Comparative Study on Behavior of Tall Structures with Diagrid System with Different Geometrical Configurations

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Abstract: The developments in construction techniques, materials, structural systems and the analytical methods for analysis and design opened the door for the growth of high rise buildings. The race towards new heights and architecture has not been without challenges. Tall structures have continued to climb higher and higher facing strange loading effects and very high loading values due to dominating lateral loads. The design criteria for tall buildings are strength, serviceability, stability and human comfort. But the factors govern the design of tall and slender buildings all the times are serviceability and human comfort against lateral loads. As a result, lateral stiffness is a major consideration in the design of tall buildings. The first parameter that is used to estimate the lateral stiffness of a tall building is drift index. Different lateral load resisting structural systems can be used to impart stiffness and reduce drift in the building. Lateral load resisting systems can take many forms depending upon the orientation, integration and addition of the various structural components. The diagrid structural system has been widely used for recent tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. In this study the concept of steel diagrid structural system is studied by conducting literature review, then behavior of structures is studied by comparing square, circular and octagonal buildings with same plan area using ETABS software.

***Keywords* – Diagrids, Tall Buildings, Wind Analysis, Steel Structure, ETABS**

I. INTRODUCTION

The motivation to build tall has changed over time, as has the definition of 'tall', the materials we use and the designs that are possible. The passion, obsession and necessity of building super tall and mega tall structures continues to challenge engineers and architects to reach new heights and 'go where no man has gone before'. Vertical habitation is not a new trend. It is one that has been risen by urbanization and overpopulation in cities for centuries. While the high-rise buildings that we know today became possible with the inventions of elevators, newer building materials and structural engineering systems, multi-storey construction. In 1852, Elisha Graves Otis created the first "Fall Safe"-hoisting system (The Elevator) facilitating vertical transportation of people and goods in multi-storey buildings. This invention made the construction of skyscrapers possible and as a result greatly affecting the way modern cities were planned and constructed. In 1885, The Home Insurance Building in Chicago, demonstrated the use of first steel framed gravity system. It was the first tall building to be supported both internally and externally by a fireproof metal frame, which allowed for large windows at the ground level of high-rise buildings. According to Indian Standards, a structure is considered to be Tall Structure if its height is higher than 50 meters up to 250 meters. Regardless of the recent flow in the construction of diagrid buildings, their origins date back close to 100 years. Norman Foster references the work of the Russian Constructivist *Vladimir Shukhov (1853–1939)* as the precedent for his diagrid tower concepts. The "idea of the diagrid" and the first constructed diagrid structure have been credited to him. The design evolved as an efficient and easily constructed tower for carrying a large gravity load at the top a water tower. The *"Shukhov Tower"*, currently located in Polibino, Russia, and designed in 1896, relies on the use of a diagonal lattice of steel angles, constrained laterally at specific intervals along the height of the tower by steel rings. The overall narrowing of the structure from base to top follows a parabolic curve.

1.1. WHAT IS DIAGRID?

Diagonalized grid structure- Diagrids- has emerged as one of the most innovative and adaptable approaches to structuring buildings in this millennium. "Diagrid is a design for constructing large buildings with steel that creates triangular structures with diagonal support beams". It is a system of triangulated beams, straight or curved, and horizontal rings that together make up a structural system for a skyscraper.

Diagrid structural system for constructing tall structures is a recent invention. Debuting in *2004* with *The Swiss Re tower, London*, this aesthetically driven structural system has centred the perfecting of its technology on the development of nodes that form its innovative deviation from standard steel tall framing methods. Over the last 10 years, diagrid structures have established to be highly adaptable in structuring an extensive range of building types, spans and forms. The diagrid in its cleanest form is capable of resisting all of the gravity loads and lateral loads on the structure without backing of a traditional structural core. This allows unique deviances from structural types that are reliant on a core for stability. Diagrid, provides for a more sustainable structure and has emerged as a new design trend for tall-shaped complex structures due to aesthetics and structural performance.

Fig 1. Swiss-Re Tower

1.2. WHY TO CHOOSE A DIAGRID?

- Mostly column free exterior and interior creates free and clear unique floor plans which makes the building aesthetically dominate and expressive.
- Generous amounts of day lighting due to absence of interior columns and structure
- Full exploitation of the structural material leads to reduction in total consumption of construction materials.
- A Diagrid has better ability to redistribute load than a Moment Frame skyscraper. Therefore, there is deserved appeal for the Diagrid in today's landscape of building.

1.3. OBJECTIVE OF STUDY:

Diagrids have appeared as one of the most innovative and practical tactics to structuring buildings in this time. Variations of the diagrid system have progressed to the point of making its use nonexclusive to the tall building.
The main objective of present work is as follows:

1. To observe the structural behavior of tall steel structure by using the diagonal diagrid element for the models.
2. To Study the various effects on performance of tall steel structure with diagrid system having geometry like square, circular, octagonal.
3. To compare behavior of the system in different seismic regions.
4. To compare the analysis results in terms of lateral displacement, storey drift, time period and steel mass of the models.

1.4. RESPONSE OF DIAGRID STRUCTURAL SYSTEM:

Diagrid structures are more operative in minimalizing shear deformation because they carry shear by axial action of diagonal members though conventional framed tubular structures carry shear by the bending of the vertical columns. Diagrid structures generally do not want higher shear rigidity cores since shear can be passed by the diagrids located on the perimeter. Diagrid system is the most effective, because the diagrid produces an exterior tube that can maximize the moment arm to resist overturning. Diagrid system has higher torsional rigidity than the other structural systems. Applying the diagrid system could make the building a milestone because of its exclusive structural system and exterior appearance.

1.4.1 RESPONSE UNDER GRAVITY LOADING:

The analysis of the diagrid structures can be carried out in an initial stage by dividing the structure height into a group of stacking floors each analogous to a diagrid module. As shown in Fig. 5.1, the diagrid module under the gravity load NG is imperiled to vertical downward force NG, which origin the compression in two diagonals and tension in horizontal chord. It has been expected that the external load is conveyed to the diagrid module only at the apex joint of the module itself.

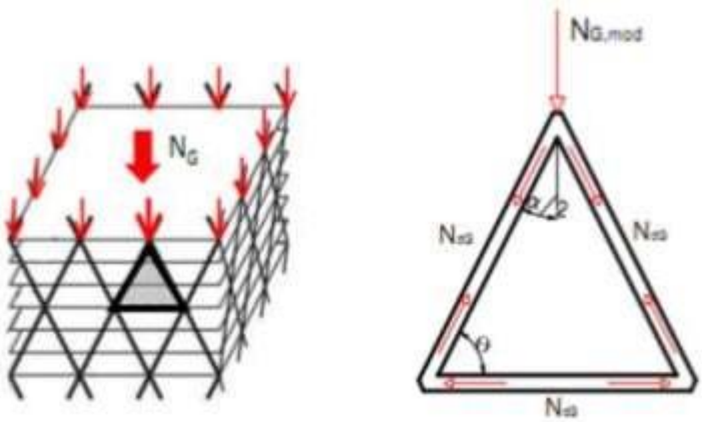


Fig 2. Response under Gravity Loading

1.4.2 RESPONSE UNDER LATERAL LOADING:

Due to lateral load W, the shear force Vw and the overturning moment Mw generate in the structure. Under the horizontal load W, the shear Vw origins a horizontal force in the top joint of the diagrid modules Vw. The shear Vw is mainly resisted by the web panels of the diagrid module. As shown in Fig.5.2, direction and intensity of Vw, mod be contingent on the position of diagrid module with respect to the direction of wind load. The parallel force Vw, mod, which cause the compression in one diagonal and tension in another diagonal. It has been expected that the external load is transferred to the diagrid module only at the apex joint of the module itself.

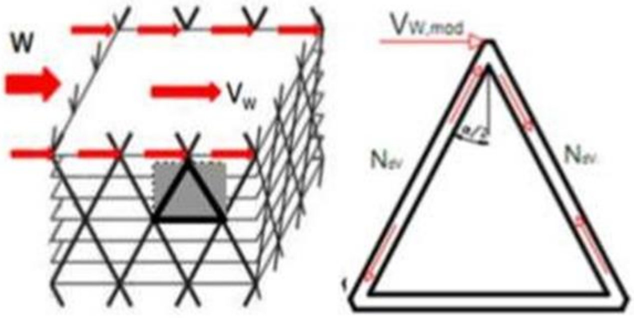


Fig 3. Response under Lateral Loading

The horizontal force W and the overturning moment Mw origins vertical forces in the peak joint of the diagrid module Nw, mod. As shown in Fig. direction and intensity of Nw, mod depends on the location of the module with respect to the way of wind load. The maximum intensity of upward and downward force develops in the modules located on the windward and leeward sides, respectively, and gradually decreasing values in modules located on the web sides. The vertical upward force Nw, mod, causes the tension in two diagonals and compression in horizontal chord. The vertical downward force Nw, mod, causes the compression in two diagonals and tension in horizontal chord. It has been expected that the external load is conveyed to the diagrid module only at the peak joint of the module itself.

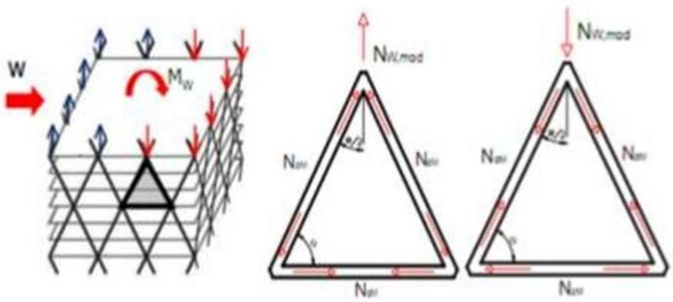


Fig 4. Response under overturning moment

2. ANALYSIS STUDIES OF 36-STOREY DIAGRID SYSTEM

In the presented paper analysis study of Building having 36-Storey Diagrid System with different plan geometry of almost same plan area. The diagrid system is also analysed for its behaviour according to its diagrid angle and effect of change in earthquake zone is also considered. Modelling and analysis is done through ETABS software. Detailed building configuration and design data are as follows.

2.1 BUILDING CONFIGURATION

The 36-Storey tall building is having different plan shapes i.e. Square, Octagonal and Circular. The plan area is kept nearly same for all the shapes for better behaviour comparison.

SQUARE PLAN			
Length	L	36	m
Width	B	36	m
Total Height	H	129.6	m
Number of Storeys	n	36	
Storey Height	h	3.6	m
Seismic Zone	z		
ZONE-3	M1	4-Storey Module	
	M2	6-Storey Module	
	M3	8-Storey Module	
ZONE-4	M4	4-Storey Module	
	M5	6-Storey Module	
	M6	8-Storey Module	
ZONE-5	M7	4-Storey Module	
	M8	6-Storey Module	
	M9	8-Storey Module	

Fig 5. Square Plan Configuration

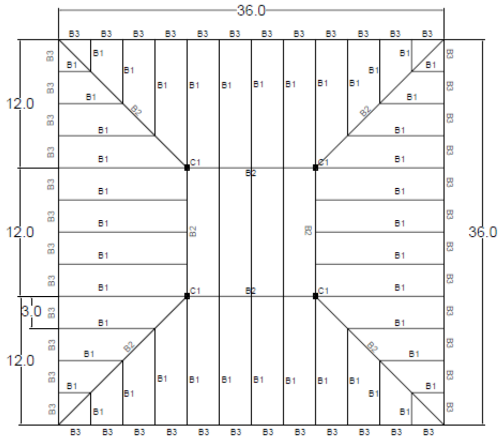


Fig 6. Square Floor Plan

OCTAGONAL PLAN			
Each Side Length	L	18	m
Total Height	H	129.6	m
Number of Storeys	n	36	
Storey Height	h	3.6	m
Seismic Zone	z		
ZONE-3	M10	4-Storey Module	
	M11	6-Storey Module	
	M12	8-Storey Module	
ZONE-4	M13	4-Storey Module	
	M14	6-Storey Module	
	M15	8-Storey Module	
ZONE-5	M16	4-Storey Module	
	M17	6-Storey Module	
	M18	8-Storey Module	

Fig 7. Octagonal Plan Configuration

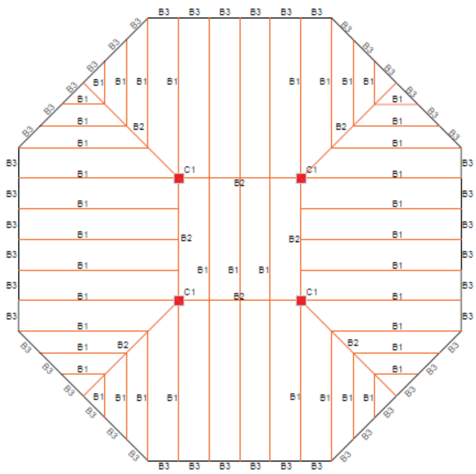


Fig 8. Octagonal Floor Plan

CIRCULAR PLAN			
Diameter	D	18	m
Total Height	H	129.6	m
Number of Storeys	n	36	
Storey Height	h	3.6	m
Seismic Zone	z		
ZONE-3	M19	4-Storey Module	
	M20	6-Storey Module	
	M21	8-Storey Module	
ZONE-4	M22	4-Storey Module	
	M23	6-Storey Module	
	M24	8-Storey Module	
ZONE-5	M25	4-Storey Module	
	M26	6-Storey Module	
	M27	8-Storey Module	

Fig 9. Circular Plan Configuration

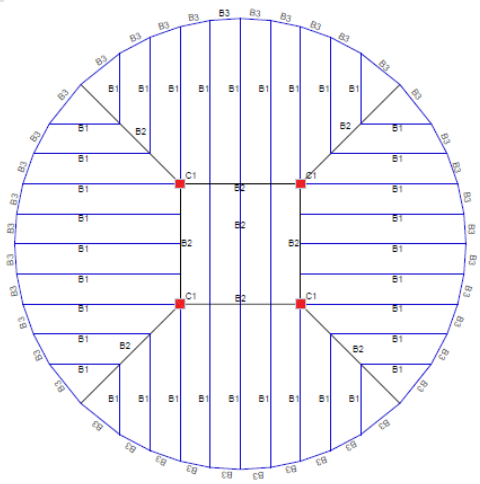


Fig 10. Circular Floor Plan

2.2 LOAD DATA

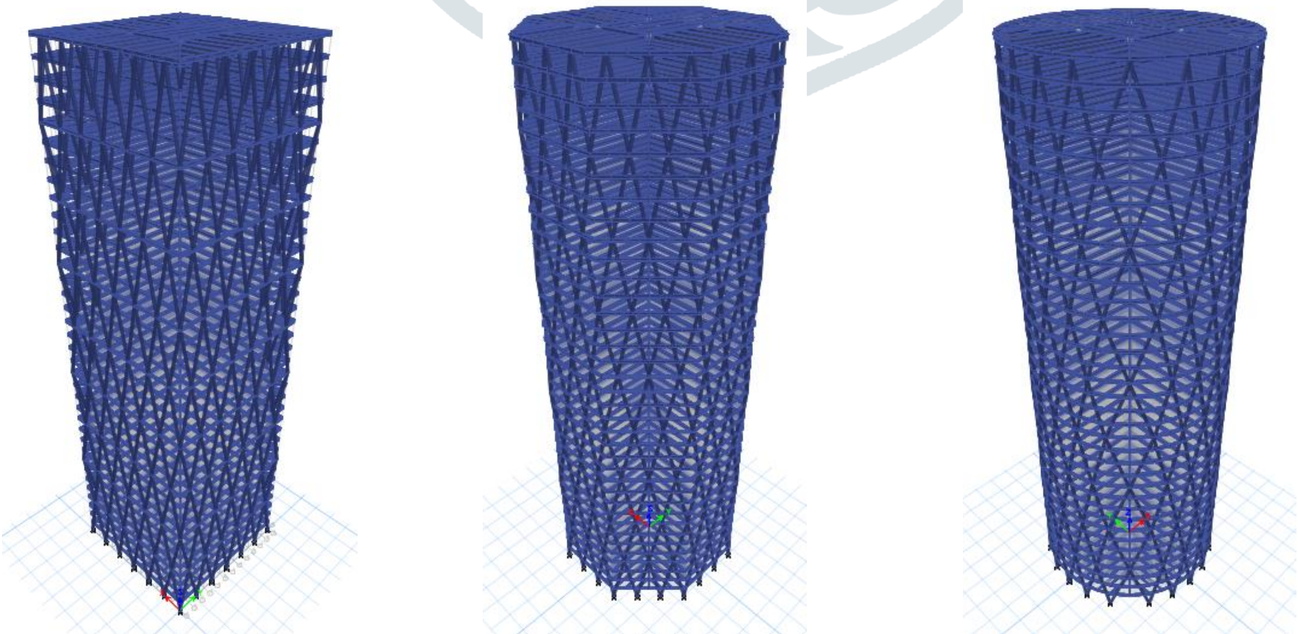
DEAD LOAD		
Dead Load	3.75	kN/m2
LIVE LOAD		
Live Load	2.5	kN/m2
EARTHQUAKE LOAD		
Location	Ahmedabad	
Zone Factor	As per model type	
Importance Factor	1	
RRF	5	
Type of Soil	Medium	
WIND LOAD		
LOCATION	Ahmedabad	
BUILDING HEIGHT	129.6 m	
BASIC WINDSPEED	39 m/s	

2.3 MEMBER PROPERTIES

BEAMS	B1-B3	ISMB600
	B2	ISWB600+220x50 mm Plate Both side
COLUMNS	C1	1650x1650
DIAGRIDS	D1	525 mm Dia. Pipe with 25 mm thickness
SLABS	SLAB	150 mm thick
STEEL GRADE		Fe250
CONCRETE GRADE		M25

2.4 MODELING & ANALYSIS

36-storey buildings having material and member properties mentioned above are modelled in ETABS software for each case of plan geometry and seismic zone factor. The buildings are analysed for both earthquake and wind loads. Dynamic earthquake and wind loads are applied as per IS 1893:2016 and IS 875(3):1987 respectively. Following are 3D models prepared for analysis for 8-storey Diagrid Buildings. Similarly, 4 & 6 Storey Diagrid buildings are prepared.



(a) (b) (c)

Fig 11. 3D Model for 8-Storey Diagrid Structures with plan (a) Square (b) Octagonal (c) Circular

3. RESULTS

Results are collected in terms of some parameters i.e. First Mode Time Period, Max. Displacement, Max. Drift, Steel Mass Consumed and Max. Axial Forces. From the comparison from above parameters one can directly conclude for selection of Plan Shape and Diagrid Module type. Here are Graphical comparison for First mode Time Period, Steel Mass Consumption and Max. Displacement.

3.1 First Mode Time Period

Fig 12 shows the Graphical representation of First Mode Time Period of Diagrids having 4,6 & 8 Storey Module and corresponding Plan Type. It shows that for almost all types of Plan Shapes, First Mode Time Period increases with increase in Storey Module. Specifically for 8-Storey Module Buildings Octagonal Plan Shapes has highest First Mode Time Period.

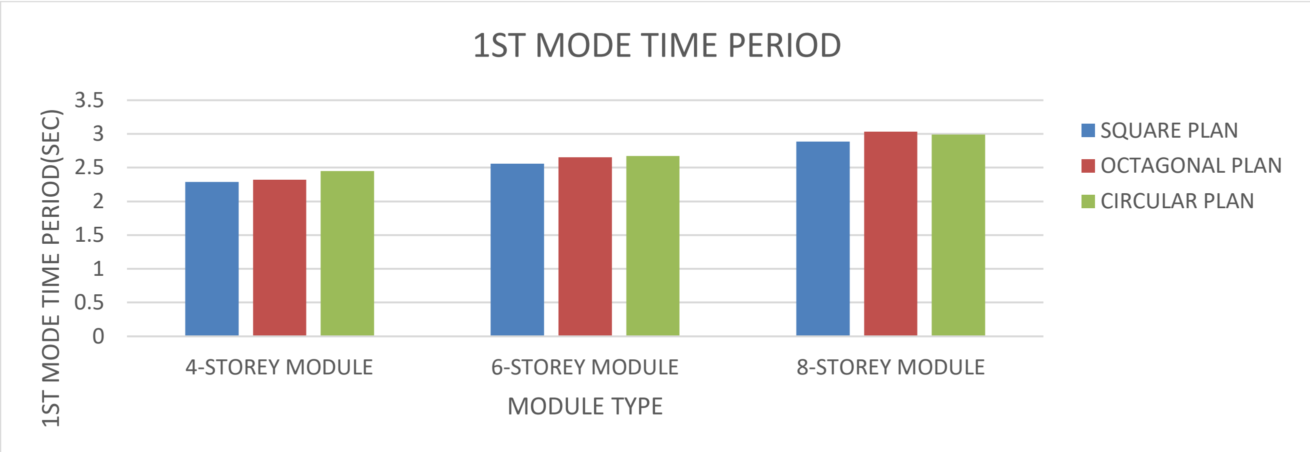


Fig 12. First Mode Time Period

3.2 Steel Mass Consumption

Maintaining almost same plan area for Square, Octagonal and Circular Shapes the Total Steel Mass Consumption can be a key parameter for estimating the cost of any project. Fig 13 shows total steel Mass Consumption of 36-Storey Diagrid Buildings having Shapes and Diagrid Configuration mention in the chart. From the graph, Steel consumption for Octagonal Building is highest for any Diagrid Configuration. Whereas, Square Plan Buildings consumes lesser steel as the Diagrid Module Size increases. Circular Plan Buildings becomes Costlier as the Diagrid module size increases.

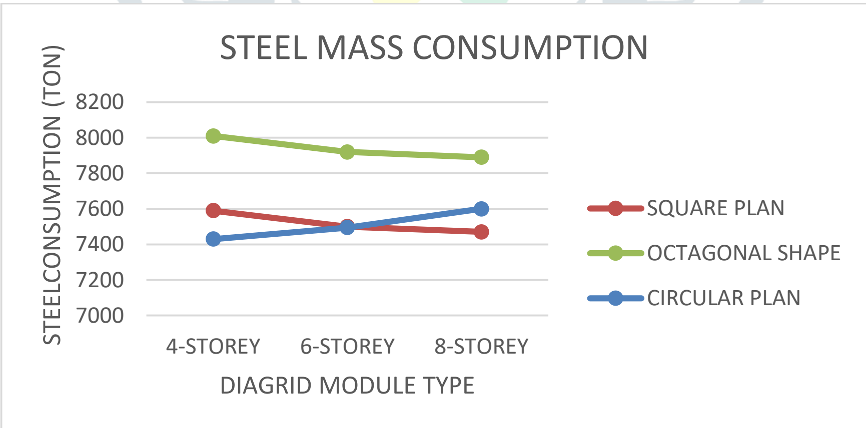


Fig 13. Steel Mass Consumption

3.3 Maximum Storey Displacement

Based on shape of building, the amount of lateral forces acting on particular building varies. With variation in Diagrid Module Configuration, the behaviour of structure as a whole varies. For all the conditions mentioned above, results are compared with a graphical representation. It is seen that Storey Displacement increases with increase in size of diagrid module. Rate of increase in Maximum Storey Displacement for Circular buildings is lesser as compared to the other two's. Adding to that for lower seismic zones behaviour of Circular diagrids is good amongst all shapes but for higher seismic zone, Square buildings performs well.

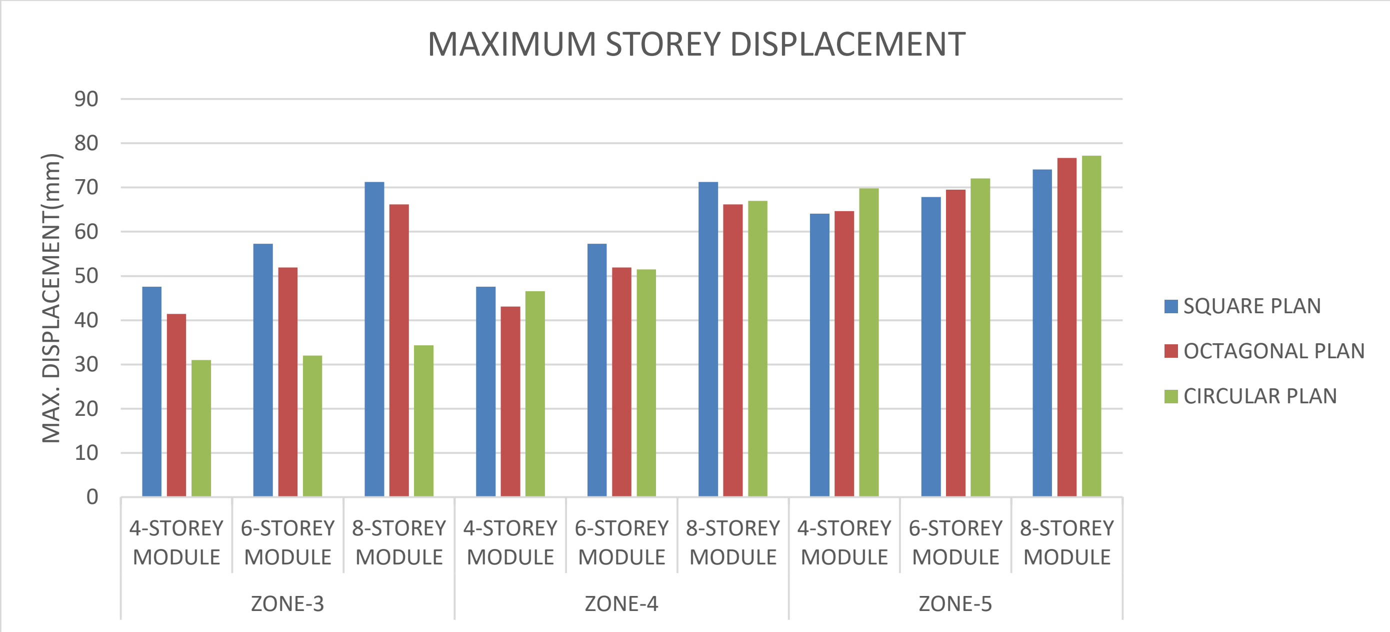


Fig 14. Maximum Storey Displacement

CONCLUSION

- Considering First Mode Time Period, Square Buildings have least time period amongst all shapes. Whereas, Circular and Octagonal Diagrid Buildings performs nearly same.
- Steel Mass Consumption is much higher for Octagonal Shaped Buildings. Also if we consider 6-Storey Module Diagrid System the steel consumption is nearly same for Square and Circular Buildings.
- Circular Buildings Performs very good for lower seismic zones in terms of Storey Displacement and as mentioned above it has lower steel consumption compared to Octagonal Shape, It can be a better choice for lower Seismic Zones.
- For higher seismic zones, behaviour and steel consumption indicates Square Buildings as a good performer.

REFERENCES

[1] Esmaeel Asadi, Hojat Adeli "Diagrid: An innovative, sustainable, and efficient structural System.", Structural Design of Tall and Special Buildings - 2013

[2] S.R.Naik, S.N.Desai "Evaluation of Lateral Stability of the Diagrid Tall Structure Under Different Earthquake Forces", Advances in Intelligent Systems and Computing-2018

[3] K. Jani, P.V.Patel "Analysis and Design of Diagrid Structural System for High Rise Steel Buildings" Procedia Engineering – 2012

[4] Kyoung Sun Moon "Optimal grid geometry of diagrid structures for tall buildings" Architectural Science Review – 2008

[5] Jatin B. Tank, Ashwin G. Hansora "Analysis of varying angle diagrid structural system for high-rise steel building." NCERTE – 2016

[6] IS: 1893(Part-I)-2002., "Criteria for Earthquake Resistant Design of Structures". Bureau of Indian Standard, New Delhi.

[7] IS: 875(Part-3)-1987., "Code of practice for design loads (other than earthquake) for buildings and structures, wind loads". Bureau of Indian Standard, New Delhi.

[8] IS:800-2007 "Code of practice for General construction in Steel" Bureau Of Indian Standard, New Delhi.