Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444
Volume 3, Issue 5, May-2016

AN EFFECTIVE STUDY ON COMPUTATION OF BLAST LOADING FOR RC FRAME STRUCTURE

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Abstract* — The structural engineering profession has experienced many significant and complex changes in the past several decades. Higher strength materials and improved computational methods allow us to design buildings to new limits of height and span. Recent events involving earthquakes, hurricanes, tornadoes, etc. produced many unexpected structural problems. This has often resulted in specific building code changes aimed at avoiding similar problems in the future. Now in the recent time of terrorism, structural engineers require new consideration of terrorist attack in the design standards .Due to different accidental or intentional events, related to important structures all over the world, explosive loads or blast loads have received considerable attention in recent years. The development in this field is made mostly through publication of the U.S. Army Corps of Engineers, Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency. In India also, the guidelines for the blast loading are published in IS 4991. In the present study, blast pressures for different weights of surface blast or TNT and varying stand-off distances are computed for a first row of column of RC framed structure. Time history loading is also obtained with parameters of reflected total over pressure and duration of positive phase of blast.

Keywords- blast loading; blast pressure; scaled distance; blast wave; framed Structure;

I. INTRODUCTION

The term blast is commonly used to describe any situation in which the rapid release of energy occurs from a chemical, mechanical or nuclear source. However, from the point of view of the effects of explosions upon structural systems, there exists a set of fundamental characteristics which must be defined and considered, irrespective of the source.

Explosions occurring in urban areas or close to facilities such as buildings and protective structures may cause tremendous damage and loss of life. The immediate effects of such explosions are blast overpressures propagating through the atmosphere, fragments generated by the explosion and ground shock loads resulting from the energy imparted to the ground.

Conventional buildings are constructed quite differently than hardened military structures and as such are generally quite vulnerable to blast and ballistic threats. In order to design structures which are able to withstand explosions it is necessary to first quantify the effects of such explosions. Typically, it takes a combination of specialist expertise, experimental tests, and analysis tools to properly quantify the effects. With this in mind, developers, architects and engineers increasingly are seeking solutions for potential blast situations, to protect building occupants and the structures.

II. EXPLOSIONS AND CLASSIFICATION OF EXPLOSIVES

An explosion is defined as a large-scale, rapid and sudden release of energy. The exact source of this energy is relatively in material; it may come from an explosive such as gunpowder, from pressurized steam in boiler, or from uncontrolled nuclear transformation.

2.1 Explosion can be classified on the basis their nature, their physical state and rate of decompositions.

- **According to their nature:**

<u>In physical explosion:-</u>

Energy may be released from the catastrophic failure of a cylinder of a compressed gas, volcanic eruption or even mixing of two liquid at different temperature.

<u>In nuclear explosion:-</u>

Energy is released from the formation of different atomic nuclei by the redistribution of the protons and neutrons within the inner acting nuclei.

In chemical explosion:-

The rapid oxidation of the fuel elements (carbon and hydrogen atoms) is the main source of energy.

- **According to physical state:**

According to physical state they can be classified as solids, liquids & gases.

According to rate of decomposition:

Explosives are classified as low and high depending on the amount of energy released by them and the consequent damage caused by them.

Low Explosives:-

They only burn, but do not detonate. They are set-off to deflagrate, rather than to detonate. An example of the low explosive is the black powder.

High Explosive:-

They are designed to shatter, rather than to push. Examples of the high explosives are Dynamite and TNT.

High explosives detonate to create shock waves, burst or shatter materials in or which they are located, penetrated materials, produce lift and heave of materials and, when detonated in air or under water, produce air blast or underwater pressure pulses.

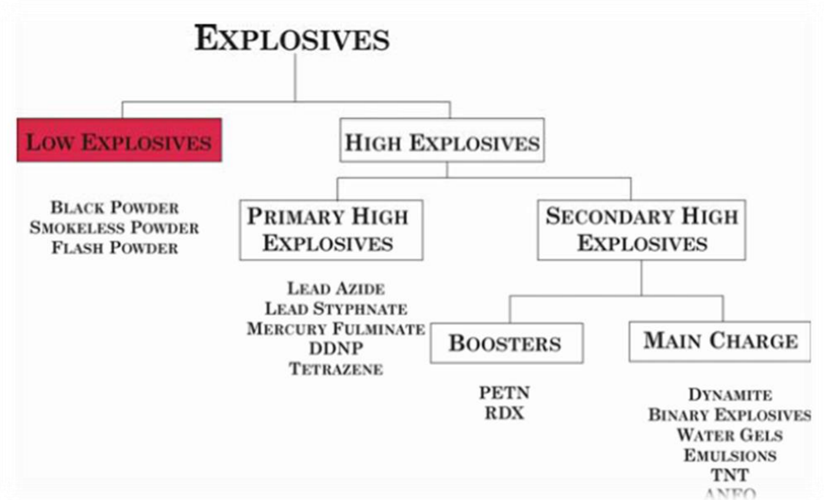

Figure – 2.1 Classification of Explosives

High explosives are conventionally subdivided into two classes differentiated by sensitivity to initiation.

Primary Explosives:-

Primary explosives are extremely sensitive to shock, friction and hit to which they will respond by burning rapidly or detonating. Material such as mercury fulminate, lead and silver azide and lead styphnate are all primary explosives. These are the sort of materials that might be found in the percussion cap of gun ammunition.

Secondary Explosives:-

Secondary explosives are also called base explosives, are relatively insensitive to shock, friction and heat. They may burn when exposed to heat or flame in small, unconfined quantities, but detonation can occure. These are sometimes added in small amounts to blasting caps to boost their powder. Dynamite, TNT, RDX, PETN and others are secondary explosives.

Use of the TNT (Trinitrotoluene) as a reference for determining the scaled distance, Z, is universal. The first step in quantifying the explosive wave from a source other than the TNT, is to convert the charge mass into an equivalent mass of the TNT to be considered. It is performed so that the charge mass of explosive is multiplied by the conversion factor based on the specific energy of the charge and the TNT. Specific energy of different explosive types and their conversion factors to that of the TNT are given in Table 1.

Explosive	Specific Energy Q_x *kJ/kg*	TNT equivalent Q_x/Q_{TNT}
Compound B (60% RDX, 40% TNT)	5190	1.148
RDX(Ciklonit)	5360	1.185
HMX	5680	1.256
Nitro-glycerine (liquid)	6700	1.481
TNT	4520	1.000
Explosive gelatine	4520	1.000
60% Nitro-glycerine dynamite	2710	0.600
Semtex	5660	1.250
C4	6057	1.340

Table-1: Conversion factors for various explosives

III. BLAST WAVE CHARACHTERISTICS AND ITS PARAMETERS:

The threat for a conventional bomb is defined by two equally important elements, the bomb size, or charge weight W, and the stand-off distance R between the blast source and the target. The incident peak over pressures Pso are amplified by a reflection factor as the shock wave encounters an object or structure in its path. Except for specific focusing of high intensity shock waves at near 45° incidence, these reflection factors are typically greatest for normal incidence (a surface adjacent and perpendicular to the source) and diminish with the angle of obliquity or angular position relative to the source. Reflection factors depend on the intensity of the shock wave, and for large explosives at normal incidence these reflection factors may enhance the incident pressures by as much as an order of magnitude.

As the expansion proceeds, the pressure distribution in the region behind the shock front gradually changes. The over pressure is no longer constant but drops off continuously nearer the center. At later times when the shock front has progressed some distance from the center, a rarefaction develops at the center, causing a drop in the pressure below the initial atmospheric value. Thus a suction phase develops. The front of the shock wave weakens as it progresses outward, and its velocity drops toward the velocity of sound in the initial cooler air. The sequence of events just described for increasing times t1 to t6 is depicted in Fig. 3.1. This shows the overpressure distribution in the shock wave as a function of the distance from the explosion at different stages in the expansion. When the negative overpressure (or suction phase) is well developed, the overpressure in the shock wave resembles the heavily drawn curve in Fig. 3.1.

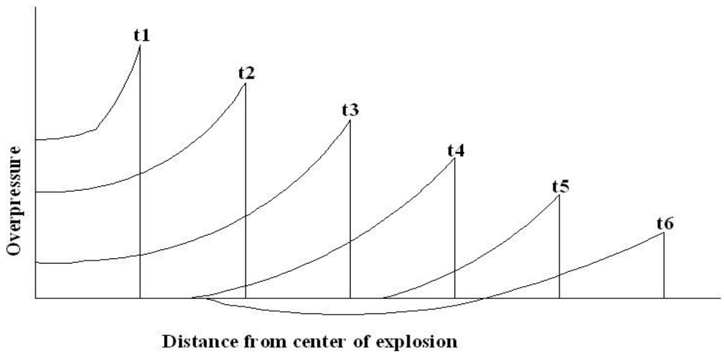

Figure 3.1 Variation of overpressure with distance from center of explosion at various times.

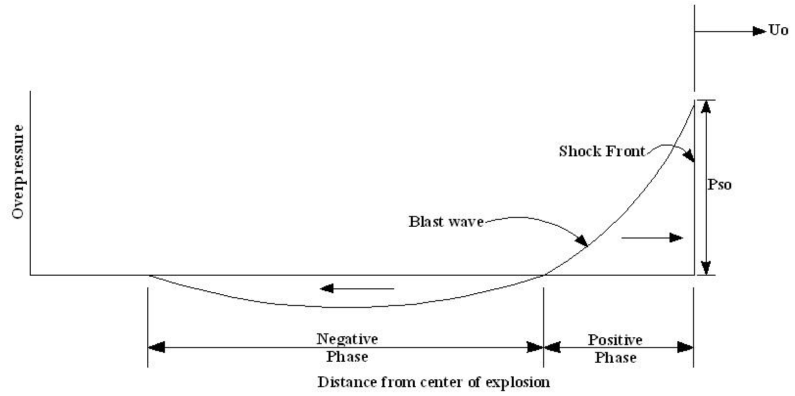

Figure 3.2 Variation of overpressure with distance at a given time.

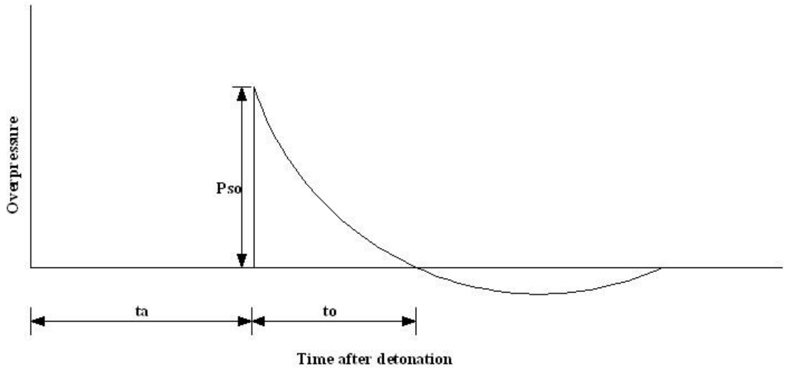

Figure 3.3 Variation of overpressure with time at given location.

The behavior of the shock wave from this time on can be considered in two different ways, as shown in Figs. 3.2 and 3.3. First, in Fig. 3.2, the heavy curve of Fig. 3.1 is redrawn and, as before, shows the variation of shock overpressure with distance at a given time. The symbol Pso represents the peak overpressure, or shock intensity, in pounds per square inch. U0 is the velocity of the shock front in feet per second. The arrows adjacent under the curve show the direction of movement of the air mass or blast wind, in the positive and negative phases. The peak overpressure in the positive phase is higher than the maximum overpressure in the negative phase. Consequently, the blast wind is of higher velocity and shorter duration in the positive phase than in the negative, or suction, phase. Second, the same wave may be considered alternatively by plotting the variation of overpressure with time a fixed location, as shown in the Fig. 3.3. The symbol ta is the time of arrival, or the time in seconds for the shock front to travel from the explosion to the given location; t0 is the duration in seconds of the positive phase; and Pso is as previously defined.

The overpressure Ps at time t after the arrival of the shock front is given by the expression

$$Ps = Pso\ (1-t/t0)\ e\text{-}t/t0$$

- **BLAST WAVE PARAMETERS:**

For blast resistant design of building, the principal parameters of the blast wave are Peak side-on overpressure Pso, positive phase duration td, and the corresponding positive impulse Io.

The blast wave attenuates as it propagates outward from the explosion epicenter. Consequently, the values of peak overpressure and impulse decrease with distance while the duration tends to increase. Values for these blast wave parameters can be determined from published data in the form scaled values (overpressure, impulse or duration) as a function of scaled distance

In addition to peak overpressure, duration, and impulse, other blast wave parameters that may enter into the determination of the blast loads for a structure include:

- Peak reflected pressure, Pr
- Peak dynamic (blast wind) pressure, qo
- Shock front velocity, U
- Blast wave length, Lw

Usually these secondary parameters can be determined from the primary blast wave parameters as discussed below.

Peak Reflected Pressure, Pr:

When the free field blast wave from an explosion strikes a surface, it is reflected. The effect of this blast wave reflection is that the surface will experience a pressure much more than the incident side-on value. The magnitude of the reflected pressure is usually determined as an amplifying of the incident pressure:

$$Pr = Cr\ Pso$$

Where,

Cr = reflection coefficient

The reflection coefficient depends on the peak overpressure, the angle of incidence of the wave front relative to the reflecting surface, and on the type of blast wave. The duration of the reflecting pressure depends on the dimensions of the reflecting surface, up to a maximum time approximately equal to the positive phase duration of the incident blast wave. This upper limit corresponds to the total reflection of the entire blast wave without any diffraction around the edges of the reflecting surface.

Dynamic (Blast Wind) Pressure, qo:

This blast is due to air movement as the blast wave propagates through the atmosphere. The velocity of the air particles, and hence the wind pressure, depends on the peak overpressure of the blast wave. Baker 1983 and TM 5 – 1300 provide data to compute this blast effects for shock waves. In the low overpressure range with normal atmospheric conditions, the peak dynamic pressure can be calculated using the following empirical formula from Newmark 1956:

$$qo = 2.5\ Pso2 / (7\ Po + Pso) \approx 0.022\ Pso2 \quad \text{(psi)}$$

$$\approx 0.0032\ Pso2 \quad \text{(kPa)}$$

Where,

Po = ambient atmospheric pressure.

The net dynamic pressure on a structure is the product of the dynamic pressure and a drag coefficient, CD. The dynamic pressure exerts the dominant blast effect on open frame structure, framed structures with frangible cladding, and on small structures or components such as poles, stacks, etc.

Shock Front Velocity, U:

In the free field, the blast wave from an explosion travels at or above the acoustic speed for the propagating medium. For design purpose it can be conservatively assumed that a pressure wave travels at the same velocity as a shock wave. In the low pressure range, and for normal atmospheric conditions, the shock/pressure front velocity in air can be approximated using the following relationship from Newmark 1956:

$$U \approx 1130\ (1 + 0.058\ Pso)0.5 \quad \text{(ft / sec)}$$

$$\approx 345\ (1 + 0.0083\ Pso)0.5 \quad \text{(m / sec)}$$

Blast Wave Length, Lw:

The propagating blast wave at any instant in time extends over a limited radial distance as the shock/pressure front travels outward from the explosion. The pressure is largest at the front and trials off to ambient over a distance, Lw, the blast wave length. Values of Lw for high energy explosives can be obtained from TM 5 – 1300. In the low pressure range, the length of the blast wave can be approximated by:

$$Lw \approx U\ td$$

Dynamic Pressure of Blast is calculated as below (Biggs),

$$q = \frac{\frac{5}{14}\left(\frac{P}{14.7}\right)^2}{1 + \frac{1}{7}\left(\frac{P}{14.7}\right)}$$

Scaling Blast Phenomena:

Scaled Distance and Scaled time is found out by below equations.

$$\text{Scaled Distance} = \frac{\text{Actual Distance}}{W^{1/3}}$$

$$\text{Scaled Time} = \frac{\text{Actual Time}}{W^{1/3}}$$

IV. COMPUTATION OF BLAST LOADING FOR A RC FRAME STRUCTURE

Computation of blast loading for a first row of column of G+4 RC framed structure has been carried out for the two cases of blast loading. Two categories of buildings are considered as per IS code 4991:1968 for blast resistant designing purposes. In the first case the equivalent TNT charge weight W has been taken as 5 Tonne and the actual effective distance from explosion i.e. R is taken as 10 m, 20 m, and 30 m. In the second case W has been taken as 7.5 Tonne and R as 10 m, 20 m, 30 m. Height of building is 20 m. The plan and elevation of the building is shown below:

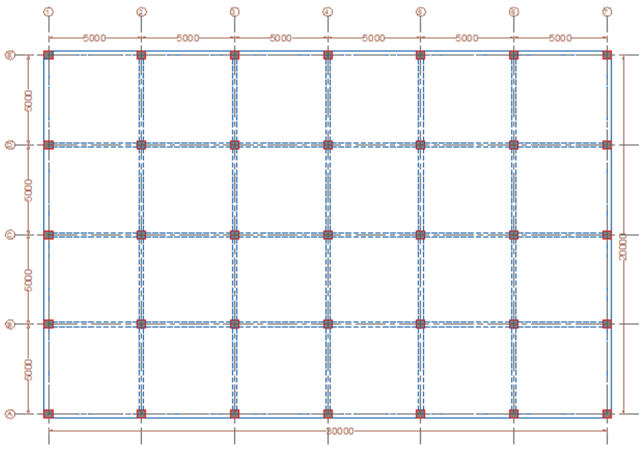

Figure – 4.1 Typical Floor Plan Layout

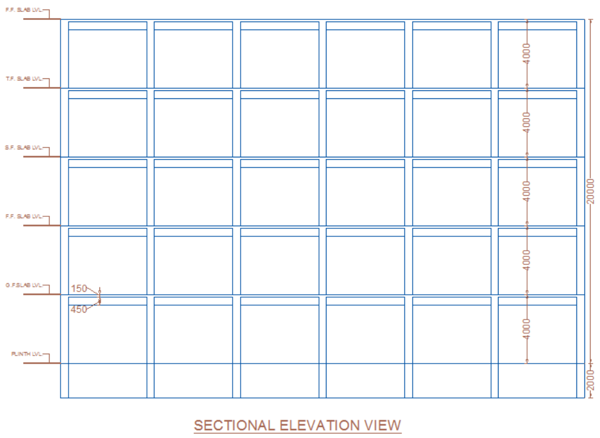

Figure – 4.2 Elevation of Building

As in Blast, Size of Explosive, Location of Blast and Distance of Blast from the structure plays important factor. Hence, Location of Blast is considered at ground level near A-3 column. As Scaled distance increases correspondingly and the value of blast pressure reduces by some amount. The blast parameters along the stand-off distance of the building are shown in Table 2 to Table 7 for all the three categories of buildings.

Column	Col. Dist. from blast (m)	Scaled Distance r (ft)	Distance r (ft)	Peak over pressure P (KN/m^2)	Scaled arrival time t_x(ms)	Arrival time (ms)	Scaled Blast duration t_d (ms)	Blast duration (ms)	Match no (M)	Dynamic Pressure q (KN/m^2)	Drag over Pressure (KN/m)
A1	14.08	27.01	25	1097.67	3.79	6.48	7.09	12.12	3.29	170.68	153.611
A2	11.14	21.37	20	1684.27	2.47	4.23	2.26	3.86	4.03	269.95	242.953
A3	10	19.18	20	2284.91	2.07	3.54	1.69	2.89	4.56	371.84	334.660
A4	11.21	21.50	25	1853.74	2.56	4.37	3.01	5.15	4.13	298.68	268.815
A5	14.19	27.22	30	1168.81	3.94	6.74	5.78	9.88	3.33	182.69	164.424
A6	18.09	34.70	35	681.82	6.11	10.45	6.47	11.06	2.63	100.75	90.676
A7	22.42	43.01	45	404.04	9.30	15.91	7.94	13.58	2.12	54.77	49.290

Table-2: Blast parameters for W= 5T and R= 10 m

Column	Col. Dist. from blast (m)	Scaled Distance r (ft)	Distance r (ft)	Peak over pressure P (KN/m^2)	Scaled arrival time t_x(ms)	Arrival time (ms)	Scaled Blast duration t_d (ms)	Blast duration (ms)	Match no (M)	Dynamic Pressure q (KN/m^2)	Drag over Pressure (KN/m)
A1	14.08	23.59	25	1566.59	3.02	5.92	4.56	8.92	3.81	250.01	225.005
A2	11.14	18.67	20	2426.28	1.97	3.86	1.55	3.04	4.68	395.84	356.260
A3	10	16.76	20	2950.99	1.62	3.16	1.06	2.07	5.14	484.96	436.463
A4	11.21	18.78	25	2227.08	1.95	3.81	1.00	1.96	4.54	362.03	325.825
A5	14.19	23.78	30	1486.12	3.01	5.89	5.50	10.77	3.75	236.37	212.737
A6	18.09	30.31	35	896.99	4.79	9.38	6.03	11.81	2.98	136.85	123.165
A7	22.42	37.57	45	542.71	7.13	13.95	6.96	13.63	2.41	77.59	69.828

Table-3: Blast parameters for W= 7.5T and R= 10 m

Column	Col. Dist. from blast (m)	Scaled Distance r (ft)	Distance r (ft)	Peak over pressure P (KN/m^2)	arrival time t_x(ms)	Arrival time (ms)	Scaled Blast duration t_d (ms)	Blast duration (ms)	Match no (M)	Dynamic Pressure q (KN/m^2)	Drag over Pressure (KN/m)
A1	22.34	42.85	45	407.96	9.24	15.80	7.91	13.53	2.13	55.41	49.865
A2	20.6	39.51	40	498.81	7.92	13.54	7.31	12.50	2.31	70.32	63.291
A3	20	38.36	40	541.71	7.48	12.79	7.11	12.15	2.39	77.42	69.679
A4	20.63	39.57	40	496.66	7.94	13.57	7.32	12.52	2.31	69.97	62.973
A5	22.39	42.95	45	405.51	9.28	15.87	7.93	13.56	2.13	55.01	49.506
A6	25.04	48.03	50	299.65	11.43	19.55	8.91	15.23	1.90	37.93	34.140
A7	28.33	54.34	55	213.76	14.38	24.60	10.08	17.24	1.69	24.54	22.087

Table-4: Blast parameters for W= 5T and R= 20 m

Column	Col. Dist. from blast (m)	Scaled Distance r (ft)	Distance r (ft)	Peak over pressure P (KN/m^2)	arrival time t_x(ms)	Arrival time (ms)	Scaled Blast duration t_d (ms)	Blast duration (ms)	Match no (M)	Dynamic Pressure q (KN/m^2)	Drag over Pressure (KN/m)
A1	22.34	37.43	45	546.13	7.07	13.85	6.94	13.58	2.41	78.15	70.338
A2	20.6	34.52	35	690.69	6.06	11.85	6.45	12.63	2.65	102.23	92.010
A3	20	33.51	35	740.00	5.75	11.26	6.35	12.43	2.73	110.49	99.439
A4	20.63	34.57	35	688.22	6.07	11.88	6.46	12.64	2.64	101.82	91.639
A5	22.39	37.52	40	573.21	7.16	14.01	6.95	13.61	2.44	82.65	74.383
A6	25.04	41.96	45	430.73	8.88	17.39	7.75	15.18	2.18	59.13	53.216
A7	28.33	47.47	50	309.52	11.19	21.90	8.79	17.21	1.92	39.51	35.555

Table-5: Blast parameters for W= 7.5T and R= 20 m

Column	Col. Dist. from blast (m)	Scaled Distance r (ft)	Distance r (ft)	Peak over pressure P (KN/m^2)	Scaled arrival time t_x(ms)	Arrival time (ms)	Scaled Blast duration t_d (ms)	Blast duration (ms)	Match no (M)	Dynamic Pressure q (KN/m^2)	Drag over Pressure (KN/m)
A1	31.5	60.42	60	158.14	17.52	29.96	11.18	19.11	1.55	16.29	14.664
A2	30.4	58.31	60	176.77	16.42	28.08	10.80	18.46	1.60	19.00	17.101
A3	30	57.54	60	183.54	16.02	27.40	10.66	18.22	1.61	20.00	18.001
A4	30.4	58.31	60	176.77	16.42	28.08	10.80	18.46	1.60	19.00	17.101
A5	31.6	60.61	60	156.45	17.62	30.13	11.21	19.17	1.55	16.05	14.445
A6	33.57	64.39	65	133.43	19.76	33.79	11.89	20.33	1.47	12.81	11.530
A7	36.09	69.23	70	111.25	22.80	39.00	12.76	21.82	1.41	9.83	8.846

Table-6: Blast parameters for W= 5T and R= 30 m

Column	Col. Dist. from blast (m)	Scaled Distance r (ft)	Distance r (ft)	Peak over pressure P (KN/m^2)	Scaled arrival time t_x(ms)	Arrival time (ms)	Scaled Blast duration t_d (ms)	Blast duration (ms)	Match no (M)	Dynamic Pressure q (KN/m^2)	Drag over Pressure (KN/m)
A1	31.5	52.78	55	232.10	13.64	26.69	9.80	19.18	1.74	27.35	24.614
A2	30.4	50.94	55	253.80	12.75	24.96	9.47	18.54	1.79	30.71	27.641
A3	30	50.27	55	261.69	12.43	24.33	9.35	18.30	1.81	31.94	28.750
A4	30.4	50.94	55	253.80	12.75	24.96	9.47	18.54	1.79	30.71	27.641
A5	31.6	52.95	55	230.13	13.72	26.85	9.83	19.24	1.73	27.05	24.341
A6	33.57	56.25	60	194.96	15.35	30.05	10.43	20.41	1.64	21.70	19.531
A7	36.09	60.47	65	158.79	17.57	34.38	11.19	21.89	1.55	16.39	14.748

Table-7: Blast parameters for W= 7.5T and R= 30 m

IV. CONCLUSION

From above results it is clear that as the stand-off distance increases from the building, the magnitude of blast pressure reduces significantly. Above calculation tables shows that blast parameters are greatly dependent on weight of blast and stand-off distance.

After the calculation for all three cases

Peak over pressure Pso is found to be increasing as the weight of blast increases and stand-off distance decreases.

Peak over pressure Pso is decreasing as the weight of blast decreases and stand-off distance increases.

Peak over pressure Pso is found to be increasing as the Arrival time and Blast duration is decreases.

Drag over pressure and Mach number (M) is found to be increasing as the weight of blast increase and stand-off distance decreases.

Arrival time and Blast duration is found to be increasing as the weight of blast increase and stand-off distance decreases.

Blast waves take milliseconds to reach the building from site of explosion and affect the building.

From above computations of blast pressures, it was observed that blast pressure was inversely proportional to blast scaled distance.

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