Comparative Seismic Analysis of Circular and Rectangular Building Structures

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Abstract – *This research examines how different geometric configurations affect a building's seismic performance. This study is crucial for providing architects and engineers with insights to optimize designs for better seismic resilience. Using STAAD Pro software, the research develops detailed models of both circular and rectangular buildings. These models undergo simulations with various loads, including dead, live, and seismic forces. The dynamic analysis considers key seismic parameters such as response reduction factor, zone factor and importance factor to assess behavior under earthquake conditions. The analysis compares maximum displacements, support reactions, bending moments, and base shear values in different directions to evaluate the structural efficiency and stability of each shape. Findings reveal that circular buildings generally perform better under seismic conditions, showing lower maximum displacements and more stable support reactions, indicating a higher resistance to lateral forces. This suggests circular buildings are more suitable for seismic-prone areas due to their enhanced stability. The results highlight the importance of geometry in seismic design and pave the way for further innovations in earthquake-resistant structures.*

***Key Words*: *Seismic Analysis, Circular Building Structure, Rectangular Building Structure, Comparison Circular and Rectangular, STAAD.Pro*.**

1.INTRODUCTION

The global increase in seismic activity has highlighted the critical necessity for buildings capable of withstanding earthquakes. Earthquake-resistant design is a fundamental aspect of modern structural engineering, focused on reducing damage and safeguarding human lives. As urbanization intensifies, particularly in seismically active regions, the significance of constructing buildings with enhanced seismic resilience becomes increasingly paramount.

The geometry of a building significantly influences its response to seismic forces. The way seismic loads are distributed and the resulting structural behavior can vary greatly depending on the building's shape. Circular and rectangular buildings are two common architectural forms, each possessing unique characteristics that affect their performance during seismic events. Circular buildings, with their symmetrical and continuous geometry, are theorized to achieve a more uniform stress distribution, which may enhance their performance under seismic loads. In contrast, rectangular buildings, defined by their linear and angular design, might demonstrate different stress patterns and vulnerabilities.

The historical backdrop of this research is rooted in the development of earthquake-resistant design principles. Structures built in the early 20th century often failed to consider the dynamic nature of seismic loads, leading to significant structural failures. Over time, advancements in structural engineering, materials science, and computational modelling have transformed our understanding of designing buildings to better withstand earthquakes. Despite these advancements, the comparative seismic performance of various building geometries, specifically circular versus rectangular structures, remains underexplored.

Previous research has examined various aspects of seismic design, such as the advantages of symmetry in load distribution and the difficulties posed by stress concentrations in angular geometries. Nevertheless, there is a notable gap in the literature regarding a direct comparison of circular and rectangular buildings under identical seismic conditions. This study aims to address this gap by using advanced structural modelling techniques with STAAD Pro software to simulate seismic events and evaluate the performance of both building types.

By conducting a thorough comparative analysis, this research intends to provide valuable insights into the seismic resilience of circular and rectangular buildings. The findings are expected to inform architectural and engineering practices, leading to the design of safer, more resilient structures in earthquake-prone areas.

1.1 Circular Building Structure

Circular buildings, defined by their cylindrical or spherical geometry, offer unique advantages in both architectural design and structural performance. These structures are characterized by a continuous, uninterrupted form that ensures uniform stress distribution, thereby enhancing their stability under various loads. During seismic events, the symmetrical shape of circular buildings minimizes torsional effects, resulting in lower displacement and deformation when compared to rectangular buildings. Additionally, the aerodynamic form of circular buildings allows for better resistance to wind loads, as smooth airflow around the structure reduces wind-induced stress.

Designing circular buildings, however, presents distinct challenges, such as the complexity of engineering the curved walls and the requirement for specialized construction techniques. Despite these challenges, circular buildings can optimize material usage and provide open, flexible interior spaces that are highly adaptable. Prominent examples of circular buildings include the Indira Gandhi Planetarium in Lucknow, Uttar Pradesh shows Figure 1.1 and the Roman Colosseum shows Figure 1.2, both of which illustrate the enduring appeal and functionality of this architectural form.

Fig 1:- Indira Gandhi Planetarium

1.2 Rectangular Building Structure

Rectangular buildings, distinguished by their linear and angular geometry, are extensively utilized due to their straightforward design and construction. The straight edges and right-angled corners of these structures simplify the planning, layout, and construction processes, making them both efficient and cost-effective.

One of the primary advantages of rectangular buildings is their flexibility in space utilization. This adaptability allows for versatile interior layouts, making rectangular buildings suitable for a wide range of applications, including residential, commercial, and industrial purposes. However, the angular design can lead to stress concentration at the corners, which presents challenges under seismic and wind loads.

Despite these challenges, advancements in structural engineering have significantly enhanced the seismic performance of rectangular buildings. Techniques such as the incorporation of shear walls, braced frames, and proper detailing have been developed to mitigate stress concentrations and improve resilience. Ex. Antilia in Mumbai shown in Figure 1.3.

Fig 1:- Indira Gandhi Planetarium

1.3 Aim and objective

The research aims to identify which geometric configuration circular or rectangular offers superior stability and safety during earthquake conditions. By evaluating these two common architectural forms, the research intends to provide valuable insights that can guide architects and engineers in designing buildings with enhanced earthquake resistance. The findings will contribute to the development of more effective design strategies for constructing structures that can better withstand seismic events, ultimately improving the safety and resilience of urban environments in seismically active regions.

Following are the objective

1. To compare the behaviour of a building in terms of response spectrum Method (RSM)..

2. To analyze the maximum displacement in the X, Y and Z directions between circular and rectangular building structures under seismic loading

3. To analyze the maximum support reactions in the X, Y and Z directions for both types of buildings

4. To analyze the maximum bending moments in the X, Y and Z directions for circular and rectangular buildings

5. To analyze the maximum base shear in the X, Y and Z directions for both building structures.

6. To compare the results for parameters such as displacements, maximum shear force, maximum bending moments, etc.

7. To draw conclusions based on the comparative analysis regarding the seismic resilience of circular versus rectangular buildings.

8. Analysis of multi-storied building using "STAAD.Pro" software.

9. To identify the best building configuration from this analysis

2. METHODOLOGY

- Considering a Three-dimensional finite element model of Rectangular and Circular Building.
- Considering Two models one of Rectangular Building Structure and other one is Circular Building Structure.
- After geometric evaluation of structural model will undergo analysis.
- To compute design seismic forces, the code requires taking into account elements like the Importance Factor (I), Response Reduction Factor (R) and Zone Factor (Z).
- Performing comparative Analysis, comparison of result from both the structure Rectangular and Circular.

2.1 Codes for Structural Analysis

- During the analysis of various models, the following IS Codes were used:
- IS 875(Part-I):1987: - Indian Standard Code of Practice for design loads (other than earthquake) for buildings and Structures (Dead load).
- IS 875 (Part-II):1987: - Indian Standard Code of Practice for design loads (other than earthquake) for buildings and Structures (Live load).
- IS 456:2000: - "Plain and Reinforced Concrete" Code of Practice - Bureau of Indian standard, New Delhi, India.
- IS 1893 (Part-1):2016: - Indian Standard Criteria for Earthquake Design of Structures (Sixth Revision).

2.2 Problem Statement

For the analysis of two structural models, one in a circular shape and the other in a rectangular shape, the geometry and material property details are provided in Table No.1 and Table No.2

Table 1. Data for Rectangular Building Structure

Property	Values
Area of building	25 X 30=750 m^2
Hight of Structure	48.00
Size of Beam (M-30)	300 X 500 MM
Size for Column (M-30)	400 X 700 MM
No of Storey	15 Nos (G+14)
Grade of Concrete	M-30
Grade of Steel	Fe 500
Earthquake Zone	5
Zone Factor (Z)	0.36
Importance Factor (I)	1
Response Reduction Factor	5.0
Soil Type	For rocky, or hard soil sites

Table 2. Data for Circular Building Structure

Property	Values
Area of building	(3.14/4)X30.90=749.90 m^2
Hight of Structure	48.00
Size of Beam (M-30)	300 X 500 MM
Size for Column (M-30)	400 X 700 MM
No of Storey	15 Nos (G+14)
Grade of Concrete	M-30
Grade of Steel	Fe 500
Earthquake Zone	5
Zone Factor (Z)	0.36
Importance Factor (I)	1
Response Reduction Factor	5.0
Soil Type	For rocky, or hard soil sites

3. MODELLING

3.1 Structural Plan of G+14 Rectangular Building Model

Fig 3: Top View of Rectangular Build Plan with Dimension

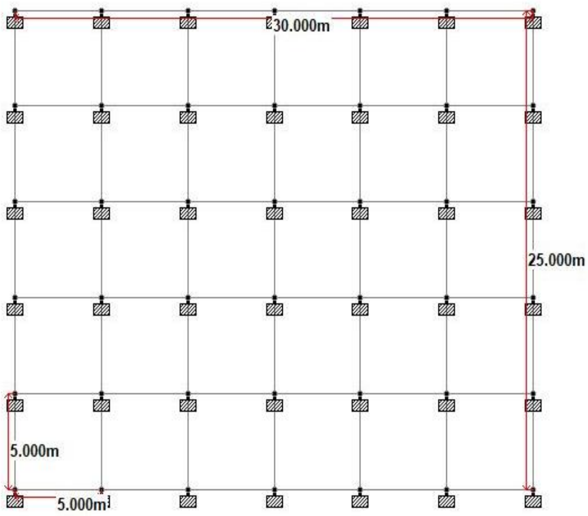


Fig 4: Wall Load & Dead Load applied on Rectangular Building

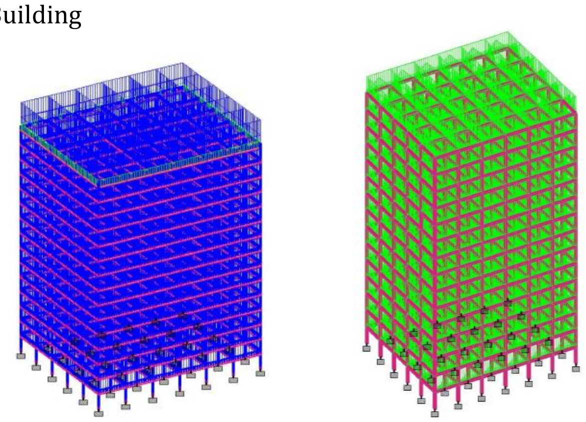
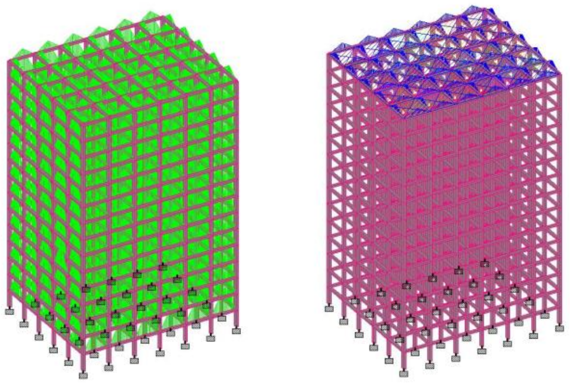


Fig 5: Live Load & Roof Load applied on Rectangular Building



tructural Plan of G+14 Circular Building Model

Fig 6: Top View of Circular Build Plan with Dimension

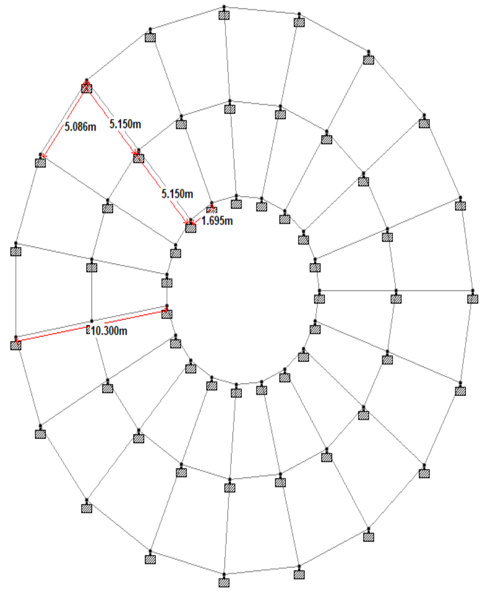


Fig 7: Wall Load & Dead Load applied on Circular Building

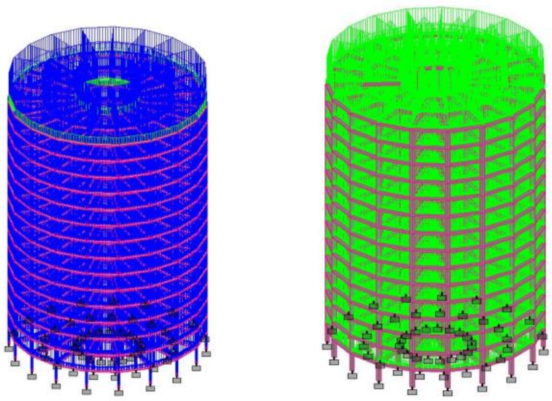
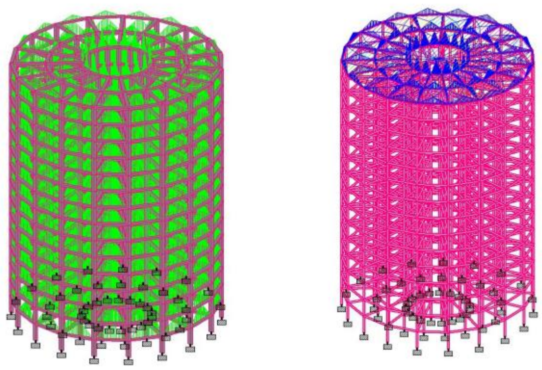


Fig 8: Live Load & Roof Load applied on Circular Building



3.3 Model I: G +14 Rectangular Building Design

Fig 9: Beam Dimensions 300 X 500 mm for all floor (Rect.)

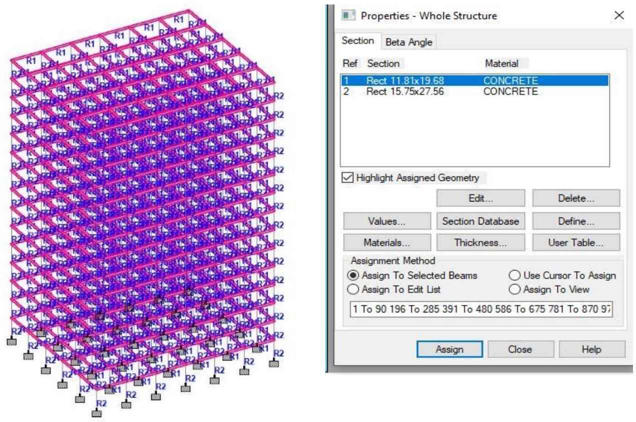
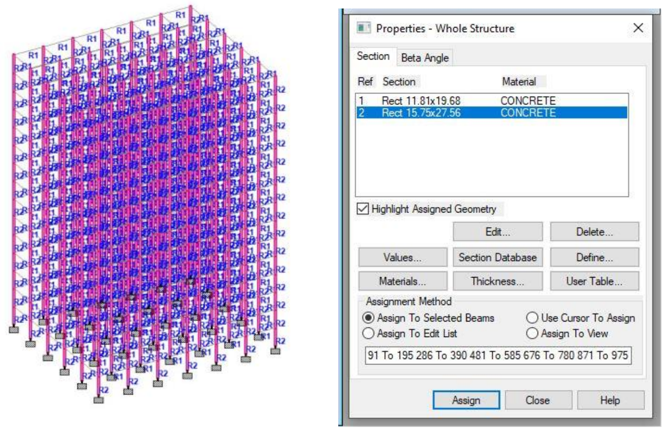


Fig 10: Column Dimensions 400 X 700mm for all floor (Rect.)



3.4 Model I: G +14 Circular Building Design

Fig 11: Beam Dimensions 300 X 500 mm for all floor (Circ.)

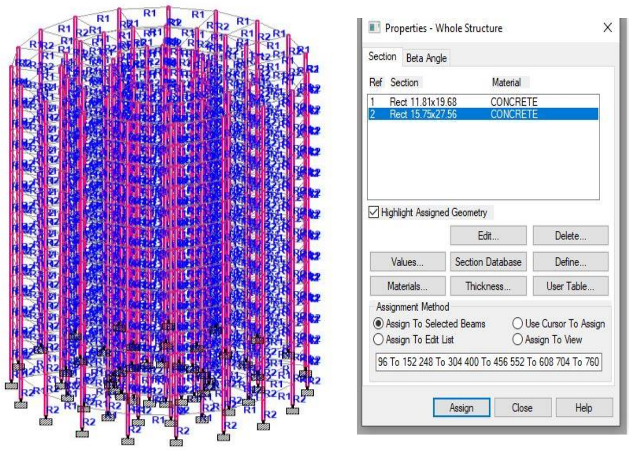
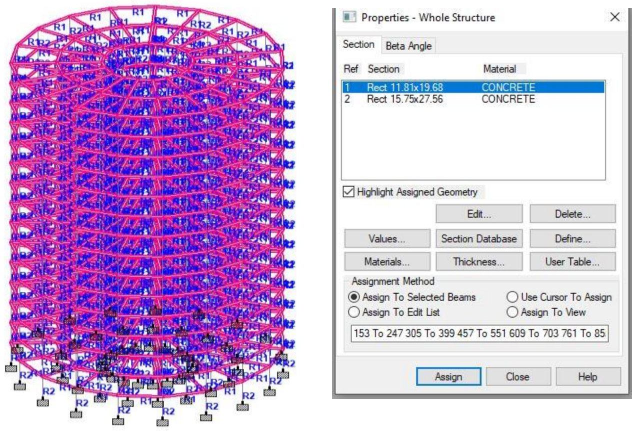


Fig 12: Column Dimensions 400 X 700mm for all floor (Circ.)



3.5 Seismic design Parameters

For the present study the following values for seismic analysis are assumed. These values are based on the reference steps provided in 1893-2016 and IS 456:2000.

- Zone factor for zone V – 0.36 [Page No. 10, Table No.3 (Clause 6.4.2)].
- Importance factor for building = 1 [Table No. 8, Page No.19, (Clause No.7.2.3)]
- Ordinary shear wall with Ordinary Moment Resisting frames (OMRF)
- Response reduction factor for an ordinary shear wall with OMRF = 3 [Page No. 20, Table No. 9, (Clause No. 7.2.6)]
- Type of soil = For Hard Soil [Page No. 13, Table No. 4 (Clause 6.4.2.1)]
- Damping percent = 5 % (0.05)

The building is a G+14 RC Building with RSM method is taken. The properties stated above are applied to the building model in STAAD.Pro. The results from the seismic loading effect analysis are compared with Circular and Rectangular Building structures.

Fig 13: Earthquake load in X-Direction

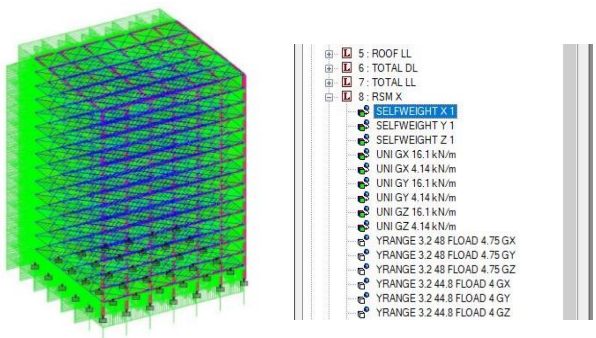


Fig 14: Earthquake load in Y-Direction

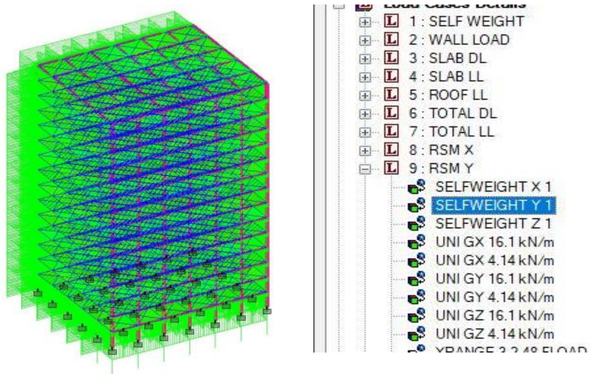
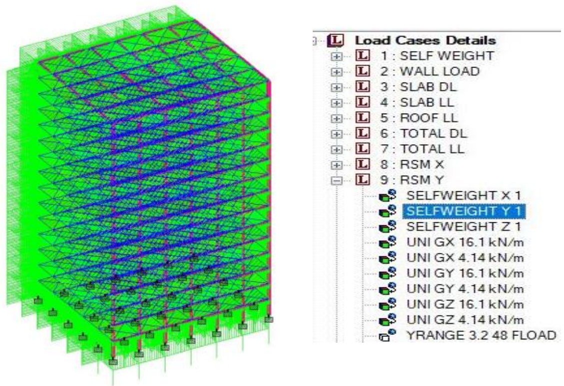


Fig 15: Earthquake load in Z-Direction



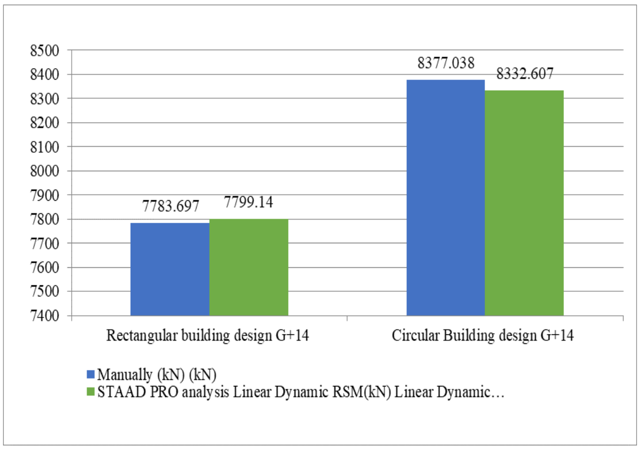
3.6 BASE SHEAR

Base shear estimates the maximum expected lateral forces that will occur due to seismic ground motion at the base of structure. It depends on soil condition and seismic activity sources due to geographical faults. The base shear represents the horizontal reaction to earthquake forces, which are a result of the storey weight. Storey weight includes the self-weight of the structure, and in RCC structures, this self-weight is significant, thereby increasing earthquake forces and maximizing the base shear. According to the static formula, base shear is directly proportional to the seismic weight of the building. This section describes the cases performed for the validation of base shear used in the dissertation. The numerical data obtained from the referenced literature is detailed below. The validation is conducted for Zone V.

Table 3. Comparison of base shear from manually and STAAD Pro analysis

Type of building	Manually (kN)	STAAD PRO analysis Linear Dynamic RSM(kN)
Rectangular building	7783.697	7799.14
Circular Building	8377.038	8332.607

Fig 16: Comparison of base shear from manually and STAAD Pro analysis



From above the total base shear has been evaluated for Rectangular and Circular building. By comparing the Base shear value from manual and STAAD.Pro software we get that the STAAD.Pro base shear is near about equal to manual. Rectangular Building shows the less base shear as compared to Circular Building (G+11). By manual calculation Circular building structure has 7.62 % higher Base shear than Rectangular building structure. By STAAD.Pro Circular building structure has 6.84 % higher Base shear than rectangular building structure

4. RESULT

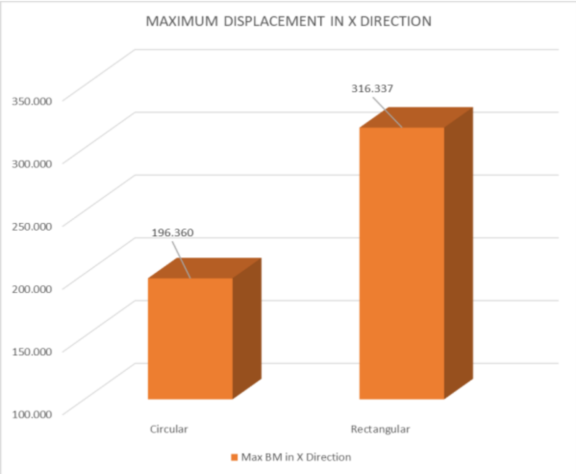
3.1 Maximum Displacement in the Storey for the X, Y and Z Direction of the Rectangular and Circular Buildings

Elements or members of a building should be designed and constructed to resist the effects of design lateral forces. STAAD.Pro provides the lateral force distribution at various levels and at each storey. The lateral force due to an earthquake is a predominant force that needs to be resisted for any structure to be earthquake-resistant. The response spectrum method has been used to find the maximum displacement in the storey for both the X and Z directions of the both the building in STAAD.Pro

Table 4. Maximum Displacement along X- Direction by Response Spectrum Method

Model	L/C	Max Dis in X (mm)
Rectangular building	RSM	316.337
Circular Building	RSM	196.360

Fig 17: Max Displacement in X- Direction

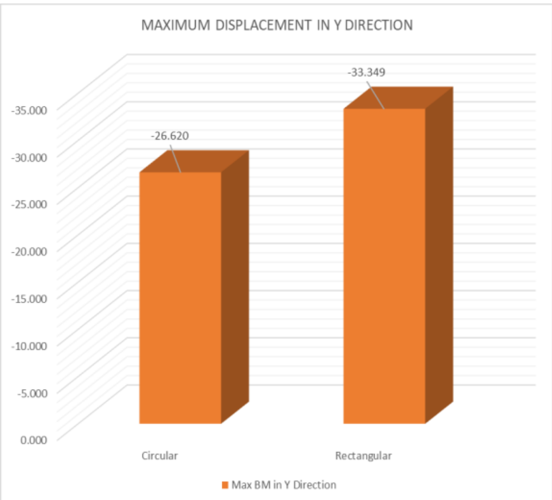


A comparison of the maximum displacement in the X direction between circular and rectangular buildings reveals that the rectangular structure shows a 61.10% greater maximum displacement than the circular structure.

Table 5. Maximum Displacement along Y- Direction by Response Spectrum Method

Model	L/C	Max Dis in Y (mm)
Rectangular building	RSM	-33.349
Circular Building	RSM	-26.620

Fig 18: Max Displacement in Y- Direction

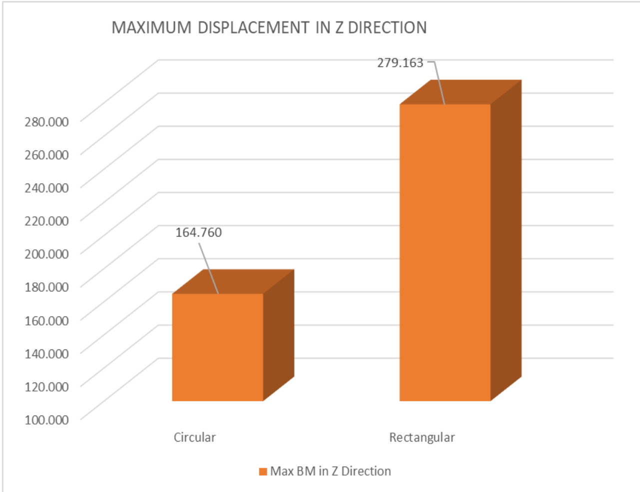


A comparison of the maximum displacement in the Y direction between circular and rectangular buildings reveals that the rectangular structure shows a 25.28% greater maximum displacement than the circular structure.

Table 6. Maximum Displacement along Z- Direction by Response Spectrum Method

Model	L/C	Max Dis in Z (mm)
Rectangular building	RSM	279.163
Circular Building	RSM	164.760

Fig 19: Max Displacement in Z- Direction

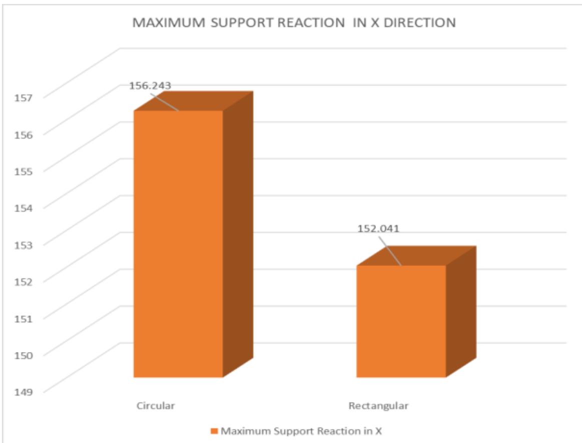


3.2 Maximum Support Reaction in X, Y and Z Direction of the Rectangular and Circular Building

Table 7. Maximum Support Reaction along X- Direction by Response Spectrum Method

Model	L/C	Max SR in X (kN)
Rectangular building	RSM	152.041
Circular Building	RSM	156.243

Fig 20: Max Support Reaction in X- Direction

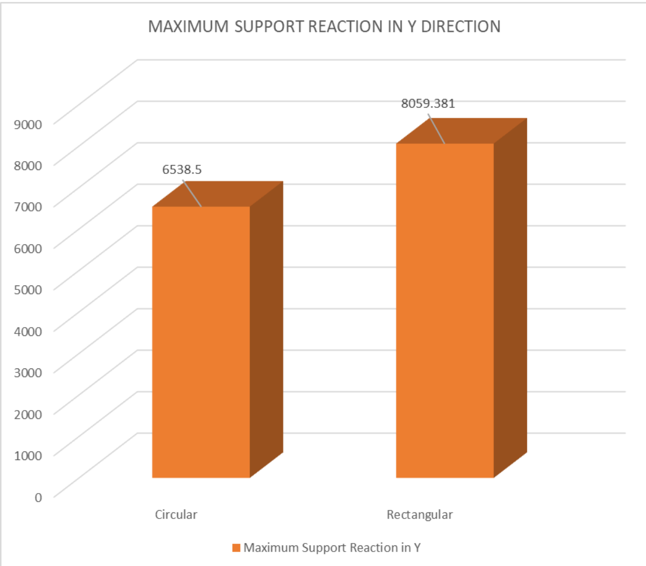


A comparison of the maximum support reaction in the X direction between circular and rectangular buildings reveals that the Circular structure shows a 2.69 % higher maximum support reaction than the rectangular structure.

Table 8. Maximum Support Reaction along Y- Direction by Response Spectrum Method

Model	L/C	Max SR in Y (kN)
Rectangular building	RSM	8059.38
Circular Building	RSM	6538.50

Fig 21: Max Support Reaction in Y- Direction

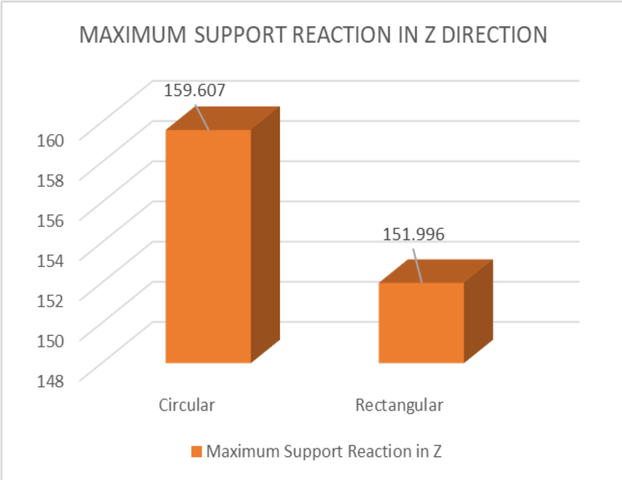


A comparison of the maximum support reaction in the Y direction between circular and rectangular buildings reveals that the rectangular structure shows a 23.26 % higher maximum support reaction than the Circular structure.

Table 9. Maximum Support Reaction along Z- Direction by Response Spectrum Method

Model	L/C	Max SR in Z (kN)
Rectangular building	RSM	151.996
Circular Building	RSM	159.607

Fig 22: Max Support Reaction in Z- Direction



A comparison of the maximum support reaction in the Z direction between circular and rectangular buildings reveals that the circular structure shows a 4.77 % higher maximum support reaction than the rectangular structure.

3.3 Maximum Bending Moment in X, Y and Z Direction of the Rectangular and Circular Building

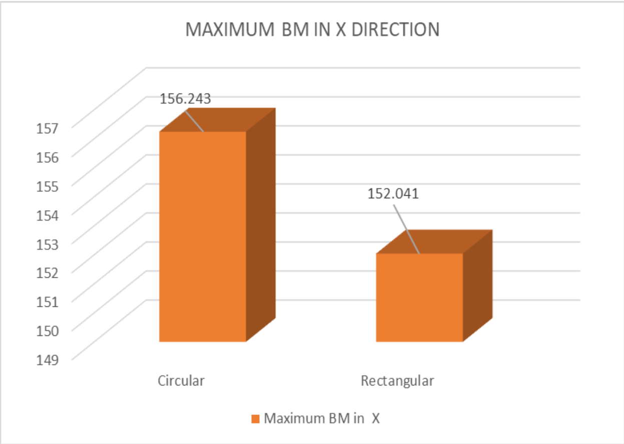
The bending moment at a section in a beam is the moment that tries to bend it and is obtained as the algebraic sum of all the moments about a section of all the forces, including the reactions acting on the beam, either to the left or to the right of the section. A bending moment measures the bending effect that can occur when external forces are applied to a structural element.

- Mx It is the bending moment in building's local X direction.
- My It is the bending moment in building's local Y direction.
- Mz It is the bending moment in building's local Z direction.

Table 10. Maximum Bending Moment along X- Direction by Response Spectrum Method

Model	L/C	Max BM in X (Kn-m)
Rectangular building	RSM	1.924
Circular Building	RSM	12.234

Fig 23: Max Bending Moment in Z- Direction



A comparison of the maximum Bending Moment in the X direction between circular and rectangular buildings reveals that the circular structure shows a 84.27 % higher maximum Bending Moment than the rectangular structure.

Table 11. Maximum Bending Moment along y- Direction by Response Spectrum Method

Model	L/C	Max BM in Y (Kn-m)
Rectangular building	RSM	748.761
Circular Building	RSM	600.598

Fig 24: Max Bending Moment in Y- Direction

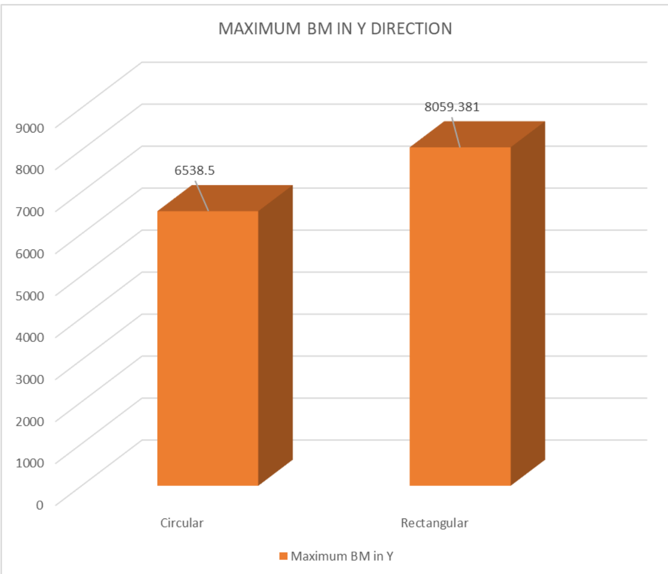
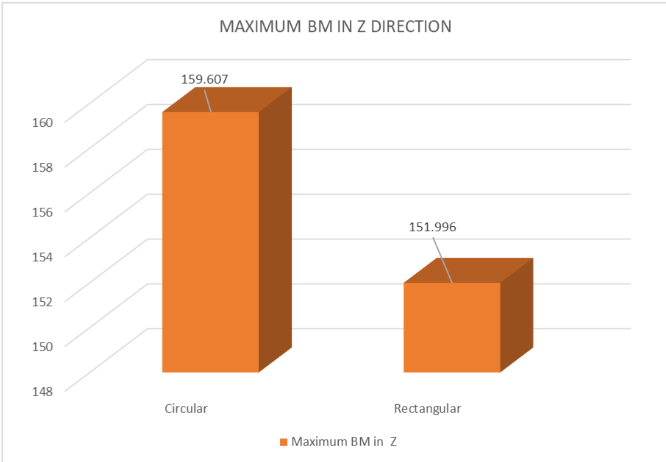


Table 12. Maximum Bending Moment along Z- Direction by Response Spectrum Method

Model	L/C	Max BM in Z (Kn-m)
Rectangular building	RSM	608.486
Circular Building	RSM	552.447

Fig 25: Max Bending Moment in Z- Direction



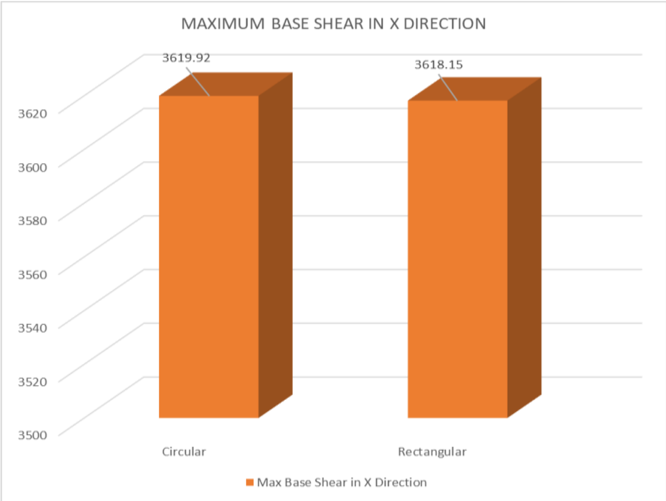
A comparison of the maximum Bending Moment in the Z direction between circular and rectangular buildings reveals that the circular structure shows a 10.14 % higher maximum Bending Moment than the rectangular structure.

3.4 Maximum Base Shear in X and Z Direction of the Rectangular and Circular Building

Table 13. Maximum Base Shear along X- Direction by Response Spectrum Method

Model	L/C	Max BS in X (KN)
Rectangular building	RSM	608.486
Circular Building	RSM	552.447

Fig 26: Max Base Shear in X- Direction

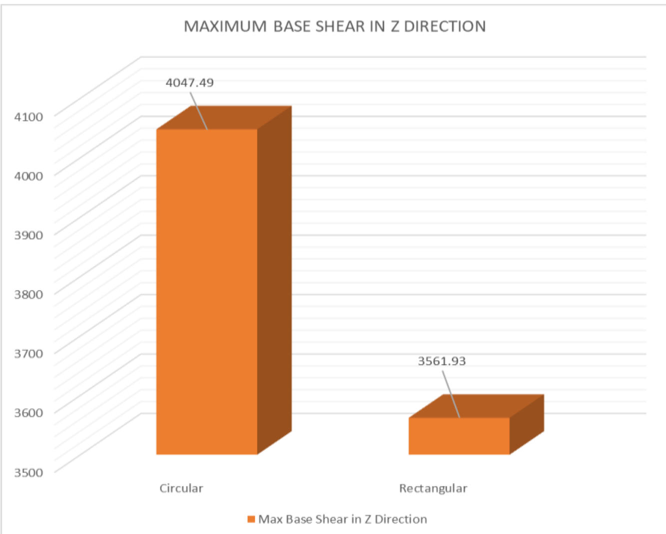


A comparison of the maximum Base Shear in the X direction between circular and rectangular buildings reveals that the circular structure shows a 0.05 % higher maximum Base Shear than the rectangular structure.

Table 14. Maximum Base Shear along Z- Direction by Response Spectrum Method

Model	L/C	Max BS in Z (KN)
Rectangular building	RSM	3618.15
Circular Building	RSM	3619.92

Fig 27: Max Base Shear in Z- Direction



A comparison of the maximum Base Shear in the Z direction between circular and rectangular buildings reveals that the circular structure shows a 12.00 % higher maximum Base Shear than the rectangular structure.

4. CONCLUSIONS

The analytical study conducted to compare the behavior of Circular and Rectangular Building. The structure subjected to dynamic analysis [Response Spectrum Analysis] Seismic loading for Zone V from the Study the following conclusions are obtained. This Comparative Study presented the seismic load effects on Circular and Rectangular Building Structures. By observing the overall analysis of results and graphs the following conclusions are as follows.

1. Maximum Displacement

• X Direction: Rectangular buildings exhibit a significantly higher maximum displacement, with a 61.10% increase compared to circular buildings.

• Y Direction: In the Y direction, rectangular buildings have a 25.28% greater maximum displacement than circular buildings.

• Z Direction: Rectangular buildings show the highest discrepancy in displacement, with a 69.44% greater maximum displacement compared to circular buildings.

2. Maximum Support Reaction

• X Direction: Circular buildings have a slightly higher maximum support reaction, with a 2.69% increase compared to rectangular buildings.

• Y Direction: Rectangular buildings display a considerably higher maximum support reaction, with a 23.26% increase over circular buildings.

• Z Direction: Circular buildings show a moderately higher maximum support reaction, at 4.77% greater than rectangular buildings.

3. Maximum Bending Moment

• X Direction: Circular buildings demonstrate a substantially higher maximum bending moment, with an 84.27% increase compared to rectangular buildings.

• Y Direction: Rectangular buildings have a higher maximum bending moment, with a 24.67% increase over circular buildings.

• Z Direction: Circular buildings exhibit a higher maximum bending moment, with a 10.14% increase compared to rectangular buildings.

4. Maximum Base Shear

• X Direction: The maximum base shear in circular buildings is marginally higher, with a 0.05% increase compared to rectangular buildings.

• Z Direction: Circular buildings show a significantly higher maximum base shear, with a 12.00% increase compared to rectangular buildings.

Overall, the analysis indicates that rectangular buildings tend to experience higher displacements and support reactions in most directions, while circular buildings generally show higher bending moments and base shears. This suggests that circular buildings may offer better stability under seismic loads, though they might experience higher bending stresses. The choice between rectangular and circular designs should consider these differences in structural behavior to optimize for seismic performance and overall building resilience.

5. FUTURE SCOPE

• The building results can be analyzed by using Pushover Analysis Method.

• As the building is analyzed in hard soil i.e type of soil, farther it can be analyzed for the soft soil as well as medium soil as per IS Codal Provisions and outcomes can be compared.

• The RC Building can be analyzed by varying the parameters.

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