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Analysis of Circular Steel Diagrid Buildings with non-Uniform Angle Configurations

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Abstract— Tall commercial buildings are primarily a response to the intense pressure on the available land. Advances in materials, construction technology, analytical methods and structural systems for analysis and design accelerated the development of tall structures. The lateral loading due to wind and earthquake is the major factor that causes the design of high-rise buildings. These lateral loads are resisted by exterior structural system or interior structural system. Diagrid is an exterior structural system emerging as structurally efficient as well as architecturally significant assemblies for tall buildings. Diagrid eliminated all vertical columns and consists of only inclined columns on the façade of the building. Shear and over-turning moment developed are resisted by axial action of these diagonals compared to bending of vertical columns in framed tube structure. These inclined columns or diagonals have an optimal angle at which the structural capability of the member is optimized for both gravity and lateral loadings. In this paper, circular buildings configured with uniform diagonal angle are compared to buildings with non-uniform diagrid angle distribution. A regular plan diameter of 40.63 m was considered for the building. ETABS software is used for modelling and analysis of structural members. 36, 50, 60, 70 and 80 storey buildings are modelled with uniform and non-uniform diagrid angle configurations. Dynamic wind analysis have carried out as per Gust effect factor method of IS:875 Part III- 1987. Comparison of analysis results in terms of top storey displacement and maximum forces developed on the diagrid member is presented in this paper.

Index Terms—Tall building, steel structures, diagrids, wind analysis, circular plan buildings.

1 Introduction

TALL buildings have developed in response to the requirements arising from the continuing increase in world population, scarcity and high cost of land. Advances in construction technology, materials, structural systems, analysis and design software facilitated the growth of tall buildings. When the height of building increases, the lateral load resisting system plays important role than the structural system that resists the gravitational loads. The lateral load resisting systems that are widely used are mainly rigid frame, shear wall, wall-frame, braced tube system, outrigger system and tubular system. Recent trend shows that the Diagrid structural system is becoming popular in the design of tall buildings due to its inherent structural and architectural advantages.

Diagrid consists of perimeter grid made up of a series of triangulated truss system. Diagrids are generally stiffer than equivalently designed tubular structures, and provide more efficient use of material. It uses an exclusive exterior frame comprised entirely of diagonal members, eliminating the vertical columns. Vertical columns in the core are capable only of withstanding gravity loads and the diagrid is useful for both gravity and lateral loading. This type of structure carries lateral wind loads more efficiently, creating stiffness that is complemented by the axial action of the diagonal member. The famous examples of diagrid structure all around the world are the Hearst Tower in New York, Swiss Re in London, Capital Gate Tower in Abu Dhabi, and Aldar Headquarters, Abu Dhabi as shown in fig 1.

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Fig.1. Diagrid buildings (a) Hearst Tower in New York, (b) Swiss Re in London, (c) Capital Gate Tower in Abu Dhabi, (d) Aldar Headquarters, Abu Dhabi.

Moon et al focused their study of diagrid structures on 60 storey building because majority of world's largest buildings fall between 50 and 70 stories. They discovered the optimal angle for the diagrid to be 35˚ when considering shear rigidity compared to 90˚ optimal angle any for maximum bending rigidity. So concluded that for any diagrid building optimum angle lies somewhere between this two values.

Most of the diagrid buildings are using the optimal diagonal angle or an angle close to the optimal value along the height of the building. When the building is taller, the bending is predominant than shear towards the bottom of the building while shear dominates at the top portion. The responses of the diagrid building could be reduced, if the building is provided with non-uniform diagrid angle configurations. In this paper diagrid buildings of circular plan of various aspect ratio and diagrid configurations are analysed. A comparative study is carried out on analysis results in terms of top storey displacement and maximum forces acting on diagrid members.

2 MODELLING AND ANALYSIS

2.1 Building configuration

Diagrid buildings of 36, 50, 60, 70 and 80 storeys height are selected for the study. Circular buildings having plan diameter of 40.63 m are modelled and analysed with uniform diagrid angle and non-uniform diagrid angle patterns. The typical plan of circular buildings are shown in fig. 2. The storey height is 3.6 m. The spacing between diagrid members is fixed as 6 m. For the uniform diagrid angle buildings, the angle of inclination is kept uniform throughout the height. For non-uniform diagrid buildings, the diagonal angle changed along the height of the building.

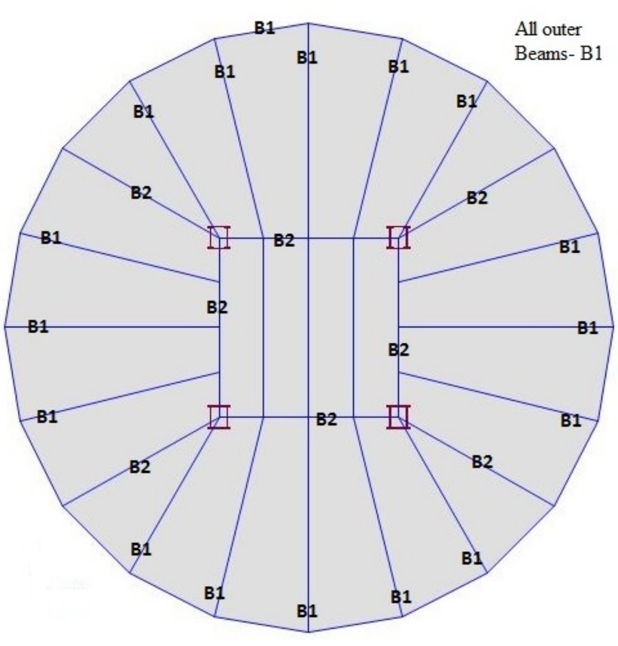

Fig.2: Typical plan for the Circular building

The dead load and live loads on floor slab are 3.75 kN/m2 and 2.5 kN/m2 respectively. The dynamic along wind loading is computed based on the basic wind speed of 30 m/sec and terrain category III as per IS:875 (III)-1987 (Gust factor method). Load combinations as per IS:800-2005 are applied. Modelling and analysis of diagrid structure are carried out using ETABS software. Beams and columns are modelled by beam elements and braces are modelled by truss elements. The support conditions are assumed as hinged.

2.2 Modelling and analysis of 36 storey diagrid buildings

Four models of the circular buildings are developed for the study of the response of 36 storey buildings. The aspect ratio of the building is 3.20.

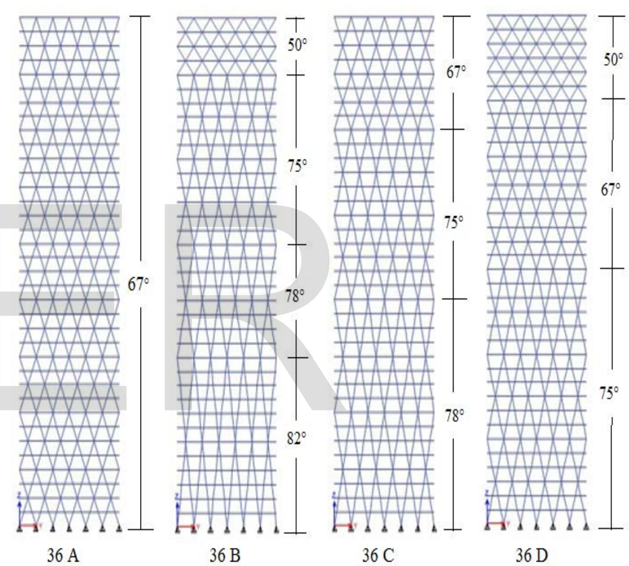

Fig.3 : Diagrid angle distribution of different 36 storey buildings.

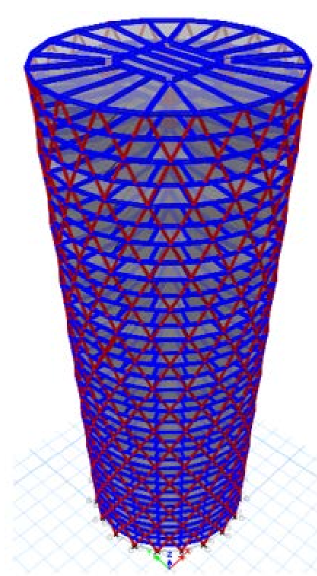

Fig.4: Extruded view of model 36 A

The first configuration having diagrid angle uniformly distributed along the height. The diagrid angle is close to the optimum value of the building. The second configuration is having its diagrid angle changes from 82 to 50 degree from bottom to top of the building. In the third model diagrid angle changes from 78 to 50 degree. In fourth configuration, the diagrid angle changes from 75 to 50 degree. The distribution of diagrid angle of different models are shown in fig.3. Circular diagrid building models are named as 36 A, 36 B, 36 C and 36 D respectively. Each models are analysed and the responses are studied. Maximum storey displacement and the maximum force on the diagrid member is considered for the study. The configuration which provide minimum displacement and stresses are noted. The graph for the building which develop minimum displacements is given in the fig.5.

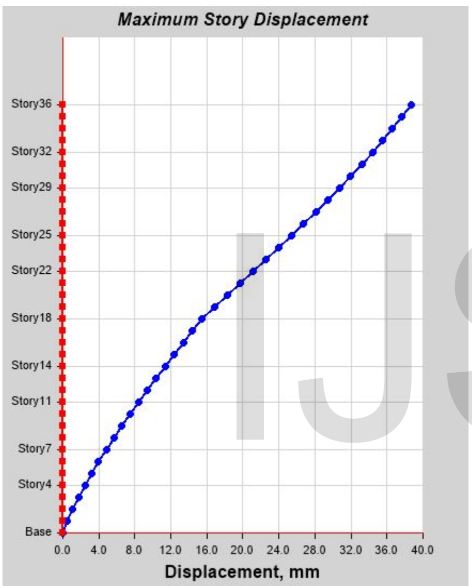

Fig.5: Displacement plot for Model 36 A

2.3 Modelling and analysis of 50 storey diagrid building

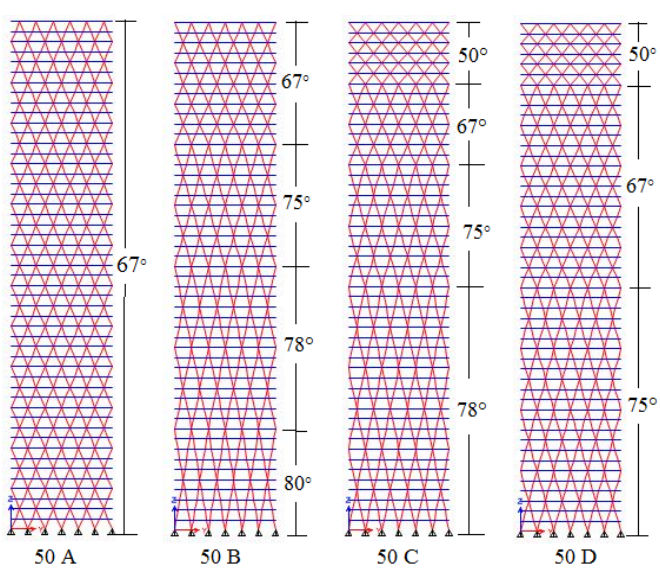

Fig.6: Diagrid angle distribution of different 50 storey buildings.

The circular buildings having height of 50 stories were modelled and analysed. The aspect ratio of the building is 4.43. Four models of the circular buildings are developed for the study of the response of 50 storey building. The building models are named as 50 A, 50 B, 50 C and 50 D respectively. The distribution of diagrid angle of different models are shown in fig.6.

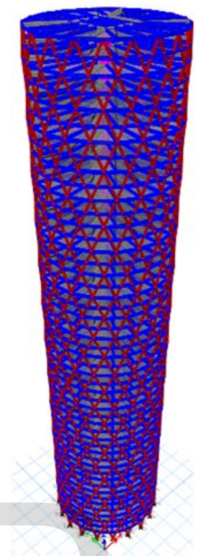

Fig.7: Extruded view of model 50 A

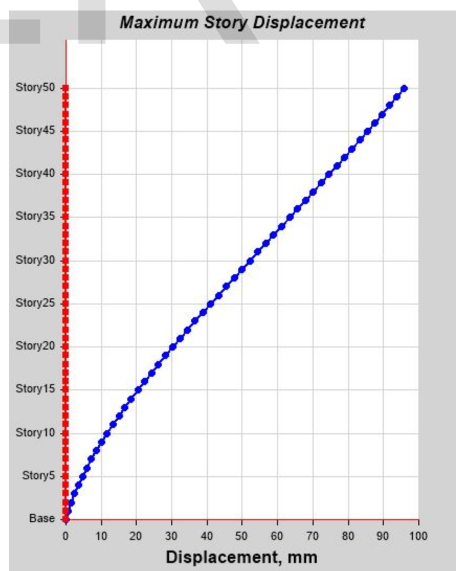

Fig.8: Displacement plot for Model 50 A

Each models are analysed and the responses are studied. Maximum storey displacement and the maximum force on the diagrid member is considered for the study. The configuration which provide minimum displacement and stresses are noted. The graph for the building which develop minimum displacements is given in the fig.8.

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2.4 Modelling and analysis of 60 storey diagrid buildings

The circular buildings having height of 60 stories were modelled and analysed. The aspect ratio of the building is 5.32. Four models of the circular buildings are developed for the study of the response of 60 storey building. The building models are named as 60 A, 60 B, 60 C and 60 D respectively. The distribution of diagrid angle of different models of 60 storey buildings are shown in fig.9.

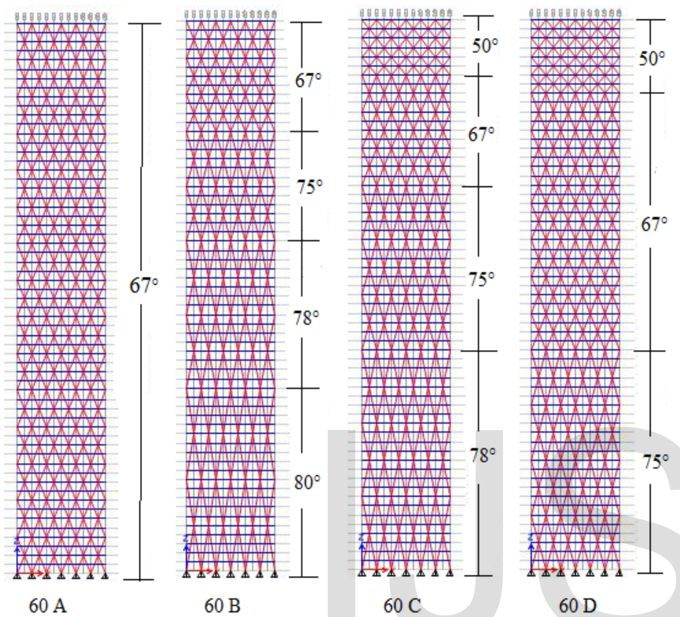

Fig.9: Diagrid angle distribution of different 60 storey buildings.

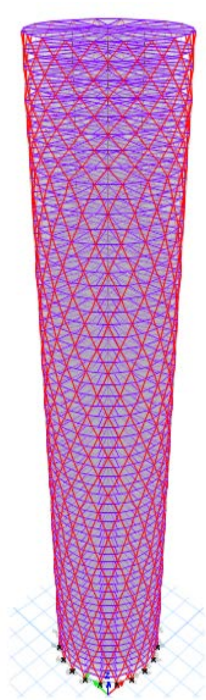

Fig.10: 3D view of model 60 D

Each models are analysed and the responses are studied. Maximum storey displacement and the maximum force on the diagrid member is considered for the study. The configuration which provide minimum displacement and stresses are noted. The graph for the building which develop minimum displacements is given in the fig.11.

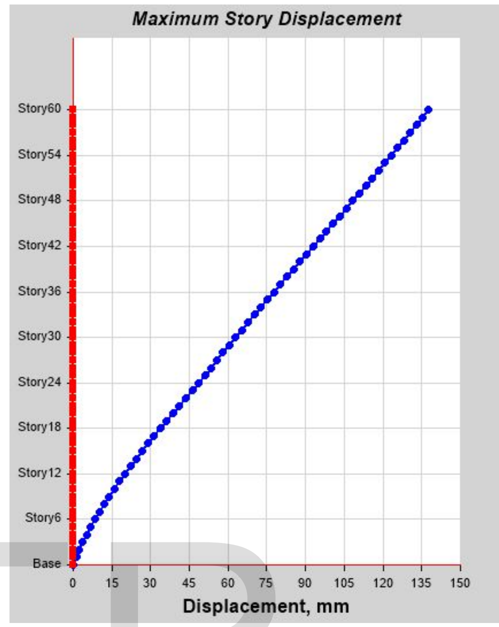

Fig.11: Displacement plot for Model 60 D

2.5 Modelling and analysis of 70 storey diagrid buildings

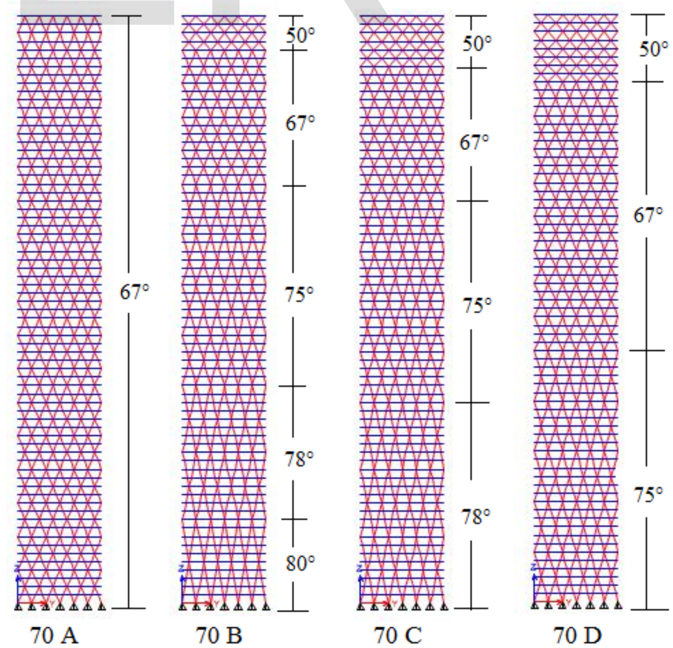

Fig.12: Diagrid angle distribution of different 70 storey buildings.

The buildings having height of 70 stories were modelled and analysed. The aspect ratio of the building is 6.20. Four

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models of the circular buildings are developed for the study of the response of 70 storey building. The building models are named as 70 A, 70 B, 70 C and 70 D respectively. The distribution of diagrid angle of different models of 70 storey buildings are shown in fig.12.

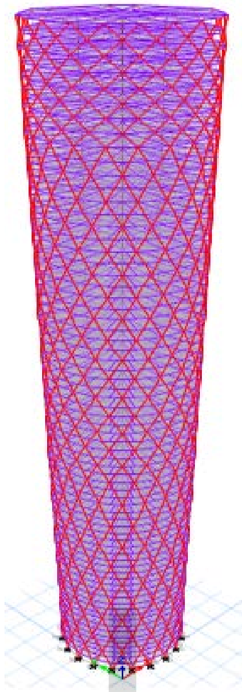


Fig.13: 3D view of model 70 D

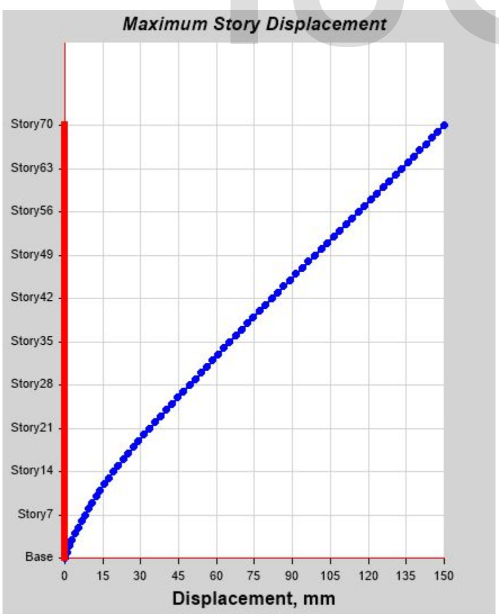


Fig.14: Displacement plot for Model 70 D

Each models are analysed and the responses are studied. Maximum storey displacement and the maximum force on the diagrid member is considered for the study. The configuration which provide minimum displacement and stresses are noted. The graph for the building which develop minimum displacements is given in the fig.14.

2.6 Modelling and analysis of 80 storey diagrid buildings

The circular shaped buildings having height of 80 stories were modelled and analysed. The aspect ratio of the building is 7.0. Four models of the circular buildings are developed for the study of the response of 80 storey building. The building models are named as 80 A, 80 B, 80 C and 80 D respectively. The distribution of diagrid angle of different models of 80 storey buildings are shown in fig.15.

Fig.15: Diagrid angle distribution of different 80 storey buildings.

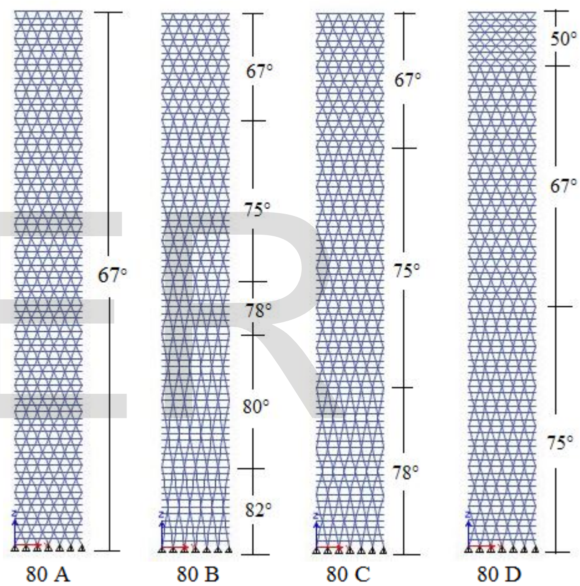
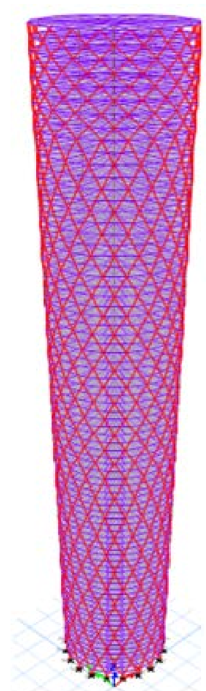


Fig.16: 3D view of model 80 D



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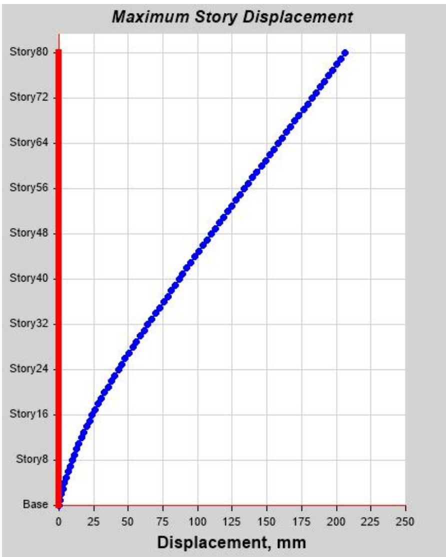
Each models are analysed and the responses are studied. Maximum storey displacement and the maximum force on the diagrid member is considered for the study. The configuration which provide minimum displacement and stresses are noted.The graph for the building which develop minimum-displacements is given in the fig.17



. Fig.17: Displacement plot for Model 80 D

3 RESULTS AND DISCUSSIONS

Circular shaped buildings of Aspect Ratio (AR) 3.2, 4.43, 5.32, 6.2 and 7.1 were modelled analysed with uniform diagrid angle and with non-uniform diagrid patterns. The dynamic wind loading as per IS 875 part III-1987 were applied to the building models. The responses from uniform diagrid buildings were compared with non-uniform diagrid buildings and the results are given in table 1. For the 36 storey circular diagrid building, the non-uniform configurations of diagrid angles does not create any better results than uniform diagrid buildings. Model 36A have the lowest displacement. The lateral displacement developed in non-uniform buildings are higher than that of developed in uniform diagrid building.

This response is same for 50 storey diagrid building also. Models 50A have the lowest displacement. The storey displacements in non-uniform buildings are higher than uniform diagrid buildings. But for the 60, 70 and 80 storey circular diagrid buildings with non-uniform diagrid angle configuration exhibit better result than uniform diagrid building. Models 60D, 70D and 80D yields the lowest displacement and develop lower forces on diagrid members compared to the uniform angle diagrid building. The comparison of results are presented as column charts in fig.18 and fig.19.

TABLE 1: Comparison of results from all models

	Model	**A**	**B**	**C**	**D**
36 Storey Building	Lateral Displacement (mm)	**39**	62	53	42
	Max force on diagrid member (KN)	2588	2411	2473	2529
50 Storey Building	Lateral Displacement (mm)	**95**	119	112	99
	Max force on diagrid member (KN)	4224	3974	4061	4145
60 Storey Building	Lateral Displacement (mm)	140	163	150	**138**
	Max force on diagrid member (KN)	6145	6199	6064	6001
70 Storey Building	Lateral Displacement (mm)	156	163	158	**149**
	Max force on diagrid member (KN)	9216	8812	8880	8960
80 Storey Building	Lateral Displacement (mm)	217	236	213	**206**
	Max force on diagrid member (KN)	12187	11628	11590	11535

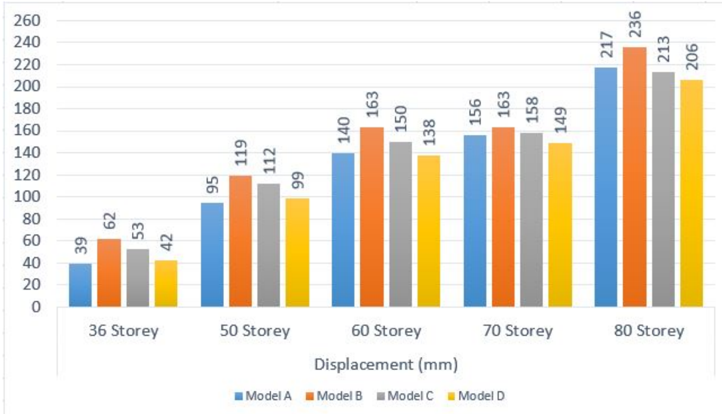


Fig18: Storey Displacement for different models.

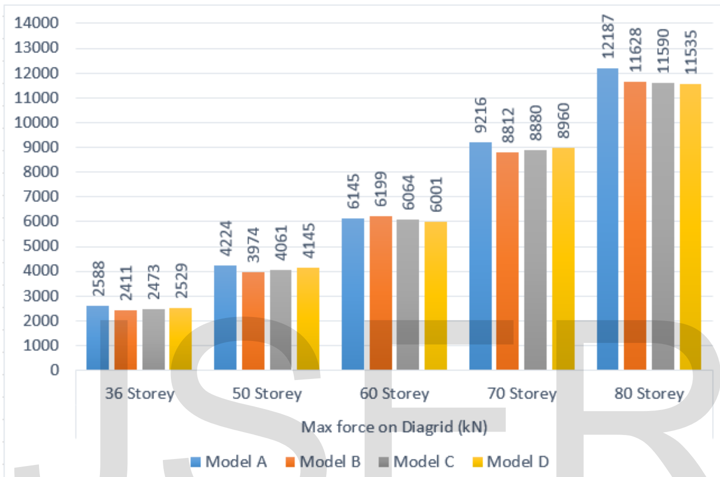


Fig.19: Maximum force on diagrid for different models

4 CONCLUSIONS

In this paper, circular diagrid buildings of different angle configurations were modelled and analysed. The plan diameter considered for the circular building was 40.63 m. 36, 50, 60, 70 and 80 storey buildings are modelled with uniform and non-uniform diagrid angle configurations. A comparative study was conducted between the results obtained from 20 models in terms of top storey displacement and maximum forces developed on the diagrid member. The following conclusions can be inferred from the study.

- Circular building of 36 and 50 storeys yield lowest displacement when configured with uniform diagrid angle.
- In 60, 70 and 80 storey buildings, non-uniform diagrid configuration provided lower displacement and diagrid forces when the diagrid angle changed from 75° to 50°. The forces on diagrids reduced around 2.5%, 3% and 5.5% in 60, 70 and 80 storey buildings respectively.
- From these observations, it could be assumed that use of non-uniform diagrid configurations of specified angles, would reduce the forces on diagrids in circular buildings having aspect ratio 5.30 and above. So designing the diagrid building with changing diagrid angle could reduce the section size required and thereby reduce the material required for the building.

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