A Review on the Study of the Response of Ground Blast Loads on RCC Structures

Ashalekshmi K G[1], Dr. Subha K[2]

[1]*PG Student, Department of Civil Engineering, NSS College of Engineering, Palakkad*
[2]*Professor, Department of Civil Engineering, NSS College of Engineering, Palakkad*

Abstract - *One of the fatal threat to every society is the increase in terrorism. Bomb blasts are associated with almost all terrorist activities. Due to this, there can be adverse effect on within and nearby the affected structures. The loading to which the structures are exposed to, is of very higher order when compared to earthquake, wind gust etc. Due to the threat from such extreme loading conditions, many studies were conducted on the behavior of structural concrete subjected to blast loads and techniques of making a structure blast resistant. The analysis and design of structures subjected to blast loads requires a detailed understanding of blast phenomena, precise estimation of blast loads and the dynamic response of various structural elements. In this thesis work, it is decided to conduct a study on explosive loading on RCC structures. Ground blast loading on an RCC bridge pier is considered for this study. The mechanisms of various blast waves are explained. The effects of change in stand-off distance of blast, change in grade of steel, diameter of main bars, change in diameter and spacing of lateral ties etc. are the parameters to be studied. The thesis is mainly aimed at generalizing the effect of ground blast loading on structures and proposing a load factor for buildings subjected to ground blast. This is a review paper prepared as a part of the thesis work.*

Key Words: ANSYS, Bridge pier, Detonations, Explosion, Ground blast, Pressure wave, TNT

1. INTRODUCTION

Technologies are developing day by day. One of the abuses of these technologies is seen in terrorism. The number of terrorist activities is increasing these days. Mostly associated with bomb blasts, terrorist activities cause catastrophic effects on within and nearby the structures. Shattering of blast loaded structures is the prime reason for the loss of life and properties. So blast resistant design of structures is essential. Designing the structures for full blast resistance is not a realistic option, however, studies are ongoing to mitigate the effects of an explosion.

An explosion is defined as a rapid and sudden release of energy in the form of light, heat, sound and a shock wave. Blast waves are produced by an explosion. Explosions can be categorized on the basis of their nature as physical, chemical and nuclear events. In physical explosions, energy may be released from the disastrous failures like volcanic eruptions, bursting of a cylinder of compressed gas, etc. In a chemical explosion, energy is released from the rapid oxidation of fuel elements whereas, the formation of different atomic nuclei by the redistribution of the protons and neutrons within the interacting nuclei is the main source of energy in the case of nuclear explosions [44].

2. THEORY OF BLAST LOADING

As already mentioned, a blast is a pressure disturbance caused by rapid release of energy. There are many forms of high explosive available and as each explosive has its own detonation characteristics, the properties of each blast wave will be different. Explosions caused by high explosives like TNT are called detonations whereas those caused by low explosives are called deflagration. TNT is being used as the standard benchmark, where all explosions can be expressed in terms of an equivalent charge mass of TNT. The most common method of equalization is based on the ratio of an explosive's specific energy to that of TNT. When a charge explodes, a pressure wave is formed by the explosion that applies a load on the surrounding building. The blast wave starts propagating from the point of explosion approximately in spherical wave-fronts and upon striking any surface or terrain, the wave-front is reflected and modified (Fig. 2.1) [2].

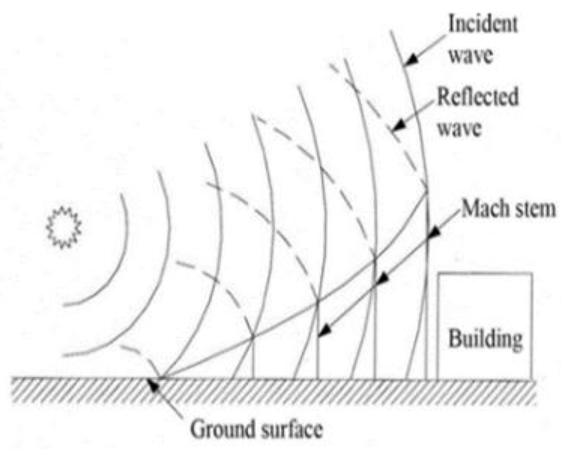

Fig -1: Propagating blast wave [44]

In the design process it is important to determine the potential danger and the extent of this danger. Most importantly human safety should be provided During an actual event, the action of the load depends on the interaction of the load with the surface of the structure, atmospheric pressure at the time of the scenario, temperature conditions at the time of blast loading and some other factors which are usually neglected for a simplified analysis. The design of such a structure when all these effects are considered will lead to lack of economy. The structural response to explosion load can be estimated, either more accurately by a calculation or approximately based on empiric formulas and criteria. [6]

2.1 Characteristics of Blast Wave

An idealized pressure-time history indicating the important parameters of a blast load is shown in Fig.2.2

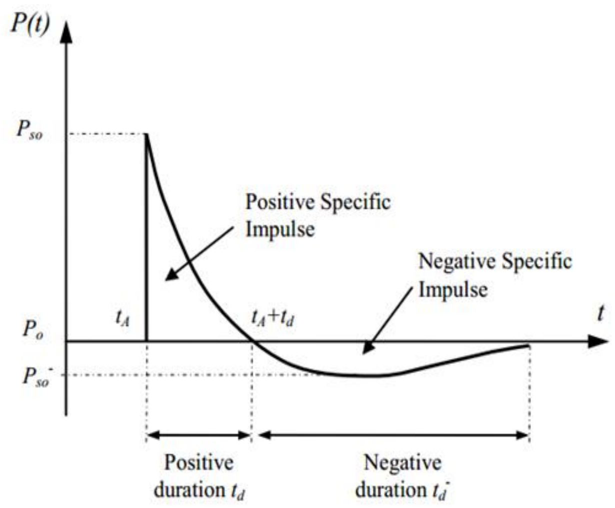

Fig -2: Blast wave pressure – Time history [8]

The various parameters of this idealized curve are:

P_o = Ambient pressure

P_{so} = Peak positive side-on overpressure

P_{so}^- = Peak negative side-on overpressure

$P_s(t)$ = Time varying positive overpressure

$P_s(t)^-$= Time varying negative overpressure

I_s = Positive phase specific impulse, the integration of the positive phase pressure-time history

I_s^- = Negative phase specific impulse, the integration of the negative phase pressure-time history

t_A = Time of arrival

t_d = Positive phase duration

t_d^- = Negative phase duration

The time at which the blast load hits a structure is called its time of arrival (t_A). At that time, the pressure at that position of the structure suddenly increases to a peak value of overpressure, P_{so}, over the atmospheric pressure, P_o. The pressure then suddenly reduces to ambient level after a time t_d, then decays further to a negative pressure P_{so}^- before eventually returning to ambient conditions at time $t_d+t_d^-$. The quantity P_{so} is referred to as the peak side-on overpressure or simply peak overpressure. All these happens within some milliseconds of time.

This profile gets modified if there is any reflecting surface or hindrance in the path of the wave. The incident peak over pressure, P_{so} is amplified by a factor as the shock wave reaches an object or a structure in its path. The reflection factor depends on the intensity of the shock wave and angle of incidence of these waves on the structure. These reflection factors are typically greatest for normal incidence of wave on the surface of a structure. For detonations using large explosives at normal incidence over a structure, these reflection factors may increase the incident pressures by a large factor [9].

Throughout the pressure-time profile, two phases of loading can be seen; loading above atmospheric pressure is called positive phase of duration t_d, while that below the atmospheric pressure is called negative phase of duration, t_d^-. As the stand-off distance increases, the positive phase duration of blast wave increases resulting in a lower-amplitude, longer-duration pulse on the structure. The negative phase is of a lower intensity and a longer duration than the positive duration. As the proximity of blast load to the structure increases, the load intensity increases and the duration of loading decreases. During the negative phase, the weakened structure may be subjected to impact by debris that can cause additional damage.

3. LITERATURE REVIEW

In conventional design of RCC structures effect of blast loads are not considered as it leads to an uneconomical design. Hence, severe damages are caused to such structures when subjected to blasts. Many studies were conducted in this field of research. Some of the main works are reviewed hereby.

One among the pioneer works in the field of blast analysis of structures was done by M.A. Cook et.al. (1962). They conducted studies on air blast wave and blast induced seismic wave measurements at long distance which are produced by chemical detonations, using results from a survey conducted by Field Service Division, Ordinance Ammunition Command. They concluded that the air blast wave impacting the ground may give rise to induced seismic waves [31]. Later Robert J. Odello et.al. (1976) conducted studies on the effects of ground shock caused from explosions on structures and their relevance. Various semi-empirical equations for estimating peak airblast induced pressure are presented and direct-induced ground shock motions are studied. It was concluded that the ground shock effects are more critical within structures than for the equipment or persons outside structures [40]. TM 5-1300/NAVFAC P-397/AFR 88-22 is a manual titled "structures to resist the effects of accidental explosions" explains several methods for establishing blast load parameters. It provides a step-by-step analysis and design procedure, including the information on blast and shock loading, principle on dynamic analysis. Provisions for reinforced concrete and structural steel design and some special design considerations are given. It gives proper guidance to blast resistant design of structures [45]. Another important work by F. B. A. Beshara et.al. (1994) explained about some former studies of the structural effects of confined explosions, contact blast and explosion-induced ground shock. The effects of providing ventilations are considered in the evaluation of dynamic loads. The loading of an on-surface explosion and the associated effects on a concrete target are determined. Finally, the evaluation of both airblast-induced ground shock and directly transmitted motion are included in simple form. Soil-structure interaction is not considered in this study. Equations for peak particle displacement, velocity and acceleration are given [18]. Later, B.M. Luccioni et.al. (2004) studied the effects of mesh size on pressure and impulse distribution of blast loads using hydrocode. A computational dynamic analysis using AUTODYN-3D was carried out over the congested urban environment of the opposite rows of buildings of a block, in the same street. The results obtained for different positions of the explosive charge are presented and compared. The effect of mesh size for different boundary conditions is also addressed. It is concluded that the accuracy of numerical results is strongly dependent on the mesh size used for the analysis. On the other side, the mesh size is also limited by the dimensions of the model and the computer capacity [10]. Chengqing Wu et.al. (2005) investigated the simultaneous ground shock and airblast forces that can be applied in structural response analysis. They conducted a parametric numerical simulation of surface explosions. Empirical expressions of airblast pressure-time history as a function of surface explosion charge weight, distance to structure etc. is provided. The time lag between airblast pressure and ground shock on structure is also determined. The empirical formulae are all given in analytical forms and they can be used in structural response analysis to surface explosions. The results from this study was used in their next study and it was found that airblast load governs structural response and damage when the scaled distance is small. When the scale distance increases, the relative importance of the ground shock on structure response increases, and ground shock will dominate the surface explosion effects on structures at large scaled distance. This result can be used in this thesis work [13]. Later, Yong Lu et.al. (2005) conducted a research on the effect of the various input parameters of blast on the ground shock parameters. The datas obtained from this research work are processed to form a suitable dataset to represent the physical problem. Artificial Neural Network (ANN) technique is then applied to identify the system pattern, which also serves as a function for the prediction of the ground shock. The neural network approach proved to be successful as it predicted the unseen test data with sufficient accuracy. The results proved the significance of blast load path orientation on the ground shock parameters [49].

T. Ngo et.al. (2007) performed an analytical study on RCC column subjected to blast loading. The 3D model of the column was analyzed using the nonlinear explicit code LS Dyna 3D which takes into account both material and geometric nonlinearity. It was observed that the increase in flexural strength was greater than that of shear strength. Thus, the increase in the material strengths under dynamic conditions may lead to a shift from flexural failure to shear failure mode [44]. Zeynep Koccaz et.al. (2008) studied about the blast resistant building theories and designs, the enhancement of building security against the effects of explosives in both architectural and structural design process and the design techniques. It was found that it is possible to build a blast resistant building with correct selection of the structural system with well-designed structural frames and connections, moment frames that transfer sufficient load and high quality material. They also explained about designing structural elements to withstand the possible blast loading [50]. Zoran Bajić et.al. (2009) studied about blast parameters of high explosives in terms of TNT equivalents. Primary blast wave parameters, overpressure, impulse and positive phase duration are calculated using modified Sadovsky equations and the modified Kingery-Bulmash equation. The calculated parameters showed significant influence of used explosives concerning the TNT equivalent [51]. Hrvoje Draganić et.al. (2012) described the process of determining the blast load on structures and provides a numerical example of an arbitrary structure exposed to this load. They arrived at a methodology for calculating the blast loading on structure. The numerical model of an RCC structure was created in SAP2000 and blast load which was analytically determined as a pressure-time history is applied to the structure. The results confirmed the initial assumption that it is possible with conventional software to simulate an explosion effects and give a preliminary assessment of the structure [23]. Designer's notebook (2014) provides various design considerations for blast resistance of architectural precast concrete façades. The book very well explains about the basics of blast loading and comparison with other catastrophic loadings like earthquakes. Various design considerations about architectural cladding, connection detailing, glazing materials and their cost considerations etc. are well explained in the book [16]. Olaniyi Arowojolu et.al. (2017) studied the response of a conventionally designed reinforced concrete bridge pier and subjected to blast loading. LS-DYNA is used for simulating blast loads using Arbitrary Lagrangian-Eulerian simulations. A conventionally designed pier was subjected to a near ground blast loading by varying the charge weight and stand-off distance while keeping the axial load constant. The modes of failure of the pier is observed for peak displacement and residual displacement. The results obtained were used to propose methods of retrofitting and repairing the bridge piers to support combined gravity and blast loading [36]. Aswin Vijay et.al. (2017), conducted a parametric study on the effects of air blast loads on RCC Viaduct Piers. Kochi Metro Project model pier is taken for the study. They studied about various aspects of blasting, types of blasting and modelling aspects of pier in ANSYS software. Modelling of bridge pier and force modelling aspects for air blast loading is presented which can be used in this thesis work [8]. Also, IS 6922-1973, Indian Standard Criteria for Safety and Design of Structures Subject to Underground Blasts, was also studied and the terms and notations used in blast loadings in India were studied. The general characteristics of blast and its effects were looked into. Equation for ground acceleration calculations was studied and can be used in the thesis work [24].

4. SUMMARY

From the literatures reviewed, a clear idea has been developed in various aspects of theory and modelling of blast loading on structures. Also it is understood that not much studies were conducted on ground blast loading on structures. So it is decided to do a project work on analytical study on RCC bridge pier subjected to ground blast loading. Rather than taking an arbitrary pier, an RCC viaduct pier of Kochi Metro Rail Project is considered. The effects of lateral ties spacing, strength of concrete etc. were studied so far. The effects of change in stand-off distance of blast, charge weight, change in grade of steel, diameter of main bars, and spacing of lateral ties are the parameters to be studied for various load conditions including maximum and minimum axial load, maximum bending moment etc. in this project work. ANSYS software is selected for the modelling and analytical purposes. Ground blast loading is applied on the pier. Direct shock effects along with ground shock effects are considered in the loading. As the loading get closer to the structure, the effect of temperature is more pronounced. But in this study, temperature and debris drag effect are neglected.

REFERENCES

[1] Aditya Kumar Singh, Md. Asif Akbari and P. Saha (2014), “Behavior of Reinforced Concrete Beams under Different Kinds of Blast Loading”, International Journal of Civil Engineering Research, 2014, Vol. 5 (1), pp. 13-20

[2] Ahmed Samir Eisa (2014), “Finite element analysis of reinforced concrete columns under different range of blast loads”, International Journal of Civil and Structural Engineering, Vol. 5 (2), 2014, pp. 155-164

[3] Alexander M. Remennikov (2003), “A review of methods for predicting bomb blast effects on buildings”, Journal of Battlefield Technology, Vol. 6 (3), July 2003, pp. 155-161

[4] Amit Goyal (2008), “Blast resistant design: critical issues”, 6th Structural Engineering Convection, Structural Engineering Research Centre, Chennai, India, December 2008, pp. 1–10

[5] Arif S. M. Sohaimi, M. S. Risby, Saiddi A. F. M. Ishak, Khalis S., M. N. Norazman, Ariffin. I., M. A. Yusof (2016), “Using Computational Fluid Dynamics (CFD) for Blast Wave Propagation under Structure”, Procedia Computer Science, Vol. 80, 2016, 10 pages

[6] Ashish Jaiswal, ANSYS Inc., A presentation on “ANSYS® Explicit Dynamics and AUTODYN® Applications”

[7] Ashish Kumar Tiwary, Aditya Kumar Tiwary, Anil Kumar (2015), “Blast Loading Effects on Steel Columns”, IOSR Journal of Mechanical and Civil Engineering, pp. 17-22

[8] Aswin Vijay, K Subha, (2017), “A Review on Blast Analysis of Reinforced Concrete Viaduct Pier Structures”, International Research Journal of Engineering and Technology, Vol 04 (03), March 2017, pp 986-991

[9] Avinash C. Singhal, Debra Larson, Sanjay Govil, Vikram Karmakar (1994), “Simulation of Blast Pressure on Flexible Panel”, Journal of Structural Engineering, Vol. 120 (7), July 1994, 10 pages

[10] B.M. Luccioni, R.D. Ambrosini and R.F. Danesi (2004), “Analysis of building collapse under blast loads”, Engineering Structures, Vol. 26, 2004, pp. 63-71

[11] Bulson P S (1997), “Explosive Loading of Engineering Structures: a history of research and a review of recent developments”, Text Book, London: E & FN Spon, 1997

[12] C K Gautam and R C Pathak (1997), “Design of Blast Resistant Structure”, Defence Science Journal, Vol. 47(2), April 1997, pp. 139-148

[13] Chengqing Wu, Hong Hao (2005), “Modelling of simultaneous ground shock and air-blast pressure on nearby structures from surface explosions”, International Journal of Impact Engineering, Vol. 31, 2005, pp. 699-717

[14] Chengqing Wua, Hong Hao (2007), “Numerical simulation of structural response and damage to simultaneous ground shock and airblast loads”, International Journal of Impact Engineering, Vol. 34, 2007, pp. 556–572

[15] Daniel Makovicka (2014), “Blast Load of Building Structure”, Engineering Mechanics, Vol. 21 (1), 2014, pp. 11–18

[16] Designer’s notebook (2014), “Design Considerations for Blast Resistance of Architectural Precast Concrete Façades”, 32 pages

[17] Digvijay Gajendra Phule, Prof. C M Deshmukh, Dr. C P Pise, Prof. S Kadam, Prof. Y P Pawar, Prof. D Mohite (2016), “Behavior of RCC Structural Members for Blast Analysis: A Review”, International Journal of Engineering Research and Application, Vol. 6 (11), November 2016, pp. 48-53

[18] F. B. A. Beshara (1994), "Modelling of Blast Loading on Aboveground Structures- Internal Blast and Ground Shock", Computers & Structures, Vol. 51(5), pp. 597-606

[19] Geoffrey C Mays and P D Smith, "Blast effect of buildings", Text Book, Thomas Telford Publishing

[20] Ghani Razaqpur, Ahmed Tolba, Ettore Contestabile (2016), "Blast loading response of reinforced concrete panels reinforced with externally bonded GFRP laminates", Composite: Part B, Vol. 38, June 2016, pp. 535-546

[21] Gholamreza Abdollahzadeh and Marzieh Nemati (2014), "Risk assessment of structures subjected to blast", Int. Journal of Damage Mechanics, Vol. 23 (1), 2014, pp. 3-24

[22] HANDBOOK FOR BLAST-RESISTANT DESIGN OF BUILDINGS, 486 pages

[23] Hrvoje Draganić, Vladimir Sigmund (2012), "Blast Loading on Structures", Tehnički vjesnik, Vol. 19 (3), 2012, pp. 643-652

[24] IS 6922-1973, "Indian Standard Criteria for Safety and Design of Structures Subject to Underground Blasts", Second Reprint, August 1997

[25] Isabelle Sochet (2011), Invited Lecture on "Blast effects of external explosions", Ecole Nationale Supérieure d'Ingénieurs de Bourges – Institute PRISME, France, Oct. 2011, 33 pages

[26] J. S. Kuanga and H. F. Tsoi (2011), "Failure of Blast Loaded Reinforced Concrete Slabs", Procedia Engineering, Vol. 14, 2011, pp. 2658–2665

[27] J. Sagaseta, P. Olmati, K. Micallef, D. Cormie (2017), "Punching shear failure in blast-loaded RC slabs and panels", Engineering Structures, Vol. 147, April 2017, pp. 177–194

[28] James T. Baylot, Denis D. Rickman (2007), "Uncertainties in Blast Loads on Structures", 2007 Structures Congress: New Horizons and Better Practices, pp. 601-634

[29] Jayashree S M, R Rakul Bharatwaj, Helen Santhi M (2013), "Dynamic response of a space framed structure subjected to blast load", International Journal of Civil and Structural Engineering, Vol. 4 (1), August 2013, pp. 98-105

[30] Kingery C N and Bulmash G (1984), "Air blast parameters from TNT spherical air blast and hemispherical burst", Technical report US Army Ballistic Research Laboratory, 1984, 11 pages

[31] M.A. Cook, R.T. Keyes and W.O. Ursenbach (1962), "Air Blast and Ground Shock Waves Generated at Long Distances from Demolitions of High Explosives", Journal of Applied Meteorology, Vol. 1 (1), March 1962, pp. 91-101

[32] Manmohan Dass Goel and Vasant A. Matsagar (2014) "Blast-Resistant Design of Structures", Practice Periodical for Structural Design and Construction, Vol. (19), 2014, 9 pages

[33] Michael M. Swisdak (1994), "Simplified Kingery Airblast Calculations", 26th DoD Explosives Safety Seminar, Miami, FL, 1994, 17 pages

[34] Mohammed Alias Yusof, Rafika Norhidayu Rosdi, Norazman M Nor, Ariffin Ismail, Muhammad A Yahya, Ng Choy Peng (2014), "Simulation of RC Blast Wall Subjected to Air Blast Loading", Journal of Asian Scientific Research, Vol. 4 (9), 2014, pp. 522-533

[35] N.H. Yi, J.W. Nam, S.B. Kim, J.H.J. Kim, K.J. Byun (2008), "HFPB Analysis of RC Structures Under Blast Loads Considering Concrete Damage Model", The 3rd ACF International Conference-ACF/VCA, 2008, pp. 796-804

[36] Olaniyi Arowojolu, Muhammad Kalimur Rahman, Baluch Muhammad Hussain (2017), "Dynamic Response of Reinforced Concrete Bridge Piers Subjected to Combined Axial and Blast Loading", Structural Congress 2017, pp. 98-109

[37] Onur Dogan, Ozgür Anil, Sami O. Akbas, Erkan Kantar, R. Tuğrul Erdem (2013), "Evaluation of blast-induced ground vibration effects in a new residential zone", Soil Dynamics and Earthquake Engineering, Vol. 50, March 2013, pp. 168–181

[38] Parag Mahajan, Pallavi Pasnur (2014), "Prediction of Blast Loading and Its Impact on Buildings", International Journal of Latest Technology in Engineering, Management and Applied Science, Vol. 3(10), October 2014, pp. 88-94

[39] Philip W. Gibson (1994), "Blast Overpressure and Survivability Calculations for Various Sizes of Explosive Charges", Technical Report, United States Army Natick Research, Development and Engineering Center, Natick, November 1994, 20 pages

[40] Robert J. Odello, Paul Price (1976), "Technical Report-Ground Shock Effects from Accidental Explosions", November 1976, 56 pages

[41] Rupert G. Williams, William A. Wilson, and Reisa Dookeeram (2016), "Analysis of the Response of a One-Storey One-Bay Steel Frame to Blast", Journal of Structures, 5 May, 2016, 11 pages

[42] Russell P. Burrell, Hassan Aoude, and Murat Saatcioglu (2014), "Response of SFRC Columns under Blast Loads", Journal of Structural Engineering, Vol. 15, October 6 2014, pp. 1-15

[43] Stanley C. Woodson, A. Kiger (1988), "Stirrup Requirements for Blast-Resistant Slabs", Journal of Structural Engineering, Vol. 114 (9), September 1988, pp. 2057-2069

[44] T. Ngo, P. Mendis, A. Gupta and J. Ramsay (2007), "Blast Loading and Blast Effects on structure", Electronic Journal of Structural Engineering, Special Issue: Loading on Structures, 2007, pp. 76-91

[45] TM 5-1300/NAVFAC P-397/AFR 88-22, "Structures to Resist the Effects of Accidental Explosions", U. S. Departments of the Army, Navy, and Air Force, 19 November 1990

[46] Vasilis Karlos, George Solomos (2013), "Calculation of Blast Loads for Application to Structural Components", Technical Report, Blast Simulation Technology Development, European Commission, December 2013, 58 pages

[47] W.E. Baker (1973), "Explosion in Air", London: University of Texas Press, pp. 27-60

[48] Yazan Qasrawi, Pat J. Heffernan and Amir Fam (2015), "Numerical Modelling of Concrete-Filled FRP Tube's Dynamic Behavior under Blast and Impact Loading", Journal of Structural Engineering, Vol. 106 (13), July 20, 2015, 13 pages

[49] Yong Lu (2005), "Underground blast induced ground shock and its modelling using artificial neural network", Computers and Geotechnics, Vol. 32, 2005, pp. 164–178

[50] Zeynep Koccaz, Fatih Sutcu and Necdet Torunbalci (2008), "Architectural and Structural Design for Blast Resistant Buildings", The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China, 8 pages

[51] Zoran Bajić, Jovica Bogdanov, Radun Jeremić (2009), "Blast Effects Evaluation Using TNT Equivalent", Scientific Technical Review, Vol. 59 (3), pp. 50-54