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

G. V. Jasmine
Department of Civil Engineering, Centurion University of Technology and Management, Paralakhemundi, Odisha, India
e-mail: jasmine.george@raghuenggcollege.in

M. R. Ponnada (✉)
Department of Civil Engineering, MVGR College of Engineering (Autonomous), Vizianagaram, Andhra Pradesh 535005, India
e-mail: markandeyaraju@mvgrce.edu.in

S. P. Mishra
Civil Engineering, Centurion University of Technology and Management, Paralakhemundi, Odisha, India
e-mail: sibaprasad.mishra@cutm.ac.in

L. Y. Loon et al. (eds.), *Advances in Construction Management*, Lecture Notes in Civil Engineering 191, https://doi.org/10.1007/978-981-16-5839-6_15

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.