Exploring Rotational symmetry in Building structures: A Comparative Analysis using Etabs Software

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Abstract - *This paper presented due to the rapid increase in urbanization and economic growth, a large demand is created on innovative constructions, in this paper a comparative analysis and influence of rotational symmetry on the structural behavior of buildings using ETABS software. Rotational symmetry structures are examined to determine how it affects load distribution, stiffness, and overall stability in building structures. Two geometric models one with rotational symmetry and another without are subjected to various loading conditions, and their structural responses are analyzed. Findings show that rotational symmetry can significantly affect structural behavior, with implications for both aesthetic and functional aspects of building design. This research contributes to advancing knowledge in architectural and structural engineering, offering valuable insights for practitioners seeking to enhance the performance and visual appeal of building structures.*

Key Words: Rotational symmetry, Finite element analysis, Etabs software, Comparison study, Performance evaluation.

1.INTRODUCTION

In the realm of architectural and structural engineering design, symmetry has long been regarded as a fundamental principle contributing to both aesthetic appeal and structural efficiency. While axial and bilateral symmetries are commonly explored in architectural compositions, the potential impact of rotational symmetry on structural behavior remains an intriguing area of investigation. Rotational symmetry, characterized by repetitive patterns around a central axis, presents unique challenges and opportunities in building design and analysis.

This paper aims to explore the affect of rotational symmetry on the structural behavior of buildings through a comparative analysis utilizing ETABS software. By systematically examining buildings with and without rotational symmetry, we seek to elucidate the role of symmetry in governing structural performance, including load distribution, stiffness, and overall stability. Through this analysis, we endeavor to provide valuable insights for architects and engineers in optimizing the design and functionality of the architectural structures

The investigation will involve the creation of geometric models of two buildings one exhibiting rotational symmetry and another lacking such symmetry. These models will be subjected to various loading conditions, and their structural responses will be analyzed using ETABS, a popular program for structural design and analysis. By comparing the behavior of these structures, we aim to discern the effect of rotational symmetry on structural performance and identify any significant differences in behavior attributed to symmetry considerations

This study is expected to contribute to corpus of information in architectural and structural engineering by shedding light on the mutual influence between symmetry and structural behavior in building design. The findings may inform design practices, allowing architects and engineers to leverage rotational symmetry as a tool for enhancing both the structural integrity and visual harmony of buildings.

1.1 HORIZONTAL/PLAN IRREGULARITY

When it comes to building design, there's a tricky concept to consider: horizontal irregularities. These are basically differences in how weight, strength, or stiffness are spread out across a building's floors. They can mess with a building's stability and safety. In this paper, we're going to dig into what these irregularities are, how they affect buildings, and what we can do about them. By blending ideas from both building design and engineering, we hope to make it easier for architects and engineers to deal with these challenges.

As per IS: 1893:2016 Code book
A. Torsional Irregularity:
Normally, a building stands straight if:

a) The walls and columns are as strong as their necessity to be where the weight is.
b) The floors are strong and not too big.
But if:
One end of a floor moves a lot more sideways than the other. It takes longer for building to twist than to move side to side, Then, it's called twisted or torsion.

B. Re-entrant corners:

Re-entrant corners in building plans exceed 15% of total dimensions. This study emphasizes using three-dimensional dynamic analysis to ensure stability and safety

C. Floor Slabs having Excessive Cut-Outs or Openings:

In buildings, holes or gaps in floor slabs make them act like flexible sheets, causing uneven distribution of lateral force on frames or columns. This becomes pronounced when the holes are close to the slab's edge. When more than half of the floor slab is cut out, the building exhibits a lack of stiffness in its plane.

In such buildings:

a) For cut-out areas of 50 percent or less, the floor slab's stiffness is determined by the size and location of the openings.

b) For cut-out areas exceeding 50 percent, the floor slab is contemplated as excessive cutout.

D. Out-of-Plane Offsets in Vertical Elements:

When vertical elements like walls or frames shift out of alignment in a building, it creates disruptions in the load path, which can compromise the building's earthquake safety. This condition is known as out-of-plane offset in vertical Components.

In buildings with such offsets:

a) If the building is in Seismic Zone II, it should be designed in accordance with expert literature.

b) If in Seismic Zones III, IV, or V, two conditions must be met:

Lateral drift must be limited to < 0.2 % in the affected storey and the storeys below.

Specialized literature should be consulted to address the irregularity caused by these offsets.

E. Non-Parallel Lateral Force System:

When buildings lack lateral force resisting systems oriented along two perpendicular plan directions, they are prone to complex earthquake-induced damage. This condition is termed as a non-parallel lateral force system, indicating that the vertically oriented structural systems that resist lateral forces are not aligned along the two primary orthogonal axes in the building plan.

For buildings with such non-parallel systems, they must be analyzed for load combinations specified in IS Codes.

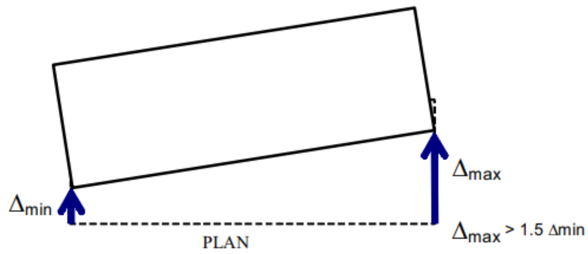

Fig-1: Torsional Irregularity

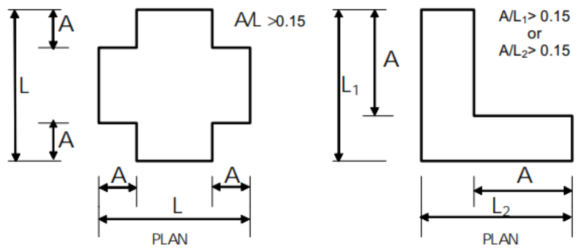

Fig-2: Re-entrant corners

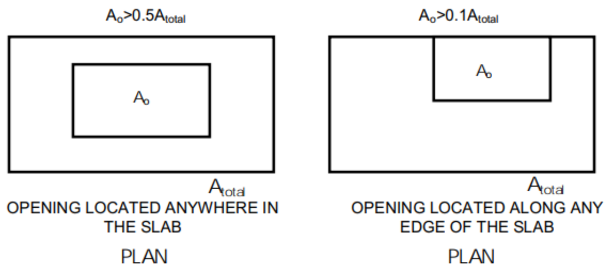

Fig-3: Floor Slabs having Excessive Cut-Outs or Openings

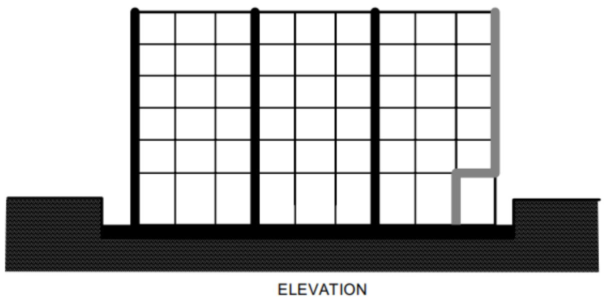

Fig-4: Out-of-Plane Offsets in Vertical Elements

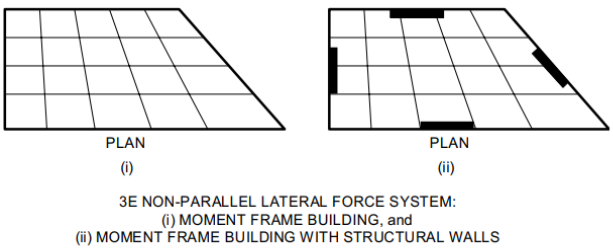

Fig-5: Non-Parallel Lateral Force System

2. LITERATURE SURVEY

S.A. Powale and N.J. Pathak's [2019].

In this study, "A Comparative Study of Torsional Effects of Earthquakes on 'L' and 'S' Shaped High-Rise Structures," found significant variations in how various building designs behaved when subjected to seismic stresses. In particular, it was found that building configurations in the 'S' form had lower joint displacements than those in the 'L' shape. The Amax/Amin ratio a torsional irregularity measure exceeded 1.5 for 'L' shaped buildings in the X direction, showing a considerable torsional irregularity, supporting this observation. Conversely, 'S' shaped structures had Amax/Amin ratios were less than 1.5, suggesting a better torsional regularity. Surprisingly, the 'S' shaped building plan demonstrated exceptional resistance to torsional impacts during seismic occurrences, indicating its possible benefits.

Kintali Sai Nanda Kishore and K Sathya [2015].

In this study the author examined the effects of wind on multi-story buildings in a 2015 study. Using the Staad Pro computer program, they compared several building shapes, including normal, 'L' shaped, and 'U' shaped ones. They discovered that the beams and columns inside structures flex more as they get shorter, particularly in 'U' shaped buildings. Additionally, buildings that are taller tend to wobble Greater than those that are not, particularly 'U' shaped buildings, which can wobble over 4.5 times more than normal shaped buildings due to wind and other factors. This indicates that a building's shape can have an impact on how it reacts to loads and the wind.

Sake Krishna Sai, Dr. H Sudarsana Rao et al [2015].

In this research the author used Etabs software to compare the structural characteristics of buildings with and without shear walls that had horizontal and vertical abnormalities. The study's conclusions presented significant new facts concerning how these kinds of Structures respond under varying load scenarios. In particular, compared to their regular counterparts, structures with uneven stiffness showed bigger inter-story drifts and lower foundation shear. Buildings with vertical abnormalities experienced torsional effects, which changed the spacing between stories and widened the interstory drifts. Plan imperfections similarly produced torsional effects that resulted in different story displacements. It's interesting to note that adding shear walls to any structure aside from plan irregular buildings showed an improvement.

Meghana H. and Dr. C. S. Vijaya Kumar [2022].

"Comparative Analysis of Regular and Horizontal Irregular Buildings on Sloping Ground with Shear Wall and Bracings as Structural Elements using ETABS," a recent study the author examined the effects of shear walls and bracings on structures located on sloping terrain. The study's conclusions showed that adding shear walls reduced displacement in every scenario that was looked at. Interestingly, it was discovered that the displacement of shear walls at the size of corners was smaller compared to that of buildings with corner bracings, which in turn showed a smaller displacement than simple buildings (shear wall < bracings). The study also showed that the addition of bracings raised the base shear value.

2. OBJECTIVE

Following are the objectives,

1. Employing the Response Spectrum approach, to explore the response of structures with 90^0 and 180^0 Rotational Symmetry structures.

2. Compare the Displacement, Drift, stiffness and Base shear reactions for Different shape models having rotational symmetry and analyzing the structures in seismic zones III to see how they perform structurally.

3. Analyze the effects of rotational symmetry structures for different load combinations and providing idea for aesthetic view structures with capability of withstanding lateral loads.

3. MODEL DESCRIPTION

Table-1: Shape of Models and column spacing

90^0 Rotational symmetry Plan irregular Structures
Swastika shape structure: Spacing B/w Two columns = 5 m
X shape Structure: Spacing B/w Two columns = 7.07 m
180^0 Rotational symmetry Plan irregular Structures
U shape Structure: Spacing B/w Two columns = 5 m
H shape Structure: Spacing B/w Two columns = 5 m

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Table-2: Model Description

Dimensions	
Plan size	70 x 70 m
Floor to floor height	3 m
Number of Stories	Residential [G+9]
Total height of structure	30 m
materials used	
Concrete grade	M30
Steel grade	Fe 550
Sections used	
Columns	
Ground to 5th floor	450 x 450 mm
6th to top floor	300 x 300 mm
Beams	
ground to top floor	300 x 450
slab	
Depth	150 mm
Structure type	SMFR
Linear dynamic analysis by using	Response spectrum method
Seismic information	
Seismic zone	III
Seismic Zone factor	0.16
place	GOA
Importance factor	1.2
Response reduction factor	5
Soil type	Medium Soil [Type II]
Wind Information	
Basic wind speed	39 m/s
Terrain category	2
K1 and K3 values	1

4. MODELLING

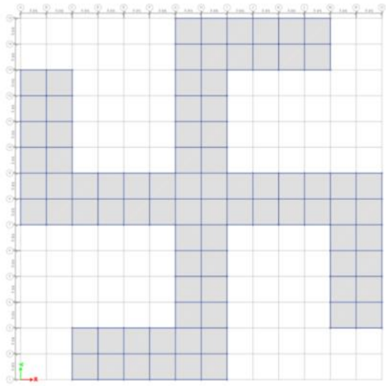


Fig-1: Swastka shape model Plan view

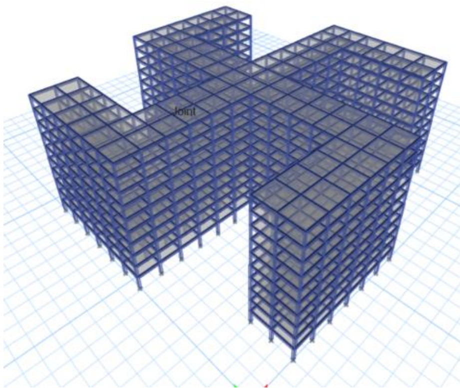


Fig-2: Swastika shape model 3D View

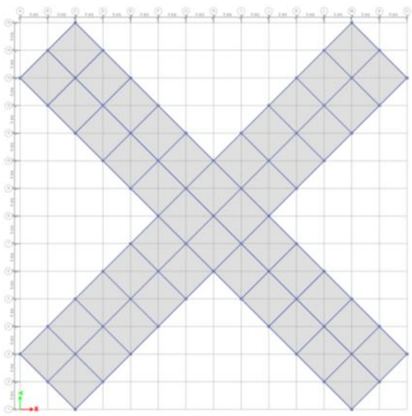


Fig-3: X shape model Plan view

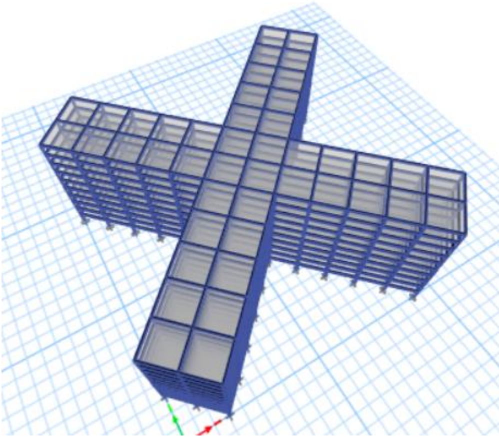


Fig-4: X shape model 3D View

Fig-1,2,3,4 refers to the modelling of 90^0 Rotational symmetry. Shapes that exhibit 90-degree rotational symmetry remain unchanged when rotated by a quarter turn (90 degrees) about their center point, such as squares, crosses, and plus signs, likewise the swastika and X shape, where their appearance remains consistent.

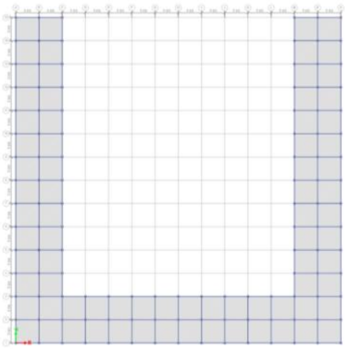


Fig-5: U shape model Plan view

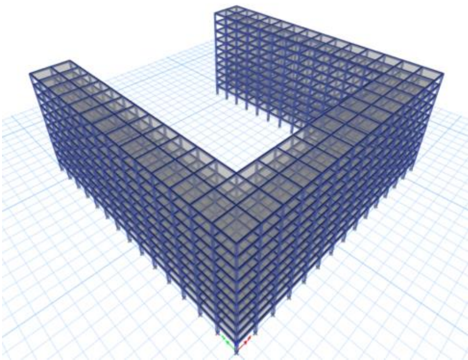


Fig-6: U shape model 3D view

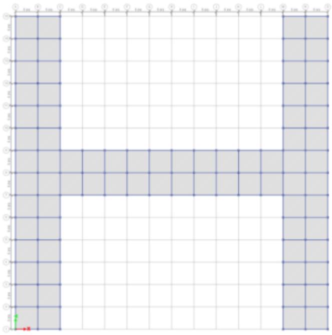


Fig-7: H shape model plan view

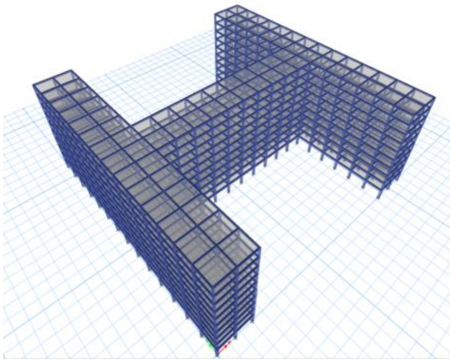


Fig-8: H shape model 3D view

Fig-5,6,7,8 refers to the modelling of 180^0 Rotational symmetry. Shapes that exhibit 180-degree rotational symmetry remain unchanged when rotated by a Half turn (180 degrees) about their center point, such as Hexagon, I, and C Shape signs, in the same way the U and H shape, where their appearance remains consistent.

I considered these Rotational symmetry shapes just to know about their maximum and minimum Displacement, Drift, Base shear and its stiffness.

4.1 CHECK FOR PLAN IRREGULARITY

As per IS:1893: 2016 the below results are obtained,

Table-3: Check for tortional irregularity

Models	Check for Torsion		
	Δmax in mm	Δmin in mm	Δmax/Δmin
Swatika	21.5	21.5	1
X shape	34.3	34.3	1
U shape	27.345	21.795	1.25
H shape	26.54	24	1.11

Table-4: Check for Re-entrant corners

Models	Check for Re-entrant corners		
	A	L	A/L
Swatika	30	70	0.43
X shape	34.35	84.85	0.40
U shape	60	70	0.86
H shape	30	70	0.43

Δmax > 1.5 Δmin = Torsionally irregular structure, as we can see our models are not Tortionally irregular structures.
A/L > 0.15 = Structure having Re-entrant corners, our structures consist of Re-entrant corners so Three-dimensional analysis is adopted.

5. RESULTS AND DISCUSSION

Using the RSM, we analyzed four structural models in-depth in this study, considering into account parameters like mass ratios, live load reduction factors, and load combinations. Comparing rotational symmetry structures with 90^0 and 180^0 rotational symmetry was our main goal, which we accomplished by following established analytical approaches. A comparison of the Swastika shape's displacement characteristics with those of the X shape, which shows higher displacement values, reveals noteworthy conclusions as shown in Chart 1. The comprehension of rotational symmetry structures and their behavior in the existance of seismic loading is enhanced by using these models.

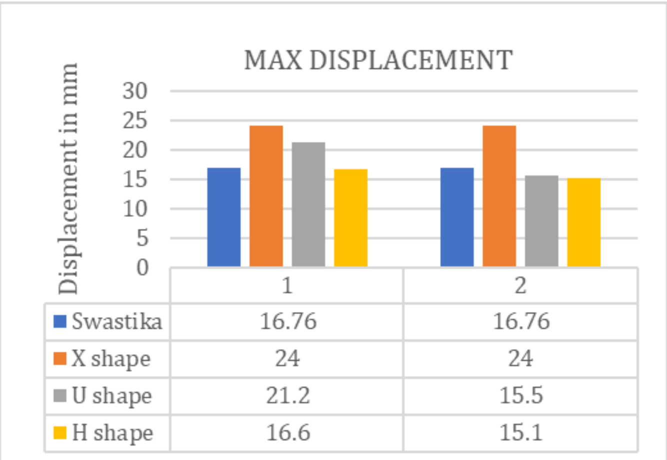


Chart-1

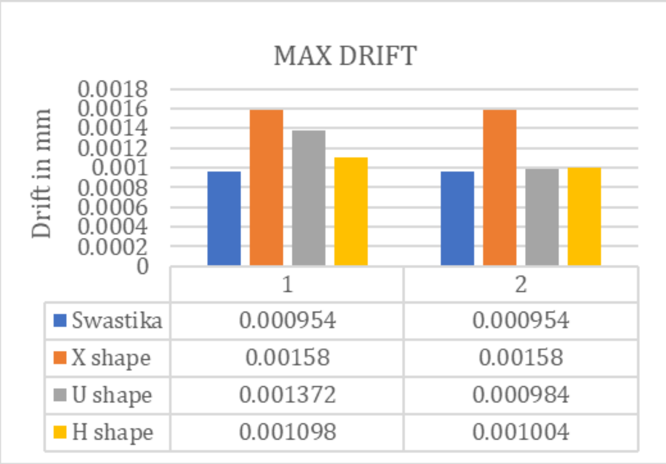


Chart-2

Max allowable Drift = 0.004 x height of the structure, i.e, 0.004 x 30m = 0.00133, In this work, we examined the structural performance of a range of geometric configurations, such as the X, U, swastika, and H forms, taking into account a maximum drift requirement of 0.004 times the structure's height. Our analysis results indicated that, despite the X and U shape models drifted beyond the specified limit, the swastika and H shape models performed well. For all models, the maximum drift was mostly observed at the 7th storey, execept for the swastika shape, which showed higher drift at the 6th storey level. These findings underscore the importance of geometric design factors are to attaining structural stability and drift criteria compliance.

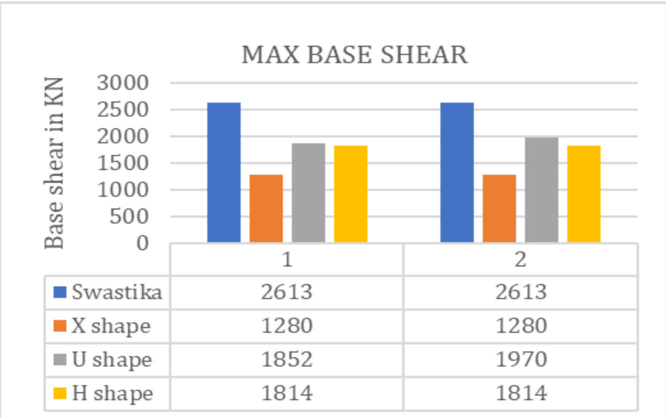
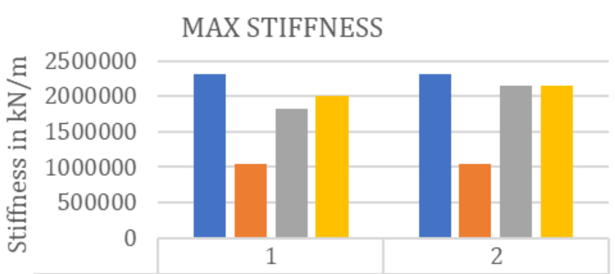


Chart-3

It is clear from examining the base shear values in Chart-3 that the X shape model has lower base shear values than the Swastika, H, and U shape models. Several factors, most notably the bigger area covered by the Swastika shape model, which naturally results in higher base shear values, might be blamed for this mismatch. Furthermore, the structural arrangement for example, the X shape's Crossbar type may affect the base shear results, making values appear smaller because of the specific configuration. These findings highlight how crucial it is to consider structural arrangements and geometric properties into account when evaluating base shear in seismic analysis.



	1	2
Swastika	2302316.289	2302316.733
X shape	1049341.794	1049341.797
U shape	1814813.78	2140582.786
H shape	2009715.197	2142738.616

Chart-4

Among all the models, except for the X shape, we observed that they exhibited satisfactory rigidity/stiffness. The X shape had less stiffness because of its positioning in both X and Y directions. Interestingly, we noticed that the stiffness was highest at the first storey in all the models. This tells us that how the structure is shaped and positioned affects how stiff it is, and the first storey is particularly important for stiffness.

6. CONCLUSIONS

As per this Study the Horizontal irregular structure are analyzed using Linear dynamic analysis RSM and Comparing their Max storey Displacement, Max storey Drift, Base shear, Stiffness results with Seismic zone III in X and Y directions, based on the analysis result following conclusions were made

Because of plan irregularity the Base shear values are higher and undergoes torsional effects, if we Provide the additional shear walls to all structures the behavior may be improved.

With the results obtained Swastika shape model shows lesser joint displacement values when compare to all other shape model

With the results obtained Swastika shape plan building model shows lesser Storey drift values when compare to X shape model and a Structures with 90° Rotational symmetry the Storey drift values are minimum compare to structures with 180° Rotational symmetry.

Both Swastika and X shape Building models have good tendency to resist Lateral loads by modifying Structural configurations like adding shear walls, bracings, base isolations, mass dampers etc.

The Swastika shape building is a 90° Rotational symmetry with Horizontal irregularity the shear values are maximum compare to all other shape structures.

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