High Rise Diagrid structure with different module angle and base width

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Abstract - *In the modern age of High rise building, Diagrid structural system is trending in all aspects of design, structural stability, architecturally pleasing and in economic consideration. Diagrid systems transfers loads more precisely than conventional framing systems, it can transfer the gravitational loads as well as lateral load by the use of triangular framing. The Diagrid structure of different story height is designed with Diagrid module with various Diagrid angles. In the paper, comparison of 40 storied Diagrid structural system of different uniform angles with respect to its base width is presented here. In this study 10 steel building of same base area and loading are modeled with different Diagrid module height for optimum model. ETABS software is used for modeling and analysis of the 10 models. Structural members are all designed using IS 800:2007 considering all load combinations. All models are designed for wind loads and earthquake loads by using Response spectrum analysis. Various parameters like fundamental time period, storey displacement, storey drift, base shear,steel usage are compared in this study.*

Key Words: *Diagrid structure, tall building, Diagrid angle, module base width, storey displacement, storey drift, steel structure, ETABS, Response spectrum analysis.*

1.INTRODUCTION

The quick growth of urban population and limitation of available land, the tall structures are ideal now a day. So when structure goes high then the consideration of lateral load is very much significant. For that the lateral resisting load system becomes more important than the structural system that resists the gravitational forces. The lateral load resisting systems that are widely used are rigid frame, shear wall, wall frame, braced tube system, outrigger system and tubular system. Lately the Diagrid – diagonal grid structural system is mainly used for high rise buildings due to its structural ability and aesthetic pleasing provided by the unique geometric composition of the system. Hence the Diagrid, for structural effectiveness and aesthetics has produced renewed interest from architectural and structural designers of tall buildings.

Diagrid has great appearance and its aesthetics are effectively perceived. The arrangement and productivity of a Diagrid framework decrease the quantity of basic component required on the façade of the structures, in this manner less obstruction to the outside view. The basic productivity of Diagrid framework likewise helps in eliminating the inside and corner columns, accordingly permitting critical adaptability with the floor plan. Diagrid framework spares around 20 percent of the structural steel weight when contrasted with a conventional moment-frame structure.
The Diagrid module in Diagrid structural systems can carry both gravity loads and lateral forces due to their Triangulated configuration. Diagrid structures are progressively viable in limiting shear deformation because they carry lateral shear by axial action of diagonal module. Diagrid structures most part needn't bother with high shear rigidity cores because lateral shear can be carried by the diagonal members located on the periphery.
The ability of a Diagrid system to dissipate loads quicker with lesser building materials, allow design of more complex yet lighter structures, making it an efficient system to use in sky scrapers and high rise buildings.

The figures below shows the concept of load distribution in Diagrid structural system, Fig(a) shows the 3D view of a symmetrical Diagrid structure having a uniform load distribution on one of its facade. Fig(b) give a 2D view of how point load acts on the inclined columns from top of the structure and load distribution towards the base. Fig(c) gives a view of uniform distributed load acting on the the horizontal member and then being transferred to the nodes and then to the inclined columns. Fig (d) provides the lateral loads being applied on the nodes and then transferring it to the Diagrid Module and then transferring towards the base supports.

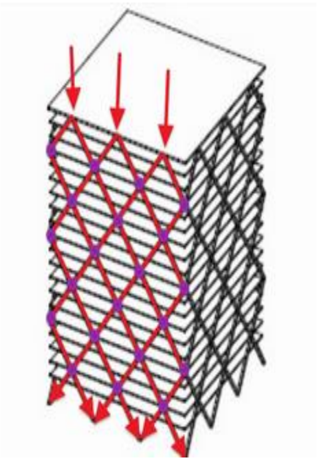


Fig (a)

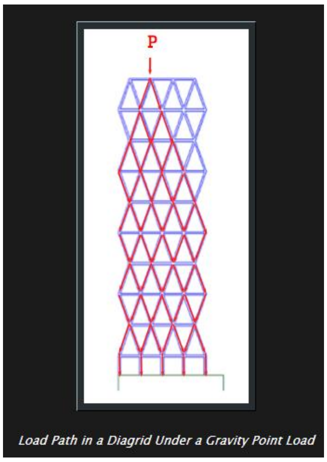


Fig (b)

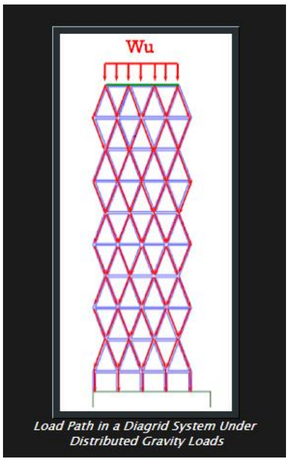


Fig (c)

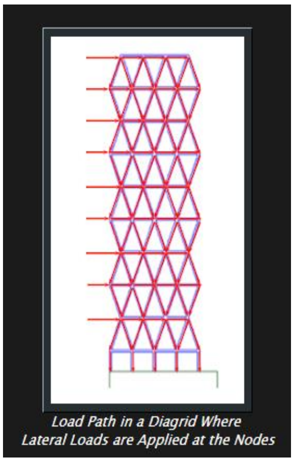


Fig (d)

In the present work 10 different models of 40 storey Diagrid structures is modeled and analyzed with shear wall as inner core, 5 models are having a base width of 5m and other 5 models are of 7.5m base width. Each model have uniform Diagrid angle. The model and analysis of all 10 models are done by using the software ETABS to find the optimum model with respect to its base width.

2.METHODOLOGY

In this work, 10 different models of 40 storey buildings are considered which are having different angle of inclination. The first 5 models which have a base width if 5m and other 5 models of base width 7.5m are represented below.

Model.1A- 2 STORIED MODULE Θ = 55.22 °
Model.1B- 3 STORIED MODULE Θ = 65.15 °
Model.1C- 4 STORIED MODULE Θ = 70.85 °
Model.1D- 5 STORIED MODULE Θ = 74.47 °
Model.1E- 6 STORIED MODULE Θ = 76.96 °

Model.2A- 2 STORIED MODULE Θ = 43.83 °
Model.2B- 3 STORIED MODULE Θ = 55.22 °
Model.2C- 4 STORIED MODULE Θ = 62.48 °
Model.2D- 5 STORIED MODULE Θ = 67.38 °
Model.2E- 6 STORIED MODULE Θ = 70.85 °

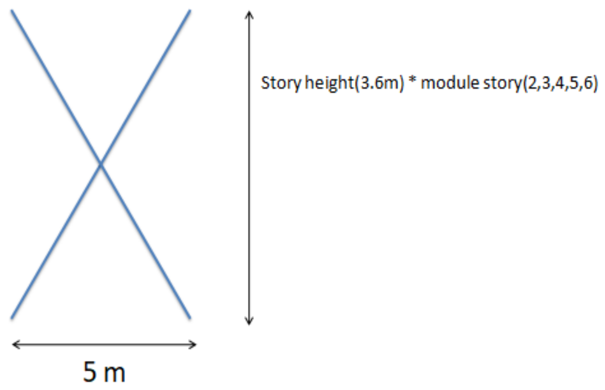


Fig (E.1) Diagrid Module for Model 1

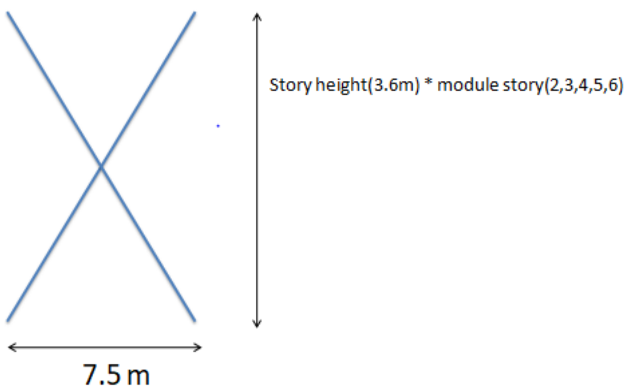


Fig (E.2) Diagrid Module for Model 2

All the Diagrid models are of 40 stories having height of 144 meters, the plan of the building is symmetrical with 45x45 meters. Five Diagrid building having the module height to be 2 storied, 3 storied, 4 storied, 5 storied and 6 storied for all having the base width as 5m and 7.5m as well. Typical floor height is 3.6 meters. The inclined columns sections are defined as pipe sections, all the support conditions are fixed. Inner core of the structure is designed as shear wall.

The triangular configuration in Diagrid models plays a major role in internal axial fore distribution and also in global shear and bending rigidity of the building. Since the optimum of columns to get maximum bending rigidity is 90 ° (conventional columns) and that of the diagonal for maximum shear rigidity is 27 °(only one storey stack per basic triangle model). It is expected that the optimum Diagrid angle of diagonal members for Diagrid structures falls between these angles, so the angles selected in this paper for analysis are between those angles.

3.GEOMETRIC DATA

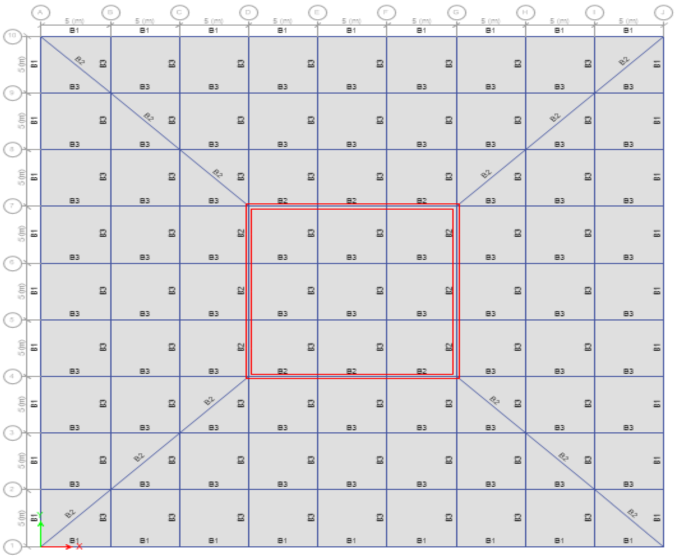


Fig (g) Typical Floor plan (5m base width)

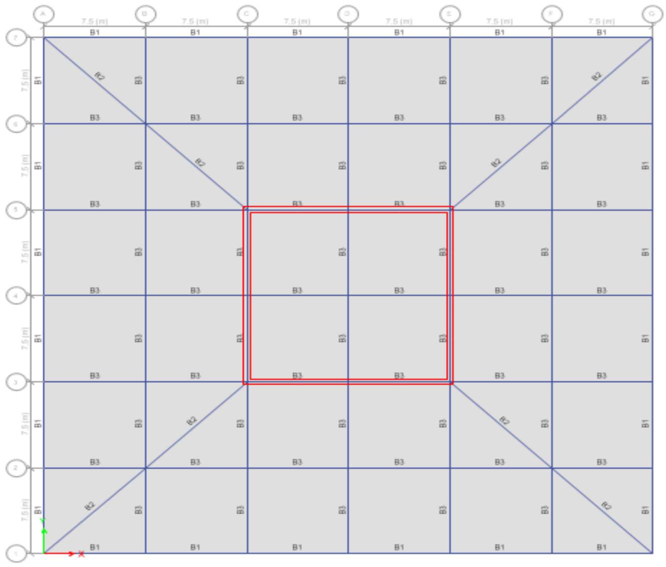


Fig (h) Typical Floor plan (7.5m base width)

Here in Fig-g and Fig-h are showing the structural plan view of the 5m base width models and 7.5m base width models in which beams are noted as B1,B2 and B3. There are 3 types of beams, all 3 are having different types of cross section. The beam B1 is the periphery beams which connects to the Diagrid module to one an other. B2 are the diagonal beams which are connected diagonally from shear wall to the 4 edges of the structure, and B3 are the interior beams placed as grid.

The member sizes of all the models are initially decided as same but later after the analysis and design results, the sizes are modified to prevent any failure.

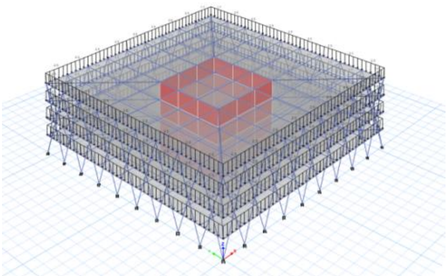
3.1 Member sizes:

Member	Notation	Dimension
Beam	B1	ISMB600 (Fe250)
	B2	ISWB600 C.P 350X22(Fe250)
	B3	ISMB550 C.P 350X30(Fe250)
Diagrid	Pipe section	700mm dia, 40mm thick
Shear wall	S1 (base to 8 stories)	500mm
	S2 (9 stories to top)	400mm

4.LOADING AND ANALYSIS

The design dead load and live load is referred as per IS875 part I and Part II. Live load considered is 3kN/m^2 respectively. Self weight of the structural system will be calculated by the ETABS software automatically. The earthquake design loads is computed based on the zone factor IV, importance factor 1.2 and response reduction factor as 5 as per IS1893-part1 2016. The design wind load is computed by its wind speed and terrain category, here we take wind speed as 50m/s and terrain category as 1. The load combinations are considered from IS1893-part1. Modeling, analysis and designing of all the structures are established by using ETABS 16.0.0 software. The design of member is carried out on the design basis of IS800:2007.

The type of analysis used in the software are Equivalent static analysis (static linear analysis) and Response spectrum analysis (dynamic linear analysis) which gives us the accurate results. The load cases used are dead load (self weight), live load, floor finish, cladding load, wind load and earthquake load and response spectrum cases. Load combinations are created for both serviceability and strength.

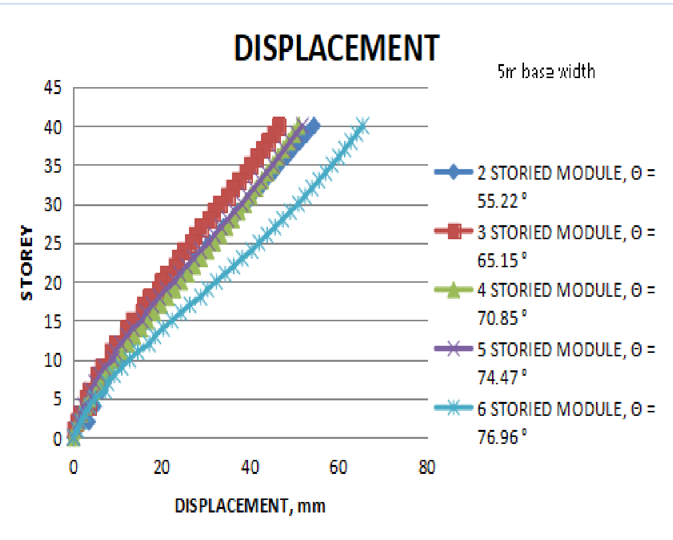


5.RESULT AND DISCUSSION

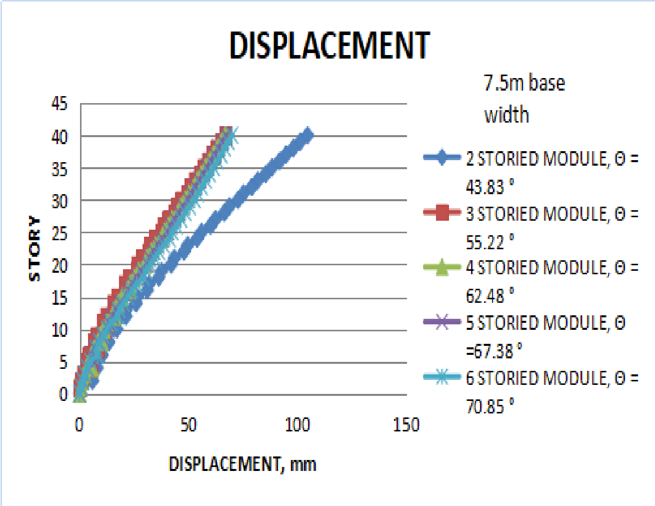
The analysis results of Model.1A, Model.2A, Model.1B, Model.2B, Model.1C, Model.2C, Model.1D, Model.2D, Model.1E, Model.2E in terms of lateral displacement, storey drift, storey shear and time period, steel usage are presented.

5.1 LATERAL DISPLACEMENT

The lateral displacement of any tall building increases with increasing the height of the building due to its lateral loading. Below is the graph of lateral displacement of 5m base width models.



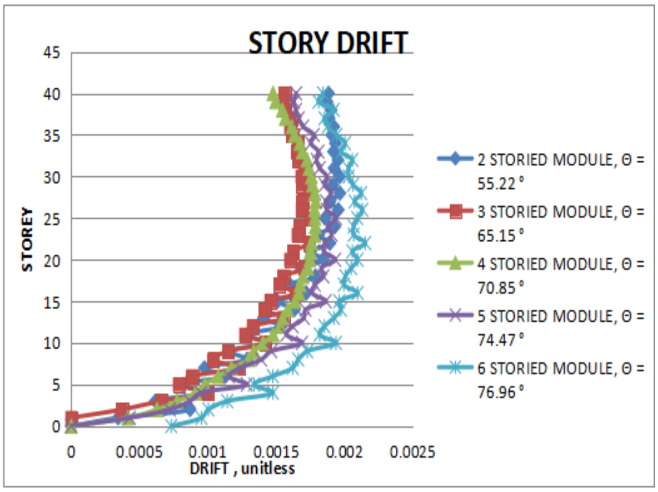
The above Figure shows that 65.15 ° angle of Diagrid has less displacement compared to other models.



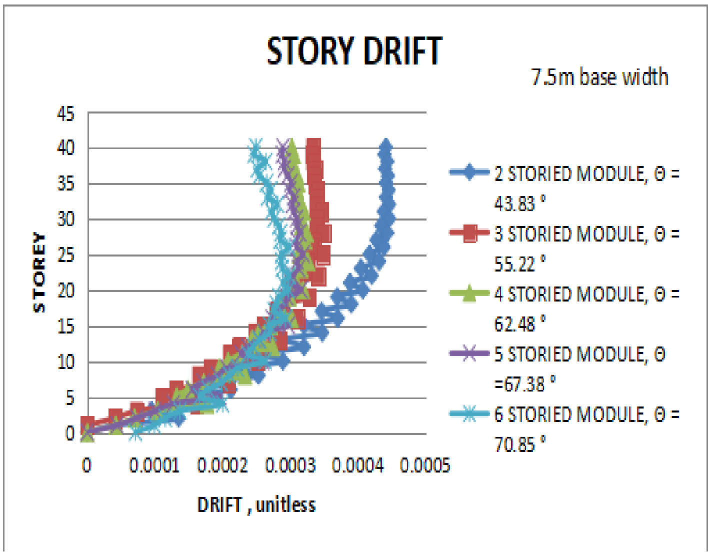
In this graph 3 models are having approximately same results which are angle of 55.22, 62.48 and 67.38. While comparing both the graph the 5m base width of 3 storied baring the angle of 65.15 gives the least results.

As per code IS: 456-2000, the maximum top storey displacement due to wind load should not exceed H/500, where H is the total height of the building. The displacement results for all the models are within the permissible limit.

5.2 STORY DRIFT



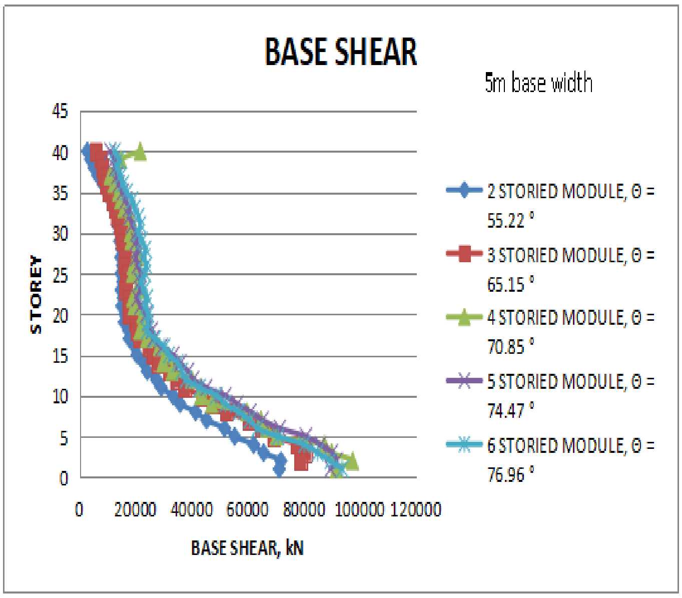
In the 5m base width storey drift graph, it can be seen that 4 storied module model shows lesser drift value than compared to other models.

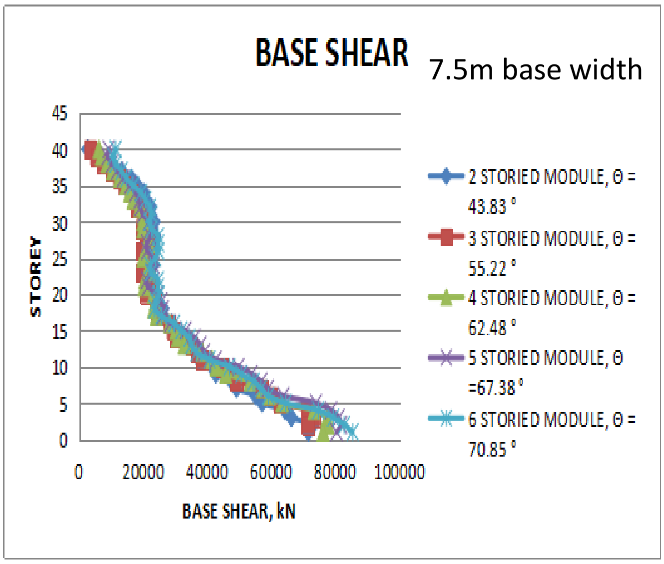


In 7.5m base width graph 6 storied module model shows less drift values and 2 storied module model shows larger drift values.

For earthquake load, as per code IS: 1893-2016, clause: 7.11.1.1 , the storey drift in any storey due to minimum specified lateral force should not exceed 0.004 times storey height that is H/250, where H = storey height in meter. The storey drift value is within the permissible limit.

5.3 BASE SHEAR

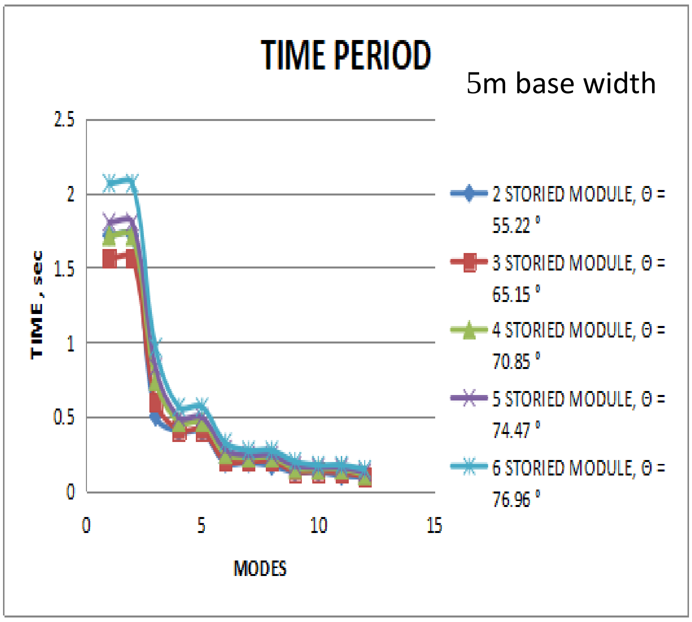


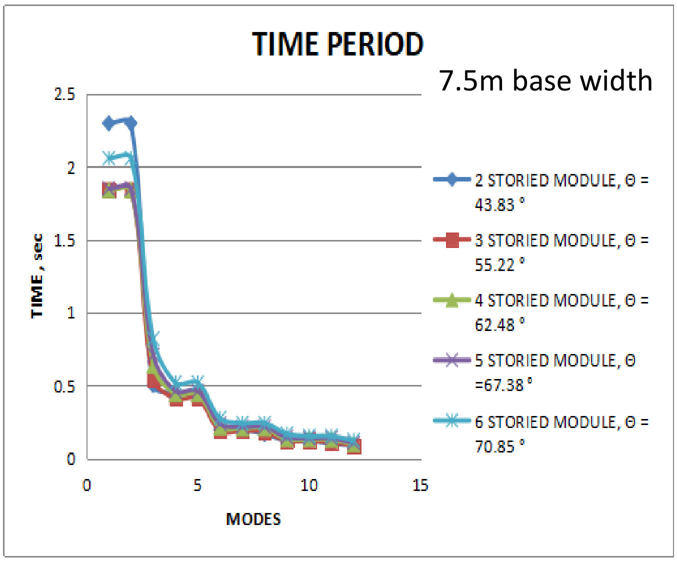


Base shear graph of 5m base width gives higher values then in 7.5m base width base shear values.

5.4 TIME PERIOD

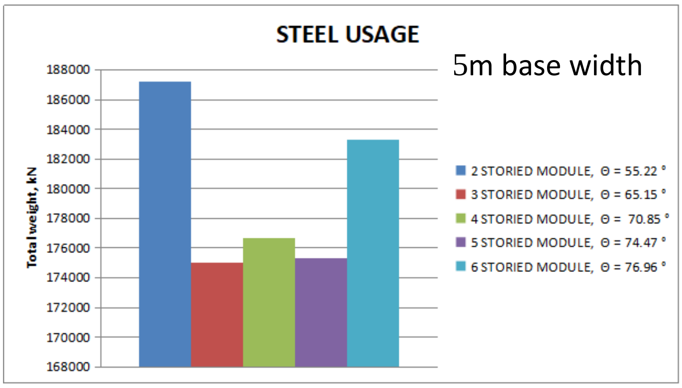
By implementing the dynamic analysis, time period is found out by considering 12 mode shape for all models, is presented here.



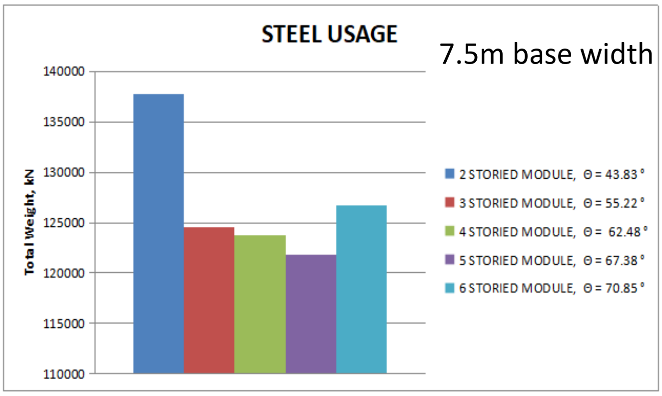


By comparing both the graphs, 7.5m base width models gives slightly more time period then 5m base width models. Time period depends upon the mass and stiffness of the structure. If the time period is more, the modal mass is more but the stiffness of the building is less vice-verse.

5.5 STEEL USAGE



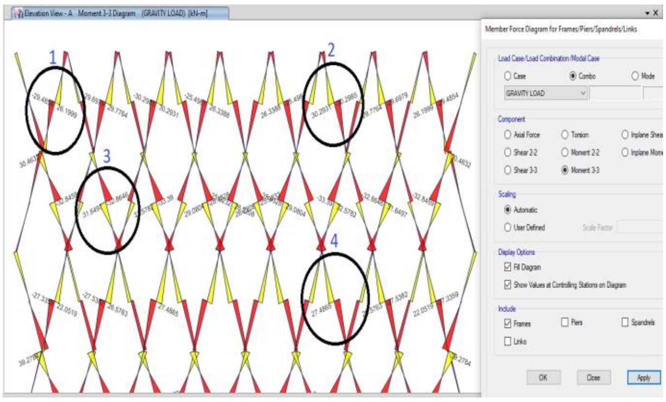
From the Fig, it is observed that the consumption of steel is highest in 2 storied module model, and least in 3 storied module model. They both have 6.48% variation in steel usage.



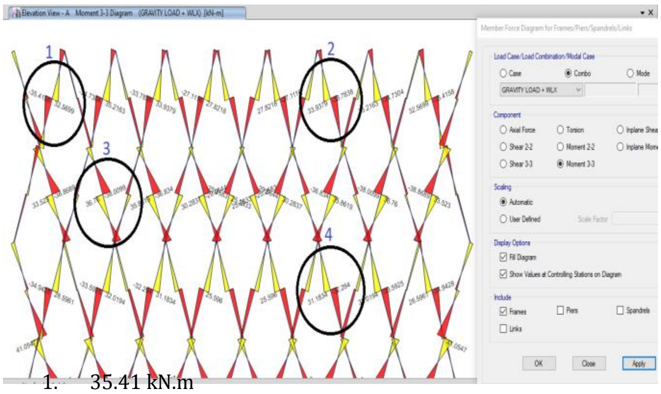
In 7.5m base width models, Steel consumption is highest in 2 storied module model and least in 5 storied module model having a 11.5% variation. Base width of 7.5m models gives less steel compared to 5m base width models.

5.6 DIAGIRD MODULE LOAD VARIATION

In case of Diagrid structures, Diagrid modules resist Gravity as well as lateral loads. In the example of 4 storied Diagrid model, the Diagrid modules moments are observed for Gravity loads and Gravity loads with lateral load.



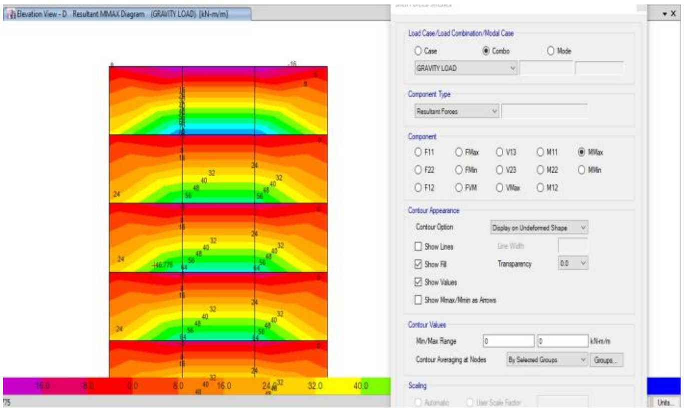
1. 29.48 kN.m
2. 30.29 kN.m
3. 31.64 kN.m
4. 27.48 kN.m



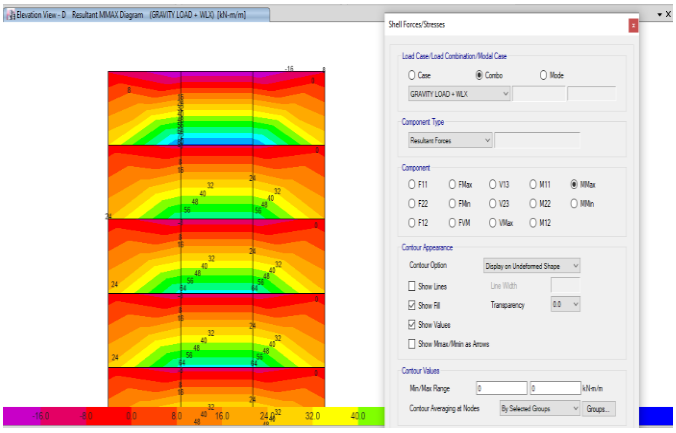
1. 35.41 kN.m
2. 33.93 kN.m
3. 36.76 kN.m
4. 31.18 kN.m

By Observing Both the Figs, it can be seen that the moments in Diagrid Modules Increases when the Lateral load is added. Thus the Diagrid Modules Resist Both lateral load and Gravity load.

5.7 INNER SHEAR WALL LOAD VARIATION



Inner Shear Wall Stresses of Gravity Load



Inner Shear Wall Stresses of Gravity Load and Wind Load

By Observing both the Fig, the Stresses for Gravity loading and Gravity loading with wind load are same.
Thus this Conclude that the Inner Shear Wall Resist the Gravity loads and the Diagrid Module Resist Gravity Load as well as Lateral loads.

6. CONCLUSION

The current study has considered 45X45 meters Diagrid plan of 10 models having different Diagrid angle and different base width. Five of the models have 5m base width and the other five have 7.5m base width.

A comparative study is carried out using the parameter such as lateral displacement, storey drift, storey shear and time period and Steel usage.

From the results obtained, it can be concluded that Diagrid angle in the region of 60 ° to 75 ° provides more stiffness to the Diagrid structural system which result in less top storey displacement, storey drift, storey shear and time period.

Also, by considering the angles, the storied module is also to be taken in account. This shows that a 3 storied module, 4 storied module and 5 storied module gives better performance than 2 storied and 6 storied modules.

However for all the models the results are within limits, 7.5m base width models require less Diagrid modules thus less steel usage in 7.5m base width models.

From the study it is observed that most of the lateral load is resisted by Diagrid columns on periphery while gravity load is resisted by both the inner core and peripheral columns.

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