



Assessment of shear wall quantity on seismic performance of high-rise building

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Received: 2 February 2024 / Accepted: 9 February 2024 / Published online: 1 April 2024
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Abstract

Buildings with shear walls are much less likely to sway in the direction of their orientation, reducing the likelihood of structural damage. In addition to providing lateral stiffness, shear walls also prevent roof or floor wobbling. If walls are strategically placed within a structure, they may be able to withstand the lateral forces caused by wind and earthquakes. The investigation of the effects of various floor area ratios on shear walls in a building with an irregular shape is explained in the paper. The primary concern is torsion formation in a structure with an irregular layout. In an irregularly shaped building, the floor area (F/A) ratio of the shear wall is discussed in this essay along with its causes, effects, and potential solutions. In Seismic Zone III, a U-shaped building with 15 stories and medium soil conditions is the subject of the study. Its damping value is 5%. CSI ETABS ver. 19 will be used to accomplish the modeling and analysis. The study will conclude by highlighting the rationale behind selecting a certain test model that demonstrates the lowest levels of story drift, time period, story displacement and base shear. This test model has a varied percent shear wall (impact of a variable floor area ratio of shear wall).

Keywords ETABS · Shear wall ratio · Lateral story stiffness · Story drift · Response spectrum analysis

Introduction

Multistory buildings in places with strong wind speeds are provided with a shear wall as a structural element. Along the length and width of buildings, these walls often start at the

foundation level. These findings caused academic scholars and practicing engineers to pay attention to shear wall-frame structures. Shear walls should be used in earthquake-resistant designs to reduce loss following earthquakes, according to experimental and analytical studies on seismic design methodologies (Akhil Ahamad & Pratap, 2020). This wall resists the lateral loads that the structure is subjected to as a result of wind, earthquakes, and occasionally hydrostatic or lateral earth pressure. The modification of various metrics with increasing shear wall ratio, such as inter-story drift or roof pitch, can be used to assess the effect of shear wall ratio on structural vulnerability (Azad & Abd Gani, 2016;

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Basavalingappa, 2020; Dahat & Autade, 2016; Ali Kaveh & Ilchi Ghazaan, 2017). Furthermore, properly engineered RC shear walls safely deflect the applied seismic energy, causing only minor or even no structural damage to the components of building. One of nature's greatest threats to both property and human life is an earthquake. The goal of engineering design is to create buildings that can withstand earthquakes of the highest magnitude for the duration of their useful lives, minimizing the risk of fatalities and property damage (Fares, 2019; Gupta et al., 2016; Kaveh et al., 2020). Shear walls are frequently employed in tall modern buildings as a vertical structural element for resisting lateral stresses that may be caused by the impact of wind and earthquakes (Kaveh & Zakian, 2012; Pandey, 2021; Shaha & Banhatti, 2016).

Investigations into solid ground movements revealed that shear wall systems that were well-planned and definite during previous earthquakes operated successfully (Hiremath & Hussain, 2012; Kaveh & Zakian, 2014; Mawle & Singi, 2020). Shear barriers constructed in areas with high seismic activity should adhere to strict enumeration requirements. But prior research showed that even buildings with maximum shear wall to floor ratios and walls with average seismic enumeration could experience high-magnitude earthquakes. These perceptions led both academic analysts and practical designers to take wall-outline structures into consideration (Banerjee et al., 2023; Parashar & Gupta, 2023; Sanjay et al., 2017; Tarigan et al., 2018). The trial and scientific research on seismic planning are about to energize the use of shear walls for a seismic tremor-safe plan to limit misfortune after earthquakes. For a period spanning from the Skopje earthquake in 1963 to the Armenian earthquake in 1988, the way current designs behaved under solid ground movements and found that, despite occasional breaking with varying degrees of seriousness, no breakdown or life misfortune occurred in structures with shear walls. It was established that excessive inter-story floats, which led to section shear disappointments, were the main cause of the collapse of numerous RC outline constructions (Edition & Duggal, 2006; Engineering, 2024; Goswami et al., 2012; Kaveh & Zakian, 2012; Yadav & Joshi, 2019). In any case, when complete disintegration went undetected, massive inter-story floats in the outlines resulted in severe property loss. The wall angle proportion, the shear wall to floor area proportion, and the wall design in plan bare were shown to be critical boundaries that affect the itemizing of a shear wall for an RC plan. But among these barriers, shear wall percentage is also recognized as a crucial boundary disturbing the global presentation of a structure subject to significant ground movements. Shear wall percentage is, therefore, chosen as the crucial limit to be investigated in this scientific evaluation (Jain & Mandal, 1992; Seeram & Kumar, 2023; Sharma et al., 2018). The diversity of different boundaries with growing shear wall proportion, such as rooftop or inter-story float, can be used to examine the impact of shear wall proportion on the main weakness. The basic methodology for seismic tremor-safe plans uses a shear wall region to floor area

ratio of roughly 1.0% as a guideline when a double framework is used. The text suggests some suggested shear wall proportions for use in the first planning stages of shear wall-outline designs. These ratios are primarily based on precise characteristics that are discovered by building surveys carried out following significant earthquakes or through logically based relationships (Dahesh et al., 2015; Mukundan & Manivel, 2015; Parashar et al., 2023).

The effects of various floor area ratios on shear walls in a building with an irregular shape are explained in this study.

Role of shear wall

Shear walls are the planar structural components that give the structure lateral stiffness or rigidity. The shear wall in a building experiences a decrease in lateral displacement with the addition of lateral stiffness. But the shear wall's advantage is in its placement. The shear wall in a building must be positioned from a stability perspective so as to prevent eccentricity b/w the center of mass and stiffness (Mohan, 2011; Ravi & Lekshmi, 2016). This is what caused the building's torsion forces to grow. In other words, shear walls are beneficial for buildings only if they do not cause torsion.

A bare frame model and eight other test models are taken into consideration for the investigation of the role of shear walls in decreasing the various parameters, such as story drift, story displacement, etc., in an irregular building (Fig. 1).

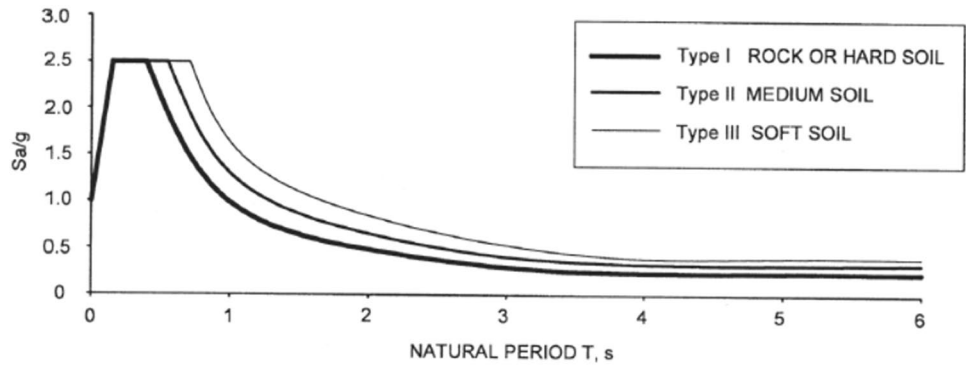
Response spectrum analysis (RS)

The response spectrum analysis is performed in accordance with the requirements of IS 1893:2016. The concrete structure's damping ratio is set at 5%, the response reduction factor for the SMRF is set at 5, and medium stiff soil used. These factors are all based on the assumption



Fig. 1 Shear wall (Source; www.constructionworld.com)

Fig. 2 Source of IS 1893:2013 (Part-1)



that the building is in zone III; importance factor (IF) for the residential building is taken to be 1.2 according to IS 1893:2016; the response reduction factor for the concrete structure; and the concrete structure’s damping ratio (Fig. 2).

the G + 15 U-shape, deviation, and asymmetry. The usual floor-to-floor distance is 3 m. There are five meters between each edge. M30-level cement and Fe500-level rebar were used in the construction. The moment-resisting frame of RC constructions is listed in Table 1.

Modeling of structural frame

The goal of this investigation is to examine the effects of seismic forces on multi-story RC (G + 15) irregular structure outlines with various time histories and seismic zones. For the seismic assessment in seismic zone III, the Reaction Range technique is utilized. This contextual analysis focuses on the commercial building with

Table 1 Geometric and loading details of the test model

S. no	Parameter	Value
1	Building type	15 Story moment-resisting frame
2	Length of bay in x direction	5 m
3	Length of bay in y direction	5 m
4	Plan dimension	45 m × 35 m
5	Floor height	3 m
6	Shear wall	0.23 m
7	Size of column	(400 × 600) mm
8	Size of beam	(300 × 500) mm
9	Modules of elasticity (concrete)	28,500 Mpa Poisson’s ratio = 0.2
10	Grade M30 (concrete)	30Mpa
11	Modules of elasticity (steel)	210,000 Mpa
12	Seismic zone	III
13	Importance factor	I
14	Soil type	II
15	Live load	4 KN/m ²
16	Dead load	1.5 KN/m ²

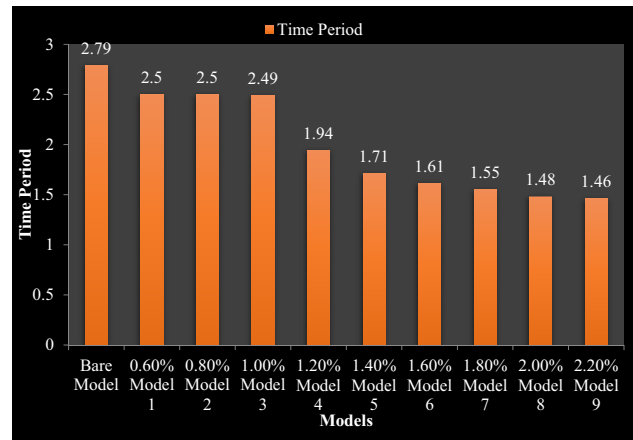


Fig. 3 Time period

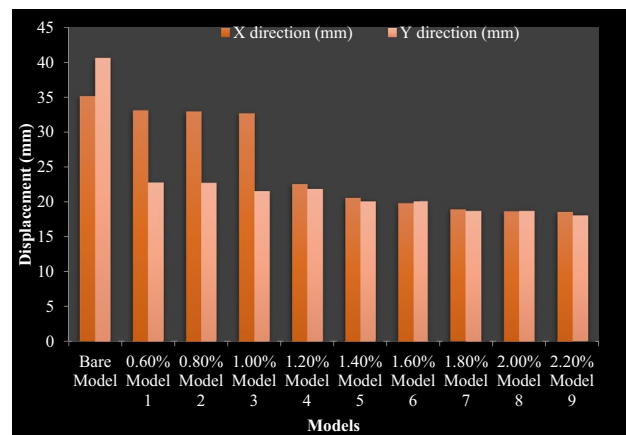
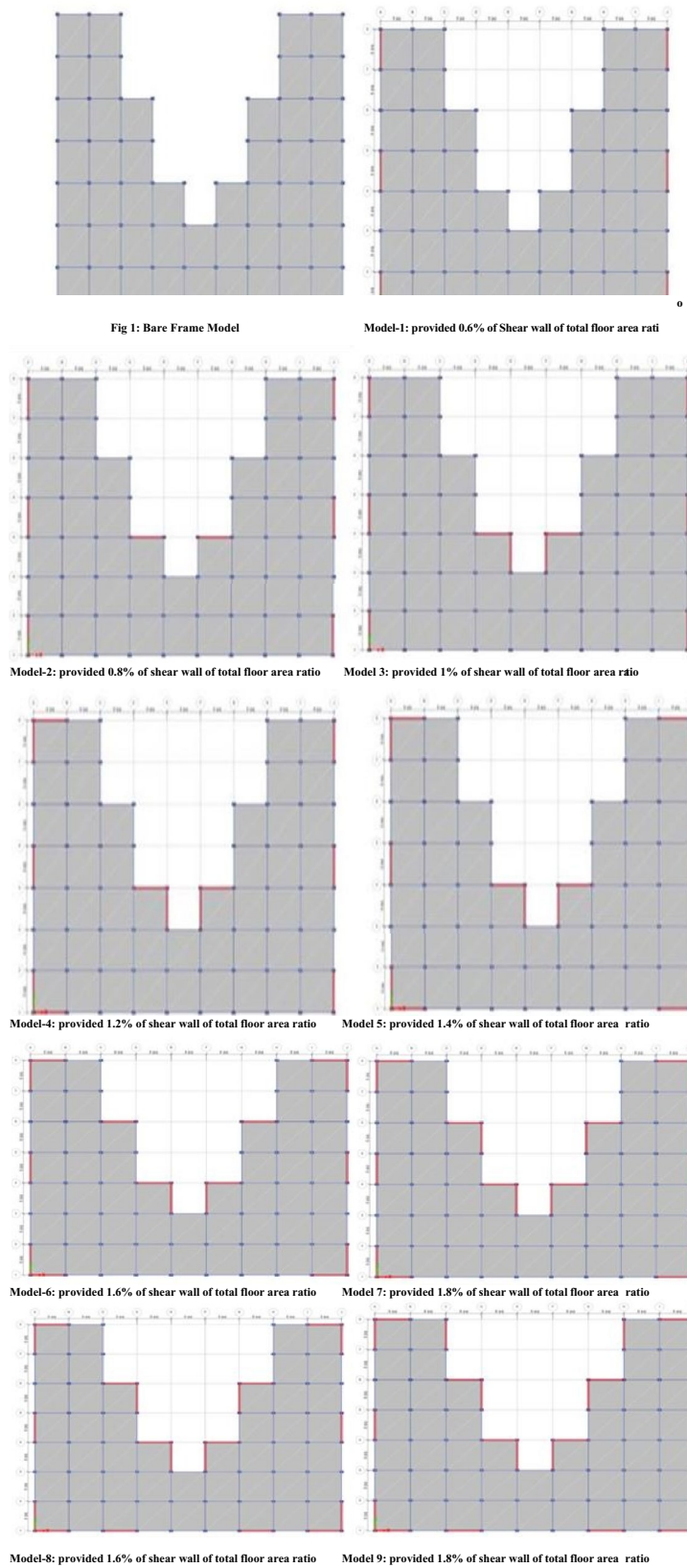


Fig. 4 Displacements of models



Result and comparison

Fundamental time period

The time it takes for a given structure to complete one complete cycle of oscillation is known as the natural period, or simply “T.” Following ETABS’s dynamic analysis, we determined the duration of time using the mode shapes of the test models.

According to Fig. 3, the time period reduces as the ratio of the shear wall to the floor area grows larger. In detail, the times for models 5, 6, and 7 are 1.71, 1.61, and 1.55 s, respectively. For the most basic model, a maximum of 2.79 s has been measured.

Maximum displacement

According to Eurocode-819, the maximum allowable displacement is $H/250$, where H is the building’s vertical height above ground. Maximum allowed displacement is calculated to be 180 mm using the formula $H/250$. Data for the vertical relocation of various models are shown in Fig. 4. After performing a dynamic analysis in ETABS, we measured the test models’ X- and Y-axis storey displacement. Base shear refers to the maximum lateral force that can be expected to act on a building’s foundation as a result of seismic ground motion.

When there is a greater ratio of shear wall area to floor area, there is a decreased displacement in both directions. For Model 5, the displacements along the X and Y directions are, respectively, 20.64 mm and 20.13 mm, whereas for Model 6, they are 19.86 mm and 20.12 mm, and for Model 7, they are 18.95 mm and 18.75 mm. For the bare model, the greatest measured narrative displacements in the X and Y axes are 35.19 mm and 40.63 mm, respectively.

Story drift

The story drift must not be larger than 0.004 times the storey height, as stated in IS 1893:2016 (Part-I), section 7.11.1. This part specifies the permissible drift in accordance with the norm that was described before (0.004 times 3000 equals 12 mm). This is the most amount of drift that is allowed under the rules. After using ETABS for dynamic analysis, the storey drift of models was calculated in both the X and Y directions. This was done so that the models would be as precise as possible (Fig. 5).

The maximum amount of story drift that is allowed in any story is 0.004 times the height of the story. The story drift for model 5 is almost identical to that of models 6 and 7, with all of them having the same value of 0.00055 in both the X and Y directions. This is valid for all three models.

Base shear

There appears to be a clear relationship between the percentage increase in shear wall to floor area ratio and the corresponding rise in base shear, as seen in the Table 2 below. When comparing models 5 and 6, model 7 has the highest base shear values. However, the bare model has the least X and Y base shear of any of the models (Fig. 6).

Eccentricity

There appears to be a clear relationship between the percentage increase in shear wall to floor area ratio and the corresponding rise in base shear, as seen in the Table 2 below. When comparing models 5 and 6, model 7 has the highest base shear values. However, the bare model has the least X and Y base shear of any of the models (Fig. 7).

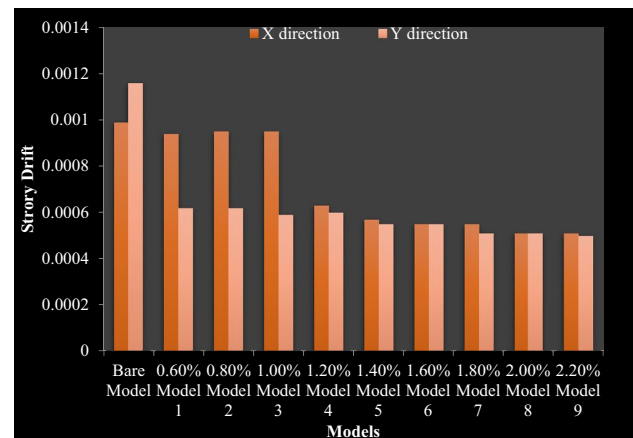


Fig. 5 Story drift

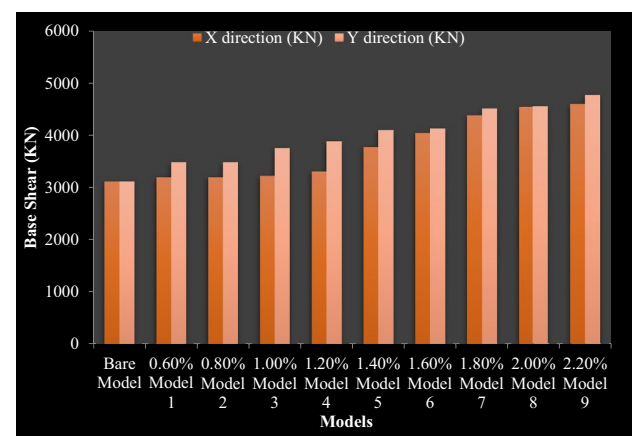


Fig. 6 Base shear

The eccentricity ratio in the response spectrum parameter is affected by the building's configuration and mass and stiffness distribution. Models 5, 6, and 7 have nearly identical eccentricities along the X axis, as seen in the Table 2. Models 5, 6, and 7 all have eccentricities of 0.2556 m in X; however, these values increase to 0.6466 m and 0.7257 m in Y.

Structural behavior

In particular, the structural behavior of a reinforced and hybrid-reinforced concrete structure is dependent on size-scale and reinforcing percentage. The outcomes of the first two modes of our model are translation in the directions of X and Y, while the outcomes of the third mode are rotation in the direction of Z. Structural behavior were shown in the Table 2.

Conclusion

The following conclusions can be drawn based on the findings of the various floor area ratios of shear walls that were evaluated, which ranged from 0.6 to 2.2%, and the

identification of the optimal model with a shear wall ratio of 1.8%:

1. Optimal shear wall ratio: The model with a shear wall ratio of 1.8% fared the best out of all of the floor area ratios that were put to the test. This leads one to believe that the proportion of shear walls to the overall floor area of the building has a substantial influence on the structural integrity and stability of the building.
2. The effectiveness of shear walls: The findings suggest that increasing the shear wall ratio by more than 1.8% did not necessarily result in an improvement in the structural performance of the building. This discovery shows that there may be decreasing results in terms of boosting the building's resistance to lateral stresses by rising the shear wall ratio any higher.
3. Efficient structural design: A shear wall ratio of 1.8% illustrates a satisfactory equilibrium between the effectiveness of the overall efficiency of the construction and the structural design. This conclusion might be especially applicable to the high-rise building construction, where it is very important to make the most of available resources while minimizing expenditures.
4. Seismic performance: It is quite likely that the model with a shear wall ratio of 1.8% had greater seismic performance when compared to models with ratios that were lower. Shear walls are vital for lessening the impact of lateral pressures that occur during earthquakes, and the distribution of shear walls within a building that has been thoughtfully constructed can strengthen the building's resistance to seismic activity.
5. Additional research: Despite the fact that the investigation determined that a shear wall ratio of 1.8% is the optimum value, additional research may be necessary to investigate a wider variety of building types, soil conditions, and architectural configurations to validate these findings in a more all-encompassing manner. In this particular instance, shear walls have been installed along the exterior boundary of the building.

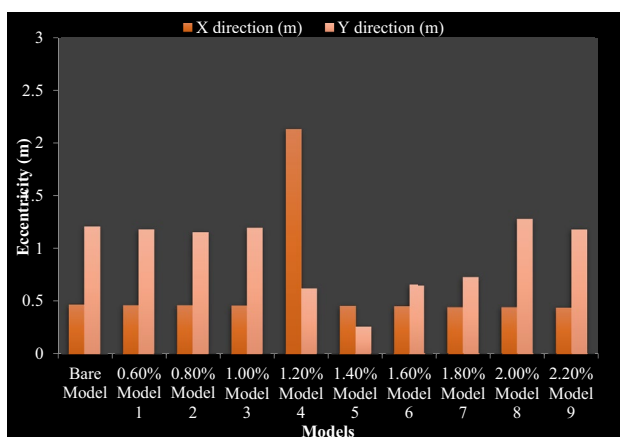


Fig. 7 Eccentricity

Table 2 Structure behavior

Model name	Behavior in 1st mode	Behavior in 2nd mode	Behavior in 3rd mode
Bare model	Translational	Rotational	Rotational
Model 1	Translational	Translational	Rotational
Model 2	Translational	Translational	Rotational
Model 3	Translational	Translational	Rotational
Model 4	Translational	Translational	Rotational
Model 5	Translational	Translational	Rotational
Model 6	Translational	Translational	Rotational
Model 7	Translational	Translational	Rotational
Model 8	Translational	Translational	Rotational
Model 9	Translational	Translational	Rotational

6. In conclusion, the study emphasizes the importance it is for architects and structural engineers to choose shear wall ratios that are acceptable for the structures they are designing. It would appear that a shear wall ratio of 1.8% offers the best possible compromise between the structural efficiency and performance of the building, but particular site and building constraints should always be taken into consideration for each individual project.

Author contributions Tabarej alam: conceptualization, methodology, writing—reviewing and editing. Rajiv Banerjee: data curation, writing—original draft preparation. Vipin Mahadeven: revision, writing—original draft preparation. Nakul Gupta: visualization, investigation. Arun Kumar Parashar: visualization, reviewing and editing

Funding The authors have not disclosed any funding.

Declarations

Conflict of interest The authors declare no competing interests.

References

- Akhil Ahamad, S., & Pratap, K. V. (2020). Dynamic analysis of G+20 multi storied building by using shear walls in various locations for different seismic zones by using Etabs. *Materials Today: Proceedings*, 43(xxxx), 1043–1048. <https://doi.org/10.1016/j.matpr.2020.08.014>
- Azad, S., & Abd Gani, S. H. (2016). Comparative study of Seismic Analysis of multistory buildings with Shear Walls and Bracing Systems. *International Journal of Advanced Structures and Geotechnical Engineering*, 05(03), 72–77. https://www.researchgate.net/publication/30877769_Comparative_study_of_seismic_analysis_of_multistory_buildings_with_shear_walls_and_bracing_systems
- Banerjee, R., Parashar, A. K., Gupta, N., & Srivastava, J. B. (2023). Study on earthquake induced torsional irregularity and lateral displacement of RC building with shear wall. *Asian Journal of Civil Engineering*. <https://doi.org/10.1007/s42107-023-00725-y>
- Basavalingappa. (2020). Analysis of High-Rise Building and its Behaviour Due to Shear Wall at Different Location and in Different Seismic Zones. *International Journal of Engineering Research and*, V9(09), 686–698. <https://doi.org/10.17577/IJERTV9IS090384>
- Dahat, I., & Autade, P. (2016). Analysis of lateral load on different orientation of shear wall Ishant Dahat PG Scholar: Department of civil engineering. *Novateur Publications International Journal of Research Publications in Engineering and Technology*, 2(12), 2454–2475.
- Dahesh, M. A., Tuken, A., & Siddiqui, N. A. (2015). Controlling the earthquake-induced lateral displacement of RC buildings using shear walls: Parametric study. *Arabian Journal of Geosciences*. <https://doi.org/10.1007/s12517-015-1903-7>
- Edition, S., & Duggal, S. K. (2006). *Earthquake resistant design of structures*. In PHI Learning Pvt. Ltd.
- Engineering, S. B. (2024). *Structural Dynamics (9 CFU) Academic Year 2023/2024*.
- Fares, A. M. (2019). The Effect of Shear Wall Positions on the Seismic Response of Frame-Wall Structures. *International Journal of Civil and Environmental Engineering*, 13(3), 190–194. <https://zenodo.org/record/2643691>
- Goswami, R., Vidyapeetham, A. V., & Ramancharla, P. K. (2012). *Earth quake protection of non-structural elements in buildings*. September 2015.
- Gupta, S., Akhtar, S., Hussain, A., Tech scholar, M., & Professor, A. (2016). Effect of Shear Wall Location on Bending Moment and Shear Force of Multistory Building Subjected to Earthquake Loading. *International Journal of Computer and Advanced Engineering Research (IJCAER)*, III-Issue(Ii), 4.
- Hiremath, G. S., & Hussain, S. (2012). Effect of Change in Shear Wall Location with Uniform and Varying Thickness in High Rise Building. *International Journal of Science and Research (IJSR) ISSN*, 3(10), 284–288. www.ijsr.net
- Jain, S. K., & Mandal, U. K. (1992). Dynamics of buildings with V-shaped plan. *Journal of Engineering Mechanics*, 118(6), 1093–1112. [https://doi.org/10.1061/\(asce\)0733-9399\(1992\)118:6\(1093\)](https://doi.org/10.1061/(asce)0733-9399(1992)118:6(1093))
- Kaveh, A., & Zakian, P. (2012). Performance based optimal seismic design of RC shear walls incorporating soil-structure interaction using CSS algorithm. *International Journal of Optimization in Civil Engineering*, 2(3), 383–405. <https://www.researchgate.net/publication/272182495>
- Kaveh, A., & Zakian, P. (2014). Seismic design optimisation of RC moment frames and dual shear wall-frame structures VIA CSS algorithm. *Asian Journal of Civil Engineering*.
- Kaveh, A., & Ilchi Ghazaan, M. (2017). Vibrating particles system algorithm for truss optimization with multiple natural frequency constraints. *Acta Mechanica*. <https://doi.org/10.1007/s00707-016-1725-z>
- Kaveh, A., Izadifard, R. A., & Mottaghi, L. (2020). Optimal design of planar RC frames considering CO₂ emissions using ECBO, EVPS and PSO metaheuristic algorithms. *Journal of Building Engineering*. <https://doi.org/10.1016/j.jobe.2019.101014>
- Mawle, M., & Singi, M. (2020). Seismic performance of flat slab multistory building with varying span-a review paper. ... of *Research and Analytical Reviews (IJRAR)*, E ..., 7(1), 195–199. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3677704
- Mohan, R. (2011). Dynamic analysis of RCC buildings with shear wall. *International Journal of Earth Sciences and Engineering*, 04(SPL), 20410346. <https://www.researchgate.net/publication/266182026>
- Mukundan, H., & Manivel, S. (2015). Effect of vertical stiffness irregularity on multi-storey shear wall-framed structures using response spectrum analysis. *International Journal of Innovative Research in Science, Engineering and Technology*, 4(3), 1186–1198. <https://doi.org/10.15680/IJIRSET.2015.0403077>
- Pandey, N. (2021). Stability analysis of shear wall at different locations in multi-storeyed geometrically irregular building using ETABS. *International Journal of Engineering Research in Current Trends (IJERCT)*, 4, 2582–5488.
- Parashar, A. K., & Gupta, N. (2023). An investigation of micro-silica inclusion in slag-based geopolymer concrete with regression and cluster analysis. *Asian Journal of Civil Engineering*. <https://doi.org/10.1007/s42107-023-00750-x>
- Parashar, A. K., Kumar, A., Singh, P., & Gupta, N. (2023). Study on the mechanical properties of GGBS-based geopolymer concrete with steel fiber by cluster and regression analysis. *Asian Journal of Civil Engineering*. <https://doi.org/10.1007/s42107-023-00937-2>
- Ravi, V. S., & Lekshmi, S. (2016). Effect of shape and plan configuration on seismic response of structure (ZONE II & V). *International Journal of Science and Research*, 5(7), 1135–1139.
- Sanjay S J Assistant Professor Assistant Professor, P. D., & M Assistant Professor, Y. H. (2017). Seismic analysis of RC residential multi-storey building for different locations of shear wall.

- IJSTE-International Journal of Science Technology & Engineering*, 3(11), 54–62. www.ijste.org
- Seeram, M., & Kumar, P. (2023). Free vibration analysis of symmetric and asymmetric RCC structures. *IOP Conference Series: Materials Science and Engineering*, 1273(1), 012010. <https://doi.org/10.1088/1757-899x/1273/1/012010>
- Shaha, T., & Banhatti, A. (2016). Earthquake behavior of RCC building for various shear wall configurations. *International Research Journal of Engineering and Technology*, 3(7), 1656–1660. www.irjet.net
- Sharma, M. L., Shrikhande, M., & Wason, H. R. (2018). Advances in Indian earthquake engineering and seismology: Contributions in honour of Jai Krishna. *Advances in Indian Earthquake Engineering and Seismology: Contributions in Honour of Jai Krishna*, 1–431. <https://doi.org/10.1007/978-3-319-76855-7>
- Tarigan, J., Manggala, J., & Sitorus, T. (2018). The effect of shear wall location in resisting earthquake. *IOP Conference Series: Materials Science and Engineering*. <https://doi.org/10.1088/1757-899X/309/1/012077>
- Yadav, P., & Joshi, R. (2019). Effect of height and position of shear wall on G+5 multi-storey building for zone III. *International Journal of Recent Technology and Engineering*, 8(3), 5452–5456. <https://doi.org/10.35940/ijrte.C4609.098319>

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