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Analysis of blast resistant RCC structure

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Abstract - *A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building's external and internal structural frames, collapsing of walls, loss of life etc. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. In addition, major catastrophes resulting from explosion causes large dynamic loads, greater than the original design loads, of many structures. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and its effects on various structural elements. Blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads. This paper presents the study of effect of Blast loading on a six storey RCC building. Effect of variable blast source weight is calculated by considering 30 m distance from point of explosion. The blast load was analytically determined as a pressure-time history and numerical model of the structure was created in SAP2000.The influence of the lateral load response due to blast in terms of peak deflections, velocity, accelerations, inter storey drift is calculated and compared*

Key Words: **Shock front, charge weight, pressure time history, positive pressure, over pressure, arrival time, clearance time, transit time**

1.INTRODUCTION

In the past few decades considerable emphasis has been given to problems of blast and earthquake. The blast problem is rather new, information about the development in this field is made available mostly through publication of the Army Corps of Engineers, Department of Defense, U.S. Air Force and other governmental office and public institutes. Conventional structures, particularly that above grade, normally are not designed to resist blast loads and because the magnitudes of design loads are significantly lower than those produced by most explosions, conventional structures are susceptible to damage from explosions.

2.EXPLOSION & BLAST PHENOMENON

An explosion is the result of a very rapid release of large amounts of energy within a limited space. Explosions can be categorized on the basis of their nature as physical, nuclear and chemical events. The sudden release of energy initiates a pressure wave in the surrounding medium, known as a shock. When an explosion takes place, the expansion of the hot gases produces a pressure wave in the surrounding air. As this wave moves away from the centre of explosion, the inner part moves through the region that was previously compressed and is now heated by the leading part of the wave. As the pressure waves move with the velocity of sound, the temperature is about 3000^0-4000^0C and the pressure is nearly 300 kilo bar of the air causing this velocity to increase. The inner part of the wave starts to move faster and gradually overtakes the leading part of the waves. After a short period of time the pressure wave front becomes abrupt, thus forming a shock front somewhat similar. The maximum overpressure occurs at the shock front and is called the peak overpressure. Behind the shock front, the overpressure drops very rapidly to about one-half the peak overpressure and remains almost uniform in the central region of the explosion. As expansion proceeds, the overpressure in the shock decreases steadily; the pressure behind the front does not remain constant, but instead, fall off in a regular manner. After a short time, at a certain distance from the centre of explosion, the pressure behind the shock front becomes smaller than that of the surrounding atmosphere and so called negative phase or suction.

The front of the blast waves weakens as it progresses outward, and its velocity drops towards the velocity of the sound in the undisturbed atmosphere. Another quantity of the equivalent importance is the force that is developed from the strong winds accompanying the blast wave known as the dynamic pressure; this is proportional to the square of the wind velocity, u and the density of the air behind the shock front, ρ:

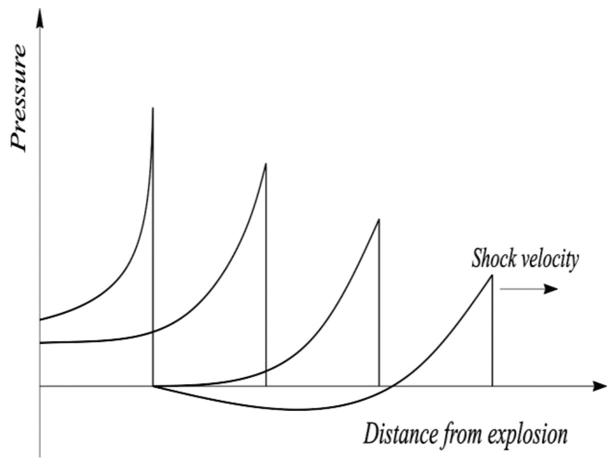


Fig -1: Variation of blast pressure with distance

The peak dynamic pressure decreases with increasing distance from the centre of explosion, but the rate of decrease is different from that of the peak overpressure. At given distance from the explosion, the time variation of the dynamic Pd behind the shock front is somewhat similar that of the overpressure Ps, but the rate of decrease is usual different. For design purposes, the negative phase of the overpressure is not important and can be ignored.

3.BLAST PARAMETERS OF EXPLOSION

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. 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 Tab. 1.

Table -1: Conversion factors for explosives

Explosive	Specific energy	TNT Equivalent
	Qx / kJ/kg	*Qx*/*Q*TNT
Compound B (60 % RDX, 40 % TNT)	5190	1,148
RDX (Ciklonit)	5360	1,185
HMX	5680	1,256
Nitroglycerin (liquid)	6700	1,481
TNT	4520	1,000
Explosive gelatin (91 % nitroglycerin, 7,9 % nitrocellulose, 0,9 % antracid, 0,2 % water)	4520	1,000
60 % Nitroglycerin dynamite	2710	0,600
Semtex	5660	1,250
C4	6057	1,340

Explosion wave front speed equation, Us, and the maximum dynamic pressure, q_s are defined as [1]:

$$Us = a0.\sqrt{\frac{6ps+7p0}{7p0}} \qquad (1)$$

$$q_s = \frac{5ps^2}{2.(ps+7p0)} \qquad (2)$$

where:

ps – Peak static wave front overpressure, bar
*p*0 – Ambient air pressure (atmospheric pressure), bar
*a*0 – Speed of sound in the air, m/s.

There are various proposals for the calculation of the main explosion parameters. Brode [12] gives the following values for the peak static overpressure for near (when the *ps* is greater than 10 bar) and for medium to far away (when the p_s is between 0,1 and 10 bar):

$$p_s = \frac{6.7}{Z^3} + 1 \text{ bar:} \qquad (p_s > 10\ bar) \qquad (3)$$

$$p_s = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019 \text{ bar:}$$

$$(0.1 < ps < 10 \text{ bar}) \qquad (4)$$

Where

Z – scaled distance,

$$Z = \frac{R}{\sqrt[3]{W}} \qquad (5)$$

Where,

R – distance from the centre of a spherical charge, m
W – charge mass expressed in kilograms of TNT.

Newmark and Hansen [13] proposed the use of the following values:

$$p_s = 6874.\frac{W}{R^3} + 93.\sqrt{\frac{W}{R^3}} \text{ b} \qquad (6)$$

Mills [14] proposed the following:

$$p_s = \frac{1772}{Z^3} + \frac{114}{Z^2} + \frac{108}{Z} - 0.019 \text{ kPa} \qquad (7)$$

Other important parameters include: *t*0 = duration of the positive phase during which the pressure is greater than the pressure of the surrounding air and *is* = the specific wave impulse that is equal to the area under the pressure-time curve from the moment of arrival, t_A, to the end of the positive phase and is given by expression:

$$i_s = \int_{tA}^{tA+t0} Ps(t)dt \qquad (8)$$

The typical pressure profile of the explosion wave in time for the explosion in the air is given in Fig. 2

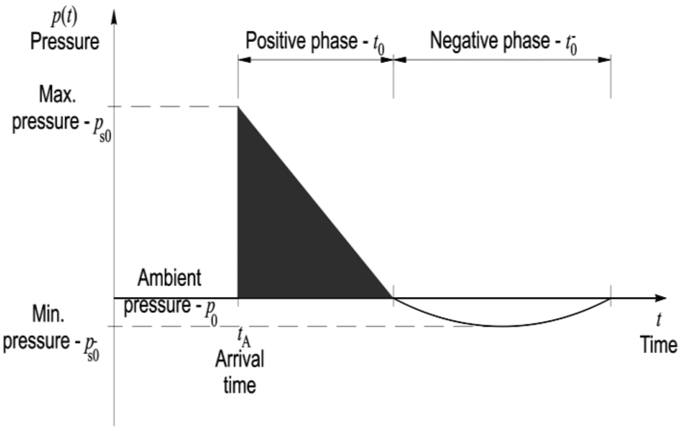


Fig -2: Pressure-time profile for the explosion wave

Where *p–* is the maximum value of negative pressure (pressure below ambient pressure) in the negative phase of the blast. Brode [12] proposed the following value for *p–*:

$$p = -\frac{0.35}{z} \text{ bar: } Z > 1.6 \quad (9)$$

And the corresponding specific impulse at this stage, 'i_s' is given by:

$$i_s \approx i_s.\left(1 - \frac{1}{2Z}\right) \quad (10)$$

4.NUMERICAL EXAMPLE

A six storey RC frame structure has been chosen for investigating the effect of blast loads. In this present study, effect of charge weight 100 kg has been studied for standoff distance of 30m.The structure is analyzed for nodal displacements, velocity, acceleration, stress resultants and moments

4.1 Building description

A six storey RCC frame building with 18.0 m height situated in seismic zone IV has been considered for the purpose of present study.

(i) Floor to floor height = 3.0 m

(ii) Size of Columns = 500 mm × 500 mm

(iii) Size of Beam = 450 mm × 500 mm

(iv) Thickness of slab = 150 mm

4.2 Material properties

(i) characteristic compressive strength fck = 30 MPa

(ii) Poisson's ratio =0.2

(iii) Density = 25 KN/m3

(iv)Modulus of Elasticity (E) = 27386128 MPa

(v) Damping = 0.05

Plan and Elevation of building for Phase 1, 2 & 3 are shown in fig

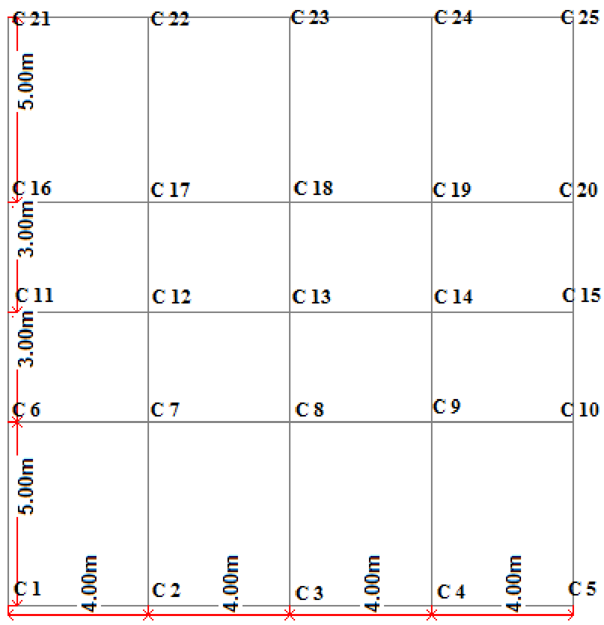


Fig -3: Frame plan of building

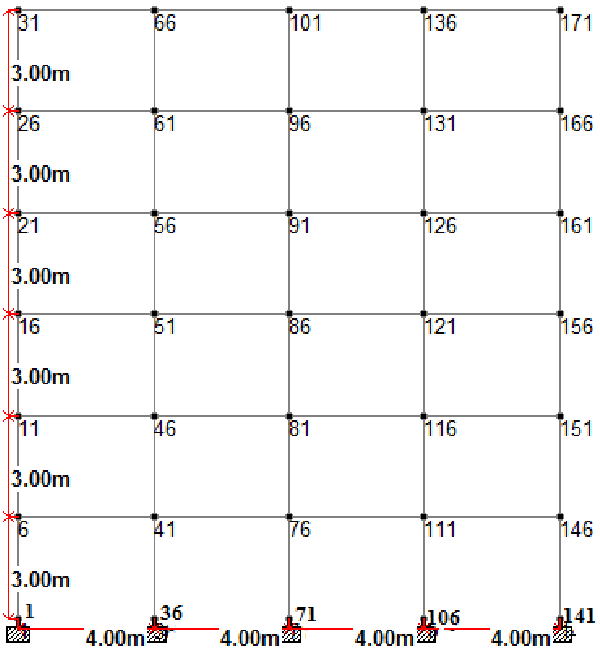


Fig -4: Frame elevation of building

4.3 Calculation of blast parameters

Calculation procedure of blast parameters produced by the explosion shock front waves such as Peak reflected overpressure, Dynamic pressure, Peak side-on pressure on structure as per IS:4991-1968 are as follows.

Step 1: Determine the explosive weight as equivalent to TNT weight 'W' in tones which is used as charge

Step 2: Determine the Standoff distance / actual distance 'R' of the point measured from ground zero to the point under consideration.

Step 3: Determine the charge height at which it is placed above the ground surface.

Step 4: Determine the structural dimensions.

Step 5: Select different points on the structure (front face, roof, side and rear face) and calculate the explosion parameters for each selected point.

i) Calculate the scaled distance 'Z' as per scaling law.

ii) Determine the explosion's parameters using Table 1 of IS:4991-1968 for above calculated scaled distance 'X' and read the values.

a) Peak side-on overpressure Pso.

b) Peak reflected overpressure Pro.

c) Dynamic pressure q_o.

d) Mach number M.

e) Positive phase duration to milliseconds (millisecond).

f) Duration of equivalent triangular pulse td milliseconds (millisecond).

The values scaled times to and td obtained from the Table 1 of code IS: 4991-1968 for scaled distance 'Z' are multiplied by $\sqrt[3]{W}$ to obtain the absolute values for actual explosion of W tones charge weight.

Step 6: Net pressure acting on the front face of the structure at any time 't' is maximum of Pr or (Pso + Cd. q_o).

Where,

Cd = Value of drag coefficient given in Table 2 of IS:4991-1968.
Pr = Reflected overpressure which decrease from Pro to overpressure in clearance time tc.

Step 7: Pressure on rear face is depends on time intervals are as follows.

i) Clearance time (t_c) = 3S/U

ii) Travel time of shock wave from front face to rear face i.e. transit time (t_t) = L/U

iii) Pressure rise time on back face (t_r) = 4S/U

Where,

S = Height 'H' or half of the width 'B/2' whichever is less
U = Shock front velocity = *M.a*

a = velocity of sound in air may be taken as 344 m/sec at mean sea level at 20 oc.

M = Mach number of the incident pulse.

$$M = \sqrt{\left(1 + \frac{6Ps}{7Pa}\right)}$$

Decay of pressure with time is given by

$$ps = pso\left(1 - \frac{t}{t0}\right)e^{-\alpha\frac{t}{to}}$$

$$q = qo\left(1 - \frac{t}{t0}\right)^2 e^{-2\alpha\frac{t}{to}}$$

If pressure rise time is more than duration of equivalent triangular pulse, there will be no pressure on rear face of the structure. i.e. {tr > td; no pressure on rear face}

4.3 Loads considered in analysis

The following loads are considered for the analysis of various phases of structure.

Gravity loads: The intensity of dead load and live load considered in the study are given below:

Dead loads: Dead load comprising of self-weight of members i.e. Beam, Column and Slab.

Live load: Live load of 4 KN/m2 on floor area.

Blast loads: IS 4991-1968 is used for blast load calculations. The maximum values of the positive side-on overpressure (P_{so}), reflected over pressure (P_{ro}) and dynamic pressure (q_o), as caused by the explosion of one tone explosive at various distances from the point of explosion are given in the following Table. And also, the duration of the positive phase of the blast **to** and the equivalent time duration of positive phase **td** are given as follows:

Table -2: Blast parameters for Phase 1
(W=100 kg at Z=30 m)

Node	Scaled dist. 'Z' (m)	T0 (ms)	Td (ms)	Pso (KN/m^2)	Pro (KN/m^2)
Level 1					
1	66.97	17.78	13.42	33.35	75.38
36	65.29	17.58	13.24	34.71	78.91
71	64.71	17.51	13.16	35.29	80.43
106	65.29	17.58	13.24	34.71	78.91

141	66.97	17.78	13.42	33.35	75.38
Level 2					
2	66.97	17.78	13.42	33.35	75.38
37	65.29	17.58	13.24	34.71	78.91
72	64.71	17.51	13.16	35.29	80.43
107	65.29	17.58	13.24	34.71	78.91
142	66.97	17.78	13.42	33.35	75.38
Level 3					
3	67.59	17.85	13.47	32.94	74.35
38	65.92	17.65	13.34	34.08	77.21
73	65.36	17.59	13.25	34.64	78.72
108	65.92	17.65	13.34	34.08	77.21
143	67.59	17.85	13.47	32.94	74.35
Level 4					
4	68.82	17.99	13.56	32.12	72.31
39	67.18	17.8	13.44	33.22	75.04
74	66.62	17.73	13.4	33.59	75.96
109	67.18	17.8	13.44	33.22	75.04
144	68.82	17.99	13.56	32.12	72.31
Level 5					
5	70.61	18.2	13.73	30.92	69.31
40	69.02	18.02	13.58	31.99	71.97
75	68.48	17.95	13.54	32.35	72.87
110	69.02	18.02	13.58	31.99	71.97
145	70.61	18.2	13.76	30.92	69.31
Level 6					
6	72.94	18.47	13.99	29.37	65.43
41	71.4	18.29	13.81	30.4	68
76	70.88	18.23	13.76	30.75	68.87
111	71.4	18.29	13.81	30.4	68
146	72.94	18.47	13.99	29.37	65.43
Level 7					
7	75.75	18.77	14.39	27.5	61
42	74.27	18.63	14.16	28.49	62.33
77	73.76	18.57	14.09	28.82	64.06
112	74.27	18.63	14.16	28.49	63.22
147	75.75	18.77	14.39	27.5	61

The structure is then analyzed for the effects of above blast forces with SAP 2000 using nonlinear dynamic analysis approach with time history functions obtained for each node from above calculated blast parameters

5.RESULT & CONCLUSION

The response of explosion of 100 kg TNT at 30 m standoff distance is given below in terms of nodal displacements, shear force, axial force, moment and torsion

Table -3: Maximum nodal displacements at each storey level

Storey level	Node	Max. displacement (mm)
1	71	0
2	72	0.34
3	73	0.61
4	74	0.83
5	75	0.99
6	76	1.09
7	77	1.12

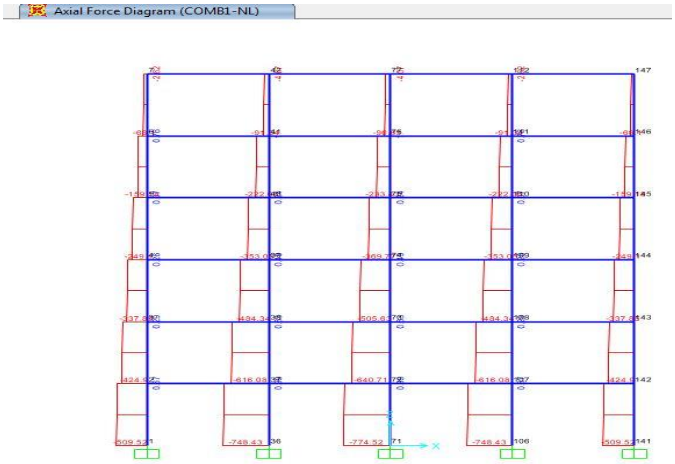
Table -4: Maximum axial force, shear force and moments in columns

storey	Max. axial force P (KN)	Max. shear force V_2 (KN)	Max. shear force V_3 (KN)	Max. moment M_2 (KN-m)	Max. moment M_3 (KN-m)
1	774.517	1.916	2.569	2.4877	1.8759
2	640.713	4.038	5.099	7.6197	5.8633
3	505.63	4.856	5.549	8.1286	7.0483
4	369.767	5.633	6.216	9.1516	8.2603
5	233.425	5.799	6.055	9.3761	8.8365
6	96.632	8.256	9.194	11.6889	10.7162

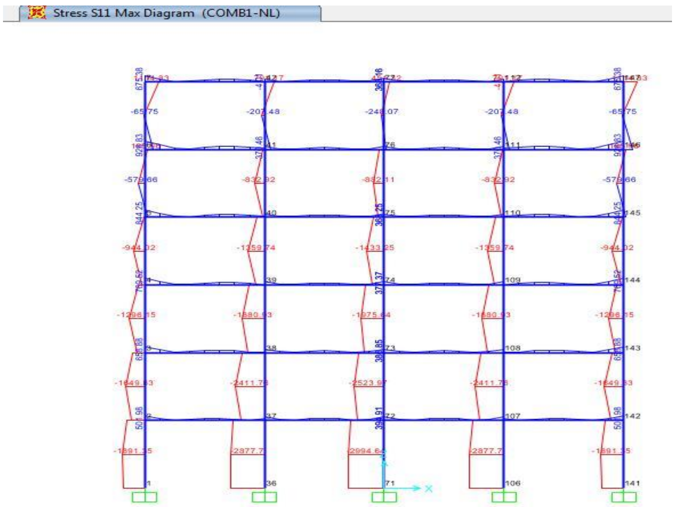
Table -5: Maximum axial force, shear force and moments in beams

storey	Max. axial force P (KN)	Max. shear force V_2 (KN)	Max moment M_3 (KN-m)
1	0.991	12.419	9.3533
2	0.63	13.872	12.3298
3	0.491	14.919	14.406
4	0.241	15.642	15.8237
5	0.998	16.328	17.3472
6	-4.072	14.495	12.8689

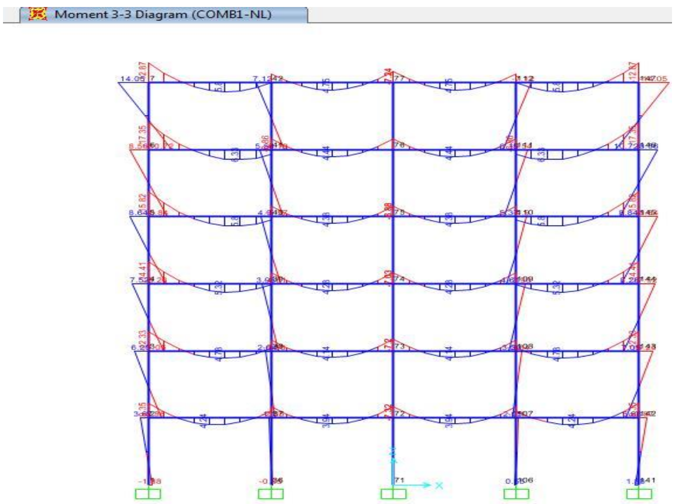
Pic -1: Axial force on front face of building for blast loads from SAP 2000



Pic -2: Shear stresses on front face building due to blast loads from SAP 2000



Pic -3: Moments on front face of building due to blast loads from SAP 2000



From above results following conclusions can be drawn.

1. The structure can be analyzed for blast load effects using conventional software like SAP 2000.
2. Though the pressures exerted are very high during explosions, the source of explosion, duration of blast wave and arrival time plays important role in overall response of structure.
3. The maximum displacement occurs at the central node of the building. Also, the displacement is maximum at the top storey.
4. The axial forces in columns are maximum at the first storey whereas shear forces and moments are maximum at the top storey in columns and beams as the distance from source of explosion increases.

The given structure can be analyzed for any standoff distance for varying charge weights by using this methodology and critical distance can be found out for the explosion for given structure.

5. SUMMARY

The explosion in or near the structure can cause catastrophic damage to the structure, formation of fragments, destruction of life-support systems (air conditioning, sprinklers). Injuries and deaths can be caused by exposure to explosion wave front, collapse of the structure, impact of parts, fire and smoke. Blast load for close explosion was determined and simulated on a model building using SAP2000, the conventional software for the static/dynamic analysis of structures. Loading was defined as a record of pressure over time (pressure-time history) with the parameters calculated by the available literature. It was necessary to analyze the loading for each point. Deformation history of particular points of interest was calculated. It is shown that the effects of blast loading can be taken into account for structural design by the use of available literature. Available commercial software for structural analysis can be used for design purposes, while further analysis should be directed towards familiarizing the phenomenon of the internal explosion. Thus, a complete picture of the explosion effects on the structure can be obtained

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