Effects of Various Bracing Angles on Steel Diagrid Building: An Analytical Approach

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***Abstract*— Three models were prepared with identical floor plans, geometry and other properties except braces and columns at exoskeleton and inner area. These models were studied for different bracing angles as 55 degree, 60 degree and 65 degrees. Analysis performed using Autocad and STAAD Pro software. Obtained results showed that model having lower angle are good against wind pressure however model with higher angles are good against seismic forces as base shear. Model with 60 degree angle performed best against storey displacements & moderately good for seismic base shear. One of the reasons that model with 60 degree angle performed best was 60 degree angle formed geometry close to equilateral triangle formation for distributing loads more evenly when subjected to lateral loading. It is also found a threshold limit at 57th storey regardless of bracing angle of model. Similar values were received for all models and overlap with allowable limit at that height.**

***Keywords* — Steel Diagrid, Storey Displacement, Variable Bracing Angles.**

I. INTRODUCTION

Steel diagrid is now a modified modern building concept. When it comes to high rise building, building design become necessity as it influences the popularity. Steel diagrid enhanced architectural flexibility and scope of versatile geometric patterns and designs. These structures allow large architectural flexibility and structural integrity against lateral loadings in skyscrapers. Diagrid is based on triangular geometric pattern formed in such a way that aesthetical requirements and structural requirements fulfill at same time. Braces are able to transfer gravity and lateral loads both to the foundation in more efficient way than general high rise steel building does. This research involves study of a steel diagrid system. A steel diagrid building model is developed with multiple cases for different angles. Analysis is performed for finding displacement at local story level and roof displacement for each case and comparison study is to be carried out.

A total of 3 models were generated to do detailed study of brace angles of diagrid. Each building model is having 60 floors system with 3900 mm floor to floor height making it total of 234 m high super structure. Each model has same floor plan with varying steel braces at periphery starting from 55º, 60º & 65º. Total of 3 models were prepared & analyzed for comparing and developed.

II. METHODOLOGY

There are total 3 models were prepared to perform this study. Each model is developed in AUTOCAD and analysed in STAAD.PRO software. All models are identical except the diagrid angles so the focus was only on diagrid braces. Diagrid angles assembled for each different model which as follows, 55º, 60º and 65º. All models have identical floor plans as shown in figure below. W18x35 sections are used as floor framing members. A composite floor is considered as floor diaphragm for each floor consisting of 110 mm thick concrete poured over 22 Ga. steel metal decking sheet. A dead load of 7 kN/sqm (including concrete weight) and live load of 4 kN/sqm is applied on each floor. A constant floor to floor height is 3.9 m is provided throughout the building height. This make a total of 234 m high analytical building model having braces at periphery of the building with constant brace angle for each model and cross bracings for the inner core area as recommended in previous studies performed by Giovanni [2]. All the sections mentioned in above table are American square steel tube sections with varying outer dimensions from 1000mm x 1000mm to 300mm x 300mm and thickness from 90mm to 10mm as described in table 3.1. Each model has different member assembly.

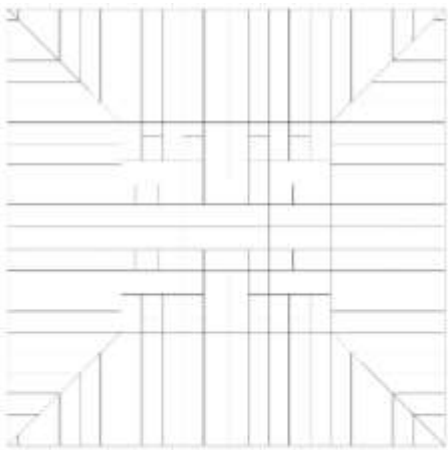


Figure 1 Floor Plan of Model

Table 1 Column & Bracing Member Sections

Columns, Internal & External Bracing Sizes		
Model – 1 – 55 degrees	***Model – 2 – 60 degrees***	***Model – 3 – 65 degrees***
1000 x 1000 x 90	-	-
1000 x 1000 x 75	-	-
800 x 800 x 80	800 x 800 x 80	800 x 800 x 80
800 x 800 x 65	800 x 800 x 65	800 x 800 x 65
800 x 800 x 50	800 x 800 x 50	800 x 800 x 50
600 x 600 x 55	600 x 600 x 55	600 x 600 x 55
600 x 600 x 50	600 x 600 x 50	600 x 600 x 50
600 x 600 x 40	600 x 600 x 40	600 x 600 x 40
600 x 600 x 30	600 x 600 x 30	600 x 600 x 30
600 x 600 x 25	600 x 600 x 25	600 x 600 x 25
400 x 400 x 20	400 x 400 x 20	400 x 400 x 20
300 x 300 x 10	300 x 300 x 10	300 x 300 x 10

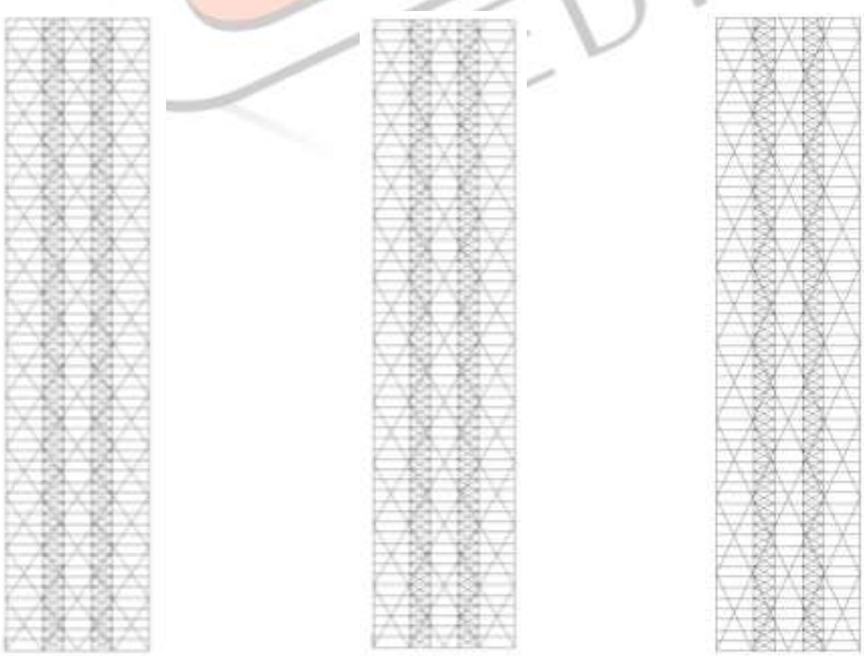
This research followed ASCE 7-10 [10] for calculating wind pressure based on speed of 49 m/s. Seismic load calculations are compiled based on ground motion spectrum values followed by its time period & acceleration at the location of the structure. Location of building is assumed to be in California region and S_{DS}, S_{MS} and other parameters are accounted as given below: S_{DS} = 0.907 & S_{D1} = 0.472.

Table 2 Seismic Base Shear as per IBC-2012

	Model 1	**Model 2**	**Model 3**
Brace Angle	55 degree	60 degree	65 degree
Weight of Building (kN)	285150	251803	223076
Cs	0.151	0.151	0.151
Base Shear V (kN)	**43057.65**	**38022.3**	**33684.5**

Figure 2 Isometric View of Bracing

Load combinations are based on ASD (Allowable Stress Design) Table 10 [11].

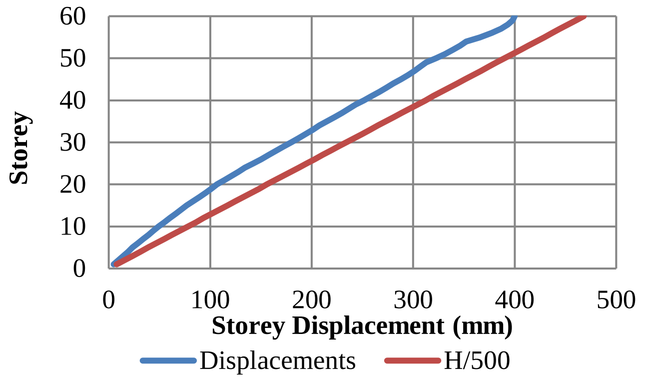


55 Degree – Model 1 60 Degree – Model 2 65 Degree – Model 3

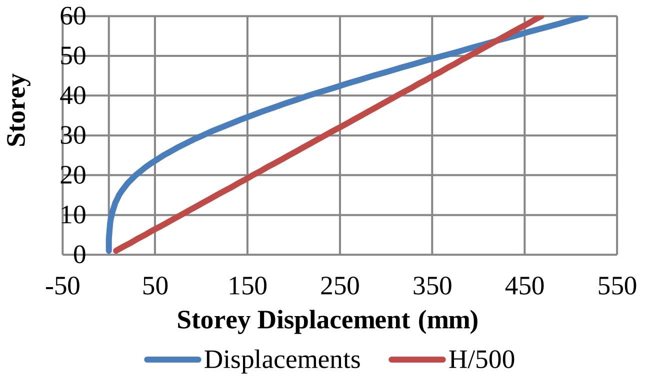
Figure 3 All Three Models with Outer Bracing Angles

III. Analysis & Results

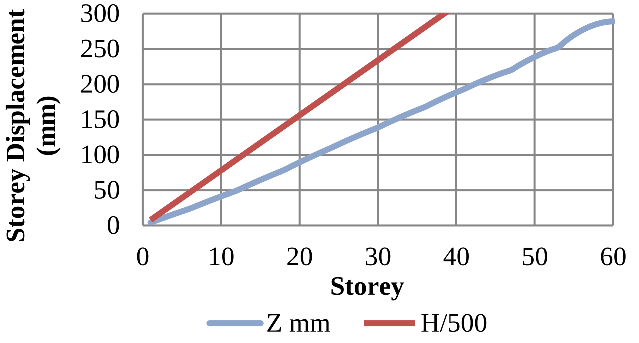
All three models were processed with design loads and combinations as per IBC 2012 [31]. Here results of analysis performed on all three models will be discussed. Each model individually processed and obtained results are noted for comparing various parameters like story drift, roof displacements & base shear.



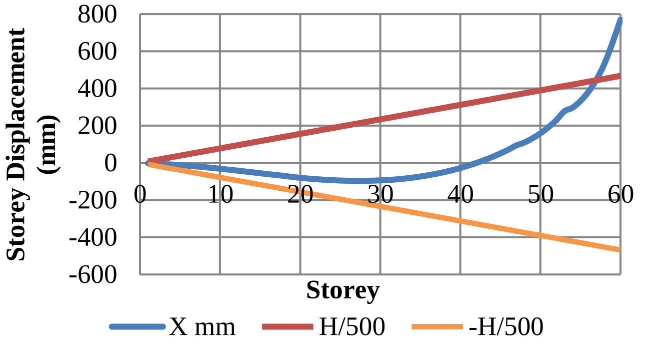
Graph 1 Model-1 Storey Displacement for Z-axis



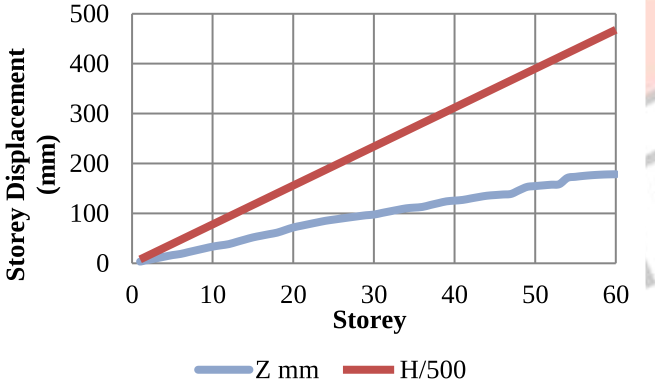
Graph 2 Model-1 Storey Displacement for X-axis



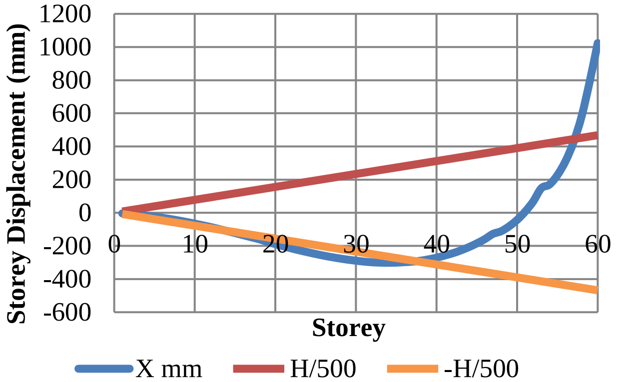
Graph 3 Model-2 Storey Displacement for Z-axis



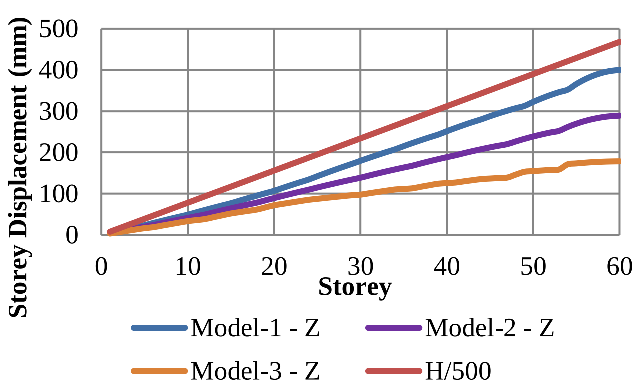
Graph 4 Model-2 Storey Displacement for X-axis



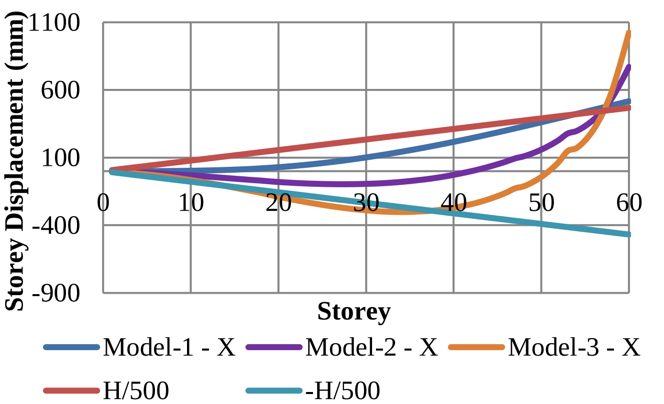
Graph 5 Model-3 Storey Displacement for Z-axis



Graph 6 Model-3 Storey Displacement for X-axis



Graph 7 All Models Displacement v/s H/500 for Z-axis



Graph 8 All Models Displacement v/s H/500 for X-axis

IV. Conclusion

A detailed study, analysis and result formation came to an end to conclude the comparison and outcomes of complete research work. This research was performed on three analytical models studied, designed and analysed in STAAD Pro software to know behaviour of displacements under influence of wind forces at significant heights for different types of bracing varying from 55 degrees, 60 degrees and 65 degrees.

Here major conclusions are noted below from all over study performed:

- Each model behaviour was different and the major cause was steel density occurred due to bracing angles. Smaller angles results in compacted cluster of frames which results in increased material quantity for a specific area. This result in dense structure which tend to behave more towards rigidity. As more rigid structure tend to resist more lateral forces.
- Model – 1 has lowest angle value of 55 degrees, this model shows lowest displacement in major axis (X-axis). Low bracing angle results in compacted exoskeleton formation and this is main reason keeping displacements lower than other models.
- Model – 1 also has highest weight among all three models because of close cluster of steel brace frames. This result in high base shear value for this model. As base shear is directly proportional to weight of the building.
- Model – 2 shows optimum results for the displacements. However displacements at some storeys exceeded the limiting values of H/500.
- Model – 3 shows highest displacements under influence of wind pressure in major axis (X – axis). The main reason behind this is low density of steel brace frame due higher angle value of 65 degrees.
- As model – 3 does have least weight among all because of lowest steel weight in the building as compared to other two. This model faces lowest amount of base shear while standing with remaining models.
- Another reason behind deciding model – 2 best among all three is angle of braces. This model kept 60 degree as brace angle for exoskeleton, while looking at geometry it can be seen that braces forming triangular shapes out of main quadrilateral geometry. Keeping 60 degree angles for this triangular geometry results in forming equilateral triangular shape. Achieving this shape will result in equal distribution of forces. This phenomenon helps in behaving whole building as homogeneous. So result in better efficiency.
- From graph 8, it is also noted that a threshold value of displacement doesn't change by changing bracing angles. For this building case, the threshold value is achieved at 57^{th} storey.

V. Acknowledgment

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