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A Comparative Study on the Structural Analysis of Diagrid Structural Systems with Conventional Structural Systems for different Plan Configurations

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Abstract*: This paper presents the structural behaviour of three models of 60 storey buildings viz., Conventional rigid framed building with rectangular plan having plan dimensions of 24mx24m, diagrid building with rectangular plan having plan dimensions of 24mx24m and diagrid building with circular plan having a plan diameter of 24m. Modelling and Analysis for all the above buildings is done for gravity, earthquake and wind loads using ETABS software. IS 800:2007 is used for the design of the structural members. All the three models are analyzed and compared using the parameters such as base shear, storey displacement, time periods, structural weight and storey drifts.
***Keywords*: Diagrid Structural Systems, Conventional Structural Systems, Equivalent Static Method, Response Spectrum Method**

I. INTRODUCTION

The fast development of the population and the shortage of land have affected the residential advancement of the city. The high expenses of the land and the want to safeguard a critical agricultural creation have prompted the development of the buildings. Tall business structures are fundamentally a reaction to the exceptional inaccessibility of land. Advances in materials, development innovation, scientific techniques and auxiliary frameworks for examination and configuration have quickened the improvement of high-rise structures. The vertical columns in the centre are intended to convey just loads of gravity and the diagrid is helpful for both gravity and lateral loadings. The diagrid uses of basic steel components to give productive arrangements as far as both quality and stiffness are not new, but rather there is presently a interest intrigue and a wide utilization of diagrid alludes to extensive ranges and high rises, especially when are described by complex geometries and bended shapes. The advancement of an elevated structure includes a few complex variables, for example, economy, appearance, innovation, metropolitan controls, and legislative issues. Among these, the economy was the fundamental administering factor. For an extremely tall building, its basic plan is normally administered by its lateral stiffness. At the point when contrasted and conventional orthogonal structures for tall structures, for example, surrounded tubes, diagrid structures convey lateral wind loads stacks significantly more productively from the pivotal activity of their corner to corner part. A Diagrid structure deals great structural efficiency without vertical sections likewise opened up new aesthetic prospects for tall structure engineering. Diagrid looks great and is effortlessly recognisable. The arrangement and productivity of a diagrid framework diminishes the quantity of basic components required on the exterior of structures, subsequently decreasing obstacle to outer vision. The auxiliary effectiveness of the diagrid framework likewise averts interior and calculated sections, taking into account extensive adaptability with the floor design. The "Diagrid" framework around the perimeter reduces around 20% of the weight of basic steel contrasted with a conventional building. Diagonal members in diagrid structural systems carry gravitational loads as well as lateral forces because of to their triangular configuration. Diagrid can save up to 20% to 30% of the amount of structural steel in a tall building. The term "diagrid" is a combination of the words "diagonal" and "grid" and refers to a structural system that has a unique thickness in nature and obtains its structural integrity through the use of triangulation. Diagrid systems can be flat, crystalline or assume multiple curvatures, often using crystalline shapes or curves to increase their rigidity. Perimeter diagrams normally support the lateral and gravitational loads of the building and are used to support the edges of the floor.

II. LITERATURE REVIEW

Mark Sarkisian and Rupa Garai (2015) in this paper they said that the use of space, the appearance of the building and the construction time are delayed construction techniques and are often complex in details and are influenced by trellis and stabilizers.

Therefore, an excellent alternative to stabilizers is the strengthening of the problems that come together in the building façade, forming an integral three-dimensional model. They have a good resilience after earthquakes recovery and sustainability. Within their response range, these problems remain incredibly elastic.

Compared to conventional structures, diagrid structures have less energy dissipation and are more elastic. To avoid deformations in the plane, they must be explicitly addressed with mooring limbs and plate reinforcements with carefully detailed nodal connections. By sharing a balanced portion of the lateral forces between the two systems, a tube in the lateral resistance system is created by combining the diagrid perimeter and the internal wall of reinforced concrete.

The used diagrid materials can be hollow steel pipes or steel pipes filled with concrete. The nodes are connected to all the alternating floors and the floors between the nodal planes are suspended from the nodal planes above. Some of the diagrid structures we are talking about in the newspaper are: Polysquare International, Beijing, China and Shenxhen CITIC Financial center, Shenzhen, China.

Vishal B, Manthan I Shah and Snehal V Mevada Patel 2016) discussed the various heights for the diagrid structures. Here, the study of the critical effects of lateral forces such as wind forces and seismic forces in the diagrid. The comparison was made in terms of aircraft movement, plane displacement, basic cutting, and time-period and steel consumption.

The design and analysis was conducted for seven steel buildings, both for conventional construction and for the construction of diagrams, modeling and analysis tools made in ETABS software.

The analysis was performed for dead loads, live loads, seismic loads and lateral wind loads. The study concluded that the percentage of steel to be used in diagrid buildings reduces with increasing height of the building. The gravitational loops are equally distributed in both the internal and peripheral diaphragm.

The wind load governs the design of the structure in more than 25 floors. For a 24-storey building, the weight of the diagrid building is 100% smaller than the conventional building.

Mir M. Ali and Kheir Al-Kodmany (2016) have studied the blend of structural and aesthetic functionality that examines possible past, present, and future towers of structural systems. A better understanding of the aesthetic developments in skyscrapers around the world summed up the concepts of structural performance and artistic creativity.

Geetha L and Nandeesh K V (2016) have shown that by half and half the structure, which is providing central nucleus at the focal point and diagrid at the edge of the structure, auxiliary efficacy and sustainability, are achieved. By opposing gravitational stress and parallel stress in tall structures, the central structures are essential parts. The main objective was to examine the response behavior of hyperbolic circular diagonal buildings with central walls made by shear walls and made by steel frames. Also, lateral oscillation of the internal structure system was compared and the effect of diagrid buildings per static method and dynamic method were discussed. Finally, the best combination of structural element was declared. In this study, they have considered the hyperbolic circular building 200.6m high, with diagrid exterior and shear wall or inverted V-versions in the core (internal structure). For zone 2 and zone 3, the analysis and modeling is done in the ETABS for wind and earthquake loads.

The deviation of the floor, displacements of floors, periods of time and comparison scissors is done. It was concluded that the shear wall gives less lateral displacement and deviations and is more rigid and shows better result for the earthquake loading. The steel bracing system is suitable for higher seismic zones and provides better performance against floor shears.

III. OBJECTIVES AND METHODOLOGY

A. Objectives

The main requirement of a tall structure is that it should have sufficient ductility, adequate lateral, strength, safety and minimum damage level. The main objective of this study is to compare the behaviour of a convention rigid frame building with a rectangular building. Further, the comparison is extended to different plan configuration of the rectangular building by altering the shape of the building to circular, for wind loads as the wind load effect depends upon the shape factor.

The objectives of the present study are-

1) To study the performance of the structural shape of the diagrid for a tall building with respect to the conventional structural shape under the lateral forces, in terms of displacement, drift between floors, basic shear, time-period, floor stiffness and weight of structural steel.

2) To investigate the effect of change in shape of the building in plan in diagrid structural forms, under wind and earthquake forces.

3) Compare the efficiency of the diagrid structural shape for a tall building for different plan configuration with conventional tall building.

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B. Material Properties

Modelling is done with the structural elements as linearly elastic elements. It is a steel structure and steel properties are assigned to all the columns beams and braces. The slab is modelled as a concrete slab. For all the models, design is done as per IS-800:2007 for both lateral loads and gravity loads. Material properties are presented in Table 1.

TABLE I: Material Properties

Concrete Properties	
Grade of concrete	M-20
Density of RCC	25 kN/m^3
Poisson's ratio	0.20
Steel Properties	
Grade of Steel	Fe-250
Modulus of Elasticity	200 GPa

C. Structural Modelling in ETABS

1) Conventional Rigid Framed Building- Rectangular Plan: The design of the convention steel building is such that there is distribution of equal loads on the perimeter of the structure, the force is transferred directly to the columns and spacing between the beams is kept maximum. The spacing between the beams is kept as 6m center to center. The force on the façade of the building should be equal. Keeping this in mind the position of the beams is decided. The floor beams are to be considered in 2 parts for modelling; one is that for transferring the loads to the perimeter structure the secondary structures are used and the other part forms the perimeter structure. The perimeter structure includes the exterior beams of floor frame. The plan and 3D view is shown in Fig. 1.

Plan dimensions: 24x24m

Column sections

1200x1200mm I-section with 120mm thick flange and web. (From storey 1 up to storey 20).

1000x1000mm I-section with 100mm thick flange and web. (From storey 20 up to storey 40).

Slab sections: 160mm thick slab of shell thin type made of M20 grade concrete

Beam sections

250mm×250mm I-section with 50mm thick flange and web (Primary beams connecting the internal columns)

400mm×400mm I-section with 45mm flange and web thickness (Secondary beams connecting internal columns to the external ones)

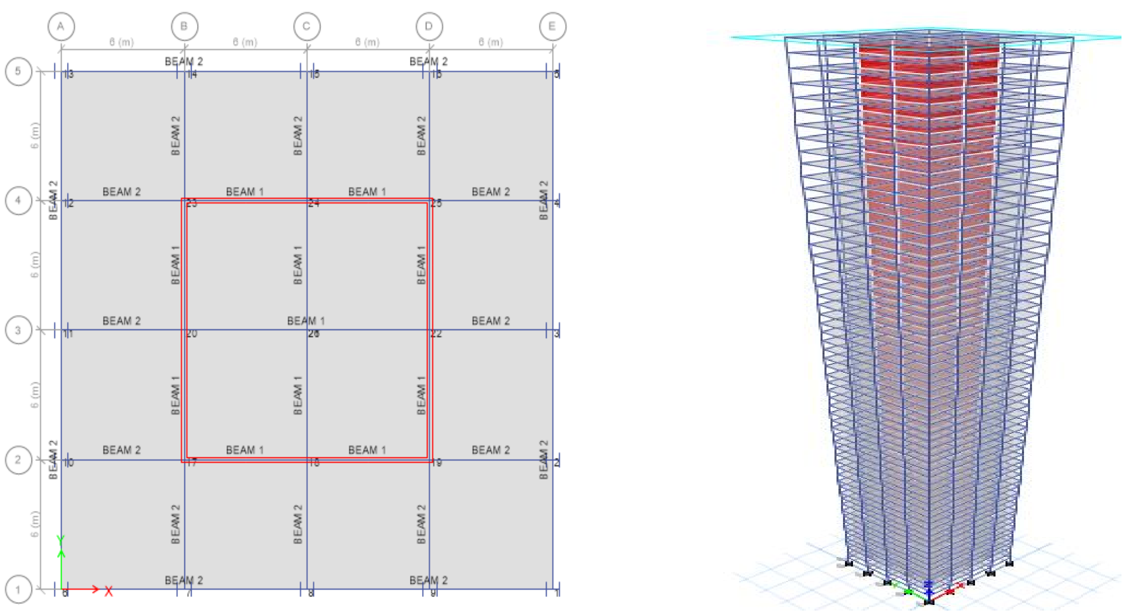

Fig. 1: Plan and 3D view of Model-1

2) Diagrid Structural System Building- Rectanglular Plan: The design of the diagrid structural steel building is such that there is distribution of equal loads on the perimeter of the structure, the beam spacing should be more than usual and modelling of the core-beam interface should be a hinge. Spacing between the beams is kept as 6m. The beams are arranged in such a way that the force entering each faces of the facade structure is the same. The primary beam supporting the secondary beam is divided longitudinally into two beams to decrease the depth of the beam. The floor beams are to be considered in 2 parts for modelling; one is that for transferring the loads to the perimeter structure the secondary structures are used and the other part forms the perimeter structure. The plan and 3D view is shown in Fig. 2.
of M20 grade concrete of shell thin type.

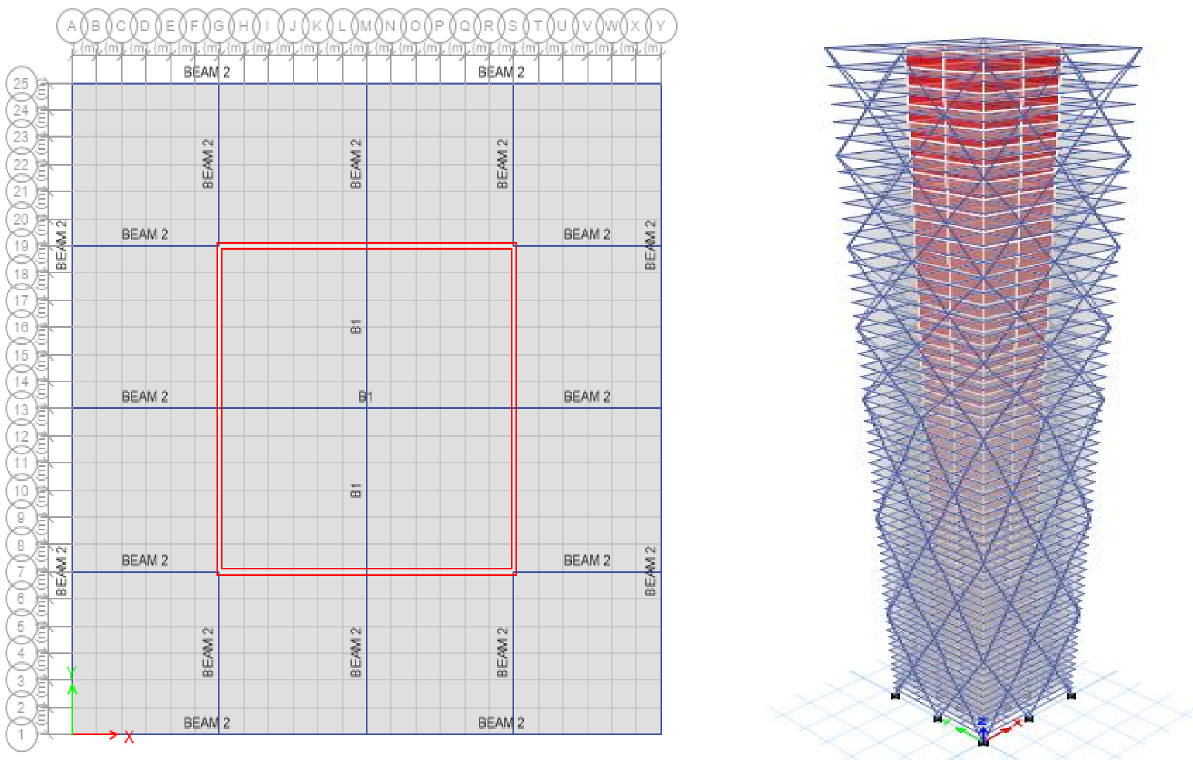

Fig. 2: Plan and 3D view of Model-2

3) Diagrid Structural System Building- Circular Plan: The design of the diagrid structural steel building is such that there is distribution of equal loads on the perimeter of the structure, the beam spacing should be more than usual and modeling of the core-beam interface should be a hinge. Spacing between the beams is kept as 6m. The beams are arranged in such a way that the force entering each face of the facade structure is the same. The primary beam supporting the secondary beam is divided longitudinally into two beams to decrease the depth of the beam. The floor beams are to be considered in 2 parts for modeling; one is that for transferring the loads to the perimeter structure the secondary structures are used and the other part forms the perimeter structure. The plan and 3D view is shown in Fig. 3.
Plan diameter: 24m
Slab sections: 160mm thick slab of shell thin type made of M20 grade concrete
Beam sections:
300mm×300mm I-section with 30mm thick flange and web (Primary beams connecting the internal shear wall)
400mm×400mm I-section with 40mm flange and web thickness (Secondary beams connecting internal shear wall to the external beams)
Bracings: Steel pipe of outer diameter 800mm and inner diameter of 100mm (From storey 1 up to storey 36 having diagrid angle of 84^{o}).
Steel pipe of outer diameter 500mm and inner diameter of 60mm (From storey 36 up to storey 48 having diagrid angle of 78^{o}).
Steel pipe of inner diameter 300mm and inner diameter of 40mm (From storey 48 up to storey 60 having a diagrid angle of 78^{o}).
Shear wall: 200mm thick wall made of M20 grade concrete of shell thin type.

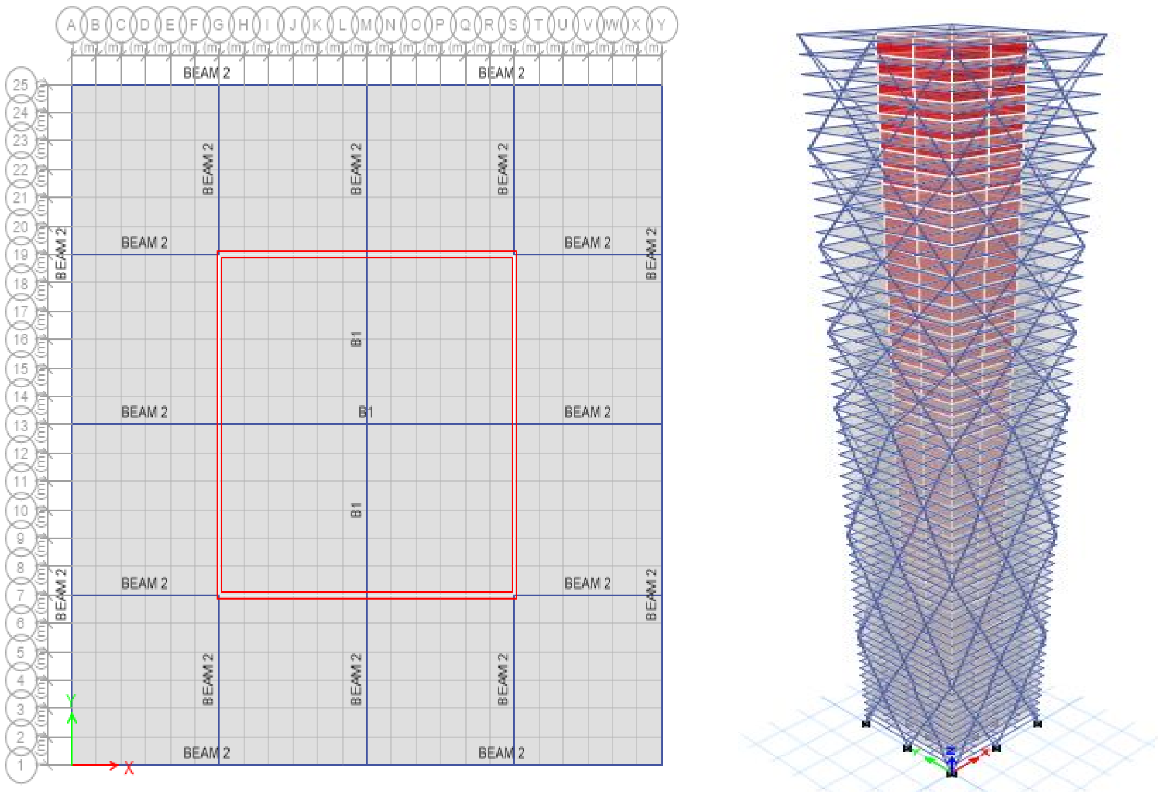

Fig. 3: Plan and 3D view of Model-3

Seismic parameters as per IS-1893:2002 and wind load parameters as per IS-875 (Part3):1987 details are given in Tables 2, 3 and 4 respectively.

TABLE 2: Seismic parameters as per IS-1893:2002

Zone Factor (Z)	0.24 (Zone IV)
Soil Type	Type II (Medium)
Importance Factor (I)	1.2
Response Reduction Factor (R)	5.0
Damping	2%

TABLE 3: Gravity loads on the Structure

Live load	
Floors	3.0 kN/m^2
Roof	1.2 kN/m^2
Dead load	
Self-weight + Finishes	1 kN/m^2

TABLE 4: Wind Parameters as per IS-875 (Part3):1987

Wind Zone	III
Basic Wind Speed	33 ms^{-1}
Terrain Category	1
Topography	Plain
Probability factor [k1]: 1.0 Height factor [k2]: varies with floor height, as in Table 3.1 of code Topography factor [k3]: 1.0	

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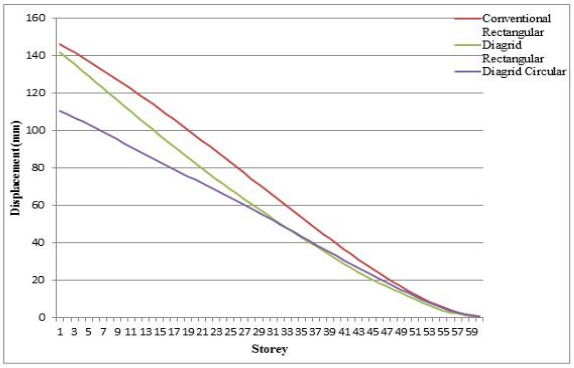
Gust factor method is used for the calculation of wind forces since the height to least lateral dimension exceeds five. The wind loads are calculated and applied at each node respectively for all the buildings and then the analysis of the model is carried out in ETABS software.

IV. RESULTS AND DISCUSSIONS

A. Comparison of Results for Different Models

1) Comparison of Storey displacements due to Earthquake loads



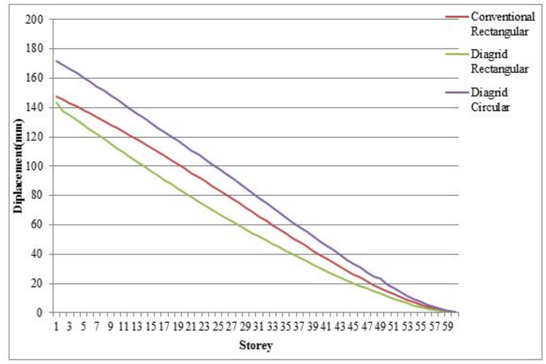
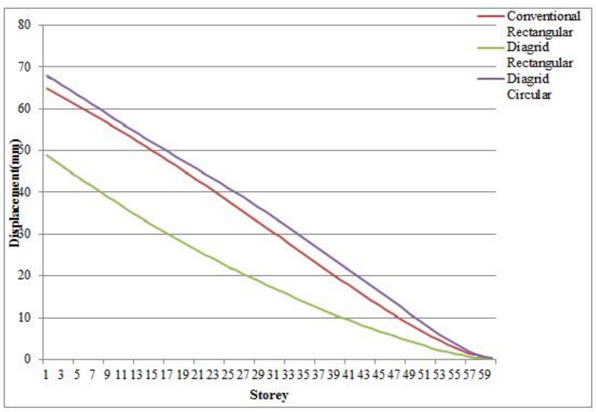


Fig. 4: Comparision of Storey Dispacements Due to Earthquake Loads by Equivalent Static Method Along X and Y Direction



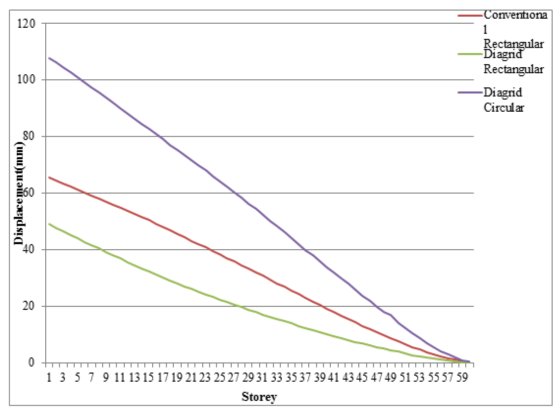
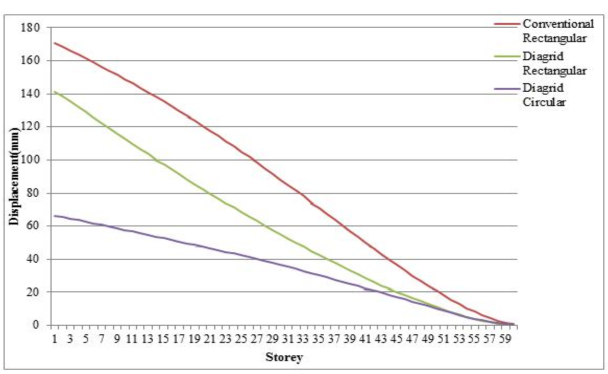


Fig. 5: Comparision of Storey Dispacements Due to Earthquake Loads by Response Spectrum Method Along X and Y Direction

a) The magnitude of storey displacement for both the diagrid structural buildings is almost the same.
b) The storey displacements due to response spectrum method are lower than earthquake loads given by equivalent static method.
c) The two diagrid structural systems considered in the study have a displacement of lower magnitude as compared to conventional rigid frame building.
d) The maximum lateral displacements due to earthquake loading along X direction are lower than those along Y direction, for all the structural forms considered in the study.

2) Comparison of Storey Displacement and Inter-Storey Drifts Due to Wind Loads



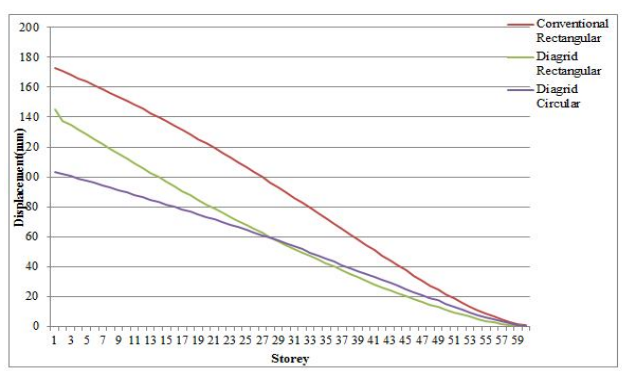


Fig. 6: Storey Displacements of Various Structural Forms Due to Wind Load Along X and Y Directions

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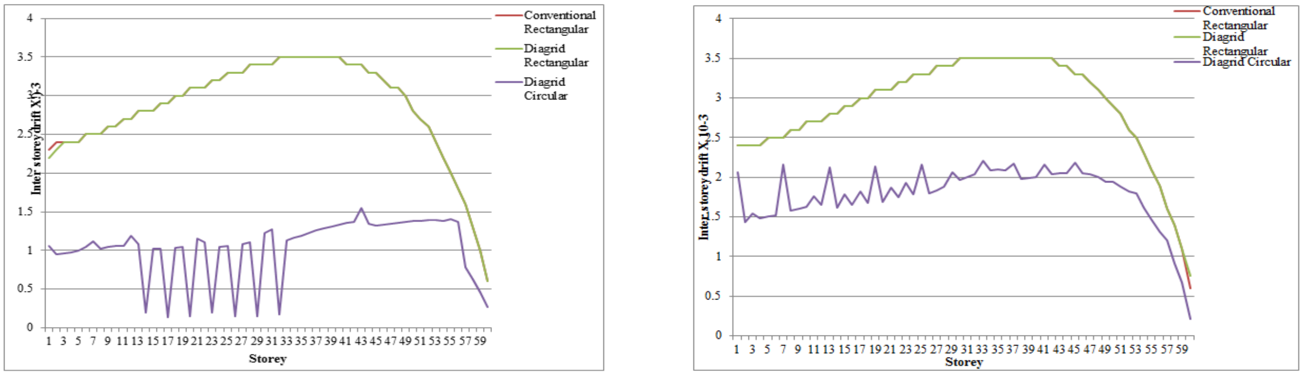

Fig. 7: Inter Storey Drifts of Various Structural Forms Due to Wind Load Along X and Y Directions

a) The two diagrid structural forms namely rectangular diagrid structural system and circular diagrid structural system have a inter storey drift and displacement of lower magnitude as compared to the convention rigid frame building.

b) The maximum inter storey drifts and lateral displacement due to wind loading along X direction is lower than that along Y direction for all the three structural forms considered in the study.

c) The two-diagrid structural systems considered in the study have a maximum storey drift and maximum displacement of lower magnitude as compared to conventional rigid frame building. Further, the maximum storey drift and maximum displacement for diagrid circular framed building is lesser than diagrid rectangular framed building.

3) Comparison of Base shear

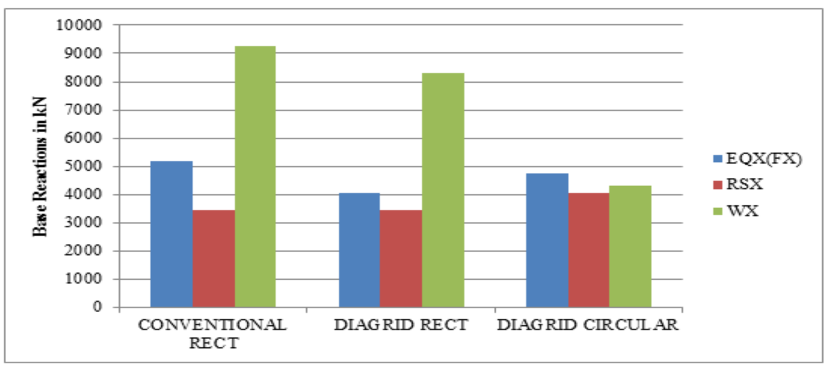

Fig. 8: Comparision of Base shear

a) For all the three models considered in the study namely conventional rigid frame building, rectangular diagrid structural system and circular diagrid structural system the base reactions due to dead load and live load are same.

b) The base reactions due to earthquake loading are lower than those of the wind loads in both X and Y, for all the structural forms considered in the study.

4) Comparison of Time Period

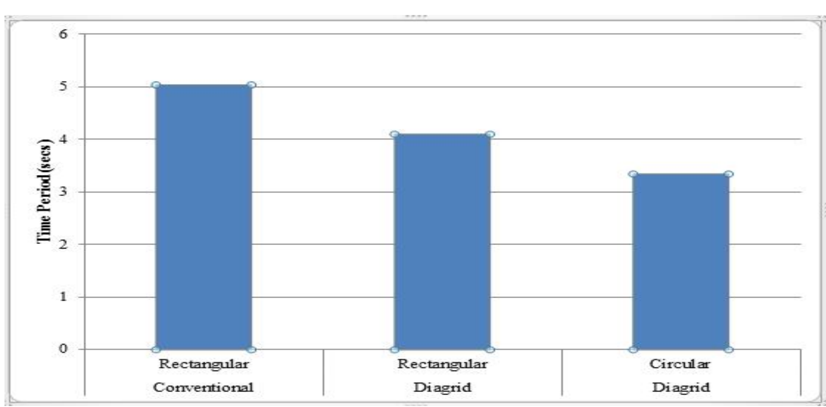

Fig. 9: Comparision of Time Periods for various Structural Forms

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The time-period of diagrid circular building is less as compared to rigid framed building and diagrid rectangular building. Further, the time-period of rectangular diagrid structural system is less as compared to conventional rigid framed building.

5) Comparison of Storey Stiffness

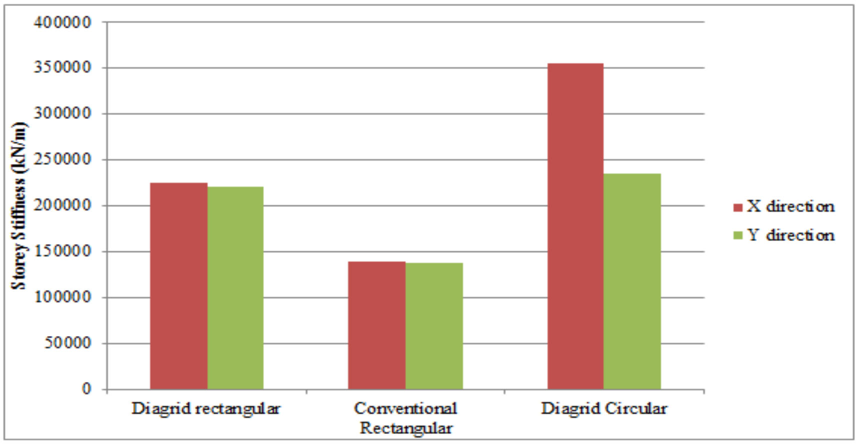

Fig. 10: Comparision of Storey Stiffness Along X and Y Directions for various Structural Forms

a) The storey stiffness along Y direction is of lower magnitude as compared to that along X direction for all the buildings that is conventional rigid frame building, rectangular diagrid structural system and circular diagrid structural system
b) The storey stiffness of the two diagrid structural forms considered that is rectangular diagrid structural system and circular diagrid structural system is more as compared to the storey stiffness of conventional rigid frame structure.
c) The storey stiffness in ascending order for the three diagrid structural forms studied are; conventional rigid framed building, diagrid circular building and diagrid rectangular building.

6) Comparison of Structural Weight

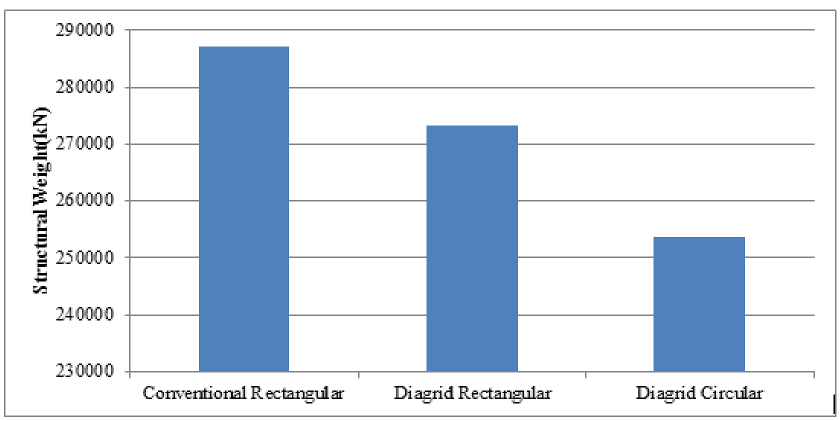

Fig. 11 Comparision of Structural Weight for various Structural Forms

a) The structural weight of diagrid circular building is less than the structural weight of diagrid rectangular building.
b) Further the structural weight of diagrid rectangular building is less than the conventional rigid frame building.

V. CONCLUSIONS

A. From The Results And Comparison, Following Points Are Concluded

1) The maximum displacement of the floor due to seismic loads is given by (h/250). The maximum displacement of the floor due to seismic loads is included in this range.
2) Since the equivalent static method is influenced by the time-period assumed, the displacements estimated due to the equivalent static method are greater than the displacements due to the response spectrum method.
3) The stiffness of the building along the X direction is greater than the stiffness along the Y direction. Therefore, the lateral displacement along the X direction is greater than the lateral displacement along the Y direction.

4) Since the displacements caused are influenced by the mass and structural shape of the building and regardless of the shape of the structure, the displacements of the planes for both the diagrid structural systems are almost the same as those obtained with the equivalent static method, the same applies to the spectrum of the analysis response method.
5) The maximum displacement of the ground due to wind loads is given by h / 500. The maximum displacement of the ground due to wind loads is included in this interval.
6) The rigidity of the building along the X direction is greater than the rigidity along the Y direction. Therefore, the lateral displacement and the maximum variations between the planes along the X direction are greater than the lateral derailment and the maximum is displaced along of the Y direction.
7) Since the increased lateral strength of the load is obtained by the axial action of the diagonals and the stiffness to be cut, diagrid structural systems perform better than the conventional rigid frame structure.
8) As the shape of the building assumes a curve, the displacements are reduced due to the wind load applied to the building surface.
9) The circular top structure has a shorter time period and therefore more rigidity. Therefore, it is more stable than the other two buildings, i.e., the conventional building with rigid structure and rectangular diagrid construction.

Therefore, from the previous points, it can be said that diagrid structural systems offer better performances in terms of performance evaluation such as efficiency and sustainability. It is seen that the diagrid structural systems have a relatively smaller deflection than the conventional rigid structure. The structural weight of the diagrid structural system is reduced to a greater extent than the construction of the conventional rigid structure. It has also been found that diagrid structural systems are more resistant to lateral forces.

VI. SCOPE FOR FUTURE STUDY

A. Seismic response of irregular diagrid structures can be studied.
B. Study on diagrid structures with different diagrid angle for irregular plans can be studied.

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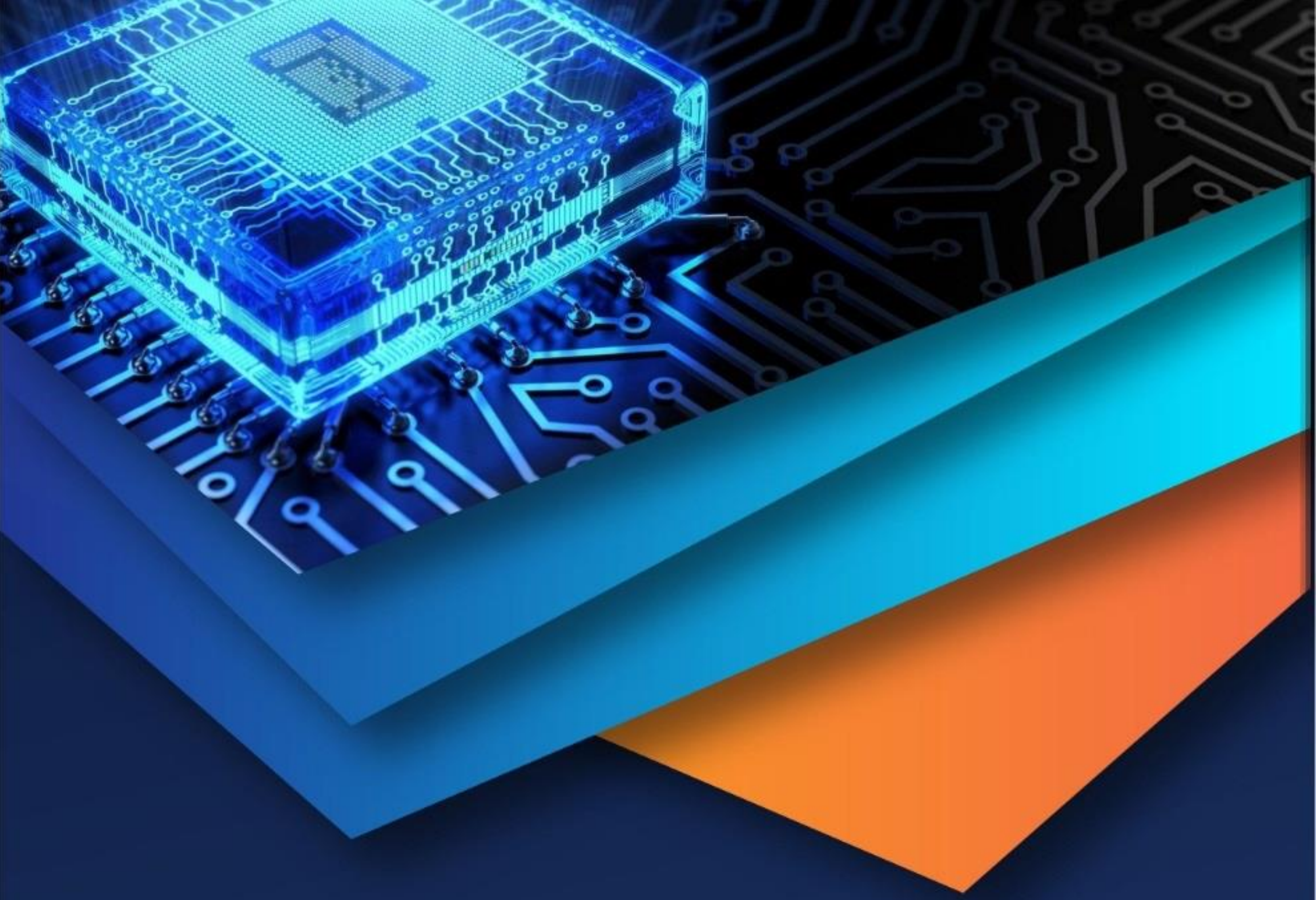

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