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Behaviour of High-Rise Buildings with Steel Diagrid System in All Seismic Zones

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Abstract -*The trend of high rise buildings is rapidly increasing due to the limitation of land for horizontal development. Various lateral load resisting systems are used for high rise buildings. The diagrid structural system is efficient and effective structural system for resisting lateral loads. Diagrid structural system is external structural system in which all the external columns are replaced by series of triangular shaped diagonal grids and internal columns are only designed for gravity loads. In diagrid structure shear and bending are resisted by axial action of diagrid. In this paper 48 storey buildings of height 168 m with steel diagrid in all seismic zones are analyzed by using ETABS software. Static analysis, dynamic analysis (response spectrum) and wind load analysis are performed. One city from each seismic zone was selected. The selected city represents the location of building in that particular seismic zone. The basic wind speed of selected city is considered for wind load analysis. The analysis results are compared in term of maximum story displacement and maximum story drift and find out optimum diagrid angle.*

Key Words: **Diagrid structure, Story displacement, Story drift, Diagrid modules, Optimum diagrid angle, Seismic zone, Response spectrum, Wind load**.

1. INTRODUCTION

The population is increasing day by day so we are facing a problem of limitation of available land. The cost of available land is also increasing that is why, recently the trend of high rise buildings has become more popular. As the height of building increases, the lateral loads become predominant than the gravitation loads. There are two types of lateral loads acted on high rise building such as wind load and earthquake load. Shear wall, rigid framed structure, brace tube, wall frame, outrigger system and diagrid system are the different types of lateral load resisting structure which are used in high rise buildings. The diagrid structural system is efficient and effective structural system for resisting lateral loads. Diagrid structure is external structural system in which all the external columns are replaced by series of triangular shaped diagonal grids and internal columns are only designed for gravity loads. It provides significant flexibility to the floor plan. The word 'diagrid' made of diagonal grids. Diagrid structural system consists of series of triangular shaped diagonal grid along the periphery of structure. Due its unique configuration it provides more stiffness than other structures. Diagrid structure provides more aesthetic appearance and gives more interior space due to less number of columns.

In the present work, 20 models of 48 story building are considered. Total height of building is 168 m. 20 models are divided in all seismic zones. Each seismic zone is having 5 diagrid modules. Two, four, six, eight and combination modules have been used in diagrid structure. The combination module is made of combination of two, four, six, eight modules. All structural members are designed as per IS 800:2007. IS 1893 part 1- 2016 is used for earthquake analysis and IS 875 part3- 2015 is used for wind load analysis. Response spectrum method is use for dynamic analysis. All the analysis results are compared in term of maximum story displacement and maximum storey drift and optimum diagrid angle is determined for all modules.

1.1 Research Objectives

a) To understand the behaviour of high rise building with diagrid system.

b) The objective of this study is to evaluate the response of high rise building with diagrid system.

c) To understand the performance of diagrid structure by locating same height of building in all seismic zones.

d) To carry out static analysis, dynamic analysis and wind load analysis and calculate result in term of story displacement, story drift.

e) The objective of this study is to analyze the structure by keeping constant height and changing the diagrid angle.

f) To find optimum diagrid angle of diagrid system in all seismic zones by considering all parameters.

1.2 Methodology

a) To understand previous researches by using literature reviews.

b) Consideration of material and section properties to all modules in each seismic zone as per IS 800:2007 and modeling of all modules in ETABS.

c) The dead load and live load are assigned for structure as per IS code.

d) Consideration of design parameters for Static, dynamic and wind load analysis using IS 1893 part 1- 2016 and IS 875 part3- 2015.

e) Analysis of all modules in ETABS

f) Result and conclusion from analysis output

2. MODELING &ANALYSIS

2.1 Building Configuration

A 48 storey building of height 168 m is considered and same height of building is located in all seismic zones. The storey height is 3.5 m. The diagrids are provided at eight meter spacing along the perimeter. Each seismic is having 5 diagrid modules. The total numbers of diagrid modules are considered for analysis are 20. All structural members are designed as per IS 800:2007. IS 1893 part 1- 2016 is used for earthquake analysis and IS 875 part3- 2015 is used for wind load analysis. The live load and dead load on floor slab are 3 kN/m^2 and 2 kN/m^2 respectively. Modeling and analysis of diagrid structure are carried out using ETABS software. The ends of diagrids are assumed as hinged. The support conditions are assumed as fixed.

Response reduction factor is taken as 5. Importance factor is taken as 1.5 because building is considered for importance service which is hospital. Plan of building looks like '**+**' symbol.

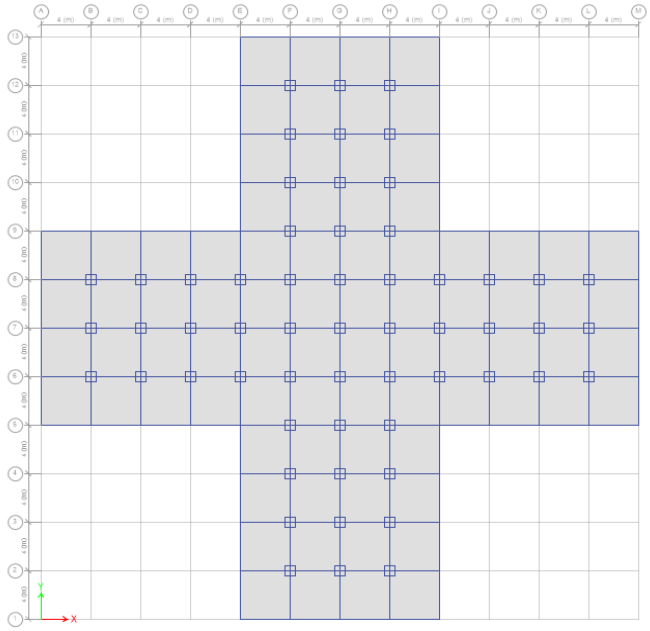

Fig-1: Plan of the building

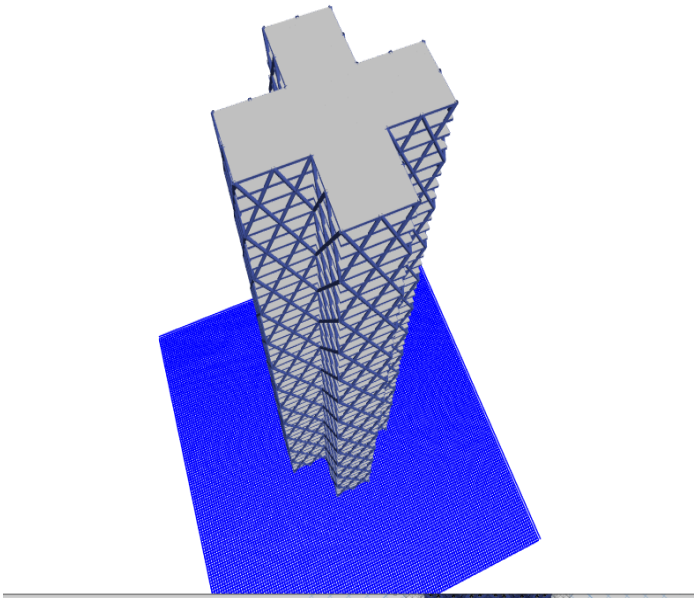

Fig-2: 3D view of the building

Zone	Zone factor	Location of building	Basic wind speed of city in m/s
II	0.10	Bangalore	33
III	0.16	Pune	39
IV	0.24	Delhi	47
V	0.36	Guwahati	50

Table -1: Basic design consideration

2.2 Diagrid Modules

Diagrid structure consist of modules and each module creates an angle. For the analysis of diagrid structure different types of modules are taken such as two story, four story, six story and eight story which create different angles. Two story module creates an angle of 41.18^0. Four story module creates an angle of 60.25^0. Six story module creates an angle of 69.14^0. Eight story module creates an angle of 74.05^0. Another module has been created by taking combination of all modules such as two, four, six and eight. There are five modules in each zone. Total number of modules is equal to 20 (5x 4 zones). The optimal angle of the columns for maximum bending rigidity is 90^0 and that of the diagonals for maximum shear rigidity is about 35^0, it is expected that the optimal angle of diagonal members for diagrid structure falls between these angles.

2.3 Section Properties of Diagrid Structure

The section properties for building models are determined from several iterations. For beams Indian standard medium beams are used and for columns steel tubes of various sizes

are used. For diagrid members steel pipes of various sizes are used. Following tables show that section properties for beams, columns and diagrids in all zones.

2.3.1 Section Properties in Zone II

Story	Beam	Column [tube section]	Diagrid [pipe section]
1-16	ISMB 550	750 X 750 X 50	750 X 25
17-32	ISMB 500	700 X 700 X 45	750X 25
33-48	ISMB 500	600 X 600 X 35	750 X25

Table -2: Section Properties in Zone II

2.3.2 Section Properties in Zone III

Story	Beam	Column [tube section]	Diagrid [pipe section]
1-16	ISMB 550	800 X 800 X 55	750 X 35
17-32	ISMB 500	700 X 700 X 50	750X 35
33-48	ISMB 500	600 X 600 X 45	750 X35

Table -3: Section Properties in Zone III

2.3.3 Section Properties in Zone IV

Story	Beam	Column [tube section]	Diagrid [pipe section]
1-16	ISMB 550	800 X 800 X 55	800 X 55
17-32	ISMB 500	700 X 700 X 50	800X 55
33-48	ISMB 500	600 X 600 X 45	800 X55

Table -4: Section Properties in Zone IV

2.3.3 Section Properties in Zone V

Story	Beam	Column [tube section]	Diagrid [pipe section]
1-16	ISMB 550	825 X 825 X 55	850 X 60
17-32	ISMB 500	725 X 725 X 50	850 X 60
33-48	ISMB 500	650 X 650 X 40	850 X 60

Table -5: Section Properties in Zone V

3. ANALYSIS of DIAGRID STRUCTURE

For the analysis, 48 storey steel diagrid building is considered. Location of building in each zone is given in table 1. Twenty diagrid modules were analyzed in ETABS. Static analysis, dynamic analysis (response spectrum) and wind load analysis are performed. IS 800:2007, IS 1893 part 1-2016 and IS 875 part3-2015 have been used for analysis parameters.

3.1 Analysis of Diagrid Structure for Zone II

Zone II is classified as low intensity zone. This Seismic zone is having zone factor value 0.10. Site types taken as 1. Importance factor taken as 1.5 because our structure is included in importance service. For the wind load consideration structure location is taken in Bangalore city and according to that basic wind speed is considered which is 33 m/s. purpose of diagrid structure is for hospital so mean probable design life of structure is 100 years and on the basis of that risk coefficient is considered which is1.05. Category of our structure is 3. Structural class is taken as C because maximum dimension that is height of structure is more than 50 m. k4 factor is taken as 1.30 which is taken as per type of structure. Windward and leeward coefficient are taken as 0.8 and 0.6 respectively. Response spectrum analysis is used for dynamic analysis. In which SSRS and CQC method are considered. Damping ratio is taken as 5%. For wind analysis in ETABS exposure from extent of diaphragms method is used. For wind exposure width data direction angle is selected as 0;90. Mass source is specified load pattern in which only 25% live load was considered because we have considered live load as 3 kN/m^2. Different load combinations are considered during analysis. For response spectrum analysis, in load case data the scale factor was selected as per Ig/2R but computed design base shear was less than static base shear so scale factor was changed and analyzed again. 50 modes were considered for analysis and 99% of the seismic weight of the building is utilized as a total participating mass of the building.

3.2 Analysis of Diagrid Structure for Zone III

Zone III is classified as moderate intensity zone having zone factor 0.16 as per codal provision. Site types taken as 1. Importance factor taken as 1.5 because our structure is included in importance service. For the wind load consideration structure location is taken in pune city and according to that basic wind speed is considered which is 39 m/s. purpose of diagrid structure is for hospital so mean probable design life of structure is 100 years and on the basis of that risk coefficient is considered which is1.06. Category of our structure is 3. Structural class is taken as C because maximum dimension that is height of structure is more than 50 m. k4 factor is taken as 1.30 which is taken as per type of structure. Windward and leeward coefficient are taken as 0.8 and 0.6 respectively. Response spectrum analysis is used for dynamic analysis. In which SSRS and CQC method are considered. Damping ratio is taken as 5%. For wind analysis in ETABS exposure from extent of diaphragms

method is used. For wind exposure width data direction angle is selected as 0;90. Mass source is specified load pattern in which only 25% live load was considered because we have considered live load as 3 kN/m². Different load combinations are considered during analysis. For response spectrum analysis, in load case data the scale factor was selected as per Ig/2R but computed design base shear was less than static base shear so scale factor was changed and analyzed again. 50 modes were considered for analysis and 99% of the seismic weight of the building is utilized as a total participating mass of the building.

3.3 Analysis of Diagrid Structure for Zone IV

Zone IV is classified as severe intensity zone having zone factor 0.24 as per codal provision. . Site types taken as 1. Importance factor taken as 1.5 because our structure is included in importance service. For the wind load consideration structure location is taken in Delhi city and according to that basic wind speed is considered which is 47 m/s. purpose of diagrid structure is for hospital so mean probable design life of structure is 100 years and on the basis of that risk coefficient is considered which is 1.07. Category of our structure is 3. Structural class is taken as C because maximum dimension that is height of structure is more than 50 m. k4 factor is taken as 1.30 which is taken as per type of structure. Windward and leeward coefficient are taken as 0.8 and 0.6 respectively. Response spectrum analysis is used for dynamic analysis. In which SSRS and CQC method are considered. Damping ratio is taken as 5%. For wind analysis in ETABS exposure from extent of diaphragms method is used. . For wind exposure width data direction angle is selected as 0;90. Mass source is specified load pattern in which only 25% live load was considered because we have considered live load as 3 kN/m². Different load combinations are considered during analysis. For response spectrum analysis, in load case data the scale factor was selected as per Ig/2R but computed design base shear was less than static base shear so scale factor was changed and analyzed again. 50 modes were considered for analysis and 99% of the seismic weight of the building is utilized as a total participating mass of the building.

3.4 Analysis of Diagrid Structure for Zone V

Zone V is classified as very severe intensity zone having zone factor 0.36 as per codal provision. Site types taken as 1. Importance factor taken as 1.5 because our structure is included in importance service. For the wind load consideration structure location is taken in Guwahati city and according to that basic wind speed is considered which is 50 m/s. purpose of diagrid structure is for hospital so mean probable design life of structure is 100 years and on the basis of that risk coefficient is considered which is1.08. Category of our structure is 3. Structural class is taken as C because maximum dimension that is height of structure is more than 50 m. k4 factor is taken as 1.30 which is taken as per type of structure. Windward and leeward coefficient are taken as 0.8 and 0.6 respectively. Response spectrum analysis is used for dynamic analysis. In which SSRS and CQC method are considered. Damping ratio is taken as 5%. For wind analysis in ETABS exposure from extent of diaphragms method is used. . For wind exposure width data direction angle is selected as 0;90. Mass source is specified load pattern in which only 25% live load was considered because we have considered live load as 3 KN/m². Different load combinations are considered during analysis. For response spectrum analysis, in load case data the scale factor was selected as per Ig/2R but computed design base shear was less than static base shear so scale factor was changed and analyzed again. 50 modes were considered for analysis and 99% of the seismic weight of the building is utilized as a total participating mass of the building.

From analysis it was obseved that, for all seismic zones dynamic base shear was less than 80% of static base shear so it was changed by using multipication of first scale factor and ratio of static base shear to the dynamic base. Basic wind speed increases, as we change the zone. Basic wind speed is more for zone V which is 50 m/s. zone V is very severe seismic intensity zone Section Properties have to be changed for each seismic zone because section properties in previous zone are not passed stress capacity check in next seismic zone.

4. RESULT & DISCUSSION

The results of the analysis are in terms of maximum storey displacement and maximum storey drift are presented here for all seismic zones. The graphical representation shows that response of diagrid structure in all zones. All the modules from two to combination gives different values in all seismic zones.

Permissible value for maximum storey displacement is limited to H/ 500, Where H is the total height of the building. The total height of our building of 168 m.

Maximum Permissible Storey Displacement = 0.336 m
= 336 mm

As per IS 1893 (Part 1): 2016, Clause 7.11.1.1, the Storey Drift in any storey shall not exceed 0.004 times the storey height (h). The storey height of our building is 3.5 m.

Permissible Storey Drift = 0.004 X 3.5
= 0.014 m

4.1 Result & Discussion for Zone II

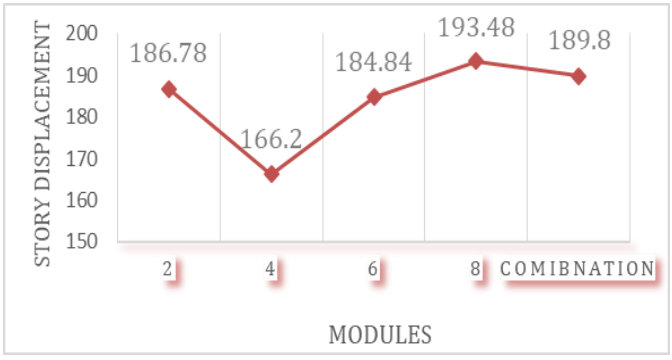

Chart -1: Max. Story displacement in zone II

The Chart -1 shows that maximum storey displacement is more in 8 module diagrid which is 193.48 mm. The smallest value of maximum storey displacement is 166.2 mm which is observed for four storey module. It is observed that the least value of maximum story displacement falls between 60^0 to 70^0.Maximum permissible storey displacement is 336 mm and it is observed that maximum story displacement of all modules in zone II is within the permissible limit. When we compare eight module with four module and six module diagrid, the maximum story displacement for four module and six module diagrid is reduced by 14.09% and 4.46% respectively.

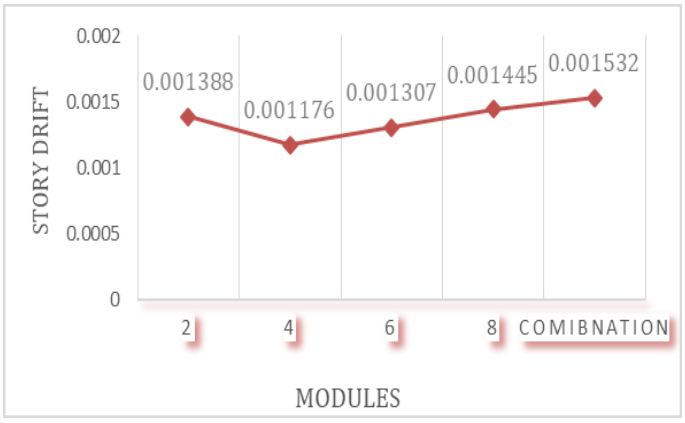

Chart -2: Max. Story drift in zone II

The Chart -2 shows that maximum storey drift is more in combination module which is 0.001532m. The least value of maximum storey drift is 0.001176 m which is found in four storey module diagrid. Maximum permissible storey drift is 0.014 m. and it is observed that maximum story drift of all modules in zone II is within the permissible limit. When we compare combination module diagrid with four and six module diagrid, the maximum story drift for four module and six module diagrid is reduced by 23.24% and 15.68% respectively.

4.2 Result & Discussion for Zone III

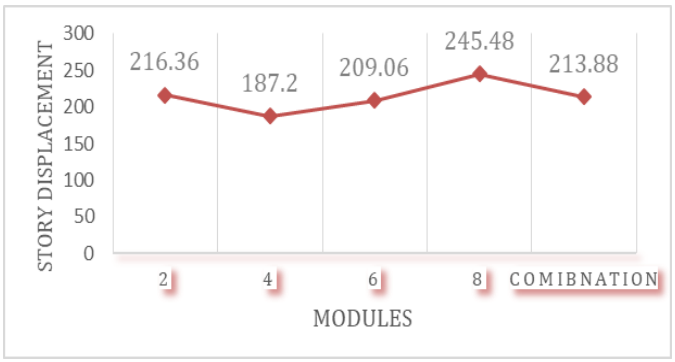

Chart -3: Max. Story displacement in zone III

The Chart -3 shows that the maximum storey displacement is more in 8 module diagrid which is 245.48 mm. The smallest value of maximum storey displacement is 187.2 mm which is observed for four storey module. It is observed that the least value of maximum story displacement falls between the ranges of 60 degree to 70 degree. Maximum permissible storey displacement is 336 mm and it is observed that maximum story displacement of all modules in zone III is within the permissible limit. When we compare eight module diagrid with four and six module diagrid the maximum story displacement for four module and six module diagrid is reduced by 23.74% and 14.83% respectively.

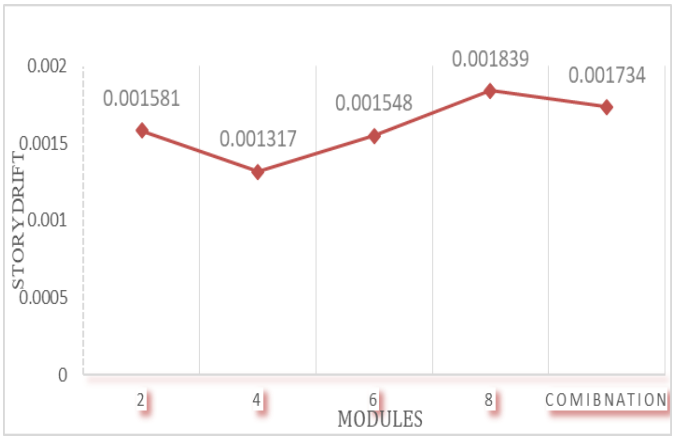

Chart -4: Max. Story drift in zone III

The Chart -4 shows that maximum storey drift is more in eight module which is 0.001839m. The least value of maximum storey drift is 0.001317 m which is found in four storey module diagrid. Maximum permissible storey drift is 0.014 m. and it is observed that maximum story drift of all modules in zone III is within the permissible limit. When we compare eight module diagrid with four and six module diagrid the maximum story drift for four module and six module diagrid is reduced by 28.38% and 15.82% respectively.

4.3 Result & Discussion for Zone IV

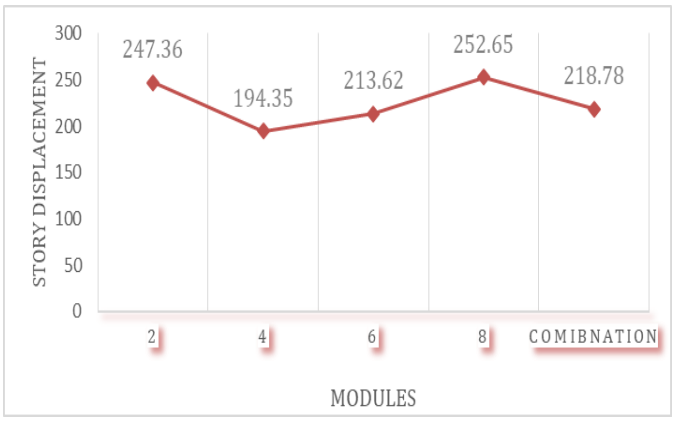

Chart -5: Max. Story displacement in zone IV

The Chart -5 shows that maximum storey displacement is more in 8 module diagrid which is 252.65mm. The smallest value of maximum storey displacement is 194.35 mm which is observed for four storey module. It is observed that the least value of maximum story displacement falls between the ranges of 60 degree to 70 degree. Maximum permissible storey displacement is 336 mm and it is observed that maximum story displacement of all modules in zone IV is within the permissible limit. When we compare eight module diagrid with four and six module diagrid the maximum story displacement for four module and six module diagrid is reduced by 23.07% and 15.44% respectively.

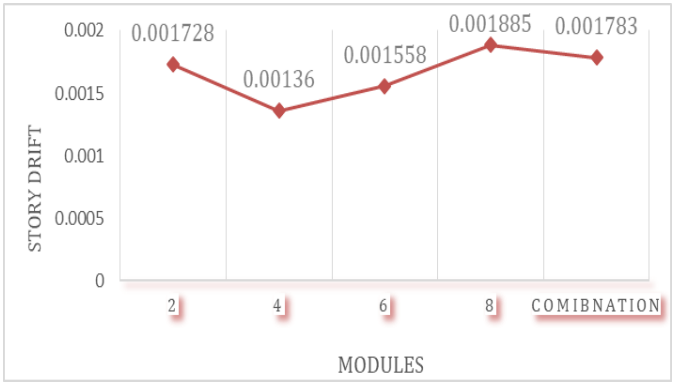

Chart -6: Max. Story drift in zone IV

The Chart -6 shows that maximum storey drift is more in 8 module diagrid which is 0.001885 m. The least value of maximum storey drift is 0.001360 m which is found in four storey module diagrid. Maximum permissible storey drift is 0.014 m. and it is observed that maximum story drift of all modules in zone IV is within the permissible limit. When we compare eight module diagrid with four and six module diagrid the maximum story drift for four module and six module diagrid is reduced by 27.85% and 17.34% respectively.

4.4 Result & Discussion for Zone V

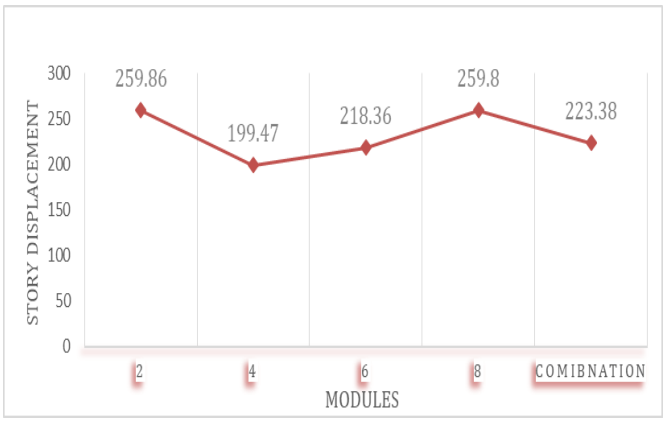

Chart -7: Max. Story displacement in zone V

The Chart -7 shows that maximum storey displacement is more in 8 module diagrid which is 259.8 mm. The smallest value of maximum storey displacement is 199.47 mm which is observed for four storey module. It is observed that the least value of maximum story displacement between the ranges of 60 degree to 70 degree. Maximum permissible storey displacement is 336 mm and it is observed that maximum story displacement of all modules in zone V is within the permissible limit. When we compare eight module diagrid with four and six module diagrid the maximum story displacement for four module and six module diagrid is reduced by 23.22% and 15.95% respectively.

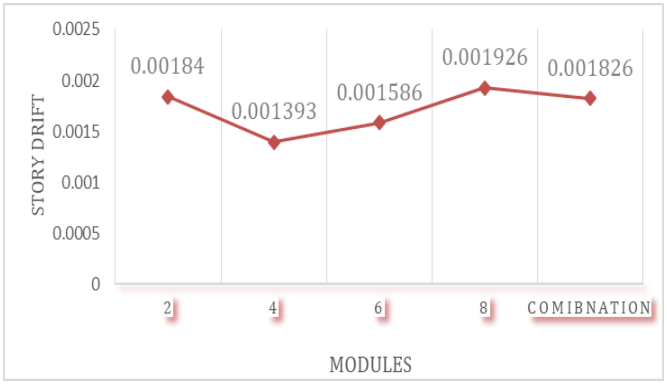

Chart -8: Max. Story drift in zone V

The Chart -8 shows that maximum storey drift is more in 8 module diagrid which is 0.001926 m. The least value of maximum storey drift is 0.001393 m which is found in four storey module diagrid. Maximum permissible storey drift is 0.014 m. and it is observed that maximum story drift of all modules in zone V is within the permissible limit. When we compare eight module diagrid with four and six module diagrid the maximum story drift for four module and six module diagrid is reduced by 27.67% and 17.65% respectively.

5. CONCLUSIONS

The present work consists of analysis of 48 storey diagrid structure. The total height of diagrid structure is 168 m. same structure is located in all seismic zones. Five diagrid modules are taken for each seismic zone. Diagrid modules are 2 storey (41.18^0), 4 storey (60.25^0), 6 storey (69.14^0), 8 storey (74.05^0) and combination module which is made of combination of 2, 4, 6, 8 module. Static analysis, dynamic analysis (response spectrum) and wind load analysis are performed. Modeling and analysis are done in ETABS. The analysis results are compared in term of maximum story displacement and maximum story drift and following conclusions have been drawn

- Four module (60.25^0), and six module (69.14^0) diagrid structure give less value of maximum story displacement and maximum story drift than other modules in all seismic zones.
- Section Properties have to be changed for each seismic zone because section properties in previous zone are not passed stress capacity check in next seismic zone.
- Four module and six module provide more stiffness to the structure that is why we get less value of maximum story displacement and maximum story drift for these two modules than other modules.
- Optimum angle of diagrid is observed in the region of 60^0 to 70^0.
- Static analysis, dynamic analysis and wind load analysis were performed on diagrid structure and it was observed that, maximum story displacement and maximum story drift are more in case of wind load analysis than earthquake analysis and response spectrum analysis.
- In all seismic zones, maximum story displacement and maximum story drift of combination module are less as compare to eight module except Max. Story drift in zone II.
- It has been concluded that for the high-rise buildings, the diagrid system is used for the better performance for lateral load and gravity load in the recent year.

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