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Research Article

Comparison of Blast Load Main Parameters Based on Indian and American Standard

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Abstract: Recently, the terrorist activities are been increased broadly. Any explosion takes place close to any building can cause significant damage of the building, death of people and occupants injuries. While, most of the researches in this field made their conclusions based on Indian Code (IS 4991-1968), therefore, this research will determine the blast load main parameters (peak reflected pressure, peak side-on pressure and positive phase duration) which cover any explosion based on American Code (Unified Facilities Criteria, UFC-2008, (formerly TM 5-1300)) and compare the results with the Indian code. The techniques used in this study for the derivation of the main blast load parameters based on empirical method, which contained equations against experimental data with little physical relationships. The comparison scope in this study covers both spherical (pressure on air) and hemispherical (pressure on ground) with short and long standoff distances. The results of peak reflected pressure and peak side-on pressure variation with standoff distance revealed that the peak pressures based on American standard is about 45% relative to Indian standard for short standoff distance (less than 18 m).While, the difference reach 10% for long standoff distance (more than 36 m). It has been observed that from the variation of positive phase duration with standoff distance of both Codes, the duration based on Indian Standard is significantly less than the duration based on American Standard for short distances and up to 32 m. However, when the distance value increased more than 32 m the duration based on Indian standard lies between hemispherical and spherical waves duration based on American Standard.

Keywords: IS 4991-1968, UFC-2008, blast load, peak reflected pressure, peak side-on overpressure, positive phase duration, standoff distance

INTRODUCTION

Threats of enemies and terrorist attack have became evolving in scope and scale all over the world special in Iraq. It is important to estimate accurately peak overpressures and associated impulses for a range of explosives expressed in terms of a scaled standoff distances based on different TNT masses which are equivalent to actual explosive for both on air and on ground charges (Cormie *et al*., 2009).

Explosions can be classified as physical, nuclear or chemical. A chemical explosion includes the rapid oxidation of fuel elements which are the main explosive compound. The rate of reaction will determine the usefulness of the explosive material for practical applications. Explosive can be classified either condensed (solid or liquid) or dispersed (gas or aerosol), (Jackson and Jackson, 2011; Petty, 2013). When a condensed high explosive is created, the explosion reaction first generates hot gas under high pressure of about 10-30 GPa and a temperature approximately ranged from 3000-4000°C. A large rapid expansion of these gaseous happens and the surrounding air is forced out of occupies volume. Only about one-third of the total explosion energy is released while the other two-third is dissipated due to the mix of explosive products with the surrounding air (Moon, 2009; Remennikov, 2003).

Substantial effort has been advocated to find the blast load parameters and structures response. In Ngo *et al*. (2007) made an overview for calculation of blast loadings for different standoff distance which is subjected to any structures. While, Rempling *et al*. (2014) summarized of ongoing research on structure subjected to blast loading and its aim was to collect, analyze and summarize existing knowledge based on meta- analysis. Process of determining the blast load effect on structures was described by Draganic and Sigmund (2012). They provided a numerical example of a fictive structure exposed to blast load. The aim of this research was to become familiar with the issue of blast load. Recently, in Qureshi and Madhekar (2015) proposed 3D nonlinear dynamic analyses of typical 45 storey high rise building under blast loading. The

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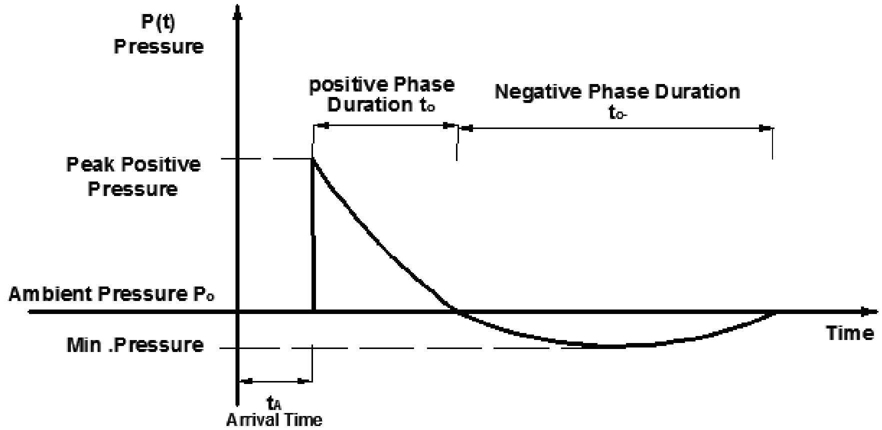

Fig. 1: Pressure-time shock wave function

building in this research had been first designed for conventional loads and then subjected to blast loading at various locations. Peak deflections, accelerations, inter-storey drifts and velocity at selected locations were investigated.

Most of researches related to blast load including a recent research in 2015 by Qureshi and Madhekar (2015) published in Springer were based on Indian Standard (IS 4991) which was edited in 1968. In this study we try to emphasis the importance to study the blast loads and its main parameters based on the latest version of American Code (Unified Facilities Criteria, UFC-2008 (formerly TM 5-1300)) and compare the blast load main parameters based on both Codes over different categories of short and long standoff distances.

BLAST PHENOMENA

Basically, the blast load derivation is based on empirical method which is used ninth-order component polynomial equations for the incident and reflected positive pressure and impulse, positive phase duration and time of arrival for different standoff distance and TNT explosions. The polynomials are produced due to curve-fits to a large body experimental data (ConWep, 1992).

At the time of explosion, rapid chemical reaction occurs in few milliseconds. The explosive material converted to very hot, dense and high pressure gas. This highly compressed air moving radial outward from the source at velocities more than sonic velocity which is called the shock wave front. As the shock wave expands, pressure decreases rapidly with the distance because of spherical divergence and dissipation of energy in heating the air. The pressure decays rapidly over time as exponential function, typically in milliseconds. Always, a blast causes often instantaneous rise in ambient pressure from atmospheric pressure to a large overpressure. As the shock front expands, the pressure drops but becomes negative as shown in Fig. 1. Usually, this negative pressure is sustained for duration longer than the positive pressure and is less important in design of structures than the positive phase (Chopra, 2007; Murty *et al*., 2006; Needham, 2010; Paz and Leigh, 2004). The magnitude and distribution of the blast loading effectively acting on a structure vary greatly with properties of explosive, standoff distance and reflections of shock front on the ground or any other structure facade.

INDIA STANDARD (IS 4991-1968)

This kind of standard covers the criteria for design of constructions for blast effects of explosions above ground. This standard would not recognize between the explosion on ground (hemispherical wave) or on air (spherical wave), (Ambrosini *et al*., 2005). This standard also does not cover the explosion that take place with very short standoff distance (Dharaneepathy *et al*., 1995). The experimental information extensive blasts over the ground are outlined in Table 1 (IS 4991-1968, 1968). The table incorporates the fundamental impact stacking parameters which are incident side-on pressure, peak reflected overpressure and positive phase duration. There is no information for these parameters when the standoff distances are short.

The way by which the energy in a blast wave is moved to a structure is done by pressure energy, which is Omni directional. Therefore, an endlessly minor object, which might not have any effect on the blast wave, will be subjected to the pressure-time history as in Fig. 1. This is the occurrence, or side-on pressure. At the point when an impact wave experiences a strong surface (or other medium denser than air), it will reflect from it and contingent upon its geometry and size, diffract around it. The reflection of the blast wave, energy is an evidence for the transfer between both the blast wave and the object. The least complex case is an infinitely large rigid perfectly considering plane which the impact wave encroaches typically. The occurrence

Table 1: Blast parameters from ground burst of 1 tonne explosive (IS 4991-1968, 1968)

Distance (m) x	Peak reflected over pressure ratio (P_r/P_a)	Peak side on over- pressure ratio (P_{so}/P_a)	Positive phase duration milli-sec t_o
3.00	No information```````		
6.00			
9.00			
12.0			
15.0	41.6	8.00	9.500
18.0	22.5	5.00	11.00
21.0	12.94	3.30	16.38
24.0	8.48	2.40	18.65
27.0	5.81	1.80	20.92
30.0	4.20	1.40	22.93
33.0	3.45	1.20	24.95
36.0	2.75	1.00	26.71
39.0	2.28	0.86	28.22
42.0	1.97	0.76	29.74
45.0	1.66	0.66	31.25
48.0	1.46	0.59	32.26
51.0	1.28	0.53	33.52
54.0	1.14	0.48	34.52
57.0	1.01	0.43	35.53
60.0	0.93	0.40	36.29
63.0	0.85	0.37	37.30
66.0	0.77	0.34	38.05
69.0	0.72	0.32	38.81
72.0	0.67	0.30	39.56
75.0	0.62	0.28	40.32
78.0	0.58	0.26	40.82
81.0	0.55	0.25	41.58
84.0	0.53	0.24	42.34
87.0	0.50	0.23	42.84
90.0	0.47	0.22	43.6

The value of Pa the ambient air pressure may be taken as 1 kg/cm^2 at mean sea level; One tonne of explosive referred to in this table is equivalent to 1.5 X 10^9 calories

impact wave is reflected from the building, delivering an area of further pressure of the air to the structure. On a molecular level, the surface applies an outside force to every air particle which is adequate to give it equal opposite direction momentum. By Newton's third law, the air applies the same external force to the surface. It is because this change of force that the pressure is privately expanded over the incident pressure which would happen at the similar area. This is named the reflected pressure. The actual time required for positive pressure is specifically positive phase duration.

UNIFIED FACILITIES CRITERIA (UFC-2008)

The foundation of this Code is also based on empirical methods for high explosives lies in the scaled-distance curves for spherical (free-air) and hemispherical (surface) blasts as shown in Fig. 2 and 3 respectively. This data in these chart explain the incident and normally reflected overpressures and impulses as a function of scaled-distance and together with the reflection coefficient information, establish the essential information to design of structures subjected to blast load (Unified Facilities Criteria (UFC 3-340-02), 2008).

A useful technique of representing important blast wave factors is to plot them against scaled distance Z. Both incident and reflected blast wave parameters might be represented in this manner. Figure 2 is adopted from charts introduced in various references,

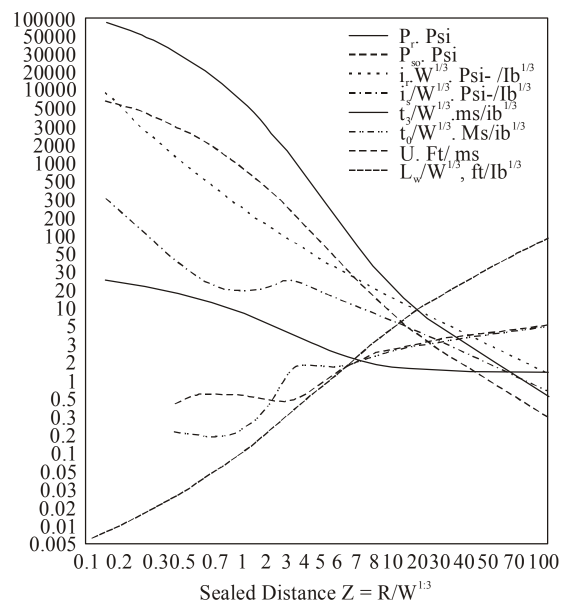

Fig. 2: Positive phase parameters for spherical (on air) shock wave (Unified Facilities Criteria (UFC 3-340-02), 2008)

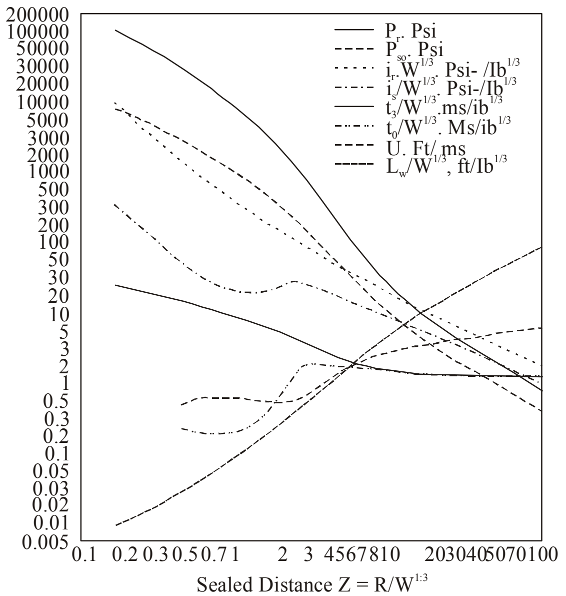

Fig. 3: Positive phase parameters for hemispherical (on ground) shock wave (Unified Facilities Criteria (UFC 3-340-02), 2008)

for example Baker *et al*. (1983), ConWep (1992) and Unified Facilities Criteria (UFC 3-340-02) (2008) and plotted these parameters against scaled distance Z.

The most broadly utilized method to deal with blast wave scaling is that derived by a cube-root scaling. Therefore, if W_1 and W_2 are two charge masses of diameter d_1 and d_2, respectively, at that point, for the same explosive material, since W_1 is proportional to d_1 and W_2 is proportional to d_2, so the cubic proportionality is given as in Eq. (1):

$$\frac{d_1}{d_2} = \left(\frac{W_1}{W_2}\right)^{1/3} \tag{1}$$

Consequently, if the two charge diameters are in the proportion $d_1/d_2 = ℷ$, then, if the similar overpressure P_{so} is to be created from the two charges, the proportion of the ranges at which the specific overpressure is produced will likewise be ℷ. Additionally, the positive phase duration ratio and the impulse. Ranges at which a given overpressure is created can hence be computed utilizing the consequence of Eq. (1) produce Eq. (2):

$$\frac{R_1}{R_2} = \left(\frac{W_1}{W_2}\right)^{1/3} \tag{2}$$

where, R_1 is the range at which a given overpressure is created by charge W_1 and R_2 is the range at which a similar overpressure is produced by charge W_2. This leads promptly to the determination of the scaled distance ($Z = R/W^{1/3}$) presented previously. So, Z is the constant of proportionality in the Eq. (2). The utilization of Z in Fig. 2 and 3 permits a compact and productive presentation of impact blast wave information for an extensive variety of circumstances.

The previous segments allude to free air explosions remote from any reflecting surface which can be described by a spherical wave. At the point when endeavoring to measure overpressures created by the blast of high explosive sources in closeness to the ground alterations must be made to charge weight before utilizing the diagrams introduced before. Great connection for hemispherical surface blasts of condensed high explosives with free air burst information comes about if an upgrade parameters of 1.8 is presumed i.e., surface blasts deliver impact waves that seem to generate from free air bursts of 1.8 times the genuine source energy. Take note of that, if the ground was an ideal reflector and no energy was dissipated in creating a hole and ground shock, the reflection factor would be 2.0. Blast wave parameters for hemispherical surface bursts are straightforwardly accessible in graphical shape and are displayed in Fig. 3. The impact wave parameters for the negative phase are accessible in graphical form, which is beyond scope of this study.

RESULTS AND DISCUSSION

Three blast load parameters which are peak reflected pressure, peak side-on pressure and positive phase duration are considered in this study. From these parameters, the blast load in the building can be defined completely. The variation of peak reflected pressure and peak side-on pressure over standoff distance are shown in Fig. 4 and 5 respectively. The variation is based on Indian Standard (IS 4991-1968, 1968) and American Standard (Unified Facilities Criteria (UFC 3-340-02), 2008). The peak pressure is classified as hemispherical and spherical wave in American Code. While, only single variation is adopted by Indian Standard. It can be seen from these Figs. the peak

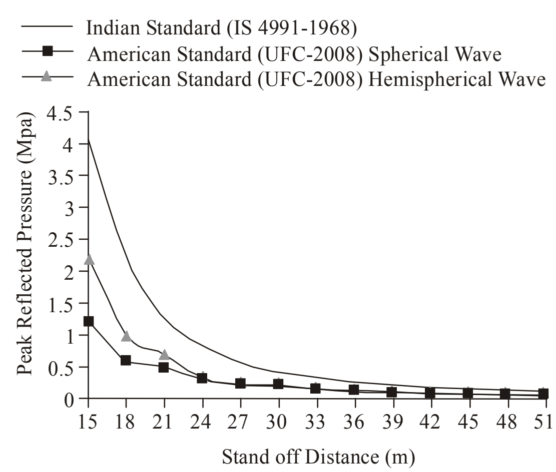

Fig. 4: Variation of peak reflected pressure over standoff distance

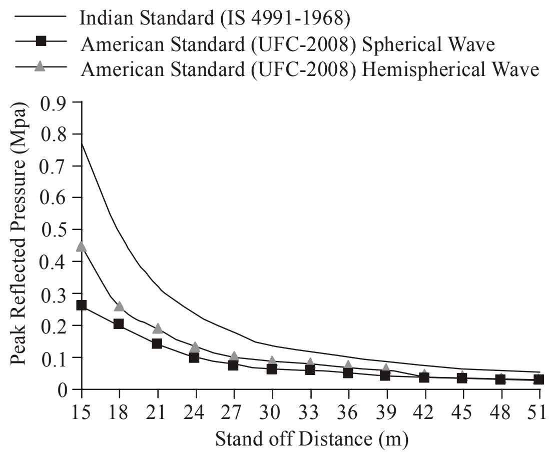

Fig. 5: Variation of peak side-on overpressure over standoff distance

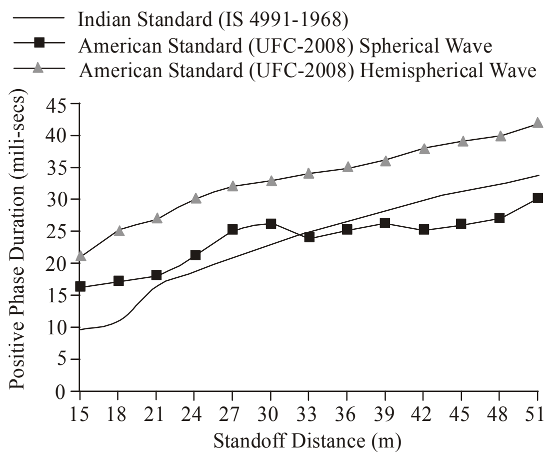

Fig. 6: Variation of positive phase duration over standoff distance

pressure reducing as standoff distance increasing. Because of blast effect is decreases as distance of blast increases. Approximately, the pressure curves follow the same pattern. Peak pressure for short standoff distance equal 15 m according to UFC decreases by 45% than peak pressure based on IS. Before 15 m (short standoff distance) there are no information about both peak reflected pressure and peak side-on pressure based on IS. Between (15-36 m) IS code is still overestimates peak pressures comparing with UFC with a significant difference value. In long standoff distance over than 36 m the pressure curves are converged with error not more than 10%. It can be also observed from these Figs. for standoff distance equal or less than 15 m (short standoff distance) the peak pressures produced from hemispherical wave 1.7 times the peak pressures come from spherical wave. While a good correlation with gradual convergence between peak pressure due to blast on ground and blast on air for long standoff distance more than 24 m.

Figure 6 show the variation of positive phase duration over standoff distance based on IS and UFC. The variation of duration based on IS code significantly lies below the time variation based on UFC for standoff distance ranges from (15-32 m). In standoff distance equal to 32 m the phase duration in IS coincide with duration based on spherical wave in UFC. For long standoff distance above 32 m, the curve of positive phase duration in IS lies between the spherical and hemispherical phase duration according to UFC.

If UFC blast parameters used properly, they are considered as powerful tools compare to IS standard and can be used effectively for majority of problems to obtain economic design for structure subjected to blast loading. However, the spherical and hemispherical blast waves have limitations in the boundary of their applicability. They are fit valid for real either spherical or hemispherical explosions, but interpolation is required for bursts at same height above the ground that lies between these boundary cases, for which there are no real guides available.

Figure 4 and 5 give a proper guide to recognize the effective boundaries between spherical and hemispherical bursts. Even in normal design, approximation is valid and spherical bursts are relatively small in number and unusual. Because usually the explosion takes place approximately near the ground and therefore the hemispherical bursts is valid. If the explosion is happened at same finite height above the ground that is small compare to the standoff distance from the center of explosion to the building, the hemispherical load case still represents a reasonable and conservative approximation for the problem under consideration. A good distinguish boundary is shown in Fig. 4 and 5 for both spherical and hemispherical load cases and this boundary can be adopted for design purposes.

CONCLUSION

The Indian Standard (IS 4991) published in 1968 did not recognize between hemispherical surface bursts on ground and free air bursts as in American Standard UFC edited in 2008. Certainly, this might lead to inaccurate and confusion design for different on-ground and on-air explosions. The Indian standard Code in terms of peak pressures gives a significant high values at a short standoff distance when the explosion closed to the target relative to UFC. The research did not recommend to use IS for design building subjected to blast load with short standoff distance due to uneconomic design results. Furthermore, the Indian standard might not provide enough information about the blast load parameters for close short standoff distance. The work conclude that the peak pressures based on-ground explosion equal about 1.7 from the peak pressure based on-air explosion when the limit of standoff distance approach zero. While the difference become very small when the limit of standoff distance approach infinite.

REFERENCES

Ambrosini, D., B. Luccioni, A. Jacinto and R. Danesi, 2005. Location and mass of explosive from structural damage. Eng. Struct., 27(2): 167-176.

Baker, W.E., P.A. Cox, P.S. Westine, J.J. Kulesz and R.A. Strehlow, 1983. Explosion Hazards and Evaluation. Elsevier, New York.

Chopra, A.K., 2007. Dynamics of Structures: Theory and Application to Earthquake Engineering. 3rd. Edn., Prentice-Hall, New Jersey.

ConWep, H.D., 1992. Fundamentals of Protective Design for Conventional Weapons. Application of TM 5-855-1, Structural Mechanics Division, Structures Laboratory, USACE Waterways Experiment Station, Vicksburg, MS.

Cormie, D., G. Mays and P.D. Smith, 2009. Blast Effects on Buildings. 2nd Edn., Thomas Telford Ltd., London.

Dharaneepathy, M.V., M.N. Keshava Rao and A.R. Santhakumar, 1995. Critical distance for blast-resistant design. Comput. Struct., 54(4): 587-595.

Draganic, H. and V. Sigmund, 2012. Blast loading on structures. Tehnicki Vjesnik, 19(3): 643-652.

IS 4991-1968, 1968. Criteria for Blast Resistant Design of Structures for Explosions above Ground. Bureau of Indian Standards, New Delhi, India.

Jackson, A.R.W. and J.M. Jackson, 2011. Forensic Science. 3rd Edn., Prentice-Hall.

Moon, N.N., 2009. Prediction of blast loading and its impact on buildings. M.S. Thesis, Department of Civil Engineering, National Institute of Technology, Rourkela, Orissa India.

Murty, C.V.R., A.W. Chrleson and S.A. Sanyal, 2006. Earthquake Design Concepts, Teaching Resource Material for Teachers of Architecture Colleges. National Information Center of Earthquake Engineering, IIT Kanpur, India.

Needham, C.E., 2010. Blast Waves. Springer-Verlag, Berlin, Heidelberg.

Ngo, T.D., P. Mendis, A. Gupta and J. Ramsay, 2007. Blast loading and blast effects on structures - An overview. Electron. J. Struct. Eng., 7: 76-91.

Paz, M. and W. Leigh, 2004. Structural Dynamics - Theory and Computation. 5th Edn., Springer, US, pp: 790.

Petty, S.E., 2013. Forensic Engineering: Damage Assessments for Residential and Commercial Structures. Taylor and Francis Group, LLC, Boca Raton.

Qureshi, Z.A.L. and S.N. Madhekar, 2015. Response of 45 Storey High Rise RCC Building Under Blast Load. In: Matsagar, V., (Ed.,) Advances in Structural Engineering. Springer, New Delhi.

Remennikov, A.M., 2003. A review of methods for predicting bomb blast effects on buildings. J. Battlefield Technol., 6(3): 5-10.

Rempling, R., J. Leppänen and M. Plos, 2014. Review of research on strengthened concrete structures subjected to impulse and blast loading. SE-412 96, Chalmers University of Technology, Göteborg, Sweden.

Unified Facilities Criteria (UFC 3-340-02), 2008. Structures to Resist the Effects of Accidental Explosion. (TM 5-1300, NAVFAC P-397, AFM 88-22), Tri-Service Regulatory Design Manual, USA.