ANALYSIS OF A RESIDENTIAL RC BUILDING SUBJECTED TO BLAST LOAD USING TIME HISTORY METHOD

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Abstract

Blast incidents in recent years, such as in the Russia-Ukraine war, indicate that most terrorist attacks target high-occupancy iconic and public buildings using high explosives. This assessment is essential for developing effective mitigation strategies to enhance the building's resilience and safety of buildings like Embassies, banks, hospitals, monumental buildings, headquarters etc. should be designed and analyzed to withstand blast effects within acceptable limits. The theoretical analysis will encompass a thorough review of prevailing design codes, standards, and guidelines concerning blast-resistant design. Furthermore, advanced computational tools will be employed to conduct numerical simulations, allowing for the simulation and analysis of the performance of reinforced concrete structures under blast loads. After collecting required data from the design of a proposed residential building for CUET professors and the soil condition from further field investigation we acquainted these data with ETABS 2018 software which was utilized in this study for load estimation and analysis purposes. After analyzing the model with standard load applications, the blast load for our chosen building (CUET Professor's Building) subjected to different explosions (100kg, 200kg, and 300kg TNT equivalent weight) from different stand-off distances (10m and 20m) has been calculated with compliance of IS code 4991.The blast load application has been validated in ETABS software by doing a blast load analysis of a portal frame as an example. The time period and the displacement due to blast load obtained by the end of the time history analysis in the software are compared with the values obtained by manual calculation from the book "Dynamics of Structure" by Ray W. Clough which has a slight marginal error of 2.12% for time period value and 1.2% for the displacement value, which is acceptable. Thus, the further blast load applications were carried out using Time History analysis. The response of the building in terms of displacement and drift is more when the blast's standoff distance is less and the charge weight is more. Thus, the response is inversely proportional to the standoff distance and proportional to the charge weight. Considering the values of different parameters, the cases of 100kg 20m blast and 200kg 20m blast are within the safe limit. In contrast, the rest of the cases exceed the allowable limit for this particular building. We have also stated a comparison between the severity of earthquake load to blast loads by plotting a story displacement and a story drift ratio curve.
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Keywords

Blast Load; Standoff distance; Charge weight; Time history analysis; Story drift curve

1. Introduction

Military installations are typically designed to remain operational after an attack, while commercial and public buildings are designed to prevent structural collapse, save lives, and evacuate victims. The "keep-out" distance is vital in the design of blast-resistant structures, as it determines the blast overpressures that load the building and its structural elements [1]. When an explosion occurs at a sufficiently great distance from a structure, the structure will be loaded in a manner that leads to global deformation. This means that all the structural elements will provide some degree of resistance to the loading [2]. The use of suitcase bombs specially has severe consequences on infrastructures as they can be placed close to or in contact with key structural elements[3]. The study of blast loads and their impact on structures has drawn significant interest in recent years, mostly due to the numerous instances of accidental or deliberate incidents causing damage to critical infrastructure [4-6]. The primary goal of this study is to identify the ideal amount of safety that should be incorporated into a structure's design in order to produce an economically viable result. To assess the likelihood of an explosion occurring during the lifetime of a building and the impact factor that should be considered based on the importance of the structure. Other objectives are to determine the response of a building to blast loads of different standoff distances and charge weights following IS Code 4991[7] using the ETABS software. The intensity of a blast load is affected by the quantity of energy released by the explosion and the distance between the explosion and the target. The distance between the explosion and the target is the stand-off distance [1,7]. The stand-off distance is crucial because it determines the severity of the blast load. The threat of an explosion will rapidly decrease over the stand-off distance. Impulsive loading is a type of loading applied very rapidly and for a concise duration. This type of loading can cause a structure to vibrate or deform significantly, even if the total force applied is relatively small. Triangular impulse is commonly used in the case of blast loading because it provides a simplified yet realistic representation of the time-dependent pressure variation induced by an explosion. The triangular impulse assumes that the blast wave reaches its peak pressure quickly and then decays linearly over time, mimicking the typical characteristics of blast wave propagation. The maximum response produced in an undamped SDOF structure by each type of impulsive loading depends only on the ratio of impulse duration to the structure's natural period. Pressure time history curve, figure 2 gives the idealized curve (Pressure v/s time) that occurred during an open-air blast arrived at a particular distance from the blast source. Initially, pressure which is present at the surrounding of the structure is equivalent to ambient pressure (P_0), and then it suddenly rises to a peak pressure (P_{S0}) at an instance (t_A) when the blast wave reaches the point. The time required to achieve peak pressure is minimal.

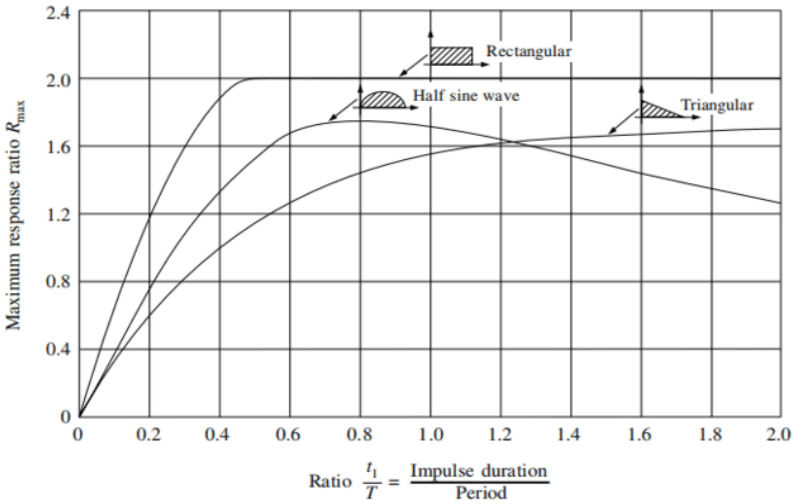


Fig 1: Displacement-response spectra

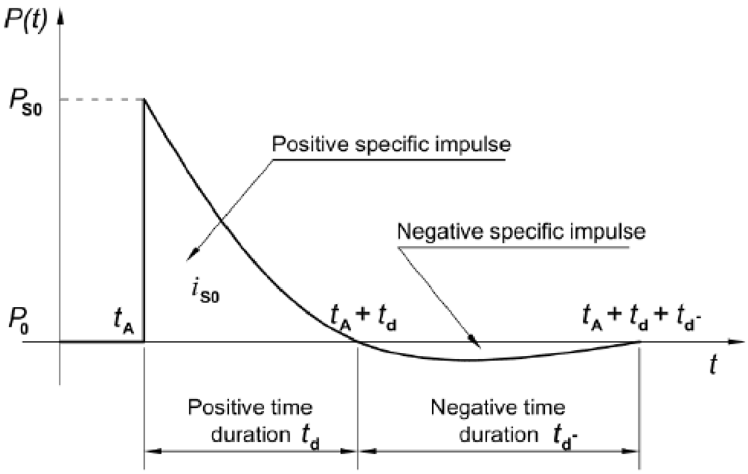


Fig 2: Pressure Time History Curve

2. Methodology

In this study, a field survey was deemed necessary to collect essential data. The survey involved visiting the designated structure and gathering information such as beam-column distances, dimensions, building length and width, and floor plans. This on-site data acquisition process was imperative to ensure accurate and reliable information for the subsequent analysis and design phases of the study. Considering all factors, ETABS 2018 was utilized in this study for load estimation and analysis purposes.After processing the collected data, the analysis of blast loads are concluded by the IS Code 4991 standards. Subsequently, the total deflection of the structure is determined by considering the various types of loads that were applied.The complete information on the structure is given below

Location: Chittagong division

Structure type: Residential

Building name: CUET Professors Building

Total height of the structure=58 ft

No of Stories: 5

Seismic Zone - 3 (According to BNBC 2020)

Zone co-efficient, Z=0.28

No. of Staircase = 1

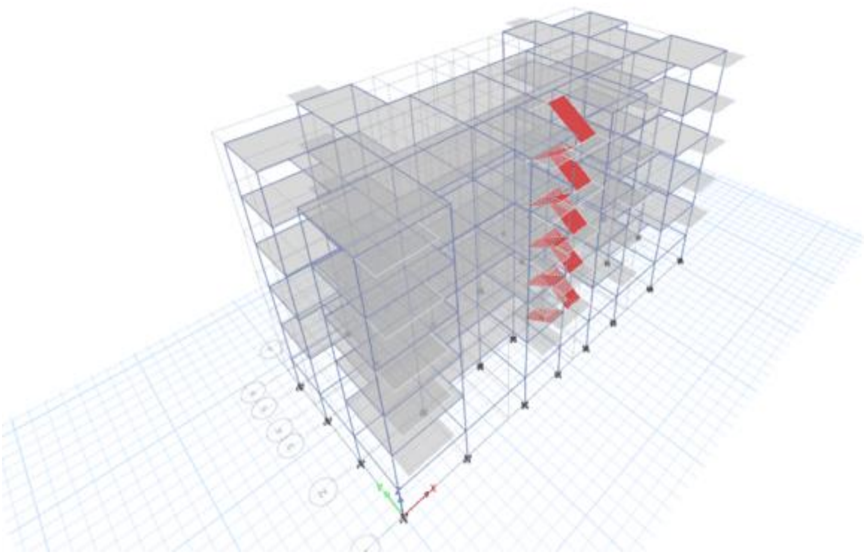


Fig 3: 3D view of the building

2.1 Calculation of Blast Load

The peak pressure for any explosion scaled distance can be defined as

Scaled distance, x = $\frac{Actual\ distance}{W^{\frac{1}{3}}}$

W = yield of explosion in an equivalent weight of the reference explosive measured in tonnes,
x = scaled distance for entering the IS code for reading peak values, and
t_0 = scaled time read from IS code against scaled distance.

From given table assuming Pa = 1 kg/cm2 and linearly interpolating between relevant values of the scaled distance over-peak reflected pressures and positive duration times are directly obtained. Calculation of joint areas for corresponding joint forces has been done in the next step.After that, multiplying the obtained pressure with the area values, blast forces were calculated. Following the steps, the blast load for our chosen building (CUET Professor's Building) subjected to different explosions (100kg, 200kg, and 300kg TNT equivalent weight) from different stand-off distances (10m and 20m) has been calculated

Joint No.	Floor level (F.L)	Actual Distance	Scaled distance Z1(20m,0.3ton)	Pressure P1 (kg/cm^2)	Pressure P1 (psi)	Area (in^2)	Force F1(lb)	Time (ms)
E & G	GROUND LEVEL	10.12	21.80	11.75	167.12	2025	338418.51	17
D & H		11.16	24.04	8.44	120.04	2025	243085.29	18.68
B & J		14.18	30.55	4.06	57.75	5730	330881.03	23.3
A & K		17.89	38.54	2.35	33.42	5730	191519.81	28
E & G	1ST FLOOR	10.55	22.73	10.37	147.49	4050	597344.67	17.69
D & H		11.56	24.91	7.67	109.09	4050	441816.16	19.34
B & J		14.49	31.22	3.9	55.47	11460	635682.76	23.75
A & K		18.14	39.08	2.27	32.29	11460	369999.97	28.26
E & G	2ND FLOOR	11.76	25.34	7.29	103.69	4050	419926.96	19.66
D & H		12.67	27.30	5.65	80.36	4050	325457.80	21.12
B & J		15.4	33.18	3.41	48.50	11460	555814.93	25.06
A & K		18.87	40.65	2.11	30.01	11460	343920.67	29.06
E & G	3RD FLOOR	13.54	29.17	4.65	66.14	4050	267854.65	22.37
D & H		14.34	30.89	3.98	56.61	4050	229260.54	23.53
B & J		16.79	36.17	2.72	38.69	11460	443347.98	26.8
A & K		20.03	43.15	1.85	26.31	11460	301541.82	30.32
E & G		15.7	33.82	3.26	46.37	4050	187786.27	25.43

D & H	4TH FLOOR	16.39	35.31	2.91	41.39	4050	167625.17	26.31
B & J		18.58	40.03	2.17	30.86	11460	353700.41	28.74
A & K		21.54	46.41	1.57	22.33	11460	255903.06	31.72
E & G	5TH FLOOR	18.09	38.97	2.28	32.43	2025	65667.59	28.2
D & H		18.7	40.29	2.15	30.58	2025	61923.39	28.27
B & J		20.64	44.47	1.71	24.32	5730	139361.22	30.98
A & K		23.35	50.31	1.32	18.77	5730	107577.08	33.23

Table 1: Blast load data for 100kg explosive at 10m

2.2 Application of blast load in ETABS

Applying obtained values from the blast load calculation, the values are defined as a triangular time-history blast load function.

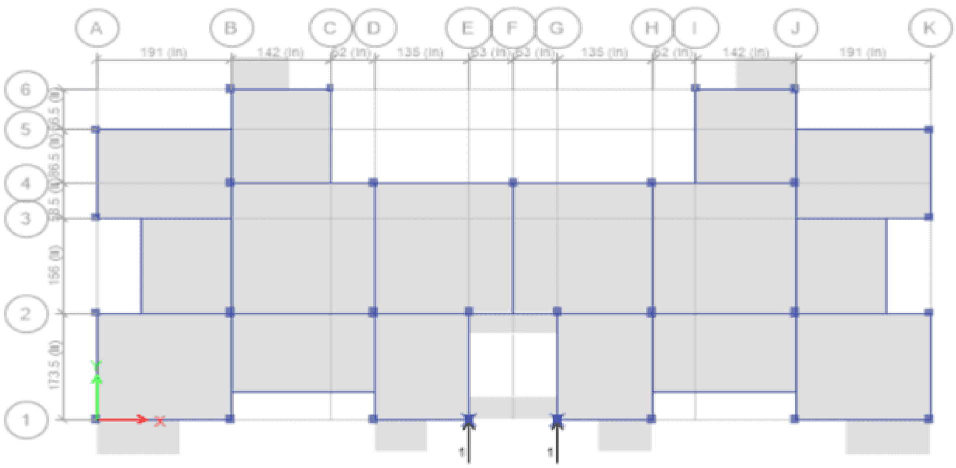


Fig 4: Plan view of blast load application on a joint

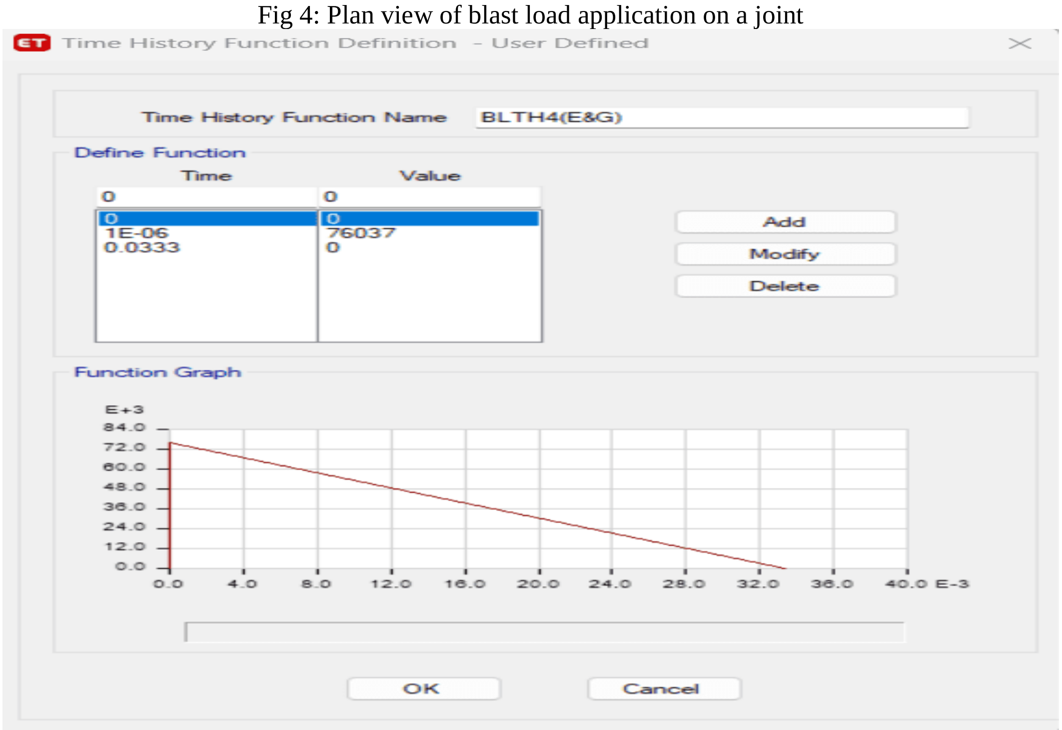


Fig 5: Time-history load function for a joint

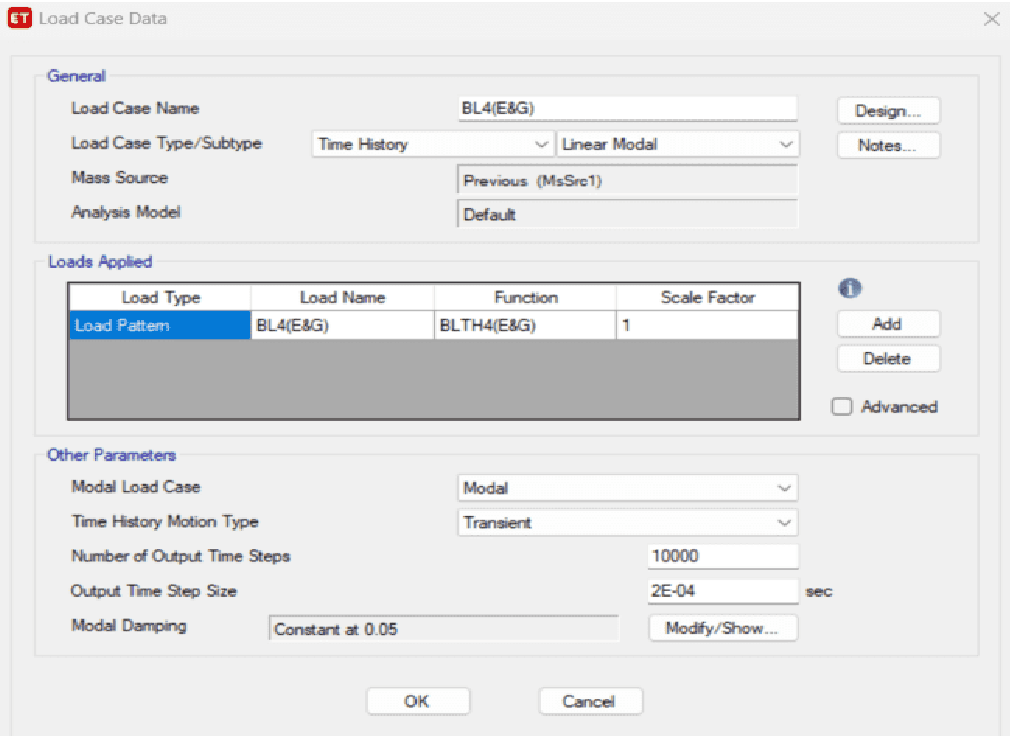


Fig 6: Load case selection for a joint

The blast load application procedure is validated by applying a certain amount of load on a portal frame both by manual calculation and ETABS software analysis. The blast load application is being validated in ETABS software by doing a blast load analysis of a portal frame as an example. The time period and the displacement due to blast load obtained by the end of the analysis in the software are compared with the values obtained by manual calculation from the book "Dynamics of Structure" by Ray W. Clough on page number 81, which has a slight marginal error of 2.12% for time period value and 1.2% for the displacement value, which is acceptable. Thus, the further work of the project is carried out using ETABS 2018 software.

3.RESULTS AND DISCUSSION

In the following section, time history graphs have been plotted for E and G. Joints at Y directions, where these points and axes are defined in the Figure 3 and **4.** The response of the building in terms of joint displacement, velocity, and acceleration is obtained. The following Figures 7 to 9 represent the plot of joint displacement (in) versus time (sec), joint velocity (in/sec) versus time (sec), and joint acceleration (in/sec2) versus time (sec) and base shear (lb) versus time(sec) respectively.

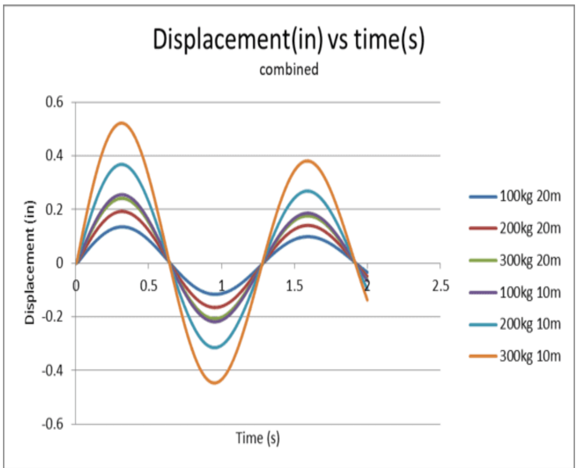


Fig 7: Joint displacement vs. time plot for different cases

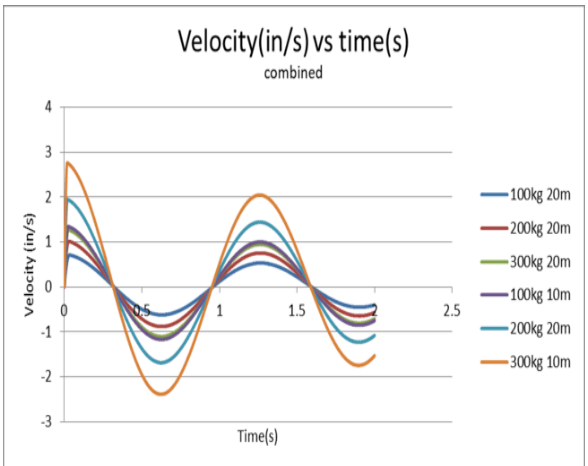


Fig 8: Joint velocity vs. time plot for different cases

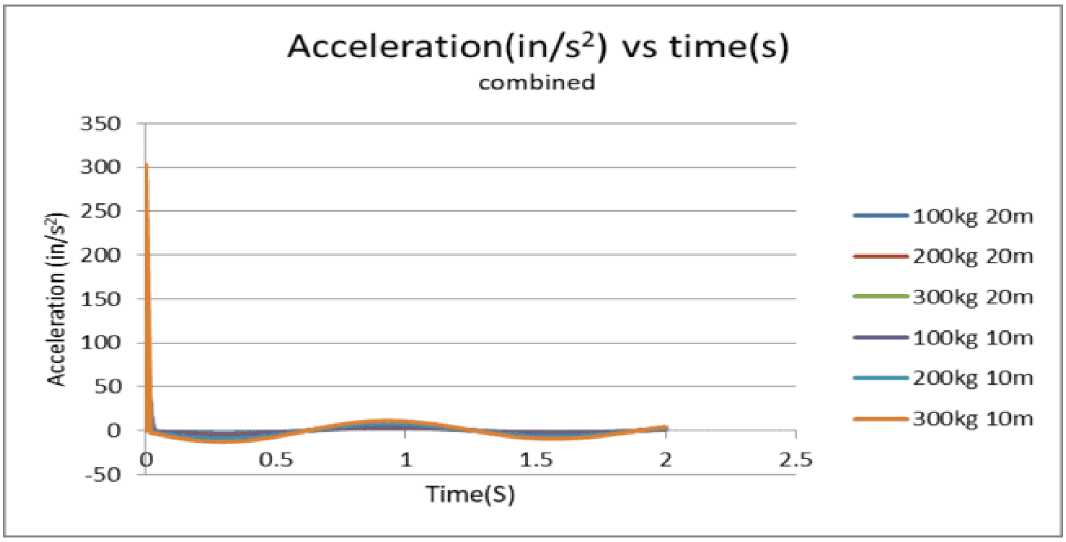


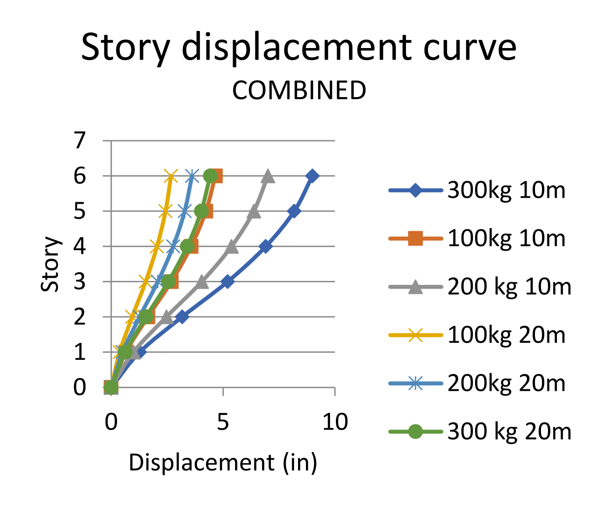
Fig 9: Joint acceleration vs. time plot for different cases

The plots in Figure 7 through 9 depict the variation of dynamic parameters at a specific location over time. The Y-axis represents time parameters, and the graphs illustrate that the parameters begin at 0 and gradually increase until reaching a maximum value before decreasing again. Additionally, the plots indicate that the parameters exhibit positive values at certain times and negative values at others. Despite assuming 5% damping, the values of these parameters initiate from 0 but do not converge to 0 by the end.This divergence occurs because the entire time history of the blast effect is not considered in this study.

The following table 2 shows the comparison of the above four graphs of maximum joint displacement, velocity, acceleration and base shear with respect to time

Response (max)	**100kg**		**200kg**		**300kg**	
	10m	**20m**	**10m**	**20m**	**10m**	**20m**
Displacement (in)	0.256	0.136	0.369	0.193	0.52	0.242
Velocity (in/s)	1.35	0.71	1.95	1.01	2.76	1.27
Acceleration (in/s^2)	106.42	43	193.5	71.01	302.63	98
Base Shear (lb)	21600	11463	31150	16320	44163	20435

Table 2: Comparison of maximum joint displacement, velocity, acceleration and base shear of the building subjected to various charge weight and stand-off distance



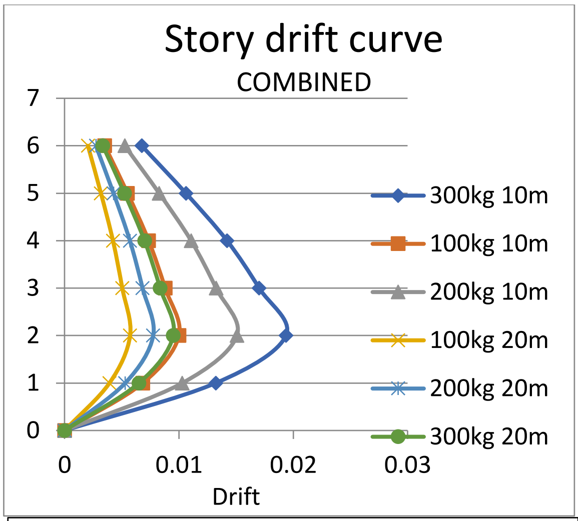


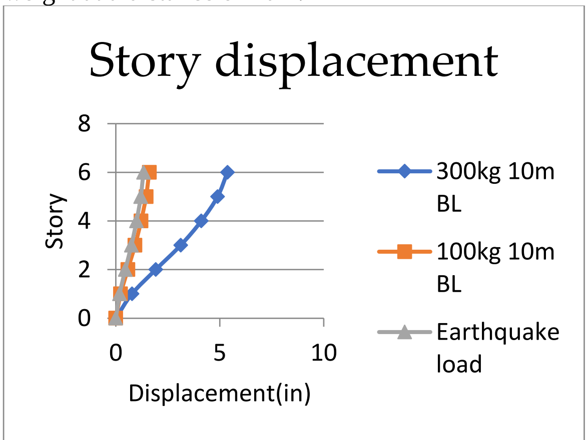
Fig 10: Story vs. Displacement (combined)

Fig 11: Story vs. drift ratio (combined)

The analysis of Figure 10 reveals that as the blast source gets closer to the building, the displacement experienced by the structure becomes more pronounced. This implies that when the distance between the blast source and the building decreases, and the charge weight increases, the displacement of each story within the building also increases. In Figure 11, the observation of story drift reveals that the drift increases as the blast source approaches the building. This indicates an inverse relationship between drift and the standoff distance, as well as a direct relationship between drift and the charge weight of the blast. Additionally, it is noteworthy that the impact of drift is more pronounced in the lower stories of the building compared to the higher stories.

3.1 Comparison between blast load and earthquake load

Figure 12, the study reveals that the highest story displacement occurs during the blast loading scenario with a 300kg TNT charge weight. In contrast, the lowest displacement is observed under earthquake loads. The impact of seismic forces on story displacement is less significant than the minimum displacement caused by a 100kg TNT charge weight at a distance of 20m. Additionally, a sudden change in displacement between the adjacent stories of story 5 is noted, likely due to a specific alteration in the vertical structure of the building. In Figure 13, the data shows that when a 300kg charge weight is detonated at a distance of 10m, the highest story drift is observed. As we move up to higher stories, the story displacement increases with the increase in story height, causing a decrease in the values of story drift. By increasing the stand-off distance and decreasing the equivalent charge weight, the story drift resulting from blast loading is minimize-drifts worth noting that the story drifts for earthquake load are even lower than the case with the lowest story drift, which occurs with a 100kg TNT charge weight at a distance of 20m.



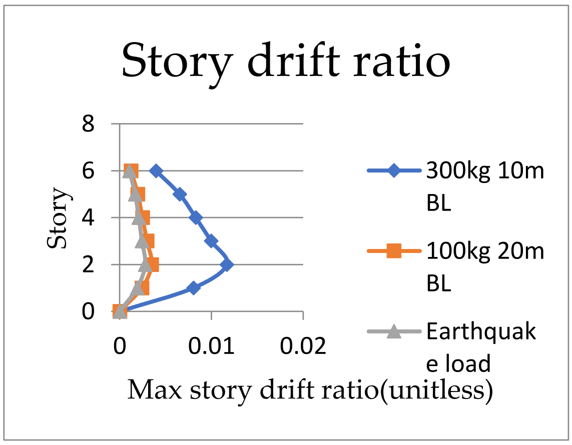


Fig 12: Story Displacement Curve for blast load comparing with earthquake load

Fig 13: Story drift ratio Curve for blast load comparing with earthquake load

4. CONCLUSIONS

The selected five-story residential building's blast load risk assessment provided significant insight into the structural response to unidirectional blast loads. The results obtained of the buildings subjected to blast load with various charge weights and standoff distances show that the story displacement, story drift, and column forces are high when the blast source point is at 20m from the front face of the building. The response of the building in terms of displacement and drift is more when the blast's standoff distance and charge weight are less. Thus, the response is inversely proportional to the standoff distance and charge weight.

Furthermore, the results of this study depicted that maximum story displacement under the blast load case (100kg at 20m) was 21.2% higher than story displacement under the effect of seismic load, which was 25.2% higher for story drift.

Again, the results of this study depicted that maximum story displacement under the blast load case (300kg at 10m) was 304.22% higher than story displacement under the effect of seismic load, which was 329.44% higher for story drift.

From this evaluation, the effect of blast load on the building is much more catastrophic than the effect of earthquake load.

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