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Seismic Analysis Of G+20 Irregular Building With Top 5 Floor Swimming Pool

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ABSTRACT

This study focuses on the seismic analysis of a G+20 irregular building with a top 5- floor swimming pool, utilizing the Response Spectrum Method in ETABS software for seismic evaluation in Seismic Zone V. The building's irregularities, especially due to the presence of a swimming pool at the upper floors, were carefully modeled to simulate their effect on the building's seismic response. The analysis aimed to evaluate the displacement, overturning moments, base shear, and storey drift under seismic loading conditions, considering the dynamic interaction between the swimming pool and the building structure. The study shows that the irregular geometries, particularly in the Squared-shaped, C-shaped, I-shaped and L-shaped configurations, lead to higher displacement and torsional effects when subjected to seismic forces, while the square-shaped building exhibited the best performance in minimizing these effects.

The findings from the seismic analysis demonstrate that although the addition of a swimming pool increases the seismic response, all structural configurations remain within the permissible limits prescribed by IS 875 and IS 1893-2016. The response spectrum method in ETABS provided a comprehensive understanding of the building's behavior under seismic loading, including the influence of irregularity and additional loads from the swimming pool. The results highlight the importance of incorporating dynamic effects such as base shear, overturning moment, and storey drift when designing tall buildings with additional loads like swimming pools, ensuring structural integrity and stability in high seismic zones like Zone V.

Keywords: *Seismic Analysis, Swimming Pool, Top floor , Mass distribution, Response Spectrum Method, Multi-story Structures, Comparative Analysis.*

1. INTRODUCTION

Contemporary Indian urban development sees a rise in reinforced concrete (RCC) high-rise buildings, often featuring rooftop swimming pools and gardens. While these enhance appeal, they introduce structural complexities, notably the concentrated weight of pools. Though manageable within standard engineering practices, a pool failure could cause localized damage. Interestingly, in certain seismic scenarios, the pool's water mass can actually improve earthquake resistance by acting as a tuned liquid damper.

Given India's geological activity, the subcontinent is susceptible to earthquakes due to the ongoing northward movement of the Indian tectonic plate. A considerable portion of India's land is earthquake-prone, and projections indicate a significant urban population will face increasing risks from earthquakes and other natural disasters. India's seismic design code divides the country into four seismic zones based on varying levels of potential ground shaking.

A substantial part of urban construction consists of buildings with structural irregularities, particularly vertical variations in stiffness and mass, which significantly alter their response to earthquakes compared to regular structures. Consequently, in-depth analysis of these irregular buildings across different Indian seismic zones and careful evaluation of performance at each level are now vital for ensuring their ability to withstand earthquakes. This research project centers on a detailed seismic analysis of a G+20 RCC building with plan irregularity and a unique architectural element: a multi-level, top five-floor swimming pool complex. The study addresses the compounded complexity arising from the substantial mass and potential water movement effects of this large, elevated water feature, aiming to understand the dynamic interplay between the building's irregular design, the added pool mass, and potential sloshing during an earthquake to ensure structural integrity.

AIMS AND OBJECTIVES

The objectives of study are outlined below.

- Analyze the dynamic response of G+20 structures with mass irregularities and a top 5 floors swimming pools are located in Seismic Zone V, utilizing the Response Spectrum method in ETABS.
- Evaluate the influence of mass irregularities on structural behavior by comparing analysis results across the square-shaped, C-shaped, I-shaped, and L-shaped plan.
- Determine the impact of the rooftop swimming pool on seismic response by comparing structural models with and without swimming pool.
- Compare and analyze key seismic parameters lateral displacement, story shear, story drift, and overturning moment across various structural models with differing plan shapes (square, C, I, L,).

2. LITERATURES REVIEW

Existing research thoroughly covers the structural analysis of tall buildings with pools and irregularities in seismic zones, using Indian Standard codes. Specific studies on G+20 irregular buildings with rooftop pools highlight the need for accurate modeling to ensure structural integrity and earthquake resilience in complex designs.

De Stefano et al. [1] review summarized advancements in understanding the seismic behavior of buildings with plan and vertical irregularities, focusing on torsional effects in plan-irregular buildings, the use of passive control strategies, and the seismic response of vertically irregular structures like setback buildings. The study highlighted the increasing research focus on these complex structural behaviors under seismic loads.

Kyoung Son Moon et al. [2] study analyzed the evolution towards diverse and complex tall building designs, like twisted and tilted structures, and explored performance-based structural engineering options for them. The research involved designing and analyzing various structural systems for different complex forms, using parametric models to understand the influence of geometric variations on structural efficiency

Shreya H. et al [3] study investigated the impact of seismic forces on buildings with swimming pools on each floor, noting the risks associated with water behavior during earthquakes and the potential for dynamic buckling. The research compared static and dynamic analyses, highlighting the significant hydrodynamic effects of water movement on the building's structural integrity during seismic events and emphasizing the need for improved design strategies.

Amol Jadhav et al. [4] explored cost-effective designs for reinforced concrete rooftop swimming pools, which are used for recreational water storage. Their research optimized these designs, considering hydrostatic pressure on walls and water weight on the base, in line with Indian standards, and analyzed the impact of material properties and pool size on construction costs using MATLAB.

Ali Ruzi Özuygur et al. [5] study detailed the seismic structural design of a 50-story Istanbul residential building with an irregular layout, a project ultimately not built. The design adhered to Istanbul's tall building seismic code, employing response spectrum and nonlinear time history analyses to address the high seismic risk and complex geometry of the linked twin-tower structure**.**

Gayathri Suja et al. [6] study examined seismic risks in multi-story building swimming pools, often overlooking earthquake-induced water sloshing. Using ANSYS 16, they modeled a rectangular pool to simulate water movement and analyze resulting structural stresses during seismic events, also considering the pool's vertical position. The research emphasized the necessity of accounting for fluid dynamics and pool location in seismic design to prevent building damage.

Pawar Jagruti Vasant et al. [7] study aimed to optimize the structural design of underground rectangular swimming pools, considering the various pressures they face and adhering to Indian Standards. Their research used MATLAB to analyze how changes in concrete grade and pool depth (capacity) affect construction costs, seeking material savings while maintaining structural safety through nonlinear programming.

Shilpa Sara Davidson et al. [8] study explored using rooftop swimming pools in tall buildings as tuned mass dampers (TMDs) to lessen wind and earthquake vibrations. They modeled concrete structures with and without optimized swimming pools in SAP2000, finding that a properly tuned pool could effectively decrease peak structural response to seismic forces, suggesting an innovative approach to building safety.

Akash Agrawal et al. [9] study analyzed how the placement of rooftop swimming pools in high-rise RCC buildings affects their seismic response. Using Dynamic Response Spectrum Analysis in STAAD.Pro, they compared one-sided, two-sided, three-sided, and centered pool positions, considering hydrostatic and seismic forces to determine the most efficient placement based on material use and structural performance like displacement and stress.

Vaishnavi B. Naik et al. [10] study investigated the seismic behavior of RCC twisted buildings with private swimming pools, using ETABS to analyze the impact of varying twist degrees (1.5-5 per floor) and different pool placements (every, alternate, specific floors). Employing the Response Spectrum Method, the research assessed how these factors influenced storey displacement, drift, and base shear, providing insights for designing seismically resilient twisted buildings with pools.

Pawar Jagruti Vasant et al. [11] study focused on optimizing the structural design of underground rectangular swimming pools, considering hydrostatic and soil pressures on walls and water weight/uplift on the base, according to Indian Standards. Using MATLAB and nonlinear programming, the research analyzed the impact of concrete grades and pool depth on cost-effectiveness, aiming for material savings without sacrificing structural safety.

SYSTEM DEVELOPMENT

This research investigates the dynamic response of G+20 residential buildings, with and without rooftop swimming pools, considering the effect of different plan irregularities: square, C, I, and L shapes. The buildings feature consistent lower story heights and taller upper stories. A rectangular swimming pool of specified dimensions was included in some models, with hydrostatic pressure accounted for in the analysis.

Structural design followed IS 456:2000, and seismic analysis was conducted using the Response Spectrum Method as per IS 875:2000 and IS 1893:2016 for seismic zone V. ETABS software was used for modeling and linear dynamic analysis to evaluate lateral displacement, story shear, story drift, and overturning moment across all building plans and pool configurations, aiming to understand seismic behavior and inform safe design in high-risk areas

STRUCTURE DESCRIPTIONS

Structural models of G+20 residential buildings with square, C, I, and L-shaped plans were created in ETABS- 2020, some including a rooftop swimming pool. These models accurately depicted varying floor heights and pool dimensions, incorporating hydrostatic pressure to enable realistic seismic analysis using the Response Spectrum Method for evaluating dynamic behavior.

Some basic structure description to designed the Structure are shown in table 1.

Table 1: Structure Descriptions

SR. NO.	SPECIFICATION	VALUE
GEOMETRY DEFINITION		
1	Plan Sizes	42 m × 42 m
2	Plan Shapes	Square-shaped, C-shaped, I-shaped, and L-shaped
3	Swimming Pool Size	6 m × 18 m
4	Swimming Pool Depth	2 m
5	Floor to floor height (Upto 15 Floors)	3 m
6	Floor to floor height (Top 5 Floors)	3.5 m
7	Bottom Story Height	2.1 m
8	Number of Floors	G + 20
9	Total height of Building	63 m
10	Thickness of Partition Walls	150 mm
11	Thickness of Slab	150 mm
12	Beam Size	400 mm × 400 mm
13	Column Sizes	1200 mm × 1200 mm (Base to 7th floors), 1000 mm × 1000 mm (7th floors to 14th floors), 800 mm × 800 mm (14th floors to 21th floors)

MATERIAL PROPERTIES		
14	Grade of Concrete	M30
15	Grade of Steel (HYSD Rebar)	Fe500
16	Density of Concrete	25 kN/m3
17	Density of Brick	20 kN/m3
18	Unit Weight of Water	10 kN/m3

LOADING CONDITIONS

Accurate structural analysis hinges on the careful consideration of loading conditions, which are determined based on IS codes for the analysis and design process. These loading conditions, detailed in subsequent tables, include:

Dead loads, representing the self-weight of the structure and its components (IS 875 Part 1: 2015). Live loads, accounting for movable loads due to occupancy and use (IS 875 Part 2: 2015).

Wind loads, lateral forces exerted by wind, calculated using IS 875 Part 3: 2015 and a specific formula involving various factors and wind speed.

Earthquake loads, lateral forces generated by the structure's response to seismic activity as per IS 1893 Part 1: 2016, considering dead weight and 50% of the live load for all earthquake zones.

For the swimming pool base, the pressure is calculated as the unit weight of water multiplied by the pool's height, resulting in 20 KN/m² for a 2-meter deep pool. On the walls, a trapezoidal hydrostatic pressure, also reaching a maximum of 20 KN/m², is applied as a plate load in the appropriate direction based on each wall's orientation in the models.

RESPONSE SPECTRUM METHOD

The Response Spectrum method, a linear dynamic analysis, directly calculates a structure's maximum earthquake responses using seismic forces. This method plots peak response against natural period for various damping ratios, expressing it as maximum relative velocity or displacement. This study uses the Response Spectrum method to analyze twelve models with different slab layouts, focusing on lateral displacement and base shear.

Table 2: Loading Conditions

SR. No.	LOADS	SPECIFICATION	VALUE	IS CODES
1	Dead Load	Self-Weight Factor	1.0 kN/m2	IS 875 (Part 1)
		Floor Finish Load	1.0 kN/m2	
		Wall Load	9.0/11 kN/m2	
2	Live Load	Live Load	4.0 kN/m2	IS 875 (Part 2)
		Water Pressure Load	20 kN/m2	
3	Wind Load	Terrain Category	3	IS 875 (Part 3)
		Windward Co-efficient (Cp)	0.8 or 0.7	
		Leeward Co-efficient (Cp)	0.20 or 0.25	
		Internal pressure coefficient (Cpi)	+/-0.5	
		Wind speed	44 m/s	
		Risk Co-efficient (K1)	1	
		Terrain, Height and Structure size factor (K2)	As per building height	

		Topography factor (K3)	1	
		Directionality factor (Kd)	0.9	
		Area Averaging Factor (Ka)	0.8	
		Load Combination Factor (Kc)	0.9	
4	Earthquake Load	Seismic Zone	V	IS 1893 (Part1)
		Zone Factor	0.36	
		Response Reduction Factor	5	
		Importance Factor	1.2	
		Soil Type	Medium	
		Damping Ratio	5 %	

PLAN AND 3D VIEW OF MODEL

G+20 residential building models with and without rooftop pools, featuring square, C, I, and L-shaped plans and varying floor heights, were created in ETABS-2020. These models were designed to represent architectural and structural features for Response Spectrum Analysis in seismic zone V, assessing their dynamic response to moderate earthquakes, considering the pool's hydrostatic load where relevant.

DESCRIPTION OF MODELS

Below is the complete list of all 8 models and shown in Figures 1 to 8.

Model 1: G+20 floors Structure of Squared Shaped with swimming pool on top 5 floors Model 2: G+20 floors Structure of Squared Shaped without swimming pool

Model 3: G+20 floors Structure of C - Shaped with swimming pool on top 5 floors Model 4: G+20 floors Structure of C - Shaped without swimming pool

Model 5: G+20 floors Structure of I - Shaped with swimming pool on top 5 floors Model 6: G+20 floors Structure of I - Shaped without swimming pool

Model 7: G+20 floors Structure of L - Shaped with swimming pool on top 5 floors Model 8: G+20 floors Structure of L - Shaped without swimming pool

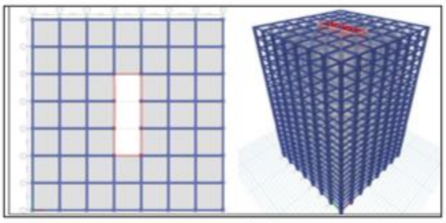

***Fig. 1** : Model 1*

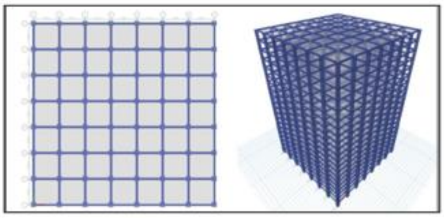

***Fig. 2** : Model 2*

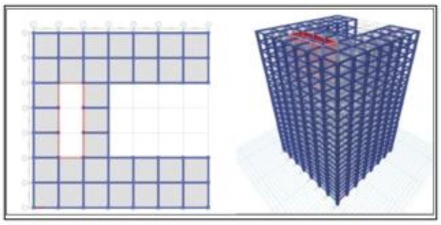

***Fig. 3** : Model 3*

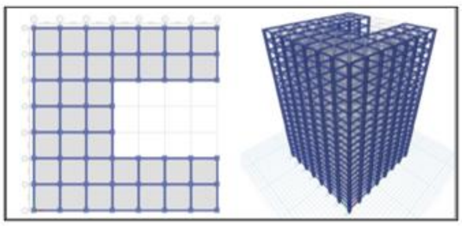

***Fig.4** : Model 4*

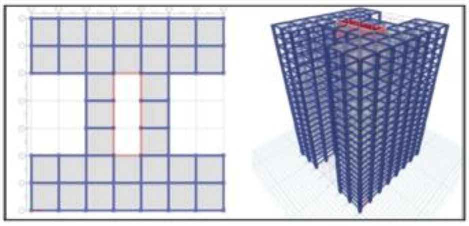

Fig. 5 : Model 5

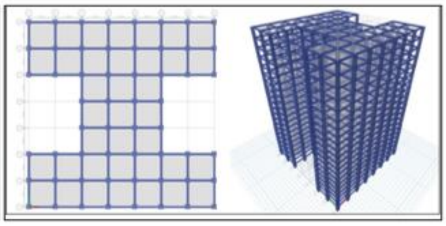

Fig. 6 : Model 6

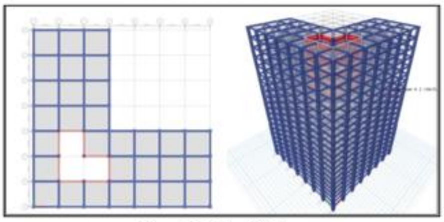

Fig. 7 : Model 7

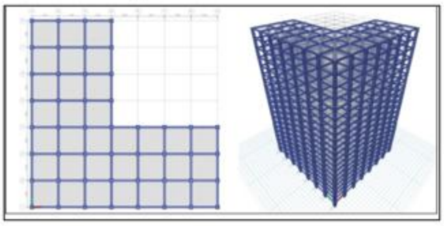

Fig. 8 : Model 8

3. RESULTS AND DISCUSSION

In this current study, a dynamic analysis is conducted on a prospective 12-story building, which incorporates both Waffle Slab systems with and without drops, across varying span sizes. The investigation utilizes the Response Spectrum Method across seismic zones III to obtain results. The evaluation of seismic performance entails classifying bifurcations, considering factors such as lateral displacement and story shear.

LATERAL DISPLACEMENT

Lateral displacements, perpendicular to a structure's main axis and caused by dynamic forces like wind or seismic activity, were analyzed. These displacements in waffle slab structures (with and without drops and beams) were compared against IS 16700-2017 limits (H/250 for seismic, H/500 for wind) to assess their movement control under dynamic loading, as shown below.

LATERAL DISPLACEMENT COMAPARISON FOR IRRUGALAR STRUCTURE WITH SWIMMING POOL LOCATED ON TOP 5 FLOORS IN X-AXIS

Table 3 and Figure 9 present lateral displacement results for irregular structural models, like square, C, I, and L-shaped with swimming pools located on the top five floors in X-axis.

No of Floors	Story Height (m)	Square Shape	C Shape	I Shape
20th floor	63	66.819	64.203	64.159
19th floor	59.4	65.631	63.166	63.126
18th floor	55.8	64.324	62.019	61.984
17th floor	52.2	62.912	60.766	60.736
16th floor	48.6	61.528	59.333	59.308
15th floor	45	59.199	57.313	57.291
14th floor	42	56.552	54.756	54.738
13th floor	39	53.245	51.537	51.521
12th floor	36	49.548	47.926	47.914
11th floor	33	45.586	44.057	44.046
10th floor	30	41.378	39.949	39.941
9th floor	27	36.949	35.631	35.624

8th floor	24	32.335	31.14	31.135
7th floor	21	27.59	26.531	26.527
6th floor	18	22.794	21.885	21.882
5th floor	15	18.086	17.336	17.334
4th floor	12	13.525	12.939	12.937
3rd floor	9	9.251	8.83	8.829
2nd floor	6	5.46	5.198	5.197
1st floor	3	2.414	2.291	2.291
Ground floor	0	0.464	0.439	0.439
Base	-2.1	0	0	0

Table 3: Displacement (mm) for Irregular structure with swimming pool [X-axis]

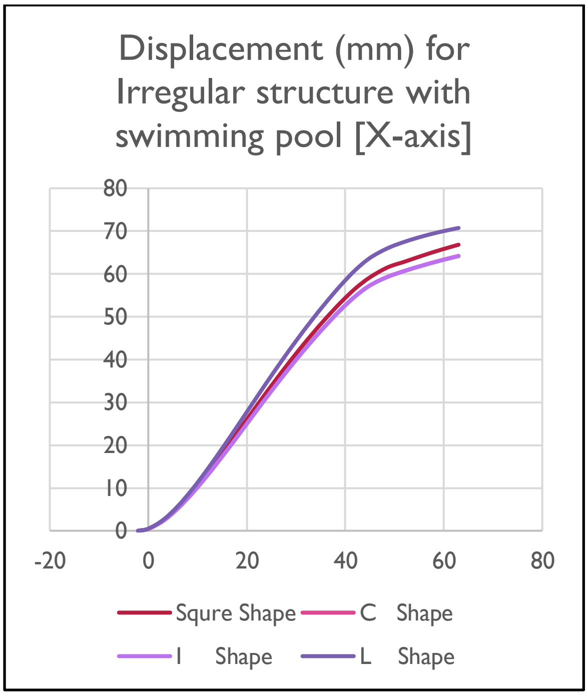

Fig. 9 : Displacement (mm) for Irregular structure with swimming pool [X-axis]

LATERAL DISPLACEMENT COMAPARISON FOR IRRUGALAR STRUCTURE WITH SWIMMING POOL LOCATED ON TOP 5 FLOORS IN Y-AXIS

Table 4 and Figure 10 present lateral displacement results for irregular structural models, like square, C, I, and L-shaped with swimming pools located on the top five floors in Y-axis.

No of Floors	**Story Height (m)**	**Square Shape**	**C Shape**	**I Shape**
20th floor	63	62.548	74.438	60.794

19th floor	59.4	62.026	73.538	60.419
18th floor	55.8	61.425	72.419	60.001
17th floor	52.2	60.748	70.997	59.547
16th floor	48.6	59.934	69.151	59.005
15th floor	45	58.465	66.517	57.807
14th floor	42	56.118	63.394	55.578
13th floor	39	52.962	59.548	52.462
12th floor	36	49.348	55.269	48.846
11th floor	33	45.443	50.702	44.931
10th floor	30	41.277	45.872	40.755
9th floor	27	36.88	40.812	36.356
8th floor	24	32.29	35.568	31.778
7th floor	21	27.56	30.211	27.077
6th floor	18	22.771	24.844	22.335
5th floor	15	18.067	19.617	17.688
4th floor	12	13.508	14.587	13.196
3rd floor	9	9.236	9.915	9.001
2nd floor	6	5.449	5.81	5.294
1st floor	3	2.408	2.548	2.331
Ground floor	0	0.462	0.484	0.446
Base	-2.1	0	0	0

Table 4: Displacement (mm) for Irregular structure with swimming pool [Y-axis]

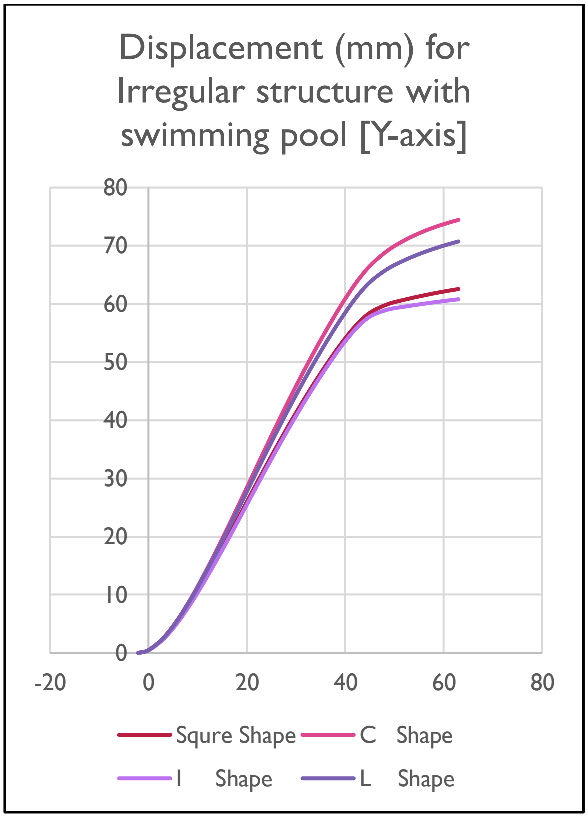

Fig. 10: **Displacement (mm) for Irregular structure with swimming pool [Y-axis]**

LATERAL DISPLACEMENT COMAPARISON FOR IRRUGALAR STRUCTURE WITHOUT SWIMMING POOL IN X-AXIS

Table 5 and Figure 11 present lateral displacement results for irregular structural models, like square, C, I, and L shapes analyzed without swimming pools in X-axis.

No of Floors	Story Height (m)	Square Shape	C Shape	I Shape
20th floor	63	73.008	71.138	71.091
19th floor	59.4	71.309	69.429	69.387
18th floor	55.8	69.183	67.314	67.277
17th floor	52.2	66.555	64.715	64.682
16th floor	48.6	63.433	61.638	61.61
15th floor	45	59.87	58.134	58.11
14th floor	42	56.613	54.932	54.911
13th floor	39	53.016	51.403	51.385
12th floor	36	49.18	47.642	47.626
11th floor	33	45.139	43.686	43.673
10th floor	30	40.893	39.535	39.524

9th floor	27	36.459	35.207	35.199
8th floor	24	31.868	30.734	30.727
7th floor	21	27.169	26.166	26.16
6th floor	18	22.435	21.576	21.571
5th floor	15	17.797	17.089	17.086
4th floor	12	13.307	12.755	12.752
3rd floor	9	9.103	8.706	8.705
2nd floor	6	5.373	5.126	5.125
1st floor	3	2.376	2.26	2.26
Ground floor	0	0.457	0.433	0.433
Base	-2.1	0	0	0

Table 5: Displacement (mm) for Irregular structure without swimming pool [X-axis]

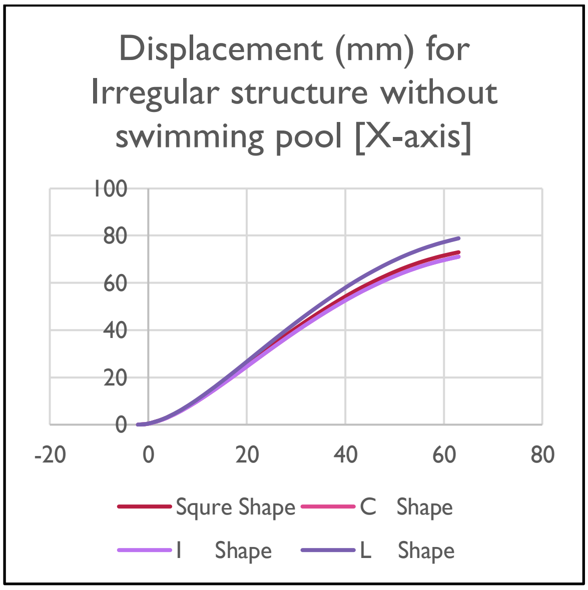

Fig. 11: Displacement (mm) for Irregular structure without swimming pool [X-axis]

LATERAL DISPLACEMENT COMAPARISON FOR IRRUGALAR STRUCTURE WITHOUT SWIMMING POOL IN Y-AXIS

No of Floors	Story Height (m)	Square Shape	C Shape	I Shape
20th floor	63	73.008	80.197	74.171
19th floor	59.4	71.309	78.063	72.298
18th floor	55.8	69.183	75.497	70.014

17th floor	52.2	66.555	72.409	67.238
16th floor	48.6	63.433	68.801	63.976
15th floor	45	59.87	64.723	60.276
14th floor	42	56.613	61.012	56.902
13th floor	39	53.016	56.949	53.193
12th floor	36	49.18	52.639	49.247
11th floor	33	45.139	48.128	45.106
10th floor	30	40.893	43.421	40.773
9th floor	27	36.459	38.54	36.266
8th floor	24	31.868	33.527	31.62
7th floor	21	27.169	28.441	26.888
6th floor	18	22.435	23.374	22.148
5th floor	15	17.797	18.451	17.523
4th floor	12	13.307	13.721	13.064
3rd floor	9	9.103	9.329	8.906
2nd floor	6	5.373	5.469	5.236
1st floor	3	2.376	2.4	2.305
Ground floor	0	0.457	0.456	0.442
Base	-2.1	0	0	0

Table 6 and Figure 12 present lateral displacement results for irregular structural models, like square, C, I, and L shapes analyzed without swimming pools in Y-axis

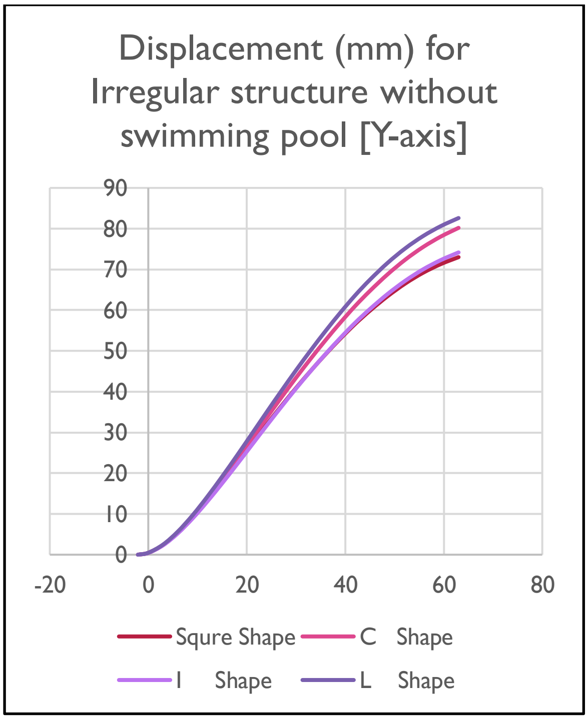

Fig. 12: Displacement (mm) for Irregular structure without swimming pool [X-axis]

Adding a rooftop pool increased displacement in all analyzed G+20 residential building shapes (square, C, I, L), with the L-shape showing the largest rise (5.5%) and the square shape the smallest (3.2%). Despite these increases, attributed to the pool's added mass and stiffness, all displacements remained below the IS 16700- 2017 limit of 252 mm.

BASE SHEAR

Story Shear, the lateral force on each building story, is a key parameter in our study for understanding structural response to lateral loads like wind or earthquakes. We also analyze the maximum story shear at the building's base, known as Base Shear, to evaluate the total lateral force on the foundation, informing the design of lateral force-resisting systems and foundations for stability.

BASE SHEAR COMAPARISON FOR IRRUGALAR STRUCTURE WITH SWIMMING POOL LOCATED ON TOP 5 FLOORS IN X-AXIS

The X-axis base shear results for irregular structural models, like square, C, I, and L-shaped in plan and swimming pools on the top five floors, are presented in Table 7 and Figure 13.

Table 7: Base Shear (kN) for Irregular structure with swimming pool [X-axis]

No of Floors	Square Shape	C Shape	I Shape	L shape
Base Shear at Ground Level	6342.5273	5138.0372	5138.0374	4501.2669

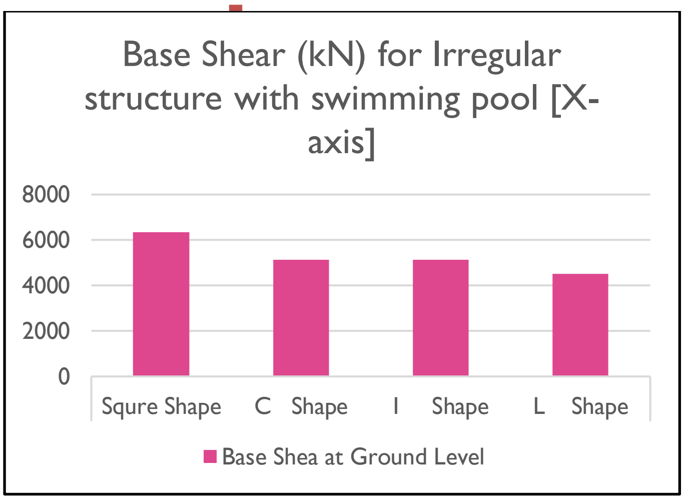

Figure 1 : Base Shear (kN) for Irregular structure with swimming pool [X-axis]

BASE SHEAR COMAPARISON FOR IRRUGALAR STRUCTURE WITH SWIMMING POOL LOCATED ON TOP 5 FLOORS IN Y-AXIS

The Y-axis base shear results for irregular structural models, like square, C, I, and L-shaped in plan and swimming pools on the top five floors, are presented in Table 8 and Figure 14.

No of Floors	Square Shape	C Shape	I Shape	L shape
Base Shear at Ground Level	6342.2196	5138.0378	5138.0421	4501.2699

TABLE 8: BASE SHEAR (KN) FOR IRREGULAR STRUCTURE WITH SWIMMING POOL [Y-AXIS]

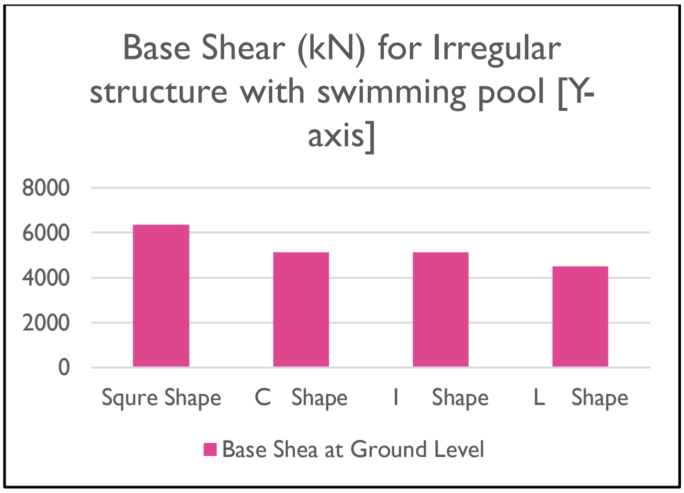

Figure 2 : Base Shear (kN) for Irregular structure with swimming pool [Y-axis]

BASE SHEAR COMAPARISON FOR IRRUGALAR STRUCTURE WITHOUT SWIMMING POOL IN X-AXIS

Table 9 and Figure 15 present lateral displacement results for irregular structural models, analyzed without swimming pools of irregular structures like square, C, I, and L shapes in X-axis.

Table 9: Base Shear (kN) for Irregular structure without swimming pool [X-axis]

No of Floors	Square Shape	C Shape	I Shape	L shape
Base Shear at Ground Level	6292.0534	5087.5371	5087.5417	4350.8539

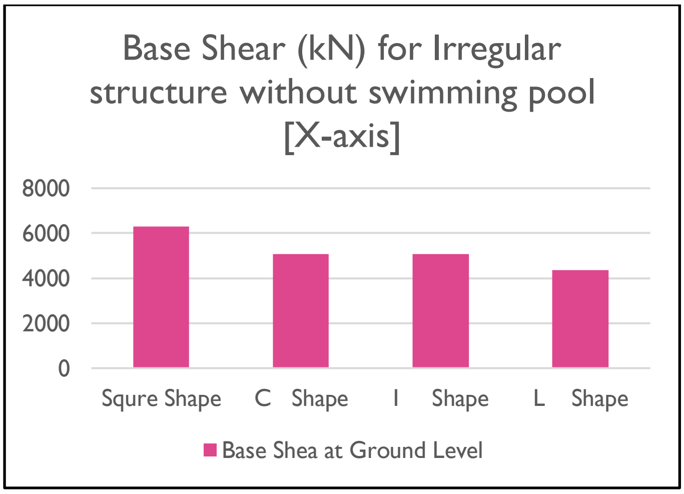

Figure 15: Base Shear (kN) for Irregular structure without swimming pool [X-axis]

BASE SHEAR COMAPARISON FOR IRRUGALAR STRUCTURE WITHOUT SWIMMING POOL IN Y-AXIS

Table 10 and Figure 16 present lateral displacement results for irregular structural models, analyzed without swimming pools of irregular structured like square, C, I, and L shapes in Y-axis.

Table 10: Base Shear (kN) for Irregular structure without swimming pool [Y-axis]

No of Floors	Square Shape	C Shape	I Shape	L shape
Base Shear at Ground Level	6291.4781	5087.5299	5087.534	4350.2629

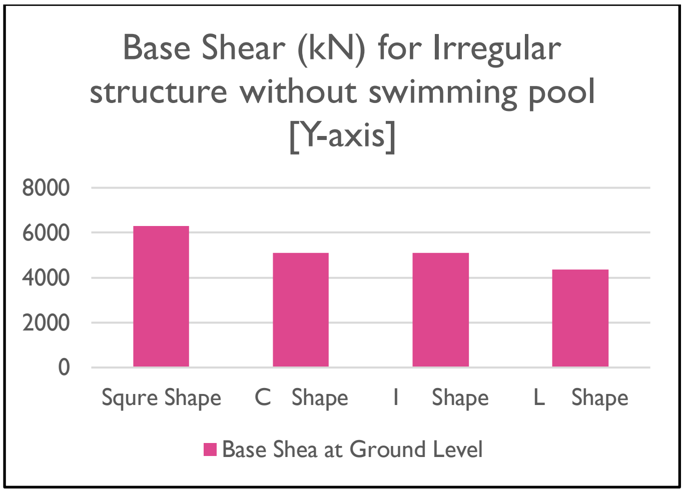

Figure 16: Base Shear (kN) for Irregular structure without swimming pool [Y-axis]

The following summarizes the X and Y direction base shear results for square, C, I, and L-shaped buildings with and without swimming pools, leading to an overall conclusion. The square shape, with its symmetry, showed the lowest base shear, indicating optimal lateral force resistance, while the asymmetric L-shape exhibited the highest. The C and I shapes displayed intermediate base shear values. While the presence of a swimming pool had a minimal impact (0.80% to 0.99% increase), structural shape was the dominant factor influencing base shear, highlighting the efficiency of symmetrical designs in minimizing this force.

4. CONCLUSIONS

On the basis of above results and observations of lateral displacements and base shear of the studied structure considering G+20 floors with and without swimming pool in different plan irregularities following conclusions are drawn as follows…

1. All four structural shapes show an increase in displacement with the addition of a swimming pool, with the L-shape experiencing the greatest rise of 5.5%. Despite these increases, all displacements remain within the allowable limits specified by IS 16700-2017, ensuring the overall stability of the structures.
2. The square shape exhibits the smallest increase in displacement at 3.2%, highlighting the efficiency of symmetrical structures in managing additional loads. Irregular shapes like the C, I, and L shapes show larger displacement increases, with the L-shape seeing the most significant rise due to its asymmetrical design.
3. Each structural shape shows an increase in overturning moment with the addition of a swimming pool, with the L-shape experiencing the highest rise at 4.0%. Despite these increases, all structures remain stable and within their design limits, demonstrating their ability to manage additional torsional forces effectively.
4. The square shape shows the smallest increase in overturning moment at 2.5%, indicating its superior ability to resist torsional effects. Irregular shapes, such as the C, I, and L shapes, experience higher increases, with the L-shape being the most affected due to its asymmetry and irregular geometry.
5. All four structures show a decrease in storey drift with the addition of the swimming pool, with the L- shape experiencing the highest reduction at 5.0%. The added mass from the pool helps stabilize each structure by improving load distribution and reducing lateral displacement.
6. The square shape shows the smallest decrease in storey drift at 3.5%, while more irregular shapes like the C, I, and L shapes experience greater reductions. The L-shape benefits the most from the added pool mass, which effectively mitigates its inherent lateral displacement.
7. The square shape exhibits the lowest base shear, demonstrating its superior resistance to lateral forces due to its symmetrical design. In contrast, the L-shape experiences the highest base shear, caused by its irregular geometry that amplifies torsional effects and increases shear demand.
8. The C and I shapes show moderate increases in base shear, with the I-shape experiencing a more significant rise of 25% due to its slender form. While the swimming pool's influence on base shear is minimal, the shape's inherent properties still significantly impact shear resistance.
9. The addition of a swimming pool results in increased displacement and overturning moments across all shapes, with the L-shape showing the largest increase in both parameters. Nonetheless, all structures remain within allowable

limits, demonstrating that even irregular shapes gain additional stability from the pool.

10. The square-shaped structure performs the best overall across all parameters, showing the lowest increases in displacement and overturning moment. Its symmetrical design provides optimal resistance to lateral forces, making it the most efficient structure when subjected to additional loads such as a swimming pool.

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