Dynamic Analysis of Building Structures Under Explosive Loading: A Study of Structural Response

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Abstract. This study investigates the dynamic response of a G+3 building structure subjected to explosive loading through computational analysis. A 2×4 bay reinforced concrete frame structure was modeled and analyzed using ANSYS to evaluate the effects of TNT explosions at varying stand-off distances (10m, 15m, 20m, and 25m) while maintaining a constant explosive charge of 1.6 tons. The analysis focused on total and directional deformation characteristics of the structure. Results demonstrate that the structural orientation and stand-off distance significantly influence deformation patterns, with lower deformation observed when the explosion occurs on the shorter side of the structure. The study also highlights the importance of building placement and setback distances in mitigating blast effects. The findings provide valuable insights for blast-resistant design and structural vulnerability assessment in urban environments.

Keywords: Blast loading, Dynamic analysis, Stand-off distance, Structural deformation, TNT explosion

1. Introduction

The increasing occurrence of explosions in densely populated urban environments has become a significant concern for structural safety and human protection. Explosions, characterized by rapid energy release over microseconds, generate high-temperature fireballs and high-pressure blast waves that propagate at supersonic velocities into the surrounding environment [1]. Recent events like the 2020 Beirut blast have demonstrated the devastating consequences of explosive events in urban settings, with data showing that when explosive weapons are used in towns and cities, 91% of casualties are civilians [2], [3].

Urban environments comprise diverse geometries and layouts that significantly alter explosion effects and resulting blast injuries. The interaction of blast waves with urban structures leads to complex phenomena including reflection, shielding, and channeling. In confined spaces, blast waves can reflect, ricochet, and coalesce [4]. While some interaction mechanisms like shielding may be beneficial, others such as blast wave reflections from rigid surfaces can magnify overpressures significantly [5]. Analysis of historical events, such as the 2004 Madrid Train Bombings, has shown that confinement of explosions results in more severe injury outcomes [6].

The propagation and interaction of blast waves with obstacles in urban landscapes can be studied using computational fluid dynamics (CFD) modeling tools [7], [8]. These numerical methods enable examination of blast effects at different scales, from individual buildings to broader cityscapes, with varying levels of sophistication. The modeled blast loading parameters can then be used to estimate injury risk and expected casualty distribution by referring to established injury criteria [9]. However, current injury prediction methods often rely on idealized blast wave assumptions that may not accurately reflect real urban scenarios [10].

The aim of this study is to investigate the dynamic response of reinforced concrete structures under explosive loading, with specific focus on how building orientation and stand-off distance affect structural deformation patterns. Using a G+3 building with 2×4 bay configuration as a case study, this research analyzes the structural behavior when subjected to 1.6 tons of TNT explosive at varying distances (10 m – 25 m) from both longer and shorter faces of the building. The findings show significantly different deformation patterns based on the explosion's orientation relative to the building faces, with explosions on the shorter side resulting in lower deformation. This research addresses critical knowledge gaps in blast-resistant design by providing quantitative data on how structural geometry and orientation influence blast response characteristics, essential for developing more resilient urban structures.

2. Methodology

In this study, a blast analysis is conducted on G+3 structures to investigate the effects of an explosive material detonated at varying distances from one of the structure's faces, while keeping the amount of explosive material constant. The methodology involves a step-by-step procedure for simplified blast analysis and the evaluation of the explosive's effects. Dynamic analysis using ANSYS is performed to determine the explosive's energy and compare it with manually calculated values. To assess the behavior of the explosive and its impact on the structure, a G+3 structure with a 2×4 bay configuration is analyzed for different stand-off distances using a large amount of explosive.

For the determination of explosive effects on the structure a 3-story beam column frame with no infill is used. The story height and bay width is 3m. Frame is of 2×4 bay (6m×12m) and in the frame column of size of 300×500 mm, beam of size 300×600 mm (B1) and 500×600 mm (B2) and slab of thickness 125 mm have been used.

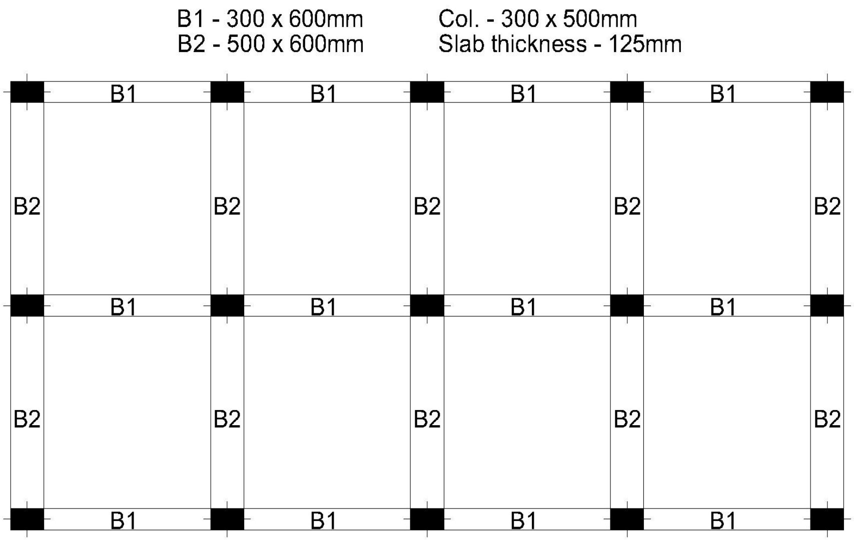

Fig. 1 Plan of the structure modelled

Table 1 Material property

S.no.	Property	Value	Unit
A	CONCRETE		
1.	Density	2300	kg /m^3
2.	Young's Modulus	30000000000	Pa
3.	Bulk Modulus	15625000000	Pa
4.	Shear Modulus	12711864406.7797	Pa
5.	Specific Heat	780	J/ kg C
6	Compressive Strength	30000000	Pa
B	TNT		
1.	Density	1630	kg /m^3
2.	Parameter A	373770000000	Pa

3.	Parameter B	3747100000	Pa
4.	Parameter R1	4.15	
5.	Parameter R2	0.9	
6.	Parameter ω	0.35	
7.	C-J Detonation Velocity	6930	m /s
8.	C-J Energy / unit mass	3681000	J /kg
9.	C-J Pressure	21000000000	Pa

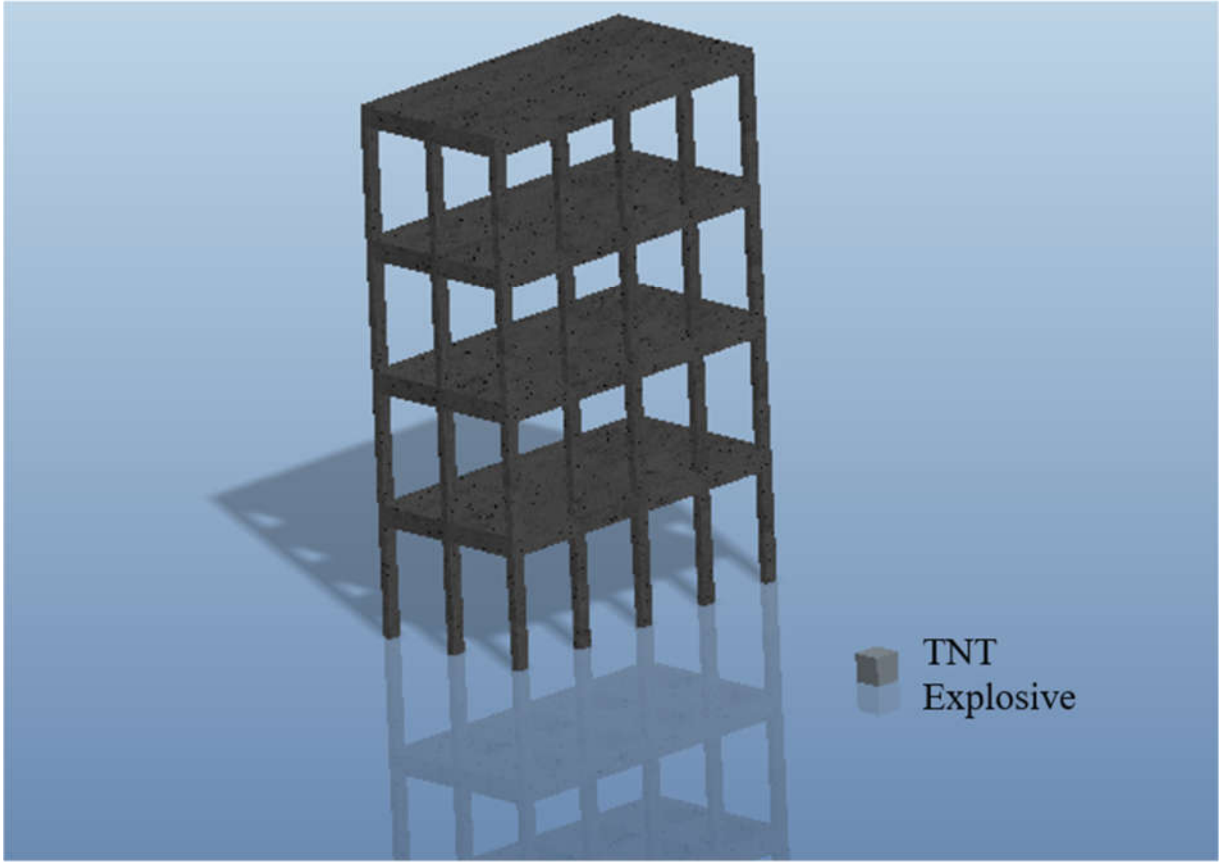

Fig. 2 G+3 structure with TNT Explosive

3. Result and Discussion

In this study, dynamic analysis is performed in order to determine the effects of blast impact on the modeled structure. Total & Directional Deformation of Structure are considered in the analysis. As explosion takes place a large amount of energy released which depends on the amount/weight/type of explosive material. In the analysis large amounts (1.6 ton) of explosive material TNT is used and detonate at different distance (10m, 15m, 20m and 25m).

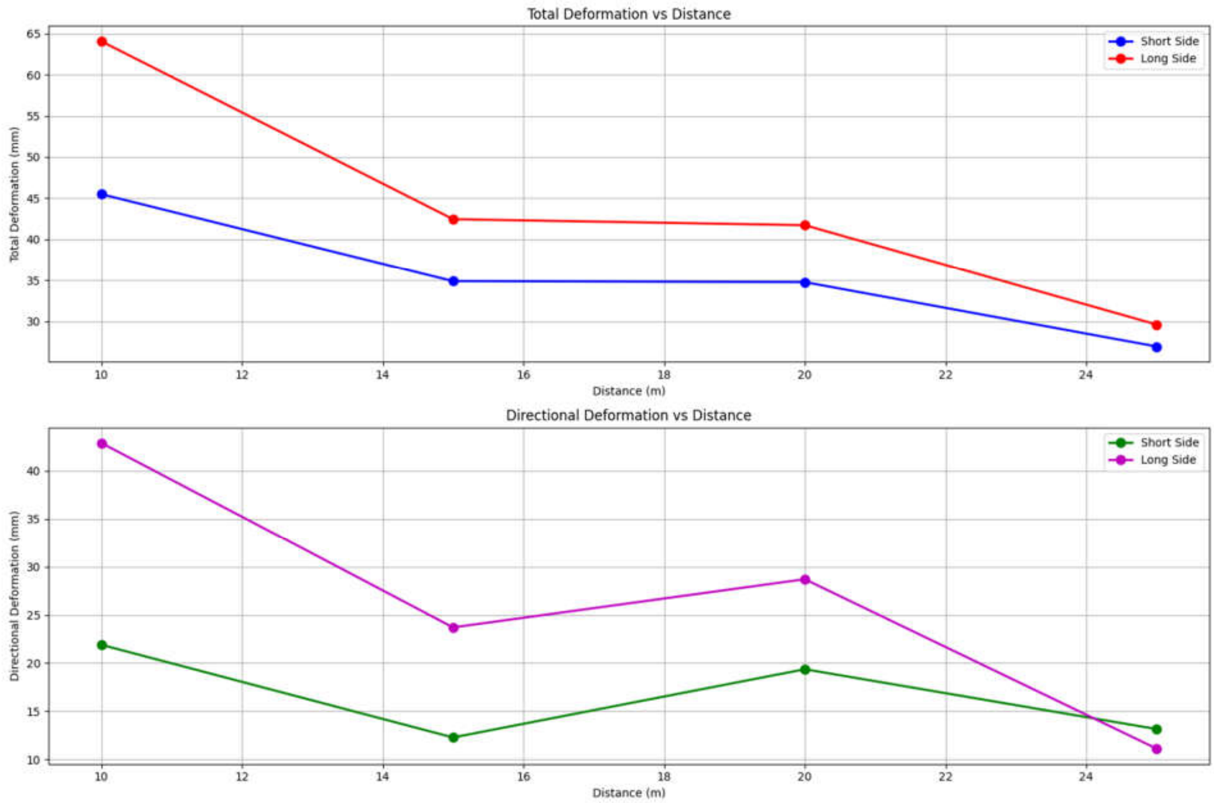

Fig. 3. Comparative analysis of structural deformation under blast loading

Fig. 3 demonstrate the significant influence of distance and structural orientation on deformation characteristics, with consistently higher deformation values observed when blast occurs on the longer side of the structure. It is also observed that deformation in the structure is less when explosion takes place in front of shorter side, as well as pressure on the structure is less when explosion takes place in front of longer side. Analysis of structural deformation revealed distinct patterns based on the explosive's location relative to the building faces. When detonation occurred on the shorter side of the structure, maximum total deformation ranged from 26.94 mm at 25m standoff distance to 45.5 mm at 10m standoff distance. Directional deformation values varied from 13.15 mm to 21.9 mm across these distances. For explosions on the longer building face, total deformation was notably higher - reaching 64.07 mm at 10m standoff distance and decreasing to 29.60 mm at 25m. Directional deformation followed a similar trend, measuring 42.92 mm at 10m and reducing to 11.12 mm at 25m standoff distance.

The data demonstrates that deformation was consistently greater when the explosion occurred on the longer side of the structure. For instance, at 10m standoff distance, the total deformation was approximately 41% higher for the longer side (64.07 mm) compared to the shorter side (45.5 mm). This pattern held across all tested standoff distances, though the difference became less pronounced at greater distances The deformation values decreased non-linearly with increasing standoff distance in both cases, showing the expected decay in blast wave energy over distance. The rate of decrease was more pronounced between 10m to 15m compared to 20m to 25m, indicating the non-linear nature of blast wave attenuation.

4. Conclusion

Based on the analysis and results presented in this study, several key conclusions can be drawn:

- Stand-off distance plays a crucial role in structural response to blast loading, with deformation decreasing as the distance increases from 10m to 25m.
- Building orientation significantly affects blast impact, with lower deformation observed when explosions occur facing the shorter side of the structure compared to the longer side.
- Building placement and setback distances are critical considerations in reducing structural vulnerability to blast effects. The common practice of creating large plaza areas in front while minimizing setbacks on other sides increases vulnerability on those faces.
- For more accurate assessment of blast effects in real-world scenarios, detailed modeling and analysis considering specific structural configurations and site conditions are essential.

These findings contribute to the understanding of blast-structure interaction and can inform better design practices for blast-resistant structures in urban environments.

5. References

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