal of Safety Research*, 698–707.
13. DeJoy, D. M., Schaffer, B. S., & Wilson, M. G. (2009). Creating safer workplaces: Assessing the determinants and role of safety climate. *Journal of Safety Research*, 81–90.
14. Haslama, R. A., Halide, A. G. F., Gibbb, D. E., Gayi, Pavitt b. S., Atkinson, L., & Dul, A. R. (2010). Contributing factors in construction accidents. *Applied Ergonomics, 36*, 401–415.
15. Gangolells, M., Casals, M., Forcada, N., Roca, X., & Fuertes, A. (2010). Mitigating construction safety risks using prevention through design. *Journal of safety research, 41*(2), 107–122.
16. Anandh, K. S., Prasanna, K., Soundarya Priya, M. G., Manna Simon, S. (2020). An industrial study of just in time (JIT) management in precast construction projects. *AIP Conference Proceedings*, Vol. 2277, p. 240011.
17. Antony, S., Anandh, K. S., & Siddharth, B. (2019). An investigation into the evolution of lean construction, education in Indian industries and universities. *International Journal of Innovative Technology and Exploring Engineering, 8*(6), 898–902.
18. Topali, A. E., & Papazoglou, L. A. (2011). Occupational risk of building construction. *Reliability Engineering and System Safety*.

Investigating the Ways to Optimize the Production of Ready Mix Concrete Plants

S. Senthamizh Sankar, K. S. Anandh, S. Raja Pandian, and K. S. Aravinth

Abstract This paper investigates the internal and external factors affecting RMC plants and optimizes the production by suggesting risk control measures, which increase the company's profit. The proposed approach for this research includes three stages of risk: identification, categorization, classification, prioritization, and quantification. Two tools are used for risk prioritization: the QRA sheet (Qualitative Risk Analysis sheet) and P–C Matrix (Probability–Consequences Matrix). A questionnaire containing 120 risks to determine the high consequence risks and high probability risks was distributed to the team members, consisting of plant managers and key personnel. SPSS software is used for data analysis. Out of 120 identified risks, 12 risks are prioritized as having a high probability of occurring, which have high consequences. The ranking of risks is done based on the mean value. Possible measures are suggested for each risk. This paper offers some steps to improve the quality of the concrete and its materials; Proper maintenance and inspection with proper time intervals will reduce the breakdown and downtime of machines. The risks analyzed here can be interpreted in terms of costs by earnest monetary value to find the risk's total cost. Research can also be done on human factors, leading to a broader view of the risk impact on humans working in the RMC plant.

Keywords Ready mix concrete · Risk management · Operational risks · Productivity

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1 Introduction

Ready Mix Concrete (RMC) is defined as "Concrete delivered at the site or into purchaser's vehicle in the plastic condition and requiring no further treatment before being placed in a position in which it is to be set and hardened." RMC is considered for its eco-friendly characteristics. It is an excellent solution for conventional method of concrete [1].

It provides customized solutions to customers' issues, as well as ensuring customer loyalty and consistent quality. It also removes the need to store concrete-making materials on project sites. RMC is now a mature industry in both Europe and the United States. The RMC route accounts for approximately 75% of cement consumption in these countries (National Ready Mix Concrete Association). The use of ready mix concrete is becoming common in India, thereby creating higher housing and infrastructure projects. The RMC industry in India has taken a significant turn as a result. Many organized and unorganized players are foraying into RMC in India, anticipating colossal potential. The RMC industry, like other industries, is vulnerable to a variety of threats. There is growing knowledge and understanding of the value of risk management in European countries [2–4].

RMC's operations managers Plants in European countries are required to focus on risk control at their manufacturing and distribution facilities. Risk management at RMC plants in India is not given the attention it deserves. According to data collected from RMC plants in India, the Indian RMC industry does not use a formal risk management strategy [5].

2 Literature Review

The word "risk" has been used in several different ways in the literature with many other terms such as danger or uncertainty. Risk is defined as "The probability of loss, damage, drawbacks, or destruction," according to Webster's dictionary [4].

According to Jamal et al. [6], inferred the risk could be made as (Eq. 1) [6],

$$\text{Risk} = \text{f(Uncertainty of event, Potential L/G in from event)} \tag{1}$$

where, L = Loss, G = Gain.

2.1 Summary of Literature Review

In the following section, the reviewed works of literature are summarized.

2.1.1 Modeling Global Risk Factors Affecting Construction Performance Cost

Risk has differed from individuals, depending on their perceptions and experiences of their nature of work. The professionals working in the construction industry gazing at risk from a technical standpoint; lenders and developers, on the other hand, look at risk from an economic and financial perspective; and health practitioners, environmentalists, and chemical engineers look at risk from a safety and environmental standpoint. As a result, the risk is regarded as problematic term to quantify [7].

2.1.2 An Exploratory Study: Perception of Human Risk Factors in Construction Projects

Various authors and scholars have suggested a variety of different risk assessment approaches. Identification, analysis and assessment, response management, and system administration are the four risk management processes. Risk recognition, risk analysis, risk response preparation, and risk monitoring and control are the four steps in the risk management process [8].

2.1.3 The Impact of Corporate Safety Culture on Construction Safety Performance: A Framework

Risk avoidance, transfer, reduction, and acceptance are the four response strategies listed in the PMBOK [5]. Appropriate response strategies for the identified potential risks should be chosen and enforced, and they should be constantly monitored. Excellent risk strategies will simultaneously reduce the likelihood and effect of risk event triggers [9].

2.1.4 A Review at Risk Management Techniques in Projects

One of the most crucial steps in risk management is identifying risk. At this point, all possible risks that may impact the Project's goals are established. It is the process of analyzing a situation to determine what could go wrong at any point during the Project. Checklist, Brainstorming, Tree Diagram, Cause-Effect Diagram, Failure mode, and effect analysis, Hazard and operability research are some of the approaches used for risk identification. Interviews, Delphi Technique, and Fault Tree, and Decision Tree Risk assessment can be qualitative or quantitative. Qualitative risk assessment is fast and low-cost [10].

Just in Time concept can be adopted in construction to prevent the various categories of risks. Professionals working in RMC plants can incorporate lean concepts, along with this will entails assigning probabilities and outcomes to individual risks and determining risk exposure. Risk exposure provides an idea for prioritizing risks to have a significant impact on business goals for quantification and quantitative evaluation [11, 12].

2.1.5 Project Risk Management Practices

The word “risk management” has a variety of connotations. Many people confuse this word with risk assessment. Many people associate it with risk analysis, risk monitoring, and risk regulation. In reality, these are all phases of risk management; risk management is a “process for identifying and assessing risks so that they can be clearly identified and efficiently managed to prevent accidents.” Risk management tends to be a significant aspect of project management for significant building, engineering, and technical projects to minimize risks and achieve project performance [13].

Human factors are neglected in many automated plants that lead to vulnerable risk in construction [14, 15].

2.1.6 Systematic Risk Management Approach for Construction Projects

Various authors and scholars have suggested different risk assessment approaches. Risk recognition, risk analysis and evaluation, response management, and system administration are the four risk management processes suggested [6].

3 Objectives

- To identify the risks involved both inside and outside of RMC plants.
- To suggest the control measures for the risks involved.
- To optimize the production through the introduction of improved safety measures.

4 Methodology

Risk is described in this Project as a potential occurrence that harms production and supply costs for a company operating an RMC plant and whose possible outcomes can be predicted using probability. The proposed method is divided into three phases of risk are as follows:

- Identification and classification
- Prioritization
- Quantification

The flowchart is given in Fig. 1 portrays the research methodology.

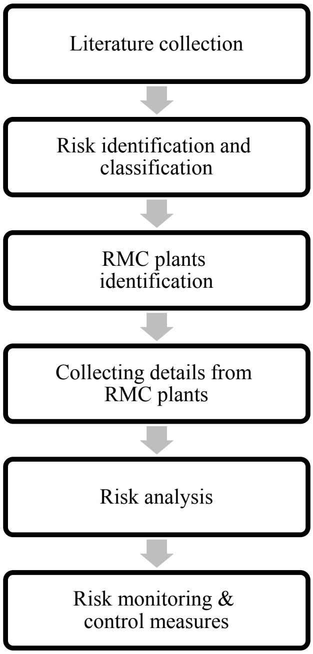

Fig. 1 Methodology

4.1 Risk Identification and Classification

Since there is no earlier evidence of the various types of risks in RMC plants in India, a group of plant administrators and critical staff employed at particular RMC plants must be interviewed. Before interviewing this group of plant managers and key staff, the idea of risk management was explained to them. These interviews resulted in a list of 120 risks divided into various categories. This provided a foundation for risk quantification. A list of known threats, along with their classes and varieties are shown in Fig. 2.

4.2 Risk Prioritization

Risk prioritization is carried out to screen risks and pick those that significantly impact RMC's business goals for quantification. Individual threats are allocated probabilities and effects on a subjective basis using the methods below.

- QRA sheet (Qualitative Risk Analysis sheet)
- P–C Matrix (Probability–Consequences Matrix).

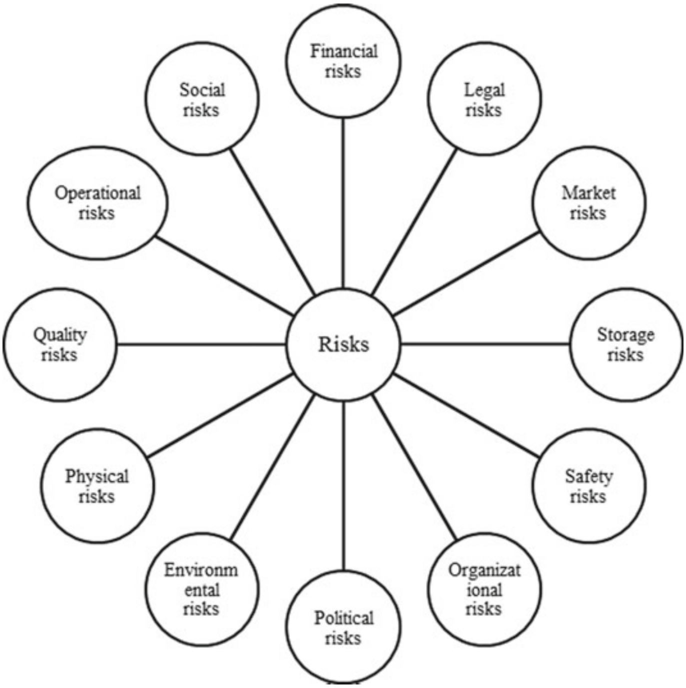

Fig. 2 Risk categories

4.2.1 QRA Sheet

The QRA Sheet is specifically designed to evaluate individual risk subjectively. On the left-hand side column of the sheet, there is a list of known and classified threats. It will ask for the subjective likelihood and consequence of each risk. A probability scale must be used when assigning probabilities. The possibility will be allocated using this scale, which ranges from unusual, unlikely, probable, and likely to almost sure. The same scale would be used in the form of risk outcomes. This scale will be used to subjectively assign effects ranging from insignificant, minor, moderate, major, and catastrophic. Project managers and key staff from each RMC plant will meet as a group to determine the likelihood and implications of individual risks. After finding a consensus, a QRA sheet will be filled out, with only tick marks going into the relevant boxes in the QRA sheet for assigning probabilities and implications to the individual risks.

4.2.2 Probability–Consequence Matrix

Using the P–C Matrix, the responses in the QRA sheet will be used to investigate risk exposure (Probability–Consequence Matrix). It should have a vertical column for likelihood and a horizontal column for consequences, all of which should use the same scale as the QRA sheet. This Matrix will be used to express the cumulative effect of each risk's likelihood and consequences. The scale used in this Matrix ranges from nil, rare, unlikely, possible, likely, almost inevitable, insignificant, minor, moderate, major to catastrophic.

Risks in the shallow and low zones of the P–C Matrix will be excluded from quantification since they will have a marginal impact on RMC's cost objectives. Risks that fall into the "Significant" and "High" zones of the P–C Matrix can have cost implications for RMC's business goals and should be quantified. These risks must be considered for risk quantification because they have a significant impact on a company's goal while operating an RMC facility.

5 Data Collection

The instrument used for the study is the Questionnaire survey (QS) method. Structured QS is used by directly submitted to the various personnel in RMC plants. QS is comprised of closed-end questions. Based on the factors identified concerning the study's objective, the questionnaire consists of a 5 point likert scale to indicate the likelihood of these risks as high, high, usual, low, and very low.

A questionnaire survey is performed to select experienced staff who play a role in risk management in RMC plants. Respondents are contacted for a direct interview to assess the current state of risk in RMC plants. Personal contacts and web pages are used to create contact points. Once appropriate contacts were identified, the direct interview is scheduled across 20 sites in Tamilnadu.

6 Results and Discussions

The following section deals with the result and discussion of the analysis made from the data collected among various RMC plants.

6.1 SPSS Analysis Results

A survey has been conducted from different ready mix concrete plants. The collected results were analyzed using the software SPSS.

This bar chart shows the risks, which are having a high consequence of risks (Fig. 3) and a high probability of risks (Fig. 4). The risks of having their mean value more than 9 are considered the high consequence risks and high probability of occurring risks. The risks, which are having a high probability of occurring and high consequences, are considered significant risks.

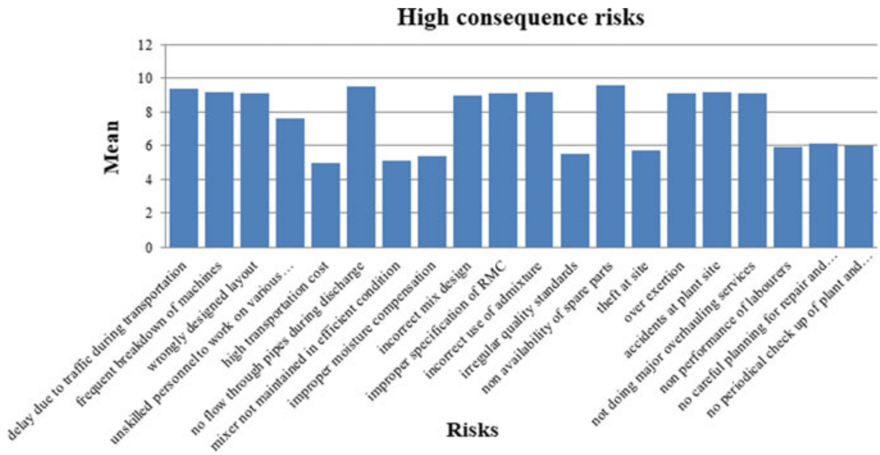

Fig. 3 High consequence risks

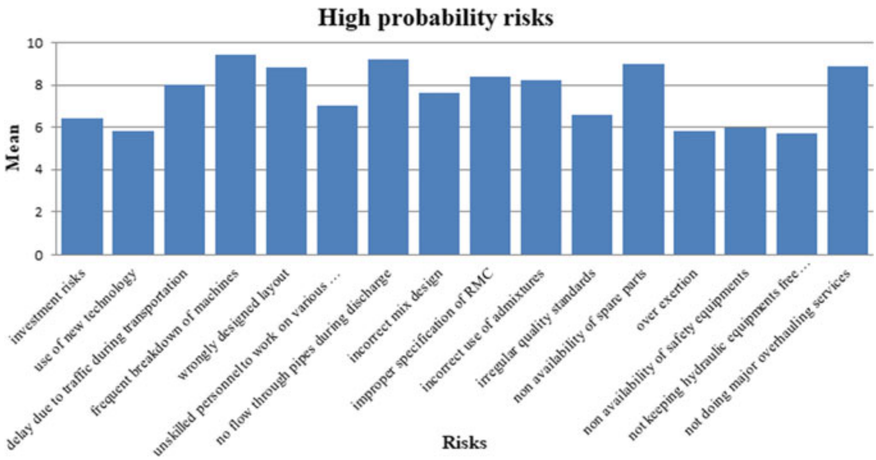

Fig. 4 High probability risks

6.2 *Major Risks*

The significant risks identified from this study are as follows:

- Traffic delay
- Recurrent failure of M/Cs. Plant
- Faulty layout design
- Poor workmanship
- Blockage of pipes during discharge of concrete at site
- Inappropriate mix design

- Unsuitable specification of RMC
- Inappropriate admixtures usage
- Non-availability of spare parts
- Overexertion
- Accidents at the plant site
- Not doing primary services with experts.

6.2.1 Means of Significant Risks

Factors considered critical for ranking are:

- The high mean of risk
- The high standard deviation of risk
- The graphs showing how the means of individual risks are found using SPSS are shown below, while the curve shows the mean value of the risks, and frequency is represented in the y-axis and mean in the x-axis.

6.3 Ranking of Risks and Possible Preventive Measures

Based on the mean value of the risks, the risks are arranged in ranking order. The mean values for the risks are generated by using SPSS. The ranking order of risks is discussed in Table 1.

7 Conclusion

There are many risks involved during the operation of RMC plants. By works of literature, the significant risks that affect the Productivity and RMC are identified. By using quantitative analysis, some suggestions regarding problems and the primary source of the risks are identified. A detailed analysis report has been derived using the SPSS application, which shows the probability of significant risks. To avoid these risks, some suggestions had made by referring to standard codes and safety measures.

In this Project, there are some suggestions made to avoid the risks involved. The new techniques like patented grinding technology will help in the control of incorrect mix design. To improve the quality of the concrete, the materials should go under proper tests. Proper maintenance and inspection with appropriate time intervals will also help to reduce the breakdown and downtime of machines.

Table 1 Ranking order of risks

Rank	Name of risks	Mean	Possible measures
1	Non-availability of spare parts	9.80	• Do proper maintenance and periodic inspections to avoid replacement • Procure spare parts and always store them at the site • Purchase machinery from companies whose spare parts are locally available • Obtain spare parts locally if possible to avoid import tax • In case of spare parts needed, order them much before
2	Unskilled personnel to work on various operations	9.50	• Give proper job descriptions to the employees • Describe the quality-related issues of your company • Begin from the interview process and continuing throughout their career with your organization • Get them membership in industry technical committees
3	Incorrect use of admixtures	9.40	• Give training on IS for admixtures • Always keep a supervisor for checking admixture proportion at batching plant • Use a high-range water reducer (HRWR) or super-plasticizer based on site conditions • In case of known errors in aggregate proportions, adjust admixtures proportionately
4	Delay due to traffic during transporting	9.40	• Trucks may not stop for food or breaks on the way • The speed control device must be fixed on the RMC truck • Any concrete spillage is reported immediately to the site • Address several safety issues to the driver • Use GPS in RMC trucks for monitoring them • Use a high-range water reducer (HRWR) or super-plasticizer
5	Accidents at the plant site	9.30	• Promote more use of machinery • Try to give alternative works for the employees • Promote automation and robotics in construction
6	No flow through pipes during discharge	9.30	• Do proper maintenance of M/c and periodic inspections • Periodically check the leaking and faulty hose • Use proper HRWR or super-plasticizer for concrete to pump • Always keep a technician for the repair of the concrete pump • Give breaks from continuous operations
7	Frequent breakdown of machines	9.20	• Do proper maintenance of M/c • Do periodic inspections • Periodically check leaking and faulty connection
8	Not during primary overhauling services	9.10	• Give maintenance training for the workers • Insist the importance of maintenance and give rigorous training • Do regular maintenance to avoid repair maintenance which costs more • Call for expert maintenance services by outsourcing if it is not locally available in the company • Purchase machinery from companies that provide maintenance services at cheaper rates for their machines

(continued)

Table 1 (continued)

Rank	Name of risks	Mean	Possible measures
9	Overexertion	9.10	• Promote more use of machinery • Try to give alternative works for the employees • Promote automation and robotics in construction
10	Improper specification of RMC	9.10	• Minimum of one test per week for each product purchased • Specific gravity, absorption, and petrographic analysis test results every three years • Do gradation and fineness modulus representing a minimum of one sieve analysis for every 200 tons
11	Wrongly designed layout	9.10	• Collect the full details of the site layout • Designed a layout, which takes minimum usage of covering the area • Correctly designed the layout
12	Incorrect mix design	8.90	• Use a computerized batch mixing system • Always keep a supervisor for checking specifications at batching plant • Get proper specifications from the customer

7.1 Recommendation to RMC Plants

- All the safety measures should be maintained strictly to avoid accidents at sites.
- Introducing new techniques in the mixing of the materials will control the incorrect mix design.
- Materials receiving for the mixing of concrete should be accepted after checking its specification.
- Works should be allocated to each person based on their working skill.
- Machinery should be maintained regularly based on the usage.
- Materials and concrete flowing pipes must be adequately washed after use.
- Avoid giving more workload to the laborers and make them feel pressured.
- Alternative methods or spare parts to be maintained correctly to avoid delay of the work.
- Admixtures are needed to be used based on the setting time and the traveling time of the vehicle.
- The most critical risk factor is a delay due to wrong decisions on layout, so it should be avoided.

References

1. National Ready Mix Concrete Association. https://www.nrmca.org/.
2. Handbook of OSHA construction safety and health.
3. Indian Standard 4926-2003, Bureau of Indian Standard, New Delhi.

4. Lifson, M. W., & Shaifer, E. F., Jr. (1982). *Decision and risk analysis for construction management*. Wiley Inc.
5. PMBOK. (2004). A guide to the project management body of knowledge, Project Management Institute.
6. Jamal, F., Al-Bahar, & Keith, C. (1990). Crandall, systematic risk management approach for construction project. *Journal of Construction Engineering and Management, 116*(3), 123–128.
7. Baloi, D., & Andrew, D. F. (2003). Modeling global risk factors affecting construction cost performance. *International Journal of Project Management, 21*, 261–269.
8. Vicknayson, T, & Mawdesley, M. J. (2004). Perception of human risk factors in construction projects. An exploratory study. *International Journal of Project Management, 22*, 131–137.
9. Molenaar, K. R. (2009). Framework for measuring corporate safety culture and its impact on construction safety performance. *Journal of Construction Engineering and Management,* 488–496.
10. Ahmed, A., Berman, K., & Sataporn, A. (2007) A review of techniques for risk management in projects. *Benchmarking: An International Journal, 14*(1), 22–36.
11. Anandh K.S., Prasanna, K., Soundarya Priya, M. G., Manna Simon, S. (2020). An industrial study of just in time (JIT) management in precast construction projects. *AIP Conference Proceedings, 2277*, 240011.
12. Antony, S., Anandh, K. S., & Siddharth, B. (2019). An investigation into the evolution of lean construction, education in Indian industries and universities. *International Journal of Innovative Technology and Exploring Engineering, 8*(6), 898–902.
13. Akintoye, A. (2008). Project risk management practice: The case of a South African utility company. *International Journal of Project Management, 26*, 149–163.
14. Anandh, K. S., Gunasekaran, K., & Mannan, M. A. (2020). Investigation on the factors affecting lifestyle of professionals in the construction industries (Kerala and Tamil Nadu). *International Journal of Integrated Engineering, 12*(9), 246–252.
15. Anandh K. S., Gunasekaran, K., Senthamizh Sankar, S. (2020). An envisage on emotional intelligence among superior-subordinate in construction sector of Chennai City, India. *AIP Conference Proceedings, 2277*, 240012.

Stochastic Project Network Scheduling Technique for Construction Projects Using GERT

K. Pregina and M. Ramesh Kannan

Abstract An extensive application of project network analysis in construction project management has been observed in the last few decades. The scheduling of construction projects is generally carried out using the conventional project scheduling methodologies such as Critical Path Method (CPM), Precedence Diagramming Method (PDM), Programme Evaluation and Review Technique (PERT), and so on. However, construction processes are highly repetitive in functionality. This characteristic makes construction projects more robust and stochastic, and thus requires a neoteric scheduling method rather than the conventional project scheduling techniques thereof. Consequently, an intriguing stochastic project network technique known as Graphical Evaluation and Review Technique (GERT), which is generally used in the industrial scheduling, is proposed to overcome the shortcomings of conventional construction scheduling. The nature of GERT includes probabilistic branching, feedback looping, multiple sink nodes, and multiple node realizations which cannot be achieved in the conventional construction scheduling methodologies. These remarkable features permit the construction personnel to model and analyse projects and systems of a very repetitive nature and high complexities. GERT is the solution with paragon to many real-life projects that face problems like probabilistic occurrences of events, false-starts, activity repetition and multiple outcomes. This research tries to provide a comprehensive implication of GERT for a real-time construction project.

Keywords Stochastic project network · CPM · PERT · Construction scheduling · GERT

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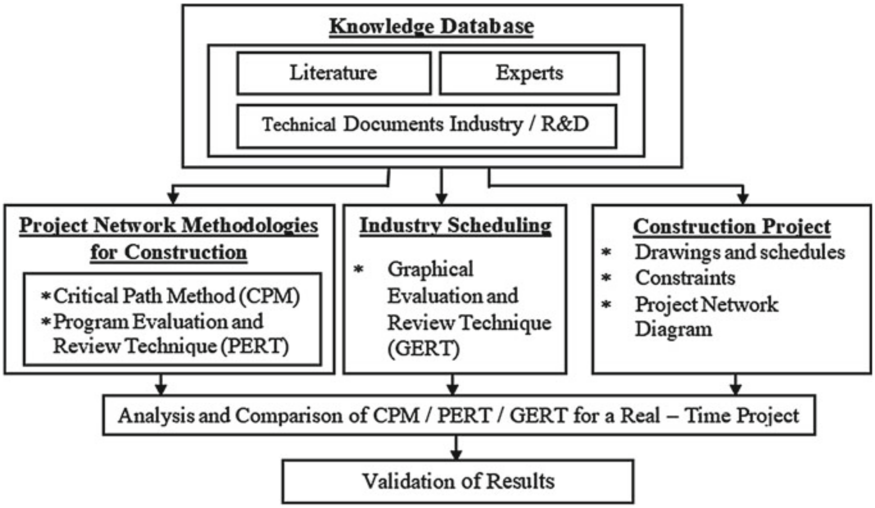

Fig. 1 Conceptual framework of this research

1 Introduction

The drastic improvements in the construction industry have created a rise in demand for more complex projects to be delivered at a velociously high speed cost-effectively. This may be achieved by effective planning, scheduling, and control of construction projects which results in a cutback of construction time, cost overrun, and disputes. The execution of construction projects often involves a complex environment that is highly uncertain. Adequate time management is one of the predominant and crucial factors to bring the consummation of construction projects. The scheduling of the majority of construction projects is carried out using conventional project scheduling methodologies such as Critical Path Method (CPM), Precedence Diagramming Method (PDM), Programme Evaluation and Review Technique (PERT), and so on. Several activities in construction projects are repetitive and the conventional techniques do not consider repetitiveness or looping characteristics. Hence there arises a need for a scheduling method that is suitable for producing robust and stochastic work schedules. Figure 1 illustrates the conceptual framework of this research work.

2 Project Network Methodologies for Construction

The conventional project network methodologies adopted for construction projects are elucidated as follows:

2.1 CPM and PERT

CPM is a scheduling technique where the sequence of activities in a project is depicted using a network diagram. After defining the path, the critical path is identified from the longest path of the calculated duration of each path, which determines the total duration of the project. PERT is a project network analysis technique that is used to focus on the time and the cost each activity takes. Time taken to complete the activity is assumed as a variable representing the application of resources concerning performance (i.e.) Optimistic Time, Most-likely Time, Pessimistic Time. The sequence of activities is ascertained and a network is constructed. The probabilistic time duration is calculated and the longest path with no buffer or slack time calculated connecting the events is the critical path.

2.2 Industry Scheduling

A detailed description of an innovative industrial scheduling methodology is discussed in the following section.

2.2.1 Graphical Evaluation and Review Technique (GERT)

GERT is a stochastic network analysis technique that analyses the logic of a probabilistic network and estimates the activity duration of a project developed by A. A. B. Pritsker and W. W. Happ in 1966 [1]. This approach overcomes most of the limitations of the other conventional scheduling techniques, namely PERT, and CPM. The looping between the tasks is permitted in GERT. The method considers different attributes of activities to provide a satisfactory schedule and can be used as a powerful tool to evaluate complex networks. The main components of a GERT network consist of directed branches which include arcs, edges, transmittances, and logical nodes or vertices. The two parameters associated with the branch are, the probability 'p' that a branch is taken, given that the node from which it emanated is realized at a required time 't', to accomplish the activity. The time 't' may be a random variable. The time for the activity represented by the branch is zero, if the branch of the network is not realized. The steps involved in applying GERT [1] are as follows:

1. The qualitative description of the system is converted into a model in network form.
2. The necessary data required for branches of the networks are collected.
3. An equivalent one branch function between nodes is obtained.
4. The equivalent function is converted into performance measures of the network.

    1. The probability 'p' that a specific node is realized.
    2. The moment generating function of the time 't' associated with an equivalent network.

From the above information, interpretations are made regarding the network under study.

3 Analysis and Comparison of CPM, PERT and GERT for a Real-Time Project

This research aims to assimilate the GERT technique to alleviate the schedule of a real-time residential project. Figure 2 shows the plan of the residential building and Table 1 gives the schedule of activities.

The sequence of activities is illustrated through a network diagram. Figure 3 shows the scheduling of activities using the Critical Path Method. The duration in CPM Network is deterministic and the total estimated time for the considered project is 155 days.

In PERT, time duration is incorporated as probabilistic values i.e., three-times estimate. The sequence of activities is illustrated through a network diagram. Figure 4 shows the scheduling of activities using the PERT method, the estimated time for completion of the project is 160 days.

The CPM and PERT network demand that all preceding activities can be completed before a node is realized. In situations where the realization of a node depends on the completion of not all but one or more incoming activities, GERT

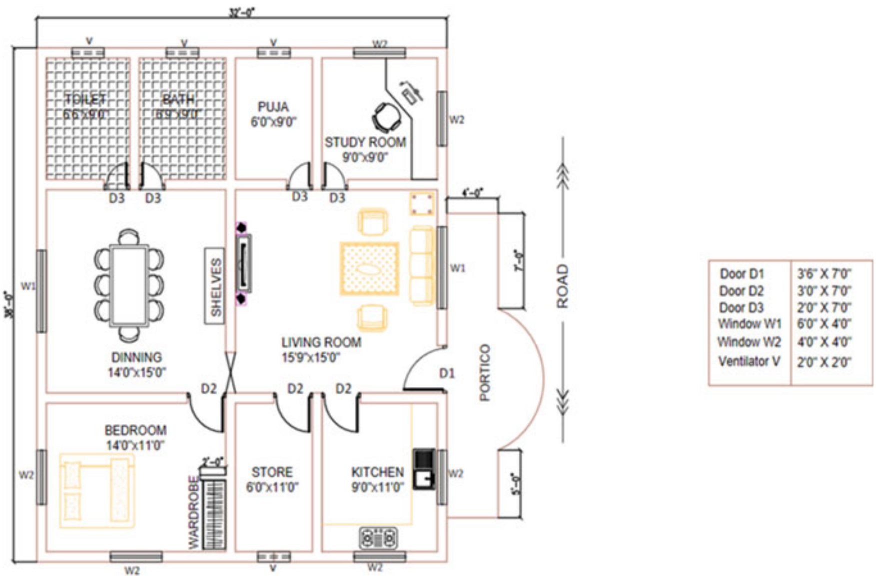

Fig. 2 Floor plan of a real-time residential building [2]

Table.1 Schedule of activities

Activity	Code	Duration (days)
Preparatory works	A_1	4
Excavation by mechanical means & PCC	A_2	4
Foundation	A_3	9
Superstructure–columns	A_4	12
Underground structures	A_5	9
Plinth beam construction	A_6	9
Basement work & brickwork below plinth level	A_7	14
Lintel beam construction	A_8	10
Brick work	A_9	19
Roof slab construction	A_{10}	28
Fabrication of doors, windows and ventilator frames	A_{11}	11
Internal plastering works	A_{12}	10
Grade slab construction	A_{13}	12
Flooring	A_{14}	8
Sanitary and electrical fittings installation	A_{15}	8
Head room construction	A_{16}	9
Parapet wall construction	A_{17}	3
Roof screed, waterproofing and tiling works	A_{18}	10
External plastering works	A_{19}	11
Fixing of door/window/ventilators	A_{20}	5
Carpet and porch area tile/skirting laying works	A_{21}	11
Interior painting and architectural work	A_{22}	9
Exterior painting and architectural work	A_{23}	10
Furnishing and fencing	A_{24}	7
Miscellaneous works	A_{25}	3

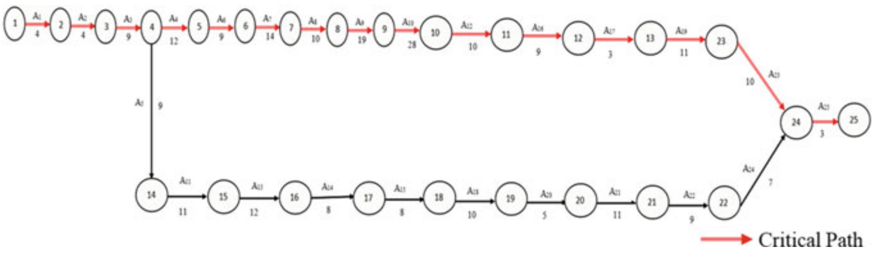

Fig. 3 Project network diagram (schedule) for CPM

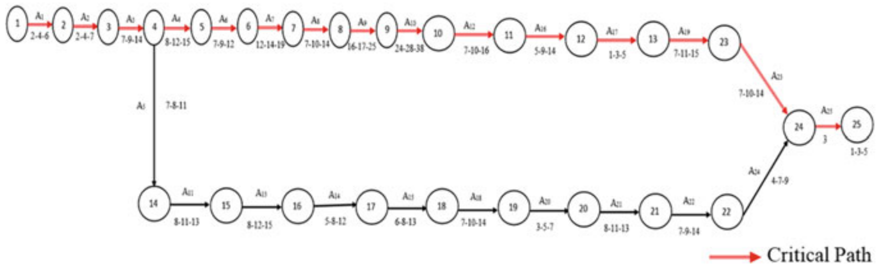

Fig. 4 Project network diagram (schedule) for PERT

is implemented [3–14]. GERT allows loops that may start from any node and be incident to any previous node [15]. Despite many advantages in the incorporation of GERT for construction scheduling [9], it has not gained much popularity in the construction industry over academic research [16]. To reinforce the importance of GERT in practical point of view, it is incorporated to the construction scheduling of a real-time construction project. The distribution of duration of different activities, as assessed by Project In-charge is in Table 2. The scheduling of the activities in the real-time construction project using GERT is illustrated in Fig. 5. The estimated time for completion of the project using GERT is 176 days.

The construction duration obtained from the real–time site data is 180 days. It is observed that the total estimated time calculated using GERT is more proximate to the real–time data when compared to the total duration obtained using CPM and PERT.

4 Conclusion

This research provides a comprehensive overview of the application of GERT for construction projects. Initially, a detailed floor plan for a real–time construction project is taken to elucidate the implications of convention project management methodologies such as CPM, and PERT. Later, the information of the same project is considered for developing the GERT network diagram. From the comparison of these three project management methodologies, it is inferred that the solution derived out of the GERT network resembles closer to the actual site data. This intriguing concept can be further extended to multifarious construction projects with varying complexities.

Table.2 Distribution of durations (in days)

Activity	Type of distribution	Code	t_o	t_m	t_p	Dur.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
Preparatory works	Normal	A_1	2	4	6	–	–	–	–	–	–	–	–	–	–	–
Excavation by mechanical means & PCC	Discrete	A_2	2	4	7	–	0	0.03	0.03	0.04	0.2	0.3	0.4	0	0	0
Foundation	Normal	A_3	7	9	14	–	–	–	–	–	–	–	–	–	–	–
Superstructure - columns	Normal	A_4	8	12	15	–	–	–	–	–	–	–	–	–	–	–
Underground structures	Discrete	A_5	7	9	11	–	0	0	0	0	0	0	0.03	0.07	0.2	0.3
Plinth beam construction	Discrete	A_6	7	9	12	–	0	0	0	0	0	0	0.01	0.04	0.05	0.2
Basement work & brickwork below plinth level	Discrete	A_7	12	14	19	–	0	0	0	0	0	0	0	0	0	0
Lintel beam construction	Constant	A_8	–	–	–	10	–	–	–	–	–	–	–	–	–	–
Brick work	Discrete	A_9	16	19	25	–	0	0	0	0	0	0	0	0	0	0
Roof slab construction	Normal	A_{10}	24	28	38	–	–	–	–	–	–	–	–	–	–	–
Fabrication of Doors, Windows and ventilator frames	Constant	A_{11}	–	–	–	11	–	–	–	–	–	–	–	–	–	–
Internal Plastering works	Constant	A_{12}	–	–	–	10	–	–	–	–	–	–	–	–	–	–
Grade slab construction	Normal	A_{13}	8	12	15	–	–	–	–	–	–	–	–	–	–	–
Flooring	Normal	A_{14}	5	8	12	–	–	–	–	–	–	–	–	–	–	–
Sanitary and electrical fittings installation	Constant	A_{15}	–	–	–	8	–	–	–	–	–	–	–	–	–	–
Head room construction	Discrete	A_{16}	5	9	14	–	0	0	0	0	0.002	0.008	0.01	0.06	0.09	0.13
Parapet wall construction	Normal	A_{17}	1	3	5	–	–	–	–	–	–	–	–	–	–	–
Roof screed, waterproofing and tiling works	Constant	A_{18}	–	–	–	10	–	–	–	–	–	–	–	–	–	–
External plastering works	Constant	A_{19}	–	–	–	11	–	–	–	–	–	–	–	–	–	–
Fixing of door/window/ventilators	Discrete	A_{20}	3	5	7	–	0	0	0.03	0.07	0.2	0.3	0.4	0	0	0
Carpet and porch area tile/skirting laying works	Constant	A_{21}	–	–	–	11	–	–	–	–	–	–	–	–	–	–
Interior Painting and architectural work	Constant	A_{22}	–	–	–	9	–	–	–	–	–	–	–	–	–	–
Exterior Painting and architectural work	Constant	A_{23}	–	–	–	10	–	–	–	–	–	–	–	–	–	–

(continued)

Table.2 (continued)

Activity	Type of distribution	Code	t_o	t_m	t_p	Dur.	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
Furnishing and Fencing	Constant	A_{24}	–	–	–	7	–	–	–	–	–	–	–	–	–	–
Miscellaneous works	Constant	A_{25}	–	–	–	3	–	–	–	–	–	–	–	–	–	–
Activity	Type of Distribution	Code	t_o	t_m	t_p	Dur.	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}
Preparatory works	Normal	A_1	2	4	6	–	–	–	–	–	–	–	–	–	–	–
Excavation by mechanical means & PCC	Discrete	A_2	2	4	7	–	0	0	0	0	0	0	0	0	0	0
Foundation	Normal	A_3	7	9	14	–	–	–	–	–	–	–	–	–	–	–
Superstructure - columns	Normal	A_4	8	12	15	–	–	–	–	–	–	–	–	–	–	–
Underground structures	Discrete	A_5	7	9	11	–	0.4	0	0	0	0	0	0	0	0	0
Plinth beam construction	Discrete	A_6	7	9	12	–	0.3	0.4	0	0	0	0	0	0	0	0
Basement work & brickwork below plinth level	Discrete	A_7	12	14	19	–	0	0.004	0.006	0.02	0.03	0.04	0.2	0.3	0.4	0
Lintel beam construction	Constant	A_8	–	–	–	10	–	–	–	–	–	–	–	–	–	–
Brick work	Discrete	A_9	16	19	25	–	0	0	0	0	0	0.004	0.006	0.009	0.014	0.017
Roof slab construction	Normal	A_{10}	24	28	38	–	–	–	–	–	–	–	–	–	–	–
Fabrication of Doors, Windows and ventilator frames	Constant	A_{11}	–	–	–	11	–	–	–	–	–	–	–	–	–	–
Internal Plastering works	Constant	A_{12}	–	–	–	10	–	–	–	–	–	–	–	–	–	–
Grade slab construction	Normal	A_{13}	8	12	15	–	–	–	–	–	–	–	–	–	–	–
Flooring	Normal	A_{14}	5	8	12	–	–	–	–	–	–	–	–	–	–	–
Sanitary and electrical fittings installation	Constant	A_{15}	–	–	–	8	–	–	–	–	–	–	–	–	–	–
Head room construction	Discrete	A_{16}	5	9	14	–	0.19	0.01	0.2	0.3	0	0	0	0	0	0
Parapet wall construction	Normal	A_{17}	1	3	5	–	–	–	–	–	–	–	–	–	–	–

(continued)

Table.2 (continued)

Activity	Type of Distribution	Code	t_o	t_m	t_p	Dur.	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}
Roof screed, waterproofing and tiling works	Constant	A_{18}	–	–	–	10	–	–	–	–	–	–	–	–	–	–
External plastering works	Constant	A_{19}	–	–	–	11	–	–	–	–	–	–	–	–	–	–
Fixing of door/window/ventilators	Discrete	A_{20}	3	5	7	–	0	0	0	0	0	0	0	0	0	0
Carpet and porch area tile/skirting laying works	Constant	A_{21}	–	–	–	11	–	–	–	–	–	–	–	–	–	–
Interior Painting and architectural work	Constant	A_{22}	–	–	–	9	–	–	–	–	–	–	–	–	–	–
Exterior Painting and architectural work	Constant	A_{23}	–	–	–	10	–	–	–	–	–	–	–	–	–	–
Furnishing and Fencing	Constant	A_{24}	–	–	–	7	–	–	–	–	–	–	–	–	–	–
Miscellaneous works	Constant	A_{25}	–	–	–	3	–	–	–	–	–	–	–	–	–	–

Activity	Type of Distribution	Code	t_o	t_m	t_p	Dur.	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	T_e
Preparatory works	Normal	A_1	2	4	6	–	–	–	–	–	–	4
Excavation by mechanical means & PCC	Discrete	A_2	2	4	7	–	0	0	0	0	0	6
Foundation	Normal	A_3	7	9	14	–	–	–	–	–	–	11
Superstructure - columns	Normal	A_4	8	12	15	–	–	–	–	–	–	12
Underground structures	Discrete	A_5	7	9	11	–	0	0	0	0	0	10
Plinth beam construction	Discrete	A_6	7	9	12	–	0	0	0	0	0	11
Basement work & brickwork below plinth level	Discrete	A_7	12	14	19	–	0	0	0	0	0	18
Lintel beam construction	Constant	A_8	–	–	–	10	–	–	–	–	–	10
Brick work	Discrete	A_9	16	19	25	–	0.02	0.03	0.2	0.3	0.4	24
Roof slab construction	Normal	A_{10}	24	28	38	–	–	–	–	–	–	31
Fabrication of Doors, Windows and ventilator frames	Constant	A_{11}	–	–	–	11	–	–	–	–	–	11
Internal Plastering works	Constant	A_{12}	–	–	–	10	–	–	–	–	–	10

(continued)

Table.2 (continued)

Activity	Type of Distribution	Code	t_o	t_m	t_p	Dur.	t_{21}	t_{22}	t_{23}	t_{24}	t_{25}	T_e
Grade slab construction	Normal	A_{13}	8	12	15	–	–	–	–	–	–	12
Flooring	Normal	A_{14}	5	8	12	–	–	–	–	–	–	9
Sanitary and electrical fittings installation	Constant	A_{15}	–	–	–	8	–	–	–	–	–	8
Head room construction	Discrete	A_{16}	5	9	14	–	0	0	0	0	0	12
Parapet wall construction	Normal	A_{17}	1	3	5	–	–	–	–	–	–	3
Roof screed, waterproofing and tiling works	Constant	A_{18}	–	–	–	10	–	–	–	–	–	10
External plastering works	Constant	A_{19}	–	–	–	11	–	–	–	–	–	11
Fixing of door/window/ventilators	Discrete	A_{20}	3	5	7	–	0	0	0	0	0	6
Carpet and porch area tile/skirting laying works	Constant	A_{21}	–	–	–	11	–	–	–	–	–	11
Interior Painting and architectural work	Constant	A_{22}	–	–	–	9	–	–	–	–	–	9
Exterior Painting and architectural work	Constant	A_{23}	–	–	–	10	–	–	–	–	–	10
Furnishing and Fencing	Constant	A_{24}	–	–	–	7	–	–	–	–	–	7
Miscellaneous works	Constant	A_{25}	–	–	–	3	–	–	–	–	–	3

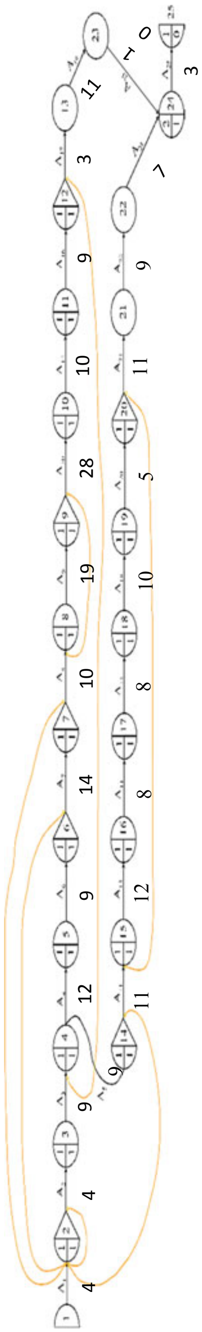

Fig. 5 Project network diagram (schedule) for GERT

References

1. Pritsker, A. A. B., & Happ, W. W. (1966). GERT: graphical evaluation and review technique: Part I, fundamentals. *Journal of Industrial Engineering, 17*(6), 267–274.
2. Philip, A. M., & Ramesh Kannan, M. (2021). Constructability assessment of cast in–situ, precast and modular reinforced concrete structures. *Materials Today: Proceedings, 45*(7), 6011–6015.
3. Bonham, T. W., Clayton, E. R., & Moore, L. J. (1975). A GERT model to meet future organizational manpower need. *Personnel Journal, 54*(7), 402–406.
4. Anderson, P. F., & Taylor III, B. W. (1977). Marketing/quality control interface: The GERT approach. *Industrial Marketing Management*, *6*(6), 420–428.
5. Moore, L. J., & Taylor III, B. W. (1977). Multiteam, multiproject research and development Planning with GERT. *Management Science*, *24*(4), 401–410.
6. Taylor, B. W. (1978). Project management using GERT analysis. *Project Management Quarterly, 9*(3), 15–20.
7. Yu, L., & Zuo, M. (2008). An estimating method for IT project expected duration oriented to GERT. In L. D. Xu, A. M. Tjoa, & S. S. Chaudhry (Eds.), *Research and practical issues of enterprise information systems II*. IFIP International Federation for Information Processing (Vol. 255). Boston: Springer.
8. Wyrozębski, P., & Wyrozębska, A. (2013). Challenges of project planning in the probabilistic approach using PERT, GERT and Monte Carlo. *Journal of Management and Marketing, 1*(1), 1–8.
9. Ramani, T., & Kannan, R. (2014). Scheduling of industrialized construction project using graphical evaluation and review technique (GERT). In *Proceedings of Second International Conference on Advances in Industrial Engineering Applications* (ICAIEA 2014), Anna University, India.
10. Kannan, R. (2014). Graphical evaluation and review technique (GERT): The panorama in the computation and visualization of network–based project management. In *Advances in secure computing, Internet Services, and Applications* (pp. 165–179). IGI Global Publisher.
11. Ghaeli, M., & Sadi-Nezhad, S. (2017). Recent advances on graphical evaluation and review techniques. *Journal of Project Management*, *2*(3), 107–112.
12. Todorova, M. (2019). GERT model of a technical station for determining the passenger trainset delay. *Transport Problems, 14*(1), 81–93.
13. Globa S. B., Maslovsky, V. P., Butakova, N. M., Berezovaya, V. V. (2020). Application of the GERT method to visualize the process of managing receivables and payables of an enterprise. In: R. Silhavy, P. Silhavy, & Z. Prokopova (Eds.), *Software engineering perspectives in intelligent systems. CoMeSySo 2020.* Advances in Intelligent Systems and Computing (Vol. 1294). Springer.
14. Dorrer, M., Dorrer, A., & Zyryanov, A. (2021). Numerical modeling of business processes using the apparatus of GERT networks. In: A. G. Kravets, A. A. Bolshakov, & M. Shcherbakov (Eds.), *Society 5.0: cyberspace for advanced human-centered society*. Studies in Systems, Decision and Control (Vol. 333). Springer.
15. Pant, J. C. (2001). *Project management CPM, PERT, GERT and linear programming* (4th ed.). New Delhi: Jain Brothers.
16. Mubarak, S. A. (2019). *Construction project scheduling and control* (4th ed., pp. 369). New York: Wiley.

Integrating Lean and Sustainability Approach for Construction Firms

S. Anandh, S. Sindhu Nachiar, Preethiba Mariappan, and C. S. Sai Abeshek

Abstract Lean construction is the mode of production which is designed to minimize the cost, materials and time. Virtually the lean technique is to reduce the poor quality and maximize the favourable outcomes in the construction industry. This study provides basic understanding of lean in construction, obstacles of lean in construction, factors for lean construction, lean techniques and benefits of lean construction. The objective of the research is to identify the link between lean and sustainability, barriers of lean and sustainability, success key factors of lean and sustainability, benefits of linking lean and sustainability, area of link between the lean and sustainability.

Keywords Lean construction · Barriers · Factors of lean · Lean techniques · Sustainability

1 Introduction

The construction industry have been earmarked with very low matriculate of novelty when distinguished with manufacturing industry. Innovation in the construction industry is the exploit of acquainting and utilizing fresh ideas, processes proposed for dealing with problems, perceiving things in various view, enhancing the efficiency, increasing the standards of living. Construction faces the demands of reducing the demands of reducing the environmental collision of its own devouring of energy and materials [1]. Construction firms preoccupy natural resources to a confounded immune. When it comes to waste, the construction industries generate high amount of waste which bangs the environment. To avoid the impact of waste construction industries concentrate more in reuse and recycling of waste. The predominant origin of waste production are:

- Unprivileged material care
- Less in rank quality of materials

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- Material storage controversies
- Order taking complexity
- Corrigendum in quantity surveys
- Lack of supervision
- Improper waste management

The benefit of utilizing recycled waste materials safeguard the natural resources and environment. And it aims for the reduction in cost and minimizes the space required for landfill purposes [2]. A classic Architecture Engineering Construction (AEC) firm frequently works in a largely ambitious environment and consequently there is a constant activity in the industry to enhance new concepts to develop organizational effectiveness. AEC research workers have investigated on the successful key factors enhanced within the manufacturing zone and the greatest means of arriving is choosing lean concepts in construction [3]. Construction industries notably in India is covering double problems. The fundamental problem is adverse on people, society and environment. And the next problem is decreased commercial appeal of the business. The most common opinion of many researchers are to approach sustainable construction and lean construction [4].

1.1 Lean

The lean theory was first introduced in automobile firms of Toyota was the origin of lean in manufacturing which was advanced to minimize and eliminate the wastes. The word "LEAN" was derived as latest production theory popularized in Toyota after World War II. Later lean arrived as the main technique for enhancing productivity and efficiency in many industries. Lean concepts targets on bottom-up, worker-led enhancement and in places where lean is applied successfully will minimize the coat and enhances the quality [5]. The extremely valuable incentive of construction is alleged to be reliable workflow and labour flow but lean in construction has replaced the traditional prospect of the project as revolution and accept the theory of flow.

1.2 Lean Construction Techniques

There are many techniques which have been considered and embraced in the construction field. The followings are few techniques:

1. 5S Techniques
2. Last Planner System
3. Increased Visualization Technique
4. Daily Huddle Meeting.

1.2.1 5S Techniques

It is a standardized technique utilized by the management comes in five Japanese terms:

1. Seiri (Sort)
2. Seiton (Set in order)
3. Seiso (Shine)
4. Seiketsu (Standardize)
5. Shitsuke (Sustain)

The 5S techniques assist to systematize the workplace for ability and reduce the waste and advances the quality and productivity by the means of supervising the management environment. This 5S technique targets in normalizing the works done in the construction site and it also minimizes the waste that occurs by rework and consumption of time.

1.2.2 Last Planner System

Last planner system is authorized professional the one who has direct connect with the work to schedule the tasks. The conventional work planning organizes time frame but does not been adequately build the task which is required for the completion of the project. This system is oriented on minimum of three stages of scheduling and master pull schedule which recognize the main project stage and the look-head schedule which utilizes the elements pulled from the master schedule and was utilized to control the workflow and the weekly work plan contributes to the brief work plan.

1.2.3 Increased Visualization Technique

Developed visualization is a method which is embraced to incorporate last planner system (LPS) and 5S techniques in sync. Developed visualization is essentially carried to change of possession ofthe information visually more productively than any other source of communication.

Methods of communicating visually are:

- Charts
- Boards
- Kanban Cards
- 4D, 5D software (Large scale companies)

which helps in minimizing the rework and all other issues in the workplace by combining everything at the office level.

1.2.4 Daily Huddle Meeting

It demands on another revolution in the culture, a culture in which a project manager who has a authority to arrange and carry out the plan versus the common culture for the issue to happen and then handle the issue. Daily huddle meeting is produced in the project execution stage to equalize the work activities. This technique is a huge tool of communication used to identify the problem in a project like weather, environment, security and quality and gives the format of communication [6].

1.3 Sustainability

The common theory of sustainable advancement emerge in United Nations conferences at the time of 1980 and 1990. The main accomplishment of the conference is the acceptance of Agenda 21 which tells the basic principles of sustainability and enhances the indicators of sustainable enhancement. In 1992 United Nation was dependent on the voluntary national testing and group consultations. The main set of indicators were coordinated into four pillars, fifteen themes, thirty-eight subthemes and fifty-eight indicators in 2001. There are number of sustainability principles advanced in many organizations and nations in that United Nations were selected as template for enhancing this course based on few reasons. The reasons are listed below:

- Are hugely recognized and referenced.
- More number of regional indicators are built based on them.
- Are arranged in a hierarchy form which helps in selecting the desired stage of detail [7].

1.4 Sustainable Construction

Sustainability in construction is the appeal of sustainable enhancement in construction firms. A clear explanation of sustainability in construction was given by Raynsford, "The set of processes by which a profitable and competitive industry delivers built assets" such as:

- Improve quality of life and offers the satisfaction of the customers.
- Flexibility offer and prospective to cater for end user differs in future.
- Support and gives desirable natural environment.
- Use of resources in high range.

The explanation given by Raynford sets priority on the product and the process which brings the view of economic, social and environmental sustainability. A much clear explanation was given by Construction excellence which brings the sustainability in construction is the trump card of sustainable enhancement in the construction industry. And it desires the sustainable enhancement which promises for a good quality of life for all and future generation by:

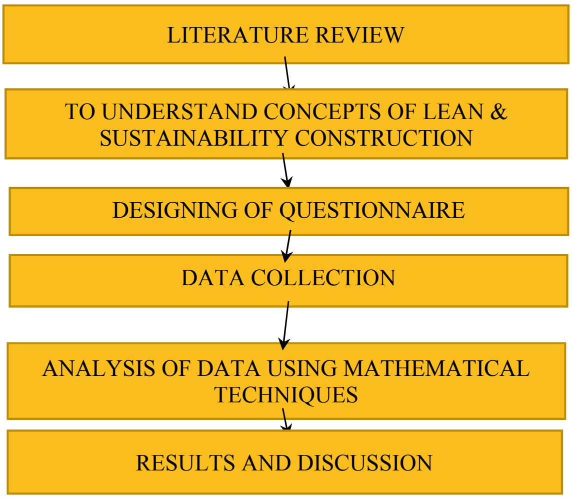
- Social advancement which identifies the needs of all.
- Managing the high phases of employment and financial growth.
- Improving the environment.
- Utilizing the natural resources.

Sustainable enhancement clutch the three subject matters of economic, social and environmental accountability which is called as triple bottom line. Sutainable construction generally incorporates various perspectives which involve social, economic and environment. The incorporation and the importance of sustainable construction will be hugely based on the needs and conditions of the growing countries are different from the growing world. The knowledge of sustainable construction is much lower. Landman from US tells that training and education in sustainable construction is inadequate [8].

2 Methodology

The below given Fig. 1 is the representation of scheme of work followed for this project of interest. Certain set of journals were studied and facts were being considered for the part of research. From these journals, certain data were understood and taken to contemplate with the need of this research. Conclusion of the factors which mainly tend to affect the root the study is classified from the data collected from the journals. Questions were prepared from the available sources of information for this

Fig. 1 Scheme of work



study of research. By studying the provenance of the research, type of the mathematical analysis can be withdrawn and put into course of action. Results can be concluded and discussed. A sample of conceptual model can be developed and made easier for the understanding. And the study can be concluded for the final dissertation.

2.1 Design of Questionnaire

Questionnaire was classified into 5 parts.

Under each part 6–9 questions were framed and totally the questionnaire was containing 40 nos. of questions. This questionnaire was framed based on Benefits of lean construction and sustainable construction, obstacles of lean construction and sustainable construction, Success factors of lean construction and sustainable construction, intersection of lean and sustainability and the questionnaire's last part was about the area of link between lean and sustainability.

2.2 Data Collection and Analysis

Initially from the separated factors collected from the literature, a set of few questions were framed, 8–10 under each factor. Since the study is generalized and pilot study of these questions was done. From the pilot study, questionnaire was developed with 8–10 questions under each factor with 5-point Likert Scale varying from Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree. To check whether the prepared questionnaire is apt for the project studies certain tests like Cronbach's Alpha Test were done.

2.3 Preliminary Study

This pilot study is a preparatory study is done to find out the feasibility of the questionnaire prepared for this project. It helps in detail the prior plan of the project and the extension of profitable positivity of this study from the history and personal interviews done. All the data were put together 20 samples were collected. A set of 20 questions were framed and provided to the employers of different companies.

2.4 Cronbach's Alpha

Cronbach was utilized for checking the internal consistency of a data and its reliability of one factor with the rest of it. The hypothetical value ranges from 0 to 1. The

Table 1 Cronbach's Alpha value and its standard range of values

Cronbach's Alpha	Internal consistency
<0.5	Not acceptable
0.5–0.6	Poor
0.6–0.7	Low/questionable
0.7–0.80	Average
0.8–0.9	Good
0.9–1	Excellent

Table 2 Cronbach's Alpha for the pilot study

Reliability statistics	
Cronbach's Alpha	No. of questions
0.8914	40

cronbach's alpha has a rule which tells that the reliable 0.7 or <0.6 is known as the low acceptable origin. The Table 1 equivalence among the responses of 21 certify the measure of flexibility caused internally, it can be done again with different samples until the required is reached.

Formula

$$\mathrm{Cronbach's\ alpha} = (\mathrm{K}/\mathrm{K} - 1)) * (1 - (\mathrm{Si2}/\mathrm{Sy2})) \tag{1}$$

Where,

K is the no. of questions
Sy2 is the variance of total column
Si2 is the sum of variance

From our collected samples, Cronbach's Alpha Test was carried out in Table 2.

3 Results and Discussion

Non-parametric tests were carried out; like, Chi-Squared Test and One-Sample T-Test. The Chi-Squared Test explains about extension of the possible outcome the responses could have got from the samples. How much it can to adjusted or to what extend received values are not up to the grade of expectation. These tests can be used when all of the data from a study have been measured on nominal case—that is, the data are in the form of frequency of different categories. With the assumption of Null Hypothesis. A Chi-Squared statistic follows an approximate well-known Chi-Square Distribution. One-Sample Test is a statistical procedure used to identify whether in case a sample of observations could have been produced by a process with a determined mean. There are usually two types of hypotheses in this test. The alternate hypothesis differentiates between true mean (μ) and comparison value (m0), but the ultimatum lies where there is no null hypothesis difference to exists. The purpose is to reject the null hypothesis of the sample given.

References

1. Ogunbiyi, O., Oladapo, Akanbi, A., & Goulding, J. S. (2011). Construction innovation: The implementation of lean construction towards sustainable innovation. In *IBEA Conference, Innovation and the Built Environment Academy*, 7–9th October 2011, South Bank University, London.
2. Prakash Arul Jose, J., Rajesh Prasanna, P, & Prakash, F. (2018). Lean design strategy of waste minimization in construction industries. *International Journal of Applied Engineering Research,13*(6), 4593–4598. ISSN 0973-4562.
3. Harsha, N., Suresh, A. V., & Nagaraj, N. (2013, May). Implementation of lean concepts in the construction engineering project. *International Journal of Engineering Research & Technology (IJERT), 2*(5). ISSN: 2278-0181.
4. Jagannathan, M., Kamma, R. C., Renganaidu, V., & Ramalingam, S. Enablers for sustainable lean construction in India. In V. A. González (ed.), *26th Annual Conference of the International. Group for Lean Construction (IGLC)*, Chennai, India, pp. 910–922.
5. Kundu, G. K. (2015, February). Lean wastes: classifications from different industry perspectives. *ICTACT Journal on Management Studies, 1*(1).
6. Vimal Kumar, U., & Ramasamy, G. (2016) A critical study of various lean techniques in practice and developing a framework for different construction building projects. *International Journal Chemical Science, 14*(SI).
7. Wang, Y. (2009). Sustainability in construction education. *Journal of Professional Issues In Engineering Education and Practice, 13*(1), 21–30.
8. Sourani, A., & Sohail, M. (2011). Barriers to addressing sustainable construction in public procurementstrategies.*In Proceedings of the Institution of Civil Engineers – Engineering Sustainability* (Vol. 164, No. 4, pp. 229–237).

Analytical Case Study

Identification of the Mitigation Methods to Be Adopted that Prevents Time Overrun in Construction Projects

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Abstract The time overrun in construction projects causes cost escalation that leads to stoppage for a long time period or closing of the project. The various reasons for time overrun in construction projects from the scheduled time of project have been identified through various studies and research. This project work was carried out to examine those factors causing time overrun in construction projects and then find the mitigation methods that can be adopted to reduce or prevent time overrun. The study was done based upon the construction field workers opinion and developers in residential, commercial projects. This was carried out by a number of expert interview response by personal conversational interviewing and journal study was done to identify the various methods, techniques, process that can be implemented or followed to avoid time overrun and these were used to prepare the questionnaire. Based on the responses, the important methods, techniques that can be very influential in the omission of time overrun factors and probably reduce the construction time were identified by ranking the various methods, techniques. This study considered the sample frame and target population within India. For a developer, the main benefit of reduced or on-time completion of the project is an opportunity to make customer's feel satisfied and be their potential partner in future projects as well.

Keywords Conversational interviewing · Sample frame · Target population · Mitigation methods

1 Introduction

The construction is a complex process. It involves many different participants doing activities from initial planning till final execution [1]. Building a major construction project is now experiencing schedule delays and cost overruns and often become the

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exception. There are many factors that contributes to poor results, which have been identified through various studies and research [2, 3]. Many studies reveal that due to delay in work progress, there will be cost escalation, and the budget of the construction project would not meet the demand at that point in time which in turn leads to a reduction in the quality of the construction project. The management of the time factor can be expensive, deal with pressure, and is usually a subject of uncertainty. Thus, finding out a solution for preventing the time delaying factors from occurring in construction projects have become a necessity and need of the hour. There are few methods and technology being adopted to reduce the time of construction, but while executing practically the various other factors like low labour productivity, management inefficiency and owner's slow decision making, disputes and litigation causing time delay can't be avoided [4, 5]. In order to find the possible mitigation methods and techniques, this study will help to identify them by doing journal study, personal interviews with experts in the construction field and a questionnaire that could find the best possible solutions. The most influential persons for identifying the time extension factor at its root and implement the mitigation methods would be the developer, owner, engineers, project managers, architects, contractors and subcontractors [8]. Therefore identifying the root cause of the time overrun in construction project and implementing the mitigation methods is very important as rectifying it and providing a proper solution to it will help to enhance the effective management and the administration of the contract time, which prevents time delay [7].

Delay in the construction project is an act or event which extends the actual time required to perform or complete the work of contract manifests and take some additional days of work for its completion. This delay can be cut down at its very root by identifying them at the beginning and providing the best optimal solution to prevent time delay or perhaps even reduce the time for completion of the work. There are numerous research efforts done to study the schedule overrun factors in construction project across various regions in different countries of the world, and also a varied solution based upon the condition of each country and its type of work front has been provided by researchers. For example, graphical modelling classification for construction project scheduling can be adapted to communicate the scheduled time frame of work in an easy and understandable manner [4], All members of the construction team must be trained and educated on schedule overruns and how to take up quick decision in order to minimize time delays [6], adopting performance information procurement system (PIPS) to improve project performance and minimize delays [1], The labour productivity improvisation by proper monitoring and inspection will lead to efficiency improvement in construction and on schedule completion [9].

All these factors causing time delay in construction project were considered for this research and also the recommendation provided by existing research's were taken into account, and then personal interviews were conducted, a questionnaire survey was done. Based on the response, the relative importance index was found for the mitigation methods that could be adopted and were also analysed by SPSS for its reliability. This gave the most suitable solutions that can be adopted in construction projects to reduce time delays and also, it mitigates the factors causing schedule overrun in construction projects.

1.1 Objectives

- To find mitigation methods that could be possible solutions that can be adopted for avoiding time overrun in the construction project.
- The solutions according to their relative importance will be ranked.
- The data obtained will be statistically analysed to check its reliability.

1.2 Need and Scope of Present Work

The need and scope of this work were to identify the mitigation methods and solutions to the time delaying factors within India in order to avoid schedule overrun and cost escalation in construction projects. This will help by implementing these solutions in construction projects and do a case study to see if there is a significant difference in the completion of the construction project on time by doing future research work and ensure on-time completion of the project.

1.2.1 Need for Present Work

This study will provide various possible solutions that can be adopted based upon the nature of the time delay factor occurring in the construction project and also to improve the performance and prevent time delay.

1.2.2 Scope of Present Work

- The data collection was done by sending the questionnaire to 180 construction project workers, out of which 133 respondents were observed, and the category of people approached was Owner, Project Manager, Contractor, Planning Engineer, Site Supervisor.
- The identification of mitigation methods to avoid schedule overrun and finding the best possible solutions for the time delaying factors is confined to construction projects undertaken by India based construction companies (residential & commercial).

2 Data Collection

The data collection for the research was done by sending the questionnaire to the various designated people in the construction industry. The questionnaire was prepared based on the personal interview with the experts in the construction field and literature study. This questionnaire was sent to a number of construction companies for the response, and the category of people approached were owners, project managers, contractors, planning engineers, site supervisors having a good experience.

2.1 Participants

The quantitative study approach is adopted in this research project. The questionnaire was sent to owners, project managers, contractors, site supervisors and planning engineers of residential and commercial projects.

2.2 Questionnaire Preparation

The questionnaire was divided into two sections. Section 1 consisted of respondent's demographic information. In Sect. 1, questions consist of respondents name, firm/company, designation, experience, age. Section 2 is composing of 25 questions that could be possible mitigation methods most likely to improve performance and prevent schedule overrun. These possible solutions were taken into consideration based on two perspectives that are of the direct personal interview and literature study. The different possible solutions to enhance performance and reduce time delay in construction project were scored on a five (5) point Likert scale with 1 denoting Very Low and 5 denoting Very High. The Likert scale is used because it is relatively easy to construct and makes data collection and analysis easy. The respondents were requested to indicate their score for the various solutions in this range.

2.3 Questionnaire Administration

After the questionnaire was prepared, it was distributed to 180 questionnaires to be identified sample of owners, project managers, contractors, planning engineers, site supervisors of commercial and residential projects. A letter was attached to the questionnaire that states the study purpose. In this, the right of anonymity, confidentiality, privacy, informed consent was followed. The questionnaire was sent to the email ids of the individuals and also in person. The filled questionnaires were received back

Table 1 Demographic information of respondents

Designation	Total no. of response returned	No. of response for this designation	% of response returned for designation
Owner	133	20	15.04
Planning engineer	133	21	15.79
Site supervisor	133	31	23.31
Contractor	133	34	25.56
Project manager	133	27	20.30

through emails. Among 180 questionnaires that were initially distributed to respondents, 133 were returned from the respondent. The respondents were from the leading construction firm with experience in site operations.

The questionnaire used for the survey has 25 mitigation methods that can be possibly adopted to increase performance and reduce or prevent time delays in construction projects. The questionnaire with the possible mitigation methods was asked to be rated on a scale of 1–5.

2.4 Demographic Information

The demographic profile of the respondent is illustrated in Table 1.

A total 133 response were received, representing a 73.89% response rate. According to Table 1 demographic characteristics of respondents reveal that 15.04% ($n = 20$) of respondents were owners, 15.79% ($n = 21$) were planning engineers, 23.31% ($n = 31$) were site supervisors, 25.56% ($n = 34$) were contractors and 20.30% ($n = 27$) were planning engineers.

3 Data Analysis and Discussion

3.1 Reliability Test

The internal consistency method was adopted to estimate the reliability of the mitigation methods that serve as possible solutions to prevent schedule overrun. Internal consistency of the scale was measured using Cronbach's alpha coefficient. The most common measure of internal consistency ("reliability") is done by the Cronbach alpha coefficient method. It is most commonly used when there are multiple Likert questions in a survey/questionnaire that form a scale and to determine if the scale is reliable. From Table 2, we can say that the questionnaire done for this project is reliable.

Table 2 Cronbach alpha value

Mitigation methods	Cronbach Alpha value
Overall (25 methods)	0.887

3.2 Relative Importance Index (RII)

RII method was adopted in this research for finding out for which attribute the response was given more frequently at the project formation (Table 3). RII calculated for the various variable as per the below equation.

Table 3 RII and rank of various mitigation methods

S. no.	Mitigation methods	RII	Rank
1	Providing incentives and appraisal	0.525	R25
2	Choosing an accountable contractor	0.629	R19
3	Have a skilled labour workforce	0.580	R22
4	Procurement of resources on time	0.708	R11
5	Practising inventory management for large scale project	0.690	R14
6	Proper monitoring of the labour workforce	0.798	R4
7	Follow the rules and regulations throughout the project	0.639	R18
8	Proper and detailed planning	0.735	R7
9	Practising 6 Sigma lean construction method	0.701	R13
10	Selection of suitable resource for the project	0.684	R15
11	Bill payments to be made on time	0.771	R5
12	Ensuring proper maintenance throughout the project	0.626	R20
13	Effective decisions to be made by the management	0.802	R3
14	Simplified and understandable design	0.761	R6
15	Providing training to improve skill level	0.705	R12
16	Maintaining detailed record for the entire project	0.836	R2
17	Completion of internal works during extreme weather conditions	0.528	R24
18	Adopting BIM technology to reduce complexity	0.671	R16
19	Consistent fund flow through-out the project	0.884	R1
20	Effective communication	0.711	R9
21	Providing safety measures at the site	0.720	R8
22	Making use of modern construction materials	0.535	R23
23	Frequent inspection at project site	0.710	R10
24	Increasing work time under unavoidable circumstances	0.589	R21
25	Motivating the labourers for effective working	0.654	R17

$$RII = \frac{\sum W}{(A \times N)} \quad (1)$$

where RII = Relative importance index

$\sum W$ = Weighting given to each factor by the respondent (1–5 here)

A = Highest weight (5 in this case)

N = Total no. of respondent.

The RII value had a range of 0–1. The higher the RII value, means the high frequency of response recorded for it. According to RII, we will find out which factors are the most influencing solutions that can prevent time overrun in construction projects. The most influencing solution or mitigation method to prevent time delay in construction projects, as observed from Table 4 to be consistent fund flow throughout the project (rank1). Out of the 25 factors, consistency of the fund flow was ranked 1 in the RII value, which seems to be highly influential in the construction industry. Funds are the factors involved throughout the life cycle of the project. Followed by funding the maintaining the records during the project has the major response. Thus, it shows the importance of the documents and their necessity while the time and in the future. Effective decision making also one of the leading factors which are given by most of the respondents. At the time of necessity, effective decision making helps the project to have a smoother run without any delays. Proper monitoring of the labours can help in avoiding unnecessary wasting the time and causing delays in the work. Bill payments on time for the materials can reduce the causes of the delay due to the procurement of the materials (Fig. 1). Making the design and detailing be understood by all category of the people, planning the work in the proper way, providing all the required safety measures to avoid uncertain situations, proper communication between the labours and the management, inspecting the site often are the factors that highly influence the time overrun of the project.

Table 4 Top 10 rank of mitigation methods

S. no.	Mitigation methods	RII	Rank
1	Consistent fund flow throughout the project	0.884	R1
2	Maintaining detailed record for the entire project	0.836	R2
3	Effective decisions to be made by the management	0.802	R3
4	Proper monitoring of the labour workforce	0.798	R4
5	Bill payments to be made on time	0.771	R5
6	Simplified and understandable design	0.761	R6
7	Proper and detailed planning	0.735	R7
8	Providing safety measures at the site	0.720	R8
9	Effective communication	0.711	R9
10	Frequent inspection at project site	0.710	R10

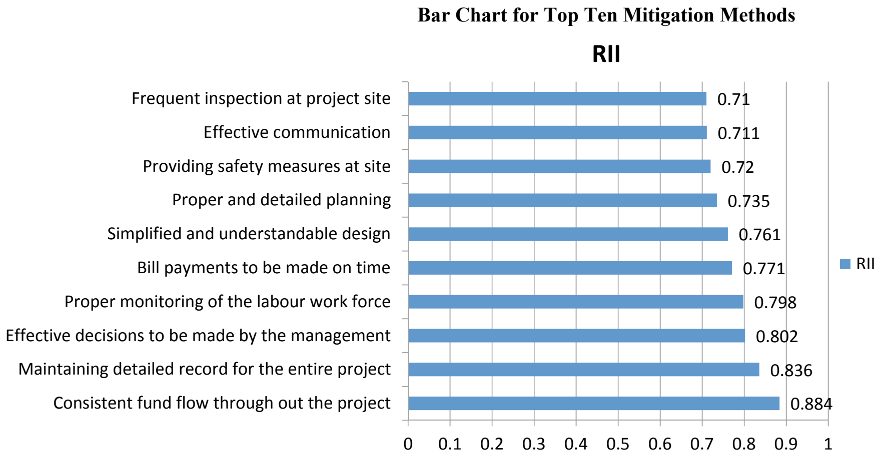

Fig. 1 Bar chart with RII of top ten mitigation methods

4 Conclusion

The questionnaire survey done to the experts has been used to find out the most influencing solution that could mitigate time overrun factors and prevent schedule overrun in construction projects by using the relative important index based on the frequency of the responses by the respondents. The most influencing solution that, when adopted, can mitigate time delay in construction project was observed to be consistent fund flow throughout the project. These results will help in improving the time management and the area of concentration to mitigate time delay in construction projects by enhancing the performance.

Based on the responses and also from the input suggestions given by the experts in the construction field, the paper recommends that the Consistent fund flow can help in the continuous work progress without any delays and changes in the scheduled progress.

The record maintenance helps in avoiding unnecessary time delays by readily having all the data required during the progress of work. This also helps in tracking the project with the mitigations and its impacts on the progress in future.

Effective decisions making by the management, Proper monitoring, Bill payments made on time, Simplified and understandable design, Proper and detailed planning, Providing safety measures at the site, Effective communication and Frequent inspection at the project site are the other considerable factors to be done in order to enhance the performance and mitigate schedule overruns in construction projects.

Further studies can be carried out by adopting these mitigation methods in future construction projects, and a case study can be done to find out if these solutions can possibly enhance the performance and prevent schedule overruns and also whether the new techniques can be implemented for all projects with understanding about it with fullest knowledge about it which will ensure completion of work on time according to schedule.

References

1. Alzara, M., Kashiwagi, J., Kashiwagi, D., & Al-Tassan, A. (2016). Using PIPS to minimize causes of delay in Saudi Arabian construction projects: University case study. *Procedia Engineering*, *145*(480), 932–939.
2. Aziz, R. F., & Abdel-Hakam, A. A. (2016). Exploring delay causes of road construction projects in Egypt. *Alexandria Engineering Journal*, *55*(2), 1515–1539.
3. Aziz, R. F. (2013). Ranking of delay factors in construction projects after Egyptian revolution. *Alexandria Engineering Journal, 52*(3), 387–406.
4. Francis, A. (2015). Graphical modelling classification for construction project scheduling. *Procedia Engineering, 123*, 162–168.
5. Marzouk, M. M., & El-Rasas, T. I. (2014). Analyzing delay causes in egyptian construction projects. *Journal of Advanced Research*, *5*(1), 49–55.
6. Mukuka, M., Aigbavboa, C., & Thwala, W. (2015). Effects of construction projects schedule overruns: A case of the Gauteng Province, South Africa. *Procedia Manufacturing*, *3*(Ahfe), 1690–1695.
7. Wambeke, B. W., Hsiang, S. M., & Liu, M. (2011). Causes of variation in construction project task starting times and duration. *Journal of Construction Engineering and Management, 137*(9), 663–677.
8. Siva Subramani, G., Manikanda Prabhu, S., & Dey, S. (2016). Identifying the factors causing time overrun in construction projects in Chennai and suggesting for possible solutions. *International Journal of Civil Engineering and Technology* (*IJCIET*), *7*(6), 660–668.
9. Dey, S., Manikanda Prabhu, S., & Siva Subramani, G. Identification and mitigation of factors affecting human resource productivity in construction. *International Journal of Civil Engineering and Technology* (*IJCIET*), 8(1), 2017, pp. 123–131.

Introducing Safety on Construction Industry Along with Lean Construction Hypothesis

S. Anandh, S. Sindhu Nachiar, C. S. Sai Abeshek, and Preethiba Mariappan

Abstract The construction industry being a very competitive sector throughout the world, the companies mainly aim in giving an outstanding outcome without any obstacles. From the journals studied, it was analyzed that the main obstacles faced by the industries are due to unexpected accidents which eventually affect the work operation and which can be controlled by introducing safety abstraction along with lean construction ideology. The paper mainly aims in the development of a methodology that can be practiced which helps in the enhancement of safety in the construction industry when lean concepts are implemented, which eventually reduces the accidents in the construction. It is found that by implementing lean construction concepts, the safety in the construction industry has been increased thus reducing the accidents on the construction site which enhances the productivity of the company providing the required outcome.

Keywords Safety · Construction · Accidents

1 Introduction

Workers in the construction industry are prone for accidents, unsafe work environment, mishappenings and injuries. In the Indian construction industry, about 80% of the companies lag in safety aspects. Every year 11,000 workers die in the construction industry due to unsafe working environments (2017 ILO) [1]. Safety can be explained as safeguarding oneself from danger, risk or injuries. Safety is considered as an important factor in the construction sector because by improving safety, the occurrence of accidents reduces. By reducing the disaster rate, the progress of the work can be increased. To improve the safety in construction industry, some safety management concepts are applied in the industry. In spite of introducing safety management techniques, the Indian construction industry still undergo accidents and unsafe working condition. To subdue this complication, lean construction techniques were integrated

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along with safety management concepts in the construction. Even after introducing a safety management system, no big difference was found by the construction industry. The lean construction concept concentrates on shrinking the time, effort and waste of resources. The lean concept was firstly initiated in 1990 but was not adopted into practice back then because of lack of expertise in the concept. Lean construction not only concentrates on one element of the process but also amplifies the entire process of construction [2]. Safety is introduced with the lean concept because as mentioned earlier, lean concepts mainly focuses on reduction of resource, with fewer resources, the chances of accident occurrence can be lowered. The finest technique of the lean concept can be attained by enacting this concept with all the employees of the organization irrespective of their hierarchy. When this is done efficiently, it helps the construction industries in reduction of unexpected accidents at the work-sites and also increases the production rate. When safety along with lean concepts is effectively done, it helps the industry in the production of outstanding projects.

1.1 Lean

Lean is the theory that makes a change in the management and is known as constant system management. The main aim of lean is to minimize all the forms of waste in production to make the workflow easy. Lean management studies the customer value and concentrates on it. The lean concept is to mainly focus on the needs of customers. It also targets to deliver the correct product in the perfect time and quantity needed to the customer and not more or less [3]. The benefit of integrating the lean concept in construction can minimize the cost of construction and the waste produced in construction. The construction duration can be reduced by a proper executing of lean planning. Lean techniques in construction enhance the productivity, profit and customer satisfaction [4]. Lean is a form of traditional construction. The concept of lean can be divided into six components, namely.

1. Minimization of waste.
2. Planning of production.
3. Focus on the end customer.
4. Continuous improvement.
5. Cooperative relationships.
6. Perspective of the system [5].

1.2 Lean Principles

- **Value Specification**—Exactly identifies what creates the value from the point of view of the customers. It comes under the customer satisfaction during hand over of the product.

- **Value stream identification**—Perfectly finds all the stages which give exactly the needs of customer values and eliminate the unwanted which does not add any value to the customer. It also enhances the performance of the construction work.
- **Flow**—It ensures the continuity of the workflow in the value stream. And it is a basic unit that is used for analysis in lean construction.
- **Pull—**It produces the needs of customers on time without any delay.
- **Perfection**—Focus on what the customer wants along the minimization of waste. It also works with the challenges in construction. It undergoes the stages of understanding the waste, lean techniques, lean thinking and lean implementation.

1.3 Lean Benefits

- Perfectly identify the value of the correct needs of customers.
- Exactly finds the process which gives the needs of the customer.
- Delivers the project in the correct without delaying the work and removing all non-valve stages in the workflow.
- Makes the workflow smooth and easy.
- Eliminates all forms of wastes.
- Increases the value of the project [3].

1.4 Safety Management Principles

- **Management leadership**—At the commencement of the project, the top management should give commitments regarding the elimination of hazards and assurance to improve workplace safety and health. Managers from all levels should consider safety as the main objective and set goals accordingly [6, 7]. A written policy should be given by the top management regarding safety and health and the employees should be educated about that at the appropriate time.
- **Worker participation**—Employees from all levels of the management should be active members of the program which includes identifying and reporting the accidents, investigating incidents and tracking the progress of the accidents [8, 9]. Communication barriers for employees should be addressed and rectified so there is no lack of information because of the communication gap. Employees should not be urged to complete the work by giving them the required time and resources.
- **Hazard identification and risk assessment**—Incidents, illness and injuries should be investigated then and there to find the underlying hazards, and priority for rectification of hazards is based on the degree of risk [10, 11]. High-risk hazards should be rectified immediately because it causes adverse effects at the same time low-risk hazards should also be rectified but with a given time gap. Hazards can be found in various places:

  - Electrical hazard.
  - Slip, trip and fall hazard.
  - Biological hazard.
  - Ergonomic problem.
  - Fire hazard.
  - Chemical hazard.

- **Hazard prevention and control measures**—Employees having high knowledge to analyse the conditions that cause hazards must be hired. Day-to-day investigation of the control measures taken should be monitored. The help of certified safety and health experts can be attained [12, 13]. Serious hazards that cause injuries or death should be eliminated immediately. The measures or prevention taken should be improved periodically. Personal protective gears should be used by the employees to avoid injuries.
- **Education and training**—All the workers should be educated and trained about the measures taken and how to work in these conditions [14, 15]. Top-level management should be educated and trained about the safety concepts for protecting workers' right and acknowledging the workers' reports and concerns.
- **Worksite communication and coordination**—The employers and employees should have good communication and coordination which gives both the employer and employee awareness about the hazards in the worksite, type of hazard and the reason for the hazard, and also ensures how the work is carried as per the safety guidelines [16, 17].

1.5 Risks Involved in the Construction Industry

Reduction of hazards and accidents in the construction industry is the major idea for introducing safety in the construction industry. Accidents are one of the major causes for productivity loss in the construction industry as it disturbs the workflow nature. The cause of accidents can be avoided by magnifying the concept of safety in the industry. The major accidents caused in the industry are as follows:

- **Trips and falls**—this is the most common type of accident that occurred in the industry which can be due to even because of the negligible reason. Trips and falls might lead to the absence of a day or two and can also cause severe injuries such as fractures and cracks [18].
- **Work at height**—this type of injury is generally fatal which may also lead to loss of life in some situations. Generally, this type of fall is classified into two types (i) fall of workers, (ii) fall of an object on workers in the site. The fall can generally be from ladders, staircase and temporary platforms set up for scaffoldings [19].
- **Risks related to frailty**—the risk of injury is caused by fall of objects from height in the worksite, earthquakes and collision of structures and equipment; frailty can affect the nearby structures which are already constructed or even new structures which are under construction; the cause of frailty can be due to failure of design, improper monitoring [20].

- **Electricity risks**—these injuries involve electric shocks and burns which are due to direct contact with live electric lines; these injuries can be very serious and sometimes causing fatal injuries and the degree of injury depends upon the voltage capacity they work. These injuries are caused due to improper wiring in the construction site, using low-quality wire and unintentional contact with underground cables [21].
- **Risks related to gases**—these injuries generally lead to loss of life and these are caused due to inhalation of poisonous gases. During the deep excavation process, activities such as tunneling are done; during this operation, the employees might get in contact with these gases which leads to fatal injuries [22].

2 Methodology

Required data for the project can be derived from the questionnaire developed which were categorized under four different factors as analyzed from the journals studied.

2.1 Scheme of the Work

The representation of the scheme of work followed for this project of interest is given below. Certain sets of journals were studied and facts were being considered for the part of the research. From these journals, certain data were understood and taken to contemplate with the need of this research [23, 24]. Based on the conclusion of the factors which mainly tend to affect the root, the study is classified from the data collected from the journals. Questions were prepared from the available sources of information for this study of research. By studying the provenance of the research, the type of the mathematical analysis can be withdrawn and put into a course of action (Fig. 1). Results can be concluded and discussed. A sample of conceptual model can be developed and made easier for the understanding. And the study can be concluded for the final dissertation.

2.2 Design of Questionnaire

The questionnaire was classified into six parts.

1. Financial Barriers.
2. Management Barriers.
3. Educational Barriers.
4. Government Barriers.
5. Technical Barriers.
6. Human Attitudinal Barriers.

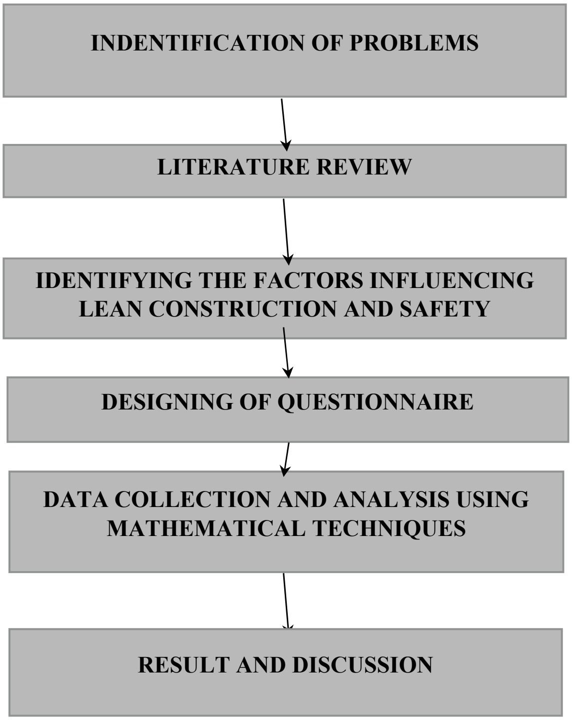

Fig. 1 Scheme of work

2.3 Data Analysis and Collection

Initially from the separated factors collected from the literature, a set of 38 questions were framed, 6 under each factor [25]. Since the study is generalized and Pilot Study was done. From the pilot study, questionnaire was developed using the Likert Scale varying from Strongly Agree, Agree, Neutral, Disagree to Strongly Disagree. To check whether the prepared questionnaire is apt for the project studies, certain tests like Cronbach's Alpha Test and the Likert Scale Analysis were done.

2.4 Pilot Study

A pilot study is a preliminary study carried out to check for the feasibility of the project. It helps in detail prior plan of the project and the extension of profitable positivity of this study from the history and personal interviews done.

Table 1 The Standard Cronbach alpha table

Cronbach's alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Table 2 The Cronbach Alpha value

Cronbach's Alpha, α	No. of questions
0.8747	38

2.5 *Cronbach's Alpha Test*

Cronbach was utilized for checking the internal consistency of a data and its reliability of one factor with the rest of it. It is a form of psychiatric test. The theoretical value ranges from 0 to 1. It has a rule of thumb followed as reliable 0.70 or higher with 0.6 as the slowest as the acceptable threshold. The correlation between the responses few validating the measure of consistency caused internally, it can be repeated with various samples till the desired is reached (Table 1).

$$\alpha = (K/(K-1)) * (1 - (S_{i2}/S_{y2})) - 1$$

Where

K is the no. of questions.

S_{y2} is the variance of the total column.

S_{i2} is the sum of variance.

From our collected samples, in random 15 samples were selected and Cronbach's Alpha Test was carried out. Samples' value are given below in (Tables 2 and 3).

3 Results and Discussion

The collected primary data was analyzed using the SPSS 16.0. We performed Descriptive Statistics for the data based on the domains. And One-Way ANOVA test was performed to find the significant difference between the various domains which

Table 3 Descriptive statistics

Descriptive statistics		
Domain	Mean	Std. deviation
1	39.2	2.38
2	19.7	1.396
3	23.19	1.647
4	15.68	1.207
5	22.96	1.658
6	28.36	2.332

explains about the various barriers of lean construction concept. The below table gives the Mean and Standard Deviation values of various domains which explains the barriers of the lean construction concept.

And we performed One-way ANOVA to find out that any significant differences were found between all barriers of the lean construction concept.

Null Hypothesis: There is so statistically significant difference between the barriers of the lean construction concept.

Alternative Hypothesis: There is a statistically significant difference among the barriers of the lean construction concept.

The below table explains about the ANOVA table and gives the p-value as (0.000). Hence, the p-value is less than 0.05, i.e., (p (0.000) < 0.05). So, we reject the null hypothesis and concluded this study as there is a statistically significant difference among the barriers of the lean construction concept (Table 4).

Then we also performed multiple comparison tests for the same dataset, to find out that there is any difference among the within models (Table 5). The Table 5 shows the multiple comparison test which also suggested that there is a statistically significant difference among the barriers of lean construction concept, because the significant value in all these within models is less than the p-value expect Technical Barriers with Educational Barriers (Fig. 2).

Means Plots

Table 4 ANOVA table

ANOVA					
	Sum of squares	df	Mean square	F	Sig
Between groups	23,137.3	5	4627.459	1390.164	**0.000**
Within groups	1358.116	408	3.329		
Total	24,495.41	413			

Table 5 Multiple comparisons table

Multiple comparisons		
(I) Scores		Sig
	Educational barriers	0.000
	Government barriers	0.000
	Technical barriers	0.000
	Human attitudinal barriers	0.000
Financial barriers	Management barriers	0.000
	Educational barriers	0.000
	Government barriers	0.000
	Technical barriers	0.000
	Human attitudinal barriers	0.000
Educational barriers	Management barriers	0.000
	Financial barriers	0.000
	Government barriers	0.000
	Technical barriers	**0.976**
	Human attitudinal barriers	0.000
Government barriers	Management barriers	0.000
	Financial barriers	0.000
	Educational barriers	0.000
	Technical barriers	0.000
	Human attitudinal barriers	0.000
Technical barriers	Management barriers	0.000
	Financial barriers	0.000
	Educational barriers	**0.976**
	Government barriers	0.000
	Human attitudinal barriers	0.000
Human attitudinal barriers	Management barriers	0.000
	Financial barriers	0.000
	Educational barriers	0.000
	Government barriers	0.000
	Technical barriers	0.000

[a]The mean difference is significant at the 0.05 level

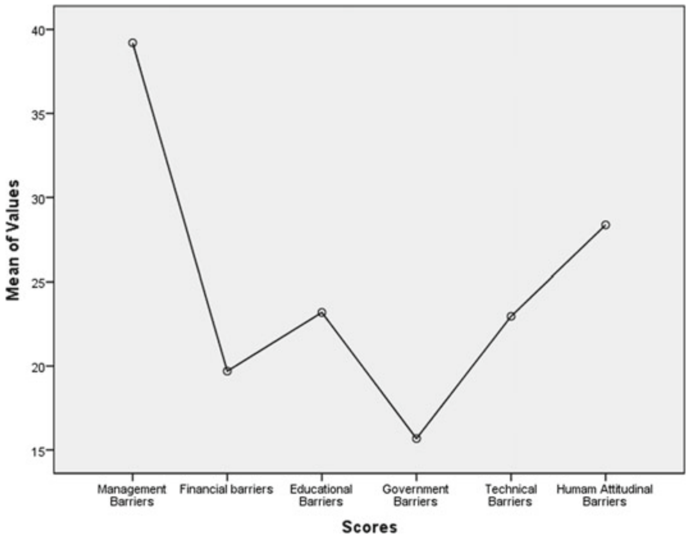

Fig. 2 Mean value of various domains

References

1. Demirkesen, S. (2019). Investigates on "Measuring impact of Lean implementation on construction safety performance: A structural equation model. *Production Planning & Control*. https://doi.org/10.1080/09537287.2019.1675914,ISSN:0953-7287(Print)1366-5871
2. Wu, X., Yuan, H., et al. (2019). Explores on "Impacts of Lean Construction on Safety Systems: A System Dynamics Approach". *International Journal Environmental Research and Public Health, 16* 221.
3. Bajjou, M. S., Chafi, A., & En-Nadi, A. (2017). Researches on "The Potential Effectiveness Of Lean Construction Tools In Promoting Safety On Construction sites". *International Journal of Engineering Research in Africa*, *33*, 179–193. ISSN: 1663–4144.
4. Melzner, J. (2015). Explains the "Integrating Lean and Safety: A process-based approach towards construction safety". *Proceedings The International Society for Computing in Civil and Building Engineering-16*, July 2016.
5. Enshassi, A., & Zaiter, M. A. (2014). Kick about the "Implementation Of Lean Tools On Safety In Construction Project In Palestine". *Proceedings International Group For Lean Construction-22*, June 2014.
6. Larios, J. A., & Amalia Sanz, M. (2012). Has studied "Construction Health and Safety From Lean Production Approach". In *XVI International Congress of Project Engineering Valencia*, July 11–13, 2012.
7. Ghoush, S., & Young-Corbett, D. (2009). Researched on "Intersection between Lean Construction and Safety Research: A Review of Literature". *Proceedings of the 2009 Industrial Engineering Research Conference.*
8. Nahmens, I., & lkuma, L.H. (2009). Tells about "An Empirical Examination of the Relationship between Lean Construction and Safety in the Industrialized Housing Industry". *Lean Construction Journal*.
9. Schafer, D., Abdelhamid, T. S. et al. (2008). Discusses on "Resilience Engineering: A New Paradigm For Safety In Lean Construction Systems". In *Proceedings for the 16th Annual Conference of the International Group for Lean Construction Safety, Quality and the Environment*.

10. Singh, S., & Kumar, K. (2019). The study aims on "Review of literature of lean construction and lean tools using systematic literature review technique(2008–2018)". *Ain Shams Engineering Journal*.
11. Dinesh, S., Sethuraman, R., & Sivaprakasam, S. (2017). The review on lean construction an effective approach in construction industry. *International Journal of Engineering Research and Modern Education*, ISSN: 2455–4200, Impact Factor 6.525, Special Issue, April-2017.
12. Vimal Kumar, U., & Ramasamy, G. (2016). A critical study of various lean techniques in practice and developing a framework for different construction building projects. *International Journal Chemical Science 14*(S1), 175–187. ISSN 0972–768X, Sadguru Publication.
13. Sami Pasha, S. M., & Harish Naik, B. (2016). An analysis of lean construction practices in tamilnadu construction industry. *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET),* 5(9). An ISO 3297:2007 Certified Organization, ISSN (Online): 2319-8753, ISSN (Print):2347-6710, September 2016.
14. Abhiram, P., Asadi, S. S., et al. (2016). This study tells us about the "Implementation of Lean Methodology In Indian Construction". International Journal of Civil Engineering and Technology (IJCIET) Volume 7, Issue 6. November-December, 2016, 641–649.
15. Hannis Ansah, R., & Sorooshian, S. et al. (2016, February 2016). Discussed on "Lean Construction: An Effective Approach for Project Management". *ARPN Journal of Engineering and Applied Sciences*, *11*(3). ISSN 1819-6608.
16. Wandahl, S. (2014). Investigated on "Lean Construction With or Without Lean-Challenges of Implementing Lean Construction". In *Proceedings International Group of Lean Construction-22*, June 2014.
17. Alves, Thais da C.L., & Milberg, C., et al. (2012). Discussed on "Exploring the lean practice, research and education". *Engineering, Construction and Architectural Management, 19*(5), 512–525.
18. Salem, O., & Soloman, J., et al. (2006). Discusses about "Lean Construction: From Theory to Implementation". *Journal of Management in Engineering*, *22*(4), 168–175.
19. Ayhan, B. U., & Tokdemir, O. B., et al. (2020). Researched on "Accident analysis for construction safety using Latent Class Clustering and Artificial Neural Networks". *Journal of Construction Engineering and Management, 146*(3), 04019114.
20. Sanni-Anibire, M. O., Mahmoud, A. S., et al. (2020). Discussed about "A risk assessment approach for enhancing construction safety performance". *Safety Science, 121,* 15–29.
21. Bhattacharjee, S., & Ghosh, S. et al. (2011). Reviewed on "safety improvement approaches inconstruction industry". In *47th Associated Schools of Construction Annual International Conference Proceedings.*
22. Törner, M., & Pousette, A. (2009). Confabulates the "Safety in construction—A comprehensive description of the characteristics of high safety standards in construction work, from the combined perspective of supervisors and experienced workers. *Journal of Safety Research, 40,* 399–409.
23. Rozenfeld, O., & Sacks , R., et al. (2009). Aims in the "Construction job safety analysis". *Safety Science, 48,* 491–498.
24. Bust, P. D., & Gibb, A. G. F., et al. (2007). Tells about "Managing construction health and safety: Migrant workers and communicating safety messages". *Safety Science, 46,* 585–602.
25. Carter, G., & Smith, S. D. (2006). Talks about the "Safety Hazard Identification Projects". *Journal of Construction Engineering and Management, 132*(2), 197–205.

Implementation of Lean Techniques in Construction Projects

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Abstract The Indian construction industry is characterized by major challenges such as low productivity and time and cost overruns. Poor work structuring is one of the major causes that leads to low productivity and time and cost overruns. Work Structuring is defined as a process that tries to align engineering design, supply chain, resource allocation and execution. The main objective of work structuring is to make the processes faster and more reliable while delivering the product to the client. This project mainly focuses on the construction supply chain-related issues to improve the construction process workflow. There are a lot of non-value-adding activities or wastes in construction practices and many among those were left unnoticed. Earlier studies have shown that there were significant amounts of values loss due to construction process flow wastes and tremendous productivity improvements can be achieved by simply targeting at reducing those waste and improve the process flow. Case studies have been carried out of different construction sites to find out the various wastes involved in the construction process. This project was conducted on the basis to study the waste concepts and the level of "leanness" in local construction practices based on philosophies and principles are drawn by Lean Construction.

Keywords Lean · Productivity · Supply chain · Work flow

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1 Introduction

Construction system is a pivotal area of the nationwide marketplace toward nations all throughout the globe, while historically it drove up a huge share from the nation's entire trade and its notable enrichment to a nation's wealth as a lump [1]. However, till now, construction planning activities are yet challenging sundry contingent difficulties that remained confined to be fixed in the earlier era. The chronic problems of construction development system are entirely identified so as low productivity, poor safety, inferior working conditions and insufficient quality [2–4]. The aspect of reduced representation furthermore situations in planning ought to extend held testified and documented via academics including practitioners everywhere this environment although in evolved nations. Now, expanding international race, the inadequacy of skillful employees, including some necessary to enhance construction system attribute hold essential challenges encountered by the production management. Reacting to these objections requires an essential requirement to boost potency, essence plus to consolidate distinct technologies [5–8] inside the manufacturing industry. A lack of responsiveness can hold back growth, and development of the needed infrastructure for the construction industries and other key activities in the country [9, 10]. Regarding the hurdles encountered by the construction development industry, copious investigations and investigations ought endured displayed out for the more prime decades to recognize the reasons of the construction system predicaments including extraordinary of them ought progressed on to recommend and justify explications to revise those recognized obstacles. [11, 12] The initial stage of those researches principally concentrated on the "terminal" surface of the construction system method amidst the installation of modern technologies and facilities to expedite up the development method and grow overall fertility. According to the learners and researchers in Lean Construction, the unique construction generation conception is deposited on the theories of transformation and current method [13, 14]. Consequently, production enhancement possibilities in development package suddenly be pleaded by assuming decay classification/ mitigation policies in the discharge methods in similarity with value-adding maneuverings with the installation of unique supervision accessories and with peculiar practice and training schedules [15–17].

2 Literature Background

According to the construction industry development bureau, there was 26% customer dissatisfaction, 33 quality problems that were not acceptable, 25% defects that were not acceptable and safety remains a concern with the construction industry.

2.1 Lean Construction

Lauri Koskela (1996) [18] proposed the idea of lean in the construction industry. This method of lean construction understands that three schools of thought have developed in production management and that those ideas are vertically interconnected: one chooses the transformed view "T", the other the flow view "F" and the third flow view "V".

2.2 Lean Project Delivery

Lean construction adopts an integrated and systematic view of project delivery, understanding that the project delivery system may be observed at different levels. Lean Project Delivery System (LPDS) tools promote effective plan and control, high value reducing wastes during the construction process [19, 20]. The LPDS design has eleven modules, designed into five triads or phases expanding from project definition to lean design to supply, then assembly and use. The LPDS has work structuring and production control modules (Fig. 1).

According to Ballard [6], the Lean Project delivery has the following four phases

- Project definition
- Lean design
- Lean supply
- Lean assembly

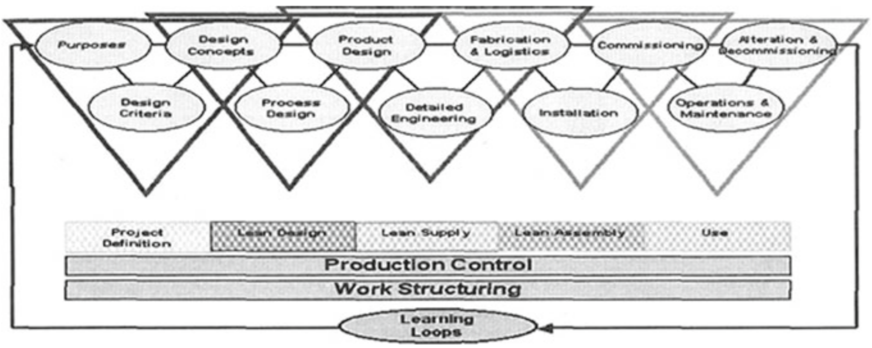

Fig. 1 Lean project delivery system

2.3 Lean Supply System

Arbulu and Ballard [4] this journal recommends a procedure to develop the control of supply methods in construction utilizing lean principles and techniques. The aim is to assure on-time transfer of data and elements to the project place at a minimum value and highest profit for the final client, the principal median for fulfilling this goal is to perform supply management purposes with the shortest waste: e.g. low supply and market safety, huge records not required to understand the variability and solid waste. The article investigates supply complexity in construction to properly explain where several varieties of waste are introduced. The plan offers the use of a web-based tool based on the latest executive method to enhance designing safety to direct variability remains decreased, the use of local logistics hubs toward delivery of components to places, the use of kanban techniques to draw elected elements on a just in time base, and a link connecting production management and supply management process at a site.

3 Methodology

A review of literature on lean construction, lean project delivery system, supply chain management, etc., were carried out in order to fulfill the following purposes:

- To understand the concept of lean techniques
- Need for lean construction management in construction industry
- To suggest suitable measures to optimize the construction supply chains

Work sampling was carried out, to calculate the amount of time, the laborers remain idle as a consequence of the non-arrival of material in the site to emphasize the loss caused in labor productivity as a result of poor management of the supply chain. However, in work sampling, the main concern is with the measurement of labor productivity. Although it does not provide a direct measurement of labor productivity yet work sampling can be used as an indicator of labor productivity. As the objective of the work sampling is to calculate the idle time of time of laborers due to material delay the modified work sampling was conducted at selected workplaces where laborers were employed as planned but work was not in progress as there were delays in bringing the materials to the workplace. This delay may be either due to the failure of the supplier in supplying the materials or due to the transportation in shifting the materials from the storage yard. The laborers were observed approximately for twenty seconds and were then classified as either, productive, idle or in travel. Similarly, ten to twelve cycles of observation were made and then average number of workers in each category was calculated. Similar kind of work sampling was carried in all the sites for formwork, reinforcements and concreting activities to enable to correlate the idleness of the laborers to the supply chain.

4 Data Collection

The sample taken for the study is a residential complex project consisting of twenty-four blocks each of which is a G + 4 storey building. The project is located in Nellore. The project duration is two years.

4.1 Issue Recognition

The site does not have a proper material storage yard and hence it was difficult to track the number of materials available on the site. Hence random materials orders were placed to the regional office. A considerable amount of time is required to pass the indents to the regional office to get the materials delivered to the site. As a consequence of this, the project encountered a material delay.

Poor housekeeping added to the problem of placing unnecessary material orders which resulted in improper stacking of materials since there was a space constraint. When steel was unloaded 8mm and l0mm were placed one on top of the other. Practically it is difficult to differentiate between 8 and 10 mm bars.

The buildings were built of concrete blocks. So initially they faced problems in finding suppliers who can provide the right quantity of concrete blocks at the right time. But the suppliers couldn't send full truck loads as concrete blocks were very heavy. So, the company had to go for multiple suppliers which in later stages proved to be non-manageable. Hence, they planned to have their casting yard to meet their demands.

A large amount of idle time was observed among the laborers who were employed on the third floor of block B-2 where work was not in progress as a result of the material delay. As 8 mm bars were not available on the site to meet the project deadline 10 mm bars were laid to complete the activity. Figure 2 shows the supply chain for formwork, reinforcement, and concrete activities. The supply chain looks manageable with very few suppliers. Yet they faced problems on the site regarding the material delay.

5 Data Analysis

An attempt has been made to bring out the various problems that arise due to the poor management of the construction supply chains and specific issues regarding the material delay in each site is discussed in detail in the following chapter. From the data analysis made, few problems existed as common problems in all the sites. As there was a scope to perform logistics management in Project, logistics management was carried out to optimize its supply chain and to manage its supply chain in a better way.

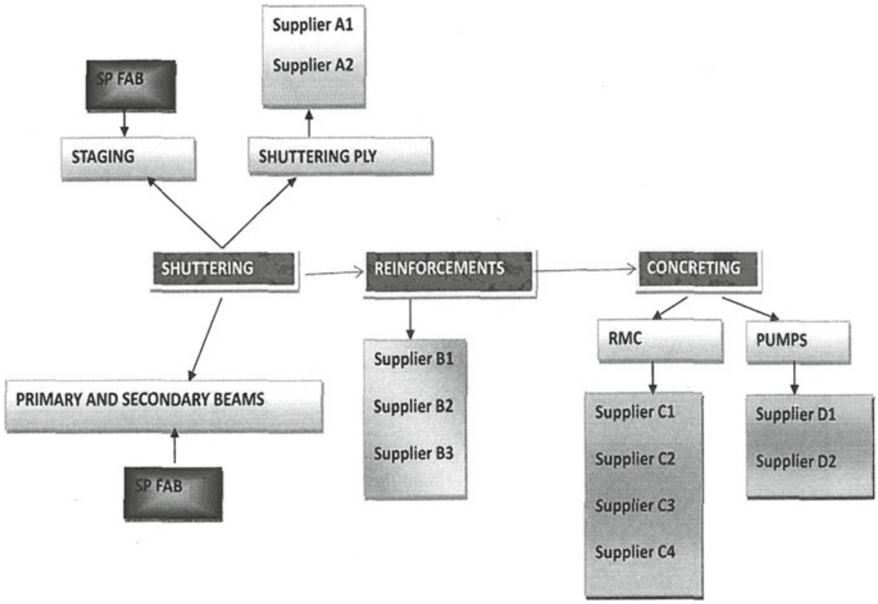

Fig. 2 Supply chain for the residential project

A modified work sampling technique is adopted in the projects to calculate the idle time of laborers due to the non-arrival of material in the site and due to the delay in shifting the materials from the storage yard to the workplace. However, in Project, there were no such delays and the problem of non-arrival of material on the site. The idleness that prevails among the laborers is attributed to various other reasons which are beyond the scope of this project. As the objective of the work sampling is to calculate the idle time of laborers due to material delay the modified work sampling was conducted at selected workplaces where laborers were employed as planned but work was not in progress as there were delays in bringing the materials to the workplace. This delay may be either due to the failure of the supplier in supplying the materials or due to the transportation in shifting the materials from the storage yard. The laborers were observed approximately for twenty seconds and were then classified as either, productive, idle, or in travel. Similarly, ten to twelve cycles of observation were made, and then an average number of workers in each category was calculated. Similar kinds of work sampling were carried in all the sites for formwork, reinforcements, and concreting activities to enable to correlate the idleness of the laborers to the supply chain. The tabulated work sampling data was collected from the sites.

Table 1 Aspects analyzed from this project

S. no.	Aspects	Discussion
1	Nature of existing supply chain	Simple and less number of suppliers
2	Site layout and material handling	Material storage yards do not have adequate capacity and poor material handling
3	Supply management	Centralized process
4	Delays encountered due to non-arrival of materials	Delays were encountered
5	Effect on labor productivity due to non-arrival of materials	Labor productivity was severely affected
6	Inventory tracking system	Not practiced

5.1 Aspects Analyzed from this Project

A complete supply analysis has been done in this project for that I have analyzed some of the aspects regarding this project (Table 1).

5.2 Work Sampling Data for Residential Project (Reinforcement)

A large amount of idle time was observed among the laborers who were employed on the third floor of block B-2 where work was not in progress as a result of the material delay. As 8 mm bars were not available on the site to meet the project deadline 10 mm bars were laid to complete the activity. The work sampling result carried out for reinforcement activity in this site is shown in Fig. 3.

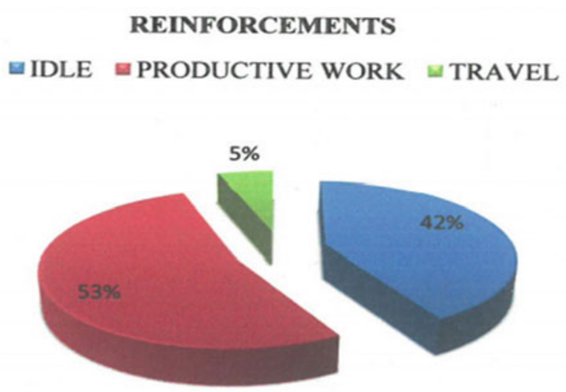

Fig. 3 Work sampling for reinforcement activity in project

Table 2 Work sampling data for residential project

Time	Productive	Idle	Travel
11:05–11:17 AM	15	17	3
11:20–11:34	23	14	4
I 1:40–11:54	19	16	0
12:00–12:15 PM	20	15	1
12:20–12:24	21	16	0
12:25–12:37	20	14	2
12:40–12:53	15	15	6
Average	19	15	2
Percentage	53	42	5

Lean Construction is a sequence of the initiation of the latest model of production management that presents a structured format in which method can be redesigned. As a result of reduction of labor hours which is ease for construction (Table 2).

5.3 Proposed Lean Steps to Optimize the Supply Chain

Following are the steps that should be followed to control the non-value-added activities

- Get the monthly schedule from the planning department
- Study of the site layout to allocate storage yards and batching plants
- Storage yard capacity would be decided based on the monthly
- Quantities of materials required.
- Planning of proper access routes for mixers and trucks
- Plan for buffer storages.
- Proper record of inventories on site.
- Material tracking is very useful to control the high inventories.
- Material logistics in the site can be optimized with least cost.

6 Conclusion

This report has recognized and explained the various lean practices performed in the construction industry and their advantages in sustainability. Based on the decisions, the subsequent conclusions are made

The following are the conclusions drawn from the analyzed case studies:

- Lean construction is a result of starting new form of production management.
- Lean thinking provides a structured arrangement in which the method can be redesigned.

- Redesigned process is a result of modification of labor hours which is efficient for construction.
- The proposed strategy targets the reduction of demand variability by stabilizing workflow on site.
- Material tracking is very useful to control the inventories.

References

1. Battula, V. R., Namburu, S. K., & Kone, V. (2020). A study on factors involved in implementation of supply chain management in construction industry. *Materials Today: Proceedings, 33*, 446–449.
2. Tezel, A., Koskela, L., & Aziz, Z. (2018). Current condition and future directions for lean construction in highways projects: A small and medium-sized enterprises (SMEs) perspective. *International Journal of project management, 36*(2), 267–286.
3. Shojaei, P., & Haeri, S. A. S. (2019). Development of supply chain risk management approaches for construction projects: A grounded theory approach. *Computers & Industrial Engineering, 128*, 837–850.
4. Arbulu, R., & Ballard, G. (2004). Lean supply systems in construction. *International group for lean construction* (pp. 1–13). Conpenhague: Dinamarcapp.
5. Aslam, M., Gao, Z., & Smith, G. (2020). Exploring factors for implementing lean construction for rapid initial successes in construction. *Journal of Cleaner Production, 277*, 123295.
6. Ballard, G. (2000). Lean project delivery system. *White paper, 8*, 1–6.
7. Babalola, O., Ibem, E. O., & Ezema, I. C. (2019). Implementation of lean practices in the construction industry: A systematic review. *Building and Environment, 148*, 34–43.
8. Goh, M., & Goh, Y. M. (2019). Lean production theory-based simulation of modular construction processes. *Automation in Construction, 101*, 227–244.
9. Tezel, A., & Nielsen, Y. (2013). Lean construction conformance among construction contractors in Turkey. *Journal of Management in Engineering, 29*(3), 236–250.
10. Koskela, L., et al. (2002). The foundations of lean construction. *Design and Construction: Building in Value, 291*, 211–226.
11. Rajprasad, J., Abinaya, T. L., & Tamilarasu, V. (2016). Planning of facilities and asset management for an integrated township. *International Journal of Civil Engineering and Technology, 14*, 393–399.
12. Tuholski, S. J., Gursel, A. P., Tommelein, I., & Bomba, G. (2009). "Lean" comparison using process charts of complex seismic retrofit projects. *Journal of Construction Engineering and Management, 135*(4), 330–339.
13. Dos Santos, A, Powell, J. Sharp, J, Formoso, C. (2015). Principle of transparency applied in construction. In *GLC-6, 6th Annual Conference of the International Group for Lean Construction*, Guaruja, Brazil.
14. Alarcon, L. F., & Calderon, R. (2003). Implementing lean production strategies in construction companies. In *Construction Research Congress: Wind of Change: Integration and Innovation.*
15. Ballard, G., Harper, N., & Zabelle, T. (2018). An application of lean concepts and techniques to precast concrete fabrication. In *Proceedings of the 10th Annual Conference of the International Group for Lean Construction, IGLC-10*, Gramado, Brazil.
16. Tsao, C. Y., Tommelein, I. D., Swanlund, E., & Howell, G. A. (2019). Case study for work structuring: installation of metal door frames. In *Proceeding of the 8th Annual Conference of the International Group for Lean Construction*, Brighton, UK.
17. Koskela, L., Lahdenpera, P., & Tanhuanpa, V. (1996). Sounding the potential of lean construction: A case study. In *Proceedings of the 4th Annual Conference of the International Group for Lean Construction.* Birmingham, UK.

18. Marzouk, M., Bakry, I., & El-Said, M. (2011). Application of lean principles to design processes in construction consultancy firms. *International Journal Construction Supply Chain Management, 1*, 43–55.
19. Sacks, R., Radosavljevic, M., & Barak, R. Requirements for building information modelling based lean production management systems for construction. *Journal Automation in Construction 19*.
20. Rajprasad, J., Thamilarasu, Annadurai, R., Choudhuri, A.R, Application of project management system in construction project. *International Journal of Civil Engineering and Technology 8*, 786–791.

Consequence of Communication Problem for Higher Authority of Construction Industry in India

J. Rajprasad, Manish Prasad, and N. Pannirselvam

Abstract The construction industry has a challenging working environment, in which communication is a key factor among the individuals involved in management (technical team). In the construction industry, people who are in different positions in the company may have ego/status problems among themself. Higher authority may or may not support the junior level employees to come forward and may not share project-specific information. So, lack of communication results in a poor working environment and mutual understanding between employees. In this study, examination of communication problems and their impacts are observed. This study is based on the parameters like cultural differences, gender differences, language, and physical barriers. The questionnaire approach is used to perform this study. The data obtained through the questionnaire is analyzed using the software. The main aim of the study is to establish a better framework for effective communication in the construction industry.

Keywords Attitude · Cultural differences · Labor productivity · Lack of motivation · Working environment

1 Introduction

The process of giving, receiving, and sharing information is known as communication; in other words, communicating, writing, and listening or reading is the act of communication [1]. Effective communicators pay attention to what people say, speak, or write simply and respect differing views. This research assesses the impact

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of effective communication problems for the higher authority of construction in India. Communication is one aspect of management that affects and influences all the other attributes in an organization [2]. Construction has a project-based nature as a decentralized and competitive market. Very commonly, difficulties with the design are known as problems of communication. The building field forms a dynamic collaboration landscape due to its particular characteristics [3]. A reality of conflicts and a loss of mutual love and trust are posed by society [4]. This research aims to enhance coordination in a comprehensive literature review on communication in construction that was undertaken to describe the issue in more depth. To achieve the study objective, and in India, interviews with experts in the field of construction were performed. This research has been done on various civil projects with a perspective of findings, results, and conclusions. In the successful execution of these projects, labor productivity, cultural differences, attitude, and lack of motivation, making a good working environment is a key determinant. Communication between the construction manager and the design team was identified as crucial to ensuring that the goals of the project were met [5]. Communication means have been categorized as formed written technological material and informal verbal communication [6–8]. Construction managers in Israel also use casual contacts in 50% of their encounters with their colleagues in the project. This research offers a feasible assessment instrument to analyze several theorized contact patterns within the IPD team [9–13]. As noted above, these behaviors include tracking sensitive details considered pertinent to the IPD initiative, cultivating an environment that encourages the challenge of the status quo, negotiating workable resolutions when possible, and maintaining team boundaries with the use of a specific project coordinator [14–18]. Multiculturalism is becoming more prevalent in the building industry [19]. The managerial task of managing a diverse workforce is immense, not least in terms of maintaining efficient coordination among the different cultural classes [19]. This paper looks at the challenges of leading workers who aren't fluent in the native tongue of their workplace. It concentrates on the issues that have been encountered in two English-speaking countries (Australia and Singapore) and upon interactions between English-speaking managers and non-English-speaking operatives.

2 Literature Background

Communication issues are at the core of the building management selection process. The ever-hanging sophistication of the schemes, the increasing need for fast-track construction and the overlap between the specific phases of the cooperation of the parties involved one of the favored sourcing approaches for fast-track construction.

2.1 Causes of Conflicts in the Construction Industry: A Communicational Approach

The author examines the roots of construction industry disputes between clients and contractors. The majority of contemporary scholars point to publicly evident indicators of conflict as the causes of conflict, according to an overview of publications on the topic. According to the writers, the primary source of controversy in the building industry is a breakdown of coordination between the customer and the contractor [20].

2.2 Communication Problems with Ethnic Minorities in the Construction Industry

Multiculturalism is becoming more prevalent in the building industry. The managerial task of managing a diverse workforce is immense, not least in terms of maintaining efficient coordination among the different cultural classes. It is concluded that English is often the minority language on-site and is restricted to the administrative stage, although there are few attempts to address the connectivity issues that may emerge [21–23].

3 Methodology

Several journals have been gone through to gather many information and parameter for research work. In my research, eight parameters (cultural differences, gender differences, language barriers, physical barriers, listening problems, lack of motivation, emotional, and verbal communication) play a vital role in research. This paper briefly covers how this research was carried out, the types of data collected, the data storage, and the data analysis processes used. It also discusses how information is presented, provides a background against which the findings are treated, and contains the research design and data sources. The other step is expert consulting in which to approach a well-known person who is a management expert. In this research, 30 questions related to research work have been formed which help to gather survey. The question is formed according to the parameter of communication problems. The question is distributed to various construction company employees. They have taken their time to understand the questions and give the responses according to their conditions. 53 responses were sent on excel for analysis work and 25 have responded.

3.1 Data Collection

The data collection has been done in construction companies in India. The company handles all types of civil works. They have a large number of employees in the company in the form of higher authority and labor but here the research focus is on the higher authority. The questionnaire was used to gather data from an Indian construction company. The research is being performed by various construction companies. The questionnaires were circulated by Google Forms to the company's higher management. The respondents used Google Forms to answer the questions and quickly returned the questionnaires to the coordinators. The questionnaire took 10–20 min to complete. They were interested to be a part of this survey. They were allowed to answer the questions individually and were expected to fill out the questionnaire according to their perception. Once the study was done at a place, the researchers retrieved all of the questionnaires.

3.2 Data Analysis Methodology

Exploratory factor analysis (EFA) was used for the study to assess the variables and select the main variables for convergent validity and reliability. The confirmatory factor analysis (CFA) was subsequently used to confirm the factor structure derived from the EFA. This methodology will deal with not only linear combinations that are similar to multiple regressions, but also the model fit of a variety of endogenous variables, exogenous variables, and latent structures in the test model at the same time.

4 Results and Discussion

These results demonstrate that, because of their high position and realistic familiarity with higher Authority in the construction industry, these respondents are suitable for this review. The below graph (Fig. 1) describes the whole research questions that were asked at the time of the survey which are shown in the form of responses. Each question contains separate bars which are indicated by different types of legend which contain different colors. The legend contains numbers of responses got through the survey according to questions scores. The responses indicate which questions have more or fewer impacts on the research and graphs show which factors played more role in research.

The above respondent's responses are reduced to eight factors. There are eight questions from several domains that fall under the first category and another eight questions from several domains that fall under the second category. Table 1 gives the factor score for all the questions taken for study. The domains which are considered in

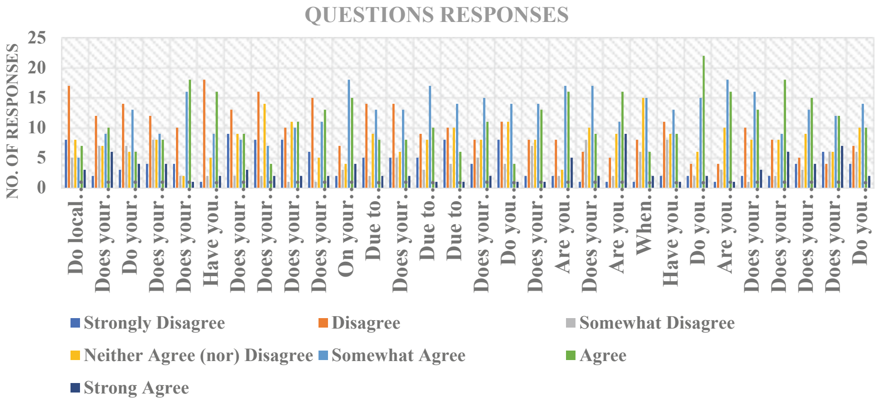

Fig. 1 Graphical representation of questions responses

Table 1 Total variance explained

Total variance						
Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	*% of variance*	Cumulative %	Total	*% of Variance*	Cumulative %
1	4.898	16.327	16.327	4.898	16.327	16.327
2	4.392	14.639	30.966	4.392	14.639	30.966
3	2.926	9.752	40.718	2.926	9.752	40.718
4	2.136	7.121	47.839	2.136	7.121	47.839
5	1.947	6.491	54.331	1.947	6.491	54.331
6	1.550	5.165	59.496	1.550	5.165	59.496
7	1.475	4.918	64.414	1.475	4.918	64.414
8	1.433	4.778	69.192	1.433	4.778	69.192
9	1.083	3.609	72.800	1.083	3.609	72.800

the study are cultural difference, gender difference, language barrier, physical barrier, listening barrier, and lack of motivation. To study the effects of communication problem for the higher authority of construction, the following domains play a major role in our study. Almost 40% of the study can be easily predicted through the first three factors. The total variance is given in above (Table 1).

The data collected is analyzed by the factor analyze method with 30 components and eight parameters. The values obtained from data analysis are shown in the form of Table 1. The table contains 30 components and its eight parameters which are used in the survey. The parameters show the largest component score of the individual question shown in the graph. All 30 components are divided equally into eight parameters by score obtained in the survey. According to that, total variance table and scree plot graph are formed which are shown in above figure. In the total variance table, the component column is the combination of all 30 questions in the form of eight parameters. Eight questions fall under the first parameter which has a 4.898 total value and 16.327% cumulative percentage. In the same way, it goes up to eight parameters which have a 1.433 total value and 69.192% cumulative percentage. The other one is nine parameters and it doesn't contain a high value and it's also reflected on the graph which shows less importance in the study. The scree plot is a graph that shows the eigenvalues concerning all of the variables. The graph can be implemented to determine how many variables can be used according to their values. Where the curve begins to flatten is the point of concern. The component number on the x-axis shows the 30 questions and the eigenvalue on the y-axis shows the value of total variance from 0 to 5. In graph, component one having a 4.898 value has 16.327%. Component 2 having a 4.392 total value has 30.966% cumulative. The graph goes in this sequence up to eight parameters which contain 69% of total information from 1 to 8 parameters and the remaining from 9 to 30 components contain 31% of the information because from 9 to 30 questions graph goes in the same line which shows the less impact on research (Fig. 2).

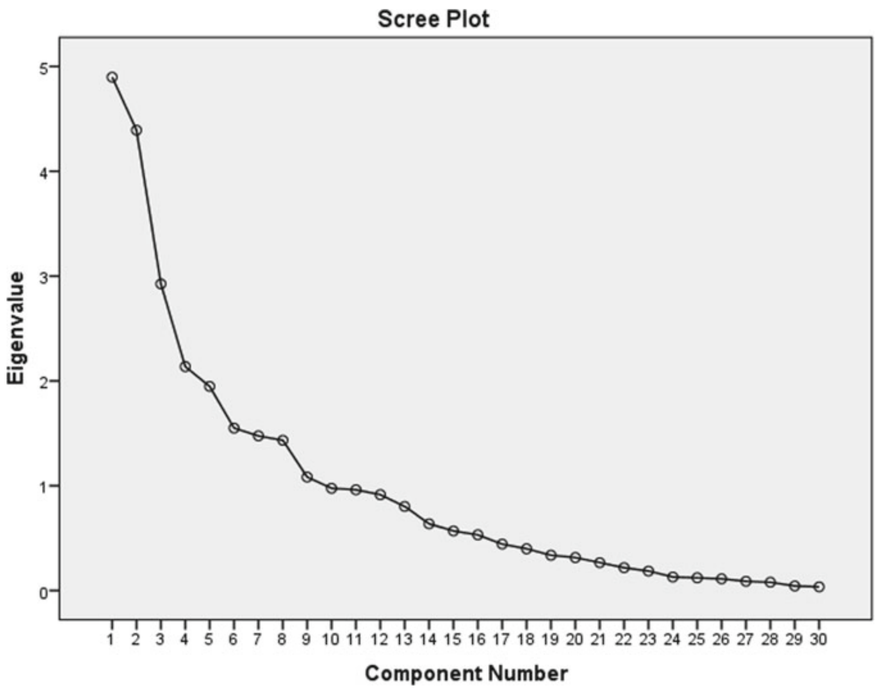

Fig. 2 Scree plot graph from Q1 to Q30

5 Conclusion

This study investigated the communication problem for higher authority in the construction industry. It is focused on the problem in the project delivered by the higher authority of construction companies. So that totally eight parameters and 30 different questions have been surveyed in existing companies to find out the problem of communication. After detailed analysis, the factors considered are analyzed through the factor analysis method. In this method, it is revealed that informal communications continue to be highly important in ensuring the efficiency of the construction manager. The 69% of cumulative represented in eight parameters consist of important questions that played a vital role in research and 31% containing remaining questions which have fewer impact on research work. There is almost 40% of the study which can be easily predicted through the first three factors with the variance of 16.327, 14.639, and 9.752% and the remaining five factors containing the variance of 7.121, 6.491, 5.165, 4.918, 4.778, and 3.609%. The cultural differences, gender differences, and language barriers followed by physical barriers, listening problems, lack of motivation, emotional and verbal communication play major roles in survey companies. So, it should be focused on these parameters for effective communication.

References

1. Shohet, I. M., & Frydman, S. (2003). Communication patterns in construction at construction manager level. ASCE, pp. 0733–9364.
2. Manata, B., Miller, V., Mollaoglu, S., & Garcia, A. J., (2018). Measuring key communication behaviors in integrated project delivery teams. ASCE, pp. 1943–5479.
3. Loosemore, M., & Lee, P. (2002). Communication problems with ethnic minorities in the construction industry. *International Journal of Project Management*, *20*, 517–524.
4. Mitkusa, S., & Mitkusa, T. (2014). Causes of conflicts in a construction industry: a communicational approach. Elsevier, 110, pp. 777–786.
5. Zulch, B. G. (2014). Communication: The foundation of project management. Elsevier, 16, pp. 1000–1009.
6. Olanrewaju, A. L., Tan, S. Y., & Kwan, L. F. (2017). Roles of communication on performance of the construction sector. Elsevier, 196, pp. 763–770.
7. Woo, C., Kim, M. G., Chung, Y., & Rho, J. J. (2015). Suppliers' communication capability and external green integration for green and financial performance in Korean construction industry. Elsevier, pp. 1–11.
8. Lee, N., & Kim, Y. (2018). A conceptual framework for effective communication in construction management: information processing and visual communication. ASCE.
9. Mohamed, S., & Stewart, R. A. (2003). An empirical investigation of users' perceptions of web-based communication on a construction project. Elsevier, 12, pp. 43–53.
10. Marshall-Ponting, A. J., & Aouad, G. (2005). An nD modeling approach to improve communication processes for construction. Elsevier, 14, pp. 311–321.
11. Baika., & Goncu. (2018). Construction and presentation of communication consultancy expertise: Turkish perspective. Elsevier, pp. 0363–8111.

12. Huang, Y. H., Sinclair, R. R., Lee, J., McFadden, A. C., Cheung, J. H., & Murphy, L. A. (2018). Does talking the talk matter? Effects of supervisor safety communication and safety climate on long-haul truckers' safety performance. Elsevier, 117, pp. 357–367.
13. El-Saboni, M., Aouad, G., & Sabouni, A. (2009). Electronic communication systems effects on the success of construction projects in United Arab Emirates. Elsevier, 23, pp. 130–138.
14. Kaskutas, V., Dale, A. M., Lipscomb, H., & Evanoff, B. (2013). Fall prevention and safety communication training for foremen: Report of a pilot project designed to improve residential construction safety. Elsevier, 44, pp. 111–118.
15. Maier, A. M., Eckert, C. M., Clarkson, P. J., (2006). Identifying requirements for communication support: A maturity grid-inspired approach. Elsevier, pp. 0957–4174.
16. Pauksztat, B (2019). Informal relations and communication about work-related problems in two multilingual crews. Elsevier, pp. 0308–597.
17. Zulch, B. (2014). Leadership communication in project management. *Elsevier, 119*, 172–181.
18. Boholm, A. (2019). Lessons of success and failure: Practicing risk communication at government agencies. *Elsevier, 118*, 158–167.
19. Ochieng, E. G., & Price, A. D. F. (2010). Managing cross-cultural communication in multicultural construction project teams: The case of Kenya and UK. *Elsevier, 28*, 449–460.
20. Butt, A., Naaranoja, M., Savolainen, J. (2016). Project change stakeholder communication. Elsevier, 34, pp. 1579–1595.
21. Reza Hosseini, M., Banihashemi, S., Rameezdeen, R., Golizadeh, H., Arashpour, M., Ma, L. (2017). Sustainability by information and communication technology: A paradigm shift for construction projects in Iran. Elsevier, 168, pp. 1–13.
22. Ellis, N., Hopkinson, G. (2010). The construction of managerial knowledge in business networks: Managers' theories about communication. Elsevier, 39, pp. 413–424.
23. Kagan, P. (2016) The engineering communication networks–the issues of use of standards for the information representation in design, construction and operation. Elsevier, 153, pp. 261–265.

Influence of Intellectual Behaviour of Labour in Construction Industry

J. Rajprasad, Ummadisettisaisravan, N. Pannirselvam, and S. Manivel

Abstract The construction industry and its business have a significant part in the country's economy and development. It is considered as the most testing, serious, open, and risky workspace. As this study relies upon the intellectual behaviour of labour in the construction industry, the recognised and focused parameters are personal stress, occupational stress, personal temperament, emotional disturbances, habits, working environment, and climatic conditions. This assessment revolves around the intellectual behaviour of labour when they are influenced by stress and pressure. The survey technique embraced in this investigation depending upon the referenced parameters and information got through the poll and is examined by SPSS software. This assessment makes recommendations to restrict the stress of labour and the pressure of works and along this fabricates the construction work profitability (construction productivity). The results reveal that routine issues, stress, helpless correspondence, between private issues within the company, fixed time spans, wage issues, absence of occupation information, work movements, work burdens, and absence of inspiration and motivation are the dominant factors, which causes stress in labour. The stress and pressure also vary according to age. The necessary recommendations are plotted in order to limit the stress in labour according to the factors considered through which fruitful health of labour can be maintained and, thus, helps in construction work profitability.

Keywords Construction work profitability · Intellectual behaviour · Inter-personal conflicts · Stress and pressure

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1 Introduction

The construction industry is the second biggest industry in India after agriculture. It represents about 11% of India's GDP. It makes a critical commitment to the public economy and improvement and gives work to an enormous number of individuals. The construction process requires a lot of physical activities that cause a lot of stress to the labour. Managing stress plays a vital role in the construction industry in order to increase job satisfaction and performance [1]. If the employee has carried away with stress, it can result to aggressiveness, delay in project completion, failure in safety, low job satisfaction and many more [2–4]. The stress may be physical, emotional (or) any other type with respect to the person.

Occupation stress alludes to an augmentation of general pressure: the idea of occupation stress is unique about general pressure, in that, work pressure is explicitly a consequence of work settings [5–7]. In work settings, different components can cause pressure, for example, the work task, the work environment, the work qualities, job strife, or specialist abilities [8]. Occupation stress undermines the well-being of the specialists and harms their work execution. Nonetheless, through poll studies, labourers can recognise their work pressure partly by abstractly depicting and rating the pressing factor. Studies have shown that delayed, significant level occupation stress can cause mental pressure, bringing about abnormal working stances and, therefore, hazardous conduct. The work pressure of bleeding-edge development labourers is remarkably high because of the great intricacy of their undertakings, a considerable lot of which are led in a brutal and dynamic climate [3]. However, this exploration is to build up a more extensive and more profound viewpoint of the elements affecting the profitability and give direction to projects and development managers for proficient use of the labour, hence, helping with accomplishing a healthy degree of efficiency and seriousness [9, 10].

2 Literature Background

In this part, the literature study is done to investigate the factors influencing the work pressure of construction labour and their intellectual behaviour when influenced by stress and to empower the improvement of a suitable occupation stress estimation survey. The related works in the application of occupational stress, scholarly work behaviour, and the examination of the relationship between work pressure and work profitability. The point of this examination is to recognise factors influencing work efficiency and to rank the factors as indicated by their overall significance and analyse them using SPSS software.

2.1 Personal and Habitual

The personal life of the construction labour has a significant impact on his work productivity. Labour with family problems, lack of personal peace and no job support or no moral support from his family members cannot concentrate while at work, which has a negative impact on productivity. As well as the day-to-day habitual nature of the labour also has the same impact on work productivity.

2.2 Workload

The workload is the measure of work an individual needs to do. There is a qualification between the real measure of work and the person's perception of the workload. For instance, an individual may feel under tension if the requests of their work (like hours or responsibilities) are more prominent than they can easily oversee. Different wellsprings of business-related pressure incorporate clash with colleagues or managers, consistent change, and dangers to employer stability, like expected repetition.

2.3 Low Wages

The wage criteria and its payments influence the labour towards their work. If they are paid low wages, it does not influence them more towards work and if they are paid with different wage criteria among themselves, then there arrive the conflicts and decrease in productivity and mental stress in the labour.

2.4 Lack of Motivation

It plays a major role in encouraging the labour towards the work and its productivity. Motivation by the organisation can be in any way either in the form of encouraging speeches or increase in wages or by providing any special allowances.

2.5 Lack of Training and Experience

Lack of training can lead to more frustration, wasted time, and unhappy employees and having employees who feel as though they are not developing and are becoming frustrated with their work. Inadequately trained employees are likely to experience poor job performance and increased levels of work-related stress [11, 12].

2.6 Poor Communication

Labour faces many problems in communicating with the workers, with the site engineers and managers and also with the higher authorities of the organisation, because of the fear of communication and lack of job knowledge and other various reasons. So, these all factors also a major role in increasing the stress levels in labour, resulting in a decrease in productivity.

2.7 Relation Between Stress and Labour Productivity

An increase in stress levels leads to reduced productivity and increased satisfaction leads to increased productivity. While the labour is performing work in the field, they begin their mind to overlap with the personal life, which gives a negative impact and affects the construction productivity. Quality work is based on conscientiousness and enthusiasm of labour in the workplace. Many of the labour cannot control their stress and anxiety and causes biggest threats to construction productivity and which affects the company in the end. The labour cannot maintain their presence of mind and body mentally if they are subjected to stress. Nevertheless, physically they may be present at the workplace but mentally they cannot follow or listen to the instructions and orders given to them. So, this not only causes effect on construction productivity but also conflicts among the labour and the administration also and, thus, creates an unsafe and conflicts influenced environment. Workload, work shifts, poor communication, wage differences, lack of training and motivation are termed as major parameters of stress, which also increases the aggressive nature of labour and, hence, the above-stated situations may occur causing the decrease in productivity and delay of projects and conflicts, etc.

3 Methodology

Through the literature review, the study on stress and its major parameters influencing the stress of construction labour is done and the parameters considered are workload, work shifts, poor communication, wage differences, lack of training and motivation [13, 14]. The design of the personal and job stress questions is plotted [15]. Further, the survey on the labour is done to verify the questionnaire prepared with considered parameters. The information on the pressure of the construction labourers was acquired through the questionnaire survey [16]. Finally, the obtained questionnaire data are analysed in SPSS software. The results and discussions are plotted and the methodology followed is presented in Fig. 1.

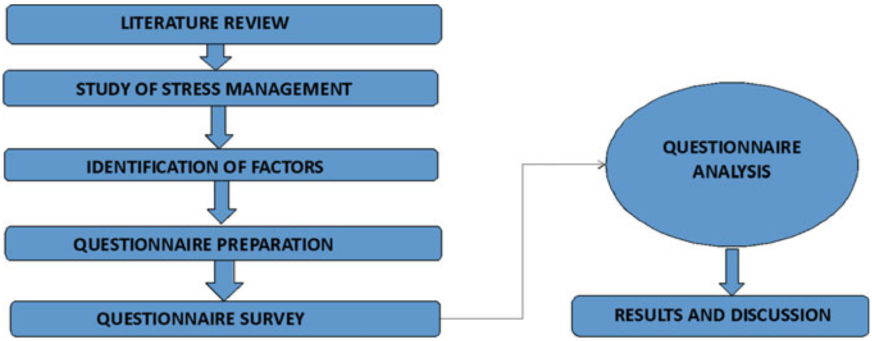

Fig. 1 Methodology

4 Data Collection

The collection of questionnaire data is done in Vijayawada city located in Andhra Pradesh, India. The data are obtained from the companies performing all types of construction and infrastructure works in Vijayawada and its premises. As this study is mainly focused on the labour and their intellectual behaviour when influenced by stress, so the questionnaire survey on labour is done with a total of 100 responses, which were designed according to the parameters influencing the intellectual behaviour of labour. The questions made were closed-end questions, so the labours have to answer it surely. There was a division of seven options for each question and labours were made to answer by choosing those options. Each option is ranked accordingly and used for further analysis.

4.1 Data Analysis

The obtained data through a questionnaire survey is interpreted in the excel sheet as an individual response and also in summary form. The questionnaire data are analysed using excel and recorded responses are represented with the help of pie bar charts. After that, the factor analysis is done in SPSS software. Exploratory factor analysis was performed to evaluate the variables and to pick the main variables for convergent validity and reliability. The confirmatory factor analysis was subsequently used to confirm the factor structure derived from the exploratory factor analysis.

5 Results and Discussion

The questionnaire survey results are projected in the form of graphical representation by analysing them in the excel software according to responses given by the labour. The graphical representation of each parameter considered is plotted accordingly. The bar chart method is used to plot the results with its legend declaration with its individual colour accordingly (Fig. 2). The responses comply with the major factors causing the stress in labour and the results plotted graphically show which parameters have a huge and tiny impact on labour stress and their intellectual behaviour (Fig. 3).

The domains we considered in our study are personal and habitual, workload, wages, lack of job knowledge, communication and lack of motivation. To study the intellectual behaviour of labour when influenced by stress, the above-mentioned domains play a major role in our study. Almost 50% of the study can be easily predicted through the first three factors. The total variance is given in Table 1.

In this study, the parameter-wise stress questionnaire of the construction labour was developed, and the responses recorded were analysed accordingly and plotted the graph for the six factors, i.e., personal and habitual, workload, wage differences, communication and language barriers and motivation as shown in Fig. 1. Through the factor analysis, personal and habitual, workload and working hours, wage differences have a major impact on labour stress levels and their intellectual behaviour. The reason behind this may be that the construction workers keep all their effort to finish the jobs when the projects have tight schedules, high intensity, and heavy tasks [7, 17, 18]. The labour who has personal and family-related issues get influenced by stress when assigned work and cannot focus on the work totally and results in a

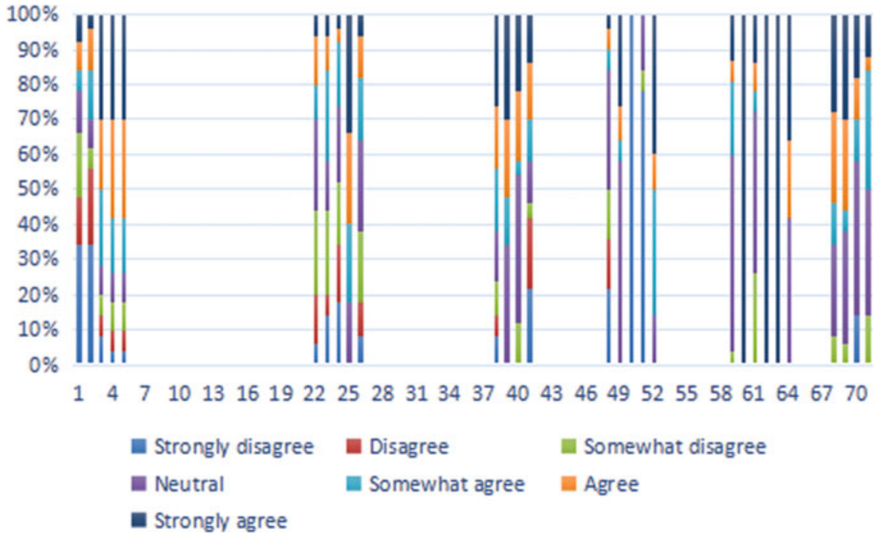

Fig. 2 Graphical representation of questionnaire analysis

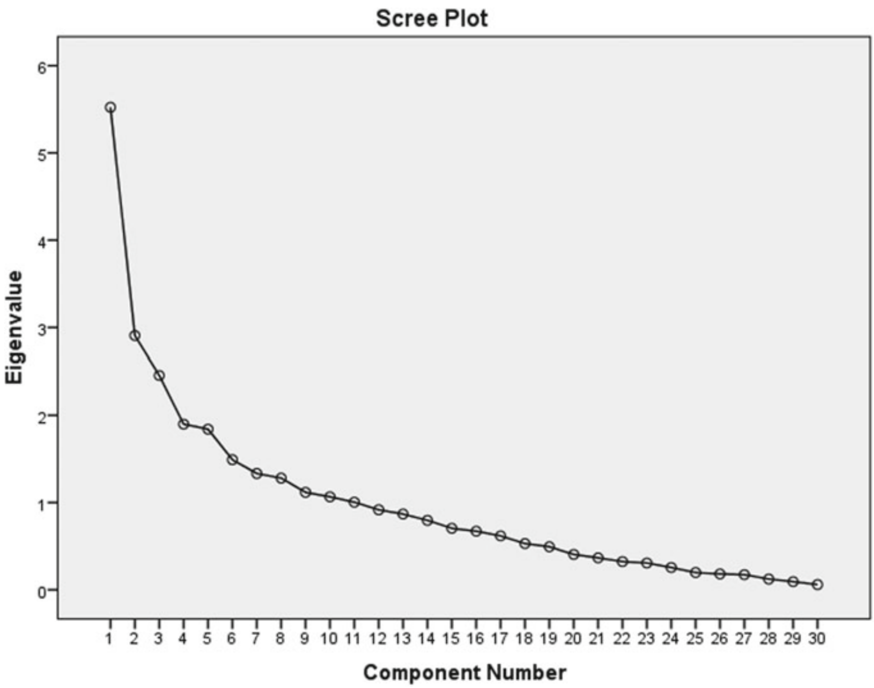

Fig. 3 Plot graph for 1–30 questions

Table 1 Total variance explained

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.523	18.411	18.411	5.523	18.411	18.411
2	2.907	9.691	28.102	2.907	9.691	28.102
3	2.456	8.187	36.289	2.456	8.187	36.289
4	1.898	6.328	42.617	1.898	6.328	42.617
5	1.841	6.136	48.753	1.841	6.136	48.753
6	1.491	4.969	53.722	1.491	4.969	53.722
7	1.333	4.444	58.166	1.333	4.444	58.166
8	1.280	4.267	62.433	1.280	4.267	62.433
9	1.117	3.723	66.157	1.117	3.723	66.157
10	1.066	3.553	69.709	1.066	3.553	69.709
11	1.004	3.347	73.056	1.004	3.347	73.056

decrease in productivity. If the labour was assigned with a task, which is more than his perceptional workload, then labours get influenced by stress, and their behaviour and dedication towards work vary. For certain labourers, they do not get sufficient time for rest, simultaneously, they are more averse to give positive efficiency [19]. Lack of job knowledge, communication and language barriers and motivation were second lowest negatively related to intellectual behaviour of labour and construction productivity. This indicates that they have the second most significant negative impact on stress and intellectual behaviour of construction labour.

At long last, the speculation of the current outcomes actually should be mindful, as the sample is especially from Vijayawada of Andhra Pradesh, India and further collected from all sorts of construction and infrastructure companies. Hence, its application varies from the labour of state to state who belong to different construction companies.

6 Conclusion

(1) Construction workers usually work in a complex physical environment. This straightforwardly impacts their feelings of anxiety and intellectual behaviour. This study was conducted to identify the intellectual behaviour of labour when influenced by stress with the help of a questionnaire method structured on the identified parameters.

(2) The majority of the labours were suffering due to the workload and immense pressure from higher authorities and do not even speak up for some work shifts and work intervals in the fear of losing job and get influenced by stress and, hence, results in a change in their behaviour.

(3) The labours are working in a helpless workplace without appropriate shelter and helpless food. Most of the labours are working 10–12 h a day but earn a low wage. There are some problems noticed among themselves, where the experienced and some favoured labours are paid higher wages than the others. This is a major reason for the stress increase in labour and also leads to conflicts among themselves and with the organisation. So, this region should be perfectly balanced by the companies.

(4) This examination contributes to the current stress-management research by creating the design of a poll on labour work pressure, including personal and constant nature, workloads, family–work strife, wage contrasts, hierarchical style of inspiration, relational relationship.

(5) The examination shows that the created work pressure can uphold the investigation on the connection between work pressure and construction productivity. The personal, job-related stress, workload, wage differences contrarily affect the conduct of development labourers. Hierarchical style of inspiration, relational relationship, communication and language barriers, and family–work

strife are second most considered factors, which have a relatively high impact on labour and get influenced by stress and, thus, the productivity rate decreases and the organisational goals cannot be achieved in a timely basis and results in loss of a company.

References

1. Al Rasheed, F., Naqvi, A.A., Ahmad, R. (2017). Academic stress and prevalence of stress related self-medication among undergraduate female students of health and non-health cluster colleges of a public sector University in Dammam, Saudi Arabia. *J Pharm Bioall Sci, 9*, 251.
2. Choi, H. J., Kwon, H. G. (2008). The stress influences on the job attitudes toward the employees of construction industries. *Korean Journal of Business administration, 21*(4), 1723–1749.
3. Chen, Y., McCabe, B., & Hyatt, D. (2017). Impact of individual resilience and safety climate on safety performance and psychological stress of construction workers: A case study of the Ontario construction industry. *Journal of safety research, 61*, 167–176.
4. Thomas Ng, S., Martin Skitmore, R., Leung, T. K. C. (2005). Manageability of stress among construction project participants. *Engineering Construction and Architectural Management, 12*(13), 264–282.
5. Tiwary, G. et al. (2013). Psychosocial stress of the building construction workers, human biology. Journal, 207–222.
6. Ashford, S. J. (1988). Individual strategies for coping with stress during organizational transitions. *Journal of Applied Behavioural Science, 24*, 19–36.
7. Tiwary, G. (2013). Psychological stress of the building construction workers. Human Biology Journal, 207–222.
8. Beehr, T. A., Newman J. E., (1978). Job stress, employee health and organizational effectiveness: A facet analysis, model, and literature review. *Personnel Psychology, 31*(4), 665–699.
9. Haynes, N. S., Love, P. E. D. (2004). Psychological adjustment and coping among construction project managers. *Construction Management and Economics, 22*(129–140), 9.
10. Jeong, T. H. (2009). The study of an analysis on job stress of affecting safety and management performance for workers in the construction industry, [dissertation]. [Gwangju (Korea)]: Chosun University, 111.
11. Yao, Y.-H., Fan, Y.-Y., Guo, Y.-X., Li, Y. (2016). Leadership, work stress and employee behaviour. *Chinese Management Studies, 8*(1), 109–126.
12. Chan, Y. S., Leung, M. Y., & Chong A. M. L. (2010) Chinese values and stressors of construction professionals in Hong Kong. American Society of Civil Engineers, 136(12).
13. Williams S, Cooper C. L. (1997) Occupational stress indicator. Scarecrow Education: Lanham, MD, USA, pp. 251–276
14. Sidman, J. (2005). Doctor's order: How to identify and relieve stress-related illnesses. *Business West, 22*(11), 412.
15. Leung, M. Y., Chan, Y. S. I., & Dongyu, C. (2011). Structural linear relationships between job stress, burnout, physiological stress and performance of construction project managers. *Engineering Construction and Architectural Management*, 18(3), 312–328.
16. Ilies, R., Wilson, K. S., Wagner, D. T. (2009). The spillover of daily job satisfaction onto employees' family lives: The facilitating role of work-family integration. *Academy of Management Journal, 52*, 87–102.
17. Wu, X., et al. (2018). Development of construction workers job stress scale to study and the relationship between job stress and safety behavior: An empirical study in Beijing. *International journal of environmental research and public health, 15*(11), 2409.

18. Priyanka, K., Anandakumar, S., & Krishnamoorthy, V. (2017) Antecedents of migrated construction workers stress–an Indian perspective. *International Research Journal of Engineering and Technology* 4.2, 63–66.
19. Avey, J. B., Reichard, R. J., Luthans, F., & Mhatre, K. H. (2011). Meta-analysis of the impact of positive psychological capital on employee attitudes, behaviors, and performance. *Human Resource Development Quarterly, 22*(2), 127–152.

Impact of Risk Assessment in Project Execution and Its Mitigation Strategies Using Modern Automation

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Abstract India's construction industry grew by 5.6% in 2016–20, compared to 2.9% in 2011–2015. In the year 2017, of the 762 construction projects in India tracked by the Ministry of Statistics and Program Implementation, Government of India, a total of 215 projects have been delayed over a period of 1 to 261 months that surge estimated project cost. The various reasons for delay include practicing conventional planning strategies and execution. Indian construction industries, therefore, need smart tools to overcome any such challenges in the future. Building Information Modeling (BIM) is a smart 3D model-based process that provides insight and tools to architecture, engineering, and construction experts to design and build infrastructure more effectively. A case study on BIM vs manual cost estimation showed that quantities calculated by BIM/Revit Software are more accurate than manual. The earlier studies estimated that implementation of BIM reduces project costs by 20%. It will help improve the quality of work with proper planning and adhering to the project cost and duration. The study recommends that construction industry in India should adopt BIM/Revit tools to minimize delay in the projects to become cost-efficient in project completion.

Keywords BIM · Project delay · Cost reduction

1 Introduction

Indian Construction Industry contributes to the enormous scope of development in the country. However, major infrastructure projects get delayed, which not only leads to the increased cost of the project but the services received are also delayed. In 2019, as per the record of 552 projects that had been delayed, in the range of

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1–12 months 187 projects have overall delay, 13–24 months a total 121 projects, surprisingly in the range of 25–60 months a total of 132 projects reflect the delay and 112 show delay of 61 months and above [1]. The main factor causing the time delay in project funding, lack of data collection and pre-design survey, which further increases to improper calculation of project costs and inadequate project preparation and implementation [2].

Timely completion of projects is an indicator of an efficient construction practice, but it is subject to a variety of resources and irrelevant features. These resources include group activities, availability of equipment, environmental conditions, participation of other parties and contractual relations. However, it is not uncommon for a project to be completed in a specific period of time. For an instance, the case of Bandra-Worli sea links the state of the project implementation system in the country. The project, which was to be completed in 2004 at a cost of Rs 300 crore, but actually the cost escalated to Rs. 1,600 crore and took five years to complete [3]. In fact, very few projects are completed within time and expense. Many factors can lead to delays in the project completion, therefore, there is a need of an alternative approach on how to avoid such situations.

Construction industries are, consisting of project work planning, time planning, evaluation, project progress, and monitoring of all project activities. Building associations such as infrastructure, energy and communications and related construction activities, water supply and disposal construction work, etc., are some of the construction activities of the construction industry. From administrative work (planning, operation, execution, monitoring), planning can be related to project completion time and related to time delays. If the length of the project (the actual duration of the actual work) is more than the detailed completion date in the contract document or more than the date the project owner and contractor agreed on the project transfer, and the expected duration is considered a delay [4]. This is when a project is out of date, and it requires additional construction costs and additional work time before a formal agreement can be reached in the contract document. For contract holders or project developers, the loss of large sums of money due to time-consuming work, higher construction costs due to inflation, increased labor costs. Often the delays in the construction industry are many times related to time management, quality and cost [5]. The construction project is recognized as successful when completed on time, within budget, according to the details and satisfaction of the clients. Delays increase workflow and late project completion leading to customer and client disagreements [6]. This can lead to disruption of project progress and loss of services, and increase costs associated with time, and ultimately, can lead to termination of the construction project and its contract. Hence the study highlights the importance of utilization of BIM so as to mitigate such risks.

2 Literature Review

Patil et al. [7] studied the possible causes of the delay in the questionnaire because they believed it was the best way to gather the necessary information. The questionnaire was designed and distributed to government clients who are responsible for community projects, businesses, entrepreneurs and their supervisors overseeing these activities. The list of research questions includes: Choice reasons for delays identified through literary review and consultation with other construction industry partners. It was clear that the consultant had little role to play in mediating construction delays.

Mali and Warudkar [8] states that construction delays as delivery later than the date of the contract or after the date when the parties involved agreed on the delivery of the project. In both cases, delays are often an expensive or time-consuming process. They did this by searching for literature on the causes of delays and secondly by marking critical issues among all nine categories by taking discussions of several sites and identifying the most sensitive items in the "Average Index" basis. The scope of the study includes large private houses and commercial buildings. Given this measure, a list of questionnaires was distributed periodically to 30 contractors representing different information and the performance of contractors working on a major project. In this way, the questionnaire provided the actual respondent. This communication method is for returning 23 completed contractor questions. Their research results showed that most of the delay factors are related to the contractor and the material. Many of the factors associated with the consultant are due to a lack of understanding of customer needs, lack of relevant project details, lack of specific details in the drawing, etc. It is assessed from the survey by the contractor that significant delays occur due to lack of jobs. Among other things due to the delays that occur are projected conditions such as site promotion, difficulties at work due to the weather.

Raut et al. [9] studied the types of contracts in construction projects; In their study, they did this by collecting reviews, reviewing surveys, finally identifying component collections and analyzing data obtained from their projects. According to their research, many factors affect the timing of project completion and its impact can have a significant impact on projects that affect the structure of projects. These include contractor delays, communication delays, project management, compensation issues, structural changes, weather effects, and labor strikes. The consequences of these delays are lower costs, more time, conflict and negative social consequences. The results of this article will help participants consider the root causes and reduce project delays.

Bagrecha and Bais [10] indicated in their study that there are many ways to complete the project on time at the current site, but they said that delays are inevitable and will ultimately affect the effectiveness of the project. Much research can be done to reduce the negative impact of operational delays and project delays. However, many projects are delayed in planning and a lot of money is lost. This has a significant impact on cost savings.

Laskar and Murty [11] stated that as the quality of construction projects increases, so do the challenges associated with new materials, equipment and technology, so Indian industry faces different challenges depending on its nature and practice—be it housing, environment, transportation, electricity or environmental. There are dangers technocrats associated with the Indian construction industry need to use new technologies and project management techniques to meet these challenges. It will perform well under the conditions required in the past and give hope to the Indian construction industry to achieve full growth in the country's infrastructure facilities and infrastructure development. Significant investments in mega projects in response to the construction industry have gradually resulted in better economy and working conditions.

2.1 Learnings from the Literature Review

As per the studies carried earlier, it is evident that due to the increased nature and scale of construction projects in India, the firms still are not advancing its methods for execution and management; compared to earlier projects. The projects today are on a much larger scale, but the construction firm lacks properly skilled laborers, though they are implementing new technologies in their work. The reasons for delay on-site are due to improper management of the work poor and incompleteness of designs and change of designs and plans by the client mid-work.

However, this could avoid if we could have a complete simulation of the project in BIM where now only 3D visualization takes place, but also the firms could deal with a problem such as clash coordination, rework.

3 Methodology

According to earlier studies in the design phase where design defects occur, due to the use of standard project design methods, can be solved with BIM use [12]. Most people are unaware of BIM and just imagine the technology or 3D figure-created preconstruction. However, BIM is more than just a 3D figure, a model with a digital definition that speaks to a visual project [13].

The basic idea is that BIM is a process that assists project management and initiates communication between multiple departments within a single operational site. Overall, this tool has proven effective in large and small construction projects and has yielded significant results. By using BIM, both parties have full access to the main model. They can not only evaluate the model but can also comment and request improvement from the start. This progresses to the decision-making process, keeps it organized, simple but timely, and provides the opportunity for positive growth for the project manager as the project progresses. According to research and the findings of NITI Aayog which means that BIM has the potential to reduce project costs by 20%, but it will depend entirely on the philanthropic project as the initial cost of purchasing and training professionals to use BIM tools requires money but in the long run, the removal of the documentation and the shortcomings of the error reduce the duration of the project, which reduces the cost of the project to what it would otherwise call for a standard construction process [14].

BIM presents many opportunities and benefits in the construction industry. Basically, it combines all the information about a building in one place, enabling anyone to access that information for any purpose. This makes it easy to integrate the various design elements effectively.

In this research, study comparison was carried out by taking real case of two-storey residential building and detailed analysis with respect to quantity estimation and cost estimation was also carried out and the 3D model output was also interpreted with respect to conventional and sustainable way (Considering building material with less carbon emission and also selecting building components and materials precisely and accurately.

3.1 Latest Tools in BIM

While 3D modeling is part of BIM, and importantly, it is not just a place for previous types of 3D modeling like AutoCAD. Complete BIM includes maintenance data, project planning, cost details.

The benefits of BIM can be seen in any size of the project, but it also has a big impact when you work with large construction projects, where you will be able to benefit the most from conflict, cost tracking, planning and so on.

BIM itself works with BIM materials—components that can be added to the 3D models in question, such as plumbing, electrical appliances, doors, windows and other building materials that can transform the final building effect.

The most notable trend so far in the BIM industry is the effort to integrate and create goals. To date, there are still many different definitions from various BIM companies to say that the industry is standardized, but there is still progress that can be seen every year.

3.2 Major BIM Tools Used in Construction Industry

3.2.1 Revit

Revit is a well-known BIM software that aims to solve various engineering and design issues. Developed by Autodesk, it is one of the most popular solutions in the industry. Many different professionals can make good use of the Revit feature list, including builders, designers, MEP engineers (mechanical, electrical and plumbing), contractors, and more. The software itself provides an intelligent approach to the various stages of the construction process with models [15].

3.2.2 Naviswork

Navisworks is not a 3D modeling system but a program that converts large REVIT 3D files into small 3D models that are highly controlled by most team members. It provides an effective tool for reviewing and resolving differences between multiple viewer models. Navisworks is a powerful application that can filter and segment-specific model details. It will not be a REVIT replacement program but a tool that works in partnership with REVIT and makes certain processes more efficient [16].

3.2.3 Tekla

Tekla is a BIM software used to build steel and concrete structures. Includes 3D modeling features for developers. In the construction industry, it is used for metal fabrication and detailed concrete construction. It directs building engineers from a visionless use of steel and concrete structures. It automizes the process of creating store drawings. With the use of Tekla, one can build any structure regardless of equipment and size (www.tekla.com).

1. Identify conflicts early in the naming process and avoid prematurity.
2. Get accurate drawings and reports from the model.
3. Simplify workflow by authorized standards.

4 Results and Discussion

BIM is a new way to look at the construction industry. The major problem in construction industry, is improper planning and design involving different levels of participation. This can be managed through BIM. Based on the data collected from a two-storey residential building. Estimation and planning were carried out using the traditional method and modified method using 3D BIM modeling. Based on the analyses using the BIM software and traditional method following results are drawn, the calculation of quantities of materials required for the construction of building using traditional method is a time-consuming process. Moreover, the cost of the building using the traditional method of construction is 20–25% higher as per the calculations. And also, the amount of CO_2 emitted from the traditional building is much higher compared to the sustainable buildings. Also, the dead weight of the traditional building is more compared to the sustainable building as the size of the structure components increases due to use of conventional materials. The use of BIM technique reduced the time consumption during planning process and also to visualize the end product and its output as represented in (Figs. 1 and 2). Based on the visualization output as represented figures. It can be inferred that by adopting BIM modeling technique it is possible to save the material quantity, material wastage and also optimum selection of material for different building components as represented in (Figs. 1 and 2).

By adopting modern tools like BIM it is possible to achieve sustainability and also material conservation and effective and precise material selection also possible and the detailed benefits of the BIM are highlighted in the following paragraph and represented in (Figs. 1 and 2).

Fig. 1 3D model BIM output for conventional/traditional model

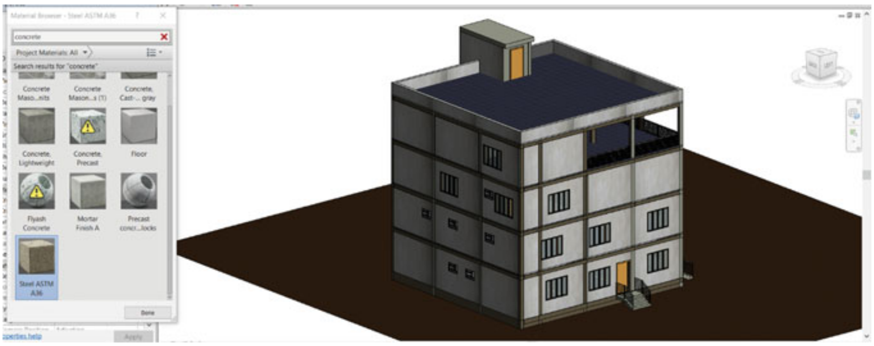


Fig. 2 3D model BIM output for sustainable model

4.1 Project Development and Partner Control

BIM improves communications between the manufacturers, customers, contractors and other relevant parties involved in this project. Because BIM works on a "single source" system; This means sharing and storing all relevant information in one place, including models, dimensions and design specifications. Everyone involved in the project has access to it, so they can offer their own advice.

4.2 Improved Productivity (Less Change, Instability, Change)

The sooner construction is complete, the less money it will cost. Also, complete the project on time or speed up the return on investment because clients can use the space much faster. With BIM, building construction is faster, and construction starts earlier. Improved workflow and other capabilities will speed up the project.

4.3 Excellent Project Quality and Performance

BIM makes statistics and its models detailed and accurate, which results in higher quality construction. In addition, the BIM process involves several viewing tools, making the structure more aesthetic.

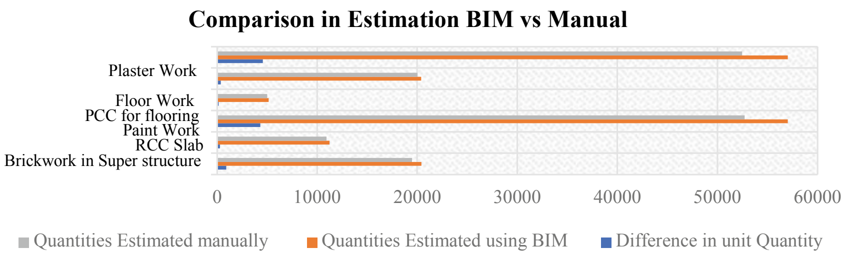
4.4 Accurate Estimation (Leading to Easy Procurement)

An important advantage of BIM is that it provides a reliable construction cost estimate long before the construction phase begins. A cost comparison of a building project is shown in (Fig. 3) below.

The main purpose of the cost estimation is to find the accurate value of the project before construction. Quantities calculated by BIM/Revit Software are more accurate than manual, what generally happens in underestimation of quantities is order and purchase is made accordingly and when during the construction process the material is, in short, a new purchase has to be made and now at a different cost which is generally higher when order smaller quantities and transportation cost to be paid extra in some cases, this also contributes to delays, and increased price.

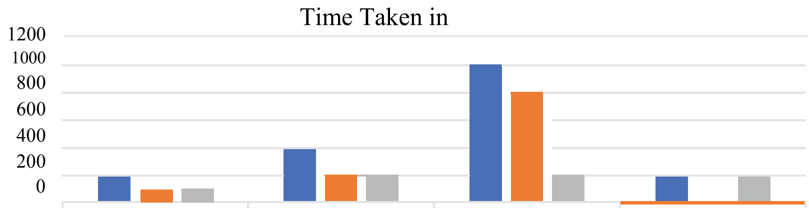
BIM can be used throughout its entire life cycle, i.e., planning, design phase, construction phase, and operation phase [18]. During this cycle, BIM can be used in different areas. This list includes current situation modeling, budgeting, depreciation, scheduling, and site analysis (Fig. 4).

The BIM implementation process can be divided into two main categories. The first step is the launching phase. The second phase is the postoperative phase. These



	Brick Work in Super Structure	RCC Slab	Plaster Work	PCC for Flooring	Floor Tile Work	Paint Work
Quantities Estimated manually	19475	10947	52702	5001.25	20005	52447
Quantities Estimated using BIM	20408	11240	57025	5170	20386	57025
Difference in unit Quantity	933	293	4323	168.75	381	4578

Fig. 3 Cost comparison of a building project [17]



	Schematic	Design development	Construction documents	Checking and coordination
CAD	190	436	1,023	175
BIM	90	220	815	16
Total Saving	100	216	208	159

Fig. 4 Comparison of efficiency of BIM and CAD in term of time taken [20]

two categories are connected and overlap. There may be more initial processes after the launching phase. In addition, the information collected during the previous implementation and during the subsequent implementation phase may be used as a guide for another organization or project. In the early stages of the experiment, BIM can be used to achieve various benefits in the life cycle. These benefits are very difficult to identify because they are often interrelated. This is usually the lowest cost on the entire life cycle of the project, the high quality of the construction project, functional design, construction and phased work. This leads to faster construction phases, better safety in the life cycle, less waste production, better risk management practices, fewer errors and higher productivity [19]. BIM platform interconnects data, all information in one place and crosslinks. There is no linkage between the data created by CAD. The efficiency of BIM in comparison to CAD is being referred to below [20].

5 Conclusion

The introduction of emerging technologies like BIMs and the usage of BIM software such as Revit, Naviswork and Tekla, etc., will enhance the project designs that would enable the manager on-site to better conduct site work and prevent rework. In India, large project delays are attributed to lack of proper on-site management and poor preparation due to traditional use of building practices. For the correct application of this technology, however, technical training among the employees is needed. The implementation of BIM will also shorten the time-frame for projects in the Indian construction industry, thus preventing costs overruns. Based on the analysis carried out with the help of a residential building it is evident by adopting modern tools will help to conserve the material 20 to 25% in terms of quantity and also it will help reducing the cost and time by way of effective planning in project execution. It is also evident from the study that modern tools are the future and it is mandatory to adopt and integrating modern tools like BIM for improving the efficiency of project.

References

1. The Economic Times (2019). 355 infra projects show cost overruns of Rs 3.88 lakh crore. https://economictimes.indiatimes.com/news/economy/infrastructure/355-infra-projects-show-cost-overruns-of-rs-3-88-lakhcrore/articleshow/71990885.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst (Retrieved May 01, 2021).
2. Tejale, D. S., Khandekar, S. D., & Patil, J. R. (2015). Analysis of construction project cost overrun by statistical method. *International Journal 3*(5), 349–355 (2015).
3. Singh, R. (2010). Delays and cost overruns in infrastructure projects: Extent, causes and remedies. *Economic and Political Weekly*, 43–54.
4. Al-Keim, A. (2017). Strategies to reduce cost overruns and schedule delays in construction projects.
5. Solís-Carcaño, R. G., Corona-Suárez, G. A., & García-Ibarra, A. J. (2015). The use of project time management processes and the schedule performance of construction projects in Mexico. *Journal of Construction Engineering, 2015*, 1–9.
6. Saeed, S. A., & Abdus. . (2009). *Delay to Projects-cause, effect and measures to reduce/eliminate delay by mitigation/acceleration.* British University in Dubai.
7. Patil, S. K., et al. (2013). Causes of delay in Indian transportation infrastructure projects. *International Journal of Research in Engineering and Technology, 2*(11), 71–80.
8. Mali, L., & Warudkar, A. (2016). Analysis on causes of delay in construction industry in Pune City. *International Journal of Innovative Research in Science, Engineering and Technology, 5*(8), 14509–14519.
9. Raut, S. P., et al. (2018). Causes of delays in construction projects. *International Journal of Engineering Science and Computing, 8*(11), 19275–19278.
10. Bagrecha, K., & Bais, A. (2017). Study on delay construction project in India. *International Journal of Innovations in Engineering Research and Technology, 4*(11), 6–10.
11. Laskar, A., & Murty, C. V. R. (2004). Challenges before construction industry in India. Department of Civil Engineering, Indian Institute of Technology, Kanpur (www.iityk.ac.in).
12. Aguiar, A., Vonk, R., & Kamp, F. (2019). BIM and circular design. *IOP Conference Series: Earth and Environmental Science*, *225*. No. 1. IOP Publishing.
13. Fazli, A., et al. (2014). Appraising effectiveness of Building Information Management (BIM) in project management. *Procedia Technology 16*, 1116–1125.

14. The Economic Times (2019). Government backs new tech to speed up infra work. https://economictimes.indiatimes.com/news/economy/infrastructure/government-backs-new-tech-to-speed-up-infra-work/articleshow/72989656.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst (Retrieved May 03, 2021).
15. Revizto. (2020). Top BIM Construction Software Tools in 2020. https://revizto.com/en/best-bim-software-tools-2020/#:~:text=separate%20list%20below.-,Revit,popular%20solutions%20in%20the%20industry (Retrieved May 07, 2021).
16. BRS. (2013). Top 10 Benefits of Autodesk Navisworks http://brsarch.com/blog/post/top-10-benefits-of-autodesk-navisworks#:~:text=Navisworks%20is%20not%20a%203D,a%20multitude%20of%20team%20members.&text=It%20will%20not%20be%20a,certain%20processes%20much%20more%20efficient (Retrieved May 10, 2021).
17. Haider, U, et al. (2020). Cost comparison of a building project by manual and BIM. *Civil Engineering Journal 6*(1), 34–49.
18. Akanbi, L. A., et al. (2018). Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator. *Resources, Conservation and Recycling 129*,175–186.
19. Tomek, A., & Matějka, P. (2014). The impact of BIM on risk management as an argument for its implementation in a construction company. *Procedia Engineering, 85*, 501–509.
20. Kumar, J. V., & Mukherjee, M. (2009). Scope of building information modeling (BIM) in India. *Journal of Engineering Science and Technology Review, 2*(1), 165–169.

An Exploratory Study to Utilize Construction 4.0 Technologies in Enhancing Communication to Get Quality Human Resources

Rabee Abo Fakher and K. S. Anandh

Abstract Construction 4.0 (C4.0) means applies industry 4.0 in the construction field by tending to digitalization and automation in the industry. The construction industry in its traditional form suffers from complexity and poor performance due to its fragmented and craft nature, however besides, with the continuing development of industry 4.0, it has become necessary for construction companies to adopt modern technologies and develop new management means to enhance the industry performance and meet the requirements of other industries and the increasing demand for residential and specialized buildings. This study aims to enhance communication in the construction industry by taking advantage of construction 4.0 to raise the construction industry's performance. A statistical survey was conducted to study the effect of the following factors (C4.0 awareness and acceptance level, C4.0 fragmented nature, communication, information sharing, C4.0 technologies, and digital training) on enhancing communication. The survey included construction specialists, ranging from site engineers to project managers distributed among construction companies working in different types of projects such as infrastructure projects and residential buildings, and it included six countries (India, Canada, Australia, Germany, Sweden, and the UAE) The collected data were analyzed using multiple regression measures. The study emphasizes the importance of communication and data sharing as a key element in increasing coordination and creating a collaborative environment that leads to raising the quality of human resources, thus raising the construction industry's performance; also, this study lays out a roadmap and recommendations for apply some important measures to the parameters mentioned above to enhance the communication.

Keywords Construction 4.0 · Communication · Information sharing · Collaboration and coordination · Quality human resources

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1 Introduction

Since 2015, the world has witnessed the start of the fourth industrial revolution. Industries adopted a fully digital approach to their everyday business; thereby, contributing to their productivity, accuracy, efficiency, and improved customer satisfaction [1]. This Industrial revolution is called industry 4.0 (I4.0). Its origin was in the German manufacturing sector [2]. It led to remarkable developments in all industries and the emergence of very modern technologies. All of this allowed the construction industry to take advantage of these modern technologies to begin applying the Industry 4.0 concepts in construction [1, 3], so the term construction 4.0 has been introduced, which means the digitalization and automation of the construction industry [4].

The construction industry went through the same stages of development as other industries [5, 6], where a transformation and changes took place in processes, practices, technologies, and capabilities during four stages, Construction 1.0, Construction 2.0, Construction 3.0, and now there are some leading construction companies like Bechtel and Skanska trying to move and apply the principles of Construction 4. 0. These stages of development can be defined as follows:

- Construction 1.0: There was not a much-specialized workforce, and the work was mostly manual based on worker,
- Construction 2.0: It began from the middle of the twentieth century when automation entered the construction sites through the invention of some equipment, and specializations such as (civil engineering, architecture, mechanical engineering, management, etc.) appeared and also some modern methods of management such as the principles of Lean appeared, but the industry remained characterized by low productivity and manual character, which mainly depends on the human workforce,
- Construction 3.0: It began in the late twentieth century, when various designs, structural analysis programs, and management software (such as CRM and Primavera) appeared, as well as new technologies such as BIM, the development of automation, and the adoption of new management principles such as Lean. However, the construction industry continued to favor its manual nature, slow production, and lag behind other industries,
- Construction 4.0: It started in the twenty-first century, especially in the past six or seven years, where there is a great tendency to rely heavily on automating and digitizing the construction industry [7–9].

Currently, the construction industry in most countries of the world, such as India, lags behind other industries despite its importance in providing the infrastructure for these industries and its economic importance in the country GDP, as it still tends to be of craft nature and also uses old paper means of communication and coordination [8, 9], these factors in addition to the site-based activities and fragmented nature of the industry tasks and disciplines, and the fear and reluctance of specialists to change, hinder the transition to the era of construction 4.0 [10].

From the foregoing, we conclude that the construction industry needs a collaborative environment in which information is handled and transmitted effectively then leads to a decrease in the cost and time of construction due to avoiding repetition of some tasks due to lack of coordination and avoiding many errors in the various stages of the project. Communication is of great importance in achieving a collaborative environment, and Construction 4.0, through its content of information technology and other technologies for capturing, transferring, and coordinating information, greatly enhances communication. This study lays out a roadmap to enhance communications by relying on the techniques and principles of Construction 4.0.

2 Construction 4.0

2.1 The Main Components for Construction 4.0

Construction 4.0 is based on integrating digital and physical technologies [11], leading to a change in the methods and concepts used in design and construction. Consequently, Construction 4.0 relies on two broad components (under which many classes of technologies are involved) (Fig. 1):

- Cyber-physical systems (CPS)
- Digital Ecosystems

Cyber-physical systems: include technologies that combine the physical and virtual worlds to form a networked world in which intelligent beings communicate and interact with each other [12].

Digital Ecosystems: They are digital platforms that bring together institutions or people by sharing information to achieve a common benefit or interest that is important to all [12].

Fig. 1 The two broad components of construction 4.0

3 Communication

3.1 *The Current Situation of Communication in Construction Industry*

The construction industry is still characterized by poor performance and a craft nature. There are many reasons for this, and these are two of the main reasons [13]:

1. The fragmented nature of the construction industry due to [14]:

   A. The geographical distribution of the tasks in the construction projects.
   B. The multiplicity of stakeholders and shareholders in the construction projects.
   C. Multidisciplinary participation in the construction process.

2. Weak exchange and sharing of information among construction project participants [15]. The solution lies in enhancing communication in the construction industry by developing methods for exchanging and sharing information among stakeholders, which will lead to [16]:

   A. Create a collaborative environment that the construction industry lacks
   B. Finding effective coordination between the various parties
   C. Saving time by reducing implementation errors
   D. Saving cost by reducing waste
   E. Raise the quality of work

3.2 *Construction 4.0 to Enhance the Communication*

Communication in construction projects is strengthened by enhancing information exchange, and information supply and sharing to achieve a collaborative environment between the various project participants, including engineers of various specializations, contractors, and the owner, as well as between the various machines operating in the site and the sources of materials [17]. The aim of achieving a collaborative environment and enhancing communication in the construction industry [18]:

A. Various data and information will become clearer and more transparent to all parties, which enhances coordination and enables smart management of construction operations,
B. Achieving synergy between the various parties, resources, and technologies, and thus enhancing productivity.

The information supply and sharing process require [19]:

A. Real-time perception and acquisition of important information covering the project work's progress, the supply of materials, and verification of quality and safety at the site and all construction environment.

B. Integrating this information in a data center to make it available and useable to all project parties. By leveraging the technology of Construction 4.0, there is the potential to provide the construction industry with an information support platform [20].

The aim of the information support platform is to achieve the two previous points, namely: real-time perception and acquisition of important information covering all aspects of the construction process, achieving the integration of information to make it available and usable by various stakeholders.

3.2.1 Information Sport Platform Structure

The platform consists of four layers: the information acquisition layer, the network layer, the construction services layer, and the data center layer (Fig. 2):

- The information acquisition layer: to obtain a lot of information from the construction project environment as information on task execution tracking, quality, the

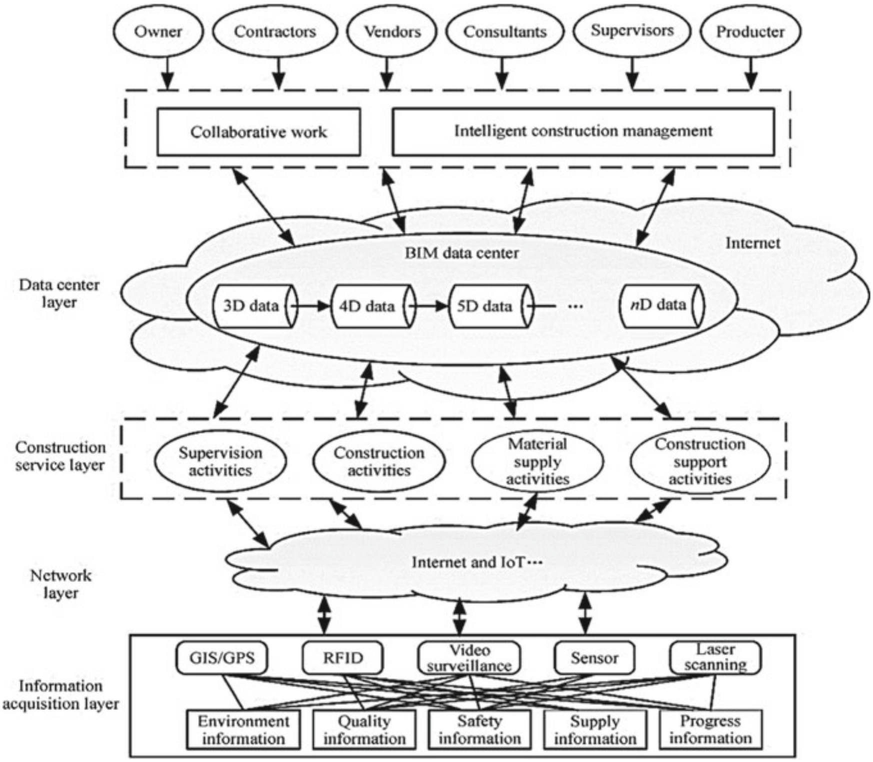

Fig. 2 Information sport platform structure

supply of building materials, safety, etc. There are many techniques like GIS/GPS, laser scanners, sensors, and RFID [19].

- The network layer: Its mission is to transfer data between different layers and between different parties, and between the various machines operating. This is done through information technologies and many networks such as the Internet, mobile network, satellite, microwave, optical fiber, and IoT [20].
- The construction services layer: this layer contains many construction activities and tasks such as execution, supervision, monitoring, tracking of material supplies, etc. This layer needs a lot of information to achieve coordination and collaboration, and it also generates a lot of information to be taken [17].
- Data center layer: This layer's task is to collect information, process it, and add new dimensions to the three-dimensional data to be studied from different perspectives such as time, cost, quality, etc. And the achievement of integration between the information coming from the various construction disciplines to make this information clear, achieving the coordination and to be available and useful to all stakeholders [16].

4 Methodology

4.1 Research Objectives

The research aims to enhance communications in the construction industry by making use of construction 4.0. Enhancing communications will enhance coordination and form a collaborative environment that the construction industry lacks. Thus, all of this will lead to improving the efficiency of human resources in the construction industry.

4.2 Problem Statement

- To explore the communication issues for improving the efficiency of human resource.
- To provide a solution to the increasing unemployment that could occur due to poor human performance in the construction industry and because of the possibility of replacing human labor with robots that are developing in the era of construction 4.0.

4.3 Hypotheses of Study

4.4 Research Method

First stage: (Table 1) collect the primary data by gathering information through research and review in articles and reports available on the Internet and the world of Google and published by Scopus Indexed magazine, Government of India, Emerald, and others. The research was conducted in documents and articles published in the last decade (2010–2020). Initially, searching for construction 4.0 technologies, in general, was conducted, and found more than 2000 elements talking about this topic. Then the search was narrowed to include a study of communications with construction 4.0, and 235 elements were found in this topic. Finally, the search was narrowed down to detailed things related to communication and construction 4.0 together, such as sharing information and associated technologies, collaborative work, coordination, and the human factor in the era of construction 4.0, technologies that enhance communication and information sharing, etc. (Fig. 3). About 30 files were selected, gave accurate information. In addition to studying a book entitled (Construction 4.0 An Innovation platform for the built environment), which was published in 2020.

Second stage:

1. The research hypotheses were developed
2. The study factors were developed, which are six factors
3. A questionnaire was formed and distributed to specialists in construction, who range from site engineers to project managers. Their experience range from (1–25) years, and their management levels range between junior, middle, and senior. The questionnaire included construction companies working in different types of projects such as infrastructure projects and residential buildings, and these

Table 1 Hypotheses of Study

	Main null hypothesis	Main alternative hypothesis
1	H_0: Construction 4.0 has no effect on the communication to enhance a quality human resource at statistical significance level of 5%	H_A: Construction 4.0 has effect on the communication to enhance a quality human resource at statistical significance level of 5%
The sub hypotheses:		
2	H_0: Construction 4.0 has no effect on the communication between different stakeholders at statistical significance level of 5%	$H_{A:}$ Construction 4.0 has effect on the communication between different stakeholders at statistical significance level of 5%
3	H_0: Construction 4.0 has no effect on the fragmentation at statistical significance level of 5%	$H_{A:}$ Construction 4.0 has effect on the fragmentation at statistical significance level of 5%

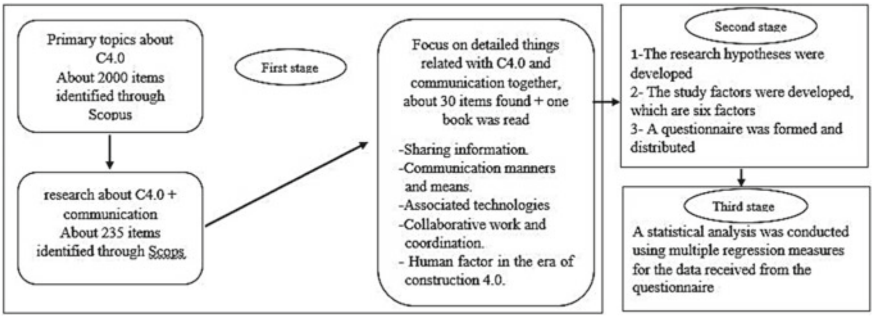

Fig. 3 Research method

companies distribute between six countries (India, Canada, Australia, Germany, Sweden, and the UAE).

Third stage: A statistical::analysis was conducted using multiple regression measures for the data received from the questionnaire, and the results and recommendations obtained (Fig. 3).

5 Data Analysis

Multiple regression is used to test the hypotheses.

1. Test the main hypothesis**.**

- Null hypothesis (H_0): Construction 4.0 has no effect on the communication to enhance a quality human resource at statistical significance level 5% while;
- Alternative Hypothesis (H_A): Construction 4.0 has effect on the communication to enhance a quality human resource at statistical significance level 5%.

Interpretation:

From the multiple regression results in (Table 2), it can be said that there is a statistical significance effect for the studied dimensions of construction 4.0 on the communication to enhance the human resource quality. So, we reject the null hypothesis which says that there is no effect and accept the alternative hypothesis that said the construction 4.0 has effect on the communication to enhance a quality human resource at statistical significance level 5%.

2.- Test the first sub-hypothesis.

- Null hypothesis (H_0): Construction 4.0 has no effect on the communication between different stakeholders at statistical significance level 5%, while;
- Alternative Hypothesis (H_A): Construction 4.0 has effect on the communication between different stakeholders at statistical significance level 5%.

Table 2 Multiple regression test results for main hypothesis

Dependent variable	R	R^2	Adjusted R^2	Calculated (F)	Sig	DF		Beta		Calculated(T)	Sig*
Communication to enhance a quality human resource	0.743	0.551	0.511	13.524	0.000	Regression	5	Awareness and acceptance level	0.286	2.395	0.020
						Residuals	55	Information sharing and access level	0.087	0.786	0.435
						Total	60	Stakeholder Training	0.104	0.832	0.409
								Adopted technologies	0.471	2.577	0.013

Interpretation:

From the multiple regression results in (Table 3), it can be said that there is a statistical significance effect for the studied dimensions of construction 4.0 on the communication between different stakeholders. So, we reject the null hypothesis which says that there is no effect and accept the alternative hypothesis that said the construction 4.0 has effect on the communication between different stakeholders at statistical significance level 5%.

3.- Test the second sub-hypothesis.

- Null hypothesis (H_0): Construction 4.0 has no effect on the fragmentation at statistical significance level 5%. While;
- Alternative Hypothesis (H_A): Construction 4.0 has effect on the fragmentation at statistical significance level 5%.

Interpretation:

From the multiple regression results in (Table 4), it can be said that there is a statistical significance effect for the studied dimensions of construction 4.0 on the fragmentation. So, we reject the null hypothesis which says that there is no effect and accept the alternative hypothesis that said the construction 4.0 has effect on the fragmentation at statistical significance level 5%.

6 Findings and Suggestions

Results and recommendations Based on the statistical analysis of the collected data:

1. The main result: Moving to Construction 4.0 by digitizing the construction industry will enhance communications thus, enhance the quality of human resources and improve performance in the industry,
2. Increasing the awareness of construction 4.0 leads to enhance communications and reduce the impact of the fragmented nature of the construction industry. To achieve that, it is recommended:

   A. Conducting seminars, workshops, and training courses to increase knowledge of the construction principle 4,
   B. Educating the construction industry shareholders about the economic profits and benefits due to the adoption of construction 4.0, which will reduce their fear of the value of the initial investment for the application of construction techniques 4.0 and reduce their fear and reluctance to change.

3. Enhance the information sharing and data access level lead to enhance the communication and reduce the effect of the construction industry fragmented nature. To achieve that, it is recommended:

Table 3 Multiple regression test results for first sub-hypothesis

Dependent variable	R	R^2	Adjusted R^2	Calculated (F)	Sig.*	DF		Beta		Calculated (T)	Sig.*
Communication between different stakeholders	0.701	0.491	0.444	10.598	0.000	Regression	5	Awareness and acceptance level	0.415	3.257	0.002
						Residuals	55	Information sharing and access level	0.035	0.297	0.767
						Total	60	Stakeholder Training	0.075	0.569	0.572
								Adopted technologies	0.614	3.154	0.003

Table 4 : Multiple regression test results for second sub-hypothesis

Dependent variable	R	R^2	Adjusted R^2	Calculated (F)	Sig.*	DF		Beta		Calculated (T)	Sig.*
Fragmentation	0.647	0.419	0.366	7.928	0.000	Regression	5	Awareness and acceptance level	0.288	2.120	0.039
						Residuals	55	Information sharing and access level	0.149	1.177	0.244
						Total	60	Stakeholder Training	0.193	1.366	0.178
								Adopted technologies	0.018	0.088	0.930

   A. Creating a digital platform on which data is uploaded regularly. This platform can be found using construction 4.0 technologies such as cloud computing technologies,
   B. Defining a specific level of management for the participants who are entitled to upload and access information, for example, the participants who start from the level of a site engineer up to the level of the project manager have the right to upload and access information on the digital platform,
   C. Upload information regularly and within a certain frequency that may not be increased or decreased,
   D. Establishing certain standards to ensure that the submitted information is complete and consistent, as the presence of incomplete and inconsistent information leads to errors in implementation.

4. Training construction stakeholders to use digital technologies and modern means of communication will enhance communication and reduce the impact of the construction industry's fractured nature. To achieve that, it is recommended:

   A. Courses should be conducted to increase digital skills which enhance communication and coordination efficiently.
   B. Workshops and seminars should be held to raise awareness of the importance of communication and coordination in enhancing the human performance.

5. Utilizing construction 4.0 technologies will enhance communications and decrease the impact of the construction industry's fragmented nature. To achieve that, it is recommended:

   A. There is a need in construction sites for smart computing and communication tools that can withstand site conditions (heat, humidity, dust, etc.).
   B. Work to take advantage of construction 4.0 technologies that enhance communications in the construction industry (these techniques are mentioned in paragraph (2.2.2)
   C. BIM techniques form the basis for coordination between various disciplines in all project phases
   D. Using cloud computing technologies is considered the main base for information organizing and sharing platform in construction 4.0.

6. Additional recommendations to deal with construction industry fragmented nature:

   A. Fragmentation is the primary nature of the construction industry and should be adopted and deal with,
   B. Exist defined protocols for information creating and representing will decrease the impact of fragmentation and achieve efficient information exchange and sharing,

C. Exist uniform communication means between the various parties reduces the impact of fragmentation and achieves efficient information exchange and sharing,
D. Using BIM for multi-trade prefabrication technology is one of the best techniques which decrease the impact of fragmentation and enhance information exchange and sharing in the construction industry.

7 Conclusion

In the conclusions, the author would like to emphasize that the digital technologies listed under Construction 4.0 can enhance communication in the construction industry which will increase coordination between the various parties involved in the construction project and creating a collaborative environment in the industry. Increasing coordination and creating a collaborative environment will lead to an increase in the efficiency of human resources and thus raise the construction industry's performance. Also, the researcher concluded through the research study that increasing awareness of construction 4.0, enhancing information sharing and data access, training workers in the construction field to use modern digital means, and using the technologies provided by construction 4.0 leads to enhance communications and reduce the impact of the construction industry's fragmented nature, thus increasing coordination and collaboration, and raising the quality of the human factor which will Save time and cost by reducing implementation errors, preventing the repetition of some tasks, and reducing waste.

Main recommendations: Holding seminars, workshops, and training courses to increase awareness of Construction 4.0 and its economic benefits, clarify the importance of communication and coordination, and train workers in the construction industry to use digital technologies. Creating a digital platform for uploading and sharing information, determining who is entitled to use that platform, setting controls for the frequency of uploading information, ensuring that the information uploaded is complete, and providing construction sites with smart digital tools that resist the difficult site conditions and use the C 4.0 technologies.

It is also recommended that fragmentation is the nature of the construction industry, and it must be dealt with by creating defined protocols for forming and representing information, using unified means of communication, and using some technologies such as use BIM for multi-trade prefabrication technology. Future directions include studying different management methods under the umbrella of Construction 4.0 to improve communication, cooperation, and coordination in the construction industry.

References

1. Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry 83*, 121–139.
2. Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of industrial information integration, 6*, 1–10.
3. MacDougall, W. Industrie 4.0: Smart manufacturing for the future. *Germany Trade and Invest*.
4. Montgomery, D., & Norman, J. (2017). The future for construction product manufacturing. Digitalisation, industry and the circular economy." Retrieved on the 1st September (2017).
5. Buss, M., & White, M. (2017). The rise of construction 4.0." Retrieved on the 1st September (2017).
6. Rastogi, S. (2015). Elimination of wastes in construction: A case study. In *Indian lean construction conference ILCC 2015, proceedings Feb, 2015*.
7. Rastogi, S. (2017). Construction 4.0: The 4th generation revolution. In *Indian lean construction conference–ILCC 2017*.
8. CIDB (Construction Industry Development Board of South Africa). (2011). Construction Quality in South Africa; a Client Perspective.
9. Tipili, L. G., & Ojeba, P. O. (2014). Evaluating the effects of communication in construction project delivery in Nigeria. In *Proceedings of the multi-disciplinary academic conference on sustainable development*.
10. Shrestha, G. B., & Kumaraswamy, M. M. (2000). Problems in technology transfer vs potential for technology exchange. In *2nd international conference on construction in developing countries: Challenges facing the construction industry in developing countries*. BONCIC, University of Botswana and CIB.
11. Jacobides, M. G., Sundararajan, A., & Van Alstyne, M. (2019). Platforms and ecosystems: Enabling the digital economy. In *Briefing paper world economic forum.*
12. Gartner. (2017). *Seize the digital ecosystem opportunity*. Gartner, Inc. https://www.gartner.com/cioagenda.
13. Gamil, Y., & Rahman, I. A. (2017). Identification of causes and effects of poor communication in construction industry: A theoretical review. *Emerging Science Journal, 1*(4), 239–247.
14. Miozzo, M., & Dewick, P. (2004). Networks and innovation in European construction: Benefits from inter-organisational cooperation in a fragmented industry. *International Journal of Technology Management, 27*(1), 68–92.
15. Lin, K. A. N. G., Hongxia, L. I. U., Jian, W. A. N. G., & Cong, L. I. (2011). Construction and application of the transportation information exchange and sharing platform." *Journal of Transport Information and Safety, 3.*
16. Tam, C. M. (1999). Use of the internet to enhance construction communication: Total information transfer system. *International Journal of Project Management, 17*(2), 107–111.
17. [Book] Sawhney, A., Riley, M., & Irizarry, J. (eds.). Construction 4.0: An innovation platform for the built environment. Routledge, Taylor & Francis Group.
18. Bozoglu, J. (2016). Collaboration and coordination learning modules for BIM education. *Journal of Information Technology in Construction (ITcon), 21*(10), 152–163.
19. Zhou, H., Wang, H., & Zeng, W. (2018). Smart construction site in mega construction projects: A case study on island tunneling project of Hong Kong-Zhuhai-Macao bridge. *Frontiers of Engineering Management, 5*(1), 78–87.
20. Wang, X., Wang, S., Song, X., & Han, Y. (2020). IoT-based intelligent construction system for prefabricated buildings: Operating mechanism and implementation—A China study. *Applied Sciences, 10*(18), 6311.

BIM in Construction and Maintenance of Infrastructure Projects

Albaraa Alasskar and P. Jagannathan

Abstract BIM is the latest technique, tool, methodology, and workflows in construction projects. Initially, the construction industry was using the BIM technology only for the construction of buildings, on knowing the advantages of this technology the Architecture, Engineering, Construction, Operator and Owner (AECOO) industry around the world has started using it for vertical and horizontal projects. This paper discusses the adoption of BIM in the vertical building and the horizontal projects in construction and asset management in the life cycle of the structure. Usage of BIM helps the stakeholders from the planning stage to completion and during maintenance of the structure by providing high clarity to everyone involved in the project. The requirement of time as 4D and money as 5D for each stage of construction can be incorporated while modeling the structure. The specification of each item of the work in the structure can be incorporated in the model to refine the same in the future. The conditions of the structure in later time can be marked in the model to arrive at the suitable remedial measure and also BIM modeling helps to know the time periodical maintenance.

Keywords Building information modeling (BIM) · 4D-BIM · BIM in infrastructure · Bridge information management · Operation and maintenance

1 Introduction

Building information modeling is an intelligent tool that provides the AECOO industrial professionals to find any infringement in the construction of the structure as per the drawings generated to execute the project [1, 2]. The efficiency

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will be in, designing planning, construction, operation, and maintenance and generating the building and civil projects [3]. The creation of a BIM model includes managing, storing and generating digital information for all elements and objects of a building or structure throughout its cycle life of the project [4, 5]. Adoption of BIM in construction enhances the communication between stakeholders especially the designer, contractor and owner [6]. Adopting BIM in the infrastructure projects that focus on the development of the country and offer services, facilities, for people [7]. These infrastructure projects can be funded by private, public sector, or partnership as a public–private partnership. There are two main types of infrastructure investments, these include economic infrastructure, which includes sewage, communication, water, roads, power and airports [8, 9]. Social infrastructure, which includes affordable housing, education building and health care building. Implementing BIM technology for the construction of horizontal structures require the interest from the public and private sector who were executing these type of projects [10]. Improving the quality of the asset in the life cycle of the infrastructure projects by modeling the asset in the 3D model that makes clarity for all the parties to understand the project [11]. Also integrating the time 4D and cost 5D with the model makes the engineer know the time and money requirements for each stage of construction [12, 13].

The monitoring and controlling the progress and cost of construction by comparing the model created. The model can be updated based on the present situation and requirements. The result of applying BIM in project management for a bridge in terms of developing and monitor the schedule of the work, the cost and quantity takeoff that smooth the execution of the work. Also, BIM mitigates the clashes, conflicts and reworks in the project. The recommendation is to develop the model with artificial neural networks to monitor the condition of the asset and use the information of the model in the operation phase to recommend the maintenance that is needed**.**

2 Literature Review

BIM has become established as an useful process enabler for new architecture, engineering, and construction (AEC) [14]. With BIM technique, virtual models of a building project are created digitally [15] will be more accurate in all the models and make high clarity [16]. The BIM supports all the phases of the project from planning through design, making better analysis, monitor, control in the construction phase and reuse of the model in the operation of the asset to develop the conditions and maintenance phase [17]. These BIM models have data and accurate geometry needed to support the fabrication, procurement and construction activities, through which the project is realized, operated and maintained [16]. Because of lack of resources in BIM in infrastructure exactly, the literature review has Publications consisting of conference papers and journal articles. The Information has collected in the previous research is related to construction civil projects, BIM in infrastructure, and BIM in the building. Applying BIM in building projects to civil projects should identify the similarities and differences between the horizontal and vertical projects. Reports were also collected from Autodesk, thesis and standards in the countries that have experience with BIM. The articles related to Bridge information modeling were collected which were explaining the construction and modeling of the bridge. BIM is technique and an information-rich, model-centric process with the power to add value during the lifecycle of infrastructure project and transform project delivery [6, 14].

Developing the communication in construction projects to monitoring them remotely and the need for remote monitoring is an essential in the construction projects today as the high number of projects has increased significantly and the expertise available to resolve site-related issues are not easily available [18]. BIM can represent the project digitally by object-based modeling, there are remarkable changes in the key delivery processes involved in constructing project and changes in how a model is built from traditional CAD solutions [10]. With the growing use of BIM for buildings, the adoption of BIM in infrastructure projects gradually increases in industry [19]. The companies that construct infrastructure facilities are expecting the use of BIM since they have noticed high benefits in investment coming from BIM for building projects [13, 20]. And also BIM has the ability to significantly improve efficiencies, increase sustainability, reduce waste across infrastructure projects during their life cycles [21]. 4D mode, virtual construction, computer simulation, and virtual prototyping are modern topics in the construction industry [22]. the possible use of BIM in infrastructure structure, specifically in highway construction [23]. The technology is not created only for the vertical building but also can be adopted in the horizontal projects such as bridges [24, 25].

Using Bridge Information Modeling (BrIM) framework that uses BMS features including; inspection module, databases and condition assessment module and use BrIM in time and cost management of infrastructure bridges that enable Bridge Management Systems (BMS) play an important role in rehabilitation and maintenance decisions [26–28]. 3D models can provide a perfect numerical expression of drawings from design results [29]. 3D models for bridge structures can get better design quality in terms of constructability, accurate drawings, collaboration and Architecture of the 3D Bridge Information Model [30]. The management functionalities related to bridge have been tried by Bridge life cycle management to be conducted, in the bridge from the initiating stage to the end of their useful life, during the design, construction, operation and maintenance stages [1]. Analyzing the workspace conflict for decrease interferences and clashes caused by equipment or labor work is also a crucial management factor [31]. Building Information Modeling (BIM) and Augmented Reality (AR) will be the base of the revolution in the processes of management of infrastructure projects, designing and construction including bridge structures [32]. Infrastructure projects have adopted BIM can help reduce the funding gap by increasing potential sources of funding with more predictable return of investment(ROI) and decrease costs [33].

3 BIM and Infrastructure

3.1 Implementation of BIM in the Infrastructure Projects

As construction is important in the growing of the economy in the countries, how engineers, contractors, and owners dealing with their construction projects. Applying the latest techniques provides the opportunity to smoothen the construction process. The consequences of applying BIM in the vertical projects have motivated the AEC industry to conduct the BIM in the horizontal projects [22]. Infrastructure take an important role in construction projects as it consumes the highest capital cost. Civil infrastructure is a utility, facility or structure which needed to support and facilitate activities and human civilization [13]. Transportation infrastructure facilitates the life of people and gives them free service, so the government pays attention to the plans for transportation infrastructure projects. The AECOO industry is trying to improve and develop the implementation of BIM in construction infrastructure projects. 3D improves the visualization for the project and the clarity to the stakeholders to understand the project, clarity in the scheduling and sequences of the activities are obtained using 4D [6]. The government and private sectors started implementing BIM in the horizontal project to increase transparency, enhance the process, collaboration and coordination between all the parties during all phases of the project, help to avoid conflicts and clashes [34]. Further, usage of BIM reduced the cost of the project and saved money for the owners to be cost-effective. And also avoided the clashes in the first stage of project and reduced the request for information (RFI) and changed order in the construction and rework decreases the waste in time, money and material [22].

For more advantages, the public sector should apply the BIM technique on infrastructure projects, support and encourage the efforts in the adoption of BIM in civil construction. The following Questions are asked to implement the BIM in the market:

- Which sector does implement the infrastructure projects?
- What are the types of infrastructure project will get benefits from BIM?
- How the adoption of BIM in the infrastructure projects may affect the process of the project and provide positive results?
- What are the software packages available in the market?
- Who is responsible to implement, develop and care about the BIM software, techniques, workflow, and process in projects?

3.2 BIM in Infrastructure Projects

Most researchers in both academia and industry area have more researches and implementations in the vertical projects. Using BIM and its software packages in the phases of the project, by modeling the project 3D, makes it easy for all the parties to understand How will it build and give them the reality of the project in the initial time of the project. Also, the owners knew where they expend their money, what is the

Fig.1 Appears the quantity takeoff in bridge by using BIM [11]

result of the project? And is it suitable for the environment and market and its needs? Further study of the financial side of the project depends on quantity takeoff and its cost estimation accurately [35]. That gives the stakeholders the transparency about their project to start the execution work and the clarity for engineers, contractors and owners to understand the construction phases, Fig. 1 appears the quantity takeoff in bridge by using BIM. Also, understand the sequences of the activities and the accumulative cost for each stage of the project. And identify the budget for each activity and all the project by simulating all the activities sequences with own cost [36]. All the benefits in the building projects it is an awake state in the civil infrastructure. Modeling the infrastructure projects as a bridge by start modeling the substructure and the superstructure of the bridge [37]. Define the activities in bridge construction, model the activities with their code, and scheduling the activities that enhance the process, coordination and collaboration on the construction in bridge projects [22].

The transition from traditional planning and design to BIM helps planners make their plans for the project in primavera software by identifying the organization breaks down structure (OBS), work breakdown structure (WBS), the activities, and the resources to primavera. The output of the plan is clear for the planner but it is not clear for the other parties that make misunderstanding in the planning and the scheduling in the project [38]. BIM removes all the barriers with its technique in 4D the scheduling and sequences with relevant cost 5D for every activity and the whole of the project [39]. Working BIM in the 4D time it is very important to avoid delay and clashes [27]. Identify the work breakdown structure for the project, organization break down structure, resources and get the planning from the traditional technique in primavera software, in the parallel time make a model of the project and integrate them. The integration of the model with planning to simulate the activities and make visualization for the scheduling to be better clear than traditional planning [30].

Visualization and simulation for the scheduling of the project by 4D help all the parties in the project to notice the progress in their project how is it? And how to cost it in this stage. Further, it helps the maintenance department to make a smooth process for the maintenance without any issues by identifying the problem in any component and which type is it? [33]. As we knew the most the application in the building projects, so adopt these techniques, methodology, and workflows in the infrastructure project till has lack implementation in the industry and academia domains. Infrastructure projects such as the transportation projects have huge capital from the balance sheet of the government and reflect the condition of the development in the state that pushes the public and private sector in the last years to enhance and develop infrastructure projects by adopting BIM [22]. Also, notice some countries implement BIM in their infrastructure projects and find BIM improves the younger staff to understand the progress of the project how will it go.

The 3D model helps the parties to knew what is the project and how will it be, and establishing consistent and repeatable project delivery and maintaining the business with a past client, decrease the time need for the documentation in the same time increase the time in the design [33]. The benefits of applying BIM mitigate the errors, risk, rework and cost. Also, give a better understanding of the project in all the phases and improve the schedule and optimize the design (Fig. 1). Further BIM provides value for people who author the model and for who extract the value from authored model and makes interdisciplinary project between all the stakeholders and all the phase of the project [22, 33].

3.2.1 Bridge Information Modeling (BrIM)

Applying BIM to the bridge project needs to model the elements of the bridge substructure and superstructure. So how the model will be and how can model it, what are software packages need? Modeling the bridge help stakeholders to understand the bridge from the planning stage, design, construction, operation and maintenance. Contractors, engineers and owners get benefits in adopting BIM in their bridge projects. Extracting the quantities from the model integrates the model with time 4D, cost 5D, develops the model and collects data about the condition of the asset to evaluate the state of the bridge [30, 40].

Applying the BIM techniques, methodology and workflows in the bridge projects enhances the clarity of the bridge for all the parties by display the planning engineers their plans in the initial phase of the project for the other stakeholders that do not have a background in engineering [41]. Also understanding the plans and drawings, submit the plans to the owner with the schedule and cost of each activity and the whole project in a visual way. that help to avoid the difficulties of traditional planning in primavera, that need skills to use it and update your schedule and it confuses the parties to understand the updated state of the project [19].

All of the AEC industry ask what is the process that improves the proficiency and process of the bridge projects by adopting the 3D model to increase the transparency of the asset in all the phases of the life cycle, integrate the 3D model with time to get the fourth dimension 4D [42]. The 4D smooth the process of communication, coordination, and collaboration by schedule the activities of the project and enhance the sequence of tasks needed in the execution to avoid clashes during the execution of activities. Adopt the time with the model to ease the cost estimation of the bridge project by adding the fifth dimension 5D, the owners, engineers, and contractors monitoring and control the bridge construction project with relative cost and compare the adopted model with actual work [43]. The monitoring and controlling by comparing the planned model in cost and time with actual for each activity and whole the project [33].

Improving the model by developing the model to add the 6D in the operation and maintenance and 7 D energy efficiency and n D in the asset management, Fig. 2 illustrate the component of briges by using Infraworks tools [21]. The planning phase needs data that go under the planning layer to contain the condition of the design and requirements needed, alternatives and participants after that start the design phase, need in this phase the design properties of the material, member force and design intention. The construction phase begins when the planning and the design phase finish, in the constriction layer, need the actual properties of the material product environment and condition that mean in the construction phase need for quality assurance and quality control to improve the quality of the project QA/QC. After the AEC industry has observed the return on investment in the vertical building, that makes the AEC industry increase the effort in adopting the BIM technique in civil construction projects. Construction projects have a huge amount of information through the life cycle of the structure [20].

The model has information in 3D and integrates it with time and cost in the planning, design and construction phase (Fig. 2). Also in the latest technique store, the information that makes the operators and owners use is to facilitate the process in operation and maintenance. Using BIM as a tool in the construction of the bridge for the quality management for the information, integration, coordination, collaboration, sequences, and schedule during the life cycle of the bridge [1, 27]. The quality management in the bridge projects achieving the property of the materials and check

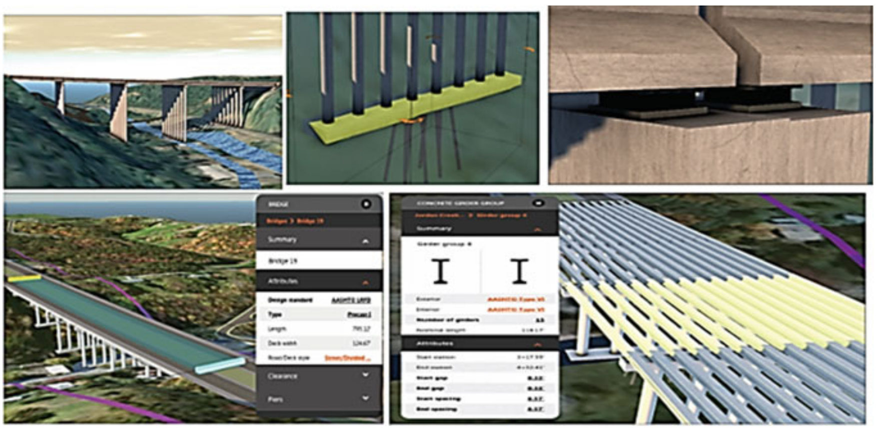

Fig. 2 Illustrate the component of bridges by using Infraworks tools [11]

the quality of the transformation of information between the platforms and the interoperability, the condition of the asset and the resources. Usage of BIM in bridge construction achieves the customer satisfaction and quality of construction during execution and lowers the risk in construction, wastage of time, wastage of materials and avoids the conflicts and clashes [10, 20].

3.2.2 Modeling the Bridge Structure

Since the use of the first simple bridges made from a single beam that had to bear all the forces of compression, tension, shear forces and torsion by itself. The entire engineering field was formed, and there are a lot of bridge designs were created utilizing many parts, components, and brand modern terminology that describe them. All the basic components and parts are placed inside three main bridge areas—foundation (which holds the deep basement or shallow of the bridge and transfers its load to the bearing strata, this includes the abutments below starting points of the bridge), foundations below the main span of the bridge, and Substructure (abutments, piers, spandrels, bearing, caps and other components that holds the upper construction) and superstructure (all the parts of the bridge that are mounted on top of the supporting substructure system, it covers elements such as slab, girders, decking and everything placed above the main deck such as steel truss system posts, bridge girder, cable suspended systems, cable-stayed system and more). How to model the components of the bridge, what are the elements need to model? What are software packages use?

Many software packages are available in the market, as AEC industry adopts BIM in how they model 3D visualization. There are Midas civil can model the elements of the bridge girder, suspension, and cable-stayed bridge, also Bentley Leap Bridge is used for the design and analyses for the structure of the bridge and the Revit is a software used for making drawing and virtual for the bridge and supports the BIM. Revit and anther applications and platforms make and support the building information modeling for the project. The modeling enhances the collaboration and coordination by make simulation and visualization for the project during the lifecycle and the communication between the owners, designers, architects, engineers, suppliers, workers and all the participants in the project by integrating all the processes and transform the information.

3.2.3 Bridge Information Modeling with Operation and Maintenance

BIM for the bridge is a modern technique that gathers the information in the model from the planning, design, construction to the operation and maintenance [44]. Bridge management or asset management helps the owners and operators get benefits from the model. BIM is a tool that facilitates the procedure for contractors, subcontractors, engineers and owners [45]. In the last few years, the AECO give efforts to research and work to adopt modern techniques in the construction of the project [46]. Improving

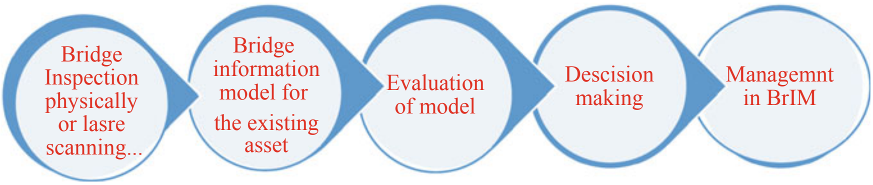

Fig. 3 Illustrates the process BIM in bridge maintenance

the performance of the collaboration, the design, planning and construction will be done in high quality and high performance. And the schedule of the construction activities has improved and avoids the issues in the process, miscommunication, and conflicts during the phases of the life cycle of the project. In the operation and maintenance phase of the asset monitor the condition of the asset. As the bridge is reinforcement concrete (RC) or prestressed concrete (PC), what are the issues that occur in the components during the operation cycle? That prevents the asset from uncertainties increases the life of the bridge and enhances the performance of the asset.

Operation and maintenance what is the link between the model and two phases? How the owner and operator link the condition of the asset with the model? And how will they link the inspection to the model? Bridge in RC or PC, there many deficiencies such as cracks, spalling, delamination and efflorescence [47–50]. Modeling the deficiencies in the original model and upgrade the model with new conditions of the asset [48] Fig. 3 illustrate the process BIM in bridge maintenance. Revit can model the element with code, the property of material, and cross-section and physical properties. The families and parameter types are available in Revit, in the design phase the engineers identify the property of the concrete, steel, and all the material in the model (Fig. 3). In the operation and maintenance phases, the operators and owner inspect the asset manual and type the changes in an excel sheet, by laser scanning, drones, and sensors and link them with the model [1, 18]. Identifying the damage in the model as cracks what is the length, width and spreading, identify the condition of deterioration by reducing the cross-section and change the property of the element, from the editing in the model and link the updated model to structural analysis (finite elements) to assess the condition of the asset [28].

3.2.4 Bridge Management with Update Model

Using BIM for Infrastructure projects can help the owner close the funding gap by increasing potential sources of funding with more predictable ROI and reducing costs. Management specifies to manage the project from the planning to demolition phase in the decision making, planning, cost estimation and quantity. Using BIM with operation and maintenance in the management of the project, your function or task identify the issues, reusing the information model to model the condition of the element as it, make structural analysis to decide on the maintenance, what are the recommendations of maintenance?, what is the type of maintenance?, what is the area of the damage in the element?, what is the quantity takeoff need in the maintenance, the cost, and the time?, all the questions have been asked and the disruption in the operation of an asset helps to manage the site to avoid clashes and conflicts during the maintenance.

BIM or updated BIM identify the damage in the bridge, area, severity, type and integrate the changes with the model then ingrate the new model with all the platforms, that enhance the maintenance by using 3D for visualization of the damage and 4D integrate the process of maintenance with time and cost 5D**,** (Fig. 4) illustrate the developing 4D-BIM schedule for bridge. Owners and operators use the benefits of adopting BIM in design and construction of the bridge in operation and maintenance phase, improve the proficiency of work, communication, coordination, and collaboration and avoid conflicts and clashes and mitigate the risk, cost and rework in the operation and maintenance phases.

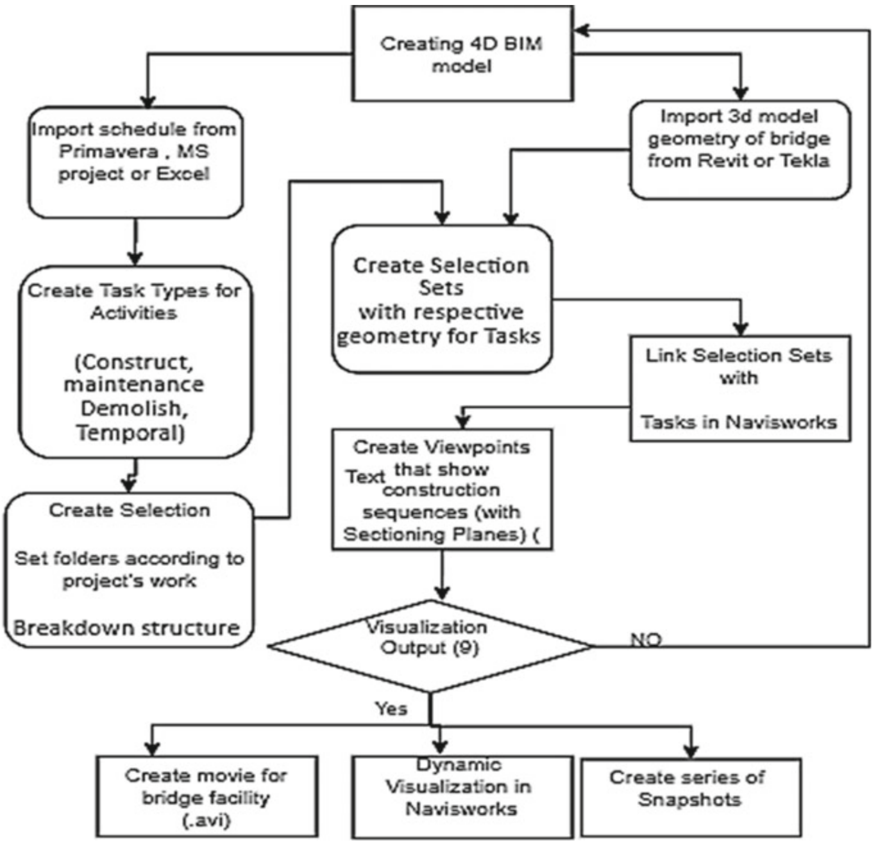

Fig. 4 Illustrate the developing 4D-BIM schedule for bridge

3.2.5 Tools and Software Packages in BIM and Infrastructure

According to software tools in the market for Autodesk, Bentley, Tekla, CSI, Vico, Graph iSOFT, and FORUM8, in Bridge use AutoCAD Civil 3D, Revit, Bentley Bridge Design Software and Road Design Software, 3ds Max Design, Microstation, STAAD.Pro, Navisworks are used as tools in BIM and its usages are shown in Table 1 displays tools in BIM and uses. And how the AEC adopts the BIM techniques by using the software tools. Specifying the tool for each element of the asset by understanding the model and make interoperability between tools, the transformation the data between different platforms as Industry Foundation Class IFC for more efficiency in collaboration.

In the case study in Bridge, project making integrate between the models in Revit Autodesk in visualization and integrate the model in Revit with Infraworks, and link the model with time to make planning for the schedule of the project by identify ID for each element in Revit and also identify the planning in primavera or MS projector in excel sheet (Table 1). Here in the collaboration between the tools link the model in Revit to Navisworks to visualize the scheduling and sequences of the activities to avoid clashes. Also integrate the model with cost in 5D in the way that all the parties understand the schedule and the cost of the project in every stage in the construction and compare the plan with the actual schedule and cost, that gives an index to correct the plan to avoid the delay and increase the cost [22].

4 Result and Discussion

The exploring BIM in infrastructure general and practically in bridge projects for life cycle of facility from the conceptual; design during construction and end in operation and maintenance phases. The study goes through the benefits of BIM in building and expanding this modern technology to infrastructure projects to smooth the work and enhances the communication among various stakeholders. Depend on the previous studies the lifecycle operation and maintenance take the biggest proportion of the cost of the project as illustrated in Fig. 5, which the cost of maintenance and the cost of suspension of the facility the figure illustrates the life cost of the facility. The trend of BIM infrastructure projects has started growing increasingly to cope with the innovation of BIM in building in time and cost management [49].

The paper analyzes the parties that use BIM in their projects and mature functionalities in the adopted projects, and also relationships between project team interaction, coordination, collaboration, integration software tools and phase of project as illustrated in Fig. 5. Most of architects, engineers, managers, planners, BIM experts and civil engineers have used AutoCAD Revit in design, construction, operation and maintenance as the heist functionality in construction, capability, linking and integration with other software, the figure illustrates the high adoption Revit among other software tools.

Table 1 Tools and uses in BIM

The author	The article	The software	The use of the software
Marzouk and Hisham [26]	Bridge information modeling in sustainable bridge management	Tekla, Ansys, MS Excel, Naviswork	1. 3D bridge model 2. Structural condition assessment (integrating) 3. BrIM with Ansys software via C# programming 4. Inspection sheets and results Bridge components information
Moon et al. [31]	Development of workspace conflict visualization system using 4D object of work schedule	P3, p6 primavera, And using the bounding box	Scheduling, planning, and using the Bounding Box in workspace visualization
Francesco Abbondatia et al. [51]	BIM for existing airport infrastructures	Infraworks360, Autodesk civil 3D, Tekla structure, Excel and programs (using C#)	Visualizing the design project, sharing cloud-based models (a) creating the digital elevation model; (b) creating the horizontal alignment; (c) creating the vertical alignment; (d) modeling the 3D corridor using the edited assembly template; (e) importing grip number (GN) data measurement in the 3D model; (f) creating 3D real-world context (g) creating new attributes for each element type utilizing Application Programming Interface (API) of Tekla Structures software by using C# programming language

(continued)

Table 1 (continued)

The author	The article	The software	The use of the software
McGuire [28]	Using building information modeling to track and assess the structural condition of bridges	Excel, Graphisoft, ArchiCAD, Tekla structure, Midas civil, Bentley LEAP bridge, Autodesk Revit, Autodesk BIM360 Field, Naviswork, Primavera	1. inspection schedule in operation and maintenance 2. Architecture in Buildings 3. Architecture, Engineering, Structural 4. Detailing in Buildings and Infrastructure 5. Engineering Bridges and Infrastructure 6. Engineering Bridges 7. Architecture, Engineering Buildings and Infrastructure 8. Fieldwork and Inspections Buildings and Infrastructure 9. 4D simulation 10. scheduling

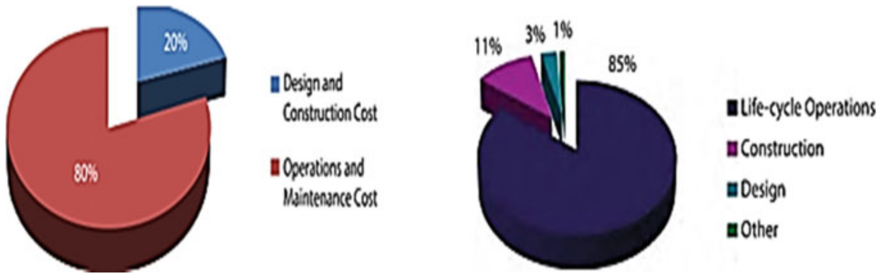

Fig. 5 Display the life cycle costs [50]

In bridge design have used Bentley LEAP Bridge, Autodesk BIM360, Tekla Structures and Infraworks tools, but the most design have been done by Tekla structure and in the last five years there is development in adoption BIM in infrastructure projects, and analysis of using tools in project between phase discover the increasing use of Infraworks, Navisworks, Primavera and Tekla structure in planning, design, construction. The latest technology of investigate the damage of facility ad laser scanning and camera and link them with model has started recently in research and industry to update the condition of assets (Fig. 5).

The study focuses on the time and cost management in infrastructure projects and tools (Figs. 6 and 7). The future research recommends to develop software tools to

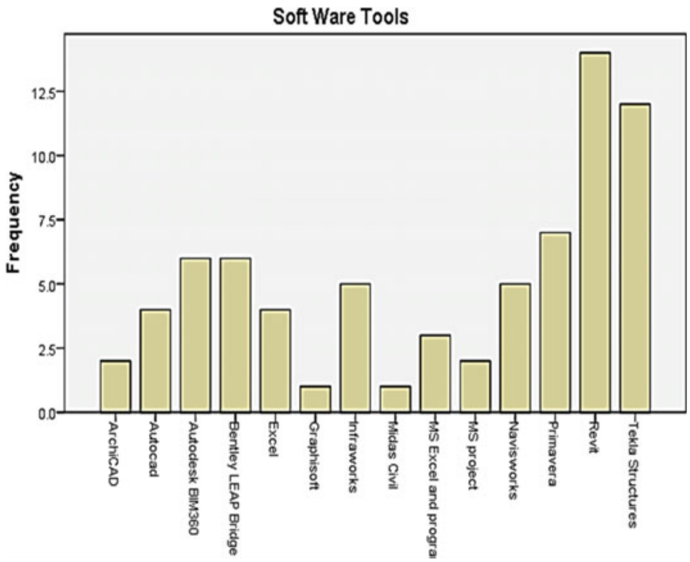

Fig. 6 Illustrate the software tools

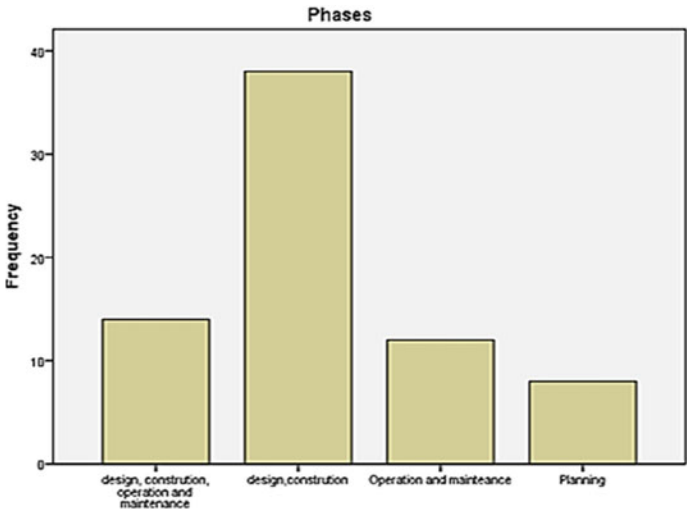

Fig. 7 Illustrate the phases of project

solve the issues faced in adopting BIM tools in infrastructure instead of building projects and combine the artificial neural networks with model that helps to predict the future maintenance.

The study summarizes the factors which influence the use BIM in infrastructure projects:

- Improved Interoperability.
- Improving scheduling capabilities with BIM software tools during construction and maintenance phases.
- Improving budgeting/cost estimation with BIM tools.
- Clash detection capabilities of BIM tools.
- Reduce number or need for information request.
- BIM ability to enhance the communication, coordination and collaboration among all stakeholders.
- Opportunity to reduce construction and maintenance cost.
- Opportunity to reduce construction and maintenance time.

5 Research Gaps and Recommendations

Implementation of BIM in the market for the infrastructural projects has huge efforts from the public and private sector after capturing the benefits in its adoption in the building projects. Applying BIM in the civil infrastructure differs in some considerations in the building projects. The similarities in building and infrastructure in the design, planning, collaboration and methodology but the main difference is the benefits or the advantages that return from the adoption of the technique in building projects to civil projects.

The vertical projects need visualization to be more coordinated and avoid clashes, but that in the horizontal projects there are no clashes, and the visualization does not give high value. Need to improve the efficiency in the infrastructure projects in Roads, Bridge, tunnels and railways and make standees of each one for example standard for adopting BIM in the Bridge, Highway and so on, and also the process of transition the information between the layers of the model and what is the standers of the accuracy of the information.

The government and construction companies encourage to apply the modern techniques in the projects, in this point motivate the researchers. Participate in the young engineers to learn the technique and make conferences about the BIM in civil infrastructure projects, also encourage the collaboration in the work of the projects as one platform to coordinate and share information between all the parties especially for government agencies. making practices in position sensors in the asset and drones and link the investigation with the model to suggest the maintenance in the right time, also integrate the Google earth, Google positioning system and geographic information system with existing project and by generating models integrate the model with GIS, GPS to update the condition of the asset and help the operator to manage the asset proficiently as monitor the traffic on the asset for example. And also work to smooth the use of the software tool in the management by adding new parameters and new techniques as ANN Artificial Neural Networks and Machine Learning in the future.

6 Conclusion

Infrastructure projects are very important in the country. The developed construction projects reflect the development in the state, also the construction of the civil projects takes the high capital expenditure of the nation's economy. Civil projects are divided into transportation, sewage, power, and so on. The paper has discussed transportation projects especially bridge projects. The advantages of adopting BIM in the building in terms of communication and collaboration and mitigate the risk, rework and conflicts and avoid the clashes detection.

The AEC industry has adopted these latest technique in civil projects and this article has discussed case study of bridge in the transportation projects, and how the BIM technique, tools, and process enhance the performance of the construction of the project in visualization, scheduling, designing, planning, and sequencing the activities with time 4D with relative cost 5D and also update the model in the operation and maintenance phases. This article discussed the researches made in the vertical and horizontal projects and provides information in future research.

References

1. Tanaka, F., Hori, M., Onosato, M., Date, H., & Kanai, S. (2016). Bridge Information model based on IFC standards and web content providing system for supporting an inspection process. *Proceedings of the International Conference on Computing in Civil and Building Engineering*, 1140–1147. http://www.see.eng.osaka-u.ac.jp/seeit/icccbe2016/Proceedings/Full_Papers/144-301.pdf.
2. Tang, F., Ma, T., Zhang, J., Guan, Y., & Chen, L. (2020). Integrating three-dimensional road design and pavement structure analysis based on BIM. *Automation in Construction*, *113*, 103152. https://doi.org/10.1016/j.autcon.2020.103152.
3. Dong, B., O'Neill, Z., & Li, Z. (2014). A BIM-enabled information infrastructure for building energy fault detection and diagnostics. *Automation in Construction, 44*, 197–211. https://doi.org/10.1016/j.autcon.2014.04.007.
4. Chapman, D., Providakis, S., & Rogers, C. (2020). BIM for the underground—an enabler of trenchless construction. *Underground Space, 5*(4), 354–361. https://doi.org/10.1016/j.undsp.2019.08.001.
5. Sacks, R., et al. (2018). *BIM handbook a guide to building information modeling for owners, designers, engineers, contractors, and facility managers.* Wiley.
6. Autodesk, (2012). BIM for infrastructure BIM for infrastructure: A vehicle for business transformation. *Autodesk*, 1–18.
7. Chappell, E. (2015). *Autodesk drainage design for infraworks 360 essentials-sybex.*
8. Thi, D., Dang, P., & Tarar, M. (2012). Impact of 4D modeling on construction planning.
9. D'Amico, F., Calvi, A., Schiattarella, E., Di Prete, M., & Veraldi, V. (2020). BIM and GIS data integration: A novel approach of technical/environmental decision-making process in transport infrastructure design. *Transportation Research Procedia, 45*, 803–810. https://doi.org/10.1016/j.trpro.2020.02.090.
10. Cheng, J. C. P., Lu, Q., & Deng, Y. (2016). Analytical review and evaluation of civil information modeling. *Automation in Construction, 67*, 31–47. https://doi.org/10.1016/j.autcon.2016.02.006.
11. Chappell, E. (2015). Autodesk bridge design for infraworks 360 essentials-sybex.

12. Mastering-Autodesk-Navisworks-2013.
13. Costin, A., Adibfar, A., Hu, H., & Chen, S. S. (2018). Building information modeling (BIM) for transportation infrastructure—Literature review, applications, challenges, and recommendations. *Automation in Construction*, *94*, 257–281. https://doi.org/10.1016/j.autcon.2018.07.001.
14. Bradley, A., Li, H., Lark, R., & Dunn, S. (2016). BIM for infrastructure: An overall review and constructor perspective. *Automation in Construction, 71*, 139–152. https://doi.org/10.1016/j.autcon.2016.08.019.
15. Structurepoint, A. Increase efficiency. American structurepoint uses autodesk BIM for infrastructure solutions to help increase efficiency on infrastructure projects.
16. Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). Introduction. *BIM handbook*, 1–31. https://doi.org/10.1002/9781119287568.ch1.
17. Pre-proofs, J., et al. (2020). Streamlined bridge inspection system utilizing unmanned aerial vehicles (UAVs) and machine learning. *Measurement*, 108048. https://doi.org/10.1016/j.measurement.2020.108048.
18. Atasoy, G., Tang, P., Zhang, J., & Akinci, B. (2010). Visualizing laser scanner data for bridge inspection. *2010 - 27th International Symposium on Automation and Robotics in Construction ISARC 2010*, 390–399. https://doi.org/10.22260/isarc2010/0042.
19. Fanning, B. (2014). Impacts and benefits of implementing bim on bridge and infrastructure projects. *Mt. Consortorium.*, p. https://www.ugpti.org/resources/reports/downloads/.
20. Civil, C. I. N. (1993). Computing in civil and building engineering. *Computing in Civil and Building Engineering*, 955–1865.
21. Fanning, B., Clevenger, C. M., Ozbek, M. E., & Mahmoud, H. (2015). Implementing BIM on infrastructure: comparison of two bridge construction projects. *Practice Periodical on Structural Design and Construction, 20*(4), 04014044. https://doi.org/10.1061/(asce)sc.1943-5576.0000239.
22. Matejka, P. (2014). The importance of a transport infrastructure construction for the implementation of BIM. In *An international science and conference* (vol. 2014, pp. 1805–6784). www.fce.vutbr.cz/ekr/PBE.
23. Minagawa, M., & Kusayanagi, S. (2015). Study on BIM utilization for design improvement of infrastructure project. *Procedia Engineering, 125*, 431–437. https://doi.org/10.1016/j.proeng.2015.11.113.
24. Li, H., Chan, N. K. Y., Huang, T., Skitmore, M., & Yang, J. (2012). Virtual prototyping for planning bridge construction. *Automation in Construction, 27*, 1–10. https://doi.org/10.1016/j.autcon.2012.04.009.
25. Marzouk, M., & Othman, A. (2020). Planning utility infrastructure requirements for smart cities using the integration between BIM and GIS. *Sustainable Cities and Society*, *57*, 102120. https://doi.org/10.1016/j.scs.2020.102120.
26. Marzouk, M. M., & Hisham, M. (2012). Bridge information modeling in sustainable bridge management. *ICSDC 2011 Integr. Sustain. Pract. Constr. Ind. – Proceedings of the International Conference on Sustainable Design and Construction 2011*, (Vol. 2004, pp. 457–466). https://doi.org/10.1061/41204(426)57.
27. Marzouk, M., & Hisham, M. (2014). Implementing earned value management using bridge information modeling. *KSCE Journal of Civil Engineering, 18*(5), 1302–1313. https://doi.org/10.1007/s12205-014-0455-9.
28. McGuire, B. M. (2014). Using building information modeling to track and assess the structural condition of bridges. *Degree Master Science, Colorado State University* (pp. 1–554).
29. Du, C., Bing, B., Mao, X., Liu, W., Liu, Y., & Xu, Q. (2020). Research on automatic monitoring and early warning system based on BIM smart infrastructure risk. *IOP Conference Series: Earth and Environmental Science*, *455*, 1. https://doi.org/10.1088/1755-1315/455/1/012197.

30. Shim, C. S., Yun, N. R., & Song, H. H. (2011). Application of 3D bridge information modeling to design and construction of bridges. *Procedia Engineering, 14*, 95–99. https://doi.org/10.1016/j.proeng.2011.07.010.
31. Moon, H., Dawood, N., & Kang, L. (2014). Development of workspace conflict visualization system using 4D object of work schedule. *Advanced Engineering Informatics , 28*(1), 50–65. https://doi.org/10.1016/j.aei.2013.12.001.
32. Salamak, M., & Januszka, M. (2015). BIM models and augmented reality for concrete bridge inspections. In *11th central European congress on concrete engineering. CCC2015* (pp. 25–28). https://doi.org/10.13140/RG.2.1.5161.0329.
33. Young Jr., N. W., Jones, S. A., Bernstein, H. M., & Gudgel, J. E. (2009). *SmartMarket report: the business value of BIM*.
34. Page, R., & Ashikian, A. (2016). TR21478-R the future of making bridges. *The Journey*.
35. BIM for Infrastructure, "BIM for infrastructure BIM for Infrastructure: A vehicle for business transformation (pp. 1–18).
36. Kim, K. J., Kim, K., & Kang, C. S. (2009). Approximate cost estimating model for PSC beam bridge based on quantity of standard work, *13*, 377–388. https://doi.org/10.1007/s12205-009-0377-0.
37. Roma, T. I. S., et al. (2020). ScienceDirect integrated railway design using infrastructure-building information integrated modeling. railway design using information the case study of the port of Venice . *Transportation Research Procedia, 45*(2019), 850–857. https://doi.org/10.1016/j.trpro.2020.02.084.
38. Kannan, S. R., & Senthil, R. (2014). Production based scheduling method for linear construction in road projects, *18*, 1292–1301. https://doi.org/10.1007/s12205-014-0431-4.
39. Liapi, K. A. (2003). 4D visualization of highway construction projects 3D graphical modeling framework for visualization, 0–5.
40. Fragkakis, N., Lambropoulos, S., & Tsiambaos, G. (2011). Parametric model for conceptual cost estimation of concrete bridge foundations, *17*(2), 66–74. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000044.
41. Jeong, S., Hou, R., Lynch, J. P., Sohn, H., & Law, K. H. (2017). Advances in engineering software an information modeling framework for bridge monitoring. *Advances in Engineering Software, 114*, 11–31. https://doi.org/10.1016/j.advengsoft.2017.05.009.
42. Kim, C., Kim, H., Park, T., & Kim, M. K. (2011). Applicability of 4D CAD in civil engineering construction: Case study of a cable-stayed bridge project, *25*, 98–107. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000074.
43. Kim, K. J., Kim, K., & Kang, C. S. (2009). Approximate cost estimating model for PSC beam bridge based on quantity of standard work approximate cost estimating model for PSC beam bridge based on quantity of standard work. https://doi.org/10.1007/s12205-009-0377-0.
44. Tah, J. H. M., Carr, V., & Howes, R. (1999). Information modelling for case-based construction planning of highway bridge projects, *30*, 495–509.
45. Markiz, N., & Jrade, A. (2014). Integrating a fuzzy-logic decision support system with bridge information modelling and cost estimation at conceptual design stage of concrete box-girder bridges. *International Journal of Sustainable Built Environment, 3*(1), 135–152. https://doi.org/10.1016/j.ijsbe.2014.08.002.
46. Yin, X., Liu, H., Chen, Y., & Wang, Y. (2020). A BIM-based framework for operation and maintenance of utility tunnels. *Tunnelling and Underground Space Technology*, *97*, 103252. https://doi.org/10.1016/j.tust.2019.103252.
47. Wang, C., Feng, K., Zhang, L., & Zou, A. (2018). ScienceDirect estimating the resistance of aging service-proven bridges with a Gamma process-based deterioration model. *Journal of Traffic and Transportation Engineering (English Edition)*, *6*(1), 76–84. https://doi.org/10.1016/j.jtte.2018.11.001.

48. Srikanth, I., & Arockiasamy, M. (2020). ScienceDirect deterioration models for prediction of remaining useful life of timber and concrete bridges: A review. *Journal of Traffic and Transportation Engineering (English Edition), 7*(2), 152–173. https://doi.org/10.1016/j.jtte.2019.09.005.
49. Fox, K. *Smart market report the business value of BIM for infrastructure.*
50. Hardin, B., McCool, D. (2015). *BIM and construction management_ proven tools, methods, and workflows*. Wiley.
51. Abbondati, F., Biancardo, S. A., Palazzo, S., Capaldo, F. S., & Viscione, N. (2020). I-BIM for existing airport infrastructures. *Transportation Research Procedia*, *45*(2019), 596–603. https://doi.org/10.1016/j.trpro.2020.03.052

Effective Ways to Handle the Change Management for Cost in Various Types of Contracts

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Abstract The usage of change management in project management field that has become crucial change within the construction can be consolidated directly or as project claims. Lots of theories and areas of concerns were spotted and claims consolidated methods and techniques to hunt best practices to resolve such problems between all construction project stakeholders. This study collects data from seven different projects in various locations, and the data sheet was distributed to Contracts professionals. The research gap is addressed by analyzing and plotting the factors affecting the contracts and also the effects of cost, change performance. The validation was carried manually. From the obtained results, there are some factors which show negative impact for contractors to complete the project without delay. The cost variations doesn't show much impact and lump sum contract can be an effective contract to achieve a project budget and on-time delivery. The achieved results can apply for upcoming project to reduce the delay and cost variation in project.

Keywords Contracting methods · Business process management · Construction claims · Change management in contract · Supply management · Cost impact

1 Introduction

Change management is scope that changes from existing contract to revised contract for the scope of works and majorly impacts for Cost and Time of the projects. All the stakeholders are also involved in the process of change management [1]. The major stakeholders are Client, End user, Consultant, Contractor, Project managers, and Contracts manager. One of the major problems faced by constructions projects is issues of variation of works which affects delays in the projects, Negative cash flow, changes in the schedule of projects, etc. [2]. Variations were common in all

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type of the construction projects. Change management is the process of commercial renegotiating with vendor and amendment to the Existing contract. The variations mainly affect Time and cost for the projects. The Time and Cost depends on the scope of the varied works. The Variation instructions would only be valid through writing and confirmed by the Client. The common tool for project planning is risk analysis to scale down the destructive consequences [3]. In 2019, Century decided to invest in coordinating supply management and CFUs, which reflects the need for supply management involvement in services purchasing in Brazil [4, 5]. There was a shortage of workers and overburden for contractors [6]. The existing building are responsible for 40% of the global energy consumption [7, 8]. The variations mainly affect Time and cost for the projects. Change orders are a very common way of altering the work defined in the original contract documents [9]. Number of studies has focused on how change orders affect the projects and results shows that many construction projects over the world are facing issues related to schedule delay and cost overrun [10]. Under contract management 80% of the project value depends on work packages and specialist services [11]. The construction field is one of the rapidly increasing fields in nowadays. Change management is the process of commercial renegotiating with vendor and amendment to the existing contract. It is generally accepted that the cheapest way for an owner to award a contract is by pure and open competition, generally by closed and sealed bids [12, 13]. The nature of construction change order makes assistance and addition of costs will make project complicated during the analysis of project cost. The quality of the building is judged not only on the basis of final delivery but also on its development of factors. In many cases, company will have data regarding the consumption of products and services they sell as well as the social network activity of the clients. Change of the design in construction project causes cost overrun or schedule growth [14]. Before project starts one of the strategies that can be considered is to think about the project and the use of tools.

The impact of events activity schedules of work packages was observed constantly in order to achieve the target cost and duration. The main objective of this study is divided into two divisions: (1) Finding the factors which are effecting the contracts. (2) Investigating the cost impact of change management in contracts. This research mainly focuses on three contracts such as Re-measurable contract, Lump sum contract, and Design and Build contract. The data collections are made with major completed projects in various locations in the India. In the proposed framework, the template sheet is created and shared to the Contract professionals to fill the required details. To analyze the information, recording data is essential. This data sheet analyses and validation were carried out manually and the ranking function is used in identifying the difference between the factors.

2 Data Collection and Methodology

The researcher mainly focused to collect data from Contracts professionals to understand their perspective towards Change management. The template sheet is created and shared to the Contracts professionals to filling the details. By tracing the individual project details, the researcher was able to analyze the information manually and comprehensive data that contains package details, change order type, impact of time, cost impact. The study identified the contracts model, factors driving the change management, and effective ways to handle the change management in the three types of contracts. This study understands the Cost impact and impact details for the different types of projects with three different contracts. The major completed project details in India is mentioned in (Table 1). The speed of construction was defined as the gross floor area in square meters, divided by the construction time in weeks [2].

Table 1 Details of the project

Data collection	Type of contract	Name of project	Details
Project 1	Design and build contract	Phoenix Aquila 12th floor at Hyderabad	Civil, interior, and services works 12th floor—appx area at 47,000.00 Sf.t
Project 2	Re-measurable Contract	Hazel Reality Pvt Ltd for S + 13 floor residential development at Chennai	Mahindra Life Spaces Ltd for S + 13 floor residential development at Hyderabad
Project 3	Lump sum contract	Base build works single block—appx area 1,10,000.00 Sf	Base build works single block—appx area 2,23,000.00 Sf.t
Project 4	Re-measurable contract	M/s. MLDL. Pvt Ltd	Base build works single block—appx area 1,10,000.00 Sf.t
Project 5	Re-measurable contract	ICC Mumbai	Base build works single block -S + 12 floors of commercial development
Project 6	Design and build contract	Commercial development for Ms. Puravankara	Civil, interior, and services works at 08th floor—appx area 35,000.00 Sf.t
Project 7	Lump sum contract	Residential development for Ms. Eden parks	Base build works single block—appx area 1,00,000.00 Sf.t

2.1 Data Analysis

The analysis was carried by ranking function. A ranking is a relationship between a set of items such that, for any two items, the first is either "ranked higher than", "ranked lower than" or "ranked equal to" the second. In mathematics, this is known as a weak order or total pre-order of objects. It is not necessarily a total order of objects because two different objects can have the same ranking. The rankings themselves are totally ordered. For example, materials are totally pre-ordered by hardness, while degrees of hardness are totally ordered. If two items are the same in rank it is considered a tie. The main advantage of the contracting management is combination of design and construction [11]. Any addition deletions or any revisions of the project during the construction to change the scope and goal of the project the management of things are consider to be change management [3]. By reducing detailed measures to a sequence of ordinal numbers, rankings make it possible to evaluate complex information according to certain criteria. Thus, for example, an Internet search engine may rank the pages it finds according to an estimation of their relevance, making it possible for the user quickly to select the pages they are likely to want to see.

3 Results and Discussion

3.1 Re-Measurable Contract Analysis on Impact of Cost

Every construction project goes through the changes in cost [13, 15, 16]. The effectiveness in terms of cost and factors that affects the changing order was measured manually and the results was plotted in Fig. 1 by considering the details in Table 1. Successfully the project completed without much cost variation [17]. The development of project Quantity variation is 12 Lakhs. The main factor that is affecting

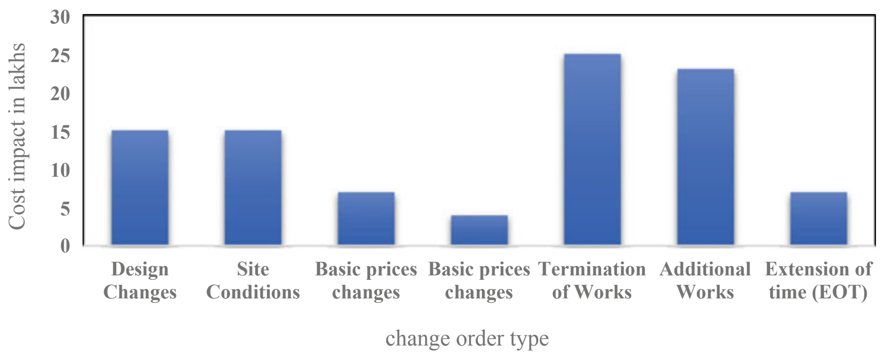

Fig. 1 Impact of cost in various type of Re-measurable contract

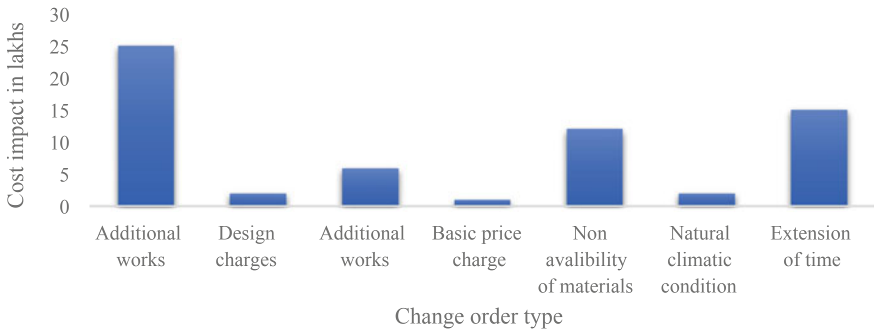

Fig. 2 The Impact of cost in various type of design and build contract

the development of project is Termination of Works. It shows the cost impact of 25 Lakhs. When the finalization of project, client and Project manager have to do the Pre-qualification for all the competitive vendors for all capability like Financial, Technical, Similar completed projects, and similar ongoing projects for avoiding the Termination of the contractor [17]. The Impact of cost in various factors in Re-measurable contracts are shown in (Fig. 1).

3.2 Design and Building Contract Analysis on Impact of Cost

Project management team should aware of detrimental changes that are not always recognized as "detrimental" until problems occurs [13]. If the more change orders are furnished during the construction phase due to design faults, then the cost and time of the design and construction phase varies [14]. The effectiveness in terms of cost and factors affecting the change of order was measured manually and the results was plotted in Fig. 2. Referring Table1, the main factor that is affecting the development of project is additional works and cost impact is 25 lakhs. During the finalization of pre-contract, the client and D&B Contractor must identify and finalize the entire scope of works for reducing the variations. The Impact of cost in various factors of Design and Build contracts is shown in (Fig. 2).

3.3 Lump Sum Contract—Impact of Cost

The effectiveness in terms of cost and factors affecting the change of the order was measured manually and the results was plotted in (Fig. 1). Referring to (Table 1), the main factor that is effecting the development of project is site condition and cost impact is 18 lakhs. During the finalization of pre-contract, the client and Project manager must analyze the Geotechnical report and get proper recommendation from

Fig. 3 The Impact of cost in various type of Lump sum contract

Table 2 Factors affecting in changing in management

Factors driving change management in Re-measurable contracts	Factors driving change management in design and build contracts	Factors driving change management in lump sum contracts
Quantity variations	Additional scope of works	Extension of time (EOT)
Basic prices changes	Basic prices changes	Site conditions
Changes in the design	Changes in the design	Additional scope of works
Extension of time (EOT)	Extension of time (EOT)	
Termination of works	Natural climatic conditions	
Additional scope of works and Site conditions	Due to imported materials (Forex)	

geotechnical consultant for reducing the variations. In lump sum contract there are only few factors which impact on cost. The Impact of cost in various factors of Lump sum contracts are shown in (Fig. 3).

The objective of this study has been achieved through Data Collection survey and with the help of experts in the construction industry. The first objective that has achieved results is mentioned in (Table 2).

3.4 *Factors Driving the Change in Management*

A contract is an offer, acceptance intention to create legal relations, consideration, and legality of both form and content. The factors affecting the three contracts are listed in (Table 2).

The second objective (effective ways to handle the change management in the different type contracts) of this study has been achieved through Data Collection survey and with the help of experts in the construction industry. Based on the data collection survey, the summary table is given below.

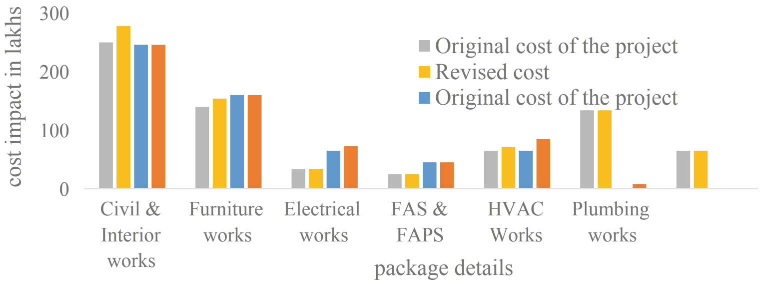

Fig. 4 Cost impact of original contract versus Revised Contract for M/s. Phoenix Aquila and of M/s. Puruvankara

3.5 Original Cost Versus Revised Cost Analysis

Cost variation is founded between original cost and revised cost. From the Fig. 4, there is a cost variation for three factors in design and building contract, such as civil and interior works, furniture works, and electrical works. The cost variation are 28, 14, and 6 lakhs and the remaining 4 factors didn't show any impact. Cost variation is founded between original cost and revised cost. From the (Fig. 4), there is a cost variation for three factors in design and building contract, such as electrical works and HVAC works. The cost variations are 8 lakhs and 20 lakhs. The remaining 3 factors didn't show any impact. The impact of the original project cost versus revised cost for M/s. Phoenix Aquila and M/s. Puruvankara was shown in Fig. 4.

Cost variation is founded between original cost and revised cost. Figure 5 illustrates that there is a cost variation for three factors in Re-Measurable Contract. They are excavation works, civil and structural works, external development works. The cost variation is 15, 55, and 38 lakhs and the remaining 2 factors didn't show

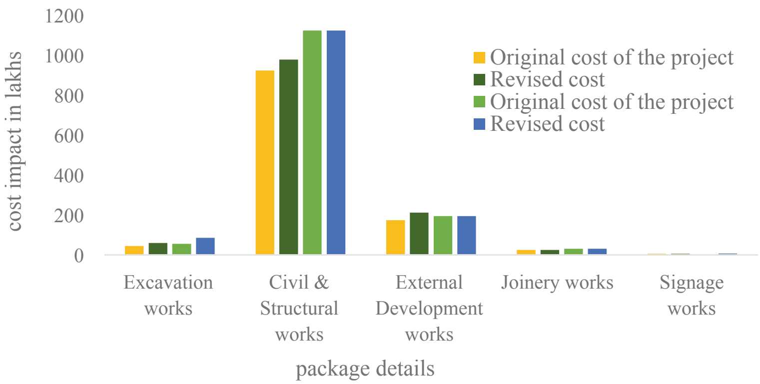

Fig. 5 Cost Impact of original contract versus revised contract M/s. Hazel Reality and M/s. MLDL. Pvt Ltd

any impact. Cost variation is founded between original cost and revised cost. From (Fig. 5), there is a cost variation for three factors in Re-Measurable Contract. This is affecting only 1 factor that is excavation work. The cost variation is 30 lakhs. The remaining 2 factors didn't show any impact. The impact of the original project cost versus revised cost of M/s. Hazel Reality Pvt Ltd and of M/s. MLDL was shown in (Fig. 5).

Cost variation is founded between original cost and revised cost. Figure 6 illustrates there is a cost variation for three factors in Re-Measurable Contract they are external development works, civil and structural works, external development works. The cost variation is 45 lakhs and the remaining 3 factors didn't show any impact The Cost Impact of Original contract versus Revised Contract for M/s ICC Mumbai projects are shown in Fig. 6.

From the results, there is no Cost variation founded between original cost and revised cost [18] So the lump sum contract can be an effective contract to achieve a project for budget and on-time delivery. The Cost Impact of Original contract versus Revised Contract for M/s. Eden parks was shown in (Fig. 7).

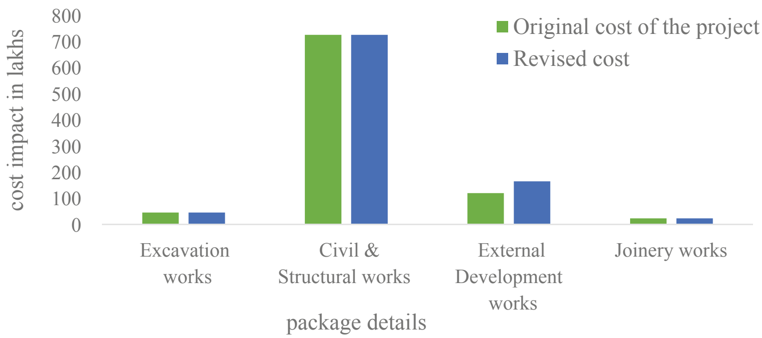

Fig. 6 Cost Impact of original contract versus revised contract of M/s. ICC Mumbai

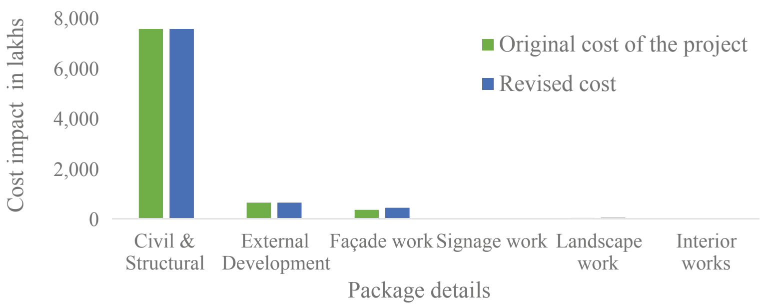

Fig. 7 Cost impact of original contract versus revised contract of M/s. Eden parks

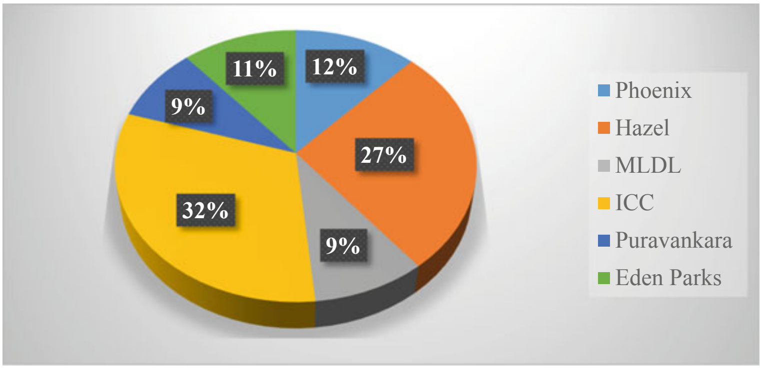

Fig. 8 Net cost impact % for all the projects

4 Overall Impact Details of Project

The major net variation is 27% of the cost. It occurs in the project of M/s. hazel reality Pvt ltd (Fig. 8). The Net cost impact details are INR 108 lakhs. The original project duration of the project is 245 days and revised project duration of the project is 287 days. The net impact details of duration are 25 days.

5 Conclusion

An attempt has been made to make a cases for re-measurable, Design and building, lump sum contracts. The researcher feels that this approach to construction field may be of help for further studies. This study identifies the contracts model, factors driving the change management, and effective ways to handle the change management in three types of contracts. This study was understanding the Cost impact and impact details for the different types of projects and different types of contracts.

- The first objective of this study is to identify what are the factors driving change management in various types of contracts. This has been achieved based on the data collection and analysis. The objective of this study has been achieved through Data Collection survey and with the help of experts in the construction industry.
- Quantity Variation, Basic prices changes, Changes in the design, Termination of works, Non available of materials, Additional scope of works, and Site conditions.
- The second objective of the study is achieved based on the data collection, the analyzed results for M/s Hazel Reality project. The original cost of the project value is INR 11.75 crore but after the variations the final cost is INR 12.83 crore. The net variation is INR 1.08 Crores.
- Re-Measurable contracts were operated in this project. The analyzed results are to cross verify the quantities with available GFC drawings, to identify and finalize

site feasibility report as per the site conditions, to Pre-qualification for all the competitive vendors for all capability like Financial, Technical, Similar completed project in such ways to avoid variations and effectively to handle the variations.

- For M/s Phoenix Aquila project the net variation is INR 48 Lakhs. Design and build contracts were operated in this project.
- The analyzed results are to identify and finalize the entire scope of works for reducing the additional scope of works, to identify the additional works, Design changes and Non-availability of materials to avoid the extension of time, in such ways to avoid variations and effectively to handle the variations.
- For M/s MLDL project the net variation is INR 37 Lakhs. Lump sum contracts were operated in this project, to analyze the Geotechnical report and get proper recommendation from geotechnical consultant, to finalize the entire scope of works for reducing the variations of Additional work, to identify the additional works in such ways to avoid variations and effectively to handle the variations.
- The minimum variation is 9% and maximum variation is 27% for M/s. Hazel reality Pvt ltd of this project. The net variation is 108 lakhs. In this study, we understood effective ways to manage to variations. In this achieved result to apply for upcoming project will be avoid the variations.

References

1. Abdel-Khalek, H. A., Aziz, R. F., & Abdellatif, I. A. (2019). Prepare and analysis for claims in construction projects using Primavera Contract Management (PCM). *Alexandria Engineering Journal 58*(2), 487–497.
2. Barbos, A. (2019). Dynamic contracts with random monitoring. *Journal of Mathematical Economics, 85*, 1–16.
3. Ibbs, W. C., & Wong, C. K. et al. (2001). Project change management system. *American Society of Civil Engineering, 17*(3), 159–165.
4. Duah, D., & Matt Syal, M. G. (2017). Direct and indirect costs of change order. *American Society of Civil Engineering, 22*(4).
5. De Giovanni, P. (2020). Blockchain and smart contracts in supply chain management: A game theoretic model. *International Journal of Production Economics, 228*, 107855.
6. (Bud) Griffis, F. H., & Butler. M. (1987). Case for cost—plus contract. *American Society of Civil Engineering, 114*, 22264.
7. Huimin, L., Xinyue, Z., & Mengyue, H. (2019). Game-theory-based analysis of Energy Performance Contracting for building retrofits. *Journal of cleaner production 231*, 1089–1099.
8. Jadbabaie, A., & Kakhbod, A. (2019). Optimal contracting in networks. *Journal of Economic Theory, 183*, 1094–1153002E.
9. Choi, K., Woo Lee, H., et al. (2016). Time cost performance effects of change order from accelerated contract provision. *American Society of Civil Engineering, 142*(3), 04015085.
10. Li, Y., et al. (2019). Design and management of a distributed hybrid energy system through smart contract and blockchain. *Applied Energy 248*, 390–405.
11. Naoum, S. G. (1995). Critical analysis of time and cost of management and traditional contract. *American Society of Civil Engineering, 20*, 687–708.
12. Smolander, K., Rossi, M., & Pekkola, S. (2021). Heroes, contracts, cooperation, and processes: Changes in collaboration in a large enterprise systems project. *Information and Management 58*(2), 103407.

13. Sun, M., & Oza, T. (2008). A benefit measurement framework for an online contract change management system. *Tsinghua Science and Technology, 13*(S1), 205–210.
14. Shrestha, P. P., & Mani, N. (2012). Impact of design cost on design bid build project performance. In *Construction research congress 2012: Construction challenges in a flat World*.
15. Vidogah, W., & Ndekugri, I. (1997). Improving management of claims: Contracts perspective. *American Society of Civil Engineering 13*(5), 37–44.
16. Chadwik, W. L. (1996). Impact of design, construction and cost on project quality. *American Society of Civil Engineering, 112*, 69–79.
17. Sathvik, S. Krishnaraj, L. (2020). A case study on impact of labours sleep deprivation in construction project using application method. *IOP Conference Series: Materials Science and Engineering, 912*(6), 062055.
18. Wang, X. (2019). Valuation of new-designed contracts for catastrophe risk management. *The North American Journal of Economics and Finance 50,* 101041.

Investing the Application of Resource-Constrained Project Scheduling Problem in a Single-Mode Construction Project

Priyanka Devagekar and M. Balasubramanian

Abstract Building information modeling (BIM) is used for 3D modelling, but due to the recent developments, it achieved various advancements. In the past few decades, the most challenging combinatorial optimization scheduling problem is solved by the Resource-Constrained Project Scheduling Problem (RCPSP) method. The extension of RCPSP is still in the account. However, an integration of the Building Information Model (BIM) which supports RCPSP is still deficient. This paper presents the easy data transfer from the information standard to the RCPSP standard with construction scheduling objectives. A work-package-based information model seizes the entire data of RCPSP. Both semiautomatic and manual tasks are introduced for workflow. This paper focused on genetic algorithm techniques to solve Resource-Constrained Project Scheduling Problem. This paper's novel appeal integrates actual construction data and the formation of effective solutions using an algorithm. Simultaneously, the work-package-based information is beneficial in the future for a similar project. The extension of BIM and comparison of the various algorithm can be determined in the future.

Keywords Algorithm · Scheduling · Resource constraint · Optimization · Data integration

1 Introduction

In construction management, the importance of scheduling cannot be neglected since it plays an essential role. It manages the delay and limited resource availability. In Reference [1], the basis term "planning and controlling" is the project objective provided by construction scheduling. In the early days, CPM and PERT were used

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to manage the project schedule. However, the logical dependencies of assuming infinite resources were not reasonable in real-life project problems, and constraints assumptions follow certain limitations. In Reference [2], genetic algorithm (GA) is proven to be effective when the deadline duration of the project is not specific and resources are constrained with availability or duration.

The highlight advantage of CPM is managing both critical and near-critical activities, primarily in large projects. The optimal solutions are not obtained and follow constraint restrictions, leading to other techniques known as Resource-Constrained Project Scheduling Problem. It is also known as an NP-hard problem and termed complex than CPM. It aims to minimize the project duration, relates to resource availability and precedence constraints. RCPSP problems are used for various information such as duration of project, earliest start time and end time, slack time.

The general objective of RCPSP is to minimize project duration and determine the start day of each activity such that both resource and precedence constraints are satisfied. RCPSP has various features like single-mode, multi-mode, renewable or non-renewable, preemptive, or non-preemptive. An algorithm such as heuristic and metaheuristics is used to solve RCPSP. It consists of activities and resources with available information of activity duration, precedence relation, resource availability, and resource demand. Recently, RCPSP is evolved with a solution by various methods. In the present scenario, most construction industry schedules the project by formulating software. Actual project data input needs a trusted structural data source which is discussed in this paper.

Building Information Modeling (BIM) is a representative model of building components with physical or functional characteristics. It places an appropriate solution due to its ability to store information and interlinking software for data exchanges, which boosts the project's work performance. For construction projects, BIM provides extensible data integration and an entire life-cycle approach [3]. BIM can link with a bill of quantities and also with enterprise resource planning information. The BIM technology has recently overcome the challenge of producing a 4D schedule from 3D. These involve the capacity to visualize construction progress, individual object and solve construction collisions. Due to this, the 4D schedules are available for use in a variety of commercial software. BIM-based 6D project management is also introduced with the addition of cost, progress, and safety information.

The information provided by BIM is not sufficient, so few researchers followed the extension of IFC. Industry Foundation Classes (IFC) is an enabler research hotspot in the AEC industry. Reference [4] exported schedule data from Industrial Foundation Class (IFC). BIM software is obligate for both experts and non-experts for the acquisition of flexible and practical data. The extension of IFC is provided in few papers as a data source. But most used the BIM-based information modeling method to cover the gap of details.

In Reference [5], genetic algorithm has been introduced. This research used a genetic algorithm (GA) for solving single-mode construction projects. In References [6, 7], genetic algorithm is selected for solving RCPSP because it is complementary in several aspects. This algorithm is categorized under metaheuristic and heuristics methods. Coding is inherited to design an algorithm. A recent function of the genetic algorithm is highlighted due to efficient and accurate results. The specific parameter study on the genetic algorithm is neglected in this study.

2 Literature Search

2.1 Resource—Constrained Scheduling Problem in Single-Mode Construction Projects

When jobs executed by resource requirement are constrained, then we have resource-constrained project scheduling either in single-mode or multi-mode RCPSP [8]. Single-mode presents that each project's activity has single execution or single-mode, and both activity duration and its requirement are assumed to be fixed. The recent research on single-mode RCPSP followed data sources from Project Scheduling Library (PSPLIB) with the adequate performance of the proposed two-stage multi-operator differential algorithm with opposition to a recent familiar state-of-the-art algorithm in resultant of compelling and competitive solution [9]. The main objective for single-mode RCPSP (SM-RCPSP) is to determine the proper activity schedule.

2.2 Building Information Modeling (BIM) Schedule

BIM with various standards has been studied for at least 30 years. Each literature on BIM has individual aspects such as data exchange standard, future usage of BIM. The integration process of BIM is technical, and few researchers discussed it. In the planning phase of construction, the productivity is predicted by Building Information Modeling (BIM) integrated simulation framework designed by surveying critical factors that affect productivity at the functional level [10]. The extensive usage of BIM in construction has not yet stretched to its full capacity. Reference [11] presented the integration of schedule with work package information, algorithm, and process simulation which lead to ease the flow of the automatic formation of optimized activity for panelized building projects under resource constraints.

2.3 Genetic Algorithm (GA)

The genetic algorithm (GA) method is a valuable procedure to solve resource-constrained project scheduling problems. Reference [12] proposed a novel approach based on a genetic algorithm that automatically forms an optimal solution for a specified architectural in IFC format to formulate multiple objectives. Reference [13] introduced certain modifications to the Genetic Algorithm system.

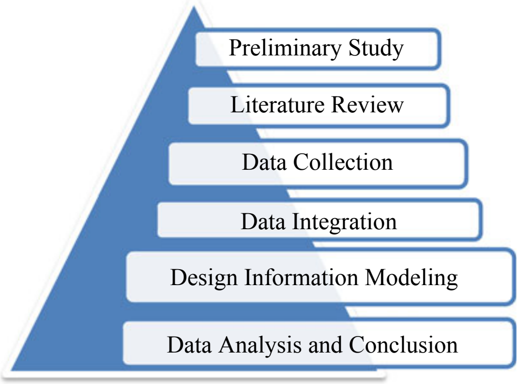


Fig. 1 Methodology of research

3 Methodology

3.1 Research Methodology

The methodology of this project includes six steps as shown in (Fig. 1). In detail the research problem is identified and the literature is studied to fill a gap. The literature study helps to gain knowledge on a particular topic and represents the various methods or tools been used to date. The next core step is data collection. The data related to RCPSP such as activities, duration, precedence relations, and new work templates are generated. The second core step is data integration. Into integration part both the above-mentioned steps, work package templates from BIM are integrated with new work package templates. The available data is then integrated with the BIM. In the last step, scheduling details are solved by using an algorithm. The final step is to analyze the data by setting it into commercial software.

3.1.1 Data Integration

Build on a literature study of RCPSP information demand using the Object-Oriented Modeling (OOM); data source structures as shown in (Fig. 2). These design structures generate a new work package template that expresses engineering experience. The work package template is utilized to a category all tasks together to organize the work effectively. In this study, the work package used is called work package instances which present construction project information. The work package instances consist primarily of information and resources. From the work package template database, the work package instances are initiated, and from the database, resources are directly ejected. The BIM and work package templates are integrated depend on present data. Basic quantity in building elements refers to the area, volume, weight, and length of

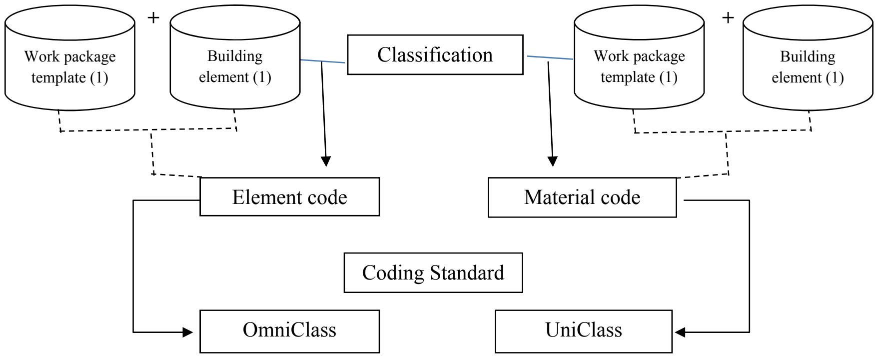


Fig. 2 Integration between BIM and work package template

the building. Element types are classified into two codes: material code and element code. The primary material is added manually.

3.1.2 Link Between BIM and Work Package Template

According to company or national level elements, the levels of detail in BIM and organized standards are classified by codes. They permit the management of project reports, estimate cost, and define material specialization. The two classification codes: material codes and element codes, use coding standards, such as UniClass and OmniClass (OCCS). The efficient result between building elements and the work package template is assured by correlating the BIM and work package templates with similar classification codes. The table under both coding standards (table Ef and Table 21) is used to structure the element code specification and add to building elements throughout the project's design phase. The two codes are linked when the work package template contains the element code of the building element. One work package template has one element code as it is parallel to one building element. The work, which includes multiple elements such as reinforcement, scaffolding, or form-works, has various work package template with different element categories. For the association of BIM and work package templates, the material code of UniClass and OmniClass (Table Pr and Table 23) is used, but this is also used during work instantiation, as shown in (Fig. 2).

The material and classification code in work package templates includes quota. The quota is defined as a type of activity with a list of required resources and every item in the record delivers an essential amount of one resource per unit quantity conforming to the activity type. Multiple material codes may persist in both BIM and work package templates. An element code tree "first matching" operation of the BIM and work package template is a deal at the starting step. The algorithm design is used to deal with the code tree's depth and abbreviate Nw as an integer of work package templates, Ne integer of building elements. The time complexity of

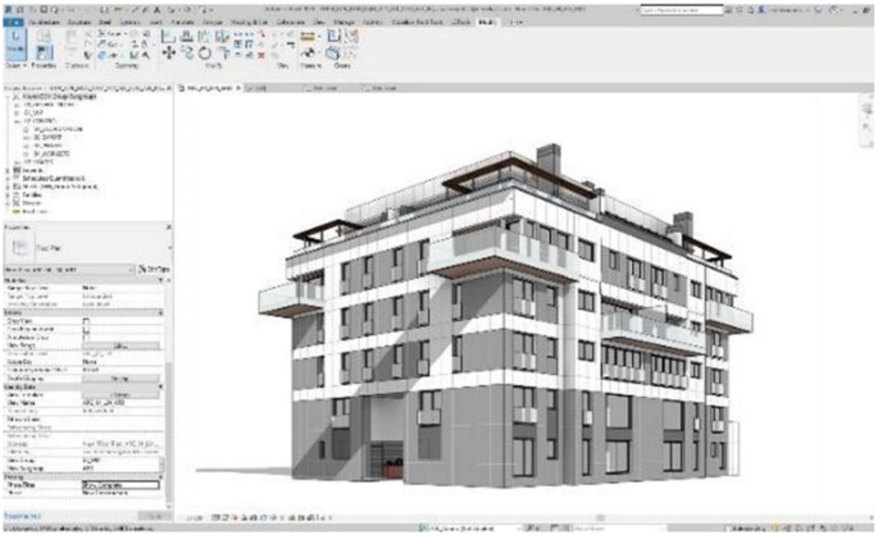


Fig. 3 Linkage between BIM and work package template

the matching process is O(Ne.D + Nc), and the time complexity of the building step is O(Nw.D). This time complexity of the algorithm is entirely dependent on Nc as well Ne. At the next step, “second matching” is proceeded by excluding the elements which restrict the matching concept of material code. The straightforward matching solution can assure material code in building elements included by the work package template’s material code. After two steps of the matching process, links were formed between BIM and the work package template as shown in (Fig. 3).

After linking work package templates and building elements, the next phase is to create a work package template using the construction area. We considered each floor as construction areas: hence, each floor’s instances would be generated with building elements by work package templates.

3.1.3 Work Package Instantiation and Reorganization

To certify building elements linked with each instance, use a similar quota work package instances that are reorganized. Building elements are divided into groups of construction areas and generate instances for each work package template. This is done by crossing all building elements and determining whether conditions of quota meet their properties. A new work package is designed when building elements use a new quota. The present quotas and their quantities have been determined and can be used for scheduling after reorganizing. While using a new quota merger in building elements, a new work package instance is formed.

3.1.4 Sequel Arrangement

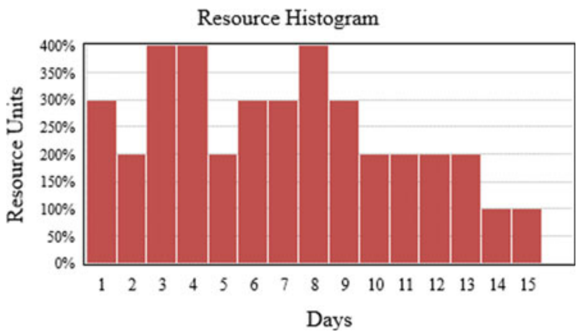
The work package instance details make the automated process possible. In construction, the events' pattern is arranged and defined as a "precedence relation" and designed in work package instances. This paper focuses on sequential logic, which is technical precedence relation followed in construction based on the primary rule. The rule descriptions are depending on element category, spatial, and construction location. The precedence relations in work package instances can be formed by exploring the attributes after describing the rule. These rules specify settings, precedence relation, and one description specify a set of work package instances, and multiple descriptions specify intersections of these sets.

3.1.5 Scheduling Process

In this paper, the scheduling problem is solved by using a genetic algorithm (GA). The objective of the algorithm is to decide the project's shortest duration with specified resource units. Alternatively, the resource allocation and leveling are done. The entire project duration determined by classic CPM analysis is 32 days by considering only the main activities of the project without eliminating resource over-allocation as shown in (Fig. 4). This duration extends to 78 days by resource allocation as well as resource leveling in software terminology.

The blind parameter of the algorithm is considered while carrying out the RCPSP problem with an extended duration. To encode a feasible solution to the optimization problem, GA requires a representation scheme. The primary operator systems of the genetic algorithm are reproduction, crossover, and mutation. A set of genes are formed and joined together, which form chromosomes. Chromosomes are viewed in form boxes as shown in (Fig. 5). Each gene in a box represents an activity on the mode. The position of the activity in the critical path can be viewed through the number on the box. In reproduction, the individual is formed, which generates next-generation production of offspring. From the population, the parents are randomly selected and recombined. Using two operators, crossover and mutation, the chromosome solution

Fig. 4 Resource histogram



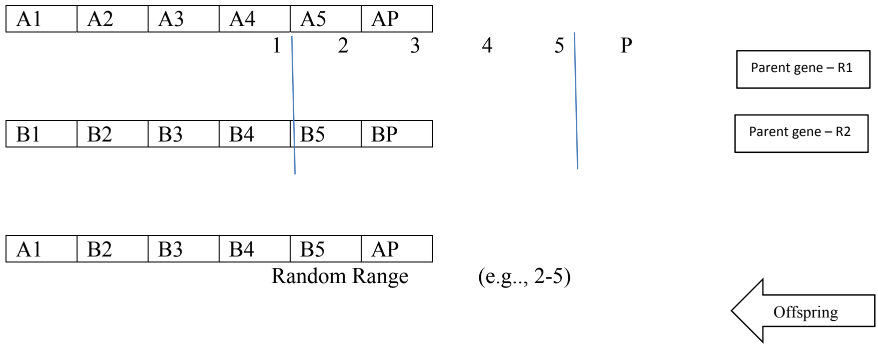


Fig. 5 Elements of genetic algorithm

is examined with criteria. Objectives evaluate the fitness solution. If the objectives satisfy, then it is a feasible solution or best solution; otherwise, it is an infeasible solution and repeats the process of evaluating the next population until getting a suitable solution. At initial, the priority for each activity is made by considering its predecessors or successors. The new chromosome is modeled in the population by interchanging the place of activities, which has a similar priority.

The parts of a good solution are recombined and obtained to form a new solution by crossover operator's probabilities. The selection of a good solution is done randomly, which leads an individual to a better solution. The two individual parents' cell are denoted as $R1$ and $R2$. s is the number selected randomly from $A1$ and AP. The crossover operator obtains new individual T1. $T1$ contains $R1$ and $R2$ from the position $I = 1$ to P. Next proceeds to mutation which alters the divisions of chromosomes from the initial stage. During the mutation process, the solution alters from the previous one and determines the appropriate result. At the final stage, some of the organisms are carried to the next generation from the current generation, resulting in an effective solution.

4 Conclusion

Scheduling of resources decides when the project will start and how the process is carried. Such decisions can cause a great impact on the total project. In this research, the outcome of the result shows the feasible application of BIM with coordination to both work package templates and algorithms (GA). The integration process of BIM enables coherent data flow from information standards to RCPSP standards. The genetic algorithm approach is an efficient method with extension in further performance and makes it possible to use in the construction industry with benefits. Additionally, the formation of RCPSP solution using the newly proposed approach takes less duration as compare to the manual solution. Also, the information model fills complete details of the project by eliminating duplication of work.

Further, BIM is expected to discover more objectives for different RCPSP model and to store more relevant data as cost estimation, resource details, and safety components. Even the tracking of schedule can be developed to automatic progress or software-based solution which is still lacking. Finally, the limitations detected for the model are: the machinery resources or crews are neglected, the algorithm parameters were not considered and this study neglects preference on dead stock or wastage of resources factor and expected to carry for future research work.

References

1. Yeoh, J. K. W., Nguyen, T. Q., & Abbott, E. L. S. (2017). Computing in civil engineering 2017: sensing, simulation, and visualization, Fhwa 2015 (p. 427). https://doi.org/10.1061/9780784480830%0A. https://doi.org/trid.trb.org/view/1558360.
2. Hegazy, T. (1999). Optimization of resource allocation and leveling using genetic algorithms. *Journal of Construction Engineering and Management, 125*(3), 167–175. https://doi.org/10.1061/(asce)0733-9364(1999)125:3(167).
3. Pinheiro, S., et al., (2018). MVD based information exchange between BIM and building energy performance simulation. *Automation Construction*, *90*, 91–103. https://doi.org/10.1016/j.autcon.2018.02.009.
4. Kim, H., Anderson, K., Lee, S., & Hildreth, J. (2013). Generating construction schedules through automatic data extraction using open BIM (building information modeling) technology. *Automation in Construction, 35*, 285–295. https://doi.org/10.1016/j.autcon.2013.05.020.
5. Kolisch, V., Hartmann, S. (1999). Heuristic algorithms for the resource-constrained project scheduling problem: Classification and computational analysis (pp. 147–178). https://doi.org/10.1007/978-1-4615-5533-9_7.
6. Kumanan, S., Jegan Jose, G., & Raja, K. (2006). Multi-project scheduling using an heuristic and a genetic algorithm. *International Journal of Advanced Manufacturing Technology*, *31*(3–4), 360–366. https://doi.org/10.1007/s00170-005-0199-2.
7. Mendes, J. J. M., Gonçalves, J. F., & Resende, M. G. C. (2009). A random key based genetic algorithm for the resource constrained project scheduling problem. *Computers and Operations Research, 36*(1), 92–109. https://doi.org/10.1016/j.cor.2007.07.001.
8. Adamu, P. I., Okagbue, H. I., & Oguntunde, P. E. (2019). A new priority rule for solving project scheduling problems. *Wireless Personal Communications, 106*(2), 681–699. https://doi.org/10.1007/s11277-019-06185-5.
9. Sallam, K. M., Chakrabortty, R. K., & Ryan, M. J. (2020). A two-stage multi-operator differential evolution algorithm for solving Resource Constrained Project Scheduling problems. *Future Generation Computer Systems, 108*, 432–444. https://doi.org/10.1016/j.future.2020.02.074.
10. Jeong, W. S., Chang, S., Son, J. W., & Yi, J. S. (2016). BIM-integrated construction operation simulation for just-in-time production management. *Sustain., 8*(11), 1–25. https://doi.org/10.3390/su8111106.
11. Liu, H., Al-Hussein, M., & Lu, M. (2015). BIM-based integrated approach for detailed construction scheduling under resource constraints. *Automation in Construction, 53*, 29–43. https://doi.org/10.1016/j.autcon.2015.03.008.
12. Tafraout, S., Bourahla, N., Bourahla, Y., & Mebarki, A. (2019). Automatic structural design of RC wall-slab buildings using a genetic algorithm with application in BIM environment. *Automation Construction*, *106*, 102901. https://doi.org/10.1016/j.autcon.2019.102901.

13. Li, H., & Love, P. (1997). Using improved genetic algorithms to facilitate time-cost optimization. *Journal of Construction Engineering and Management, 123*(3), 233–237. https://doi.org/10.1061/(asce)0733-9364(1997)123:3(233).

Identification of Cost Over Run Issue in Preventive Management in Construction Workplace—Chennai

M. Balasubramanian, T. L. Abinaya, V. R. Prasath Kumar, and S. Gopinath

Abstract Nowadays, construction industry is one of the cannonading industries that has a great impact on the economy of any nation. This report identifies the cost overrun issues in construction companies using preventive management activities in Chennai. A preventive management survey has been conducted in construction companies based on a literature and questionnaire survey. There are many serious hazards in the construction industry, including falling or being struck by heavy construction equipment, combined with the associated financial loss resulting from budget overrun, worker's compensation, indirect cost hikes, and impact of the profitability of any constriction operation. This paper aims to find the influencing factors causing accidents and thereby giving importance to those factors and preventing it from an occurrence. The most influencing factor has been identified through a questionnaire survey. The information has been assessed using statistical analysis to understand the circumstances well which will help scrutinize the factors. The tests such as reliability, ranking by RII (Relative Importance Index), and correlation for all the attributes were found to be good and so the data collected was highly consistent. The correlation test has been done and few factors are highly correlated. The RII has been calculated for every attribute and it has been found that effective preventive management can reduce the indirect cost and also avoid cost overrun and budget overrun. This study also proposes that the government should pay attention to enhancing legal enforcement and organizing safety training programs.

Keywords Construction management · Cost overrun · RII (Relative importance index) · Construction safety · Effective preventive management

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1 Introduction

All over the world, construction is one of the most hazardous industries due to its unique nature. The Indian economy has been on a very positive development curve for years now, posting impressive growth rate percentages. The Indian construction industry is an important part of the country's economy and growth, as well as a conduit for a significant portion of India's development investment [1]. The construction industry employs roughly 31 million workers, accounts for 6–8% of GDP, and is the country's second-largest employer after agriculture. In general, it has grown at a 9–11% annual rate, owing primarily to the strength of increased domestic and international manufacturing activities and industrial growth. Both practitioners and researchers are always concerned about construction safety. All the factors influencing safety performances in the construction industry were identified by workers' attitudes, construction company size, security policies, project coordination, economic pressure, management training, and safety culture. Construction sites are hazardous environments where workers can be injured, killed, or become ill [2]. It can be due to electrocution, height loss, injuries caused by tools, equipment, and machinery; moving vehicles, injuries caused by manual operations, and diseases caused by dangerous substances like dust and chemical products. Even a nail coming from a discarded piece of wood, if used with inappropriate footwear, can cause serious injury.

Accident statistics in India's construction industry are scarce [3]. In India as well as in a number of other countries, including developed ones, building industry accidents are common. UK, US, and other countries' statistics show a very large potential for hazards and fatal accident incidences in the industry. In the United Kingdom, for example, the average annual accident rate for 1000 building workers is about four times the combined rate for all manufacturing industries.

2 Problem Statement

In India, preventive measures in construction are a source of concern. The construction industry in India is the most vulnerable segment of unorganized labor. It is estimated that approximately 165 workers per 1000 are injured in the construction industry [4]. The construction industry has four to five times the number of fatal accidents as the manufacturing industry. Many construction professionals are exposed to accidents at work and health issues, including manual handling, noise, and vibration, as well as exposure to various hazardous substances, such as concrete, asbestos, soldering fumes, etc. For a construction company, accidents and disease can be extremely costly. If a worker is ill or injured by negligence unlawful, compensation may be requested that is significant if the damage or disease is serious. The basic goal in any industry is to complete the project on time and within the budget. It's the same in the construction industry. The construction industry, which is one of the most complex, fragmented, schedule-driven, and resource-driven industries, is constantly confronted with serious issues such as preventive management, low productivity, low quality, delay, cost overrun, and so on.

Construction injuries affect both the worker and the worker themselves directly. All consequences are personal injuries to the wounded worker, delays in construction, loss of productivity, higher insurance premiums due to injuries, and the possibility of liability suits for all project participants [5]. Many other indirect implications are also present, such as loss of income on the part of the owner as a result of late project delivery and lower labor morals. This study describes the results of the research in preventive management of the Indian building industry in Chennai in literature and questionnaires.

2.1 Barriers to Implement Preventive Management

The country's economy has become more dynamic and complex. As a result, economic measurement and analysis, particularly in relation to cost overruns in safety, have become more difficult and complicated. The main issue is lack of expertise or resources, tight project deadlines, the fragmented nature of the construction industry, incorrect perception or underestimation of risk, onerousness, and variability of legislation, and a lack of safety awareness. This process is further complicated by the collection of questionnaire surveys from the industries [6]. Questionnaire survey data is quite difficult to collect and sorting resulting from variations in the importance given to the preventive measures by the industries. Much effort has been expended in determining the factor that influences preventive management. Apart from that, some factors influencing the occurring of accidents are more as a Safety net, Work environment, Scaffolding, Welding and Electric, and Underground services.

2.2 Importance of Cost Overrun in Preventive Management

The construction industry, which employs the most people in the country, has been responsible for approximately 11% of all occupational injuries and 20% of all occupational deaths. At all times, health and safety must be prioritized in all aspects of construction [7]. The construction industry is rife with hazards and the potential for accidents. Accidents can occur as a result of poorly implemented health and safety techniques, design, and management. Illness and, in extreme cases, death accidents cost a lot of money. However, the financial cost is not the only reason why a contractor should be aware of preventive measures.

3 Research Methodology

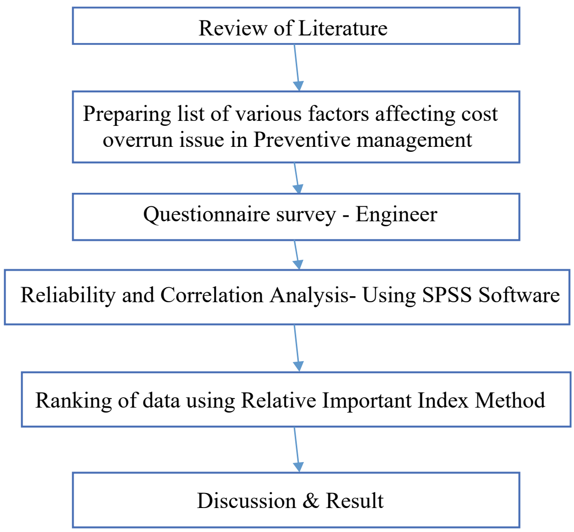
The first step of the research discusses the background, various definitions, measurements, problem statements, misconceptions, and facts related to the cost overrun issue in preventive management. The second step focuses on the previous study about cost overrun and preventive management issues and preparing various factors affecting it from the professional journals and texts. The third step of this research is the preparation of the questionnaire and based on the various factors the cost overrun issue in preventive management [8]. The fourth step of the research is a personal survey and data collection from the Project Managers, Assistant Project Engineer, Site Engineer, Site Supervisor, and Engineer. The fifth step of the research is data analysis. The Relative Importance Index (RII) method is used to perform the required analysis. Further comparison, results, and discussions will be made after analyzing the data. The methodology of the project is explained in a flowchart (Fig. 1).

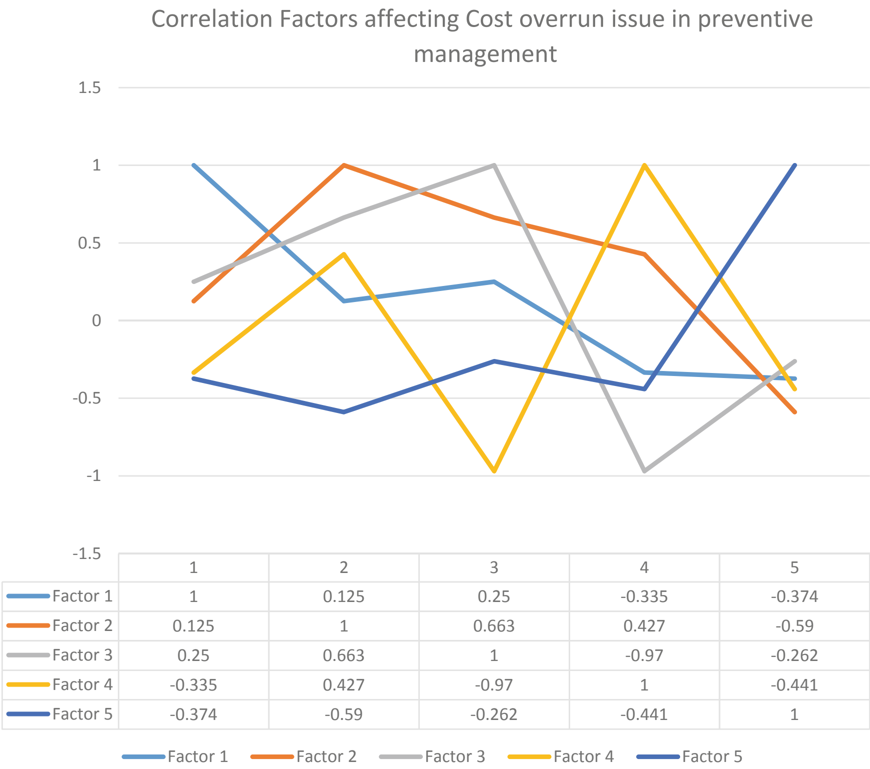
Hypotheses shall be stated and data from the RII analysis will be used for testing. Further SPSS software shall be used for reliability analysis, correlation analysis shall be carried out to verify the reliability and correlation between the values collected during the questionnaire survey (Fig. 2).

3.1 Questionnaire Survey

Collecting general information on various factors influencing the cost overrun issues in preventive management in building construction was the basic aim of the survey. Questionnaire survey is used to collect data either by direct interview or by site

Fig. 1 Flowchart of research methodology





	1	2	3	4	5
Factor 1	1	0.125	0.25	-0.335	-0.374
Factor 2	0.125	1	0.663	0.427	-0.59
Factor 3	0.25	0.663	1	-0.97	-0.262
Factor 4	-0.335	0.427	-0.97	1	-0.441
Factor 5	-0.374	-0.59	-0.262	-0.441	1

Fig. 2 Correlation factors affecting cost overrun issue in preventive management

investigation. A comprehensive assessment of probability, occurrences, and impacts on project goals has been conducted on the basis of several building firms in and around the region of Chennai [9]. The questionnaire is also distributed by mail, verbal commitment through telephone to participate in the survey. A web-based survey format questions will take less time and cost the researcher less money, while allowing respondents to answer freely. However, in comparison to face-to-face interviews, the response rate for this approach usually is lower. To ensure proper follow-up to the error reduction procedure, respondents were fully explained about the purpose and approach employed in the survey. During the survey period, some monitoring was done to ensure that the process was run smoothly and consistently. The questionnaire survey was conducted among 34 site engineers and labors of different construction firms.

4 Data Collection and Analysis

Collecting general information on various factors influencing cost overrun issues in preventive management in building construction was the basic aim of the survey. To achieve the objective of the project successfully, it is the most important phase to collect accurate and reliable data from the project manager, assistant project manager, site supervisor, and engineer [10]. Data collection is a process through which the critical data collection, sample observations, or population of observations can be collected. For the research study, questionnaires were given to the respondents in person, a brief discussion on cost overrun issues in preventive management was conducted. Further, the intentions of the project have been explained to rate the degree of effect precisely. Reasons for the degree of effect marked have also been discussed with the respondents. Responses were collected on an individual basis and also interviews were conducted with respect to questionnaires distributed.

4.1 Reliability Analysis—Using SPSS Software

Reliability analysis has been carried out to verify the internal consistency of the data having multiple scales. This test is to find whether the information collected is fit for analysis. Here, the Cronbach α test was used to verify the internal consistency of the survey questionnaire. To prove the consistency level of the questionnaire, the Cronbach α value should be greater than 0.7. The Cronbach α value for the factors affecting cost overrun issue in preventive management in the view of respondents is found to be 0.758 so the data collected were consistent and they are fit for analysis [10].

4.2 Data Analysis—RII Method

It is widely believed that there may be disturbances with varying degrees of danger during various construction projects. In order to deal with these differences, three conditions were taken into account: The three evaluation levels are excellent, satisfying, and unsatisfactory. In order to distinguish the degree of each adverse level, it was necessary to clearly specify the standard conditions. For prevention factors, the concept of different levels of severity had been used by other studies [11, 12]. After reviewing the typical conditions with the participants during the pilot survey, minor changes were made. In addition, a detailed questionnaire survey was created to rate the factors influencing cost overruns in building construction preventive management. The level of measurement must be investigated in order to select the most appropriate technique of study. There is a method that can be used for each type of measurement. Ordinal scales were used in this study.

4.3 Method of Analysis

A plan for collecting field information and developing an assessment process and numerical values was drawn up to facilitate the study. In order to ensure a clear understanding of all applicable definitions, procedures, and guidance used in the data collection, it was necessary to provide direct communication with respondents. Results of the survey were analyzed with the RII method. Ranking by engineers, the site supervisor, and the project manager of various factors according to their importance. The RII was used to determine the views of different respondents in building projects. RII is calculated as stated below (1).

$$\text{RII} = \frac{W}{A} x N \tag{1}$$

where W-Weight given to each factor by the respondents range from 1 to 3.
H-Highest weight 3.
N-Total number of responses collected for the ordinal scale.

The RII is used in preventive management to classify the different factors affecting the cost overrun problem. This classification allows the relative importance of the factors that the respondents perceive to be cross-comparable. Each RII factor that all respondents perceive should be used to assess the overall ranking of each individual factor to provide an overview of the issue.

5 Result and Discussion

5.1 Ranking of Factors by RII Method

Table 1 shows the RII value for the highest five factors that affect cost overrun issues in preventive management in building construction. It also clearly depicts that the top factors are work environment, safety net, scaffolding, welding and electric,

Table 1 RII value for the factors that affect cost overrun issue in preventive management

S. no	Factors affecting cost overrun issue in preventive management	RH (Weighted average)
Factor1	Safety net	78.17
Factor2	Work environment	78.38
Factor3	Scaffolding	77.88
Factor4	Welding and electric	77.00
Factor5	Underground services	76.14

underground services [13]. This bar chart representing the factors that affect the cost overrun issue in preventive management. Further, Fig. 1 shows the relative importance index of the various responses for individual factors are safety net, work environment, scaffolding, welding and electric, underground services respectively.

5.2 Correlation Analysis—Using SPSS Software

The correlation test helps to determine the strength of the association among the variables as well as to establish a mutual connection between two or more variables [14]. It is important for the construction professionals to understand the similarities perception on cost overrun issue in preventive management factors. Here, the Pearson correlation test has been used to find the degree of association between the variables. Its value varies from –l to + 1 according to the level of agreement. If the value is close to + 1 (positive correlation) indicates the extent to which those variables increase or decrease in parallel then the variables are said to closely related to each other and have a positive relationship [15]. If the value is close to –1(negative correlation), it indicates the extent to which one variable increases as the other decreases then the variables are said to be unrelated to each other and have a negative relationship. The values will be high if the observations have chosen a similar or identical rank for any attribute. The correlation coefficient test has been done for the five factors ranked by the RII method. For these factors, the correlation test has been carried out to find their degree of association.

It has been found that the pair of factors having values above 0.663 were said to highly correlate and the pair of factors having values below –0.970 were said to have a low degree of correlation [16].

As per the analysis performed for the collected data, the shortlisted list of 35 factors influencing the cost overrun issue in preventive management has been studied and interpretations have been made. Initially, the collected data were checked for reliability to find the internal consistency of the data. The test Cronbach was used to test the data that should have values over 0.7 in order to make the data valid. As per the criteria, all the factors listed were found to be above 0.7 and this showed that the data were highly reliable and fit for analysis.

6 Conclusion and Recommendations

The assessments have been done to identify the most influencing factors that result in increasing indirect costs in construction projects. The degree of importance given by the respondents has clearly been investigated and correlated. All the factors were clearly discussed among the respondent's in order to give a suitable degree of importance for the factors. From all the factors work environment ranked high among the remaining factors. This should be controlled and eliminated by proper supervision and necessary steps to take by the organization to avoid accidents and also to reduce indirect cost, cost overrun, and budget overrun.

Further safety net related factors are the safety nets less than 30 feet below the working surface ranked first high among the remaining degrees of importance. This can be controlled and eliminated with the help of effective preventive management techniques and also can control the cost overrun issues. In the work environment, workplace should have sufficient ventilation to enable workers to carry out work ranked the high among remaining degrees of importance. This can be controlled and eliminated with the help of preventive measures that should be taken by the organization to avoid accidents.

Case of scaffolding related factor, couple of respondents have a high degree of importance. There is one thing if there is a safe manner for employees who are building or using the scaffold to get on and off the scaffold-like ladder, trained and monitored to confirm their structural capacity. This can be controlled and eliminated with the help of preventive management that should be taken by the organization to supervise properly and also to take necessary actions against this to avoid the issues. In welding and electric related factor, whether firefighting equipment is located near the welding work area have a high degree of importance. This can be controlled by proper supervision and also can be eliminated by preventive measures that should be followed to reduce indirect cost.

The excavations, adjacent areas, and protective systems inspected by a qualified employee daily before work begins is of great importance to the underground services factor. This can be reduced and controlled by proper preventive measures to be taken and can be properly supervised and also necessary actions to be taken by the organization to control cost overrun issues. Thus, as per the assessments, the knowledge of factors and their impact on the cost overrun issues will be prevented in the way of implementing preventive management to avoid cost overrun factors.

References

1. Hale, A. R., Heming, B. H. J., Carthey, J., & Kirwan, B. (1997). Modelling of safety management systems . *Safety Science, 26*, 121–140.
2. Aibinu, A. A., & Jagboro, G. O. (2002). The effects of construction delays on project delivery in Nigerian construction industry. *International Journal of Project Management., 20*, 593–599.
3. Chan, A. P. C., Chan, D. W. M., Chiang, Y. H., Tang, B. S., Chan, E. H. W., & Ho, K. S. K. (2004). Exploring critical success factors for partnering in construction projects. *Journal of Construction Engineering and Management, 130*, 188–198.
4. Williamson, A. M., & Feyer, A. (1997). Cairns D and Biancotti D 1997 Williamson. *Safety Science Questions for Safety Climate, 25*, 15–27.
5. Park, C. S., & Kim, H. J. (2013). A framework for construction safety management and visualization system . *Automation Construction, 33*, 95–103.
6. Baloi, D., & Price, A. D. F. (2003). Modelling global risk factors affecting construction cost performance. *International Journal of Project Management, 21*, 261–269.
7. Ai Lin Teo, E., & Yean Yng Ling, F. (2006). Developing a model to measure the effectiveness of safety management systems of construction sites *Building and Environment, 41*, 1584–92.

8. Lingard, H., & Rowlinson, S. (1997). Behavior-Based Safety Management in Hong Kong's Construction Industry. *Journal of Safety Research, 28*, 243–256.
9. Doloi, H. (2012). Cost overruns and failure in project management: Understanding the roles of key stakeholders in construction projects *Journal of Construction Engineering and Management,* 1–13.
10. Hinze, J., & Gambatese, J. (2003). Factors That Influence Safety Performance of Specialty Contractors. *Journal of Construction Engineering and Management, 129*, 159–164.
11. Dikmen, I., Birgonul, M. T., & Han, S. (2007). Using fuzzy risk assessment to rate cost overrun risk in international construction projects . *International Journal of Project Management, 25*, 494–505.
12. Bin, Y. J., & Peng, S. C. (2008). Development of a customer satisfaction evaluation model for construction project management . *Building and Environment, 43*, 458–468.
13. Iyer, K. C., & Jha, K. N. (2005). Factors affecting cost performance: Evidence from Indian construction projects . *International Journal of Project Management, 23*, 283–295.
14. Langford, D., Rowlinson, S., & Sawacha, E. (2000). Safety behaviour and safety management: Its influence on the attitudes of workers in the UK construction industry . *Engineering, Construction and Architectural Management, 7*, 133–140.
15. Dey, P. K. (2001). Decision support system for risk management: A case study . *Management Decision, 39*, 634–649.
16. Mohamed, S. (1999). Empirical investigation of construction safety management activities and performance in Australia . *Safety Science, 33*, 129–142.

Estimation of Probability on Delay in Desalination Plant Construction Projects in Lakshadweep Island

P. Divya and G. Beulah Gnana Ananthi

Abstract This paper presents the use of relative importance index (RII) technique combined with fuzzy logic and thereby supporting the contractors early to the bidding stage so that possibilities of delay in the construction of desalination plants in Lakshadweep islands can be predicted. To achieve the objective, 76 delay issues are recognized, characterized into 10 major sets through a comprehensive literature study in addition to telephonic discussions with construction professionals who are involved in the desalination plant construction in Lakshadweep islands. The relative reputation of these delay issues and sets is measured using the RII technique. Ranking between issues with sets is established conferring to stages in outcome towards delay. Delay valuation pattern is suggested by making use of a fuzzy set of delay issues in the desalination plant works in Lakshadweep islands. The valuation model is done by making use of a commercial software product. This planned procedure is verified in an actual study while the delay in the scheme is assessed to be satisfactory.

Keywords Delay · Desalination plant construction · Relative importance index · Fuzzy theory · Probability

1 Introduction

Any structural work is said to be successful only when it is done within a stipulated time, inside the estimated budget, and should have met with all the specifications recommended in the standards. In the construction sector, contractors may have tendency to make profit by which the market share is increased. To attain this purpose, it's always a challenge for builders to sensibly classify the probable factors which will disturb the scheme and assess the impacts right before the start of bidding. Construction delay means non-completion of work within the estimated target time.

The possible delay is high in the Lakshadweep Island building works compared to construction projects on the mainland. So the contractors undertaking construction

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projects on the island should carefully look into the likelihood of delays in construction. Thus, there is a requirement to identify and establish a suitable technique that will assess the likelihood of time extended or delayed in building the desalination plants. This will support the contractors with clear ideas well before the bidding stage.

The Low-Temperature Thermal Desalination (LTTD) plant structure project which is developed by the Ministry of Earth Sciences, India, through the National Institute of Ocean Technology (NIOT) is carried out in the Lakshadweep island region. Three LTTD plants have been successfully opened in India at Kavaratti, Minicoy, and Agatti islands in the Lakshadweep Union Territory. At Androth, Kalpeni, Kiltan islands, the construction of the desalination plant is in progress.

This paper aims to: (i) Recognize to classify delay in building-schedule-related issues (ii) Enumerate the qualified position in delay issues with sets, establishing the issue with sets by means of the relative importance index (RII), (iii) Suggest a delay investigation model to evaluate the likelihood of delays by means of using fuzzy, (iv) Testing the planned methodology and assess the probability of delays, and (v) To disclose the issues and sets that are most probable to cause delays.

1.1 Literature Review

There have been many studies conducted on construction delays over the past years. Table1 shows several studies that have been studied and acknowledged the reasons for the reasons of delay in structural works.

Substantial past studies carried out by many researchers by using a fuzzy set theory are displayed in (Table 2).

The studies conducted on reasons for the delay in construction works show that various factors affecting the schedules of a construction project, which in turn lead to delay, time, and cost overrun in projects and allows construction firms to foretell causes of delay on their construction works.

The studies on fuzzy set theory provide various applications of fuzzy theory in construction project works for various processes in order to help the organization for making decisions in a more effective manner and to increase the efficiency of production in a great way. As per the previous literature findings, there are two significant issues regarding the success rate of completing a project: (1) The specifications are in accordance and within the planned period of time (2) Satisfying the stakeholders qualitatively.

The delay in desalination plant building in Lakshadweep islands takes into account a combined method to link the RII method combined with fuzzy techniques.

Table 1 Existing studies describing delay in construction works

Author (year)	Remarks
Karthik and Ayushi [1]	Examined ways to minimize the cause of delays. The delay factors considered are drawings changes, missing funds, effectiveness in communication, and project organization inadequacy
Tsegay and Hanbin Luob [2]	Investigated the typical causes of delay at different stages of construction and its effect in the Ethiopian construction projects. The methodologies used in this research are relative important index (RII). Based on the comparison, the impact of delay is found as, construction stage, pre-construction stage, and post-construction stage sequentially
Rahul and Akhil [3]	Estimated the various kinds of delay and the causes of the delays which are presently impacting the progress of major construction works in the India. Methods of mitigation or acceleration are analyzed and possible solution are recommended
Amin et al. [4]	Analysed the factors that causes delays in building construction work in Morowali Regency. By using the factor analysis method (SPSS 17), the research results are obtained
Iman et al. [5]	Investigated the reasons and analyze the issues responsible for the delay in building works at Oman. They have reported that the client-related factors, equipment-related factors, and material related factors have an notable impact on the completion of building works
Omid et al. [6]	Identified the most prominent causes of delays, classify and rank them to find the origin in delays, also suggesting suitable solution

Table 2 Existing studies describing Fuzzy Set Theory

Author (year)	Remarks
Ali and Gopal [7]	Built the model by using Fuzzy Logic Toolbox MATLAB Programming Software to evaluate and rank the factors of poor planning which cause a construction delay. Finally, it concluded that the developed fuzzy logic model, named the Mamdani model is more accurate and simple to use, and efficient to analyze the delay in construction projects
Mohammad and Aminah [8]	Developed a procedure for the expansion of fuzzy models in construction, and its application is showed using a case study
Aminah [9]	Discussed the limits of FL and how it is combined with other techniques to develop fuzzy hybrid methods, and describing the aspects of building difficulties and choice deciding that mostly affect using these techniques
Mathew and Reshma [10]	Described the application of fuzzy logic toolbox of MATLAB Software for identifying the scheduled delays in construction projects. Fuzzy logic provides a convenient deduction of result with vague input. The scheduled delay was obtained to be 32.9 percent from the actual schedule

2 Quantifying the Delay Issues Applying the RII Method

2.1 General

The main objective of this study is to quantify the importance of delay issues in desalination plant construction projects. Results from this study established the issues with sets in relation to delay. This finding helped to define the weights by creating a valuation pattern to evaluate the likelihood of delay.

2.2 Methodology

The procedure for the quantification of the comparative position in delay issues by the RII method is summarized as follows: Research literature has been collected and interviews with professionals who were involved in the desalination plant construction in Lakshadweep island is also carried out for the better understanding and to conceive the overall picture of the factors that caused a delay in building works in islands. Finally, 76 factors of delay were identified, and then they are split into ten primary categories that include contractor, consultant, design, material, labor, equipment, site, finance, rules and regulations, and external related factors, to attain a better knowledge of the root cause for these delays.

An online survey questionnaire was prepared based on the factors identified. A Likert-style rating scale allocating the standard of the importance of issues ranging between 1 and 5 (from low to very high level of importance) is considered in the survey as a measure of how strongly the causes of delay may affect the progress on the projects and how frequently they occur in the structural works. Then, the questionnaire was circulated to 67 practicing construction experts including consultants, contractor employees, scientists, and designers, the data acquired were analyzed using the RII method. According to relative importance indices, the positioning of different causes is included. This investigation revealed the issues and sets that led to the delays.

2.3 Data Analysis

The collected data via online survey is analyzed by using the RII method. The impact of each delay factor is quantified by means of five-point Likert scale adopted in the questionnaire survey, ranging from 1 to 5 and it is used to calculate the relative importance index (RII) for each factor using Eq. (1).

$$\mathrm{RII} = \frac{\Sigma Wi}{(A * N)} \tag{1}$$

where, RII = Relative Importance Index, varies from 0 to 1.

W = Weight given to each factor by the respondent range from 1- 5.

A = Highest weight equals 5.

N = Number of respondents in total.

For every delay factor, the RII value is calculated and it was used to rank the factors causing delay on the Low-Temperature Thermal Desalination plant project in Lakshadweep islands. These rankings are used to identify the significant factors causing delay based on the relative importance of the delay factors as per the responses obtained from the respondents. The higher the RII value the higher the rank of the factors. The highest rank represents the factors causing a delay which has more significance on project delay.

2.4 Results and Discussion

Based on the position of the sets, the factors of each set that pay way for most of the postponements are as follows:

1. **Contractor: RII - 0.521.** In this set, postponement issues are important towards delay. This is due to relevant errors (RII - 0.767), improper planning and scheduling (RII - 0.625), and inadequate contractor experience (RII-0.584);
2. **Material: RII - 0.508.** In this set, the most noteworthy issue is late transportation of materials (RII - 0.805), shortage in materials (RII - 0.654), and delay in manufacturing materials (RII - 0.606);
3. **External: RII - 0.443.** The outside issue takes the third vital set. The substantial issues are natural disasters (RII - 0.823), weather conditions (RII - 0.789), and pandemic conditions (RII - 0.760);
4. **Design: RII - 0.426.** The design set of delay issues ranks as the fourth most important set. The eminent issues are non-availability of design and drawing on time (RII - 0.565), faults and delays in making design reports (RII - 0.528), and poor using advanced engineering design software (RII - 0.458);
5. **Finance: RII- 0.413.** The fifth vital set is the finance set. The noticeable issues are trouble in procuring materials at reasonable prices (RII - 0.668), cash flow problems during constructions (RII - 0.623), and material and labor wage escalation (RII - 0.497);
6. **Labour: RII- 0.4.** The labor issue is the sixth vital set. The substantial issues are native of labor (RII - 0.655), low productivity of labor (RII - 0.622), and strike (RII - 0.585);
7. **Rules and regulations: RII - 0.388.** An alien with the labor-related set, the rules and regulations related set of delay issues ranked as the seventh most important set. The distinguished issues are coastal construction control line

permit (RII - 0.683), obtaining permits for laborers (RII - 0.657), and changes in laws and regulation (RII - 0.404);

8. **Consultant: RII - 0.376.** The eighth significant set is the consultant-linked set. The noticeable issues are lack of skill in construction project RII - 0.559), lesser communication with other parties (RII - 0.443), followed by late in reviewing and approving plan documents (RII - 0.402);
9. **Site: RII - 0.357.** The site connected issues ranked as the ninth significant set. The noticeable issues are unexpected underground condition (RII - 0.550), geological problems on-site (RII - 0.495), and effects of subsurface condition (RII - 0.461); and
10. **Equipment: RII - 0.305.** The equipment-linked issues is the last significant set. The noticeable issues are inappropriate equipment (RII -0.522), slow mobilizing of the equipment (RII - 0.391), and frequent breakdown of equipment (RII - 0.363).

3 Projected Fuzzy Valuation Pattern to Evaluate the Likelihood in Delay

3.1 General

Probability analysis has impreciseness and uncertainty in its essence. The fuzzy theory is suitable to process linguistic manner, and is also employed by suggesting a structured uncertainty system of modeling. For developing the proposed model of fuzzy assessment to evaluate the delay probability in desalination plant construction, the subsequent steps are adopted:

Step 1: The delay issues and sets which are well-known in the earlier sections are the base input issues and sets of this valuation model;

Step 2: The fuzzy associated functions and linguistic variables are determined;

Step 3: The fuzzy guidelines are constructed, the RIIs of issues and sets of factors which are calculated previously are allotted as weights and the accumulation alien with defuzzification are found to build the *fuzzy model in estimating the delay*;

Step 4: Built fuzzy valuation model is developed by using *MATLAB*;

Step 5: Built fuzzy valuation model is tested against an actual existing case.

Table 3 Delay probability outputs of the case study

Sl. No	Categories of factors	Delay Possibility (0–100%)
1	Contractor	59.6
2	Consultant	53.4
3	Design	41.8
4	Material	64.9
5	Labour	55.6
6	Equipment	47
7	Site	57.7
8	Finance	59.4
9	Rules and Regulation	64.7
10	External	69.4

3.2 Applications of the Planned Model

3.2.1 Input Issues and Sets to Build the Pattern

Seventy-six delay issues and 10 issue sets, which are recognized in the earlier section are illustrated in Table 3 as the key input issues in this assessment model.

3.2.2 Fuzzy Membership and Linguistic Variables Functions

The variables are categorized as *very low, low, medium, high, very high* on a scale of 0 to 100. Five associated purposes are well-demarcated for all variables. Figure 1 shows all the associated functions, which are characterized by a combo of trapezoidal and triangular fuzzy members.

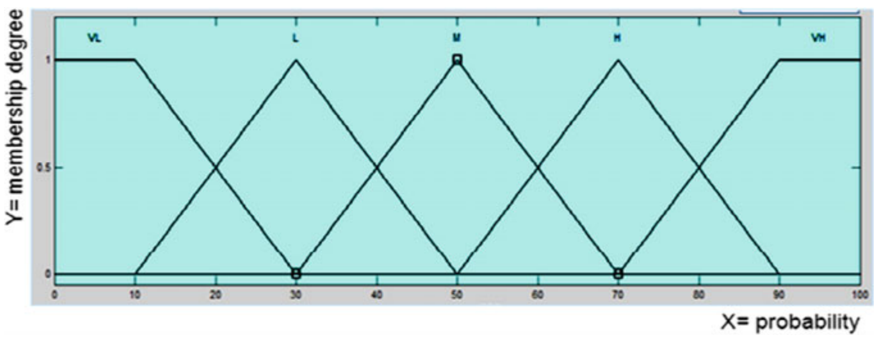

Fig. 1 Association and linguistic variable functions

3.2.3 Building the Fuzzy Guidelines

A Mamdani fuzzy rule is applied considering the advantage of Mamdani's approach which is the prevalent and well-matched to human input.

To complete the fuzzy suggestion, the guidelines that link the input and output variables are analyzed. Rather than the mathematical formulas, the desired model is used which describes the linguistic variables.

- Abbreviations of the variables are VL: Very-Low; L: Low; M: Medium; H: High; and VH: Very-High;
- Abbreviations are **Contractor set**: CRG1; **Consultant set**: CRG2; **Design set**: DRG; **Material set**: MRG; **Labour set**: LRG; **Equipment set**: ERG1; **Site set**: SRG; **Finance set**: FRG; **Rules and Regulations set**: RRG; **External set**: ERG2 and
- The abbreviation in likelihood of delay as output was DP.

3.2.4 Assigning Rule Weights

To evaluate the delay, the fuzzy pattern is constructed by assigning weights to fuzzy rules. The fuzzy-rule weights are framed by using RIIs of issues. The fuzzy-rule weights differ accordingly as the RII has an unlike rate.

Each rule has a diverse weight, indicating the absolute importance of the rules.

Some samples describing the significances of the rules are described below:

- **Rule 41:** Lack of experience of the construction project (LCC)—very low (VL), then—CRG2 causing a delay with a weight of 0.584;
- **Rule 180:** Strike-related category (STR) is very high (VH), then labor-related category (LRG) will have a very high (VH) likelihood with the weight of 0.585;
- **Rule 408:** Equipment-related category (ERG1) is medium, then delay probability (DP) will have a medium (M) likelihood with the rule weight of 0.305.

4 Fuzzy Pattern Construction—MATLAB Software

Fuzzy toolbox inbuilt inside MATLAB Program Software assessment model is created. The functions built in MATLAB® environment is the Fuzzy Logic Toolbox™. There are 5 basic interface tools in observing and constructing the fuzzy systems as shown in Fig. 2.

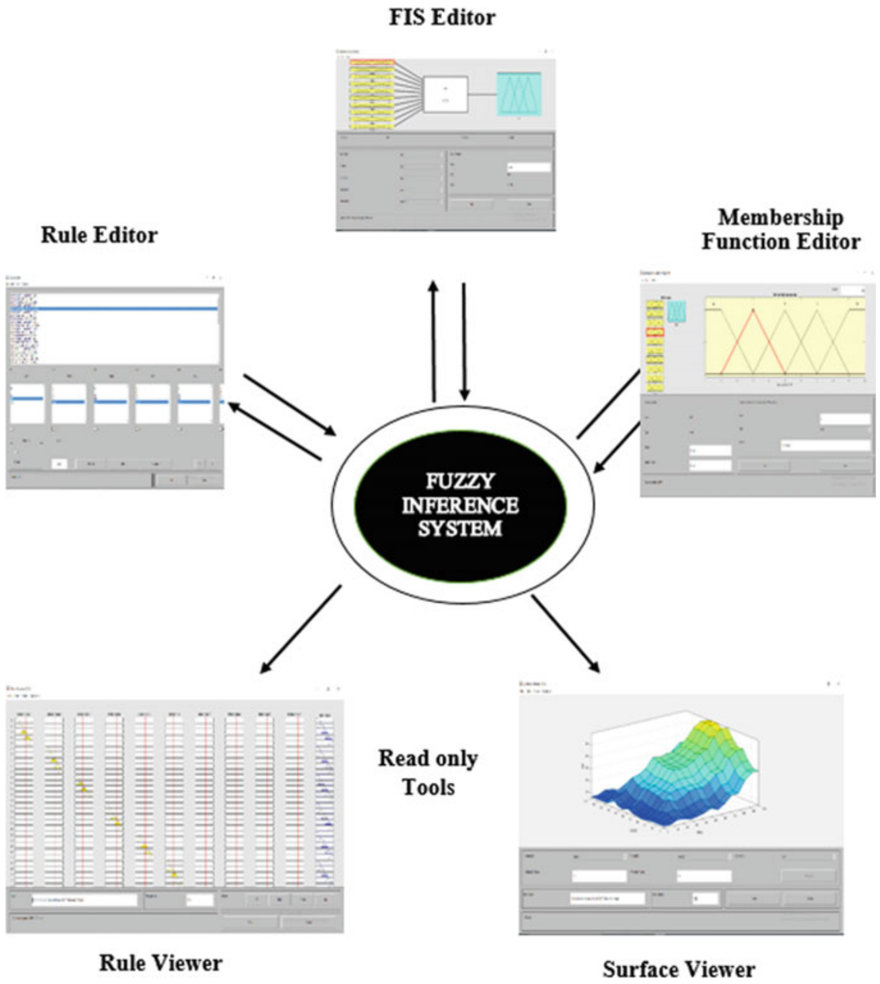

Fig. 2 Graphical user interface tools in the fuzzy logic toolbox

5 Actual Pilot Study

This constructed fuzzy pattern is experimented on the desalination plant in the Lakshadweep islands. To validate the constructed fuzzy pattern in constructing the low-temperature thermal desalination (LTTD) plant in Kiltan Lakshadweep islands, a consultation module is established to measure the insights from the professionals involved in desalination plant construction projects in islands. The project was executed by a construction company in Chennai, Tamil Nadu. The desalination plant component includes marine structures, submarine HDPE pipe, processing components of the plant. The marine structure includes a sump and an approach bridge.

The project owner was NIOT (National Institute of Ocean Technology). The planned time span was 300 days. The contract price was around ₹29 crores.

The respondents are invited to: (1) Seal up the delay likelihood assessment form by adopting values of input (factors causing delays) from 1% (VL) to 100% (VH), (2) Evaluate the delay likelihood of the work. To fulfil the responsibilities, Fig. 1 shows the membership functions for linguistic variables; very low–VL, low–L, medium–M, high—H, and very high–VH was given as an instruction to the respondents. The respondents observed notable evidence leading to construction works delays in the island and assigned the required time to carry out the required tasks. The respondents analyzed and completed the form that contained 76 issues considering the contractor, consultant, design, material, labor, equipment, site, finance, rules and regulation, and external—related delay factor categories.

5.1 Research Findings

Table 3 shows the outputs.

5.1.1 Contractor-Related Category

For the contractor factors, the delay possibility output is evaluated as 59.6% indicating a scale of medium to high possibility level. The important paying delay issues are rework because of errors with 85% (high to the very high possibility); deprived site supervision and management with 70% (high); poor communication and coordination with other parties with 60% (medium to high possibility).

5.1.2 Consultant-Related Category

For the consultant factors, the delay possibility output is evaluated as 53.4% which shows a medium to high likelihood level. The important paying delay issues are lack of practise of consultant shows 75% (H to VH); clashes between specialist with planner showing 70% (H); delayed approving shows 60% (medium to high probability).

5.1.3 Design-Related Category

For the design factors, the delay likelihood output is evaluated as 41.8%, which shows a range between low–medium likelihood levels. The important paying delay issues are the difficulty of project design with 65% (medium to high); plan and drawing not available in time with 60% (medium to high); and errors made by engineers 50% (medium).

5.1.4 Material-Related Category

For the material factors, the delay possibility output shows 64.9%, which shows medium–high likelihood level. The important paying delay issues are late distribution of materials with 100% (very high). Also, variations in material forms and stipulations while execution shows 80% (high to very high possibility) and absence of construction materials shows 70% (high possibility).

5.1.5 Labor-Related Category

For the labor factors, the delay likelihood output was assessed as 55.6% and shows medium to high likelihood standards. The important paying delay issues are strike with 85% (high-very high probability); native of labor shows 80% (high to very high possibility); and slow mobilization of labor with 80% (high to very high possibility).

5.1.6 Equipment-Related Issues

For the equipment issues, the delay likelihood output was calculated as 47% which shows a range of low to medium likelihood level. The important paying delay issues were frequent equipment breakdowns with 65% (medium–high likelihood); Inadequate modern equipment with 65% (medium–high likelihood); and less efficiency with 60% (medium to high likelihood).

5.1.7 Site-Related Delay Issues

For the site-related delay factors, the delay likelihood output was calculated as 57.7% which shows a range of medium to high likelihood level. The important paying delay issues are effects of subsurface condition with 90% (very high probability); Geological problems on site with 90% (very high probability); and Unexpected underground condition with 90% (very high probability).

5.1.8 Finance-Related Delay Issues

For the site-related delay issues, the delay likelihood output was calculated as 59.4% which shows a range of medium to high likelihood level. The important paying delay difficulties related to procurement with 85% (high to very high probability); financing by a contractor during constructions with 65% (medium to high probability); and material and labor wage escalation with 65% (medium to high probability).

5.1.9 Rules and Regulations-Related Delay Issues

For the rules and regulations factors, the delay possibility outcomes were calculated as 64.7% which shows medium to high likelihood level. This important delay factor is to earn permit for laborers with 90% (very high probability); Coastal construction control line permit with 85% (high to very high probability); and obtaining permits from the municipality with 75% (high to very high probability).

5.1.10 Outside-Related Delay Issues

For the external-related delay issues, the delay likelihood output is calculated as 69.4% shows a range of medium to high likelihood level. The important paying delay issues are weather conditions with 100% (very high likelihood); Pandemic conditions with 95% (very high probability); and natural disasters with 90% (very high probability).

6 Conclusions

By identification of causes of delay, the minimization of delays can be achieved. So, in this study, a decision-aid kit for builders prior to bidding in order to assess the delay likelihood of desalination plant structures in Lakshadweep islands making use of the Relative Importance Index (RII) technique integrated into alien with the fuzzy was proposed.

- Through literature studies and discussion with authorities who are involved in the desalination plant construction in Islands, 76 factors causing delay are determined and categorized into ten major divisions. The RII delay issues and categories of issues are allotted as weights of fuzzy rules. For all linguistic variables, five membership functions are determined.
- All of the membership functions are illustrated by grouping of triangular and trapezoidal forms of fuzzy members. The Mamdani-style fuzzy rules are created after a detailed literature study.
- So as to experiment suggested fuzzy pattern on the construction of a low-temperature thermal desalination (LTTD) plant in Kiltan, Lakshadweep islands, which was executed by a construction company in Chennai, Tamil Nadu, a final interview was developed.
- The authorities involved in the desalination plant construction evaluated the delay likelihood for the latest completed desalination plant construction work ranging between 40 and 70%, presenting a medium to high likelihood in delay.
- This suggested fuzzy pattern computed likelihood in delay as 55.5%, showing medium to high level in this particular work. These findings from the present study are found to be acceptable. In this study, an incorporated method to connect

the RII method and the fuzzy pattern to evaluate the likelihood of delay in the desalination plants construction in Lakshadweep islands is adopted.

- Hence the decision-makers may engage the suggested device to evaluate possibility in delay.

In conclusion, related studies can also be expanded in other types of construction works, such as dam structures, pipeline laying, etc. These studies can be directed to evaluate the consistent time and contingencies in building works, thereby the works can be successfully completed.

References

1. Bagrecha, K., & Bais, A. (2017). Study on delay construction project in India. *International Journal of Innovations in Engineering Research and Technology*, *4*(11), 6–10.
2. Gebrehiweta, T., & Luo, H. (2017). Analysis of delay impact on construction project based on RII and correlation coefficient: Empirical study. *Procedia engineering Creative Construction Conference, 196*, 366–374.
3. Rahul Razdan and Akhil Goyal. (2019). To study the delay to construction projects- cause, effect and measures to reduce. *Journal of Emerging Technologies and Innovative Research, 6*(6), 115–126.
4. Amin, M., et al. (2020). Analysis of factors causing the delay of implementation of building construction work in Morowali district. *International Journal of Innovative Research in Advanced Engineering, 7*(1), 1–8.
5. Maktoumi, I. S. A., et al. (2020). Assessing the factors causing project completion delays in the construction sector of Oman using SEM-Pls. *Humanities & Social Sciences Reviews, 8*(3), 900–912.
6. Abbasi, O., et al. (2020) Exploring the causes of delays in construction industry using a cause-and-effect diagram: case study for Iran. *Journal of Architectural Engineering*, *26*(3), 1–16.
7. Manea, A. K., & Gopal Naik.M. (2018). Analysis of construction delay due to poor planning using Fuzzy Logic Technique. *International Journal for Research in Applied Science and Engineering Technology*, *6*(7), 491–498.
8. Raoufi, M., & Fayek, A.R. (2018) Fuzzy agent-based modelling of construction crew motivation and performance. *Journal of Computing in Civil Engineering*, *32*(5), 1–16.
9. Aminah Robinson Fayek. (2020). Fuzzy Logic and Fuzzy hybrid techniques for construction engineering and management. *Journal of Construction Engineering and Management, 146*(7), 1–12.
10. Mathew, B. K., & Kassim, R. (2020). Fuzzy logic approach in construction delay analysis. *International Research Journal of Engineering and Technology*, *7*(3), 218–4221.

Influence of COVID-19 on Microplastics Pollution in Coastal Water and Sediment of Chennai, India

S. Ramesh and R. Nagalakshmi

Abstract Event of microplastics (plastic garbage < 5 mm) along the coast is a developing concern around the world, because of the expanded contribution of disposed of squanders from different sources. Around 400 million tons of plastic are produced per year worldwide, out of which only 18% is recycled that has led to its poor disposal practices. The significance of my work is to analyze mainly the positive impacts due to lockdown during COVID-19. The discharged plastics remain in the environment for several 100 years either in their original or fragmented form. The fragmentation of particles is caused by several factors like wind currents, wave currents, abrasions, exposure to sunlight, etc. The study of the distribution of microplastics in time and space, as well as their distribution on parameters, such as polymer type, size, shape, in different coastal environmental all over the world, is the need of the hour. This study describes a framework to assess the presence and distribution of microplastics in marine water and sediments of Adyar and Cooum Estuary along the Chennai coast. Ten sampling sites from each estuary were selected from which surface water and sediments were collected. The samples were carried over to the laboratory for analyzing the presence of microplastic content, and also basic seawater quality parameters were analyzed in the Environmental Engineering Department laboratory. The study investigated the presence and distribution of microplastics before and during COVID-19. The presence and distribution study of microplastics in coastal waters and sediments were carried out by means of FTIR and XRD spectroscopy methods. From this analysis, microplastics occur in both estuaries and there is a significant reduction in Microplastic content in both estuaries because of continuous lockdown due to COVID-19. From FTIR analysis, it was found that the concentration of Polyethylene(PE) and Polypropylene (PP) was higher than the other types of polymer in both the locations and both the times (August 2019 and 2020). And from XRD analysis, black residues were found on most of the microplastics surfaces.

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Keywords Microplastics · Chennai coasts · COVID-19 · Estuary · FTIR · XRD

1 Introduction

Plastic is widely used in everyday life in countless sectors because of its innumerable benefits and low cost. In 2018, global plastics production almost reached 360 million tonnes [1]The extended use of these plastics, combined with poor waste management practices or irresponsible behavior, has, however, lead to plastic accumulation in the environment [2]. Around 18% of the produced plastic is recycled that has led to its poor disposal practice because discharged plastics overcome in the environment for several 100 years either in their original or fragmented form. The fragmentation of particles is caused by physical, biological, and photochemical degradation of plastic surface [3] The fragments with sizes between 0.001 and 5 mm are defined microplastics [4]. Due to their size, these particles can be ingested by several animal species [5] potentially causing negative effects on these organisms, even though the translocation, bioaccumulation, and trophic accumulation are still under investigation [6]. The event of microplastics along the coast is a developing concern around the world because it has been identified as the ultimate endpoint of most of the lost plastic (Fig. 1). It is because of the expanded contribution of disposal of squanders from different sources. The main sources of the marine microplastics pollution have, however, been recognized to be land-based [7]. Land-based polymeric particles can be transported to aquatic environments via different pathways, like incomplete microplastics removal in conventional WWTPs [8] road runoff, storm water systems [9], combined and misconnected sewer systems, and so forth. Microplastics' atmospheric fallout driven by wind transportation is also suspected to contribute significantly to the spreading of microplastics in the environment [10], and is undeniably an under-investigated area, which clearly requires further investigation. The study

Fig. 1 Plastics deposited on Adyar Riverbank. (*Source* Google images)

of the distribution of microplastics in time and space, as well as their distribution on parameters, such as polymer type, size, shape, in different coastal environmental all over the world, is the need of the hour.

India has a coastline that is more than 7500 km long [11]. The diverse environments of its numerous beaches make it impossible to generalize the factors contributing to the microplastic pollution at these beaches. Micro plastic pollution is a site-specific phenomenon, although one can get insights into it by studying the pathways of pollution already identified by previous researches. However, studies are deficient about micro plastic pollution of Indian beaches. So far, only a few studies have been carried out in India [12]. These studies show that micro plastics can severely affect the marine environment. In recent years, microplastics pollution is introducing new research challenges which clearly are interdependent and need an interdisciplinary approach. Hence, there is a need for validated and trustable methods to produce reliable and comparable data [12].

This study describes a framework to assess the presence and distribution of microplastics in marine water and sediments of Adyar and Cooum Estuary along the Chennai coast. The study investigated the presence and distribution of microplastics before and during COVID-19. The presence and distribution study of microplastics in coastal waters and sediments were carried out by means of FTIR and XRD spectroscopy methods.

2 Materials and Methodology

2.1 Study Area

The study was carried out in Adyar and Cooum estuary Chennai. Chennai is the capital of the Indian state, Tamil Nadu, and is located on the Coromandel Coast of the Bay of Bengal. It is one of the megacities of India with a coastal belt of more than 19 km. The Adyar and the Cooum are two of the three rivers which wind through the city. For my Research Work, I have taken a 2 km stretch in both locations. The River Adyar, 42 km long and 860 km^2 catchment area originates near the Chembarambakkam Lake, Kanchipuram district and joins the Bay of Bengal at the Adyar estuary. The River Cooum, 72 km long, and 290 km^{2}catchment area originates from the surplus waters from the Cooum tank, Thiruvallur taluk, and is one of the shortest rivers draining into the Bay of Bengal. It runs from west to east and almost divides the city into two halves [15–19]. The riverbanks provide habitat to more than 40,000 hut dwelling families. Most of the waste from the city is discharged into these rivers. Further, there are numerous waste discharges from thermal power plants, leather ternaries, petroleum and tire industries and fishing harbors. Hence, these rivers carry a major portion of domestic and industrial wastes into the coast. Marina Beach spans 6 km between the deltas of Adyar and Cooum and is the second longest urban beach in the world. Eliot Beach lies to the south of the Adyar delta

[20–24]. These beaches are the major weekend resort destinations and a lot of non-biodegradable waste is disposed of. Although Chennai's coast has been extensively explored over the years, and many studies have been carried out to address the effects induced by extensive human activities impacting this environment, but less data is available on the occurrence of microplastics Hence, these places are chosen for monitoring the microplastics contamination. Figures 1 and 2 show images of plastics deposited on Adyar and Cooum Riverbanks respectively. Figure 3 shows the study area and monitoring stations along Chennai Coast. X-Ray Diffraction, frequently abbreviated as XRD, is a non-destructive test method used to analyze the structure of crystalline materials. XRD analysis, by way of the study of the crystal structure, is used to identify the crystalline phases present in a material and thereby reveal chemical composition information.

Fig. 2 Plastics deposited on Cooum Riverbank. (*Source* Google images)

Fig. 3 Study area and monitoring stations along Chennai coast. (*Source* Google Earth)

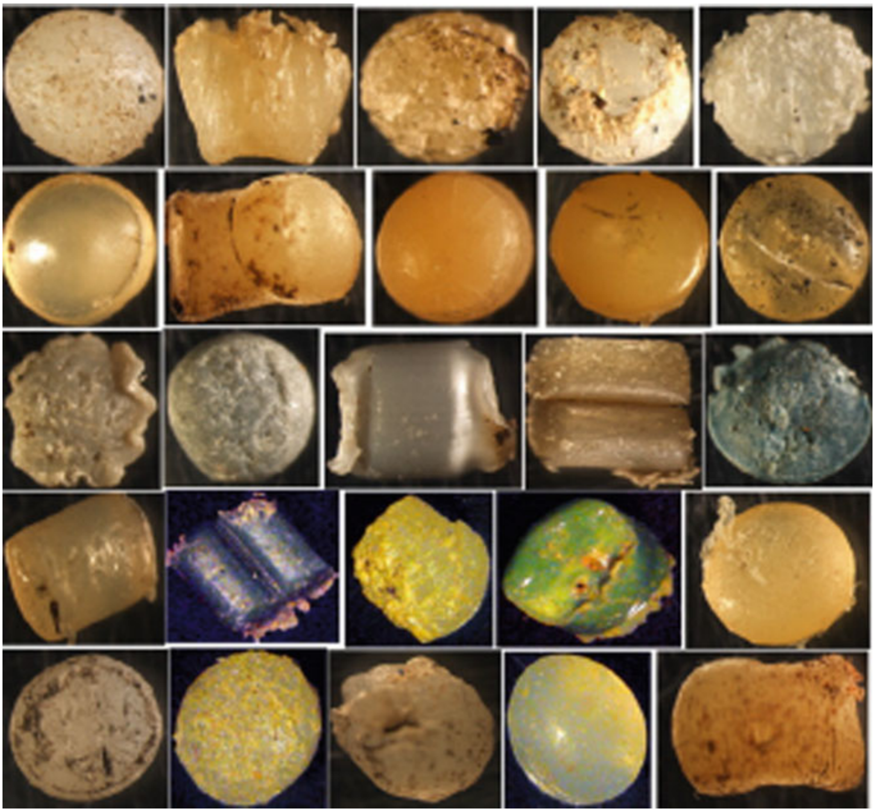

Fig. 4 Microscope images showing shapes, colors, and surface properties of microplastics. (*Source* [47])

2.2 Sampling Data Analysis

Ten sampling sites from each Adyar and Cooum estuary were selected from which surface water and sediments were collected. The figure shows the ten sampling sites on the map of Chennai Coast [25, 26]. To study the presence and distribution of microplastics before and during COVID-19 in each sampling site, sampling was conducted between August 2019 and October 2020.

Water samples were collected from each site by towing a neustonic plankton net of size 153 μm at a speed of three to five knots for 30 min [27–30]. The particulates in the net and the net tube were washed into a glass container for laboratory analysis. Water samples were first screened using a 32 μm sieve to remove the large debris. If the suspension was too turbid saturated sodium chloride solution was added to extract the low-density microplastics. The samples were then filtered using glass fiber filter paper, dried at 50 °C, and stored in Petri dishes (Fig. 4).

Water quality parameters measured in this study included temperature, pH, electrical conductivity (EC), turbidity, salinity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). Water samples were collected, transported, and analyzed following the standard methods (APHA, 1999). Portable sensors were used to measure temperature, pH, and EC [31–34]. Turbidity was measured by using Nephelometer. Salinity was determined by the Argentometric titration method. TDS were determined by filtration and gravimetric method using temperature-controlled oven. DO was analyzed by Winkler's titration method. BOD concentration was determined by measuring the decrease in oxygen concentration after five days of incubation in the dark at 20 °C. COD concentration was determined by oxidation with potassium-di-chromate in a concentrated sulfuric acid medium.

The sediment samples were collected using Ekman Grab before or after towing. The samples were freeze dried before laboratory analysis. The microplastics extraction from sediment was carried out by using sodium iodide, high-density liquid, so that the low-density microplastics would float up to the surface. The final digestion step involved oxidation using a 30% hydrogen peroxide solution. After shaking, the suspension was allowed to settle for one day and then filtered using glass fiber filter paper.

The particles retained on the filter paper were visually identified as microplastics under stereo-microscope if there was no cellular or organic morphological structure and the particles were not shiny and had consistent diameter etc. [35, 36]. The particles identified as microplastics were retrieved with forceps and transferred into Fourier Transform Infrared Spectroscopy (FTIR) for polymer-type identification [37].

A Shimadzu Fourier Transform Infrared Spectroscopy (FTIR) together with Attenuated Total Reflectance (ATR) diamond crystal attachment was used to identify the polymer compositions of microplastics [38–41]. The absorption spectra were recorded at a resolution of 4 cm^{-1} and 64 co-added scans, in the 4000–400 cm^{-1} infrared range. Polymers of different types were identified based on the absorption frequencies of chemical bonds present in samples. Polymer type was identified by comparing the sample FTIR spectra with a specific Shimadzu reference library database.

3 Results and Discussion

3.1 Water Quality Analysis

The water quality of any water body is mainly assessed by its temperature, salinity, pH, DO, BOD, etc. Table 1 shows the water qualities measurements on August 4, 2019 and Table 2 shows the water qualities measurements on August 4, 2020. In the present study, water temperature was around 29 °C for both the estuaries. Salinity

Table 1 Water quality measurement at monitoring stations along Adyar coast on August 4, 2019

Station	Water temperature (°C)		pH		EC		Turbidity (NTU)		TDS (mg/L)		DO (mg/L)		BOD (mg/L)		COD (mg/L)		Salinity	
	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020
A1	29.2	29.1	6.80	6.94	34,400	31,700	2.00	4.5	19,680	18,064	4.70	6.1	25.80	5	1250	64	17.58	16.82
A2	29.2	29.1	6.90	6.82	35,200	32,500	4.00	4.9	20,143	18,527	5.00	5.9	18.80	7	590	76	18.24	17.35
A3	29.1	29.2	7.00	6.52	36,200	33,500	6.00	4.9	20,263	18,647	3.10	6.1	9.80	6	650	67	17.95	17.95
A4	29.2	29.1	6.70	6.76	37,200	34,500	7.00	4.8	20,283	18,667	4.60	5.9	16.80	7	1320	68	17.57	17.34
A5	29.1	29.1	6.50	6.82	40,100	31,600	8.00	4.3	20,492	18,458	4.30	5.7	15.6	8	690	67	17.28	17.23
A6	29.2	29.1	6.80	6.71	39,180	30,680	8.00	4.9	20,796	18,762	4.80	5.8	24.80	6	1050	66	16.95	17.33
A7	29.1	29.2	6.60	6.90	39,750	31,250	5.00	4.6	20,999	18,965	4.20	5.1	12.80	7	680	68	17.12	16.91
A8	29.2	29.1	6.70	6.30	41,750	33,250	3.00	4.9	21,395	18,569	3.50	5.6	18.20	6	420	63	17.55	17.82
A9	29.3	29.1	6.50	6.70	43,000	34,500	7.00	4.6	21,576	18,750	3.80	5.1	12.80	8	690	61	17.96	17.22
A10	29.2	29.2	6.40	6.80	46,100	31,400	9.00	4.8	21,676	18,650	3.60	5.8	10.60	5	980	66	16.82	17.67

Table 2 Water quality measurement at monitoring stations along Cooum coast on August 4, 2020

Station	Water temperature (^{o}C)		pH		EC		Turbidity (NTU)		TDS (mg/L)		DO (mg/L)		BOD (mg/L)		COD (mg/L)		Salinity	
	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020	Aug. 2019	Aug. 2020
C1	29.1	29.1	6.90	7.39	31500	29200	9.00	12	17345	16650	3.20	6.2	18.80	9	1050	80	16.12	15.95
C2	29.0	29.2	7.10	7.41	33800	31500	4.00	15	18659	17964	3.80	6.1	24.80	7	980	88	16.66	17.88
C3	29.2	29.2	6.90	7.82	34700	32400	6.00	18	19283	17340	5.00	6.2	29.20	8	360	89	17.25	17.27
C4	29.3	29.1	6.50	7:40	35860	33560	6.00	17	19943	16680	4.20	6.9	27.80	8	400	83	17.01	17.08
C5	29.1	29.1	6.80	7.10	36800	34500	8.00	16	20913	17650	2.90	6.8	102.8	9	1360	89	16.92	17.89
C6	29.0	29.2	6.70	7.80	39800	31500	5.00	17	21153	17890	3.20	7.1	78.20	7	560	86	16.52	17.88
C7	29.0	29.1	6.90	7.30	42820	34520	8.00	14	21393	17650	3.80	6.8	63.80	6	650	80	16.91	16.81
C8	29.0	29.2	6.80	7.89	45010	32330	4.00	15	21603	17860	4.20	7.1	95.20	8	1010	79	17.21	17.03
C9	29.0	29.1	6.70	7.80	46110	31230	3.00	17	21633	17890	3.10	7.3	33.80	7	320	83	17.24	17.81
C10	29.1	29.2	7.30	6.90	47220	32340	7.00	18	21733	17990	4.80	7.9	38.70	6	420	90	17.55	17.88

ranged between 15 and 18 PSU for both the locations. pH was in the range between 7 and8 which matched reported values for the Bay of Bengal. The higher values of EC could be because of effluents from the nearby industries. The TDS ranges from 15,000 to 22,000 mg/L which may be due to insoluble organic matter. DO ranged between 3- and7 mg/L and BOD between 5 and 100 mg/L. The COD values ranged between 50 to 1500 mg/L. The BOD values at stations A6 and C5 were observed to be 24.80 mg/L and 102.80 mg/L in August 2019, respectively [42–44]. These results show that at the river mouths the pollutants' concentration was more than the other stations. A similar trend was also observed in August 2020 and with other parameters analyzed. And the results also show that in August 2020 the pollution was reduced considerably due to continuous lockdown in the country. At some stations, high BOD associated with low DO was observed due to pollution loads from different sources like domestic sewage and industrial wastes. At some stations, DO is more than 5 mg/L it could be due to wind effects and mixing patterns. Episodes of the mass fish kill were also reported in these areas. The water quality analysis results clearly indicate that the pollution levels were high in 2019 before COVID-19 and lockdown.

3.2 Microplastics Abundance and Characteristics

Microplastics less than 5 mm in size were identified at all sampling stations of the two coastal areas. There was a noticeable difference between the concentrations of microplastics in the coastal waters and sediments with time and space and are shown in Tables 3 and 4. The maximum number of microplastics pellets in coastal waters and sediments were found in August 2019 at the river mouths and near beaches [45]. The number of microplastics particles identified in August 2020 (during COVID-19) was almost 30% less than those identified in August 2019 (before COVID-19). These findings show that the human activities near these beaches are among the major sources of microplastics in these coastal areas. These results clearly show microplastics particle abundance near the rivers and the concentration decreases far away from the rivers. Microplastics are released in the environment during manufacturing and transport and are ultimately carried to sea by surface runoff and or by surface water bodies [46, 47]. Accidents during shipping can also introduce microplastics into the oceans. The higher concentration of microplastics near the mouths is mainly due to waste discharge from the rivers. The activities at the Chennai harbor also enhance the plastic pollution at the Cooum river mouth as it is very near. Along with the land inputs, microplastics are also transported by winds and currents [13].

The microplastics shapes recognized were mainly ovoid, fibrous, disk, and rod like. The colors varied widely from white to yellow, blue, gray, black, green, and red. The white microplastics were always found at the river mouths. The color changes due to various factors like exposure to UV light, high temperature, weathering, etc. The yellowing of the microplastics is caused due to photo-oxidative weathering and it usually occurs on beaches. The process of sorption of persistent organic matter generally occurs in seawater [14].

Table 3 Polymer types detected at Adyar sampling stations from coastal water and marine sediments of Chennai Coast

Station	PE				PP				Others			
	Coastal water		Marine sediments		Coastal water		Marine sediments		Coastal water		Marine sediments	
	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020
A1	275	197	45	31	97	70	16	8	15	11	3	5
A2	254	180	47	32	85	60	16	9	14	10	3	4
A3	347	247	53	37	109	78	17	10	19	14	3	3
A4	435	307	59	42	129	91	18	12	24	17	3	2
A5	680	465	161	120	190	130	45	32	36	25	9	8
A6	982	669	219	152	258	176	58	38	52	35	12	10
A7	666	471	154	108	164	116	38	24	35	24	8	8
A8	703	507	163	117	153	111	36	24	45	33	10	9
A9	480	336	141	102	97	68	28	21	30	21	9	6
A10	466	330	90	61	87	62	17	12	29	21	6	6

Table 4 Polymer types detected at Cooum sampling stations from coastal water and marine sediments of Chennai Coast

Station	PE				PP				Others			
	Coastal water		Marine sediments		Coastal water		Marine sediments		Coastal water		Marine sediments	
	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020	Aug 2019	Aug 2020
C1	244	175	65	41	86	62	23	15	14	10	4	3
C2	347	243	71	48	116	81	24	16	19	13	4	4
C3	607	426	140	89	191	134	44	27	33	23	8	6
C4	867	607	185	122	258	180	55	35	47	33	10	8
C5	1191	833	228	156	333	233	64	42	64	44	12	10
C	827	579	173	128	218	152	45	32	44	30	9	9
C7	601	385	155	114	148	95	38	27	31	20	8	9
C8	540	381	142	98	118	83	31	22	35	24	9	7
C9	396	292	119	86	80	59	24	18	25	18	8	6
C10	309	221	80	56	58	41	15	11	19	14	5	3

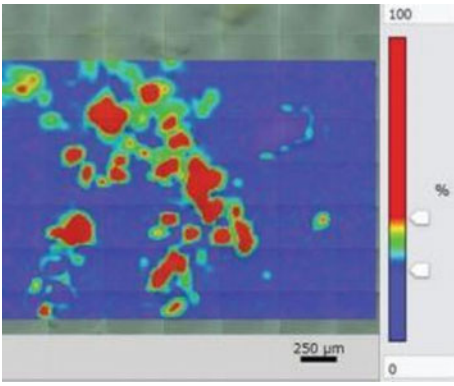

Fig. 5 PE distribution

Figure 5 shows the microscopic images exhibiting the most common surface properties of microplastics. Most of them were white with a virgin surface, adhesion, erosion, cracked and glazed surface and change in colour. These could be due to anthropogenic activities in the study area.

All the microplastics were analyzed using FTIR spectroscopy. The spectra revealed that most of the microplastics were polyethylene (PE) and polypropylene (PP). It was found that in both cases the quantity of PE and PP microplastics were higher near the river mouths. Figures 6 and 7 are colored based on corrected peak height values. The peak height from the baseline of the characteristic peak of each plastic [48]. The absorption peak for PE with wavenumber 718 cm^{-1} is caused by CH_2 rocking vibrations, the absorption peak for PP with wavenumber 2839 cm^{-1} is caused by CH_2 stretching vibrations. The red areas shown in the figure indicate points where the plastic component is present in high amounts and blue areas indicate points with low amounts. Figure 8 shows the typical infrared spectra from the areas in (Figs. 6 and 7).

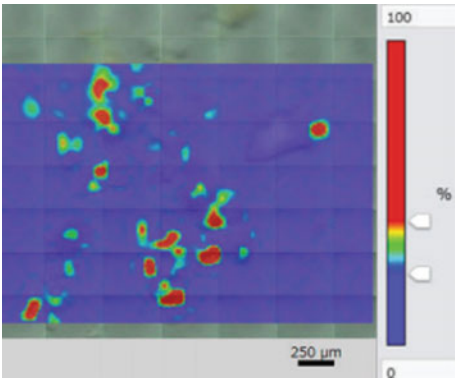

Fig. 6 PP distribution

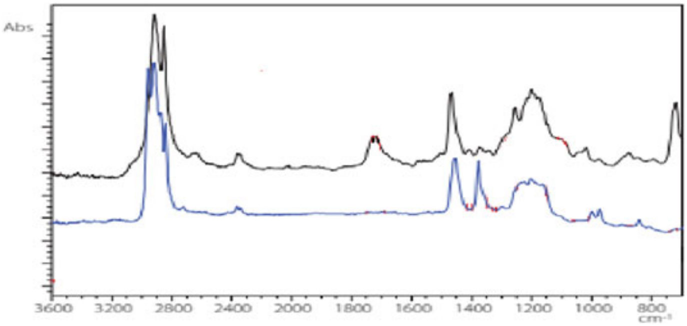

Fig. 7 Infrared spectra Blue PP

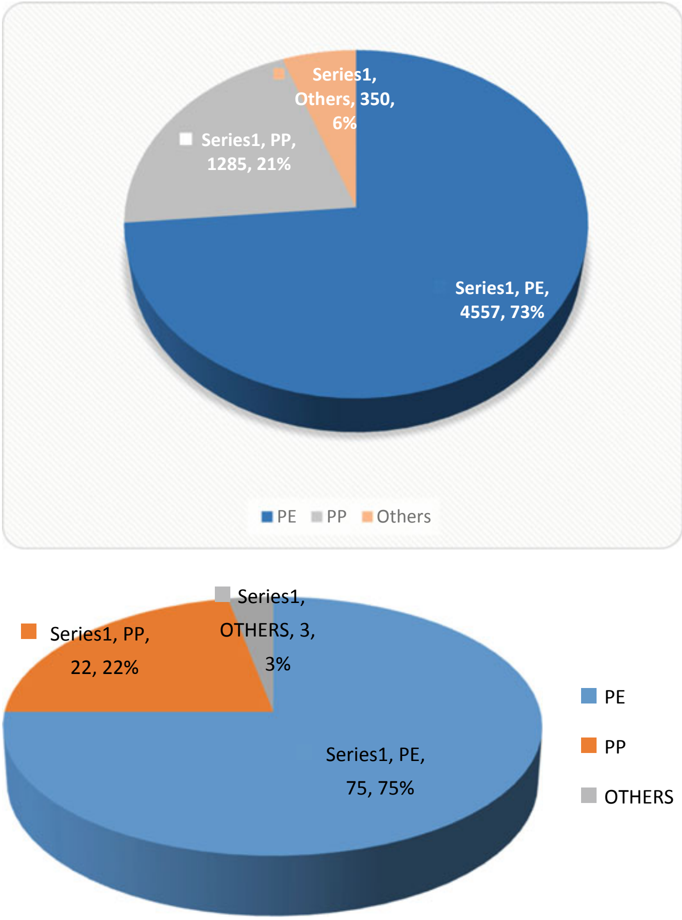

Fig. 8 **a**, **b** Proportion of microplastics recovered from Chennai coastal waters and sediments from August 2019 to August 2020

Figure 7 shows the proportion of microplastics recovered from Chennai coastal waters from August 2019 to August 2020. It is found that 76% of Mps are PE, 20% are PP and 4% belong to other polymer types. Figure 8 shows the proportion of microplastics recovered from Chennai marine sediments from August 2019 to August 2020. It is found that 73% of Mps are PE, 21% are PP and 6% belong to other polymer types.

3.3 XRD Analysis

FTIR spectroscopy method is capable of performing only qualitative analysis of organic matter and some inorganic matter, hence this method was used to identify the main components of plastic pellets of sediments of Chennai coast. X-ray diffractometers can perform both qualitative and quantitative analysis of substances non-destructively. The results showed that there were black residues (Petroleum hydrocarbons) on the microplastics surfaces. These could be oil residues from Chennai harbor and shipping activities. The results of XRD analysis are not mentioned in this paper because before and during COVID-19 what about the volume of different types of plastics collected from the site is very important.

4 Conclusion

Microplastics have evolved as an emerging pollutant in recent years. Despite significant progress in this field of science, scientific knowledge in this area is still considered limited. But the amount of knowledge available has made society realize that it is a real threat. The influence of COVID-19 on microplastics pollution was studied along the Chennai coast. It was found that around 30% of pollution occurred because of various beach activities. The investigations also showed that the stations near the river mouths and beaches were highly polluted. From FTIR analysis, it was found that the concentration of Polyethylene (PE) and Polypropylene (PP) was higher than the other types of polymer in both the locations and both the times (August 2019 and 2020). It is seen that from XRD analysis black residues were found on most of the microplastics surfaces.

Microplastics pollution is highly influenced by various complex hydrological and geological features. The Adyar and Cooum river discharges carrying domestic sewage and waste from heavily industrialized areas are the biggest land-based sources. Microplastics pollution is also influenced by winds, tides, waves, and currents which can carry floating debris far away from its origin.

Beach cleaning activities have to be enhanced to reduce the level of pollution. There is a need for the development of standards to check the extent and severity of microplastics pollution. Developments in the sampling protocols, sample preparation procedures and analysis are important for detailed studies on microplastics pollution and for developing effective management practices. The procedures for tracking Microplastics sources have to be developed and more research has to be carried out to develop more effective Microplastics pollution management strategies.

References

1. APHA. (1999). *Standard Methods for Examination of Water and Wastewater* (20th ed.). Washington.
2. Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin, 62*, 1596e1605.
3. Apitz, S. E., Degetto, S., & Cantaluppi, C. (2009). The use of statistical methods to separate natural background and anthropogenic concentrations of trace elements in radio-chronologically selected surface sediments of the Venice Lagoon. *Marine Pollution Bulletin, 58*, 402e414.
4. Ashwini, S. K., Varghese, G. K. (2019). Environmental forensic analysis of the microplastic pollution at "Nattika" Beach, Kerala Coast, India. Environmental Forensics.
5. Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society (B2), 364*, 1985e1998.
6. Bernardello, M., Secco, T., Pellizzato, F., Chinellato, M., Sfriso, A., & Pavoni, B. (2006). The changing state of contamination in the Lagoon of Venice. Part 2: heavy metals. *Chemosphere, 64*, 1334e1345.
7. Browne, M. A., Galloway, T. S., & Thompson, R. C. (2010). Spatial patterns of plastic debris along estuarine shorelines. *Environmental Science and Technology, 44*, 3404e3409.
8. Buchanan, J. B. (1984). Sediment analysis. In N. A. Holme, & A. D. Mc Intyre, (Eds.), *Methods for the study of marine benthos* (p. 41e65). Oxford-Blackwell.
9. Carr, S. A., Liu, J., & Tesoro, A. G. (2016). Transport and fate of microplastic particles in wastewater treatment plants. *Water Research, 91*, 174–182. https://doi.org/10.1016/j.watres.2016.01.002
10. Cecconi, G. (2005). Morphological restoration techniques. In: Fletcher, C. A., Spencer, T. (Eds.), *Flooding and environmental challenges for Venice and Its Lagoon. State of knowledge* (p. 461e472). Cambridge University Press.
11. Claessens, M., de Meester, S., Van Landuyt, L., De Clerck, K. D., & Janssen, C. R. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin, 62*, 2199e2204.
12. Collignon, A., Hecq, J. H., Galgani, F., Voisin, P., Collard, F., & Goffart, A. (2012). Neuston-icmicroplastic and zooplankton in the NorthWestern Mediterranean Sea. *Marine Pollution Bulletin, 64*, 861e864.
13. Cooper, D. A., & Corcoran, P. L. (2010). Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii. *Marine Pollution Bulletin, 60*, 650e654.
14. Corcoran, P. L., Biesinger, M. C., & Grifi, M. (2009). Plastics and beaches: A degrading relationship. *Marine Pollution Bulletin, 58*, 80e84.
15. Cucco, A., & Umgiesser, G. (2006). Modeling the Venice Lagoon residence time. *Ecological Modelling, 193*, 34e51.
16. Dris, R., Gasperi, J., Mirande, C., Mandin, C., Guerrouache, M., Langlois, A., & Tassin, B. (2017). A first overview of textile fibers, including microplastics, in indoor and outdoor environments, *221*, 453–458. https://doi.org/10.1016/j.envpol.2016.12.013
17. Gacic, M., Kovacevic, V., Cosoli, S., Mazzoldi, A., Paduan, J. D., Mancero-Mosquera, I., & Yari, S. (2009). Surface current patterns in front of the Venice Lagoon. *Estuarine, Coastal and Shelf Science, 82*, 485e494.

18. Gacic, M., Kovacevic, V., Mazzoldi, A., Paduan, J. D., Arena, F., Mosquera, I. M., Gelsi, G., & Arcari, G. (2002). Measuring water exchange between the Venetian lagoon and the open sea. *EOS, Transaction, American Geophysical Union, 83*, 217e222.
19. Galgani, F., Feet, D., Van Franeker, J., Katsanevakis, S., Maes, T., Oosterbaan, L., Poito, I., Hanke, G., Thompson, R., Amato, E., & Janssen, C. (2010). *Marine strategy framework directive*. Task group 10, Marine Litter Report. European Commission Joint Research Center.
20. Gasperi, J., Wright, S. L., Dris, R., Collard, F., Mandin, C., Guerrouache, M., Langlois, V., Kelly, F. J., & Tassin, B. (2018). Microplastics in air: Are we breathing it in? *Current Opinion in Environmental Science and Health, 1*, 1–5. https://doi.org/10.1016/j.coesh.2017.10.002
21. Gregory, M. R., & Andrady, A. L. (2003). Plastic in the marine environment. In Andrady, A. L. (Ed.), *Plastic and the environment*. Wiley. ISBN 0471- 09520-6.
22. Harrison, J. P., Ojeda, J. J., & Romero-Gonzáles, M. E. (2012). The applicability of reflectance micro-Fourier-transform infrared spectroscopy for the detection of synthetic microplastics in marine sediments. *Science of the Total Environment, 416*, 455e463.
23. Hidalgo-Ruiz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the marine environment: A review of the methods used for identification and quantification. *Environmental Science and Technology, 46*, 3060e3075.
24. Imhof, H. K., Schmid, J., Niessner, R., Ivleva, N. P., & Laforsch, C. (2012). A novel, highly efficient method for the separation and quantification of plastic particles in sediments of aquatic environments. *Limnology and Oceanography: Methods, 10*, 524e537.
25. Jan Kole, P., Löhr, A. J., Van Belleghem, F. G. A. J., & Ragas, A. M. J. (2017). Wear andtear of tyres: A stealthy source of microplastics in the environment. *International Journal of Environmental Research and Public Health 14*. https://doi.org/10.3390/ijerph14101265
26. Waldschläger, K., Lechthaler, S., Stauch, G., & Schüttrumpf, H. (2020). The way of microplastic through the environment – Application of the source-pathway-receptor model (review). *Science of the Total Environment*.
27. Klein, M., & Fischer, E. K. (2019). Microplastic abundance in atmospheric deposition within the Metropolitan area of Hamburg. *Germany. Science Total Environment, 685*, 96–103. https://doi.org/10.1016/j.scitotenv.2019.05.405
28. Liu, F., Olesen, K. B., Borregaard, A. R., & Vollertsen, J. (2019). Microplastics in urban and highway stormwater retention ponds. *Science of the Total Environment, 671*, 992–1000. https://doi.org/10.1016/j.scitotenv.2019.03.416
29. Mancero-Mosquera, I., Gacic, M., & Mazzoldi, A. (2010). The effect of wind on the residual current velocities in the inlets of Venice lagoon. *Continental Shelf Research, 30* (8), 915e923.
30. Martins, J., & Sobral, P. (2011). Plastic marine debris on the Portuguese coastline: A matter of size? *Marine Pollution Bulletin 62*, 2649e2653.
31. Molinaroli, E., Guerzoni, S., Sarretta, A., Cucco, A., & Umgiesser, G. (2007). Links between hydrology and sedimentology in the Lagoon of Venice, Italy. *Journal of Marine Systems, 68*, 303e317. https://doi.org/10.1016/j.jmarsys.2006.12.003.
32. Moore, C. J. (2008). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. *Environmental Research, 108*, 131e134.
33. Moschino, V., Delaney, E., Meneghetti, F., & Da Ros, L. (2011). Biomonitoring approach with mussel Mytilusgalloprovincialis (Lmk) and clam Ruditapesphilippinarum (Adams and Reeve, 1850) in the Lagoon of Venice. *Environmental Monitoring and Assessment, 177*(1e4), 649e663. https://doi.org/10.1007/s10661-010-1663-5.
34. National Portal of India, Ministry of Electronics &Information Technology, Government of India. 2005. November. "India at a glance: Profile". https://www.india.gov.in/india-glance/profile.
35. Ng, K. .L., & Obbard, J. P. (2006). Prevalence of microplastics in Singapore's coastal marine environment. *Marine Pollution Bulletin, 52*, 761e767.
36. Eller, P. M., & Cassinelli, M. .E. (Eds.). (1994). *NIOSH manual of analytical methods (NMAM)* (4th ed.), U.S. Department of Health and Human Services.
37. Ojeda, J. J., Romero-González, M. M., & Banwart, S. A. (2009). Analysis of bacteria on steel surfaces using reflectance micro-Fourier transform infrared spectroscopy. *Analytical Chemistry 81*, 6467e6473.

38. Pellizzato, M., Galvan, T., Lazzarini, R., & Penzo, P. (2011). Recruitment of tapes philippinarum in the Venice Lagoon (Italy) during 2002e2007. *Aquaculture International, 19*, 541e554.
39. Plastics Europe. (2019). Plastics e the facts 2012. http://www.plasticseurope.org/Document/plastics-the-facts-2019.aspx?FolID¼42.
40. Srinivasa Reddy, M., Basha, S., Adimurthy, S., & Ramachandraiah, G. (2006). Description of the small plastic fragments in marine sediments along the Alang - Sosiya ship breaking yard, India. *Estuarine Coastal and Shelf Science 68*, 656e660.
41. Simon, M., Vianello, A., & Vollertsen, J. (2019). Removal of > 10 μmmicroplasticparticles from treated wastewater by a disc filter. *Water (Switzerland) 11*. https://doi.org/10.3390/w11091935
42. Song, Y. K., Hong, S. H., Jang, M., Han, G. M., Jung, S. W., & Shim, W. J. (2018). Corrections to " Combined effects of UV exposure duration and mechanical abrasion on microplastic fragmentation by polymer type, *7*, 3831–3832. https://doi.org/10.1021/acs.est.8b00172
43. Sruthy, S., & Ramasamy, E. V. (2017). Microplastic pollution in Vembanad Lake, Kerala, India: The first report of microplastics in lake and estuarine sediments in India. *Environmental Pollution, 222*, 315–322.
44. Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Roeland, S. J., John, A. W. G., McGonigle, D., & Russel, A. E. (2004). Lost at sea: Where is all the plastic? *Science, 304*, 838.
45. Unice, K. M., Kreider, M. L., & Panko, J. M. (2013). Comparison of tire and road wear particle concentrations in sediment for watersheds in France, Japan, and the United States by Quantitative Pyrolysis GC/MS analysis. *Environmental Science and Technology, 47*, 8138–8147. https://doi.org/10.1021/es400871j
46. Usero, J., Gonzalez-Regalado, E., & Gracia, I. (1996). Trace metals in the bivalve mollusc Chameleagallina from the Atlantic coast of southern Spain. *Marine Pollution Bulletin 32*, 305e310.
47. Veerasingam, S., et al. (2016). Influence of 2015 flood on the distribution and occurrence ofmicroplastic pellets along the Chennai coast, India. *Marine Pollution Bulletin*. https://doi.org/10.1016/j.marpolbul.2016.05.082
48. Zonta, R., Bettiol, C., Collavini, F., Fagarazzi, O.E., Zaggia, L., & Zuliani, A. (2001). *Project report. Drain project fresh water and pollutant transfer from the drainage basin to the Venice Lagoon* (Vol. 15B).

Estimation of Shortest Route with Minimum Travel Time Using GIS and MSSTT Algorithm

A. Jackulin Mahariba, R. Annie Uthra, and R. Golda Brunet

Abstract The proposed methodology aims at dynamically allocating ambulance service and providing the shortest route for emergency medical service with improved response time as per the demands across spatial and temporal heterogeneity. Whenever a road traffic accident occurs, the victim's life will be saved only if the victim receives appropriate treatment within the golden hour. Geographic Information System plays a predominant role in handling spatial data and non-spatial data. Geo-database enables the identification of the nearest ERS and hospitals for EMS. Dynamic routing for the identified ERS towards the incident location and adjacent hospital with reduced ART in real-time traffic challenge is addressed in this research work. A multiple-source shortest travel time (MSSTT) algorithm is proposed to determine the route with limited travel time to reach the destination. Traveling time is contemplated as the primary element in determining the optimal route. MSSTT algorithm combined with the tools of GIS contributes an efficient approach for effective utilization of ambulance service to save the life. The proposed system can be adapted to the wide geographic area of any developing nation without any additional requirement of new road infrastructure at a low cost.

Keywords Emergency rescue service · GIS · Road accidents · Shortest route

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1 Introduction

Emergency management in case of road accidents requires adequate planning to reduce the accident response time (ART) to prevent the loss of human life. ART is defined as the time duration between the accident reported to the emergency service providers and admission of the victim to the nearby hospital for emergency medical service (EMS). Reducing ART reduces the fatality rate in a road accident. With the available number of emergency vehicles (EV), the reduction in ART can be achieved by reducing EV travel time either in reaching the incident location or in dispatching the victim for EMS. Across India, each state has its policies and regulations to be followed for EMS. Accordingly, the average ART changes for each state. For Tamil Nadu, the average ART is 13 min [1] if there is a clear provision of accident location spotted with standard traffic conditions. The biggest challenge in emergency management of traffic accidents is the lack of coordination and effective flow of information to the first responder Unit (FRU), especially in many developing countries. The anti-social behavior, lack of humanity, fear of legal queries, crowding on the location affected are some of the causes for delay in emergency response.

To reduce the delay in operational time in traffic accidents, emergency planning is to be carried out beforehand. Adequate planning is required in the case of highly populated urban areas with good road infrastructure. On the other hand in rural areas, the road infrastructure is a major drawback in emergency routing. Emergency planning and emergency management for a traffic accident is an interdependent process to reduce the response time and saves a human life. Particularly there is a tremendous increase in emergency call volumes and reduction in response time in urban areas nowadays due to higher traffic volumes, increased number of intersections, narrow roads, and more traffic signals.

Navigation is the main task in emergency planning and it should result in an optimized route. Identifying or building such a navigation system is a hardship and it involves research and experimental analysis for the required geographic location. A geographic information system (GIS) is one of the solutions to achieve such a navigation system. In approaching strategic applications where information is organized in the database as multilayered documents, GIS is becoming supportive of its location. GIS also provides various features, and it has proved its usefulness by solving numerous types of problems in many scientific disciplines, which has made it so common and wide ranging. It enables accurate visualization and presentation of emergencies as a device capable of collecting, examining, and delivering data associated with various geographic regions. It has been used for various purposes to examine the spatial and temporal variations of emergency call volume raised due to different reasons. GIS software is used to model the shortest route using spatial data and it can also be used to automate relocation through network analysis.

Hence, traffic road safety systems and emergency management and planning for road accidents cannot be formulated and generalized because the dependent parameters to design such a model are varying concerning the environmental condition, road infrastructure, type of government policies, traffic safety regulations, and so on. Scenario or case study area-based model is to be framed for each country according to their demands and policies.

2 Literature Survey

The de-centralized emergency plan is laid in three levels such as basic, standard, and regional level [2]. A GIS-based web portal is designed at the basic level to managing the different hazardous situations, which can be accessed by all the citizens of the nation. The standard level includes emergency as well as evacuation plans at the municipal level. The regional level is the extension and ordered information present in the standard level to a national wide application. The results and conclusions of the proposed work by [3] stated that adjacent regions should work together to design their traffic management strategies to mitigate the negative structural effects resulting from those regions and to benefit from the positive location, where the crashes are very minimal. Availability of hospitals with intensive care unit (ICU) or casualty care unit (CCU) will also play a predominant role in reducing the mortality rate of traffic accidents. The population density and number of fatal accidents crashes, and injuries of any region are considered to decide the establishment of an emergency care center in that location [4].

Other than the presence of medical services, the logistic issue is one of the primary factors in emergency management. Allocation of an emergency vehicle to the correct CCU via an optimal route is the objective of emergency planning. A mixed-integer programming model is proposed for the allocating of ambulance services for a large-scale disaster [5]. This model can even provide dynamic reallocation services based on the patient's condition.

Maximum expected coverage location problem (MECLP) and set covering location problem (SCLP) are combined to select the emergency management service providers with minimal service time [6].

Vehicular communication was used efficiently to manage traffic congestion and a content-centric network [7] was used to identify the fastest route during rescue service for roadside accidents. Some authors have proposed techniques to handle emergency arises due to road accidents through intelligent transportation systems (ITS). Vehicular communication plays a key role in ITS, in which vehicles communicate to other vehicles and the roadside unit (RSU) through different modes of communication like dedicated short-range communication (DSRC), Microwave, infrared, global navigation satellite system (GNSS), and cellular networks [8, 9]. To make vehicular communication secure and safe, vehicle communication messages are encrypted using blockchain [10] was introduced. But developing and underdeveloped countries did not have such a good and advanced road infrastructure to utilize the ITS solutions.

A route plan with less obstruction and minimal construction cost is identified using GIS [11] for utility mapping. As an emergency requirement for any cause is completely uncertain, Bo Zhang et al. proposed a location set covering model with uncertainty theory to find the optimal solution for an emergency facility location that covers a widespread geographical location. A system status management strategy [12] with GIS spatial analysis and mixed-integer programming was proposed to provide an efficient solution for EMS in Singapore. The results are superior when compared against the discrete event simulation model for reallocation of ambulance service in a dynamic environment. The GIS modeled route is compared with the actual route estimated using GPS [13]. The GPS-modeled routes show very close proximity with the actual routes and it performs better at some locations. Exploration of the active and potential route is possible using GIS while GPS routes are precise with environmental context [14].

The spatial data is geocoded in GIS and the nearest ambulance service was found with the shortest straight line distance [15] from the incident location, then the shortest path was identified through the GPS data collected from the ambulance. The emergency response time is shortened by allocating the ambulance to the incident location and thereby providing medical service to the patient very quickly. A study was made to compare the routes identified by the global positioning system (GPS) and GIS. No remarkable difference was found between routes identified by GPS and GIS [16]. But the number of traffic barriers is not examined using GIS.

The localization problem was solved by considering the moving vehicles as robots. The digital navigation systems along with multiple lidars [17] on the body of the vehicle are used to identify the optimal route with high accuracy. An impedance model [18] was developed with sub-variables such as weather condition, road type, sight-seeing, tourism, security, facilities, and so on. These attributes are added along with the road segments in GIS for route planning. Hence efficient routes are identified using the impedance model on GIS.

Dynamic maximum expected coverage location problem (DMEXCLP) and penalty heuristic methods [19] are combined to solve the navigation problem for roadside accidents. So that the emergency medical service and dynamic relocation were provided with the improved response time.

There are many shortest path algorithms available to find the shortest and fastest route for emergency medical service. As the road environment is highly dynamic, there is always a requirement of rerouting whenever an unexpected event occurs at the path, which can increase the estimated travel time to be higher. Hence rerouting should also be planned in emergency management and planning. Modified Dijkstra's algorithm [20] was used to find the alternate route for the emergency vehicle during unfavorable conditions like an increase in traffic flow. The unexpected increase in rescue time was assessed by calculating the critical flow time in road traffic continuously. Distance capacitated vehicle routing problem (DVCRP) [21] was proposed using a loose coupling strategy of spatial decision support system in GIS to solve the vehicle routing problem.

The inference obtained from the literature for emergency navigation systems consolidates the existing techniques on three major disciplines. They are navigation systems based on vehicular communication with ITS, emergency routing based on graph theory algorithms, and GIS. A generalized system would not serve the purpose due to the diverse geographical nature and traffic laws of each country. A new emergency navigation system for road accidents is suggested based on the infrastructure and policies of the selected study area. As the selected study area lacks well-built road infrastructure with ITS, the suggested framework makes use of both GIS and graph theory algorithms.

3 Proposed System

The emergency response to road accidents requires detailed knowledge of the study area and adequate planning [22]. The implementation of an Emergency Rescue Service (ERS) using a standalone software-GIS and proposed MSSTT algorithm is carried out in the following Sects. 3.1 and 3.2.

3.1 ERS Using GIS

To accomplish the efficient navigation system for ERS, GIS requires precise and prevalent data spatially. Chennai city in Tamil Nadu, India, is chosen as the study area. The study area extends its boundary over 426 km^2, lies at a mean altitude of 6 m above sea level, 12° 59’ and 13° 9’ at the northern latitude and 80° 12’ and 80° 19’ at east longitude with 11,235,018 population. Based on the current ‘Accidental Deaths and Suicides in India 2019’ survey of the National Crime Record Bureau, a total of 69,064 traffic incidents were observed in 53 cities during 2019. The fatal road accidents are high on national highways followed by state highways. The proportionate of road fatalities over different types of roads are depicted in Fig. 1.

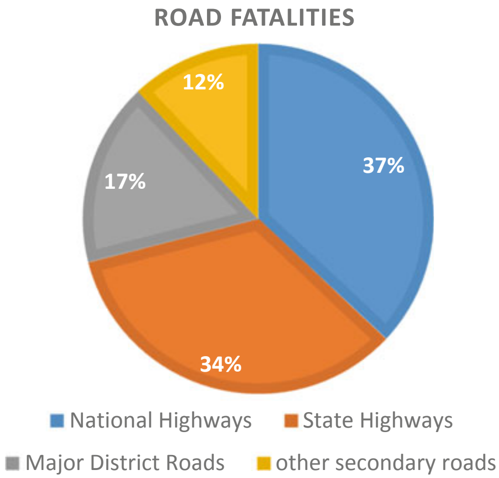

Fig. 1 Number of road fatal accidents over different types of roads adapted from [1]

The study area, “Chennai”, is chosen wisely to have both the police-controlled and uncontrolled areas in its geographical origin. Of the overall road accidents recorded in the cities, Chennai recorded 10.2% (6,871 out of 67,228 cases) [1].

The geo-database for ERS must be precise, up-to-date, and exhaustive. Decentralization access of database management will help in constructing, maintaining the robustness, validating, and updating the data (Fig. 1). The spatial data are visualized and configured in the structure of layers. The base map of the city is georeferenced using the ground control points (GCP) accurately and the boundary is digitized. The road network is added as a line layer and overlayed on the base map. The geo-database of ERS requires the uncondensed road network of the entire city from highways to tertiary roads/streets. The road network layer covers each turn-by-turn direction in the form of edges. Junctions of roads are interpreted in the form of intersections of road segments. Edges and intersections are topologically related to one another at intersections must bind to other outlines such as boundaries, and the migration from edges in the network is passed via intersections to other edges. The road network with all primary (highways), secondary, and tertiary roads are digitized to generate the study area road network base map as explained in (Fig. 2).

Hospitals, ambulance on-call services, and other important hotspot locations required for ERS are created as separate point layers and added to the generated base map of Chennai city. Each layer has an attribute table that contains non-spatial and metadata about the spatial structures included in the map. The attribute table

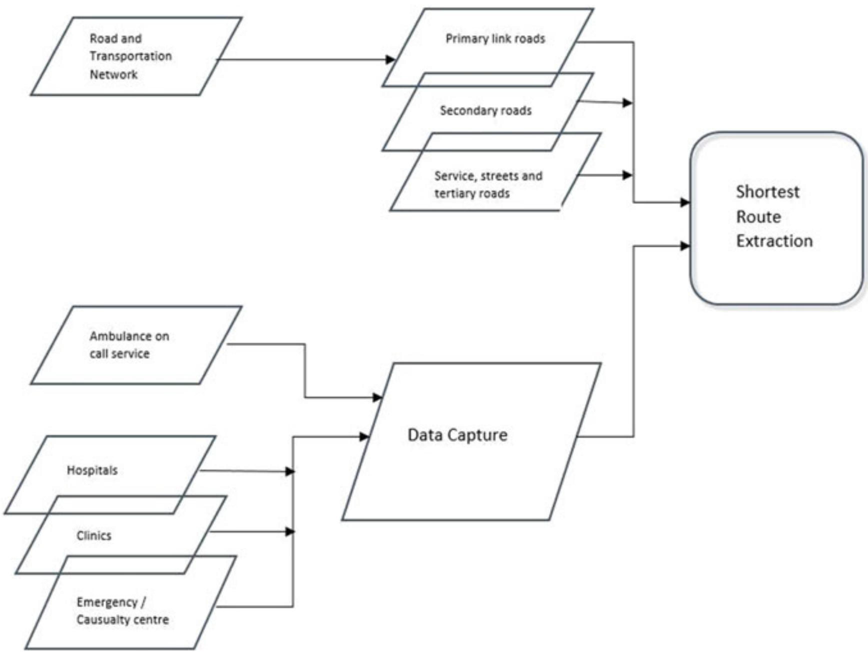

Fig. 2 Construction of geo-database to identify the shortest path using GIS

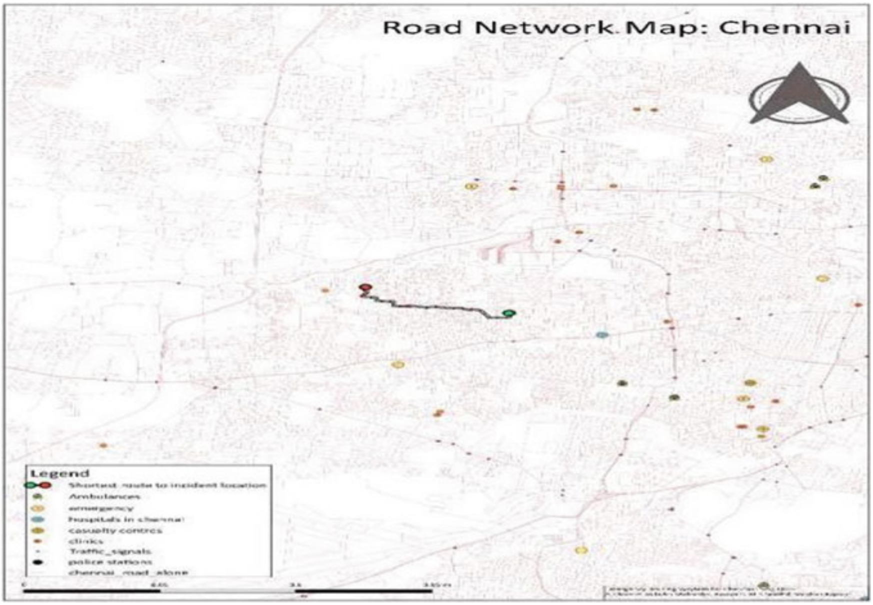

Fig. 3 Chennai city road network map with the required hotspots

contains the object id of each edge, length of each edge in meters, and the location expressed in lat/long. The required hotspot locations to drive the emergency planning and routing are added along with the road network layer in the generated base map (as shown in Fig. 3) and the incident location can be assumed to be randomly on any road as depicted in (Fig. 3) with the red marker symbol on the map.

Figure 4 displays the magnified view of the shortest path identified from the nearest ambulance service to the incident location.

3.1.1 Identification of Nearest Available Hospital Using Buffer Tool

The nearest hospital from the incident location is identified through buffering. As the map is constructed using a projected coordinate system, euclidean buffers are best suited to provide the boundary precisely. The distance can be specified in linear units such as meters and kilometers. Internally the linear units are converted into feet and applied to the selected feature. To find the hospitals with closer proximity, a buffer distance of 1 km is initially applied to check for availability as shown in Fig. 5. Scrutinized for the immediate three adjacent hospitals. If the hospitals are not available within the buffer distance of 1 km, then the distance is incremented by every 1 km radius to get at least 3 hospitals. The green circle in Fig. 5 represents the buffer created around the incident location to identify the nearest hospital. The gray shaded line in Fig. 5 represents the shortest path identified from the nearest available ambulance location to the incident location.

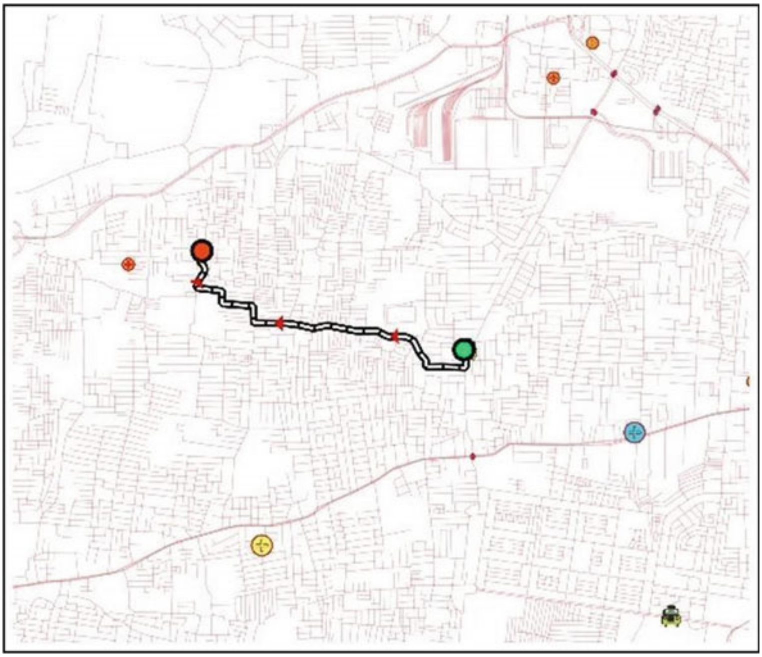

Fig. 4 Routing result from nearest ambulance to incident location

QGIS has a provision to modify the attribute table of the polyline (road segments) at user convenience. The road graph plugin of QGIS accommodates the preference of adding attributes such as road direction, length, and speed value. The road direction can be specified as forward, reverse, or two-way direction. The length of the road segment can either be entered or extracted by the tool without deviation. The speed value is entered in kilometers. These three attributes are brought to bear the shortest path between any two points.

3.1.2 Identification of Shortest Path to Reach Accident Location and the Nearest Hospital

The network analysis of QGIS uses Dijkstra's algorithm to extract the path in the road network. Dijkstra's algorithm operates with the input parameters such as graph (G), source vertex (s), and destination vertex (t). The shortest path is stored in the form of an array. To reduce the time complexity, a binary heap is used to extract the path from the output array and it is visualized in the graph. The pseudocode of Dijkstra's algorithm is given below (Fig. 6).

The final solution with the shortest path on the map is exported in the form of a URL, which can be communicated to any ambulance service driver. It is visualized using any browser as an interactive map as shown in (Fig. 7).

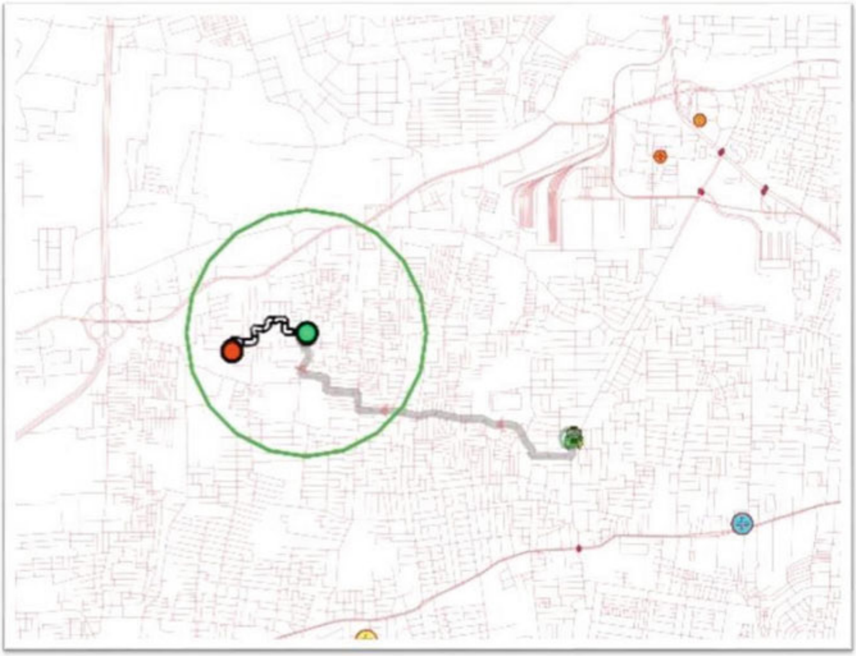

Fig. 5 Nearest hospital identified using Buffer of 1 km radius

```
pseudocode Dijkstra(G, s, t):
     for each vertex x in G:           // Initialize
       weight[x] := 999
      shortest_path[x] := NULL
    weight[s] := 0
    V := {v1,v2,v3,...,vn}
    while V!=NULL                  // finds the shortest path
       a := vertex in V with least weight[]
       if weight[a] = 999:
          break                         // vertex a is processed
       V=V-{a}
       for each adjacent b of a:
          total := weight[a] + cost(a, b)
             if total < weight[b]:             // minimum weight updated
                 weight[b] := total
                 shortest_path[b] := a
          if(b==t):
              break
     return shortest_path[]
```

Fig. 6 Pseudocode of Dijkstra's algorithm

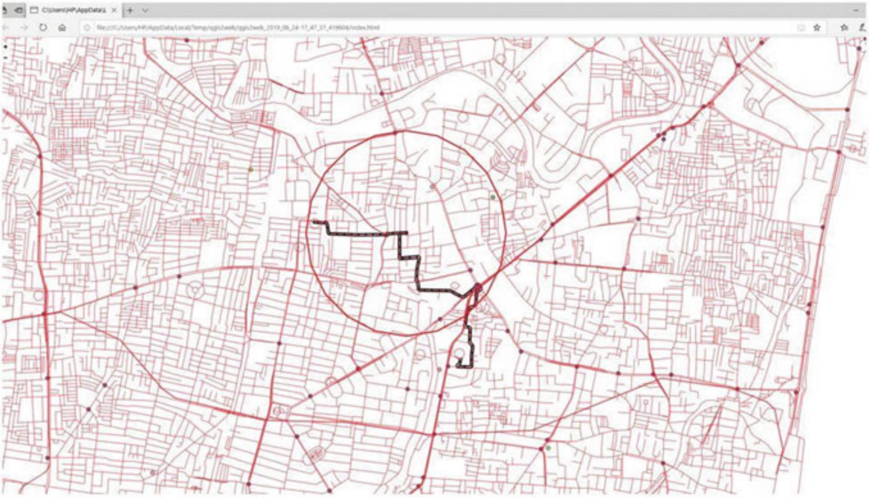

Fig. 7 Routing results exported in the form of an interactive map

3.2 ERS Using Conventional Gps Based Navigation System

The case study is implemented in the same study area (Chennai) as used in ERS using the GIS method. The city map is considered as a weighted directed graph G(V, E, w) with ambulance services and hospitals are taken as vertices. The road network is taken as the edges between them and w represents the cost of each edge.

3.2.1 Identification of Nearest Available Fru

Let G be the graph with V number of vertices and E number of edges. The ambulance locations are taken as vertices to construct G. Once the accident notification is received with the accident location is represented in latitude and longitude (φ1, λ1). It is considered as the new vertex and inserted in the graph. To identify the nearest ambulance service (φ2, λ2) in the graph, the haversine formula is used. The haversine formula is used to find the distance between the accident location and ambulances.

$$a = \sin^2(\Delta\phi/2) + \cos\phi 1.\cos\phi 2.\sin^2(\Delta\lambda/2) \tag{1}$$

$$c = 2.a\tan 2(\sqrt{a}, \sqrt{(1-a)}) \tag{2}$$

$$d = R.c \tag{3}$$

where R = 6371 km, the radius of the earth; $\Delta\varphi$ is the difference between latitudes of the two locations; $\Delta\lambda$ is the difference between longitudes of the two locations.

On substituting, the real values of Eqs. (1) and (2) in (3), the distance between the geo-locations will be determined. If all the nearest ambulances are examined as sources, then the time complexity of the proposed algorithm will be increased. So, the ambulance available within 1 km or three nearest ambulance services are added to the source list (S) and the destination is the accident location. The time complexity of finding the nearest FRU using the haversine formula is O(n), where n is the number of ambulance services currently available.

3.2.2 Multi-source Shortest Travel Time (Msstt) Algorithm

The MSSTT algorithm identifies the optimal path by using time as the heuristic function rather than distance. The weight matrix of the graph contains the travel time of each edge.

Let G be the Graph with V number of vertices and E number of edges. The intersections of roads are taken as vertices to construct G. The weight matrix of size EXE is generated. Each W_{ij} represents the travel time of the route with source 'i' and destination 'j'. The MSSTT algorithm takes the entire graph, list of sources in set S (obtained from Sect. 3.2.1), and incident location 'I' as the input. On each execution of this algorithm, 'I' is considered as the destination node. The algorithm initially checks for the reachability from each source to destination through exhaustive search. The multisource BFS is utilized as the search algorithm with the time complexity O(V.E). Once the search is performed the cost of each path from source to destination is updated and stored in the form of a minimum heap tree along with a table. The table contains the set of vertices involved in the shortest path. In the minimum heap tree, the root node contains the minimum travel time and its corresponding path is extracted. In case of the non-availability of any ambulance service, the other nodes in the minimum heap tree and its corresponding path will be utilized.

The pseudocode of the MSSTT algorithm and construction of a minimum heap is given in Fig. 8. To identify the nearest hospital from the incident location, again the haversine distance is calculated among the list of available hospitals, clinics, and emergency centers. Standard Dijkstra algorithm is used to find the shortest path between the incident location and identified the nearest hospital. The path is then communicated to the ambulance driver in the form of a URL, which guides the driver to reach the hospital with minimal travel time.

The geo-location of ambulance on-call service and the hospitals in the entire study area is extracted in the form of a XML file from google earth. These files are then converted into an attribute table with three columns namely, latitude, longitude, and name. Once the accident notification is received from a geo-location(X, Y), the haversine formula is used to find the set S. The algorithm is executed and its results are compared with the results obtained using GIS in Sect. 3.1. The proposed algorithm selects the optimal route with less travel time. The time complexity of the simple BFS algorithm is O(V.E). The worst-case time complexity of multisource BFS is

```
Routine MSSTT(G, S, I)

Input : G: Graph, S: set of all sources/ ambulance locations, I: Incident location.
Output: minimum cost value of the path
  1. for i=1 to number of sources
       a. if S[i] reachable to I
            i. cost[i] =search(S[i],G)
           ii. Order_heap(cost[i],G)
          iii. Set a[i]=1
       b. Else
            i. Set S[i]=-1
  2. return cost

Routine Order_heap( C, x)

Input : C: Cost of the edges stored in an array with x is the index of it.
Output: modified C array with x in the root as the minimum element.
  1. i← left(x);
  2. J← right(x);
  3. If i<= |C| && C[i]<V[x] then
       i.  min←i;
  4. else
       i.  min←x;
  5. if j<= |C| && C[j]<C[min] then
       i.  min←j;
  6. if min!=x then
       i.  Swap C[x] and C[min];
       ii. Order_heap (C,min);
```

Fig. 8 Pseudocode of proposed algorithm

given as O (α *(V.E)). The time complexity of constructing, inserting, and searching a node in a minimum heap tree is O(log n), where n is the number of nodes in a minimum heap tree. In the worst case, the tree will be constructed with α number of nodes. And O(n) is the worst-case time complexity for the algorithm used to identify the nearest ambulance service. Hence, the time complexity of the MSSTT algorithm is

$$T(n) = \begin{cases} 3(V.E) + \log 3 + O(n) & \text{If there is no or less than 3 ambulance available within 1 km} \\ \alpha * (V.E) + \log \alpha + O(n) & \text{Otherwise} \end{cases} \tag{4}$$

If the travel time is increasing than the estimated travel time due to an unfavorable scenario, in such case an alternate route can be identified through the same proposed algorithm. The request is made with the current geo-location and dynamic route planning is carried out automatically. The newly identified route is communicated in the form of a URL.

3.3 A Hybrid Model for ERS

ERS using GIS and the conventional system has its own merits and demerits. A hybrid model can be crafted in such a manner that it utilizes the advantages of both the GIS and MSSTT algorithms of the conventional system. The following steps are required to implement hybrid model,

Step 1: To identify the nearest ambulance to the incident location can be identified easily by applying the buffer of varying diameter from 1 km until finding at least three ambulances that are close to the location. In the conventional system, identification of ambulance service through haversine formula increases the time complexity of the system.

Step 2: In the network analyst tool of GIS, Dijkstra's algorithm is used to find the shortest route between any two lats/longs on the map. But it works well on the directed acyclic graph. In a real-time road network map, there are many parallel roads between the source and destination location points, which leads to forming a cycle in the graphical representation. The proposed MSSTT algorithm can provide better results with the existence of parallel edges and cycles in the graph. Hence implementing the MSSTT algorithm as a plugin in GIS software will serve the purpose. The time complexity of the MSSTT algorithm is reduced when the proposed algorithm is blended with the tools available in QGIS.

$$T(n) = \begin{cases} 3(V.E) + \log 3 & \text{If there is no or less than 3 ambulance available within 1 km} \\ \alpha * (V.E) + \log \alpha & \text{Otherwise} \end{cases} \tag{5}$$

As the MSSTT algorithm uses traveling time as the cost metric and it selects an optimal route out of all available routes to reach the incident location and the nearest hospital for EMS.

4 Conclusion

In this study, the problem of reducing ART was addressed by combining the ERS using GIS and the conventional system. The objective is to develop a web-based centralized emergency management system for road traffic accidents to cover emergency demands. The hybrid model utilizes the proposed MSSTT algorithm with the available tools in GIS. It aims to prevent rerouting so that the cost and time exploited in identifying the shortest route will not be in vain. The time complexity of the proposed algorithm is low when compared to the existing shortest path algorithms such as set covering localization problem, DVCRP, genetic algorithm, and DMEXCLP. Also, the model can serve the purpose across political boundaries. Future enhancement of the work can automate the entire process of emergency management with minimal resources.

5. References

1. S.R.C. The hindu, "News:Cities:Coimbatore:thehindu.com," 28 October 2018. https://www.thehindu.com/news/cities/Coimbatore/dpr-for-proposed-flyover-on-avinashi-road-getting-ready-cm/article25349527.ece.
2. Francini, M., Artese, S., Gaudio, S., Palermo, A., & Viapiana, M. F. (2018). To support urban emergency planning: A GIS instrument for the choice of optimal routes based on seismic hazards. *International Journal of Disaster Risk Reduction,* 121–134.
3. Soro, W. L., Zhou, Y., & Wayoro, D. (2017). Crash rates analysis in China using a spatial panel model. *IATSS Research,* 123–128.
4. Mohri, S. S., Akbarzadeh, M., & Matin, S. H. S. (2020). A Hybrid model for locating new emergency facilities to improve the coverage of the road crashes. *Socio-Economic Planning Sciences,* 1–8.
5. Fancello, G., Mancini, S., Pani, C., & Fadda, P. (2017). An emergency vehicles allocation model for major industrial disasters. In *World conference on transport research - WCTR 2016 Shanghai*, *2017*.
6. Villegas, J. G., & Castañeda, C. (2017). Analyzing the response to traffic accidents in Medellín, Colombia, with facility location models. *IATSS Research,* 47–56.
7. Siddiqua, A., Shah, M. A., Khattak, H. A., Din, I. U., & Guizani, M. (2019). iCAFE: Intelligent congestion avoidance and fast emergency services. *Future Generation Computer Systems,* 365–375.
8. Tonguz, O. K., & Viriyasitavat, W. (2013). Cars as roadside units: A self-organizing network solution. *IEEE Communications Magazine,* 112–120.
9. Jordán, J. G., Soriano, F., Graullera, D., & Martín, G. (2001). A comparison of different technologies for EFC and other ITS applications. In *IEEE Intelligent Transportation Systems Conference Proceedings*, *Oakland (CA) USA, 2001.*
10. Lei, A., Cruickshank, H., Cao, Y., Asuquo, P., Ogah, C. P. A., & Sun, Z. (2017). Blockchain-based dynamic key management for heterogeneous intelligent transportation systems. *IEEE Internet of Things Journal,* 1–12.
11. Cheng, M. Y., & Chang, G. L. (2001). Automating utility route design and planning through GIS. *Automation in Construction,* 507–516.
12. Lam, S. S. W., Zhang, J., Zhang, Z. C., Oh, H. C., Overton, J., Ng, Y. Y., & Ong, M. E. H. (2015). Dynamic ambulance reallocation for the reduction of ambulance response times using system status management. *American Journal of Emergency Medicine,* 159–166.
13. Chen, L., Shang, S., & Guo, T. (2020). Real-time route search by locations. In *The thirty-fourth AAAI conference on artificial intelligence, New York, USA.*
14. Dalton, A. M., Jones, A. P., Panter, J., & Ogilvie, D. (2015). Are GIS modelled routes a useful proxy for theactual routes followed by commuters? *Journal of Transport & Health,* 219–229.
15. Fumihito Fukushima, T. M. (2020). Objective evaluation study on the shortest time interval from fire department departure to hospital arrival in emergency medical services using a global positioning system — potential for time savings during ambulance running. *IATSS Research,* 1–8.
16. Duncan, M. J., & Mummery, W. K. (2007). GIS or GPS? A comparison of two methods for assessing route taken during active transport. *American Journal of Preventive Medicine,* 51–53.
17. Aynaud, C., Bernay-Angeletti, C., Aufrere, R., Lequievre, L., Debain, C., & Chapuis, R. (2017). Real- time multi sensor vehicle localization. *IEEE Robotics and Automation Magazine,* 65–74.
18. Sadeghi-Niaraki, A., Varshosaz, M., Kim, K., & Jung, J. J. (2011). Real world representation of a road network for route planning in GIS. *Expert Systems with Applications,* 11999–12008.
19. van Barneveld, T., Jagtenberg, C., Bhulai, S., & van der Mei, R. (2018). Real-time ambulance relocation: Assessing real-time redeployment strategies for ambulance relocation. *Socio-Economic Planning Sciences,* 1–42.

20. Wei, X., Lv, W., & Song, W. (2013). Rescue route reselection model and algorithm for the unexpected accident. In *The 9th Asia-Oceania Symposium on Fire Science and Technology, Hefei, 2013*.
21. Krichen, S., Faiz, S., Tlili, T., & Tej, K. (2014). Tabu-based GIS for solving the vehicle routing problem. *Expert Systems with Applications,* 1–11.
22. Zhang, B., Peng, J., & Li, S. (2017). Covering location problem of emergency service facilities in an uncertain environment. *Applied Mathematical Modelling,* 429–447.

Correction to: Greenhouse Gases Emission from Municipal Solid Waste in Thanjavur

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