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Earthquake and Wind Analysis of Diagrid Structure

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Abstract: This research paper consists of earthquake and wind analysis of Steel Diagrid Structure with different shapes in plan. The Indian standard code of practice IS- 1893 (Part I: 2002), IS- 875:1987(Part III), IS-800-2007 guidelines and methodology are used to analyse and design building. Etab2015 structural analysis software is used to analyse buildings under the effect of wind and earthquake forces in zone III. Equal area of 1296 m^2 used for Circular, Square, Rectangular plans. Seismic and Wind analysis done by Linear Static method. The behaviour of building components was examined and compared on the basis of displacement, story drift, and base shear.

Keyword: Diagrid Structure, Etab 2015, different shapes in plan, Linear Static method, seismic analysis, wind analysis, displacement, storey drift, base shear.

I. INTRODUCTION

With their structural efficiency as a varied version of the tubular systems, diagrid structures have been emerging as a new aesthetic trend for tall buildings in this era of pluralistic styles. Early designs of tall buildings recognized the effectiveness of diagonal bracing members in resisting lateral forces. Most of the structural systems deployed for early tall buildings were steel frames with diagonal bracings of various configurations such as X, K, and chevron. However, while the structural importance of diagonals was well recognized, the aesthetic potential of them was not appreciated since they were considered obstructive for viewing the outdoors. Thus, diagonals were generally embedded within the building cores which were usually located in the interior of the building. A major departure from this design approach occurred when braced tubular structures were introduced in the late 1960s. For the 100-story tall John Hancock Center in Chicago, the diagonals were located along the entire exterior perimeter surfaces of the building in order to maximize their structural effectiveness and capitalize on the aesthetic innovation. This strategy is much more effective than confining diagonals to narrower building cores. Despite the clear symbiosis between structural action and aesthetic intent of the Hancock Tower, this overall design approach has not emerged as the sole aesthetic preference of architects. However, recently the use of perimeter diagonals – thus the term "diagrid" – for structural effectiveness and lattice-like aesthetics has generated renewed interest in architectural and structural designers of tall buildings. The difference between conventional exterior-braced frame structures and current diagrid structures is that, for diagrid structures, almost all the conventional vertical columns are eliminated. This is possible because the diagonal members in diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration in a distributive and uniform manner. Compared with conventional framed tubular structures without diagonals, diagrid structures are much more effective in minimizing shear deformation because they carry shear by axial action of the diagonal members, while conventional tubular structures carry shear by the bending of the vertical columns and horizontal spandrels. The diagrid can be compared with another prevalent structural system, the outrigger structures. Properly designed, an outrigger structure is effective in reducing the overturning moment and drift of the building. However, the addition of the outrigger trusses between the shear core and exterior columns does not add lateral shear rigidity to the core. Thus, tall buildings that employ outrigger systems still require cores having significant shear rigidity. The diagrid structure provides both bending and shear rigidity. Thus, unlike outrigger structures, diagrid structures do not need high shear rigidity cores because shear can be carried by the diagrids located on the perimeter, even though super tall buildings with a diagrid system can be further strengthened and stiffened by engaging the core, generating a system similar to a tube-in-tube. An early example of today's diagrid-like structure is the IBM Building of 1963 in Pittsburgh. With its 13-story building height, this building was not given much attention by architects and engineers, and it was not designed as a three-dimensional system as is done at present. In the early 1980s Humana Headquarters competition, a diagrid structure was proposed by Sir Norman Foster. However, the winning entry at that time was a historicist building of the post-modern style designed by Michael Graves. Only recently have notable diagrid tall buildings been commissioned. Examples are the 30 St. Mary Axe in London also known as the Swiss Re Building and the Hearst Headquarters in New York, both by Sir Norman Foster, and Guangzhou Twin Towers in Guangzhou by Wilkinson Eyre. Another ultra-tall building currently being

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designed by Skidmore, Owings and Merrill is the Lotte Super Tower in Korea, which employs a diagrid multi-planar façade. While the example diagrids presented so far are steel structures, which clearly express their regular diagrids on their facades, another new design approach uses reinforced concrete, creating new architectural aesthetic expressions different from that generated by steel structures. Both the COR Building in Miami by Chad Oppenheim Architecture and Ysrael Seinuk of YAS Consulting Engineers and the O-14 Building in Dubai by RUR Architecture employ reinforced concrete diagrids as their primary lateral load-resisting systems. Due to the properties of concrete, the structural diagrid patterns, which are directly expressed as building façade aesthetics, are more fluid and irregular in these buildings, and different from the explicit and pristine features of steel diagrids.

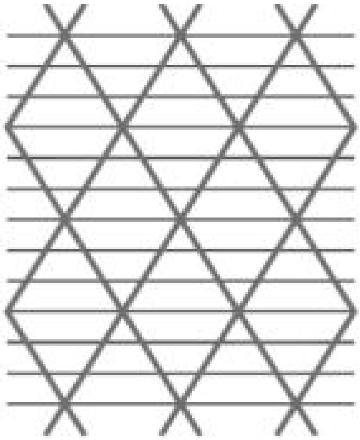

Fig. 1. Diagrid buildings (Swiss Re in London)

A. The Objective of the Paper is to be

1) To carry out wind and seismic analysis of Diagrid Structure with variable shapes in plan using E-tab 2015 software.
2) To compare the results of analysis of Diagrid structures considering parameters such as displacement, base shear and storey drift of three shapes.

II. STRUCTURAL DATA

A. Structural Configure Ration

1) *Plan Dimension:* Rectangular plan size 54m X 24m, Square plan size 36m X 36m, Circular plan size 40.62m Dia
2) *Height of Floor:* 3m
3) *Slab Thickness:* Deck Slab 120 mm thick
4) *Number of Storey:* 60
5) *Concrete:* M20 for deck slab, M40 for infill concrete
6) *Steel:* YST 310 grade for fill and infill tube section , fy 250 for deck section

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B. Seismic Data (As per IS: 1893-2002)
1) *Zone Factor:* 0.16 (Zone III)
2) *Response Reduction Factor:* 5 (SMRF)
3) *Important Factor:* 1
4) *Type of Soil:* II, (Medium Soil)

C. Wind Data (As per IS: 875-1987)
1) *Wind Speed:* 39 m/s
2) *Terrain Category:* 2
3) *Structure Class:* B
4) *Risk Coefficient k:* 1
5) *Topography Factor k:* 3: 1

D. Loading Data (as per IS 875-Part I & II)
1) *Wall Load (Cladding):* 6 KN/m
2) *Parapet Wall Load:* 3KN/m
3) *Roof Live Load:* 1.5 KN/m^2
4) *Floor Live Load:* 3 KN/m^2
5) *Floor Finish:* 1 KN/m^2

E. Combinations

TABLE 1 LOAD COMBINATION

Name	Load Case/Combo	Scale Factor	Type
UDStlS15	DEAD	1.5	Linear Add
UDStlS15	FF	1.5	
UDStlS15	Cladding	1.5	
UDStlS16	DEAD	1.5	Linear Add
UDStlS16	LIVE	1.5	
UDStlS16	FF	1.5	
UDStlS16	Cladding	1.5	
UDStlS17	DEAD	1.2	Linear Add
UDStlS17	LIVE	1.2	
UDStlS17	FF	1.2	
UDStlS17	Cladding	1.2	
UDStlS17	EQX	1.2	
UDStlS18	DEAD	1.2	Linear Add
UDStlS18	LIVE	1.2	
UDStlS18	FF	1.2	
UDStlS18	Cladding	1.2	
UDStlS18	EQX	-1.2	
UDStlS19	DEAD	1.2	Linear Add
UDStlS19	LIVE	1.2	
UDStlS19	FF	1.2	
UDStlS19	Cladding	1.2	
UDStlS19	EQY	1.2	
UDStlS20	DEAD	1.2	Linear Add
UDStlS20	LIVE	1.2	
UDStlS20	FF	1.2	
UDStlS20	Cladding	1.2	
UDStlS20	EQY	-1.2	
UDStlS21	DEAD	1.5	Linear Add

UDStlS21	FF	1.5	
UDStlS21	Cladding	1.5	
UDStlS21	EQX	1.5	
UDStlS22	DEAD	1.5	Linear Add
UDStlS22	FF	1.5	
UDStlS22	Cladding	1.5	
UDStlS22	EQX	-1.5	
UDStlS23	DEAD	1.5	Linear Add
UDStlS23	FF	1.5	
UDStlS23	Cladding	1.5	
UDStlS23	EQY	1.5	
UDStlS24	DEAD	1.5	Linear Add
UDStlS24	FF	1.5	
UDStlS24	Cladding	1.5	
UDStlS24	EQY	-1.5	
UDStlS25	DEAD	0.9	Linear Add
UDStlS25	FF	0.9	
UDStlS25	Cladding	0.9	
UDStlS25	EQX	1.5	
UDStlS26	DEAD	0.9	Linear Add
UDStlS26	FF	0.9	
UDStlS26	Cladding	0.9	
UDStlS26	EQX	-1.5	
UDStlS27	DEAD	0.9	Linear Add
UDStlS27	FF	0.9	
UDStlS27	Cladding	0.9	
UDStlS27	EQY	1.5	
UDStlS28	DEAD	0.9	Linear Add
UDStlS28	FF	0.9	
UDStlS28	Cladding	0.9	
UDStlS28	EQY	-1.5	
UDStlD3	DEAD	1	Linear Add
UDStlD3	FF	1	
UDStlD3	Cladding	1	
UDStlD4	DEAD	1	Linear Add
UDStlD4	LIVE	1	
UDStlD4	FF	1	
UDStlD4	Cladding	1	
DCmc1	DEAD	1.4	Linear Add
DCmc1	FF	1.4	
DCmc1	Cladding	1.4	
DCmc2	DEAD	1.2	Linear Add
DCmc2	LIVE	1.6	
DCmc2	FF	1.2	
DCmc2	Cladding	1.2	

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TABLE 2 SECTION PROPERTIES

Sr No	Description	Data / Value
1	Beam	ISB 475X475X50
2	Inner Column	a)storey 1-21 Infill column 2200X2200X50 b)storey 22-33 Infill column 2000X2000X50 c)storey 34-45 ISB 2000X2000X75 d)storey 46-60 ISB 1800X1800X50
3	Peripheral Column	ISB 900X900X75
4	Deck Slab	120 mm thick

III. ANALYSIS OF DIAGRID STRUCTURE

A. *Models of Diagrid Structure*

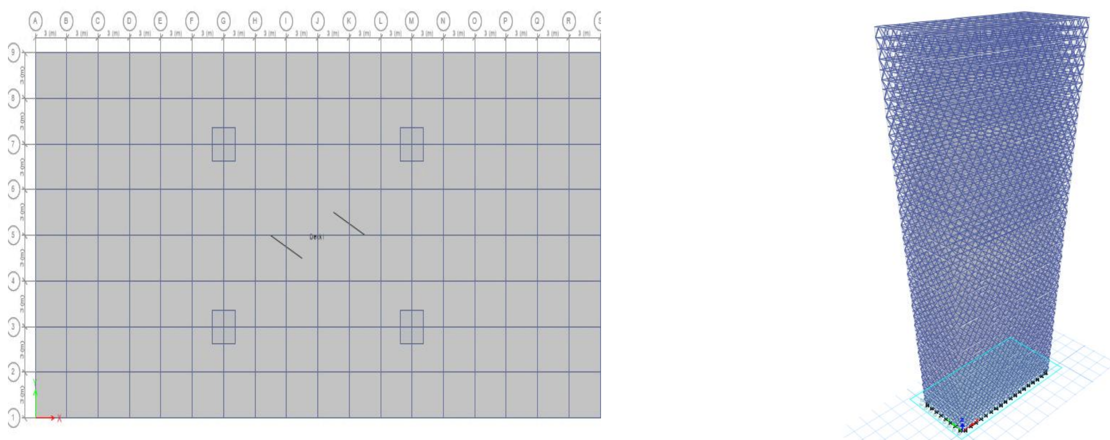

Fig. 2 Model of Rectangular Diagrid structure

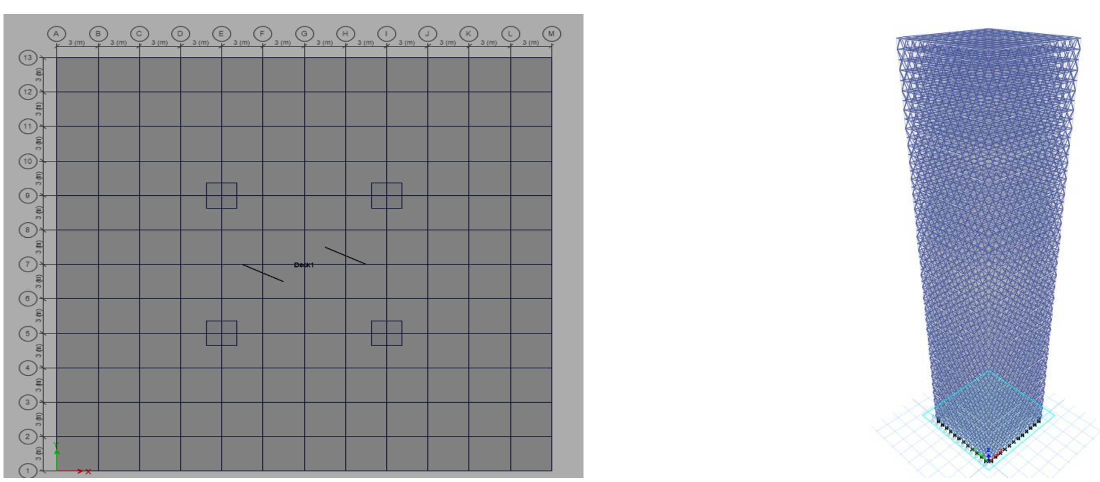

Fig .3 Fig. 3 Model of Square Diagrid structure

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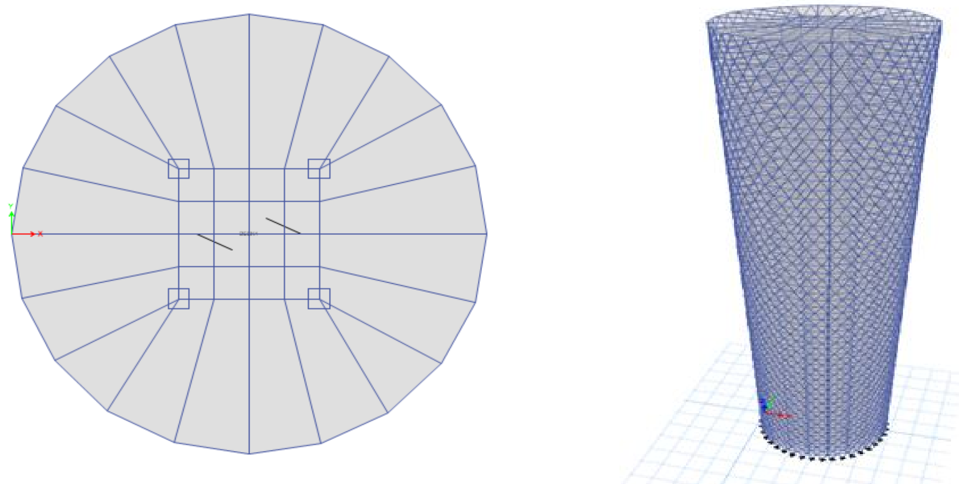

Fig .4 Model of Circular Diagrid structure

B. *Earthquake Analysis of Diagrid Structure*

TABLE 3 EARTHQUAKE ANALYSIS - Y DIRECTION RESULT

	Circular plan	Square plan	Rectangular plan
Storey displacement (mm)	45.8	43.9	58.9
Storey drift	0.000656	0.000472	0.000548
Base shear(KN)	10654.9725	13242.7011	10170.2155

TABLE 4 EARTHQUAKE ANALYSIS - X DIRECTION RESULT

	Circular plan	Square plan	Rectangular plan
Storey displacement (mm)	46.6	43.9	32.1
Storey drift	0.000671	0.000471	0.000485
Base shear(KN)	10724.3015	13242.7011	18425.5402

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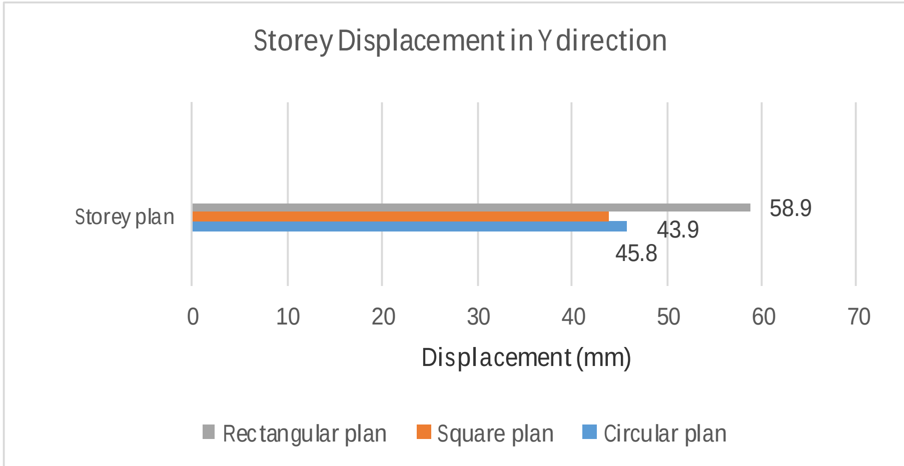

Fig. 5 Comparison of Storey displacement for three shapes in plan in Y direction -Earthquake analysis

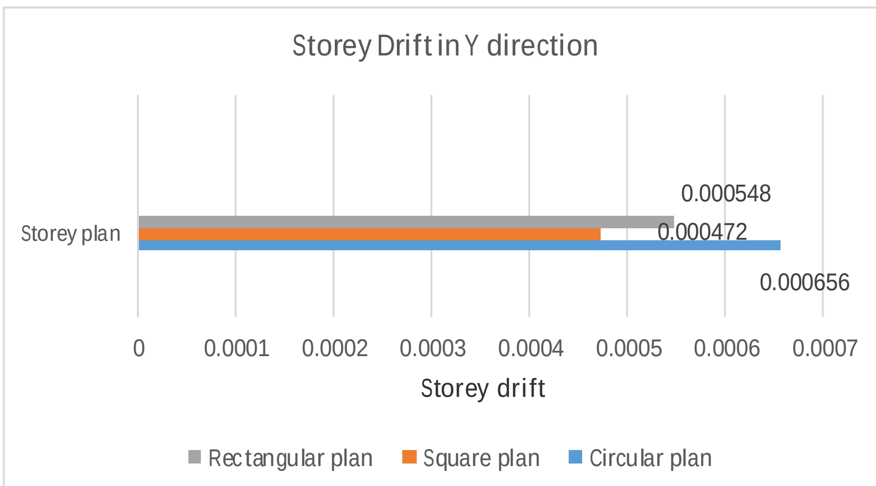

Fig. 6 Comparison of Storey drift for three shapes in plan in Y direction -Earthquake analysis

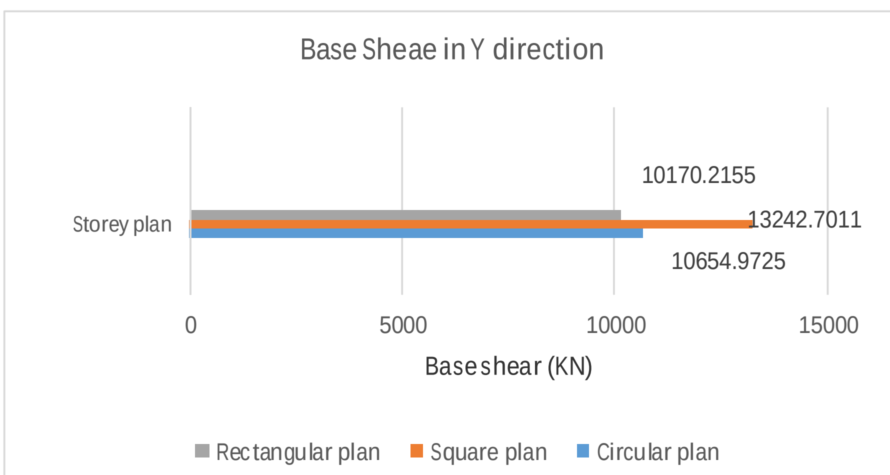

Fig. 7 Comparison of base shear for three shapes in plan in Y direction -Earthquake analysis

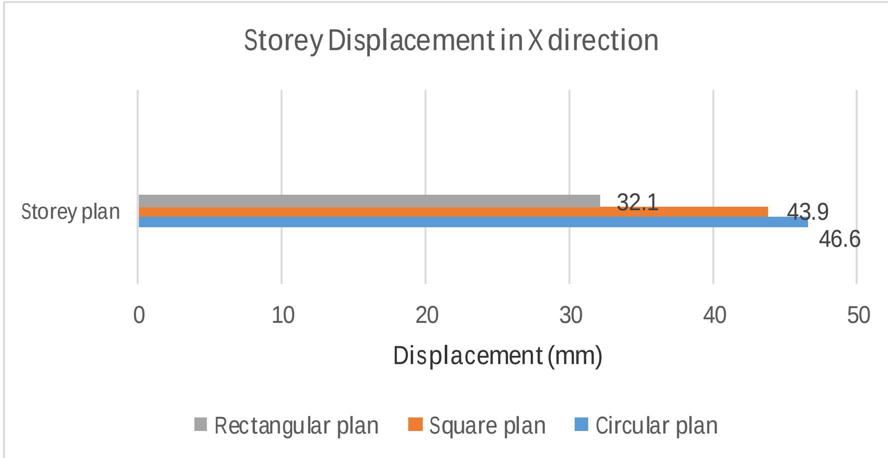

Fig. 8 Comparison of Storey displacement for three shapes in plan in X direction -Earthquake analysis

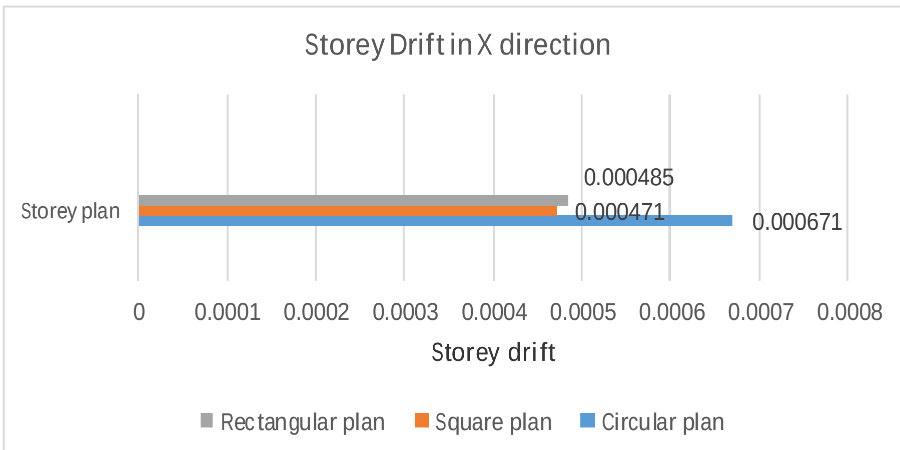

Fig. 9 Comparison of Storey drift for three shapes in plan in X direction -Earthquake analysis

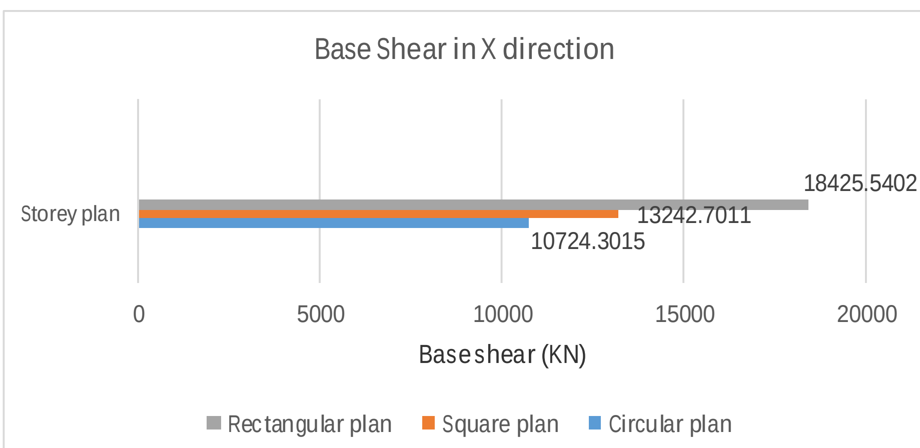

Fig. 10 Comparison of base shear for three shapes in plan in X direction-Earthquake analysis

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C. Wind Analysis Result

TABLE 5 WIND ANALYSIS - Y DIRECTION RESULT

	Circular plan	Square plan	Rectangular plan
Storey displacement (mm)	44.9	28.9	70.9
Storey drift	0.000673	0.000447	0.000627

TABLE 6 WIND ANALYSIS - X DIRECTION RESULT

	Circular plan	Square plan	Rectangular plan
Storey displacement (mm)	30.3	19	10.2
Storey drift	0.000606	0.000408	0.00046

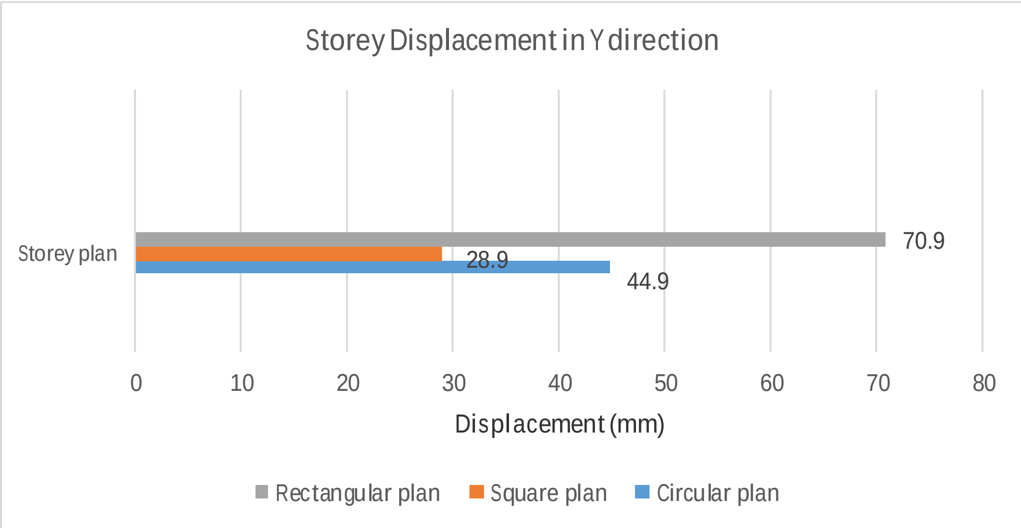

Fig. 11 Comparison of Storey displacement for three shapes in plan in Y direction –Wind analysis

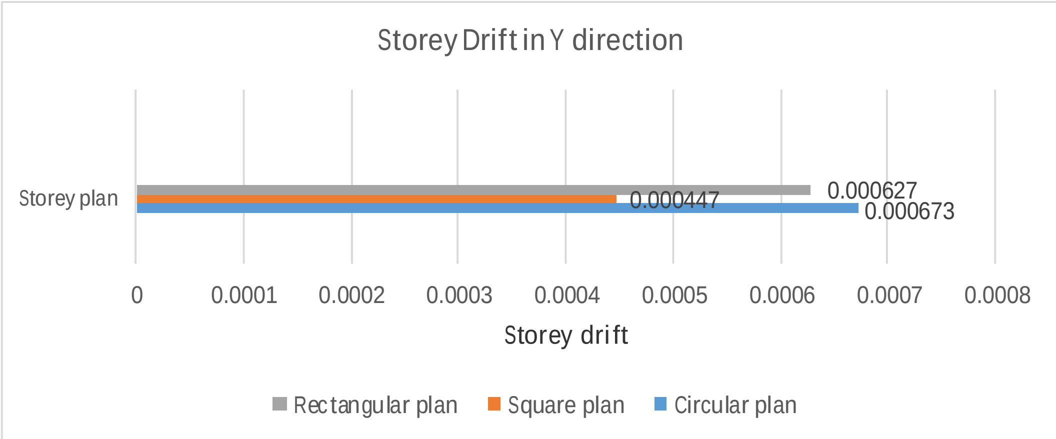

Fig. 12 Comparison of Storey drift for three shapes in plan in Y direction -Wind analysis

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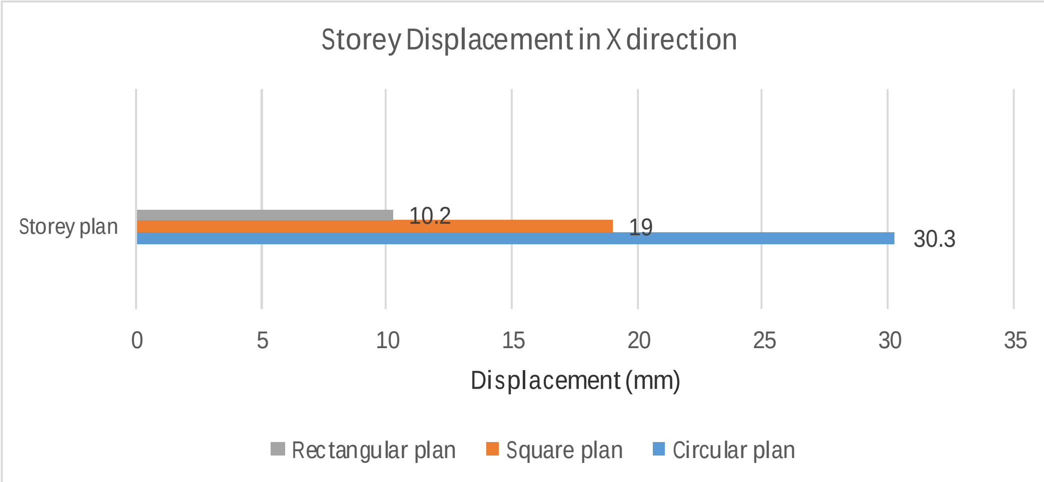

Fig. 13 Comparison of Storey displacement for three shapes in plan in X direction –Wind analysis

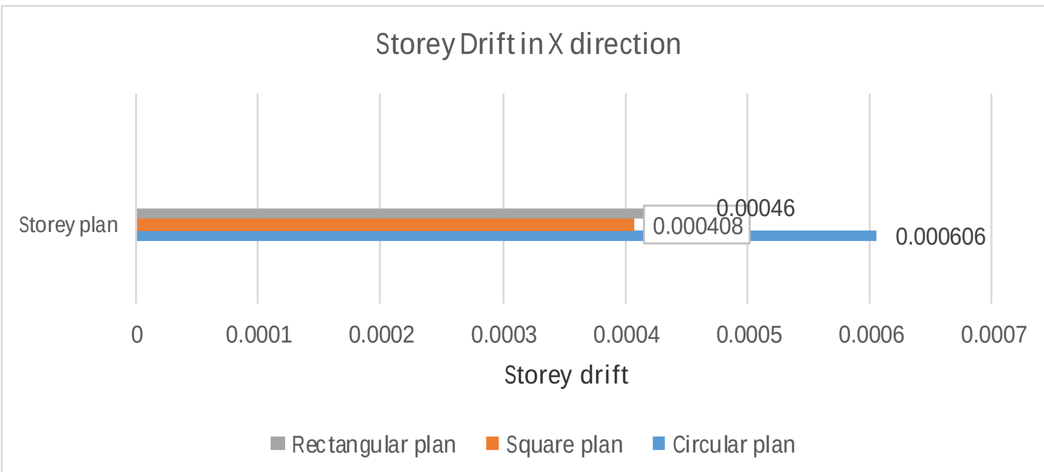

Fig. 14 Comparison of Storey drift for three shapes in plan in X direction -Wind analysis

D. Permissible Values

Maximum Storey displacement is limited to H/500, Where H is the height of the building. For 60 storey Building of 180 m height,

Permissible Maximum Storey displacement = 180/500

= 0.36 m

As per IS 1893 (Part 1): 2002, Clause 7.11.1, the Storey Drift in any storey shall not exceed 0.004 times the storey height (h) . The storey height of the models under study is 3 m.

Permissible Storey Drift = 0.004h

= 0.004 x 3

= 0.012

IV. CONCLUSIONS

In this paper, comparative analysis of 60 storey Diagrid structural system- Square, Rectangular and Circular in plan are presented. ETABS 2015 software is used for modelling and analysis of structure. Analysis results like storey displacement, storey drift, base shear are presented here. Following are the conclusions inferred from the study:

A. For all the buildings considered for the study the storey displacement and storey drift values are within the permissible limit.

B. Square and Circular Diagrid Buildings have lower Maximum Storey Displacement and Storey Drift values compared to Rectangular Diagrid building.

C. Square building has high base shear values than other two shapes.

D. Square Diagrid buildings perform better than Circular Diagrid Building and Rectangular Diagrid building.

V. ACKNOWLEDGMENT

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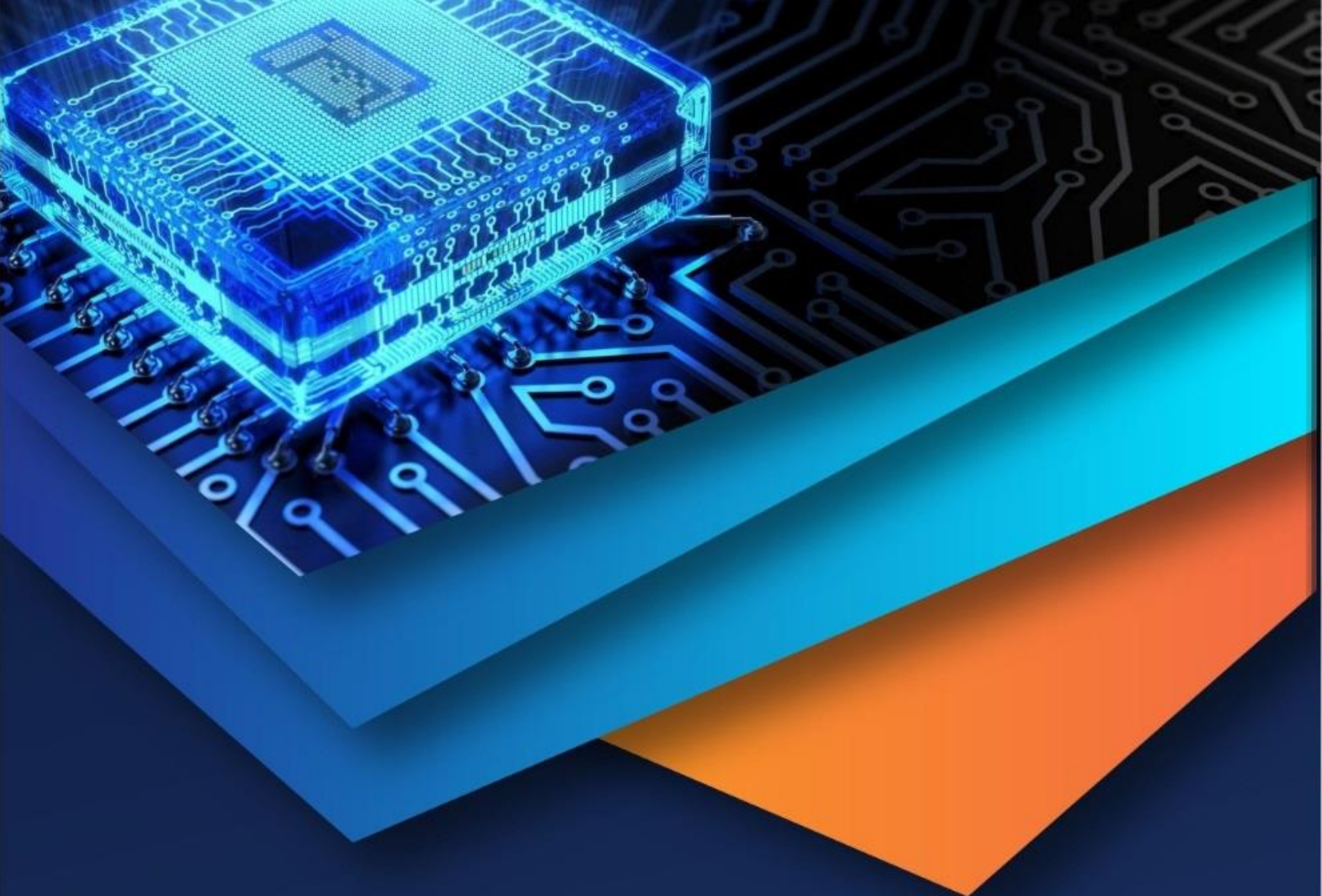

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