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Comparative Study Of Different Types Of Building Under The Effect Of Blast Load

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Abstract: The increasing frequency and severity of terrorist attacks, both domestically and internationally, have heightened concerns about the safety of our infrastructure. With population growth rapidly accelerating, cities and towns are expanding at an unprecedented rate. Traditional buildings are generally not designed to withstand the immense forces generated by explosions due to the massive loads involved and the high cost of construction and design. A blast results in blast loading, which is the sudden and rapid release of stored energy. This type of load poses a significant threat to buildings, causing damage both externally and internally. Like wind and earthquake forces, blast loads are dynamic and need to be accurately calculated. This study focuses on analysing blast loads for a G+12 storey building, taking into account two variations in charge weights (100 kg and 200 kg) and standoff distances (20 m and 30 m), while incorporating shear walls and bracing systems. The research, titled "Comparative Study on Different Types of Buildings under the Effect of Blast Load," calculates the blast parameters according to IS 4991:1968 and applies them as joint loads to the structure. The study then examines the building's responses, including storey drift and displacement, to assess its performance under these extreme conditions.

***Index Terms* – Shear wall, Standoff distance Charge Weight, Blast load, Comparison, ETABS, Design.**

I. INTRODUCTION

A blast load consists of a rapidly expanding shock wave that can create pressures far greater than those experienced during even the strongest hurricanes. However, the duration of the explosion is very brief, and the peak intensity only lasts for a short amount of time. The shockwave hits the exposed surfaces of the structure, and this force is then transferred through the building's various elements. As a result, the response of each individual element becomes critical, unlike ground motion, which influences the entire structure at once. To design a structure capable of withstanding the inertia effects of these intense, short-lived loads, the members and joints are allowed to experience significantly greater deflections and strains than would normally be acceptable for static loads. This enables the material to operate fully within its plastic range. The amount of energy absorbed during this deformation greatly reduces the conventional strength typically required for design within the elastic range. Furthermore, the material's strength tends to increase with the rate of loading, and within a certain time frame, this relationship can often be accurately described. The World Trade Center in 1993, the "Murrah Federal Building" in Oklahoma City in 1995, and the US embassies in Nairobi in 1998 all saw terrorist explosive assaults that employed 816.5 kg of trinitro-toluene (TNT). Mumbai's Zaveri Bazaar bombing case (2007), Glasgow International Airport's car bomb explosion outside the main terminal (2007), and the Aleppo Hotel bombing in Syria (2014). Due to the explosion's numerous defects, people have died and important structures that were expensive to construct have been destroyed. The increase in terrorist assaults on people and buildings in recent decades has led structural engineers and architects to look for ways to safeguard people and buildings against bomb tragedies.

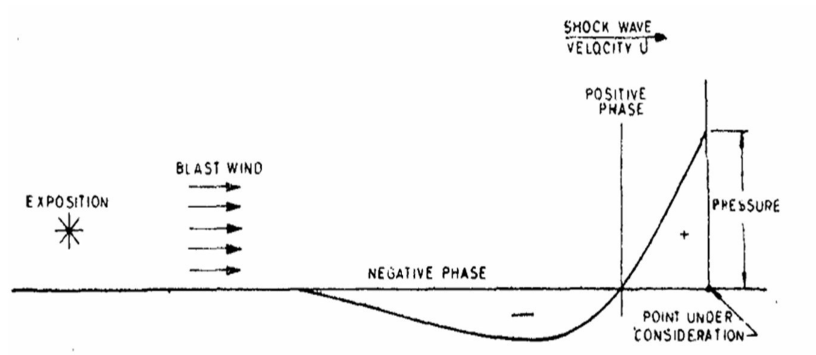

Figure 1: shock wave produced by the blast

1.1 Explosion

An explosion happens when a specific amount of matter undergoes a sudden and intense release of energy, usually producing high temperatures and high-pressure gases. Sometimes, explosions are caused by a slower expansion that wouldn't normally be forceful. However, if this expansion is confined, pressure builds up until the container is ruptured, causing the matter to expand explosively.

Shock Wave: An explosion sends a shock wave through the atmosphere that travels quickly in all directions from the point of explosion, producing time-dependent suction and pressure effects at every location along its path. Figure 1 above illustrates how the shock wave is composed of a positive pressure phase at the beginning and a negative (suction) phase at any point.

2. METHODOLOGY AND MODELLING.

According to IS 4991:1968, the current goal of this work is to examine how various structure types behave when exposed to blast loads that include varying charge weights and standoff distances. The parametric investigations include storey displacement, and storey drift. Blast load was calculated as per IS 4991:1968 and applied to the structure as joint loads. Non-Linear Dynamic analysis was considered for analysis of different types of buildings under blast loads in ETABS software.

2.1 Description of Models

This study involves twelve structural models to analyze the blast load impact on different types of buildings for different charge weights for different standoff distances.

The study includes various models of a G+12 building subjected to blast loads under different conditions. Model 1 consists of a framed building with a 100 Kg blast charge and a 20m standoff distance. Model 2 features a similar building but with a shear wall, while Model 3 incorporates bracing for added support. Model 4 evaluates a framed G+12 building with a 200 Kg blast charge and a 20m standoff distance. In Model 5, the same blast charge is applied to a building with a shear wall, and Model 6 includes bracing in place of the shear wall. The next set of models examines the same structural configurations but with a 30m standoff distance. Model 7 features a framed building with a 100 Kg blast charge, while Model 8 introduces a shear wall, and Model 9 uses bracing. Finally, Model 10 investigates a framed G+12 building with a 200 Kg blast charge at a 30m standoff distance, while Model 11 includes a shear wall, and Model 12 uses bracing to mitigate blast effects.

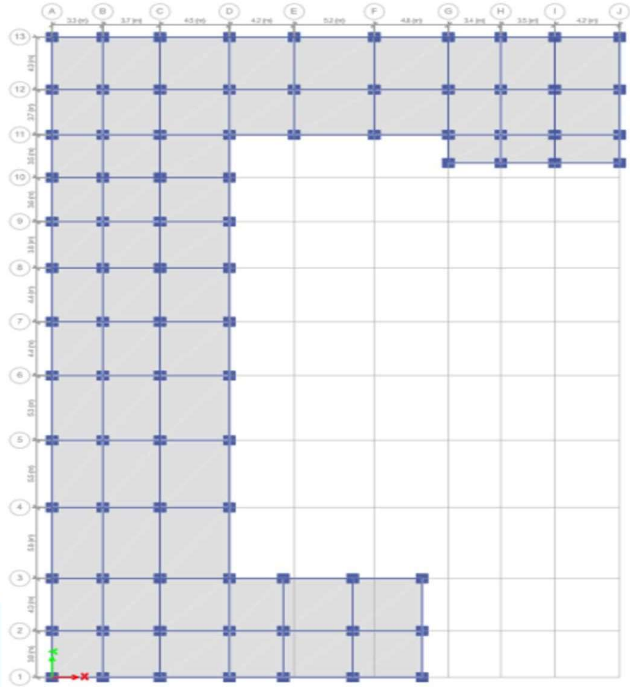

Figure 2: Plan of G+12 model

Fig 2 illustrates the floor plan view of the typical floors modeled in ETABS 2021 for different types of building for different types of charge weights and different standoff distances.

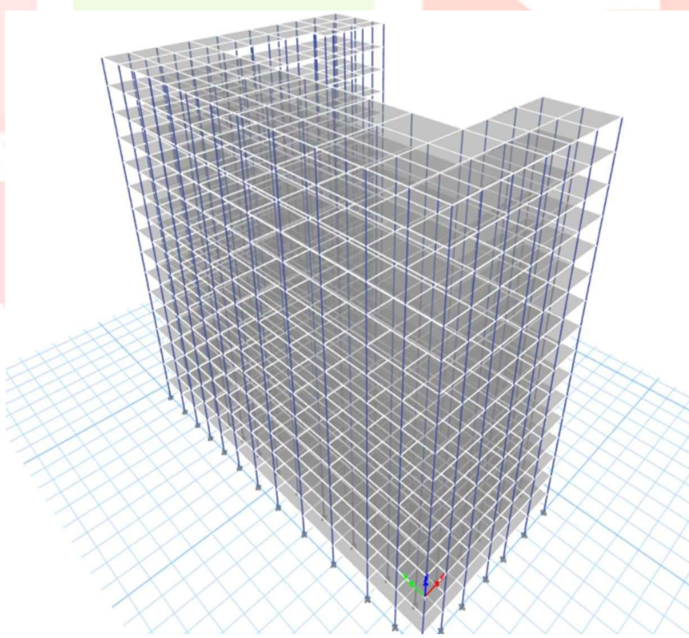

Figure 3: Three-Dimensional View of G+12

Fig 3 illustrates the Three-Dimensional View of G+12 modelled in ETABS 2021 for different types of building for different types of charge weights and different standoff distances.

2.2 Loads Considered

Fundamental load parameters have an impact on the structure's design. According to IS 875 (part 1):1987, dead load was computed using the materials employed in the structure. The building's occupancy was used to assume the live load in accordance with IS 875(Part 2):1987. In accordance with IS 4991:1968, blast load was computed. In ETABS, blast loads were applied as joint loads.

Loads considered during analysis of Multi Storey buildings:

1. Floor finish: 1 kN/m^2 as per IS 875(Part 1):1987
2. Dead load (self-weight of building): automatically computed by ETABS software.
3. Live load on building: 3 kN/m^2 as per IS 875(Part 2):1987.
4. Blast Load was calculated as per IS 4991:1968.

2.3 steps to calculate Blast load

Below is a sample calculation for one case of 100kg with a standoff distance of 20 m as per IS4991:1968. The blast load was considered perpendicular to the structure, and the actual distance and scaled distance x were calculated. The charge weight of 100kg was converted into tonnes, equal to 0.1 ton. Pressure on the front face was calculated.

By considering actual distance Z as 20m, scaled distance was calculated from the formula. Scaled distance

$$X = \frac{\text{Actual distance}}{W^{1/3}} = \frac{20}{0.1^{1/3}} = 43.088 \text{ m/tonne}^{1/3}$$

For x= 43.088 m/tonne$^{1/3}$, it is referred from Table 1 of IS 4991:1968 to calculate the values of t_o, t_d, P_{so}, P_{ro} by interpolation. Positive phase duration t_o is 30.28 milliseconds. Duration of Equivalent Triangular pulse t_d is 20.70 ms. Total positive duration = $t_o + t_d$= 30.28+20.70=50.98 ms. Peak side on over pressure P_{so} is 0.72371*98.066= 70.97 kN/m^2. Peak reflected over pressure P_{ro}= 1.8575*98.066= 182.158 kN/m^2. Force on node = Peak over reflected pressure*Area=182.158*3.44=626.62 kN. Pressure on rear and side face was calculated according to height of the building or half of breadth i.e. H or B/2.

S=H or B/2. 36.8/2 = 18.9m or S = 39m. Using the formula U=M.a, where U is the shock front velocity, M is the Mach number, and a is the velocity of sound in air, which can be taken as 344 m/s at mean sea level at 20° C. The Mach number was determined from the table. U is calculated by the formula, U= M.a = 1.275 * 344 = 428.3 m/s.

The calculation of clearance time was tc = 3S/U = 3 * 18.9/428.3 = 0.13238 * 1000 = 132.38 ms. Transit time was calculated as t_t =L/U= 52.4/428.3= 0.122344*1000= 122.34 ms.

Pressure rise time was calculated as tr=4S/U=4*18.9/428.3=0.176511*1000=176.51ms. As pressure rises time becomes greater than duration of equivalent triangular pulse, therefore there will be no pressure on rear face.

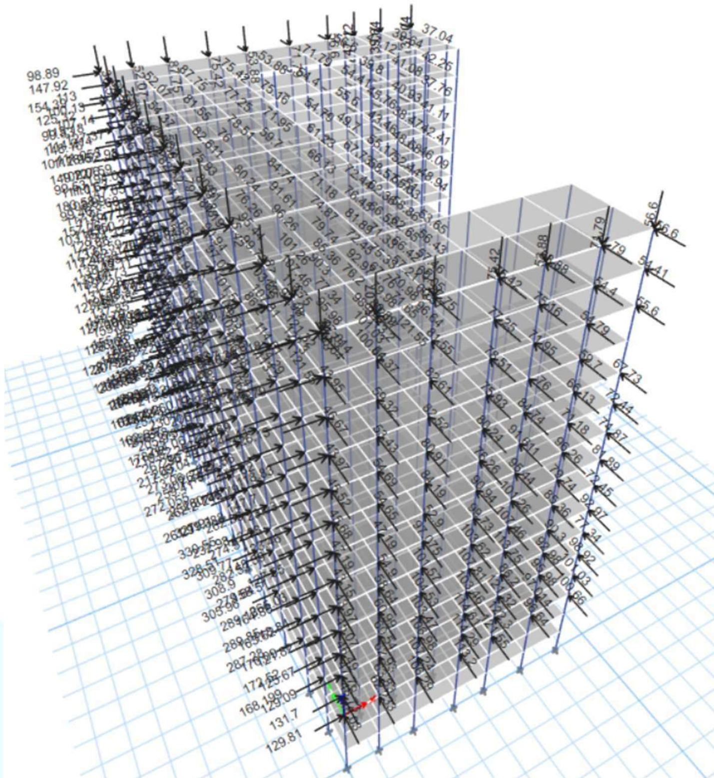

Figure 5: Blast load applied to Framed building on front, side and roof

According to IS4991:1968, the blast load applied to the Framed building's front, side, and the roof as shown in Figure 5 above. The charge weight was 100 kg, and the standoff distance was 20 meters.

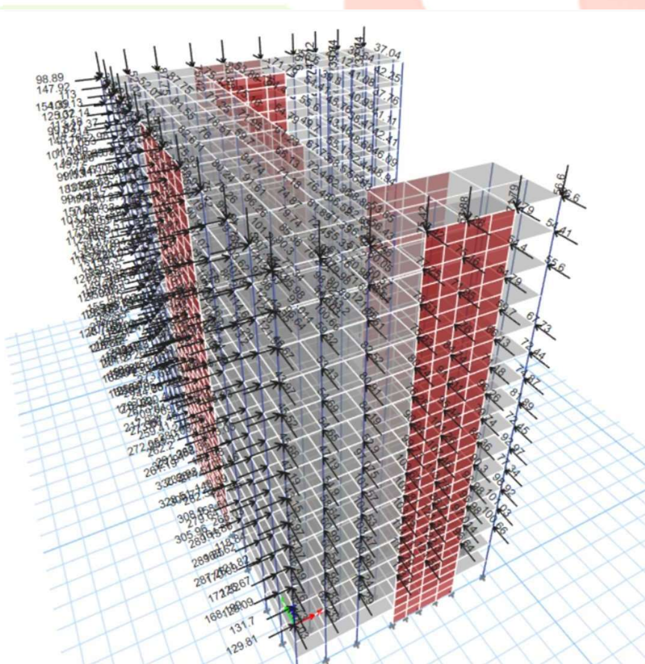

Figure 6: Blast load applied to building with shear wall on front, side and roof

The figure 6 above shows the blast load applied to the front, side, and roof of a shear wall building. It was computed using IS 4991:1968 for a charge weight of 100 kg and a standoff distance of 20 meters.

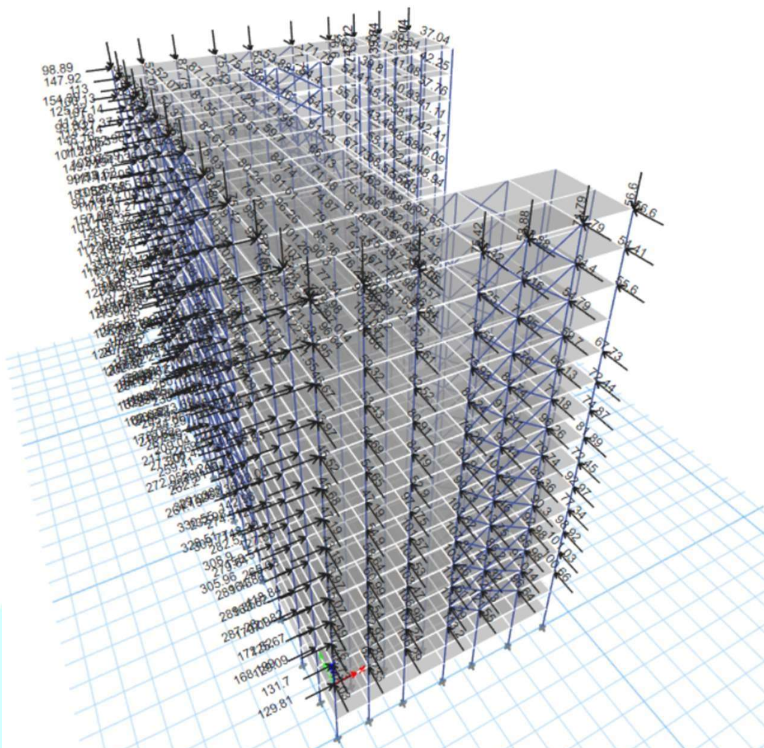

Figure 7: Blast load applied to building with bracing x on front, side and roof

The blast load applied to the building's front, side, and roof with X bracing as shown in Figure 7 above. It was computed using IS 4991:1968 for a charge weight of 100 kg and a standoff distance of 20 meters.

3. RESULTS AND DISCUSSIONS

Blast load values for various structural types, considering different charge weight and standoff distances, were determined in accordance with IS 4991:1968. The impact of these loads on building characteristics, such as storey displacement and storey drift are analyzed. The following figures provides a comparison of the results based on these parameters.

3.1 Storey Displacement

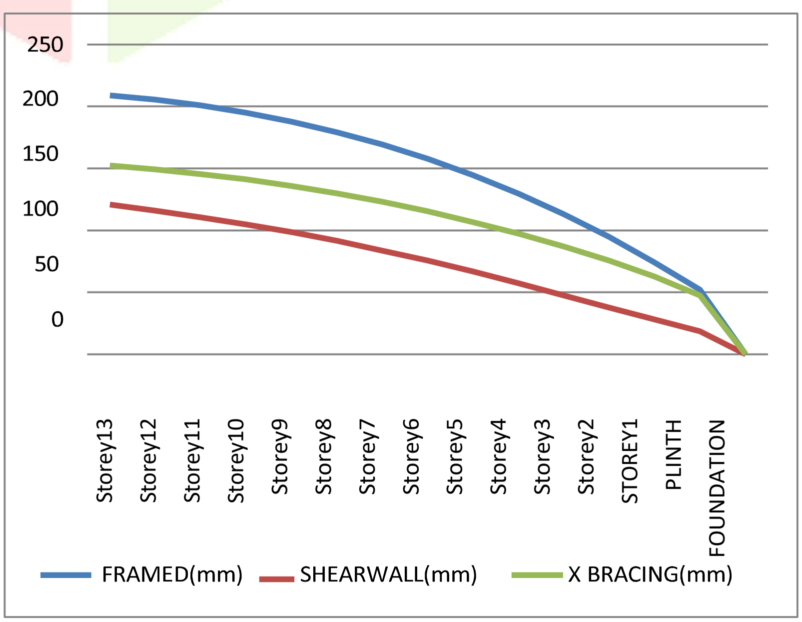

Figure 8: Displacement values for 100kg charge weight 20m standoff distance

From figure 8, it is observed that the Framed building shows the highest displacement, with a maximum of 209 mm at Storey 13, while the shear wall and X-bracing systems reduce the displacement to 120 mm and 152 mm, respectively, at the same level. This indicates that the shear wall reduces the displacement by about 43%, and the X-bracing reduces it by around 28% compared to the Framed building.

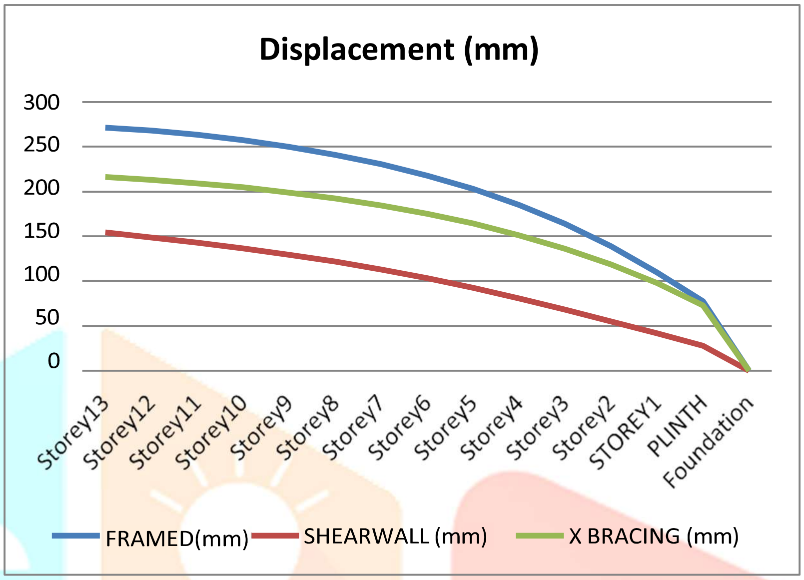

Figure 9: Displacement values for 200kg charge weight 20m standoff distance

The figure 9 presents a comparative analysis of storey-wise lateral displacement for three structural systems—Framed, shear wall, and X bracing—subjected to a 200kg charge weight at a 20m standoff distance. The Framed structure demonstrates the highest lateral displacement, reaching 271 mm at Storey 13, indicating its relatively low lateral stiffness. Incorporating X bracing significantly improves performance, reducing the maximum displacement, which corresponds to a 20% reduction compared to the Framed structure. The shear wall system offers the best performance, achieving a 44% reduction relative to the Framed system and a further 25% reduction compared to X bracing.

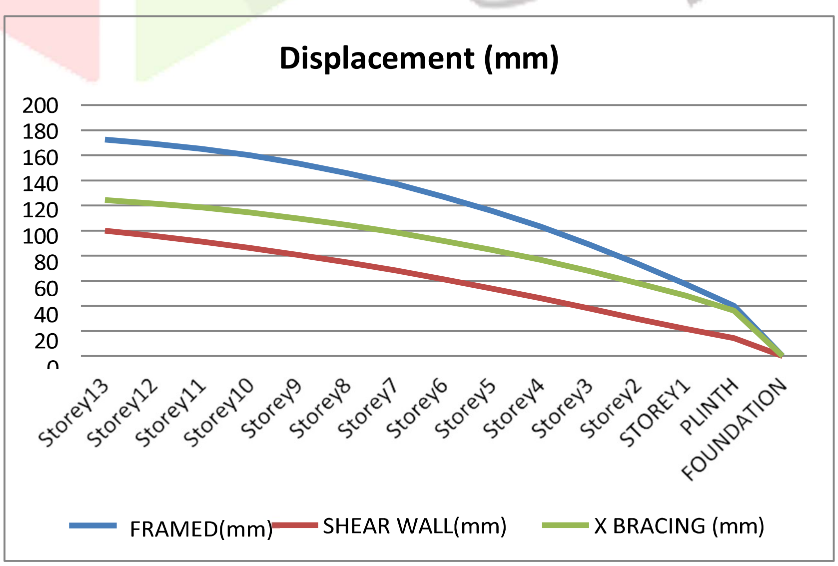

Figure 10: Displacement values for 100kg charge weight 30m standoff distance

The figure 10 provides the storey displacements for Framed building, shear wall, and X bracing structural systems under the impact of a 100kg charge weight at a 30m standoff distance. The Framed structure exhibits the highest displacement values across all storeys, with a maximum displacement of 172mm at Storey 13, gradually reducing to 57mm at Storey 1 and further to 39 mm at the plinth before reaching zero at the foundation. In contrast, the X bracing system shows improved performance, with a maximum displacement of 124 mm at Storey 13, representing a 27% reduction compared to Framed, and a displacement of 48 mm at Storey 1, marking a 16% reduction at the base. The shear wall system demonstrates the best performance, with the lowest maximum displacement of 100 mm at Storey 13, achieving a 42% reduction compared to Framed and a 20% reduction compared to X bracing. At Storey 1, the shear wall displacement is 21 mm, showing a 62% reduction relative to Framed and a 55% reduction compared to X bracing.

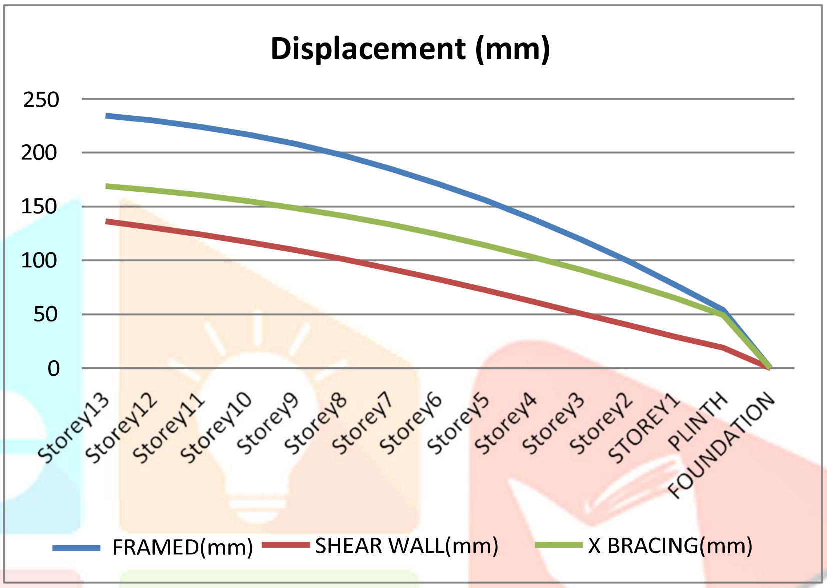

Figure 11: Displacement values for 200kg charge weight 30m standoff distance

The above figure 11 shows the storey-wise displacement for Framed, shear wall, and X bracing structural systems under a 200kg charge weight at a 30m standoff distance. The Framed structure shows the highest displacement, with a maximum of 234 mm at Storey 13, reducing to 77 mm at Storey 1 and 54 mm at the plinth. The X bracing system demonstrates improved performance, with a maximum displacement of 168.812mm at Storey 13, reflecting a 28% reduction compared to Framed, and a displacement of 65 mm at Storey 1, achieving a 16% reduction at the base. The shear wall configuration provides the best structural response, with the lowest maximum displacement of 136 mm at Storey 13, representing a 41% reduction compared to Framed and a 19% reduction relative to X bracing. At Storey 1, the shear wall displacement is 29 mm, which is 62% reduction relative to Framed and a 55% reduction compared to X bracing.

3.2 Maximum Storey Drift Ratio

The figure 12 shows storey drift ratios for Framed, shear wall, and X bracing structural systems under a 100kg charge weight at a 20m standoff distance. The Framed structure shows the highest drift ratios at most storeys, with a maximum of 0.00749 at the plinth and 0.007341 at Storey 1, which is not in limit, i.e. 0.004. The building with X bracing also exceeds the limit, i.e. 0.004. Whereas building with shear wall is in the drift ratio limit, i.e. 0.004.

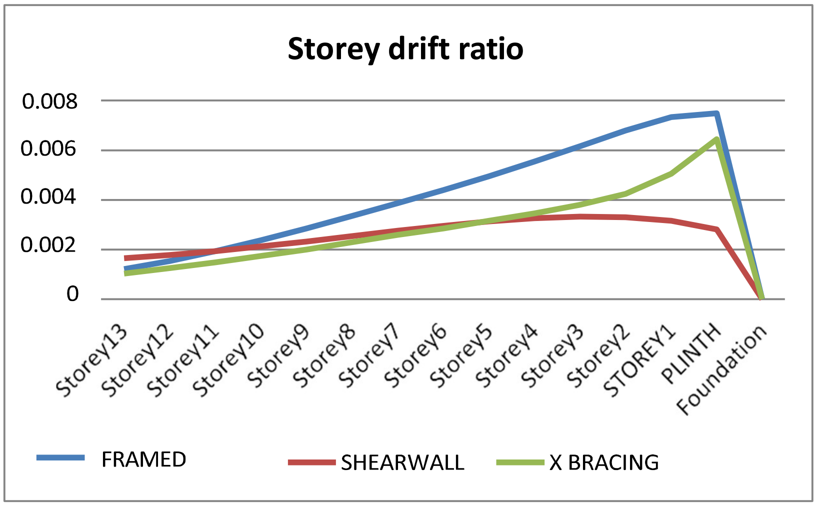

Figure 12: Storey drift ratios for 100kg charge weight 20m standoff distance

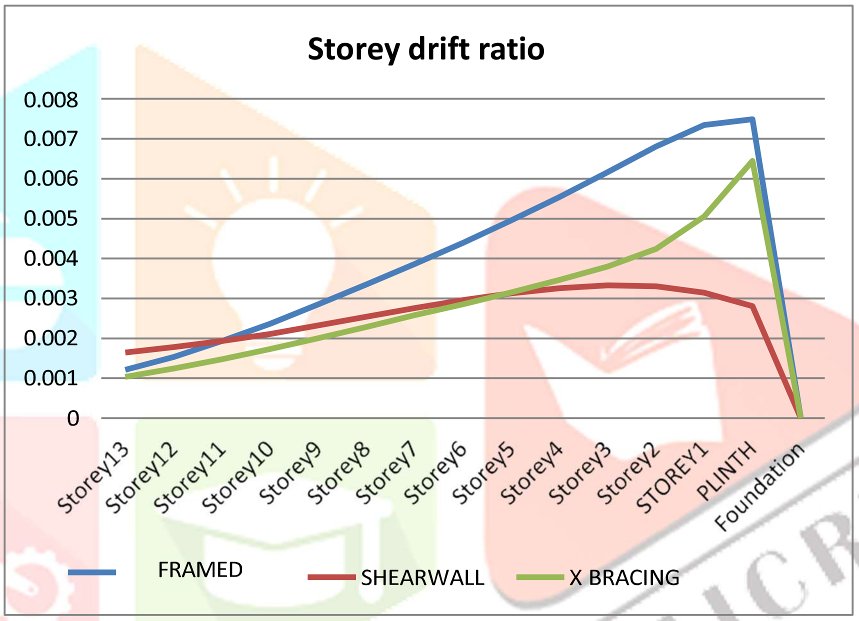

Figure 13: Storey drift ratio values for 200kg charge weight 20m standoff distance

The figure 13 shows the storey drift ratios for Framed, shear wall, and X bracing systems under a 200kg charge weight at a 20m standoff distance. The Framed structure exhibits the highest drift ratios across all storeys, with a maximum of 0.011124 at the plinth and 0.010781 at Storey 1, which is not in a limit of drift ratio i.e. 0.004. The X bracing system consistently reduces drift ratios compared to Framed, with a maximum of 0.010022 at the plinth, representing a 10% reduction compared to Framed, and 0.008354 at Storey 1, achieving a 23% reduction at that level.

At upper storeys, the X bracing drift ratio is 0.001208 at Storey 13, reflecting a 15% reduction compared to Framed (0.001416). At the plinth, the shear wall drift is 0.004143, achieving a 63% reduction compared to Framed and a 59% reduction relative to X bracing.

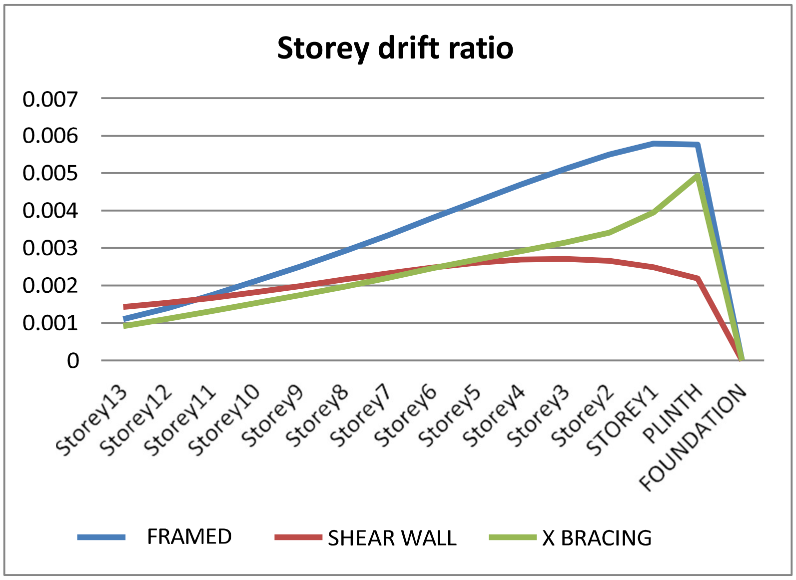

Figure 14: Storey drift ratio values for 100kg charge weight with 30m standoff distance

The figure 14 above shows the storey drift ratios for Framed, shear wall, and X bracing systems under a 100kg charge weight at a 30m standoff distance. The Framed structure exhibits the highest drift ratios across all storeys, with a maximum of 0.005785 at Storey 1 and 0.005765 at the plinth, reflecting significant deformation. The X bracing system consistently reduces the drift ratios, achieving a maximum of 0.004935 at the plinth, which represents a 14% reduction compared to Framed, and 0.003957 at Storey 1, indicating a 32% reduction. In the upper storeys, X bracing reduces the drift from 0.0011 (Framed) to 0.000916 at Storey 13, achieving a 17% reduction. On the other hand, the shear wall system provides substantial reductions at lower levels, with the drift at the plinth decreasing to 0.002188, a 62% reduction compared to Framed, and 0.002497 at Storey 1, resulting in a 57% reduction. However, at the upper storeys, the shear wall drift ratio increases.

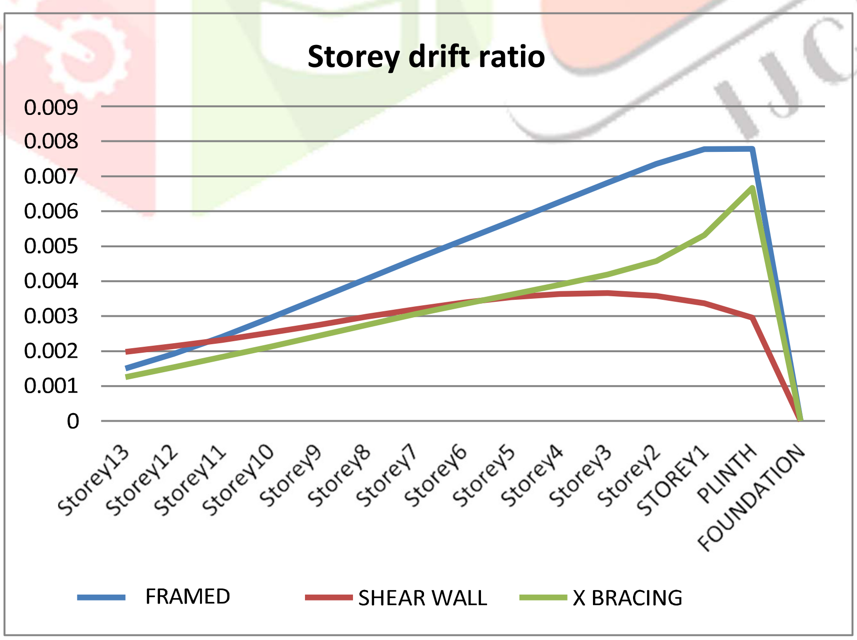

Figure 15: Storey drift ratio values for 200kg charge weight with 30m standoff distance

The figure 15 shows the storey drift ratios for Framed, shear wall, and X bracing systems under a 200kg charge weight at a 30m standoff distance. The Framed structure shows the highest drift ratios across all storeys, with a maximum value of 0.007785 at the plinth and 0.007777 at Storey 1, reflecting significant deformation under the given conditions.

The X bracing system demonstrates consistent reductions across all levels, with the drift ratio reduced to 0.006669 at the plinth, achieving a 14% reduction compared to Framed, and to 0.00532 at Storey 1, reflecting a 32% reduction. In the uppermost storey (Storey 13), X bracing reduces the drift from 0.001497 (Framed) to 0.001252, achieving a 16% reduction.

Comparison on Displacement of Same Charge Weight of 100kg With Different Standoff Distance of 20m and 30m

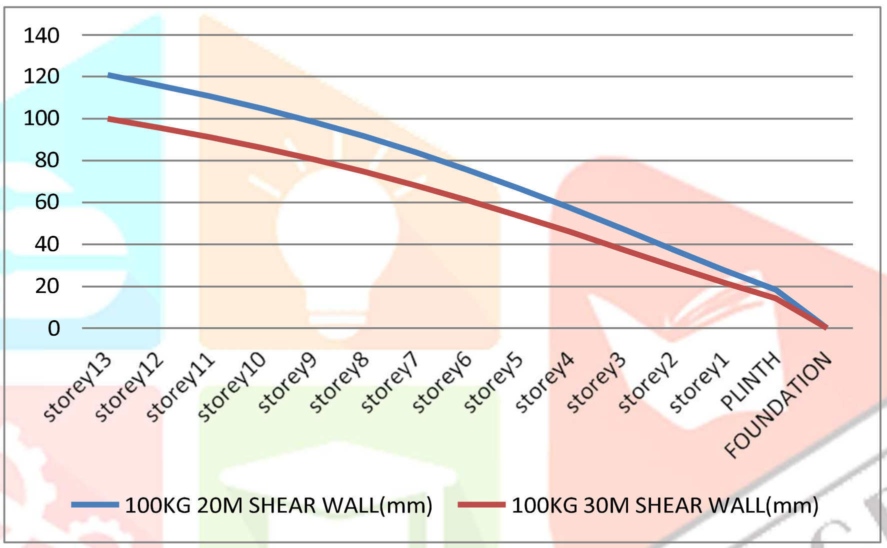

Figure 16: comparison on displacement of 100kg charge weight with 20 and 30m standoff distance

The figure 16 illustrates the comparison of storey displacements for a shear wall system subjected to a 100kg charge weight at two different standoff distances: 20m (blue line) and 30m (red line). From the graph, it is evident that the displacements decrease consistently across all storeys when the standoff distance is increased from 20m to 30m.

The maximum displacement is observed at Storey 13, with a value of 121mm at 20m and 100mm at 30m, indicating a significant reduction. Similarly, at lower levels, such as Storey 1, the displacement decreases from 28mm at 20m to 22mm at 30m. This consistent reduction in displacement across all storeys highlights the substantial influence of increased standoff distance in mitigating structural responses to blast loads.

Comparison on Displacements of Same Charge Weight of 200kg with Different Standoff Distance of 20m and 30m

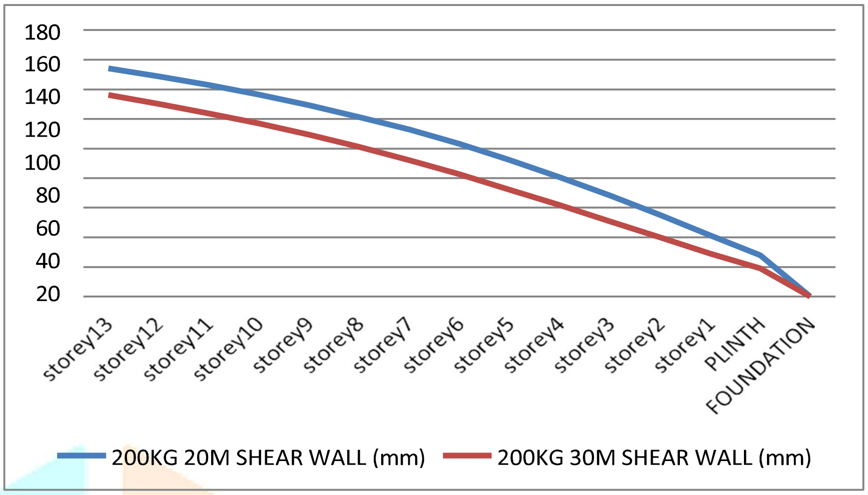

Figure 17: Comparison on displacements of same charge weight 200kg with different standoff distances 20m and 30m

The figure 17 comparing the displacement of a shear wall system under a 200kg charge weight at standoff distances of 20m and 30m indicates a clear reduction in displacement as the standoff distance increases. At Storey 13, the displacement is 154mm for a 20m standoff and decreases to 136mm for a 30m standoff, showing a reduction of 18mm. Similarly, at Storey 1, the displacement drops from 41mm at 20m to 29mm at 30m, with a reduction of 12mm.

Comparison on Displacements of Different Charge Weight of 100kg and 200kg with Same standoff Distance of 20m

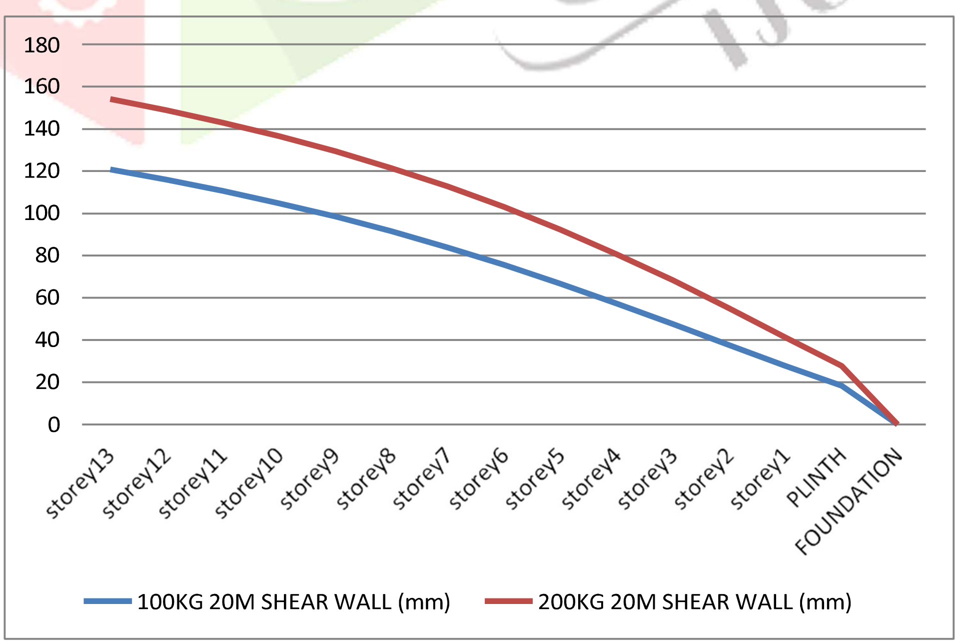

Figure 18: comparison on different charge weights of 100kg and 200kg with same standoff distance 20m

The figure 18 shows the comparison of displacements for shear wall systems under 100kg and 200kg charge weights at a standoff distance of 20m reveals a consistent trend of increased displacement for the 200kg charge across all storeys. At Storey 13, the displacement for the 100kg charge is 121mm, whereas it rises to 154mm for the 200kg charge, showing an increment of 28%. Similarly, at Storey 1, the displacement increases from 28mm to 41mm, marking a difference of 49%.

Comparison on Displacements of Different Charge Weight of 100kg and 200kg with Same Standoff Distance of 30m

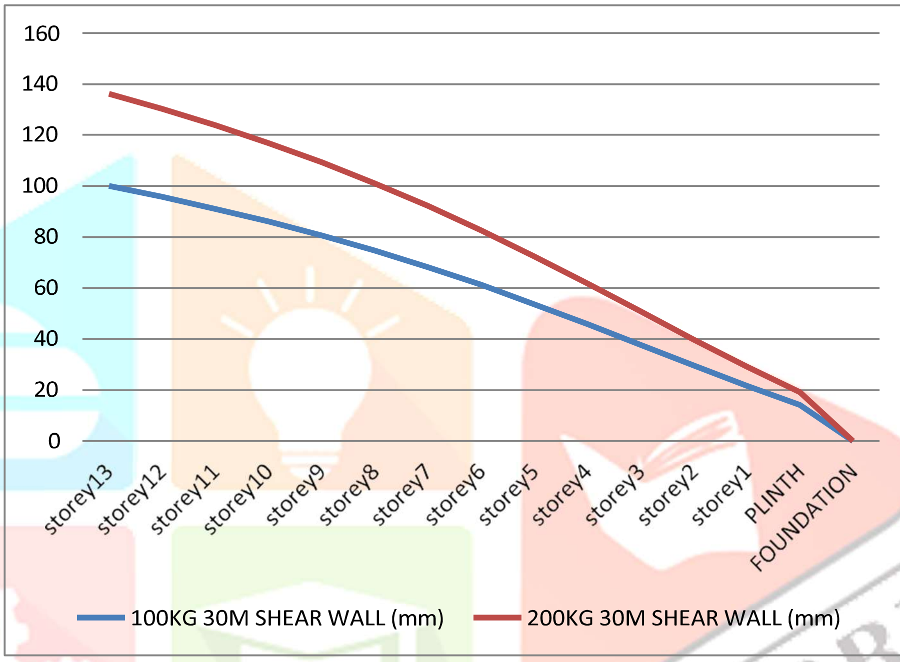

Figure 19: comparison on different charge weights 100kg and 200kg with same standoff distance 30m

The figure 19 demonstrates that increasing the charge weight from 100kg to 200kg at a constant standoff distance of 30m leads to consistently higher displacements across all storeys. For instance, at Storey 13, the displacement rises from 100mm for the 100kg charge to 136mm for the 200kg charge, indicating a significant increase of approximately 36%.

4 CONCLUSIONS

1. Maximum storey displacements are more for Framed building and the displacements are reduced for building with Shear wall and building with X bracing.

2. At a standoff distance of 20 meters, displacement is decreased by 28% for the building with X bracing under a 100 kg charge weight and is decreased by 20% under a 200 kg charge weight.

3. Building with Shear wall can resist more blast loads than building with X Bracing, and the displacement for building with shear wall is reduced by 43% under a 100kg charge weight at a standoff distance 20m and is reduced by 45% under a 200kg charge weight at a standoff distance of 20m.

4. The displacement for building with shear wall is reduced by 42% under a 100kg charge weight at a standoff distance 30m and is reduced by 41% under a 200kg charge weight at a standoff distance of 30m.

5. Increase of the charge weight from 100kg to 200kg at a constant 20-meter standoff distance results in an increase in the displacements of the shear wall building by 22%. As the charge weight increased, the displacements of the buildings increased.

6. The displacement of the building with shear wall under a 100kg charge weight at standoff distances of 20m and 30m is decreased by 17%. As the standoff distance increased, the displacements of the buildings are decreased.

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