BEHAVIOR OF FRAMED STRUCTURE SUBJECTED TO EXPLOSION ON THE GROUND

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Abstract - *The threat of terrorist activity is a rising problem all over the globe from past few decades. The buildings are generally not designed to resists the explosive loads and these loads causes disastrous damage to structural members or results in collapse of buildings. Thus, it is essential to understand the performance of structures under explosive load. In the present work, a RCC building of G+4storey subjected to RDX explosive of 100kg is considered for the study. The positive phase parameters of explosive load of various standoff distances are determined as per UFC 3-340-02. The linear static analysis is performed using ETABS 2015. The response of the building is determined in terms of storey drift, column and beam forces and displacement of the building. The structure was found to be critical when the source of blast is nearer to the building. The structure is safe at 80m standoff distance.*

Keywords: Explosive load, RDX explosive, Standoff distance, Etabs 2015

1. INTRODUCTION

The term blast is usually used to depict any circumstance where an enormous amount of energy is released from a nuclear or chemical or mechanical source. However, from the perspective of the impacts of blast load upon structural frame systems, there exists a set of basic attributes which must be characterized and considered without depending on the type of source. Blasts happening in metropolitan cities nearer to the buildings may causes massive damage to the structure and adjoining structures and may result in loss of life. Such impacts causes immediate effects such as propagation of blast overpressures through the surrounding air, failure of cladding units and generates ground shock waves resulted due to interaction of energy released with the ground. Thus, significant attention has been given to protect structures in metropolitan urban communities because occurrence of explosion (Bombs, trinitrotoluene TNT, and so forth.,) inside and around the structures can cause disastrous effects on the integrity of the structure such as collapse of walls, failure of cladding units, damage to internal and external members. Also, occupants may suffer from injuries or loss of life may occur due to collapse of structure.

Due to various accidental or deliberate events, the behavior of structures subjected to blast load has been the subject of interest in recent years. Regular structures are constructed uniquely in contrast to the military structures and thus, these structures are found to be more vulnerable against blast loads. Traditional structures, mainly those above the ground are generally not designed to withstand the blast loads. Since, the magnitude of design loads is considerably lesser than those produced by most explosions, traditional structures are more liable to damage caused due to explosions. As a result the engineers are in search of solutions for the problem of blast situations in order to protect the life of people and the integrity of structures. Thus, in order to design blast resistant buildings, it is important to understand the behavior of building under blast load and its effects.

I.N. Jayatilake et.al [4] performed the dynamic analysis of tall structures with and without setbacks (12 different configurations) subjected to a surface explosion of 500kg TNT using SAP 2000. Based on the result, they concluded that the building with wider setbacks around the tower part of the building was found to be better compared to building without setbacks. S. M. Jayashree et.al [3] conducted an analysis to study the dynamic behavior of SIFCON and RCC frames subjected to blast load. Time history and modal analysis using SAP 2000 was carried out. Based on the result, it was concluded that the strength and stiffness of SIFCON frames were found to be high compared to RCC frames and also, frames with SIFCON material was found to be less displaced compared RCC frames. Quazi Kashif et.al [6] studied the response of RCC building subjected to two different charge weights of 100kg and 500kg with detonation point at 30m. Here, the blast load was computed as per IS: 4991-1968 code and a non-linear time-history analysis were carried out using SAP2000. In this study, it is observed that response of building subjected to charge weight of 100kg TNT equivalent weight is found to be well compared to other building. Amy Coffield et.al [1] described the behavior of three different steel frames such as moment resisting frames, frames with concentric and eccentric bracings subjected to blast loads of 9kN (2kips) and 18kN (4kips) with source of blast considered at a height of 4.6m (15ft). Applied element method and plastic hinge analysis was carried out and based on the result; they concluded that

the concentric braced building was found to have high resistance against blast load compared to other buildings. P. Vinothini et.al [8] carried out the dynamic analysis of high rise building (10storey) subjected to two different blast load of 30kg and 60kg with source of blast considered at three different points from 10m to 15m using SAP2000. It was reported that the vibration produced during explosion and displacement were found to increases with increase in charge weight and decreases with increase in standoff distance. Thus, it was concluded that the effect of blast load was more when the magnitude of blast load is more.

In India, most of the buildings are low rise (H/D less than 1.5) in nature. The effect of explosion on such buildings is more compared to high rise (H/D greater than 3) buildings. This is because the distance between the source point and corresponding storey is less. Thus, in present study, the behavior of low raised RCC frame structure subjected to explosive (RDX) of 100kg detonated on ground is evaluated by linear analysis using ETABS 2015.

2. EXPLOSION AND BLAST WAVES

A chemical response that occurs with rapid release of enormous amount of hot gases and vitality is known as explosion. The explosion occurs within few moments releasing hot gases which results in producing very high pressure and temperature. The hot gases discharged during the blast will proliferate through the encompassing space in the form of waves. In addition to these hot gases discharged, the air around the encompassing volume where explosion has occurred will spread and the air molecules will ascend and subsequently there will be generation of waves known as explosion or blast wave. The blast wave includes the vitality produced during detonation and these waves propagate at speed higher than the sound.

3. CLASSIFICATION OF EXPLOSION LOADS

The different types of blast load available and load produced by them are as shown in table 1 [5]

Table -1: Loads produced by different types of explosion loads

Confinement of charge	Types	Pressure loads
External or Unconfined explosions	1. Free-air blast 2. Air blast 3. Surface blast	Unreflected waves Reflected waves Reflected waves
Internal or Confined explosions	4. Fully vented	Internal shock waves Leakage
	5. Partially confined	Internal shock waves Internal gas pressure Leakage
	6. Confined fully	Internal shock waves Internal gas pressure

4. INTERACTION OF BLAST WAVE WITH STRUCTURE

During a blast, the impact wave created will spread through the encompassing air and subsequently results in the formation of shock or front wave (the contours formed by waves are assumed to be invariable). These waves will encompass the whole structure which gets refracted and diffracted.
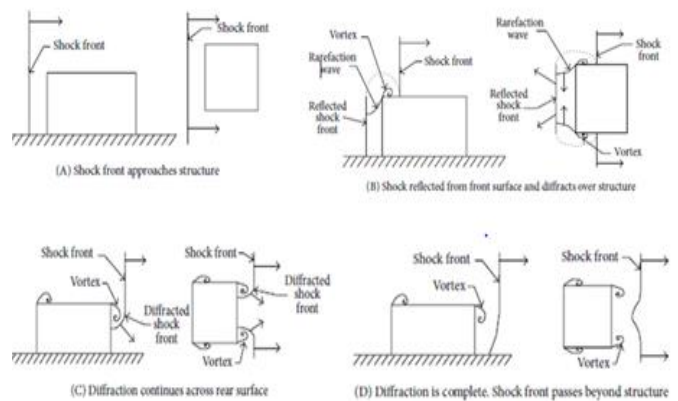

Figure -1: Building and shock wave interaction

Figure 1 demonstrates the pictorial portrayal of shock wave interaction with structures. During explosion, the building is subjected to blast pressure (reflected and overpressure) and actions (drag forces) due to introduction of primary waves which result in formation of vortex which are unpredictable in nature. During refraction, the blast load acts normal to the surface exposed to explosion. Here, the structure deflects towards the right when the pressure acts on the left side of the structure and then the structure deflects slightly towards the left as the refraction of the pressure ends. The drag forces exerted on the structure will push the structure from the left side. Later these waves pass over the structure which results in development of forces known as suction forces. Finally, the amplitude of pressure decreases as the time elapses.

5. METHODOLOGY

In the present work, a five storey RCC building having a base dimension of 16m x 15m is considered. Table 2 and table 3 represent the description of the model and material properties considered. The plan of the building considered for the analysis is shown in figure 2.

Table -2: Properties of material considered

Grade of concrete	M25
Grade of steel	Fe415
Density of concrete	$25 kN/m^3$
Density of steel	$78.5 kN/m^3$
Poisson's ratio	0.2

Table -3: Description of the model

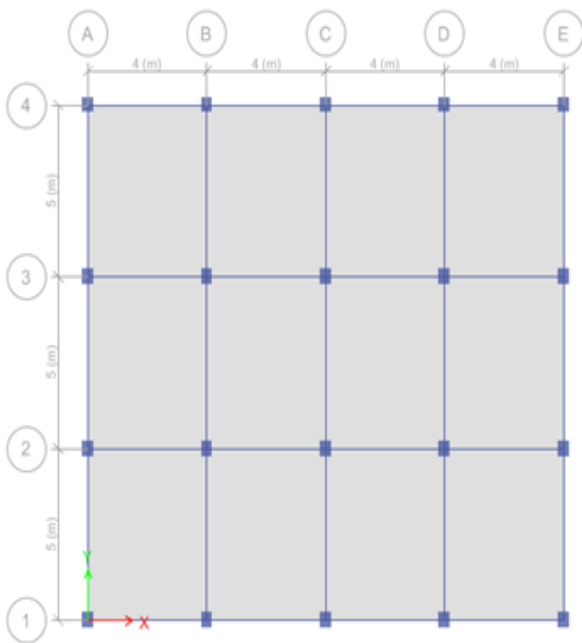| Number of bays in X-direction	4
Number of bays in Y-direction	3
Width of bays in X-direction	4m
Width of bays in Y-direction	5m
Height of each storey	3.5m
Column	380mm x 450mm
Beam	230mm x 450mm
Slab	150mm
Wall	230mm

Figure -2: Plan

The building subjected to an explosive of RDX of 100kg weight detonated at various distance from 10m to 80m was analyzed using ETABS 2015. Here, the blast load is applied as a point load and linear equivalent static analysis is carried out.

6. COMPUTATION OF BLAST WAVE PARAMETERS

A RDX explosive of 100kg weight is considered for the study. The source of blast is considered at a distance of 10m, 15m, 20m, 25m, 30m, 50m, 60m, 70m, 75m and 80m. The various parameters of blast wave are obtained from the chart shown in figure 3.

Scaled distance, $Z = \dfrac{R_h}{\sqrt[3]{W}}$ ...... (1)

$R_h = \sqrt{R^2 + h^2}$ ...... (2)

$R_h = \sqrt{10^2 + 8.75^2} = 13.3m$

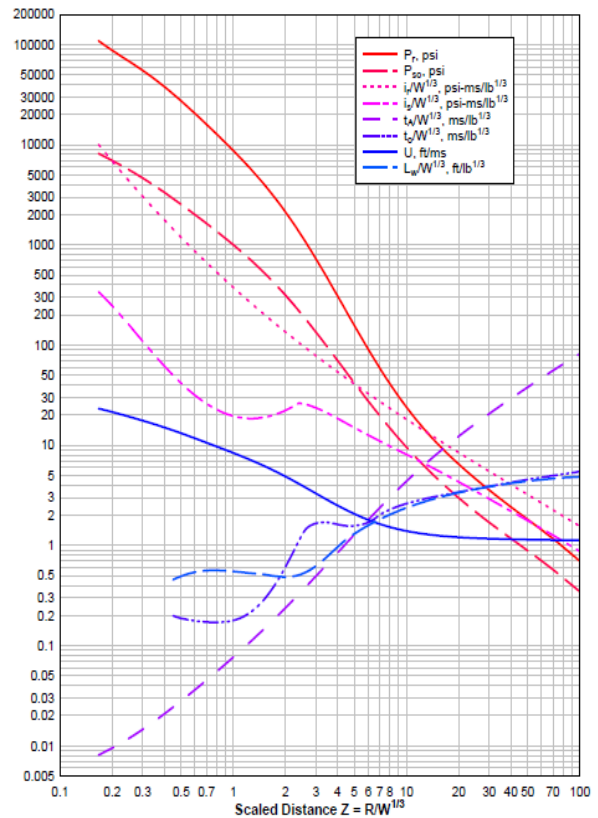$Z = \dfrac{13.3}{\sqrt[3]{118.5}} = 2.7 \dfrac{m}{kg^{\frac{1}{3}}}$

Figure -3: Parameters of surface blast (positive phase)
Source: UFC 3-340-02 (2008) [7]

The parameters of blast at various standoff distance are computed as per UFC 3-340-02, 2008 {page 90} and tabulated as shown in table 4. Table 5 indicates the pressure and joint load acting on the surface of the structure for various standoff distances from 10m to 80m. Figure 4 represents the 3-D view of the building with the blast load (static point load) at joints for the distance of 10m.

Table -4: Pressure acting on front face of the building at different standoff distance

Stand-off distance (m)	Scaling distance, Z (m/kg^1/3)	Incident Pressure, P_{so} (kN/m²)	Reflected Pressure, P_r (kN/m²)	Arrival time, t_a (ms)	Positive duration, t_o (ms)	Pressure on front face (kN/m²)
10	2.7	150	400	14.7	12.8	210
15	3.54	80	206	24.6	16.2	100
20	4.4	53	135.4	34.4	17.7	61
25	5.4	36.7	80	46.7	19.6	41.2
30	6.4	28	60	58.94	19.65	30.6
50	10.33	15.38	30	133.36	24.56	16.13
60	12.34	13.08	27	132.62	24.56	13.68
70	14.36	10	20	147.35	26.72	10.5
75	15.37	9	19.	167	27	9.5
80	16.38	8	17.23	192.54	27.31	8.5

Table -5: Blast load acting at different joint

Stand-off distance (m)	Pressure (kN/m²)	Joint 1		Joint 2		Joint 3		Joint 4	
		Area (m²)	Load (kN)	Area (m²)	Load (kN)	Area (m²)	Load (kN)	Area (m²)	Load (kN)
10	210	3.5	735	7	1470	7	1470	14	2940
15	100	3.5	350	7	700	7	700	14	1400
20	61	3.5	213.5	7	427	7	427	14	854
25	41.2	3.5	144.2	7	288.4	7	288.4	14	576.8
30	30.6	3.5	107.1	7	214.2	7	214.2	14	428.4
50	16.13	3.5	56.455	7	112.91	7	112.91	14	225.82
60	13.68	3.5	47.88	7	95.76	7	95.76	14	191.52
70	10.5	3.5	36.75	7	73.5	7	73.5	14	147
75	9.5	3.5	33.25	7	66.5	7	66.5	14	133
80	8.5	3.5	29.75	7	59.5	7	59.5	14	119

Table -6: Number of members failed

Standoff distance (m)	Total no. of columns	Total no. of beams	Number of columns failed	Number of beams failed
10	120	186	120	90
15	120	186	100	75
20	120	186	90	75
25	120	186	65	66
30	120	186	53	60
50	120	186	21	26
60	120	186	15	16
70	120	186	6	0
75	120	186	6	0
80	120	186	0	0

Figure -4: Blast load for the case of standoff distance at 10m

7. RESULTS AND DISCUSSIONS

Figure -5: Pressure versus standoff distance

Figure -6: Drift of the storey for various distances
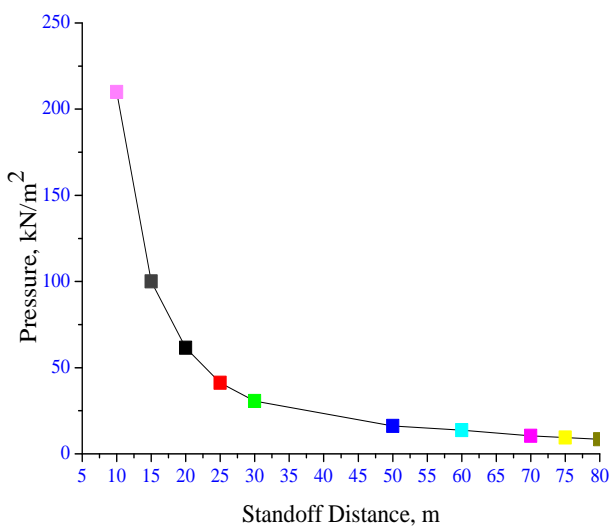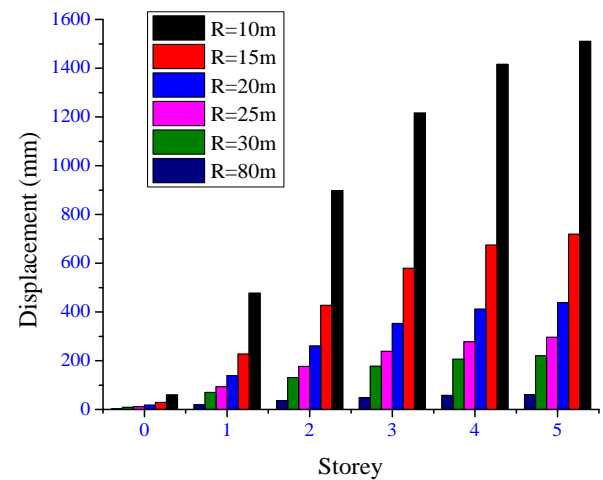

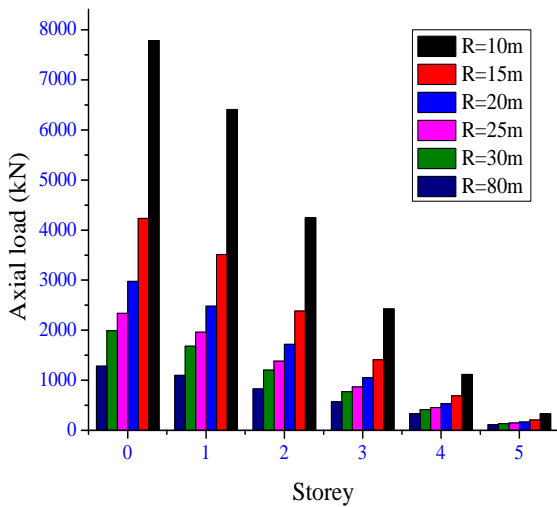**Figure -7:** Displacement of building for various distances

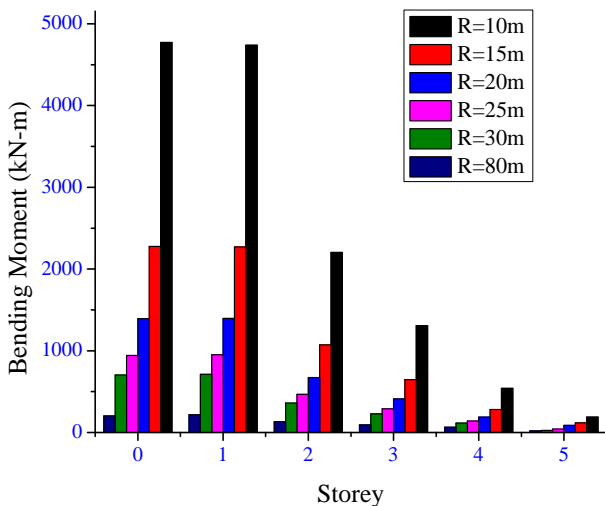**Figure -8:** Axial load of column for various distances

Figure -9: Bending moment of column for various distances
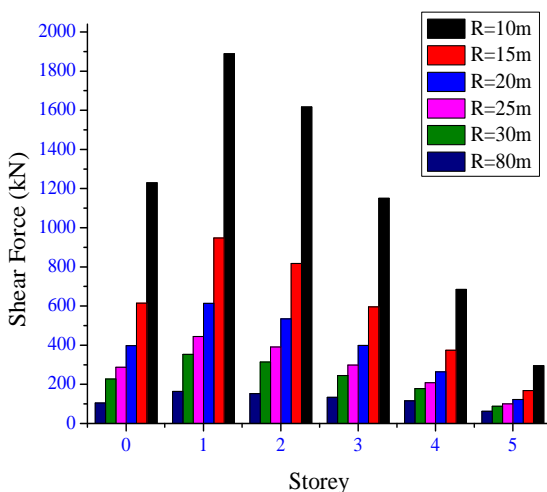

Figure -10: Shear force of beams for various distances
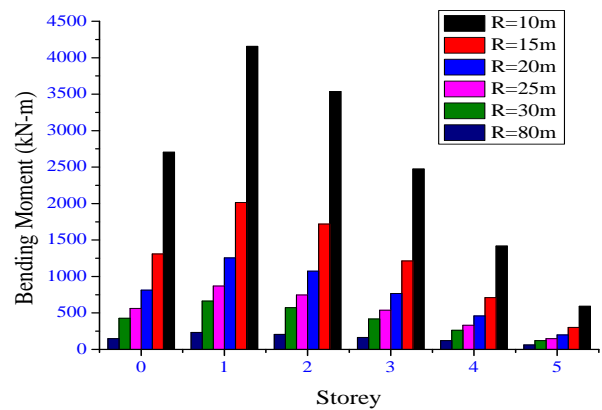

Figure -11: Bending moment of beams for various distances

From figure 5, it is observed that the amplitude of pressure generated during explosion decreases as the standoff distance increases. Thus, the pressure acting on the building reduces as the distance increases. When the explosion takes at a distance of 80m the low rise structure is found to be safe against blast load, where no failure of members will occur as presented in table6.

In figure 6 and 7, the drift and displacement of the building are presented for different standoff distance. It is observed that as the standoff distance increases, the drift and displacement decreases. These values are found to be high when the explosion occurs at 10m.

Figure 8 to figure 11 shows the axial loads on columns, bending moment variation in columns, Shear force and bending moment in beams when exposed to explosion at various standoff distances. The bending moment, axial load and shear force are found to be very high when the explosion occurs nearest to the building and vice versa. Thus, standoff distance is one of the significant factors which influence the effect of detonation.

8. CONCLUSIONS

In the present work, a G+4 storey RCC building subjected to blast load of 100kg at various standoff distances from 10m to 80m was analyzed using ETABS. Based on the results of linear equivalent static analysis, following conclusions were made:

i.   The pressure is high when the source of blast (detonation) is nearer to the building and reduces as the source of blast is away from the structure.
ii. The pressure varies inversely with standoff distance.
iii. Storey drift and displacement decreases when the point of detonation is far away from the building.
iv. Storey drift decreases as the height of the building increases.
v.   Column forces (axial load and bending moment) are more when the standoff distance is less and vice

versa. Also, beam forces (shear force and bending moment) decreases as the standoff distance increases.

vi. Storey drift and displacement are found to be within safe permissible limit, when the source of blast is at 80m. Thus, the safe attenuation point is at 80m for the chosen model.

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ACKNOWLEDGEMENTS

BIOGRAPHIES

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