Analysis of Multi-Storey Buildings Under Blast Loads: Influence of Floor Shape on Structural Performance

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Abstract: In general, two different types of loads act on structure artificial and natural loads. Loads due to some material comes in artificial and wind, earthquakes are neutral load, but in this modern world blast load also consider. Blast load applied sudden and extreme on structure, cause of structure can be vary depending on situation either it is gas cylinder blast, chemical blast or terrorist activity and many more. During the explosion blast waves propagate rapidly and exert high-pressure of building surface that could damage the structural elements and lead to structural failure. The primary objective is to establish correlations between floor shape and blast resistance, offering insights into design improvements for enhanced structural performance. For this study four different shapes (L, T, C and Hexagon) of plans of building modelled in E-tabs. Midair blast was considered, and load pressure was calculated. A triangular function for blast load applied in E-tabs and analysis was performed. Deformed shape of structure, storey drift, shear force, overturning moment were analyzed and columns sections which are in front of blast, are also analyzed based on axial force. After all the analysis found that hexagon shape of floor plan performed batter than the other floor shape. Displacement was 65–70% lower than the C-shape. Overturning moment was 55–60% less than in T and C shapes. Storey drift was consistently minimal across all floors. Critical column forces were the lowest in axial force. Its symmetrical and closed layout ensured uniform force distribution, minimal stress concentration, and superior blast resistance.

Keyword: Blast load, Building structure, E-tabs, Structural Analysis.

1. INTRODUCTION

The structural safety of buildings under extreme loading conditions has become an essential area of study in both civil and defense engineering. Among these extreme conditions, blast loads pose a particularly high risk due to their sudden onset, high intensity, and potential to cause widespread structural damage and loss of life. As urban infrastructure grows denser, especially in sensitive or high-risk areas, the ability of buildings to withstand such impulsive loads has become a pressing concern for structural engineers and policymakers.

The increasing frequency of blast-related incidents whether due to industrial accidents or deliberate attacks has brought structural safety under renewed focus, particularly in urban environments. Among the various parameters influencing a building's response to such dynamic loads, the shape of the floor plan is a key architectural factor that can significantly affect how blast energy is distributed and absorbed by the structure. This research focuses on evaluating the blast load response of buildings with different floor plan geometries using ETABS, a widely adopted structural analysis and design software. By modeling various floor shapes, including rectangular, circular, L-shaped, and T-shaped layouts, the study examines how geometric configurations influence parameters such as lateral displacement, base shear, and stress distribution under a uniform blast scenario. All the properties of each building model is same including material and loading conditions to make comparison effective

The increasing occurrence of blast events—whether due to industrial accidents, terrorist attacks, or military actions—has led to heightened interest in the blast-resistance of buildings, particularly in densely populated urban.[1] Shape of floor is very important factor to understand how blast load distributed in structural system [2]. In recent studies done by Li et al and Chakraborty & Roy recommended that unsymmetrical floors of buildings can give rise to stress concentration and uneven load distribution during the blast. By using a uniform modelling approach with consistent material properties, this study provides a comparative framework for understanding the benefits and vulnerabilities associated with different soil geometry under explosive forces. The results of this study contribute to a performance-based design approach for explosion resistant buildings and are expected to influence architectural decisions in both new construction and remodelling projects [3,4].

These findings support safer urban development in areas that are under the threat of a potential explosion. The main goal of this study is to numerically analyse the effects of explosions on multistorey buildings with different floor

geometries. This study focuses on the shapes of various floorplans and their impact on key structural parameters such as maximum-deflection, stress concentration, and failure mode.

2. MODELLING

For the study four different building floor shapes—L-shape, T-shape, C-shape, and Hexagon-shape generated in E-Tabs to understand how floor geometry influences structural performance under blast loads. The analysis considers a 10-storey building designed with M25 concrete for beam and M30 for column, with beam size of 350 x 600 mm and column size of 400 × 400 mm. Each building model has 10 floors, ground floor height is 3.5 m and typical floor height is 3 m.
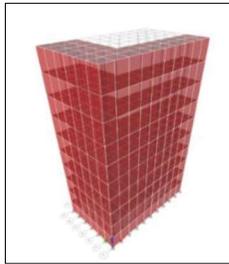

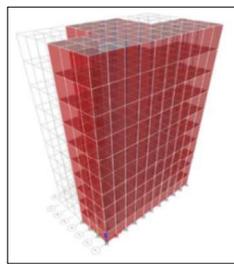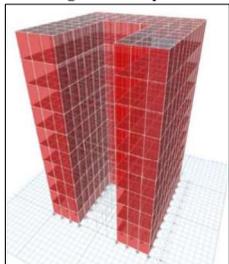**Fig. 1** L- shape model   **Fig. 2** T- shape model
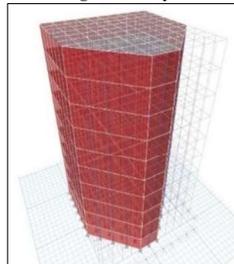

Fig.3 C- shape model   Fig.4 Hexagon-shape

On building models total three types of loads are applied dead, live and blast load. For dead and live load IS code 875 part 1 and part 2 were used. All the building were considered as a residential building. In compliance with UFC 3-340-02: Structures to Resist the Effects of Accidental Explosions (DoD, 2008), blast loads were applied. To guarantee the dependability of the applied loading parameters, additional guidelines were also cited from ASCE (2010)-Design of Blast-Resistant Buildings in Petrochemical Facilities.[5,14] For the mid-air blast pressure following equations are use for different values:

Scaled Distance (Z)
$$Z = \frac{R}{W^{1/3}}$$
Z is the scaled distance in m/kg, R is the actual standoff distance (m), W is the TNT equivalent mass (kg)
Peak Overpressure (Ps)
$$P_s = 22.17 \times Z^{-1.38} \quad (for\ 1 \leq Z \leq 10)$$

Peak overpressure (Ps), Positive phase duration (tp), Impulse (I)

Impulse estimation is based on:
$$I = 70.8 \times Z^{-0.46} \quad (for\ 1 \leq Z \leq 10)$$

Reflected Overpressure (Pr)
For normal reflection, the overpressure is:
$$P_r = P_s \left(2 + \frac{6}{\gamma+1}\right)$$
where γ=1.4 (specific heat ratio for air).

Dynamic Pressure (q)
$$q = 0.5\rho_o u^2$$
where
$$u = \sqrt{\frac{2P_s \times 10^3}{\rho_o}}$$
ρo is ambient air density (kg/m³)
u is the blast wave velocity (m/s)[5]

Estimate Blast Wave Arrival Time
The shock wave arrival time (ta) can be estimated using:
$$t_a = \frac{R}{C_o}$$
where C_o is the speed of sound in air (~343 m/s at sea level).

For the blast we consider 500 kg TNT explosive from that results are: Scaled Distance (Z): 0.38 m/kg^1/3 Peak Overpressure (Ps): 84.90 kPa, Impulse (I): 110.5 kPa-ms, Reflected Overpressure (Pr): 382.01 kPa, Dynamic Pressure (q): 8.5 kPa.
A blast load follows a typical triangular or exponential decay function,[13] where: The peak pressure rises almost instantly (shock wave), the pressure decays over time (positive phase duration). A simple approximation for pressure-time variation is:
$$P(t) = P_r \times e^{-t/t_p}$$
where: P_r = 382.01 P_r = 382.01 P_r = 382.01 kPa (reflected pressure), tp = Positive Phase Duration
For scaled distances around Z=0.38, the approximate positive phase duration is: $t_p \approx 1.8 \times W^{1/3} \times Z^{0.22}$.
Substituting W=500 Kg and Z=0.38 $t_p = 1.8 \times 500^{1/3} \times 0.38^{0.22} = 11.53\ ms = 0.0115\ sec$.

3. RESULTS AND ANALYSIS

3.1 Displacement
It was assumed that the explosion happened at height of fifth floor. So floor displacement is maximum at that level.
Displacement in all building shapes gradually increases with height, peaking at the topmost floor, as expected under lateral blast loads. Because of its open and uneven geometry, the C-shaped building exhibits the greatest displacement among the four shapes, suggesting the highest lateral flexibility and the least stability.
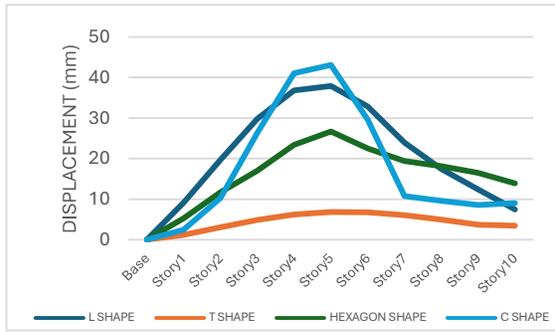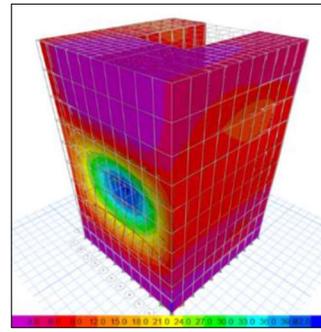
Fig.4 Overturning-moment comparison

Table 1: Max Displacement

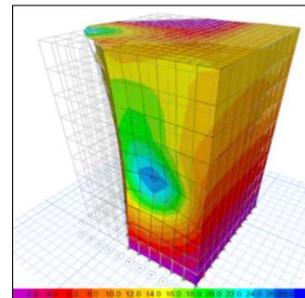| Max. Displacement (mm)				
Storey	L-shape	T-shape	C-shape	Hexagon shape
Story10	7.476	3.454	8.977	13.896
Story9	12.401	3.681	8.587	16.491
Story8	17.407	4.984	9.587	18.159
Story7	23.917	6.078	10.763	19.407
Story6	32.839	6.711	29.714	22.531
Story5	37.914	6.831	43.106	26.675
Story4	36.756	6.219	41.062	23.425
Story3	29.843	4.857	26.352	17.066
Story2	19.694	3.026	10.269	11.664
Story1	9.078	1.177	2.427	5.222
Base	0	0	0	0

Because of its symmetrical and contained design, which improves structural rigidity and resistance to lateral stresses, the hexagon-shaped building shows the least amount of movement. [8]
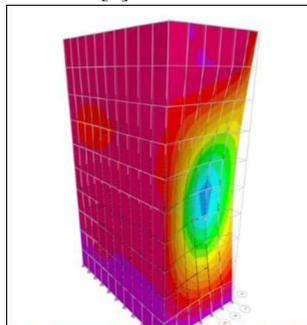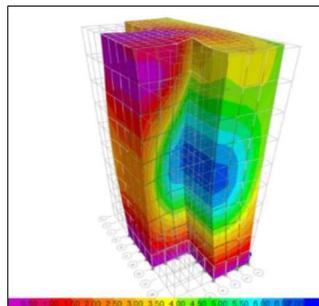

Fig. 5 Deformation in L-shape

Fig. 6 Deformation in T-shape

Fig.7 Deformation in C -shape

Fig.8: Deformation in Hexagon Shape

With moderate displacement values, the L-shaped and T-shaped buildings are in the middle, demonstrating how their capacity to manage lateral deformation is impacted by plan asymmetry. These patterns clearly show how floor design affects overall stability, with symmetrical arrangements offering greater resistance and less flexibility when subjected to dynamic stresses.

3.2 Storey Drift

Table 2: Storey Drift

Storey Drift (kN-m)				
Storey	L-shape	T-shape	C-shape	Hexagon shape
Story10	0.003127	0.000575	0.000465	0.003936
Story9	0.003576	0.000533	0.001135	0.00193
Story8	0.003242	0.000472	0.003995	0.002045
Story7	0.00263	0.000337	0.005677	0.0016
Story6	0.001533	0.000144	0.003826	0.002503
Story5	0.000676	0.000227	0.000584	0.000928
Story4	0.001975	0.000414	0.004203	0.002459
Story3	0.0029	0.000523	0.004595	0.001587
Story2	0.003033	0.000533	0.002478	0.001888
Story1	0.003026	0.000392	0.000809	0.001741
Base	0	0	0	0

The storey drift graph clearly shows that the C-shaped building experiences the highest and most irregular drift values, with sharp peaks—particularly at Storeys 3 and 7—indicating significant lateral flexibility and reduced structural stability. The L-shaped building displays moderate drift, with noticeable variations that suggest localized deformation due to its asymmetrical geometry.[6]
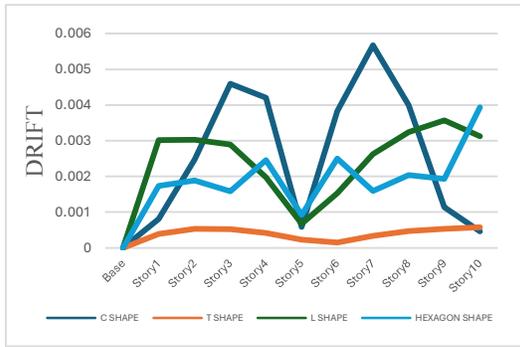
Fig. 9 Storey drift comparison

The Hexagon-shaped building maintains relatively consistent and lower drift values across all storeys, reflecting its symmetrical layout and efficient load distribution, which enhance lateral stability. The T-shaped building shows the lowest and smoothest drift profile, indicating good stiffness and minimal inter-storey movement, though this performance may also depend on specific load conditions or structural configuration.

3.3 Overturning Moment

Building stability under lateral or in our case blast load loads is directly influenced by the intensity of overturing moment, generated due to blast load C-shaped buildings have the highest overturning moment, caused by irregular, open geometry that causes uneven load distribution. The T shape also exhibits a high overturning, while the L-shape works moderately. In contrast, hexagonal building has the lowest overturning-moment. This emphasizes excellent stability due to geometric symmetry and balanced stiffness.

Table 3: Over-turning moment

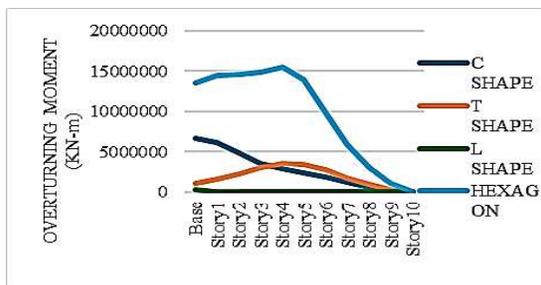| Over -Turning moment (kN-m)			
Storey	L-shape	T-shape	C-shape	Hexagon shape
Story10	1.84E-6	0	0	0
Story9	400.725	351433.2	140609.025	1016314
Story8	0	939859	543775.883	3056831
Story7	0	1756169	1210438.17	5855629
Story6	0	2727405	1917061.78	9832776
Story5	187.730	3477981	2432761.88	13975593
Story4	820.759	3596374	2848844.04	15486559
Story3	0	3082183	3569210.69	14810304
Story2	0	2296814	4830498.93	14620456
Story1	15992.4	1542821	6193747.00	14438130
Base	235922.	1119681	6663666.21	13581239

Fig.10 Overturning-moment comparison

3.4 Shear Force

Geometry affects the way loads pass through the structure, so the distribution distribution and load path efficiency vary widely depending on the ground shape. The C-shaped building shows the highest comprehensive power. This indicates inefficient load paths and force concentrations in a particular area.

Table 4: Shear Force

Shear Force (kN)			
Storey	L-shape	T-shape	C-shape	Hexagon shape
Story10	1343961	624147	1725093.29	351145
Story9	2075714	947750	3255545.98	319442
Story8	2014612	916519	4116635.25	138914
Story7	1228446	593288	3411237.72	0
Story6	129726	80592.5	875732.934	1117549
Story5	3031990	1516995	5049686.06	3036535
Story4	0	0	0	0
Story3	0	0	0	0
Story2	0	0	0	518145
Story1	0	0	0	0
Base	0	0	0	0

In contrast, the Hexagon-shaped structure displays the lowest shear force, highlighting an efficient and uniform load distribution thanks to its symmetrical and enclosed form.
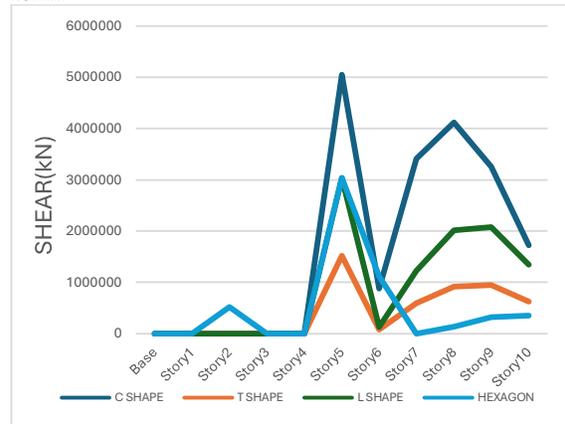

Fig.11 Shear force comparison

This improved shear resistance enhances overall structural stability and reduces the likelihood of local failures. From a design perspective, buildings with higher shear demands, particularly those with irregular layouts, require larger and more heavily reinforced members to ensure safety, whereas symmetric shapes like the hexagon allow for more optimized member sizing and economical reinforcement detailing.

Critical columns for all the models are also analysed for the axial force due to blast loads. Blast occurs at the height of 5th floor so all the columns which are at 5th floor and face the blast explosion directly were analysed.[7]

Table 5: Axial force in critical column

Axial Force (kN) in Critical column			
Time	L-shape	T-shape	C-shape	Hexagon shape
0	0	0	0	0
0.001	-3.9313	-7.8314	-0.3002	2.2233
0.002	-25.402	-50.827	-1.5698	15.3051
0.003	-59.481	-120.14	-1.9076	40.3186
0.004	-93.369	-192.11	1.9971	75.847
0.005	-114.06	-243.40	13.5485	120.4171
0.006	-111.67	-257.47	35.2802	172.7219

The axial load-carrying demand varies considerably with floor shape, affecting the stress concentration and risk under blast loading. The C-shaped and T-shaped buildings exhibit the highest axial forces in critical columns, indicating concentrated compression zones near the central and re-entrant areas due to uneven load paths and irregular geometry. These zones become highly stressed and susceptible to failure under additional dynamic loads, increasing the risk of progressive collapse, especially if one column fails and triggers a chain reaction.[9]
The L-shaped structure shows moderately high axial forces, particularly around the corner junctions where force flow changes direction. On the other hand, the Hexagon-shaped building demonstrates the lowest and most evenly distributed axial force, thanks to its closed and symmetric form, which allows for balanced load-sharing among vertical elements. This reduces critical stress points and enhances redundancy, making the structure less vulnerable to collapse in extreme scenarios.
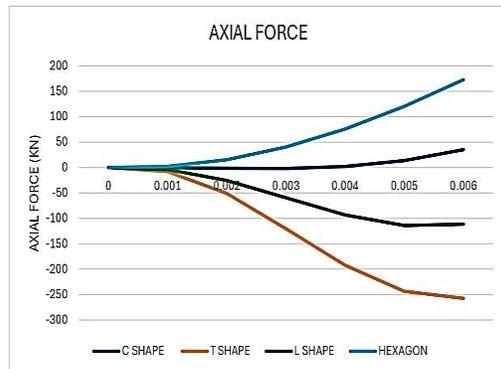

Fig.12 Axial force comparison in critical column

3.5 Fundamental Model Period of vibration:
Compared to the L-shape (0.051 s), T-shape (0.050 s), and C-shape (0.047 s), the hexagon-shaped building consistently exhibits the shortest fundamental period (0.036 s) according to the modal period data. This suggests that the hexagon is the stiffest and will therefore likely experience the least overall displacement under blast loading. Because of their longer fundamental periods and higher number of modes below 0.02 s, the L- and T-shaped buildings are more flexible and display complex dynamic behavior, which leaves them more susceptible to localized amplifications at re-entrant corners and torsional effects.

Compared to the L-shape (0.051 s), T-shape (0.050 s), and C-shape (0.047 s), the hexagon-shaped building consistently exhibits the shortest fundamental period (0.036 s) according to the modal period data. This suggests that the hexagon is the stiffest and will therefore likely experience the least overall displacement under blast loading.

Table 6: Fundamental Model Period of vibration for 12 mode

Case	Mode	L-shape	T-shape	C-shape	Hexagon shape
		Period	Period	Period	Period
		sec	sec	sec	sec
Modal	1	0.051	0.05	0.047	0.036
Modal	2	0.032	0.034	0.036	0.031
Modal	3	0.026	0.019	0.026	0.024
Modal	4	0.02	0.018	0.022	0.022
Modal	5	0.017	0.012	0.02	0.021
Modal	6	0.016	0.012	0.019	0.02
Modal	7	0.014	0.012	0.016	0.019
Modal	8	0.013	0.012	0.014	0.018
Modal	9	0.013	0.011	0.014	0.016
Modal	10	0.012	0.01	0.014	0.016
Modal	11	0.012	0.01	0.013	0.016
Modal	12	0.011	0.009	0.013	0.015

Because of their longer fundamental periods and higher number of modes below 0.02 s, the L- and T-shaped buildings are more flexible and display complex dynamic behavior, which leaves them more susceptible to localized amplifications at re-entrant corners and torsional effects.
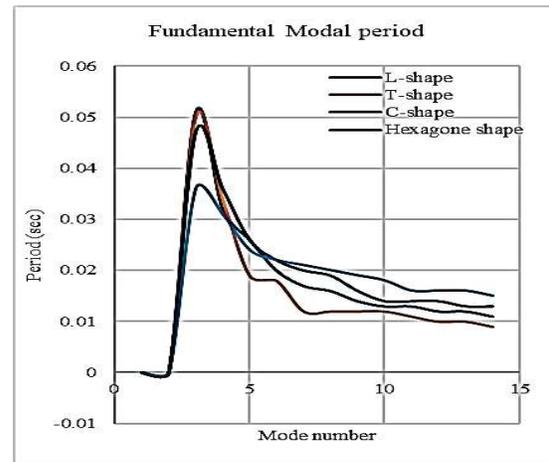

Fig.13 Fundamental Modal Period

In the middle is the C-shape, which has moderate modal distribution and stiffness. In general, irregular L- and T-shapes are less desirable because of their vulnerability to torsional coupling and higher displacement demands, whereas the hexagonal plan provides superior blast resistance in terms of global stability and decreased displacements.

4.CONCLUSION

This study titled "Numerical Analysis of Multi-Storey Buildings Under Blast Load – Influence of Floor Shapes" has successfully fulfilled its objective of evaluating the effect of floor geometry on the structural performance of buildings under blast loading. Four different floor plans— T-shaped, C-shaped, L-shaped, and Hexagon-shaped were analyzed using numerical simulations, focusing on parameters such as maximum displacement, overturning moment, shear force, storey drift, and the behavior of critical columns under axial force, shear, and bending moment.[10]

Hexagon Shape: Best Overall Performer. Displacement was 65–70% lower than the C-shape. Overturning moment was 55–60% less than in T and C shapes. Storey drift was consistently minimal across all floors. Critical column forces were the lowest across all categories (axial, moment, and shear). Its symmetrical and closed layout ensured uniform force distribution, minimal stress concentration, and superior blast resistance.

L-Shape: Moderate Performance. Displacement was around 30–40% lower than in the C-shape. Shear and bending forces in critical columns were noticeable but manageable. Showed better performance than T- and C- shapes but still had localized weaknesses at re-entrant corners. Required moderate reinforcement in critical regions to ensure structural safety.

T-Shape: Below Average Performance. Overturning moment was second-highest, suggesting torsional imbalance. Critical column shear and bending moments were 35–45% higher than in the hexagon. Geometry caused force concentration at the stem-crossbar junction, reducing blast efficiency. Adequate for moderate conditions but required detailed design reinforcement.

C-Shape: Least Blast-Resistant. Recorded the highest values in all key metrics, Displacement, Storey drift, Overturning moment, Axial and shear forces in critical columns. Open and irregular floor plan caused inefficient load paths and stress concentration. Required extensive reinforcement and design corrections to perform safely under blast scenarios.

This study effectively evaluated shear forces, bending moments, and stress distribution under blast loading for each of the selected building shapes. By analysing both overall structural response and localized behaviour in critical columns, the research provided a comprehensive picture of how forces develop and propagate within different geometries. Graphs and data tables highlighted the magnitude and variation of these parameters, allowing direct comparison of structural demands across T, C, L, and Hexagon shapes. For example, the C-shape consistently recorded the highest shear and moment values, particularly in columns located near re-entrant corners, indicating greater force concentration due to irregular geometry.[11] The research clearly showed the effect of floor configuration on structural robustness and blast cause stimulating. Open and asymmetric shapes like the C- and T-shaped buildings exhibited greater displacement, overturning moment and storey drift, which contributed towards less stability. On the other hand, the Hexagon shape that has a plan closed and symmetrical arrangement showed a better superstructure performance of the lateral and vertical loads. These observations are consistent with the purpose of quantifying the effect of floor plan disposition, and they support the classical structural hypothesis of the more regular geometry providing better load spreading over the structure, and less deformation. Furthermore, different failure modes were observed in each type of building. The T-shaped form indicated torsional yielding at the junctions of the stem to arm, and the C-shaped one demonstrated high drift and stress concentrations at corners, indicative of possible sliding or diagonal cracking failures. These results satisfy the purpose of comparing failure characteristics between different geometries and indicate the necessity of taking into account a shape-induced imperfection in the geometries design. If the behavior is known and understood, then an engineer can predict where in a test piece a failure might begin and can place controls to control that failure.[12]

The study was also successful in determining which crucial structural elements were most impacted by blast loads. It was discovered that in buildings with irregular shapes, critical columns at corners or junctions bear noticeably greater axial and shear forces. Targeted reinforcement recommendations were made possible by the moment and shear analysis in these columns. These revelations confirm the accuracy of the numerical results, as does the observed behavior's alignment with established structural theory. Overall, the research concludes hexagon-shaped buildings provide the most blast-resistant configuration, confirming the final objective and offering valuable guidance for future design in blast-prone environments.

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