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RESPONSE OF HIGH RISE STRUCTURES SUBJECTED TO BLAST LOADS

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***Abstract*— Design and Structural Evaluation of the Building systems subjected to blast load form the important task of the present generation. Unlike earthquake design, blast resistant design is a new concept which has gained huge importance in order to make structures safe again blast effect. Due to different accidental and intentional acts, the response of the structures for these high impulse, impact loads forms a necessary subject in the recent times.**

An explosion such as a bomb blast, gas cylinder explosion within or near a building frame system causes a series of effects which are grievous in nature, such as shattering of window panels, damage to the structural elements, collapse of walls and floors, etc. All these situations along with after blast effects such as structural affliction, smoke, fire and debris lead to the loss of life, damage to the surrounding properties and social havoc.

In the present work, the importance of standoff distance (distance from the point of explosion) is studied. Two high-rise structures (Closed Structure and Open RC frame Structure) are subjected to blast overpressure at distances of 0.030 km, 0.050 km, 0.070 km, 0.090 km, 0.110 km and 0.150 km respectively. The minimum distance at which the structure is safe against the blast force is found in both the structural cases. A finite element tool, ETABS is used for the numerical analysis.

***Index Terms*— Blast effect, Closed Structure, Explosion, Open Frame Structure, standoff distance.**

I. INTRODUCTION

An Explosion is defined as a rapid chemical reaction that occurs in the few milliseconds resulting in the very fast release of energy and hot gases into the surrounding atmosphere. It results in the generation of high pressure and temperature. During explosion the hot gases that are generated occupy the space surrounding, resulting in wave propagation through space which is transmitted spherically or hemispherically through a surrounding medium.

Explosions can be differentiated based on the nuclear, chemical and physical chaos,

Physical Explosion - Energy release may be due to the dangerous explosion of compressed gas cylinders or a combination of two liquids at very high temperature etc.

Nuclear Explosion - Energy release due to redistribution of protons and neutrons within in nucleus resulting in the formation of atomic nuclei.

Chemical Explosion - Energy release is due to high rate oxidation of hydrocarbon elements such as carbon and hydrogen atoms.

Type of Explosion mainly classified as

1) Surface burst
2) Air Blast
3) High altitude blast
4) Underground explosion
5) Underwater blast

The rapid discharge of energy causes waveform of a pressure in the surrounding space described as Shock front. Due to the explosion, accumulation of hot gases occurs. As a result of this, a wave of a pressure is generated in the medium. The waves propagate with the speed of sound. The temperature in the surrounding region is around 3000^o - 4000^o C. The absolute maximum pressure over and above the atmospheric pressure occurring at the shock wave is called as maximum or peak value of Overpressure. Following the shock wave, overpressure reduces to around one-half the maximum overpressure and persists approximately even at the central zone of the explosion. The phase in which pressure due to explosion is greater than the atmospheric pressure is called as Positive phase.

As the standoff distance ascends, the effect of overpressure in a shock front decreases uniformly and its speed reduces to the speed of the sound of a un-disturbed surrounding medium. After a certain time, the overpressure in the shock front reduces to value less than that of the medium and hence it is called as a Negative phase.

The study in this section is limited to Surface blast only. The dynamic loads on the structure subjected to this type of blast are estimated. It should be noted that the structure cannot be protected completely from the explosions.

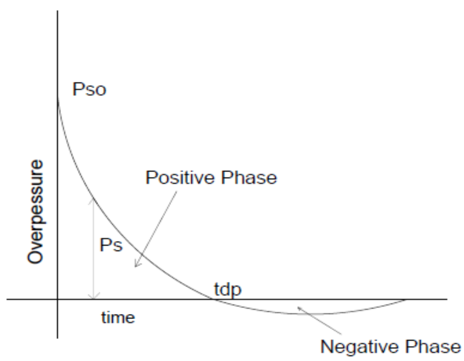

Fig.1.1 Variation of Overpressure [P_{so}]

The overpressure with duration for a particular distance is described in Fig.1.1 to illustrate the time span of positive phase and end time of the positive phase. In addition to overpressure, there is a parameter which is of equal importance known as Dynamic pressure [P_{do}]. This is in proportion to the air density rearward the shock wave and square of the velocity of the wind. Variation of dynamic pressure with time is shown in Fig.1.2.

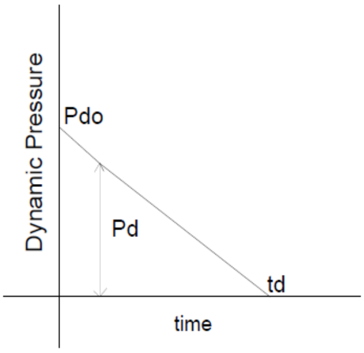

Fig.1.2 Variation of Dynamic pressure [P_{do}]

Dynamic pressure P_{do} expressed by an equation

$$P_{do} = \frac{1}{2} r u^2 \qquad (1.1)$$

Where, u = velocity of air, m/s
r = air density, kg/m^3

The Maximum value of Dynamic Pressure decreases with the increase in standoff distance (distance from the point of explosion).

Scaling Laws: One of the important criteria for blast load calculation is the distance of the point of explosion from a structural point of interest. The ultimate values of overpressure, dynamic pressure, velocity of a shock wave which are discussed earlier, reduces subsequent with the increase in standoff distance.

The effect of standoff distance for assessing the blast load parameters can be taken into consideration by the introduction of Scaling laws. A formalized sketch of the blast load parameters can be given by this scaling law.

Scaled value of Distance (Z) = R /($W^{1/3}$) , mkg $^{-1/3}$ (1.2)
Where, R = distance from the point of burst, m
W = the weapon quantity, kg

Scaling laws provide interdependence between an appropriate blast and standard weapon charge of the same material type.

II. PREDICTION OF BLAST LOADS

The computation of blast loads on the structure is carried out for nuclear-blast pressures which forms the basic requirement for the calculation of forces on the structure subjected to blast loads.

When a rapid release of energy occurs, a spherical shock wave is generated and transmitted away from the explosion point. As a shock wave impinges on an object such as a building system, diffraction effect occurs, producing forces which are generated by high pressures due to the effect of reflection of the blast waves at the striking end. The application of blast load on the structure is non-uniform i.e. the front, sides, roof and back face of the structure are subject to blast loads with a time lag. Air move with high velocity behind the shock front imparts drag force on the structure.

Thus, the total impact on the structure is mainly due to three important consequences, namely, [Biggs (1964)]

- Effects of initial overpressure.
- Reflection effects.
- Drag force due to dynamic pressure.

A. *Peak value of Overpressure [P_{so}] and Dynamic pressure [P_{do}]*

The variation of the peak value of overpressure, dynamic pressure and time of the positive phase of overpressure with the range or distance from the point of the blast is plotted for weapon quantities 10 kN, 10 MN (10^4 kN) and 10 GN (10^7 kN). The values of range and time duration for a distinct weapon quantity are obtained using scaling laws.

Scaling law for range for a particular weapon quantity is

$$\frac{R1}{R2} = \left(\frac{Y1}{Y2}\right)^{\frac{1}{3}} \qquad (2.1)$$

Where R1 is the range to obtain an overpressure with a yield of Y1 and R2 is the range with a yield of Y2, where yield is defined as a measure of the size of the explosion expressed in an equivalent weight of reference explosive. [IS 4991.1968]

Scaling law for time duration for a particular weapon quantity is

$$\frac{t1}{t2} = \left(\frac{Y1}{Y2}\right)^{\frac{1}{3}} \qquad (2.2)$$

Where ti and t2 are the time duration for same weapon quantity, but with different yield.

Eg. To find a distance and time duration for weapon quantity of 0.5x10^7 kN using 10 GN (10^7 kN) graph (Fig.2.3 a)
Using range scaling law,

$$\frac{R0.5}{R1} = \left(\frac{Y0.5}{Y1}\right)^{\frac{1}{3}}$$

$$R(0.5) = R(1) * \left(\frac{0.5}{1}\right)^{\frac{1}{3}}$$
$$= R(1) * 0.80$$

Similarly, using time scaling law, $t(0.5) = t(1) * \left(\frac{0.5}{1}\right)^{\frac{1}{3}}$
$= t(1) * 0.80$

Thus, the range and duration for 0.5x10^7 in weapon are obtained by multiplying the range and duration of 10^7 kN graph with a factor 0.80.

B. *Velocity of Shock Wave*

The velocity of the shock wave is obtained by the expression

$$V = V_o \left[1 + \frac{6P_{so}}{7P_o}\right]^{\frac{1}{2}} \text{ m/s} \qquad (2.3)$$

Where V_o is the velocity of sound, m/s (331 m/s)
P_{so} = peak overpressure, kPa
P_o = atmospheric pressure, (101.325 kPa)

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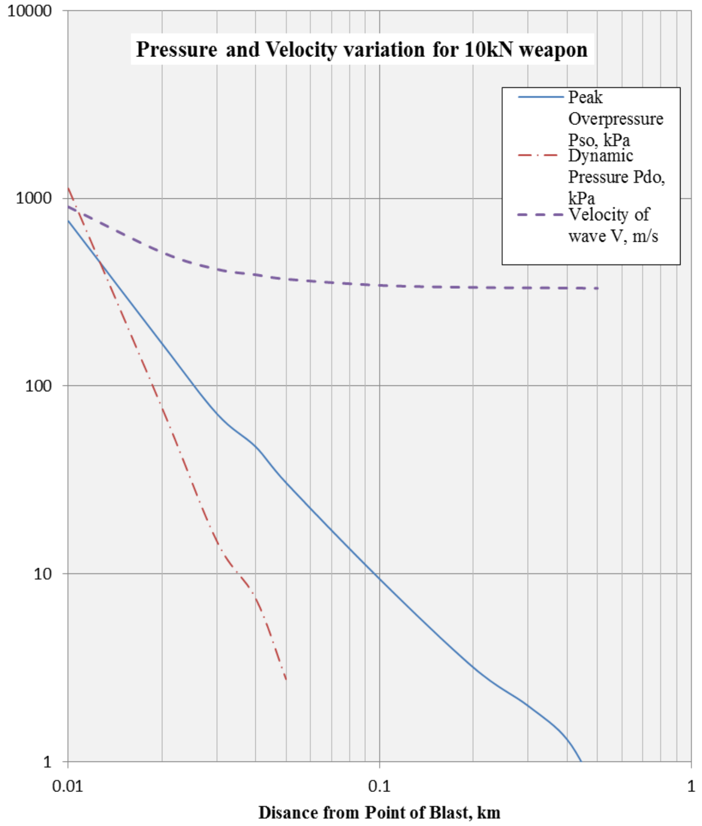

Fig.2.1 (a) Variation of Overpressure, Dynamic Pressure and shock front velocity with distance for 10 kN weapon.

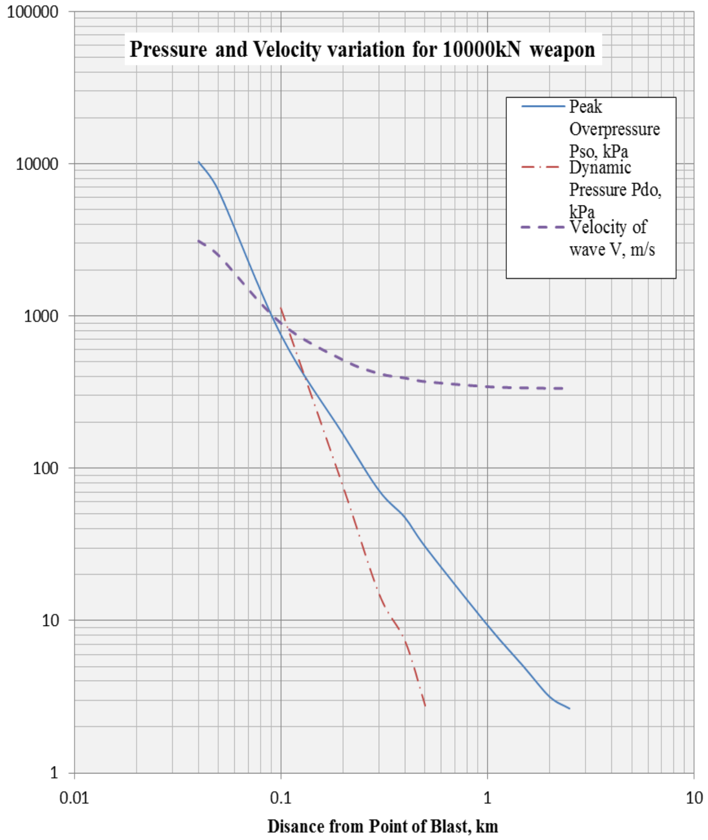

Fig.2.2 (a) Variation of Overpressure, Dynamic Pressure and shock front velocity with distance for 10 MN weapon.

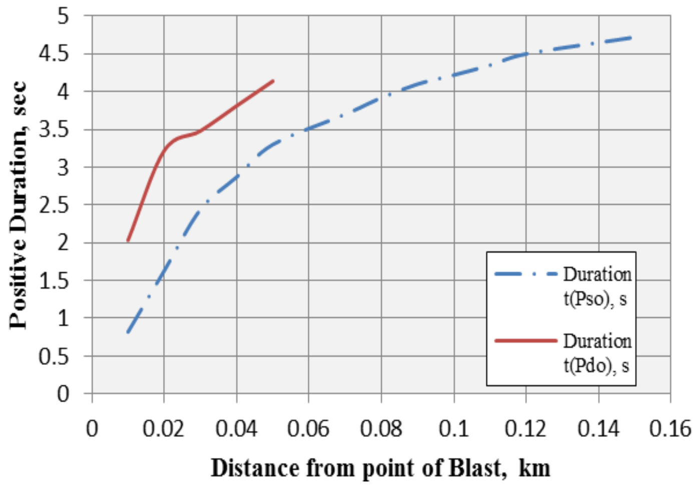

Fig.2.1 (b) Variation of Duration of positive phase of Overpressure and Dynamic Pressure with distance for 10 kN weapon.

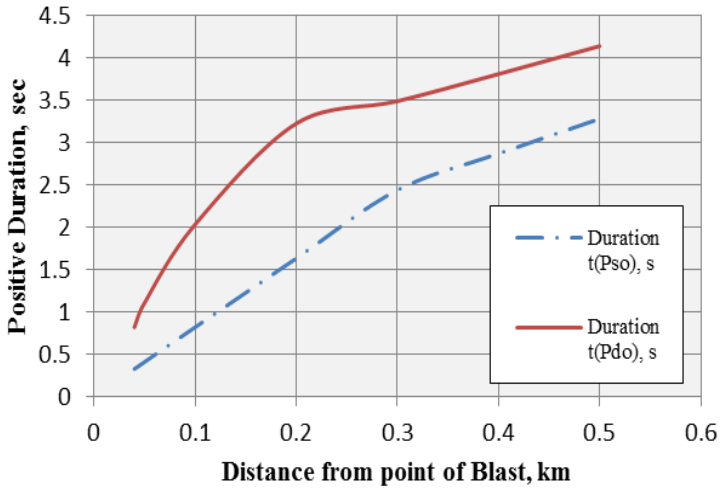

Fig.2.2 (b) Variation of Duration of positive phase of Overpressure and Dynamic Pressure with distance for 10 MN weapon.

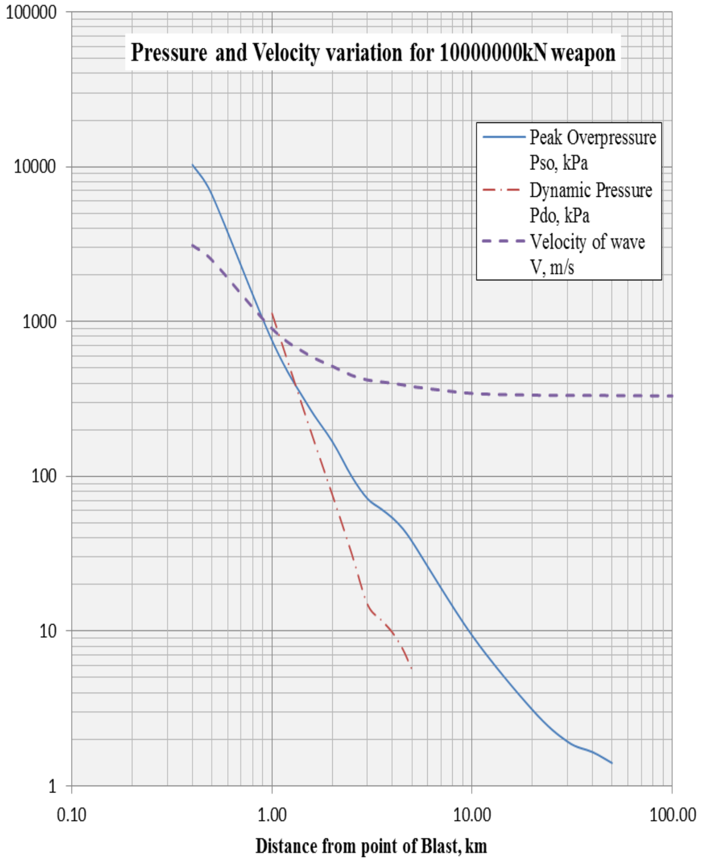

Fig.2.3 (a) Variation of Overpressure, Dynamic Pressure and shock front velocity with distance for 10 GN weapon.

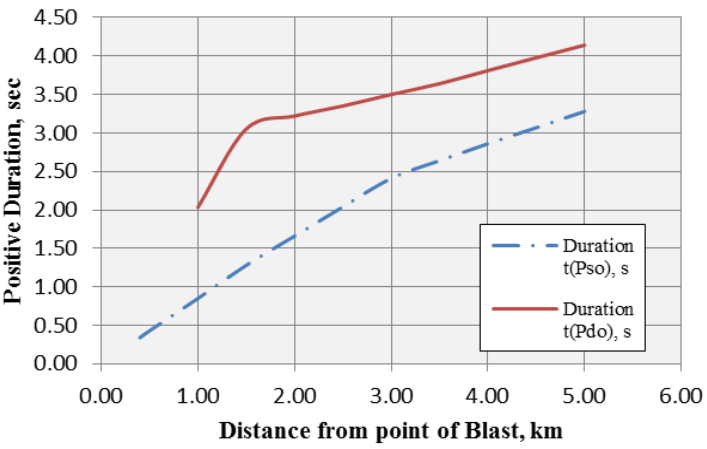

Fig.2.3 (b) Variation of Duration of positive phase of Overpressure and Dynamic Pressure with distance for 10 GN weapon.

C. Reflected Pressure [P_r]

When a shock wave front impinges on the solid structure placed at right angle to the direction of propagation of wave, a reflection of shock front occurs which is approximate twice the peak overpressure.

The Reflected pressure acting on the surface is computed using an expression

$$P_r = 2P_{so}\left[\frac{7Po+4Pso}{7Po+pso}\right] \text{ kPa} \qquad (2.4)$$

Where P_{so} = peak overpressure, kPa
P_o = the atmospheric pressure, kPa

Effect of reflected pressure is assumed to deplete linearly and it disappears to the sum of overpressure and dynamic pressure at a clearance time of t_c shown in Fig.2.4 (a); Biggs (1964) which is expressed as

$$t_c = \frac{3S}{V} \text{ seconds} \qquad (2.5)$$

Where S is half of the width of the structure or its height, least of the two.

V is the velocity of the shock front, m/s.

The maximum acceleration of joint 1 for both Closed structure and Open RC Frame structure is shown in the above table.

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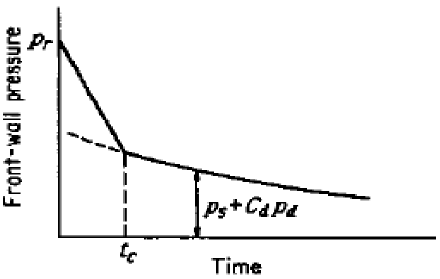

Fig.2.4 (a) Variation of Reflected Pressure v/s time [Biggs (1964)]

The side of the rectangular closed structure shown in Fig.2.4 (b); Biggs (1964) is subjected to overpressure along with drag pressure, which is negative in this case. The rear face of the structure is also subjected to the same loading combinations, but with a time lag. The time required after striking the front face, for a blast wave to reach the rear end is approximately calculated as L/V, where L is a span of the structure and V is the velocity of the shock wave. Time taken for pressure to reach the maximum value at the rear face is 4S/V where S and V are same as in equation (2.5)

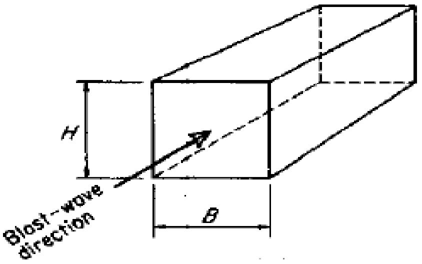

Fig.2.4 (b) Rectangular Closed structure subjected to blast loading [Biggs (1964)]

The total transient force acting on the structure is the algebraic sum of forces at both front and back end of the structure. It is important to understand the presence of an opening in the structures which make the situation more complicated in assessing the forces on the structure subjected to these high impact loads. However, in order to make a structure safe against the effect of blast loads, it should not have any openings.

III. BLAST LOAD CALCULATION

The effect of blast load on any structure is very dynamic with different arrival time of impulse on all the sides of the structure under consideration. Front side of the building is the one which comes in contact with the shock wave of the blast. it is highly impossible to predict the direction of propagation of blast pressure. Therefore, all the four sides of the building are considered as front face and parameters of explosion such as overpressure, dynamic pressure, and time duration of both the pressures and velocity of shock front are computed.

Closed Rectangular Structure

Consider a closed rectangular structure as shown in the below diagram 3.1. The dimensions are marked in the diagram. The structure is subjected to maximum overpressure, P_{so} = 37.57 kPa produced by a yield = 12000 kN

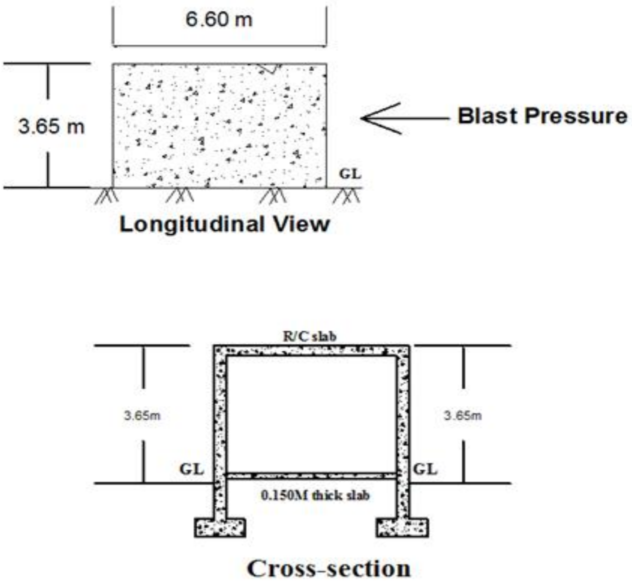

Fig.3.1 Rectangular Structure with no openings

Velocity of shock front, V from equation (2.3)

$$V = V_o\left[1+\frac{6Pso}{7Po}\right]^{\frac{1}{2}}\ m/s$$

$$V = 331\left[1+\frac{6*37.57}{7*101.325}\right]^{\frac{1}{2}}\ m/s \qquad (3.1)$$

V= 380 m/s

From Fig.2.2 (a) the distance of overpressure = 37.57 kPa for 10^4 kN .i.e. R_1 = 0.43km

From Fig.2.2 (b) the duration of positive phase overpressure for 10^4 kN i.e. t_{p1}= 0.314 s

For 12000 kN, the range and positive phase duration can be determined by using equation (2.1) and (2.2) respectively.

Range scaling law $$\frac{R1}{R2} = \left(\frac{Y1}{Y2}\right)^{\frac{1}{3}}$$

$$\frac{R1(12000)}{R(10000)} = \left(\frac{Y(12000)}{Y(10000)}\right)^{\frac{1}{3}} \qquad (3.2)$$

$$R(1.2) = 0.43\left(\frac{1.2}{1}\right)^{\frac{1}{3}} = 0.460 \text{ km}$$

Time scaling law $$\frac{t1}{t2} = \left(\frac{Y1}{Y2}\right)^{\frac{1}{3}}$$

$$\frac{t(12000)}{t(10000)} = \left(\frac{Y(12000)}{Y(10000)}\right)^{\frac{1}{3}} \qquad (3.3)$$

$$tp1.2 = to = 0.314\left(\frac{1.2}{1}\right)^{\frac{1}{3}} = 0.33 \text{ sec}$$

From Fig.2.2 (a) the dynamic pressure for 10^4 kN, weapon,
P_{do} = 4.48 kPa

From Fig.2.2 (b) duration of dynamic pressure for 10^4 kN,,
t_{do} = 0.39 s

Positive duration for 12000 kN , t_d = 0.41 s
The peak reflected pressure from equation (4)

$$P_r = 2P_{so}\left[\frac{7Po+4Pso}{7Po+pso}\right] \text{ kPa}$$

$$P_r = 2*37.57\left[\frac{7*101.325+4*37.57}{7*101.325+37.57}\right] \text{ kPa} \qquad (3.4)$$

P_r = 86.47 kPa

Clearance time, t_s from equation (2.5)

$$t_c = \frac{3S}{V} = \frac{3*2.56}{380} = 0.020\ s \qquad (3.5)$$

Average Pressure on Front face

$t_p = t_d$ = 0.33 s (approximation)
At time t = 0, P_{front} is equal to P_r = 86.47 kPa
at clearance time t = t_c = 0.020 s

P_s and P_d are found from the Fig.3.2 and Fig.3.3 respectively (Biggs (1967)),

From Fig. 3.2,
t/t_p= 0.020/0.33 = 0.060
P_s/P_{so} = 0.85
Therefore,
P_s = 0.85 * 37.57 = 31.93 kPa

From Fig.3.3
t/t_d = 0.020/0.41 = 0.048
P_d/P_{do} = 0.784
Therefore,
P_d = 0.784 * 4.48 = 3.51 kPa

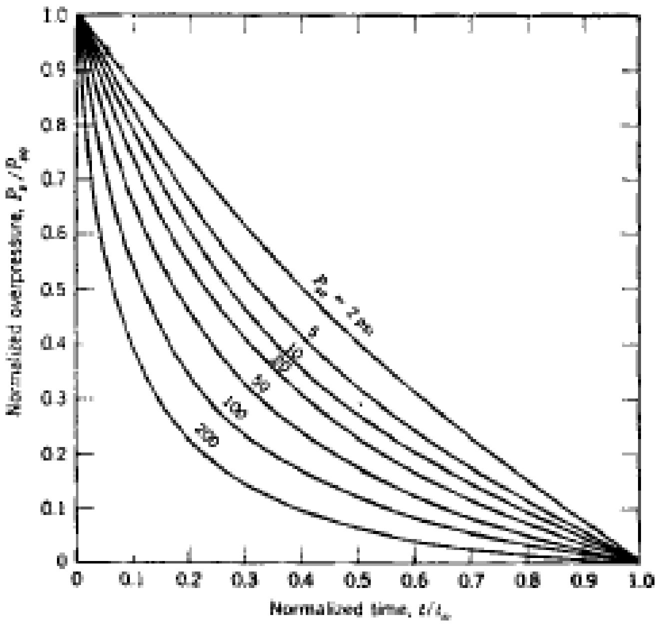

Fig.3.2 Decay of overpressure [Biggs (1967)]

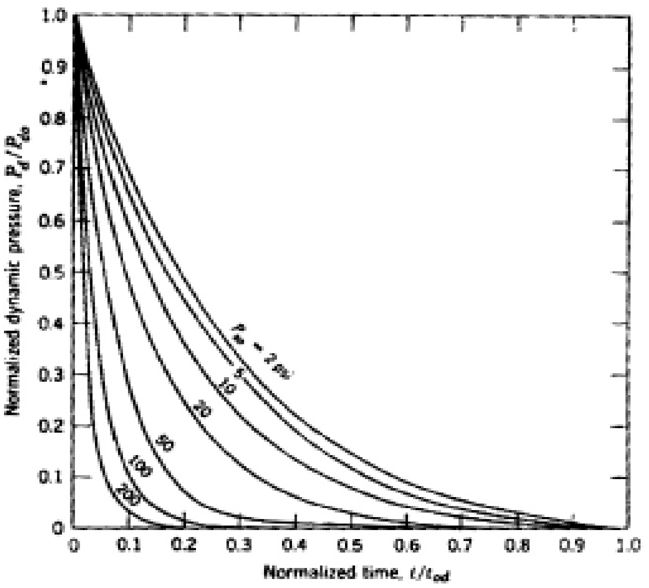

Fig. 3.3 Decay of dynamic pressure [Biggs (1967)]

At Clearance time, t_c,

$$P_{front} = P_s + C_d\, P_d$$

Where, P_s is Overpressure, kPa

P_d is Dynamic Pressure, kPa

C_d is Drag Coefficient = 1 for front vertical side (IS 4991.1968)

$$P_{front} = P_s + C_d\, P_d = 31.93 + (1)\,(3.51)$$
$$= 34.91 \text{ kPa}$$

Fig.3.4 shows the variation of pressure due to blast load on the front face of the structure. When a pressure wave hits the face, it is amplified due to the action of reflection. As the time elapses to clearance time, reflected pressure reduces to the value of $P_s + C_dP_d$.

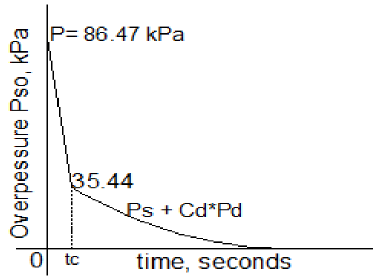

Fig.3.4 Average front face pressure with respect to time

IV. HIGH RISE STRUCTURES SUBJECTED TO BLAST LOADS

A 30 storey Structure with Peripheral Shear Wall and RC frame structure with the central shear wall are modelled and analyzed for blast loads of weapon 10 kN using ETABS. Blast loading is defined as a load-time triangular function in the model. Standoff distance is the very important factor in determining the blast load parameters such as overpressure, velocity of sound, etc. as the distance from the point of the blast increases the effect of impact load reduces to its lowest range and falls into the underpressure zone and finally diminishes out.

A. Building Model

The RC frame building systems are modelled in the software tool, namely

- Closed RC structure with the shear wall at both outer periphery and core.
- Open RC Frame structural system with the shear wall at the central region.

Table 4.1 Structural details

Grade of Concrete, f_{ck}	Column	M40
	Beam, Slab and Shear wall	M30
Grade of Steel, f_{st}		Fe 500
Young’s Modulus of M40 concrete, E		31622.77 MPa
Young’s Modulus of M30 concrete, E		27386.12 MPa
Young’s Modulus of steel, E_{st}		$2x10^5$ MPa
Concrete density		25 kN/m^3
Steel Density		78.5 kN/m^3
Poisson's ratio, U		0.2

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B. Model Description

Table 4.2 Model Description			
Number of bays in x-direction		5	
Number of bays in y-direction		5	
Width of single bay in both the directions		5.00m	
Number of Storeys		30	
Height of each storey		3.50m	
Structural Elements	Column	600 mm x 1200 mm	0 - 5 storeys
		500 mm x 1000 mm	5 - 10 storeys
		400 mm x 800 mm	10 - 15 storeys
		300 mm x 600 mm	15 - 30 Storeys
	Beam	300mm x 600mm	
	Slab	125mm thick	
	Shear wall	300 mm thick	

C. General Loadings

Live load and floor finish are applied to the floor slabs of both the building systems, according to IS 875-1987 part 2. Wall load is applied as a uniformly distributed load on the beams.

D. Closed Structure

A Closed RC frame structure is a regular building system with walls in the outer periphery. Plan and overall view of the building are depicted in the Fig.4.1. The dimension of the building is 25.00 m in both x and y direction with a floor height of 3.50 m. The overall height of this 30 storey building is 105.00 m. The building consists of a concrete wall of grade M40 in the outer region and at the core region.(shown in Fig.4.1). This structural system has no openings in the outer region, making it as a closed structure.

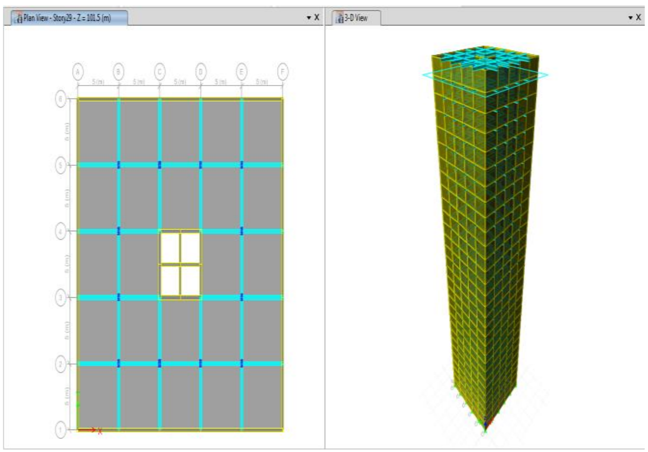

Fig.4.1 Plan and 3-D view of the Closed Structure

E. Open RC Frame Structure

The building is similar to the Closed RC structure. Shear walls are provided at the central region of the building only. Fig.4.2 shows the floor plan and three-dimensional view of the building.

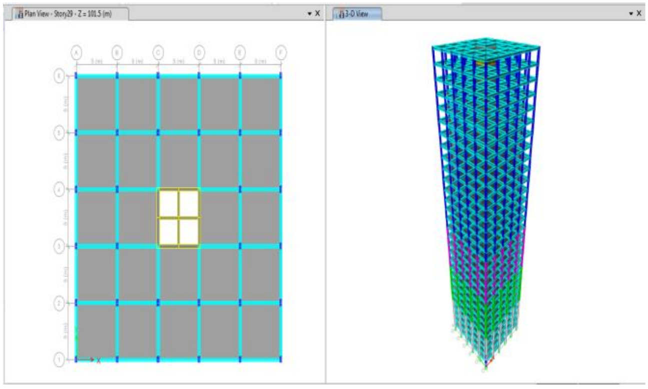

Fig.4.2 Plan and 3-D view of the Open RC Frame Structure

F. Finite Element Model

Table 4.3 Finite Element Model		
	Closed Structure	**RC Frame Structure**
Nodes	1271	1271
Frames	1440	2640
Shells	1684	1084

G. Application of Blast load

Initially, the structure is designed to resist seismic loads. It is then subjected to blast loads at various distances for a charge of 10 kN. The minimum distance at which the building systems tend to be safe is estimated. The Responses (storey displacement and storey shear) of the building at their critical distances are studied.

A blast load generated from a weapon charge of 10 kN is estimated for six different standoff distances such as 0.030 km, 0.050 km, 0.070 km, 0.090 km, 0.110 km and 0.150 km. The load is applied as a blast load-time triangular function to the above considered structures. Table 4.4 shows the variation overpressure and duration at different Standoff distances.

The overpressure and duration for 10 kN weapon at a various standoff distance is obtained from Fig.2.1 (a) and 2.1 (b) respectively.

Blast pressure is assumed to be acting per unit area of a structural element. Therefore, pressure is multiplied with unit area to obtain corresponding blast load for a particular standoff distance. Blast load obtained is applied as point loads at one side of the structure only.

Table 4.4: Variation of overpressure at different Standoff distances for 10 kN weapon charge		
Standoff Distance, km	**Overpressure, kPa**	**Duration, s**
0.03	71	2.44
0.05	31	3.28
0.07	18	3.70
0.09	11	4.10
0.11	8	4.35
0.15	5	4.72

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H. Analysis

Blast load is defined as a triangular time history function in the ETABS. Hinges are assigned to frame elements (beams and columns) at a relative distance of 0.1 and 0.9. Nonlinearity due to both material and geometry are considered. Hilber-Hughes-Taylor (HHT) time integration method with default values for alpha, beta and gamma are used. Taking 100 time steps of each 0.01 seconds step size a non-linear time history direct integration analysis is carried out.

V. DISCUSSION

The behavior of the structures for the given input load is obtained from the numerical analysis. The results obtained are tabulated as below.

A. Von Mises Stress

Table 5.1 Maximum Wall Stress for 10 kN weapon, MPa

Standoff distance, km	Closed Structure	RC frame Structure
0.03	135.48	203.22
0.05	72.33	115.72
0.07	24.64	41.86
0.09	13.20	23.00
0.11	6.92	13.76
0.15	2.69	4.94

The Von Mises stress developed on the wall elements is taken into consideration. Values of stress on both the structural type are depicted in the table 5.1.

The Fig.5.1 shows the stress values for Closed and RC frame Structure. Taking this into a consideration the minimum or critical distance for a closed structure is found to be 0.070 km and 0.090 km for RC frame structure.

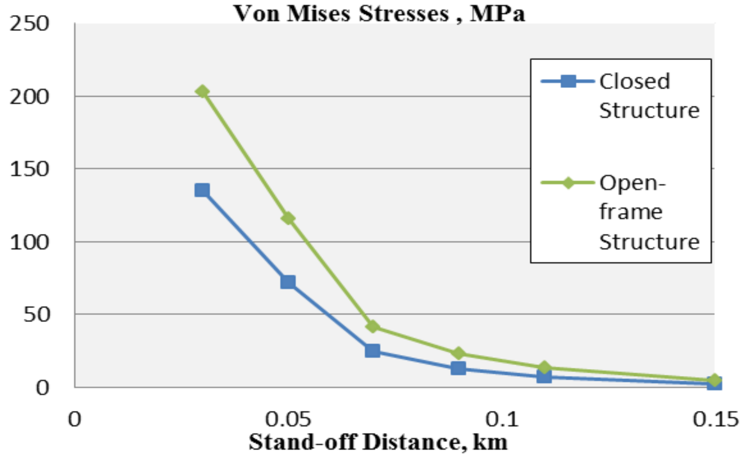

Fig.5.1 Von Mises Stress at various distances for 10 kN charge

B. Top Storey Acceleration

The maximum acceleration of joint 1 for both Closed structure and Open RC Frame structure is shown in the below table.

Table 5.2 Top Storey Acceleration, mm/sec^2

Standoff distance, km	Closed Structure	Open-frame Structure
0.03	80222	73598
0.05	15451	14175
0.07	5224	4778
0.09	1930	1964
0.11	1053	1010
0.15	411	397

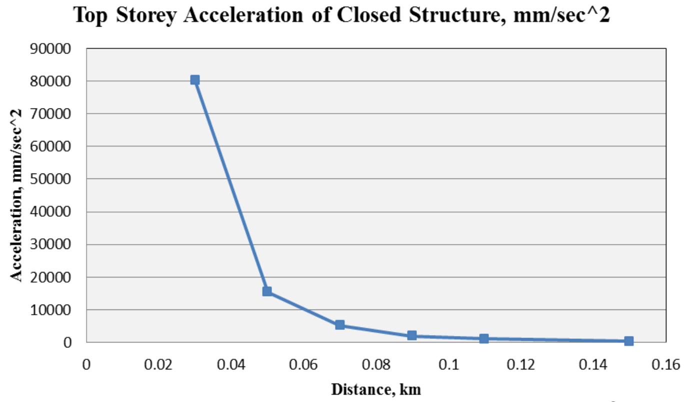

Fig.5.2 Top Storey Acceleration of Closed Structure, mm/sec^2

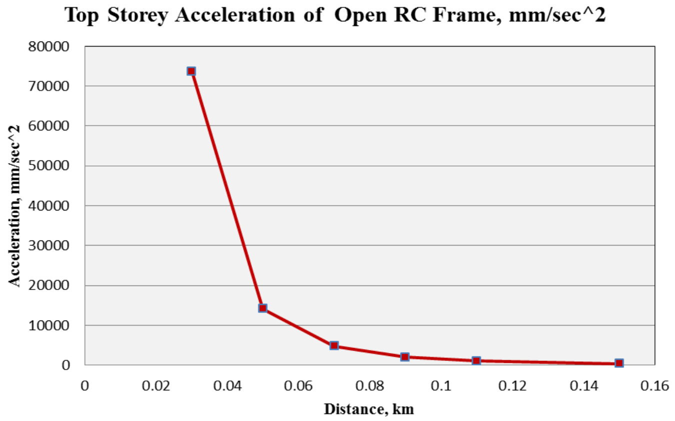

Fig.5.3 Top Storey Acceleration of Open RC Frame Structure, mm/sec^2

The pattern of variation of acceleration of joint 1 at the top storey of both the structures is similar. From the table 5.2, it is observed that the acceleration at a larger standoff distance for Closed structure is small compared to that of RC frame. As the distance decreases, the condition is found to be vice versa .i.e. the acceleration of Closed structure is high compared to that of the RC frame system.

C. Top Storey Displacement

Table 5.3 Top Storey Displacement, mm

Standoff distance, km	Closed Structure	Open-frame Structure
0.03	1629	10751.4
0.05	550	3630
0.07	186	1209
0.09	75	457
0.11	38	249
0.15	15	99

The maximum displacement of joint 1 for both Closed structure and Open RC Frame structure is shown in the above table.

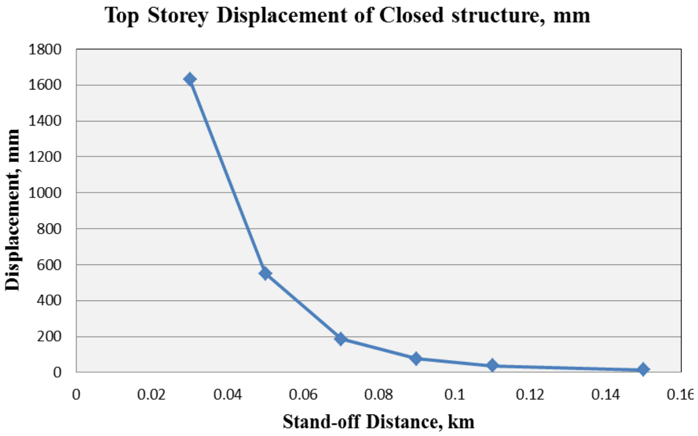

Fig.5.4 Top Storey Displacement of Closed Structure, mm

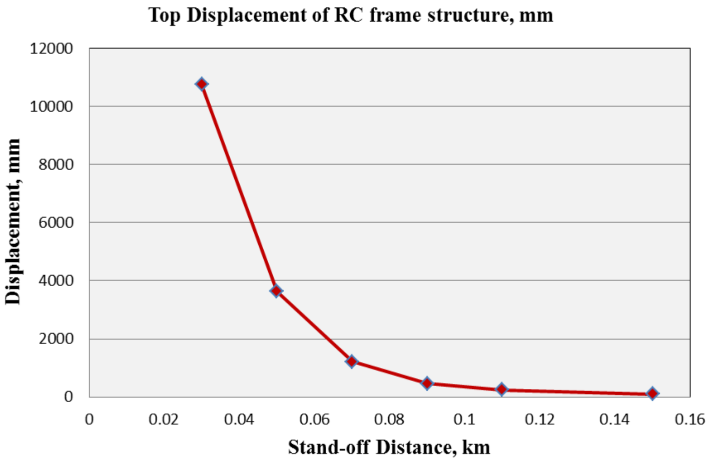

Fig.5.5 Top Storey Displacement of Open RC Frame Structure, mm

The pattern of displacement variation of joint 1 at the top storey in both the structures is same. From table 5.3, it is seen that the joint displacement of Closed Structure is less than that of the RC frame at all the standoff distances.

D. Maximum Storey Displacement.

Maximum Storey Displacement of Closed and RC frame structure at the critical distance of 0.070 km and 0.090 km respectively, for 10 kN weapon charge is shown in the above table. Fig. 5.6 shows the variation of storey displacement.

Table 5.4 Maximum Storey Displacement, mm

Storey Level	Height, m	Closed Structure	Open RC frame Structure
30	105	10.259	4.525
29	101.5	10.142	4.386
28	98	10.041	4.257
27	94.5	9.955	4.141
26	91	9.883	4.044
25	87.5	9.824	3.972
24	84	9.777	3.922
23	80.5	9.733	3.892
22	77	9.689	3.881
21	73.5	9.637	3.888
20	70	9.57	3.905
19	66.5	9.479	3.92
18	63	9.35	3.923
17	59.5	9.173	3.911
16	56	8.94	3.886
15	52.5	8.646	3.852
14	49	8.293	3.817
13	45.5	7.884	3.792
12	42	7.427	3.787
11	38.5	6.926	3.807
10	35	6.383	3.842
9	31.5	5.799	3.858
8	28	5.175	3.809
7	24.5	4.516	3.641
6	21	3.832	3.333
5	17.5	3.136	2.884
4	14	2.436	2.318
3	10.5	1.743	1.658
2	7	1.079	0.978
1	3.5	0.475	0.372
0	0	0	6.053E-06

E. Maximum Storey Drift

Maximum Storey Drift of Closed and RC frame structure at the critical distance of 0.070 km and 0.090 km respectively,for 10 kN weapon charge are shown in the table 5.5. Fig. 5.7 shows the variation of storey displacement.

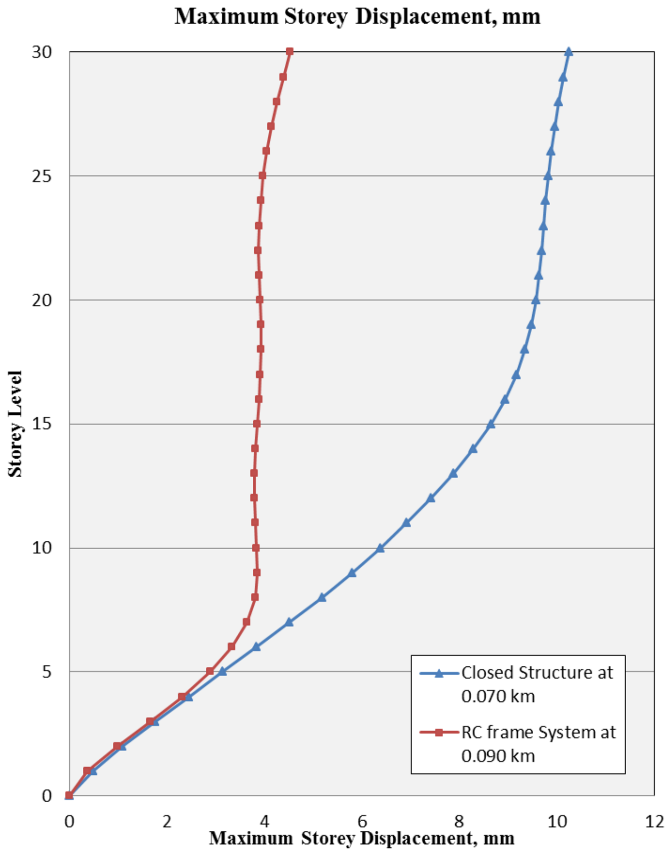

Fig.5.6 Maximum Storey Displacement at critical distance, mm.

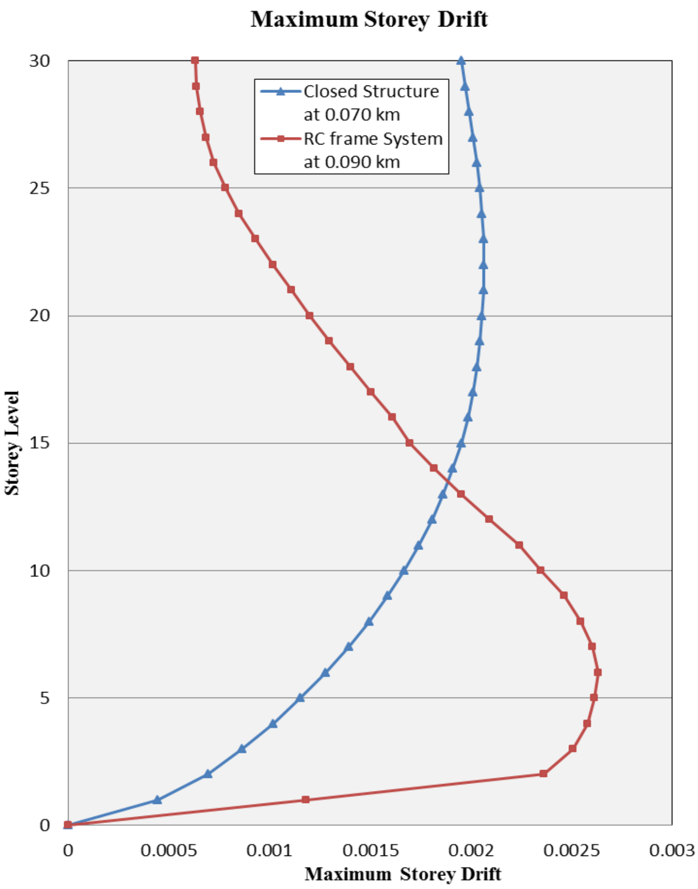

Fig.5.7 Maximum Storey Drift at critical distance

Table 5.5 Maximum Storey Drift

Storey Level	Height, m	Closed Structure	Open RC frame Structure
30	105	0.001952	0.000631
29	101.5	0.001971	0.000637
28	98	0.001992	0.000654
27	94.5	0.002012	0.000683
26	91	0.002031	0.000726
25	87.5	0.002045	0.000783
24	84	0.002056	0.000851
23	80.5	0.002062	0.00093
22	77	0.002064	0.001017
21	73.5	0.002062	0.001108
20	70	0.002056	0.001201
19	66.5	0.002046	0.001299
18	63	0.002031	0.001401
17	59.5	0.002012	0.001505
16	56	0.001986	0.00161
15	52.5	0.001952	0.001697
14	49	0.001911	0.001818
13	45.5	0.001862	0.001954
12	42	0.001806	0.002095
11	38.5	0.001741	0.002241
10	35	0.001668	0.002348
9	31.5	0.001586	0.002463
8	28	0.001495	0.002546
7	24.5	0.001393	0.002602
6	21	0.00128	0.002634
5	17.5	0.001155	0.002613
4	14	0.001017	0.002579
3	10.5	0.000864	0.002508
2	7	0.000697	0.002363
1	3.5	0.000443	0.001181
0	0	0	0

VI. Conclusions

Taking into the Von Mises stress parameter, the important factor called Critical Distance is estimated approximately. The material is said to have yielded when the maximum value of Von Mises stress obtained by the analysis after the application of blast load is greater than the strength of the material. Here in our case, we have considered stress on the Wall elements. The grade of concrete used for the walls is M40. Table 6.6 contains the stresses developed in the shear walls of both the structures. For an RC frame structure, the stresses developed on the walls are approximately 1.5 to 2 times the stresses developed in the walls of closed structure.

The Von Mises stress developed in the outer walls of the closed structure at a distance of 0.050 km is 72.33 MPa, which is higher than the characteristic strength value of concrete which is 40 MPa. At this stress, the structure is said to have collapsed. At 0.070 km, stress is 24.64 MPa. At this value, the structure is safe against collapse, but suffers damage to a certain extent.

The same scenario is followed in the case of the Open RC frame system. As there are no walls in the outer region, the stress developed is the central shear wall. At 0.070 km, value of stress is 41.86 MPa, slightly greater than 40 MPa, resulting in the collapse of the system. At 0.090 km, stress value is 23 MPa. The system is stable against the blast charge of 10 kN.

Therefore, the critical distance or the minimum distance below which the structure is damaged severely is 0.070 km for Closed Structure and 0.090 km for RC frame Structure.

The responses (Storey Displacement and Storey Drift) of both Closed and RC frame system at their respective distances are obtained.

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