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Comparative Analysis of Reinforced Concrete Structure Subjected to Internal and External Blast Loading by Finite Element Method

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Abstract-. *Internal explosion that occurs within a structure causes multiple reflections of the blast wave and a multi-impact effect of the wave on the structure is observed. This leads to a greater blast load that acts for an extended time duration than compared to when the explosion occurs externally under an open environment. This paper illustrates the calculation of different parameters of the pressure wave produced as a result of internal and external explosion. Then, the behaviour of a typically reinforced concrete structure subjected to a blast load of 50 kg TNT placed both internally and externally was analytically determined. The time for which the structure experienced the internal pressure was 7.58 times more than that for external explosion. The results showed that maximum deformation for internal blast for all structural components was several times that of for an external blast. The minimum difference of deformations for the two blast scenarios was observed in the front wall, where the maximum deformation for the internal explosion was 9.97 times more. Whereas, the maximum difference was at the slab where the internal blast produced a deformation that was 34.89 times more than the corresponding value for external explosion. Also, deformations exceeded the maximum limits of deflections as per IS 456:2000 for internal blast loading while they were within limits for external blast loading.*

Keywords: **Internal explosion, Blast load, TNT, Multi-Impact effect, Wave reflection, Structural deformation, Blast duration.**

1. Introduction

There has been a significant increase in the number and severity of terrorist attacks over the past three decades. With easy access to technology, terrorists have developed new and effective ways to deplore explosive charges and cause maximum destruction. The advancement in technology has also given the terrorists the chances of remotely detonating the explosives without actually putting themselves in the harm's way. The destruction caused to life after a charge has exploded greatly occurs due to the structural collapse the explosive causes. Thus, it has become necessary to develop the understanding of blast loads and the corresponding response of the structures. Considerable amount of research has been carried out for free field explosion, here; the blast wave is free to move in all directions in an open environment. But, in case of an internal explosion, the waves are produced under a confined environment and various reflective surfaces are present within the area. This causes multiple reflections of the wave and the structure is thus subjected to a pressure caused due to such multiple reflections. Each reflected wave takes some time to arrive at the point of impact and hence the total time for which reflected pressure acts is also significantly higher than that for the external explosion. Thus the multi-impact effect of the wave sustained for a greater period of time induces larger deformations within the structure. In this paper, the pressure due to internal and external explosion is calculated and applied to the structure in the Explicit Dynamics part of ANSYS and the resulting deformations are calculated. The deformations occurring on various typically reinforced structural elements like beams, columns and walls for the same charge weight at the same standoff distance are studied comparatively for internal and external explosion.

2. Aim

To compare the effects of internal explosion and external explosion on a typically reinforced concrete structure under an equivalent weight of explosive.

3. Objectives

3.1. Calculate the pressure parameters for 50 kg TNT for internal and external explosion which includes the different values of pressure and their corresponding acting durations.

3.2. Calculate the maximum deformations produced for various structural elements for internal and external explosion.

3.3. Compare the values of maximum deformation and conclude on the extent of extra damage caused due to internal explosion.

4. Methodology:

4.1 Development of Model

A reinforced concrete structure with room dimensions 3 m x 5 m is sketched and the structural elements are designed conforming to IS 456:2000.The charge weights are placed internally and externally at the same standoff distance of 1.5.

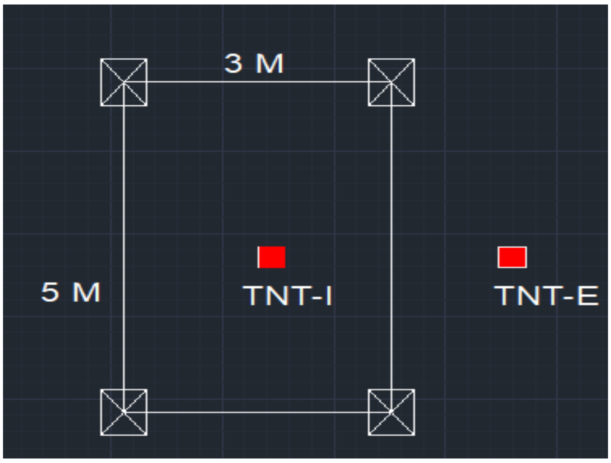

Figure 1 TNT position with respect to structure

The three dimensional modelling of the structure is carried out in the software SOLIDEDGE. The 3-D model is then imported into ANSYS Workbench. The material properties are assigned to different materials within the structure.

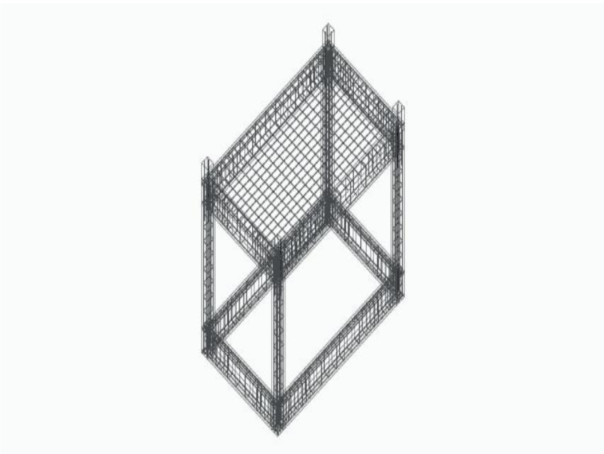

Figure 2. 3-D Model of Reinforcement

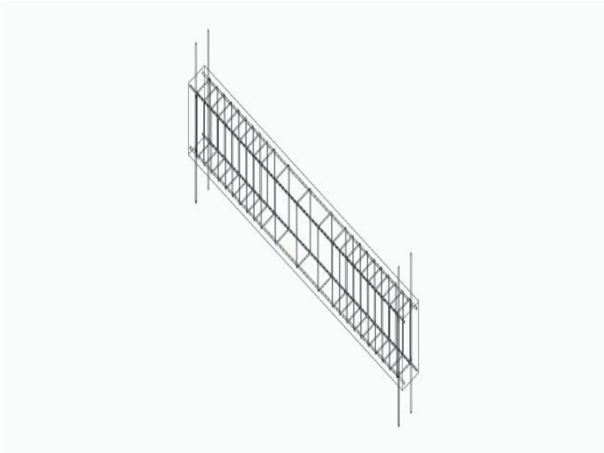

Figure 3. 3-D Model of Beam Section

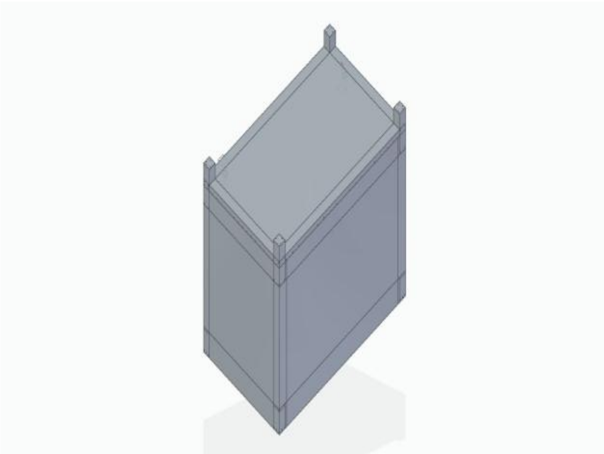

Figure 4. 3-D Model of RCC Structure

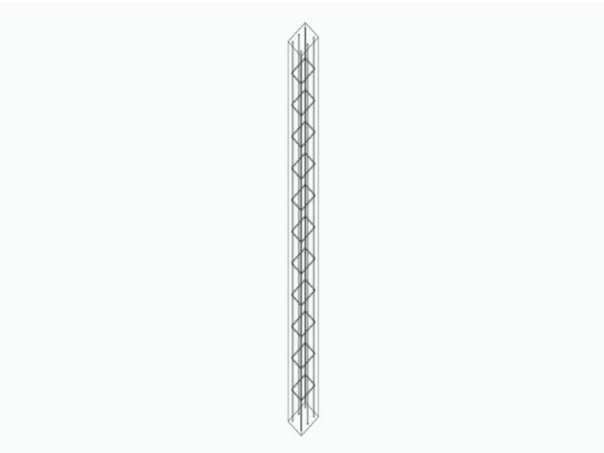

Figure 5 3-D Model of Column section

Table 1 Material properties of different components

Material	Properties
M20 Concrete	Density : 2400 kg/m³ Compressive Strength : 20 MPa
FE500 Steel	Density: 7850 kg/m³ Tensile Yield Strength: 500 MPa
Structural Steel	Density: 7850 kg/m³ Tensile Yield Strength: 250 MPa
Brick Masonry	Density: 2040 kg/m³

The reinforcement details of structural elements are as shown in table 2

Table 2 Details of reinforcement

Component	Dimensions (mm)	Reinforcement Details
Slab	3000 x 5000	Short bars: 10 170 c/c Long bars: 8 250 c/c
Beams	230 x 450 230 x 450	Bottom : 2 # 12 , Top: 2 # 12 Stirrups: 8 100(6)150(4)300c/c
Column	230 x 300	Main bars: 6 #12 Ties: 8 250 c/c

Meshing of the structure is carried out in ANSYS Explicit Dynamics.

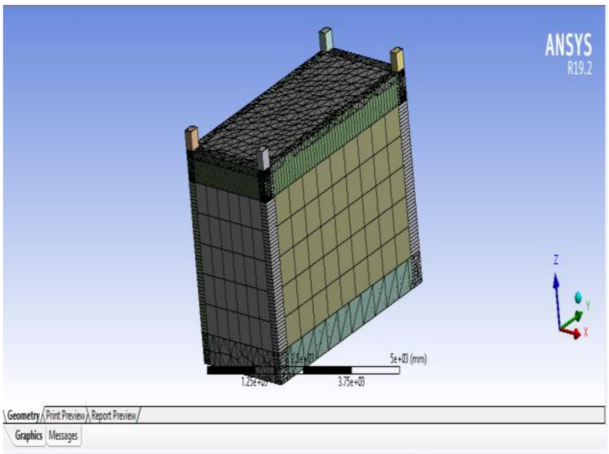

Figure 6 Meshed RCC Structure

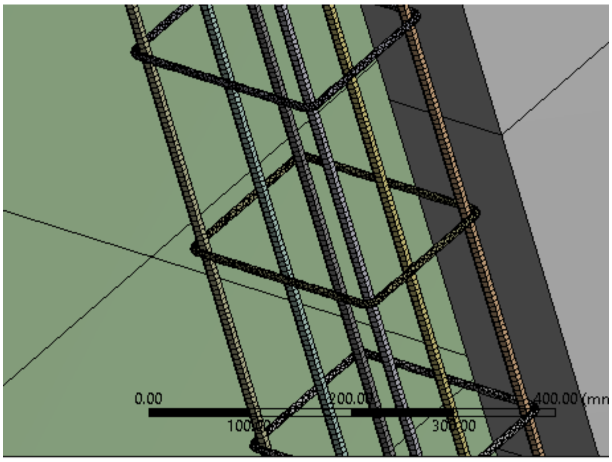

Figure 7 Meshed Column Reinforcement

4.2 Development of blast pressure

Scaled distance (Z) is calculated by,

$Z = R/ (W)^{1/3}$

Where, R – Distance from the centre of explosive charge. W- Charge mass expressed in kilograms of TNT. Kinney has presented the formulation that gives the value of peak static overpressure based on scaled distance which has extensively been used for computational purposes. According to it,

$$P_{so} = P_o \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\left\{\left[1+\left(\frac{Z}{0.048}\right)^2\right]\left[1+\left(\frac{Z}{0.32}\right)^2\right]\left[1+\left(\frac{Z}{1.35}\right)^2\right]\right\}^{0.5}}$$ .from[1]

P_o = Ambient Pressure.

The equation for dynamic pressure is stated in Draganić and Sigmund [2].

$Q = 5p_s^2/ 2(Ps + 7 Po)$

The peak reflected overpressure (Pro), is stated in IS 4991:1968. According to it,

Pro = Pso [2 + 6 Pso/ (Pso + 7 Po)]

, where Po = ambient pressure.

The time duration of wave for external explosion is calculated using [3] and IS 4991:1968. The coefficient of drag Cd for side, roof surfaces and rear surface is taken according to the values stated in available literature. The clearance time, Mach number and the time durations of blast wave for front, side and roof and rear surfaces are calculated according to the provisions given in IS 4991:1968.

The process to calculate internal explosion pressure was adopted from Siwiński and Stolarski [4]. It involves the approximate determination of the internal pressure as a function of time, where the blast waves are a series of the successive, diminishing type pulses. The value of the first reflected wave is calculated using,

$Pr_1 = 2\Delta P^+ + 6\Delta P^+ / (\Delta P^+ + 7Po)$, where

$\Delta P^+ = Po.Ps$

Here, Po = Initial atmospheric pressure and Ps = Dimensionless pressure which is given in Siwiński and Stolarski [5]. To determine the arrival time of the first shock wave to the reflecting surface, the following relationship is used, Ta = r/D, where D is the speed on the forehead of the shock wave determined by the relationship of Krzewiński [5].

$$D = \sqrt{a_0^2 + \frac{\Delta p^+(\alpha_Q + 1)}{2\rho}}$$

, here a_Q that is taken between 1.2 and 1.4 is the coefficient depending on the heat of explosion. Another important parameter to be calculated is Td. Td is the substitute time duration of each overpressure impulse and it depends on the zone in which the explosive load exists and the formulas for determining it are given in Siwiński and Stolarski [5].

The overpressure and the reflected shocks can be substituted by an approximate substitute pressure as shown in the figure.

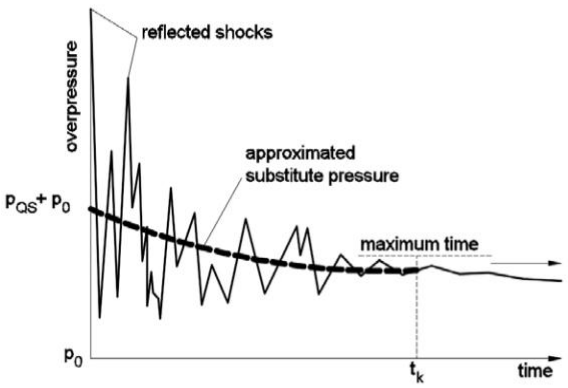

Figure 8 Reflected Wave Overpressure

The time duration of this pressure is determined by the relationship:

Tk = (5Ta + Td).

Thus any number of reflected pulses can be replaced a single, substitute impulse with a total peak pressure for 5 reflections, determined according to the relationship.

$P_{QS} = 1.9375\ [Td/ (8Ta+Td)].Pr_1$

4.3 Application of Pressure:

4.3.1 Internal Pressure application

The calculated internal pressure is applied to the internal surfaces of the structure in Explicit Dynamics as shown in figure 9.

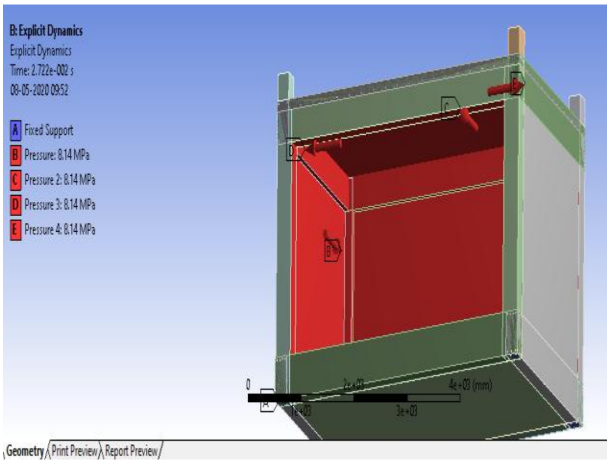

Figure 9 Application of internal blast pressure

4.3.2 External Pressure application

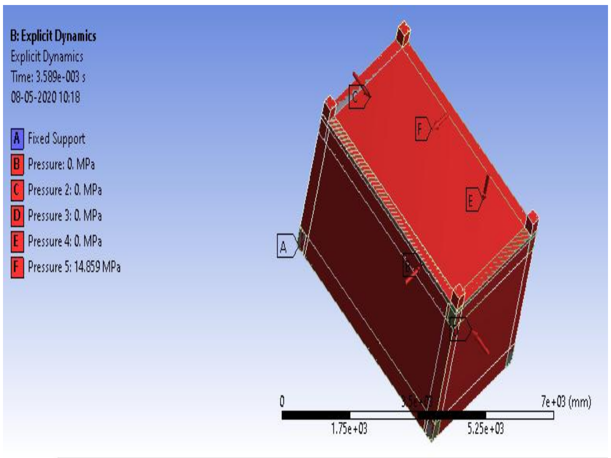

Figure 10 Application of external blast pressure

5. Analysis and results

5.1 Calculated Parameters of Internal Explosion

Table 3 Parameters of internal explosion

Parameters of Pressure	Symbols	Units	Value for 50 kg TNT
Clearance time of Peak Reflected Overpressure	Tc	seconds	0.00242
Reflected	Tr	seconds	0.02722

Pressure time			
Krzewiński Coefficient	Aq	-	1.3
Speed on the forehead of the shock wave	D	m/s	340.635
Peak Static Pressure	Ps	MPa	9.396
Peak Reflected Overpressure	Pro	MPa	71.22
Pressure of first reflected wave	Pr_1	MPa	32.547
Dynamic Pressure	Q	MPa	21.85
Reflected Pressure (5 Reflections)	P_{QS}	MPa	8.14

5.2 Calculated parameters of External Explosion

Table 4 Parameters of external explosion

Parameters of pressure	Symbols	Units	Value for 50 kg TNT
Scaled Distance	R	meters	0.4072
Time duration of wave for front face	Td	seconds	0.002618
Time duration of wave for side face and roof	Td	seconds	0.003103
Time duration of wave for rear face	Td	seconds	0.003589
Mach Number	M	-	8.99
Peak Static pressure	Ps	MPa	9.396
Pressure on front face	Pqs	MPa	31.246
Pressure on side face and roof	Pqs	MPa	18.14
Pressure on rear face	Pqs	MPa	14.86

5.3 Maximum Deformations on different Structural Components

The face of the structure directly exposed to external TNT blast, TNT-E as shown in figure 1 is stated as the front face and the corresponding elements as Front Beam, Front Wall, etc. Similar approach for denotation is adopted for side and rear surfaces.

Table 5 Parameters of external explosion

Structural Element	50 kg TNT Interior maximum deformation (mm)	50 kg TNT Exterior maximum deformation (mm)
Front Beam	16.375	0.8761
Front Plinth Beam	16.375	0.8761
Front Column	16.375	0.8761
Front Wall	19.651	1.9711
Side Beam	16.375	0.4380
Side Plinth Beam	16.375	0.4380
Side Wall	19.651	0.8761
Rear Beam	16.375	0.4380
Rear Plinth Beam	16.375	0.4380
Rear Wall	19.651	0.6570
Slab	22.926	0.6570

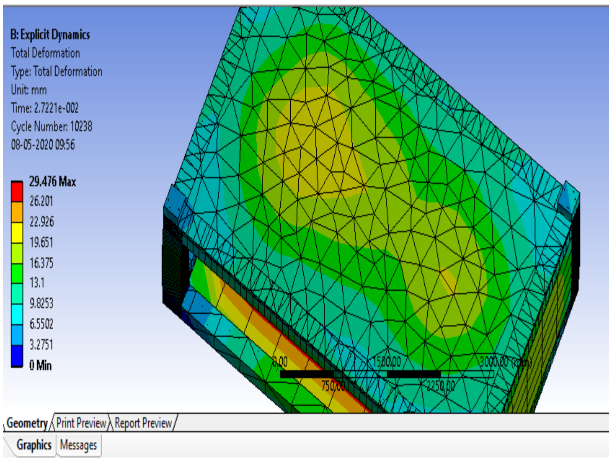

Figure 11 Deformation produced at slab for internal pressure

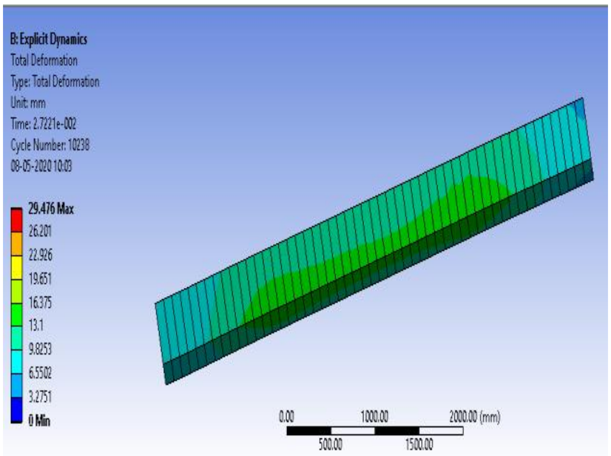

Figure 12 Deformation produced at beam for internal pressure

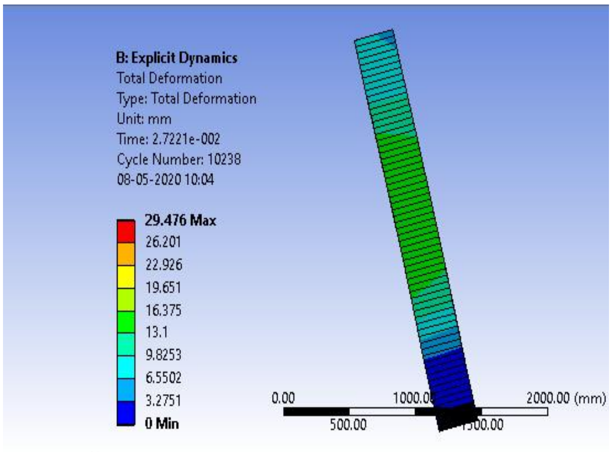

Figure 13 Deformation produced at column for internal pressure

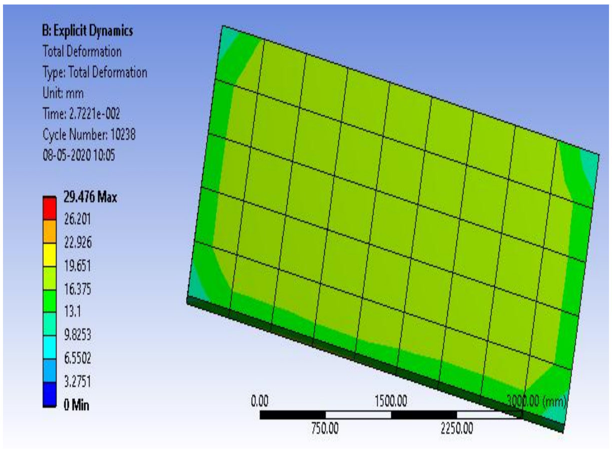

Figure 14 Deformation produced at wall for internal pressure

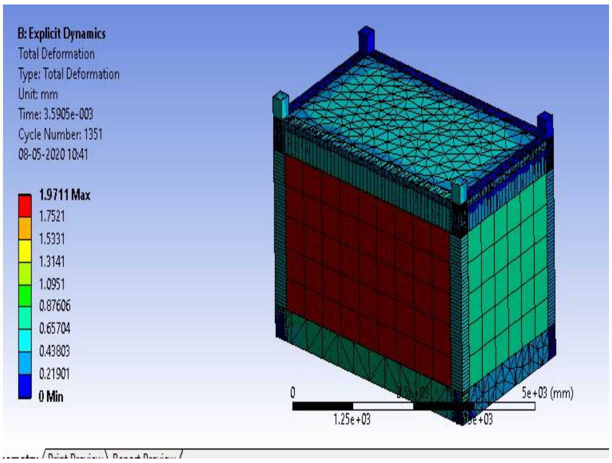

Figure 15 Deformation produced for external pressure

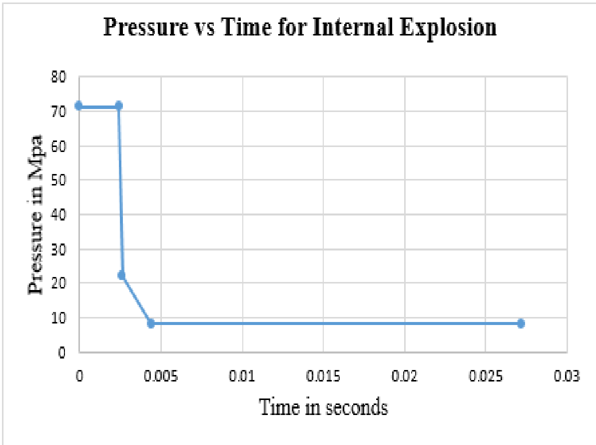

Chart 1 Pressure vs. Time profile

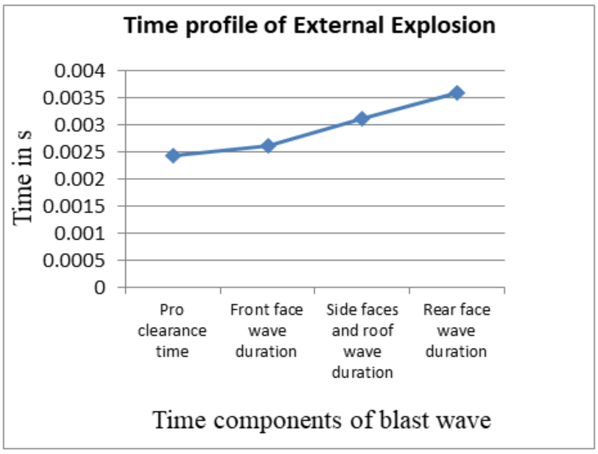

Chart 2 Time profile for external explosion

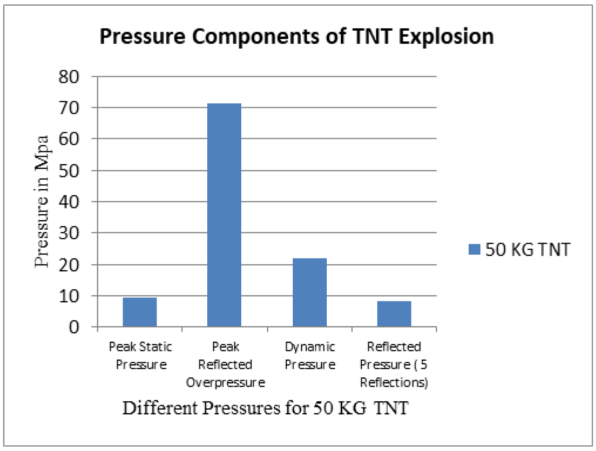

Chart 3 Pressure components of TNT explosion

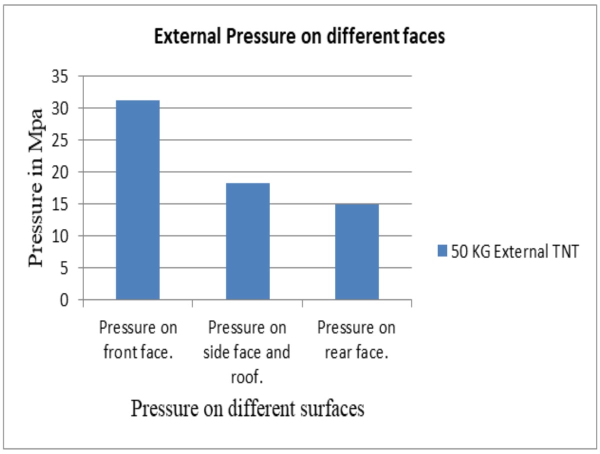

Chart 4 External pressure acting on different surfaces

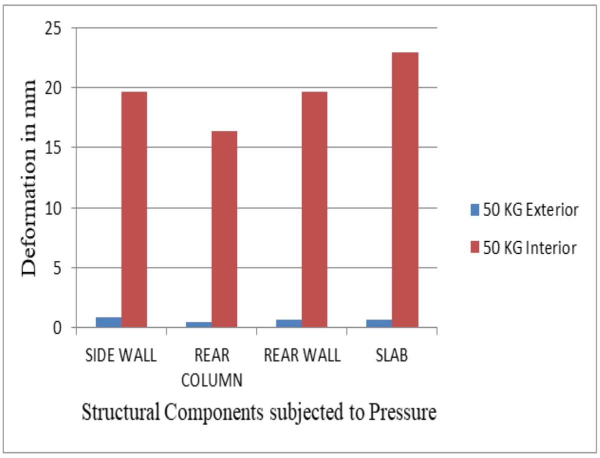

Chart 5 Deformation of structural components 1

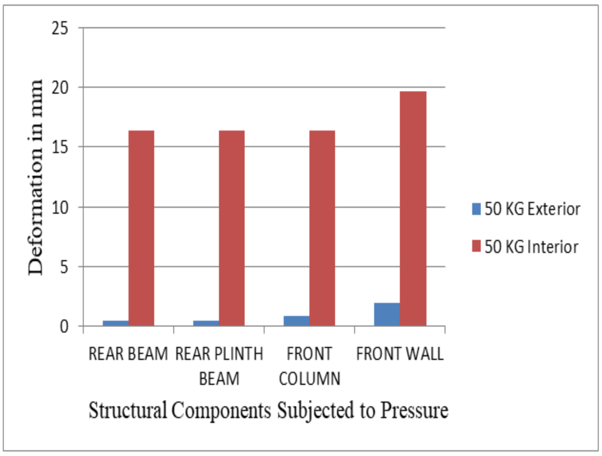

Chart 6 Deformation of structural components 2

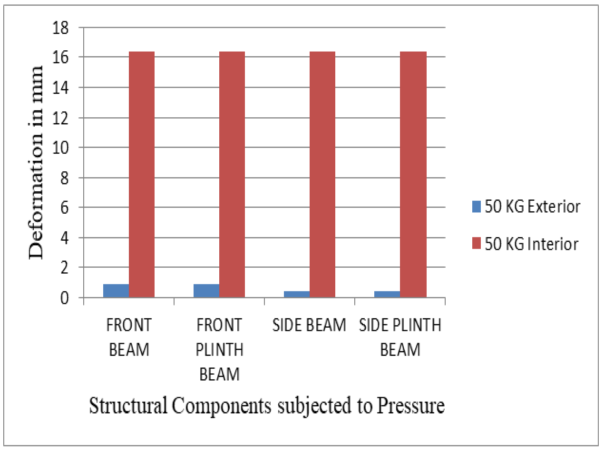

Chart 7 Deformation of structural components 3

6. Conclusions:

Internal explosion causes multi-impact effect of the wave which results in greater magnitude of pressure and a greater duration over which this pressure acts as compared to the external pressure. The study regarding the impact of internal explosion is very limited and this research paper attempts to study the effects of an internal explosion of 50 kg TNT on a typically reinforced concrete structure.

1. Based on the calculations for pressure it can be observed that a peak reflected overpressure acts for a clearance time of 0.00242 s for both external and internal loading whereas a reflected pressure of 8.14 MPa acts explicitly for an internal blast. It acts for a total of 0.02722 s.

2. The maximum time duration for external explosion is 0.003589 s, while the pressure for internal explosion acts for a total of 0.02722 s. Thus the time for which the structure experiences the pressure is 7.58 times more in case of an internal explosion.

3. An extra reflected pressure of 8.14 MPa acts in case of internal blast. Also, because the internal explosion causes

equal pressures on all the interior sides, the pressures experienced by the side, roof and the rear surfaces is extensively greater than that experienced in case of external explosion.

4. The maximum deformation experienced by the front beam, front plinth beam and the front columns is 18.69 times greater than that for an external explosion of the same charge weight of TNT.

5. The side, rear beams and the corresponding plinth beams undergo a maximum deformation of 16.375 mm that is 22.43 times more than that for external explosion.

6. The front wall experiences 9.97 times, side wall 22.43 times and the rear wall 29.91 times more maximum deformation than what it experiences for 50 kg TNT external explosion.

7. The slab which is exposed to multiple reflected pressure impulses in an internal explosion scenario undergoes a maximum deformation of 22.926 mm whereas for the external explosion it suffers a maximum deformation of 0.65704 mm. Thus the deformation is 34.89 times more causing severe damage.

8. The maximum permissible deflection calculated for the two way slab according to IS 456:2000 is 8.57 mm. This limit is exceeded for internal explosion whereas the deformation is well within limits for external explosion.

9. According to IS 456:2000, the maximum permissible deflection for beam would be 14.3 mm. In the internal explosion, this value is 16.375 mm that exceeds the allowable limit but the limit is satisfied for the external explosion scenario.

Therefore it can be concluded that internal explosion leads to much severe damage to the structure. Typically designed RCC structural elements exceed their deformation checks and can eventually fail for this type of extreme dynamic loading. Hence study regarding the internal blast loading is of prime importance. Buildings of high value that can prove to be likely targets for the terrorists must be analyzed for impact due to internal blast to prevent excessive loss to life and property. Increasing the ductility by following detailing specifications performing to IS 13920:2016 can be an approach to reduce the damage due to internal explosion. Also, the inclusion of steel fibers in concrete has improved resistance of the structure against blast loads, therefore it can also be included to examine the reduction in maximum deformations produced due to internal explosion

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