Performance of Earthquake Resistant Reinforced Concrete Building against Blast Loadings

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Abstract: ***In recent times, everyone is concerned about earthquake loadings as long as structural design is concerned. What we analyze while going for any structure, we normally head towards the effects of earthquake if concerned about the Highrise buildings. But there are some more factors are there which we need to take into account like fire and blast. As earthquakes are unpredictable, so we don't have exact magnitude of it to analyze structure. While analyzing any structure against earthquake, normally we use the magnitudes and factors as per the codes which developed from the previously occurred earthquake. The main objective of this study is to analyze a reinforced concrete building against earthquake loadings and then against blast loadings by taking different standoff distance. For the purpose of earthquake analysis, IS1893 part 1, 2016 is been used and for analysis against blast loadings, some of the literatures is been studied. After analyzing reinforced concrete building for both the uncertainties, the analysis results have been computed and compared among them. From the results, it is seen that there is a quite increase in analysis results if we are increasing charge of Trinitrotoluene TNT.***

Keywords: Earthquake, Blast, TNT

1. Introduction

As seen in history, it is not possible to design any structure as an earthquake proof. As a structural engineer what can be done is that we just design them to withstand the loadings created by that uncertainties, but still some percent of threat is there which not at all possible to take care. That is why revision of code is necessary after every time span. In this paper, G+4 storey reinforced concrete residential building is analyzed against earthquake by the use of specifications given in IS1893 part 1, 2016 and then same building has been analyzed against blast loading. For blast loading, different charge of loading from different location is taken and as per that the pressure vs time graph has made and the maximum pressure value we got has been assigned to specific location of the structure. Mean while pressure calculated because of 1 kg TNT change from 1m standoff distance has been calculated and assigned in software to get the analysis results. Further analysis results have been calculated by varying standoff distance and charge to converge towards more signified result.

a) Introduction to Earthquake Analysis

As per the new code publishes on earthquake resistant design of structure IS1893 part 1, 2016, many changes have been made as compare to previous code. The earthquake analysis has been carried out by the dynamic linear analysis by using response spectrum method in both lateral directions.

b) Introduction to Blast Analysis

Several codes are there to know the effects of blast induced on structure but proper revision of code is not there. So, to get the exact behavior some of the equations are given by the scientists. Some of the literature has worked on how to calculate parameters which needed to get the pressure according to time. As per the literature peak positive pressure (P_{pos}) and positive duration (t_{pos}) is been calculated from kinney's and Grahm's equation (Goel, et. at., 2012). Whereas, wave decay parameter can be calculated from Teich's and Gebekken's equations (Goel, et. at., 2012). Fig. 1 shows the ideal blast wave resulting from explosion in air (Goel. et. at., 2012)

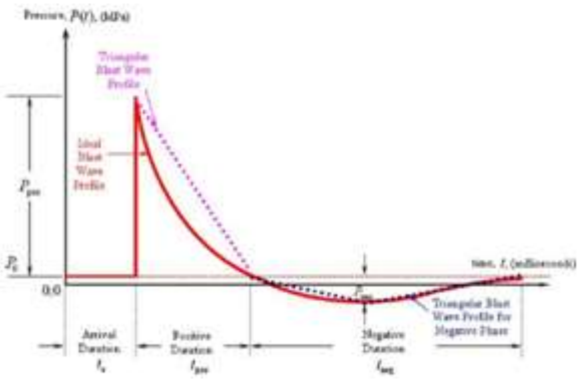

Figure 1: Ideal blast wave resulting from explosion in air (Goel, et. al.)

2. Location, Properties and Loadings

For the analysis purpose, we need to select one reinforced concrete building which has a proper dimension and has to be in symmetry. Symmetry is needed because as we know all the codes are somewhat based on assumptions, so if we are going for complicated one and still going for code then won't get exact behavior which we actually want to study.

a) Plan and elevation

As discussed above about the symmetry, a reinforced concrete building of 48 m x 30 m plan dimension and 18 m height with floor to floor height of 3 m that is G+4 storied. Fig. 2 and Fig. 3 show the plan and elevation of selected RC building respectively.

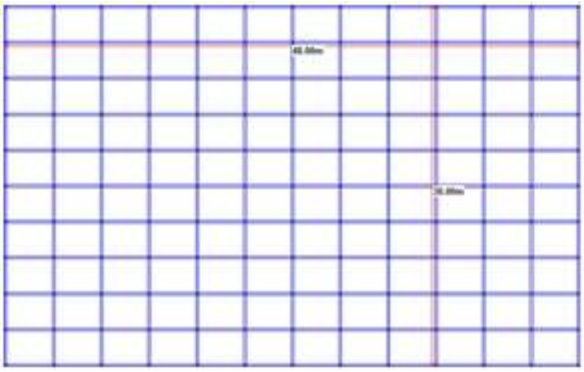

Figure 2: Plan of RC building

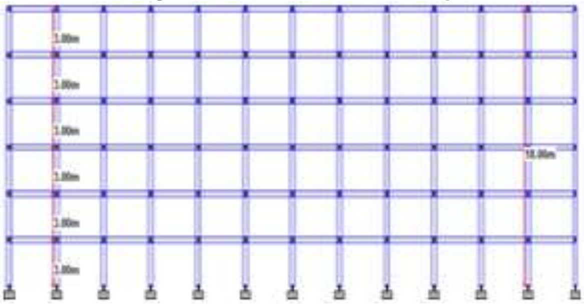

Figure 3: Elevation of RC building

b) Geometrical properties of section

For the analysis and design of building, we need to start with some trial section sizes to pursue with. But still we need to take these trial sizes as per the code specifications. Minimum width and depth of the sections are selected by the use of specifications as per the requirement given in IS13920, 2016 and IS456, 2000. Trial sections are selected properly by taking into consideration the L/d ratio given in IS456, 2000. Table 1 shows the sizes of beam and columns assigned.

Table 1: Sizes of beams and columns assigned

Sr. No.	Member	Sizes
1	Column	300 x 450
2	Beam B1	230 x 400
3	Beam B2	230 350

c) Location and parameters

For the purpose of analysis, the location of reinforced concrete building is assumed to be situated in zone III. The damping factor is considered as 5% as it is reinforced concrete building. As for plot of response spectra, soil is assumed to be medium soil. As per the type of soil and plot of response spectra will get the average response acceleration coefficient.

d) Dead Loading

Dead loads contain slab load, floor finish load, wall load and self-weight of structure. The calculations of these loadings are shown in Table 2,

Table 2: Dead load calculations

	Height (m)	Thickness (m)	γ (kN/m^3)	Loading (kN/m)
WL	3	0.23	20	13.8
PL	1	0.15	20	3
SL	-	0.125	25	3.125
FF	-	-	-	1

e) Live Loading

As per the use of building, the live load which should need to consider is specifically given as per different room in IS875 part 2, 1987. As residential building is taken for the analysis, so the live load is considered as 2kN/m^2 in rooms and 1.5 kN/m^2 at roof level as per the specifications given in IS875 part 2, 1987. Fig. 4 shows the load distribution of floor loads assigned in software.

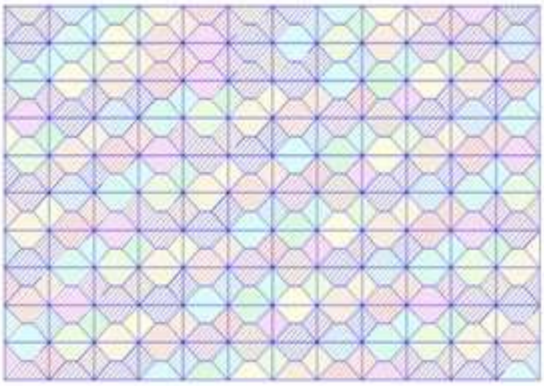

Figure 4: Load distribution

3. Earthquake Analysis of RC Building

As per the specified code for earthquake resistant building that is IS1893 part 1: 2016, the modelled building has been analyzed. The procedure given below,

a) Live load reduction

While structure is experiencing earthquake, live load is the only thing which is not strictly attached to the structure. So, consideration of exact effect of live load while experiencing earthquake is of no use, rather than reducing it. So, some of the reductions have given in code IS1893 part 1, 2016. Table 3 shows the reduction in live load at floor level and roof level

Table 3: Live load reduction

Sr. No.	Floor	Live load	% Consideration
1	Floor level	< 3kN/m^2	25
2	Floor level	≥3kN/m^2	50
3	Roof level		0

b) Earthquake forces

As live load for building is taken as 2kN/m^2, the combination for which we need forces at each of the column-beam joint is 0.25LL+DL. So, for this purpose, modifies support is assigned to these column-beam joints which give us only shear forces for that specific loading combination. After getting these forces we will further assigned these forces to same location as an input for earthquake loading and seismic weight.

c) Defining earthquake in software

For earthquake analysis of this building, ductility is the main factor that need to be consider. So, the special moment resisting frame has been used for the analysis, which gives ductility as well. By using equation (1) given in IS1893 part 1: 2016, we can calculate horizontal acceleration coefficient which is required to get the design base shear values. The value of average response acceleration coefficient (S_a/g) need not to be assigned in software, that value will be assigned as per the type of soil considered in software. The other required parameter to define earthquake is shown in Table 4.

$$Ah = \frac{z \times I \times Sa}{2 \times R \times g} \quad \dots (1)$$

Table 4: Parameters to define earthquake (IS 1893 part 1: 2016)

Sr. No.	Parameters	value
1	Zone Factor (z)	0.16
2	Response Reduction Factor (R)	5
3	Importance Factor (I)	1.2
4	*(z/2)(I/R)*	0.0192

After assigning these factor in software, we need to calculate fundamental time period in both the lateral direction by the use of equation (2) which is given in IS1893 part 1, 2016. Table 5 shows the fundamental natural period in x and z lateral directions.

$$T_a = \frac{0.09h}{\sqrt{d}} \quad \dots (2)$$

Table 5: Parameters to define earthquake

Sr. No.	Direction	Fundamental natural period
1	X	0.2338
2	Z	0.295

After defining these values in software, we need to assigned the earthquake forces which have calculated for the earthquake combination of 0.25LL+DL at each of the column-beam joint as joint load and as a joint weight as well to get the design base shear. Fig. 5 shows the assigned seismic forces at junction of beam and column.

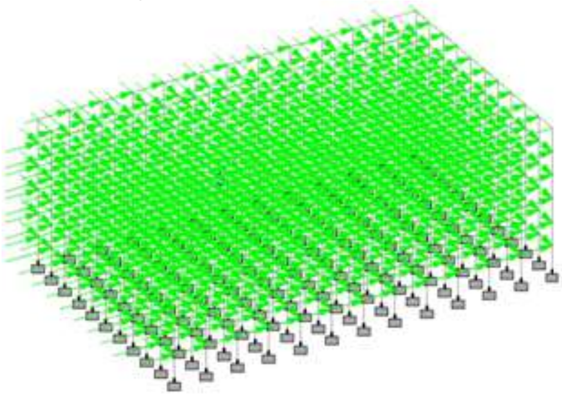

Figure 5: Seismic forces assigned at column-beam junctions.

d) Load combinations

While done with the assignment of loadings, some of the load combinations need to be considered to take into consideration the uncertainties. Some of the factors need to be considered and form several combinations against earthquake loadings. Table 6 shows the combinations used for the analysis given in IS1893 part 1, 2016.

Table 6: Load combinations for seismic analysis (IS1893 part 1:2016)

Sr. No.	Load Combination
1	1.2 [DL + IL ± (ELX ± 0.3ELY)]
2	1.2 [DL +IL ± (ELY ± 0.3ELX)]
3	1.5 [DL ± (ELX ± 0.3 ELY)]
4	1.5 [DL ± (ELY ± 0.3 ELX)]
5	0.9 DL ± 1.5 (ELY ± 0.3ELX)]
6	0.9 DL ± 1.5 (ELX ± 0.3 ELY)]

e) Frequency and modal participation factors

For the better performance of the structure, it is recommended that 1st mode of the structure has to be translation in any of the lateral direction. If not then the orientation of the columns should be changed or else unnecessarily requirement if still will be more as we need to design it for rotation. Fig. 6 shows the 1st mode of building as a translation in z direction.

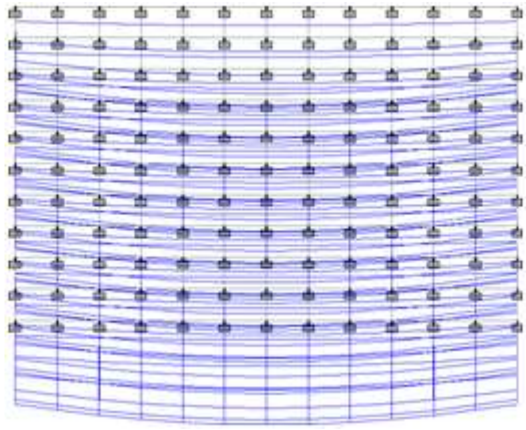

Figure 6: 1st mode showing translation in z direction.

As for the performance we need the % participation factors, period and frequency of the building. Table 6 shows the frequency, period and % participation of building.

Table 6: Frequency, period and % participation factor

Mode	Frequency Hz	Period sec.	% Participation		
			X	Y	Z
1	1.066	0.938	0.00	0.00	87.139

f) Use of master-slave

Because of the slab provided on the floor, the stiffness of members at each floor will be same. But as load has been calculated and then directly assigned as floor loads so to converge towards more realistic results we has to provided equal stiffness to each of the floor. Otherwise the results we will get will be unnecessarily overestimated. Fig. 7 and Fig 8 show the assigned master slave at each floor and at each level respectively.

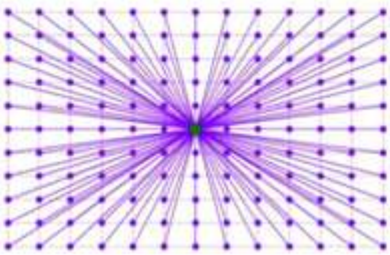

Figure 7: Assigned master-slave at C.G.

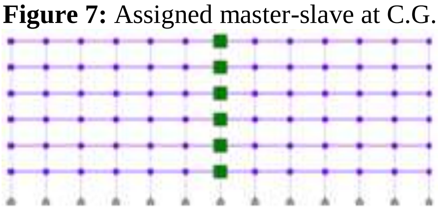

Figure 8: Assigned different master slave at different location

Failing in providing equal stiffness at every member at the same floor will lead to unpredictable behavior as long as seismic analysis is concerned. To understand the performance of building without use of master-slave is also studied. Fig. 9, Fig. 10, Fig. 11, Fig. 12 and Fig. 13 show the comparison between the node displacements, shear force Fx, shear force Fz, bending moment Mx and bending moment Mz respectively when analyzed with and without use of master-slave. Approximately 10% to 15% increase is there in shear forces and bending moments whereas 58% increase is there in node displacements when we analyze without master-slave.

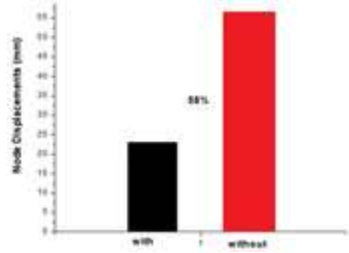

Figure 9: Comparison of node displacements when analyzed with and without master-slave

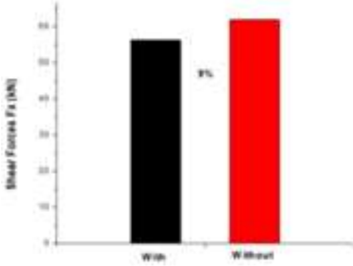

Figure 10: Comparison of shear forces Fx when analyzed with and without master-slave

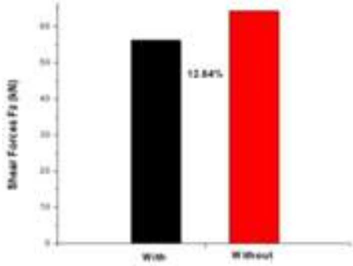

Figure 11: Comparison of shear forces Fz when analyzed with and without master-slave

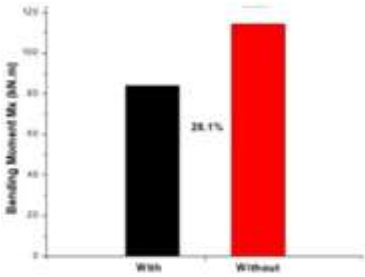

Figure 12: Comparison of bending moment Mx when analyzed with and without master-slave

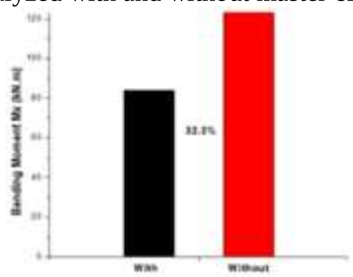

Figure 13: Comparison of bending moment Mz when analyzed with and without master-slave

4. Performance of Bare Column to Blast Loading

Before going for blast analysis of whole building, it is necessary to check whether column is getting burst or not for the charge assigned to the column from different standoff distance. For this purpose, same size of column is taken as per used in analysis of earthquake. Analysis of that column is done in ABAQUS®.

a) Combinations of charge and standoff distance

Performance of any structure cannot be judged by considering only one uncertainties, we have to be sure that it has to be able to stand even if some increase is there in the loadings. That is why several combinations of charge and standoff distance has been taken for which column has to be checked are,

a) 5kg TNT charge with 10 meters standoff distance,
b) 10kg TNT charge with 5 meters standoff distance,
c) 12kg TNT charge with 10 meters standoff distance.

CONWEP loading has been assigned with the source of the blast at the specified standoff distances from the centre of column. Fig. 14 shows the location of blast i.e. RP-1 and the point of reference at which we are measuring the analysis results i.e. RP-2.

Figure 14: Position of blast and the reference point

b) CONWEP

To analyse this above column against blast loadings, 10 kg and 5 kg Trinitrotoluene has been used. We have assigned it as an air blast CONWEP loadings which directly calculate the pressure generated due to blast to the reference point we have given in ABAQUS. Fig. 15 1shows the deformed shape of column after the analysis.

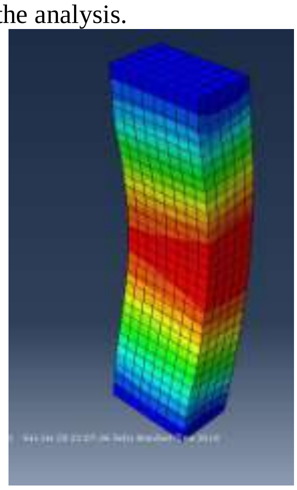

Figure 15: Deformed shape of column after analysis

As per the shape and the values which are getting from ABAQUS®, it can be seen that the column has not getting burst for the above three combinations which we have taken. So, these combinations can be used to analyse the building as a whole.

5. Analysis Against Blast Loadings

To analyze any structure for blast loadings, it is need to understand behavior of blast waves generated due to explosion in air. For these purpose, some of the literatures have been studied to get an idea about out of several equations given in codes exactly which equations are converging towards more realistic values. Due to explosion in air, pressure waves generated which directly burst on structure and due to that it affects the resistance of members if not analyzed for these type of uncertainties.

a) Blast wave pressure calculations

Several equations we have to calculate these pressure generated due to air blast. Equation (3) gives the pressure at time (t) due to air blasts (Goel, et al., 2012)

$$P(t) = P_0 + P_{pos}\left(1 - \frac{t}{t_{pos}}\right)e^{-b\frac{t}{t_{pos}}} \quad \ldots (3)$$

Where P_0 is initial pressure, P_{pos} is positive pressure, t_{pos} is positive duration and b is wave decay parameter.

These parameters are calculated by some specifc equations as per the research made in that field. After that literatures have concluded that Peak positive pressure (P_{pos}) and positive duration (t_{pos}) is been calculated from kinney's and Grahm's shown in wuation (4) and Equation (5) respectively (Goel, et. at., 2012). Whereas, wave decay parameter can be calculated from Teich's and Gebekken's shown in equation (6) (Goel, et. at., 2012).

$$P_{pos} = P_0 \frac{808\left[1 + \left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{\left[1 + \left(\frac{Z}{0.048}\right)^2\right]} \times \sqrt{\left[1 + \left(\frac{Z}{0.32}\right)^2\right]} \times \sqrt{\left[1 + \left(\frac{Z}{1.35}\right)^2\right]}} (bar) \quad \ldots (4)$$

$$t_{pos} = W^{1/3} \frac{980\left[1 + \left(\frac{Z}{0.54}\right)^{10}\right]}{\left[1 + \left(\frac{Z}{0.02}\right)^3\right] \times \left[1 + \left(\frac{Z}{0.74}\right)^6\right] \times \left[1 + \left(\frac{Z}{6.9}\right)^2\right]} (mili\ sec) \ldots (5)$$

$$b = 1.5 Z^{-0.38} \quad \ldots (6)$$

Where, Z is a scaled distance which depends on the charge and standoff distance *W*. Equation (7) shows the formula to calculate scaled distance (Goel, et. al., 2012).

$$Z = \frac{R}{W^{1/3}} \ (m / kg^{1/3}) \quad \ldots (7)$$

By the use of these equations, pressure will be calculated for every instance of time from the point of blast. As from the several procedure we can assign these pressure in software to judge the variation in analysis results. We can go for time history analysis by assigning pressure time history or by taking directly maximum pressure generated dur to that charge. As long as this study concerned three different combinations is taken with each having two different members sizes of column, one is exactly as of taken for earthquake analysis and other one is taken with more depth to get more moment of inertial so the less displacement to judge the performance against blast loadings.

Three different combinations are taken which shown below,
a) 5kg TNT charge with 10 meters standoff distance,
b) 10kg TNT charge with 5 meters standoff distance,
c) 12kg TNT charge with 10 meters standoff distance.

By taking these combinations, pressure vs time values have been plotted graphically and shown in Fig. 16, Fig. 17 and Fig. 18.

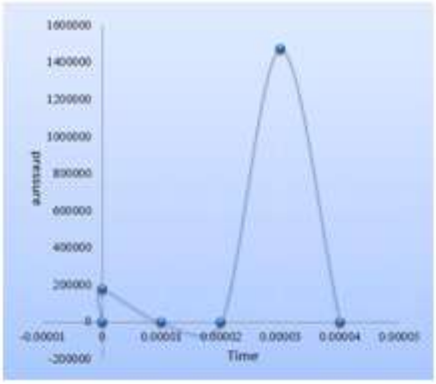

Figure 16: Graphical representation of pressure vs time for 5kg TNT with 10 meters standoff distance

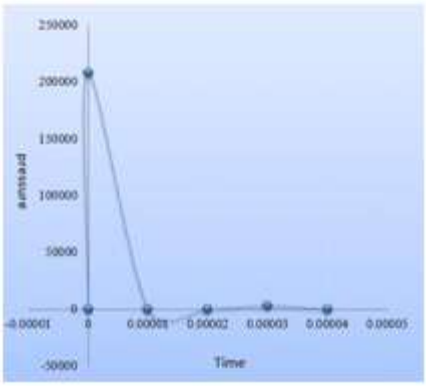

Figure 17: Graphical representation of pressure vs time for 10kg TNT with 5 meters standoff distance

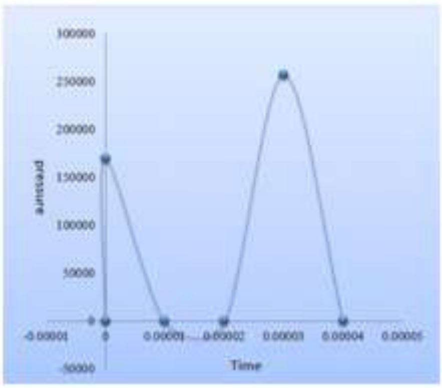

Figure 18: Graphical representation of pressure vs time for 12kg TNT with 10 meters standoff distance.

b) Location of members to assign pressure

As discussed above, there are several methods by which we can assign these pressure in software. As long as this study is concerned, three different combinations has been taken and the maximum pressure generated due to these combinations are calculated and assigned at both sides of the structure.

While assigning these pressure, once we have applied these pressure at full area uniformly to the respective x and z direction and then for the specific area is selected where the blast pressure is assigned to get the results.

As to withstand blast loadings, we need more mass of the members for the required resistance. So, firstly this building is analyzed against blast loading for the same size of column as taken for earthquake and then by increasing the size of column, again we done the analysis for blast loadings.

The use of plates in software which shows the area at which we are considering blast loadings. Fig. 19, Fig. 20, Fig.21 and Fig. 22 show the total area considered in x direction, total area considered in z direction, specific area considered in x direction and specific area considered in z direction respectively.

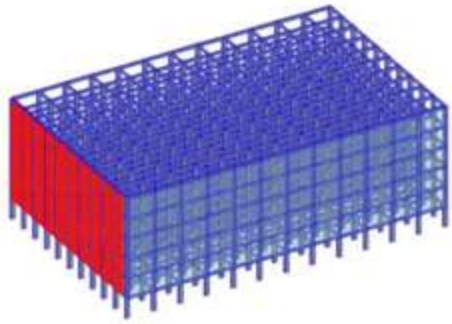

Figure 19: Total area considered to assign air blast pressure in x direction

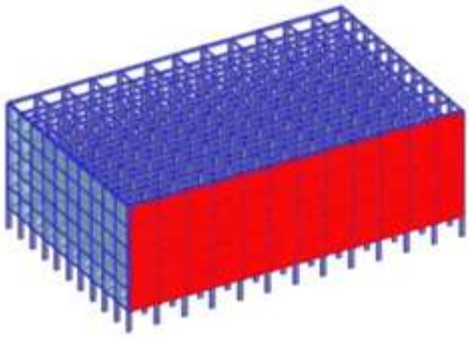

Figure 20: Total area considered to assign air blast pressure in z direction

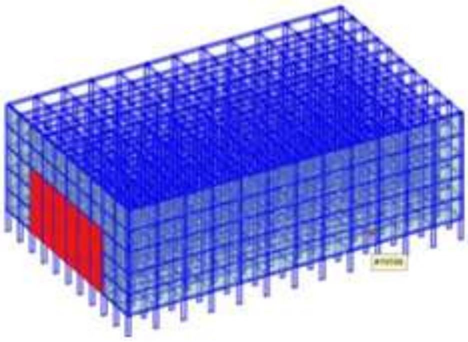

Figure 21: Specific area considered to assign air blast pressure in x direction

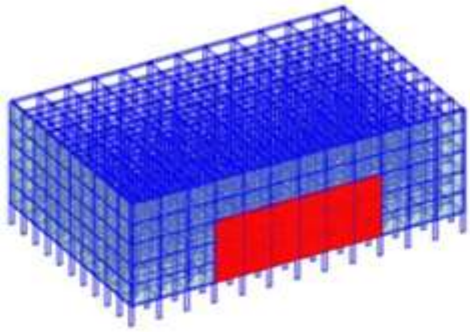

Figure 22: Specific area considered to assign air blast pressure in z direction

c) Assigning blast loadings in software

As per the data we have calculated, the maximum pressure intensities for the three different conditions which we have taken that is 5kg TNT charge with 10 meters standoff distance, 10kg TNT charge with 5 meters standoff distance and12kg TNT charge with 10 meters standoff distance are 207.5 kN/m^2, 172.5 kN/m^2 and 169.7 kN/m^2 respectively. These values of pressure generated due to air blast for the specified standoff distances have been assigned uniformly to the total area selected in both the direction one by one to overestimate the effect of blast on building and then for the realistic one, specific area is considered where these maximum pressure is been assigned uniformly.

These air blast pressure is assigned under different load cases because it won't act at time in both the direction. To take into considerations some of the uncertainties, loading combinations are taken because even if building is been analysing against blast loadings but still neglecting other loadings is not appropriate.

Fig. 23, Fig. 24, Fig. 25 and Fig. 26 shows the assigned uniform pressure at total area in x direction, the assigned uniform pressure at total area in z direction, the assigned uniform pressure at specific area in x direction and the assigned uniform pressure at specific area in z direction.

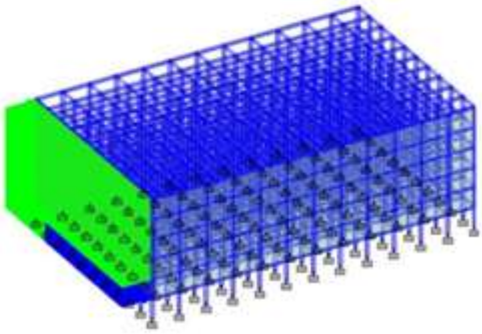

Figure 23: Assigned uniform pressure at total area in x direction

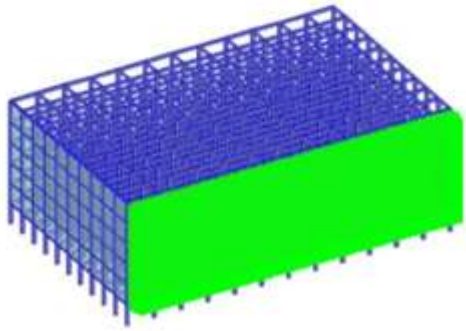

Figure 24: Assigned uniform pressure at total area in z direction

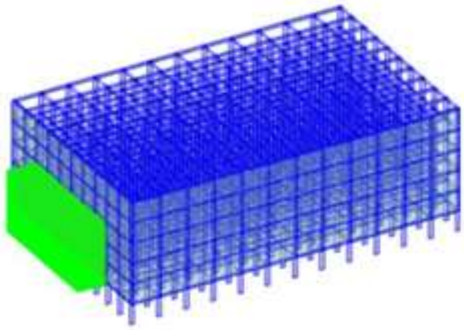

Figure 25: Assigned uniform pressure at specific area in x direction

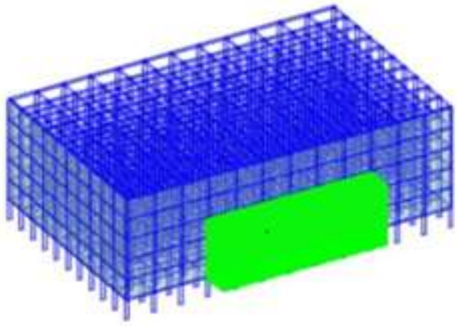

Figure 26: Assigned uniform pressure at specific area in z direction

These are the assigned pressure on plates which is created due to blast in air. After assigning these pressures in software and with different location, analysis is carried out with some of the loading combinations. As discussed above, first analysis is been done for the same sizes as taken for earthquake and then by increasing sizes of columns again analysis has been done to get the exact performance of the building.

d) Blast analysis results

After analyzing building for these many combinations that is by changing charge, by changing standoff distance, by changing location of effects of blast and by changing sizes, the displacements of all these combination is considered and shown graphically by used of origin software to converge towards more realistic value which we can further compare with earthquake analysis. Fig. 27, Fig. 28, Fig. 29, Fig. 30, Fig. 31 and Fig. 32 show the comparison among the node displacement for the same sizes of column used as used for earthquake analysis and by the used of higher sized column for all the combination of charge and standoff distances which has discussed above.

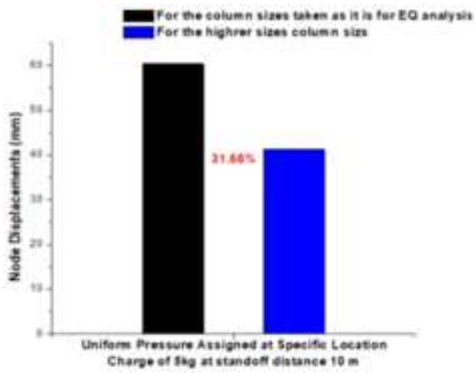

Figure 27: Comparison of node displacements for 5 kg charge at standoff distance 10 m assigned at specific locations

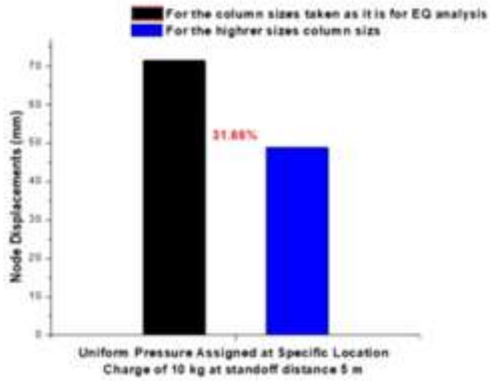

Figure 28: Comparison of node displacements for 5 kg charge at standoff distance 10 m assigned at total area

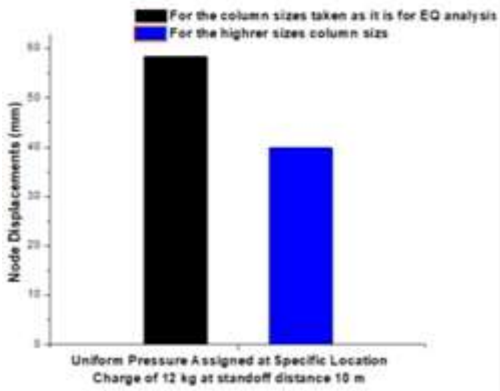

Figure 29: Comparison of node displacements for 12 kg charge at standoff distance 10 m assigned at specific locations

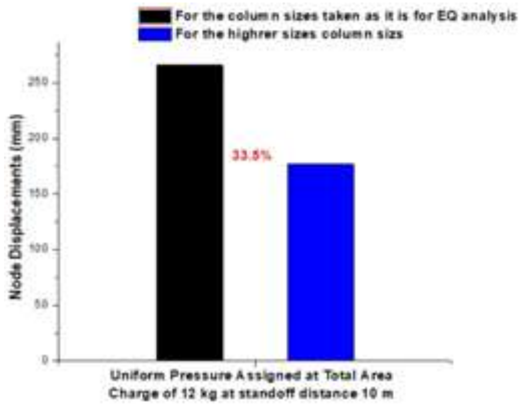

Figure 30: Comparison of node displacements for 12 kg charge at standoff distance 10 m assigned at total area

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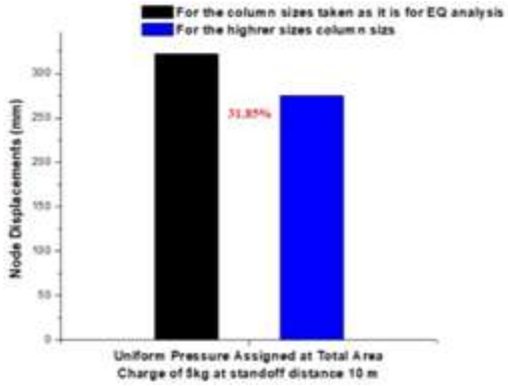

Figure 31: Comparison of node displacements for 10 kg charge at standoff distance 5 m assigned at specific locations

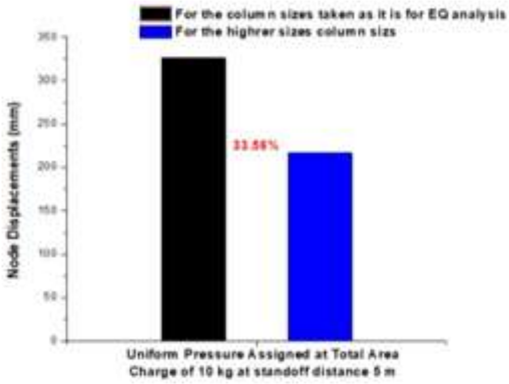

Figure 32: Comparison of node displacements for 10 kg charge at standoff distance 5 m assigned at specific locations

As from the results shown above graphically, there is a decrease in nodal displacement values by approximately in the range of 30 to 35% while we increase the sizes of columns for this purpose only we have increased the sizes of columns while analyzing against blast loadings because we need more mass as long as blast resistant structure is concerned.

6. Results and Discussions

As per the conditions of the ground, threat will always be there for the structure foe the any kind of uncertainties which can occur at any point of time whether it is earthquake, wind, landslides, fire or blast. Making any structure which can not affect by any of these uncertainties is no longer possible as analyzing structure proof from these effects are not at all possible for anyone. Everyone normally try to design it like the way so that it can resist the forces and so the effects induced by them but however some amount of risk is still there.

From analysis results of seismic and blast loadings at specific location to converge towards more realistic performance, we can see that the displacement of earthquake is almost same if compared with the analysis against blast loadings for the charge of 5 kg from standoff distance 10 m and also approximately same for charge of 12 kg from standoff distance of 10 m. but it has seen that the displacement for the charge of 10kg with standoff distance of 5 m is higher than the displacements of earthquake.

From the analysis results of blast loadings assigned at total area, gives the higher nodal displacements values than the values of node displacements we are getting from earthquake as we have overestimated blast loadings which is not at all required if it is needed to have realistic performance of building.

By increasing the sizes of column by some proper amount leads to reduction of node displacements of building, which concludes that if sizes of column is increased as per the criteria of the limitations of the displacements, we can achieve the members which can resist both blast loadings and earthquake effects as well.

References

[1] Goel, Manmohan Dass, Vasant A. Matsagar, Anil K. Gupta, and Steffen Marburg. "An abridged review of blast wave parameters." Defence Science Journal 62, no. 5 (2012): 300-306.

[2] IS 1893 (Part 1) (2016). "Criteria for Earthquake Resistant Design of Structures- Part 1 general provision and buildings*", Bureau of Indian Standards*, New Delhi, India.

[3] IS 456 (2016). "Plain and Reinforced concrete Structures*", Bureau of Indian Standards*, New Delhi, India.

[4] IS 13920 (2016). "Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice" *Bureau of Indian Standards*, New Delhi, India.

[5] IS 875 Part 1 (1987). "Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures- Unit Loads" *Bureau of Indian Standards*, New Delhi, India.

[6] IS 875 Part 2 (1987). "Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures- Imposed Loads" *Bureau of Indian Standards*, New Delhi, India

[7] ABAQUS® (2014). User's Manual, Version 6.14. Dassault Systemes Simulia Corporation, Providence, Rhode Island, USA.