Analysis of Reinforced Concrete Building under Blast Loading

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Abstract

The blasts triggered by terrorist attacks and chemical detonations are imposing as the world's growing challenges as they not only effect human life, but also threaten the stability of the structure and its resilience. This paper provides comprehensive study of a reinforced concrete building under blast loading that may be triggered by terror attacks, unintended explosions, and other explosions induced by earthworks or mines. Finite element modelling was used prior to analyzing the blast phenomena on a reinforced concrete structure. The impact of blast lateral load reaction on peak deflections, story drift, and story shear was measured and compared to the combined influence of seismic and wind load on the structure. The outcomes depicted that maximum story displacement under blast loading was 87.93% higher than story displacement under combined effect of seismic and wind load, which was 136.475% for story drift and 134.976% for story shear. After providing shear wall on building, maximum story displacement under blast loading was reduced by 28.703% as compared to building exposed to blast loading without shear wall, for story drift which is about 50.2%. Due to this destructive effect of blast on structures, structures with great values must have blast resisting capacity undoubtedly.

Keywords: *Blast Loading, Blast Resistant Design, Finite Element Modelling, Structural Safety.*

1. Introduction

Due to the immediate and accelerated release of vast quantities of energy within a small area, the blast phenomena initiates a shock wave in the ambient medium that reaches all objects within its range with tremendous force. Terrorism, accidental blasts, or other explosions meant for excavations or mining will cause blast loading on buildings, which is one of the most risky and damaging loads they can encounter throughout their lifespan (Mukherjee et al., 2017). Although the structures are not conventionally designed for blast load considering huge magnitude of loading along with high cost of construction, the increasing number of explosions in last few decades significantly imparted to perceive a sustainable method of structural analysis regarding blast loading. Understanding the blast phenomenon and the transmission of waves against the structure, as well as the structure's reaction to such shock waves, is essential for analyzing and designing blast resistance structures. Different magnitudes of charge weight, distance between source and target, and structural parameters may affect structure reaction (Sai et al., 2019). The blast results of an explosion come in the form of a shock wave, which travels outward from the explosive's surface into the surrounding air and is made up of a high-intensity shock front (Koccaz et al., 2008). Furthermore, with a small shift in the displacement of the column in the face of the blast load, the impact of the blast load reduces as the standoff distance from the system increases (Mishra and Netula, 2021; Shallan et al., 2014). Using pressure sensors, accelerometers, dynamic strain amplifiers, data acquisition boards, and strain gauges, four separate reinforced concrete walls of differing thickness were tested with changing explosive loads and scaled lengths, showing that air blast and ground shock pressure should be considered for successful structural reaction analysis (Joshi, 2020). Moreover, a comparison of the long side and short side columns exposed to blast loads showed that the critical impulse for the long column case is considerably greater, with overall short side to long side stress distribution ratios of 0.78, 0.61, 0.57, 0.56, 0.48, 0.46, 0.32, and 0.30 for eight following columns, respectively (Wakchaure, 2013). Analysis on RCC structure by different explosions with different floor sections concluded that, when explosion quantity increases the phase duration decreases (Gaikwad et al., 2017). Henceforth, the numerical analysis accurately recreates the building's collapse under the blast load, verifying the position and severity of the explosion that had previously been estimated based on other tests. The numerical analysis provides a variety of potential for use in practice to model large structure responses to blast loading (Li and Hao, 2011; Luccioni et al., 2004)**.** The primary aim of this research is to measure the blast load for a 100 kg TNT blast with a 40 m standoff gap in order to determine the efficiency of reinforced concrete structures under blast loading. A detailed picture of blast resistant building construction with enhanced protection against explosives effects can be drawn concisely by comparing overall story displacement, story drift, and base shear of structure due to blast load with story displacement, story drift, and base shear of the structure due to combined impact of seismic and wind load.

2. Methodology

In this analysis, a reinforced concrete building was subjected to a 100 kg TNT surface burst 40 meters out from the building's left side face and 1.5 meters above the ground surface. Model 1 uses the ETABS 2016 program to evaluate a G+8 story building subjected to a blast load of 100 kg TNT with a 40 m standoff radius. For normal and extreme situations, the same building is analyzed under the cumulative influence of seismic and wind loads. Normal condition delineates that the basic wind speed considered for model 2 is 80.78 mph and zone factor is 0.075 (zone I). Sever condition delineates that basic wind speed considered for model 3 is 124.27 mph and zone factor is 0.25 (zone Ⅲ) which are severe than the wind speed and zone factor considered in model 2. Model 4 is done to analyze the same building (with shear wall) under the blast effect only of same magnitude (as in model 1) to examine whether addition of shear wall can reduce blast effect or not. For all four models building materials property is similar. After analyzing all four models maximum story displacement, drift and shear is evaluated to compare among these four models.

3. Modelling and Analysis

This paper includes 4 specific models:
Model 1: Building exposed to a 100 kg TNT explosion with a 40 m standoff radius.
Model 2: Building exposed to seismic and wind load for normal condition.
Model 3: Building exposed to seismic and wind load for severe condition.
Model 4: Building exposed to blast load with shear wall.

Table 1. Building properties with dimensions

Properties	Dimensions
Plan	14m x 18m
Bay width along X direction	4m
Bay width along Y direction	5m
Size of beam	300mm x 450mm
Size of column	350mm x 500mm
Thickness of slab	150mm
Thickness of wall	120mm
Height of floor	3m
Concrete grade	M30
Density of concrete	$25\,\frac{KN}{m^3}$
Thickness of shear wall	250mm

Table 1 represents the properties and dimensions of the building considered in this study. The loads acted on the building due to the burst of 100 kg TNT were evaluated according to IS Code 4991:1968 "Criteria for Blast Resistant Design of Structures for Explosions above Ground". Blast loads applied in different joints of left side face of the building for model 1, 2,3 and model 4 are showed in Figure 1 and Figure 2.

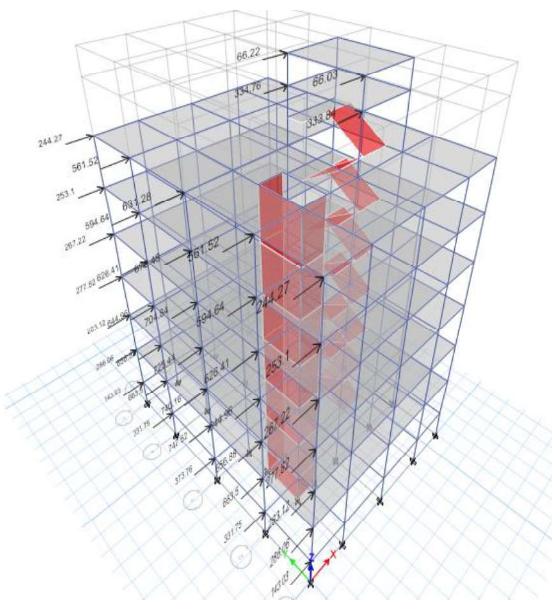

Figure 1. Application of blast load on building (model-1, 2, 3)

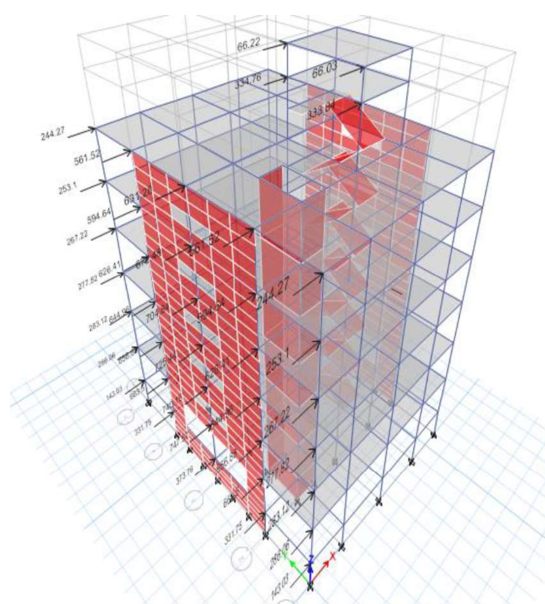

Figure 2. Application of blast load on building (model-4)

4. Results and Discussions

4.1 Story displacement

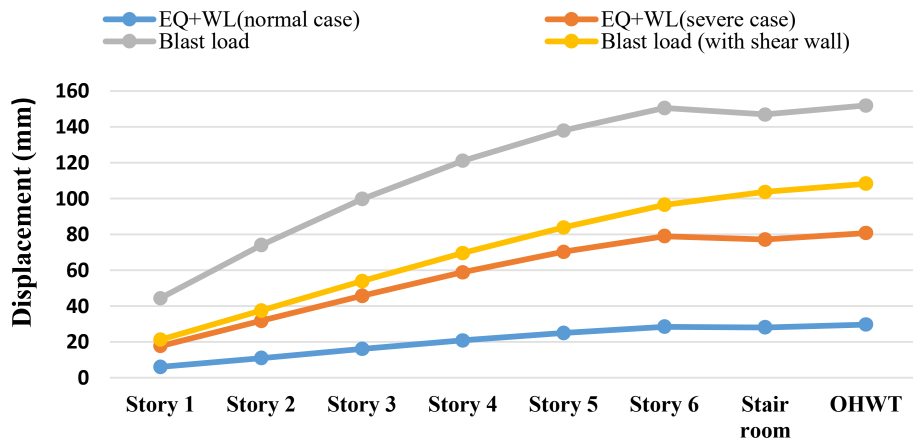

Figure 3: Displacement (mm) of different stories for various loading circumstances

From figure 3, it is clearly depicted that, for the usual case, the tale displacement is greatest under blast loading and lowest under mixed seismic and wind loads. The combined effect of seismic and wind load on the story displacement for the extreme case is greater than the combined effect of seismic and wind load on the story displacement for the usual case. After providing shear wall in building story displacement due to blast loading is reduced but still greater than the displacement under combined effect of seismic and wind load for both normal case and severe cases. Due to the certain change in vertical geometry of the building, a sudden change in displacement in between the two adjacent stories of story 6 and stair room story was observed. As there were less area to resist lateral loads in stair room story than the story 6, the lateral loads acted on the stair room story was also less than the story 6, which resulted in less displacement in stair room story than the story 6 for model 1, 2 and 3. By contrast, in the model 4, shear wall was provided on the building up to the story 6 only which reduced the displacement of story 6 to some extents to make the displacement of story 6 less than the displacement of the stair room story.

4.2 Story drift

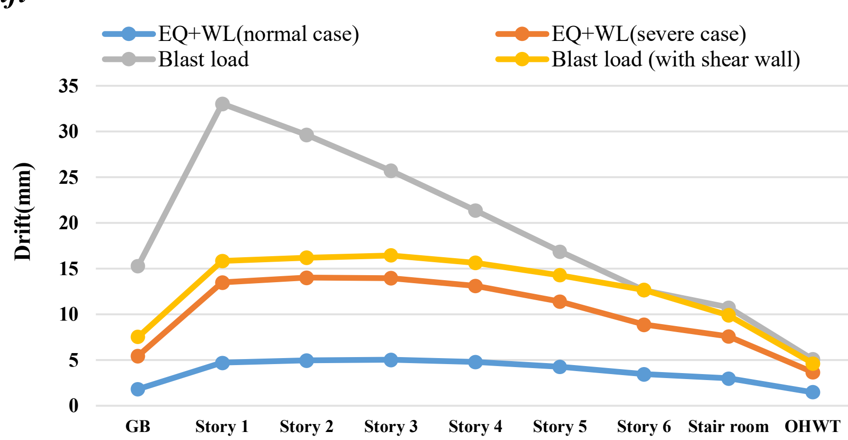

Figure 4: Drifts (mm) of different stories for different loading

Figure 4 represents that, in the usual case, tale drift is highest under blast loading and lowest under mixed seismic and wind loads. At higher stories, with the increase of story height, story displacement also increased at the same time; which eventually resulted in drop of story drifts values. The story drift for the extreme case under the combined effect of seismic and wind load is higher than the story drift for the average case under the combined effect of seismic and wind load. The story drift due to blast loading is minimized when a shear wall is installed in the house, but it is still greater than the story drift due to the cumulative impact of seismic and wind loads in both mild and extreme situations

4.3 Story Shear

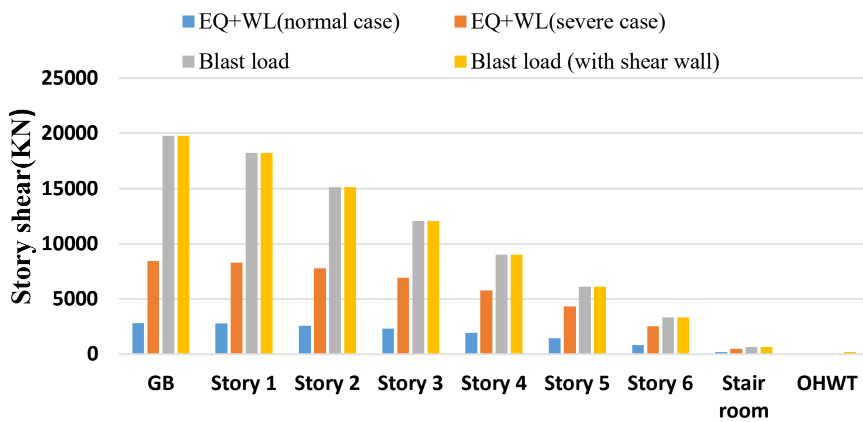

Figure 5. Shear (KN) of different stories for different loading conditions

Figure 5 indicates that for the usual case, shear of each story is highest under blast loading and lowest under combined seismic and wind loads. The combined effect of seismic and wind load on the story shear in the extreme case is greater than the combined effect of seismic and wind load on the story shear in the usual case.

5. Conclusions

The effect of blast loading on building is catastrophic. Analysis of building exposed to a blast owing to 100 kg TNT explosion showed that story displacement, story drift, story shear due to blast effect on building is far greater than effect due to other conventional loadings on buildings such as wind and seismic load. More specifically, the results for this study depicted that maximum story displacement under blast loading was 87.93% higher than story displacement under combined effect of seismic and wind load, which was 136.475% for story drift and 134.976% for story shear. After adoption of shear wall, story displacement and story drift under blast loading is reduced to some extent but still greater than the combined effect of seismic and wind load. More specifically story displacement and story drift is reduced by 28.703% and 50.2% after providing shear wall on building for equal blast effect on building. The results also presented that blast effect on building is far greater than effect due to other conventional loadings on buildings such as wind and seismic load. As the chance of a building being exposed to a blast phenomenon is really uncertain and design of a blast resistant building is costly, designer normally does not consider blast loading effect for designing. But as results showed, it would cause serious damage to structure, human life and property if a structure would ever face blast phenomena. So, buildings such as high-profile government buildings and monuments facilities, prestigious commercial office buildings, important shopping malls, dignified 5-star hotels or structures in proximity to petrochemical facilities should have blast resisting capacity.

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