Effect of Geometry on Performance of Tall Steel Structure with Diagrid System

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Abstract: Diagrid structures are prevalently used for today's tall buildings due to their structural efficiency and architectural aesthetic potentials. This paper will study structural performance of diagrid system employed for different geometry such as square and rectangle. The stiffness-based design methodology is applied to find preliminary member sizes for diagrid structural system. ETABS software is used for modelling and analysis of structural members. In this study, eighteen steel frame models of 72 storey in earthquake zone - III were chosen having different plan configuration for the analysis and design. All structural members are designed as per IS 800:2007 considering all load combinations. Dynamic wind load considered for analysis and design of the structure. Comparison of analysis results in terms of time period, displacement, inter-storey drift and steel mass of the models is presented in this paper.

Index Terms – Geometry, Diagrid System, Tall Steel Structure, 4 storey 6 story & 8 storey Module

I. INTRODUCTION

The desire to build high is nothing new for civilization and the competition for building bigger and taller is as old as civilization. Development of new technology occurs founded upon requirement, and the technology progresses towards enhanced efficiency. Subsequently at present-day higher and effective structures are evolved to exploit land uses more economically. Advancement in structural engineering, technology improvements in fabrication and construction techniques, have greatly extended the height limit. Diagrids have emerged as an architectural choice in the creation of contemporary buildings. Although there is engineering–based reasons that would suggest the use of a diagrid, discussions with engineers would conclude that architectural design has been the driving motivation. Diagrids are able to adapt to a wide range of nonrectilinear geometric forms, including irregular curves and angles. No other type of framed structure is capable of this task.

II. AIM, OBJECTIVE & SCOPE OF WORK

Aim of present work is as follows:

- The aim of my work is "A Parametric Study on Effect of Geometry on Performance of Tall Steel Structure with Diagrid System"

Objective of present work is as follows:

- Study the various effects on performance of tall steel structure with diagrid system due to geometry having square and rectangle plan.
- To observe the structural behaviour of tall steel structure by using the diagonal diagrid element for the models.
- To compare the analysis results in terms of time period, displacement, inter-storey drift and steel mass of the models.

Scope of present work is as follows:

- Building layout 20 m x 20 m, 20 m x 40 m, 20 m x 60 m, 40 m x 40 m, 40 m x 80 m, 40 m x 120 m and 72 Storey Building consider.
- For diagrid system, 4 storey module, 6 storey module and 8 storey module considered.
- Seismic zone – III and Location Ahmedabad is considered.
- Dynamic wind is considered for analysis and design of the structure.
- Modelling, analysis and design are carried out on computer program ETABS.
- Analysis & design of steel structure using IS: 800:2007.

III. BEHAVIOUR OF DIAGRID STRUCTURAL SYSTEM

Behaviour 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 Figure 1 the diagrid module under the gravity load N_G is imperiled to vertical downward force N_G, 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.

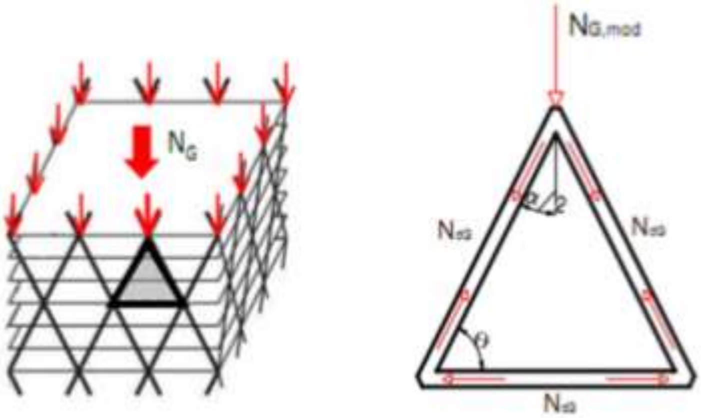


FIG 1: BEHAVIOR UNDER GRAVITY LOADING

Behaviour 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.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.

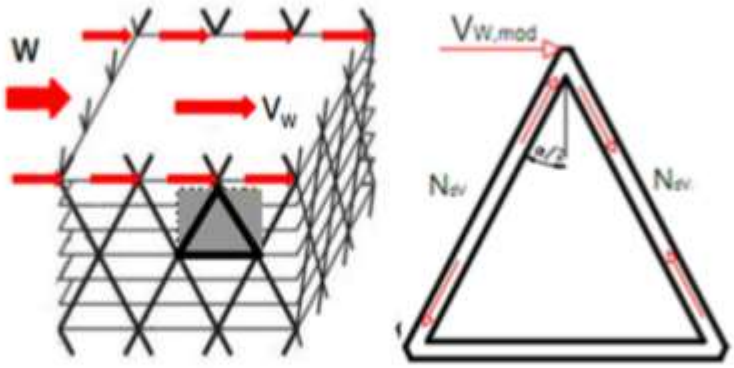


FIG 2: EFFECT OF SHEAR FORCE ON DIAGRID MODULE

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.3 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.

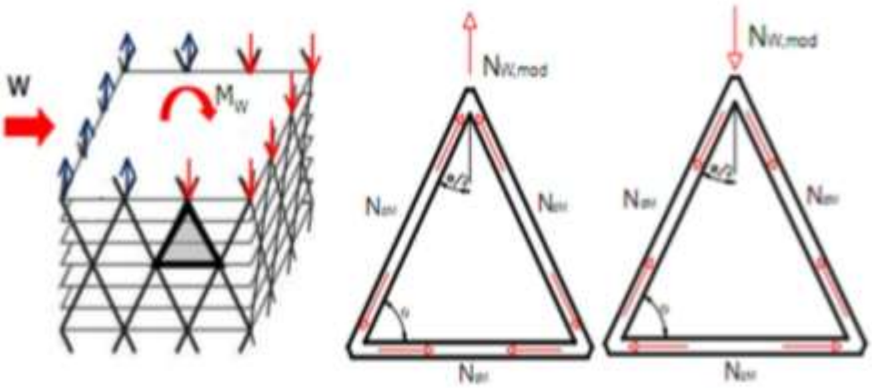


FIG 3: EFFECT OF OVERTURNING MOMENT ON DIAGRID MODULE

IV. BUILDING CONFIGURATION

TABLE 1 BUILDING CONFIGURATION

BUILDING CONFIGURATION			PLAN 1	PLAN 2	PLAN 3	PLAN 4	PLAN 5	PLAN 6
Building Length	L	m	20	20	20	40	40	40
Building Width	B	m	20	40	60	40	80	120

Building Height	H	m	216	216	216	216	216	216
Numbers of floor	N	m	72	72	72	72	72	72
Floor Height	H	m	3	3	3	3	3	3
Diagrid	4 Storey module		M1	M4	M7	M10	M13	M16
	6 Storey module		M2	M5	M8	M11	M14	M17
	7 Storey module		M3	M6	M9	M12	M15	M18

FIG 4: SQUARE GEOMETRY & 3D VIEW OF STRUCTURE

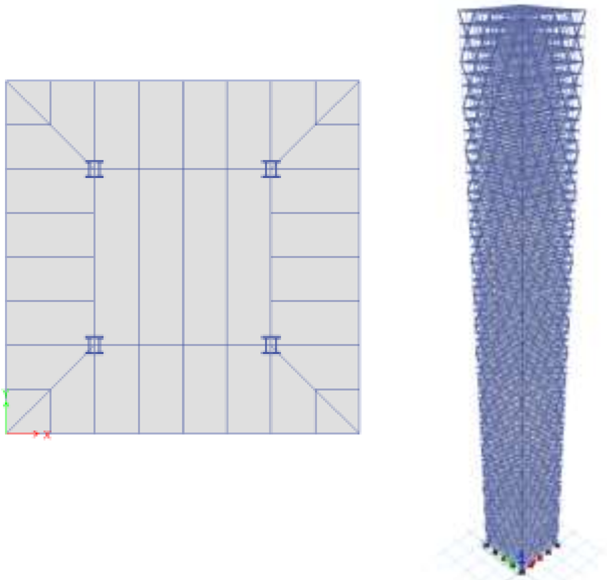
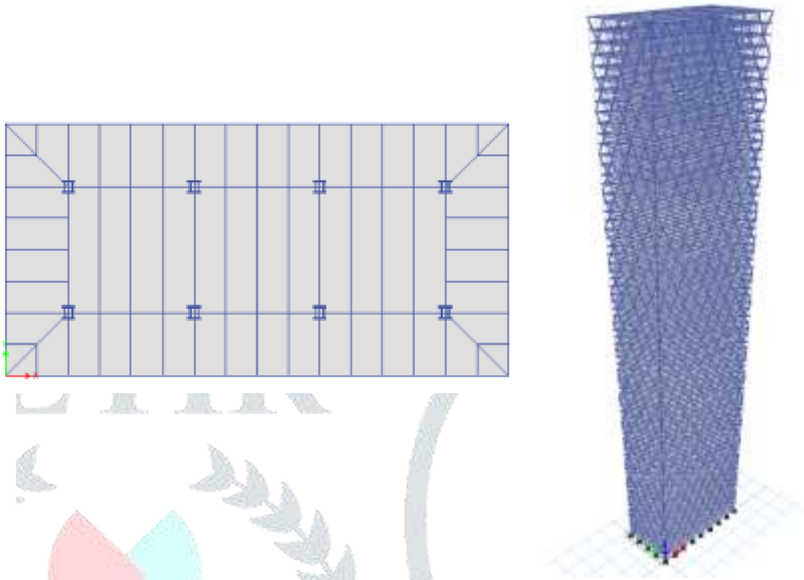


FIG 5: RECTANGLE GEOMETRY 1 & 3D VIEW OF STRUCTURE



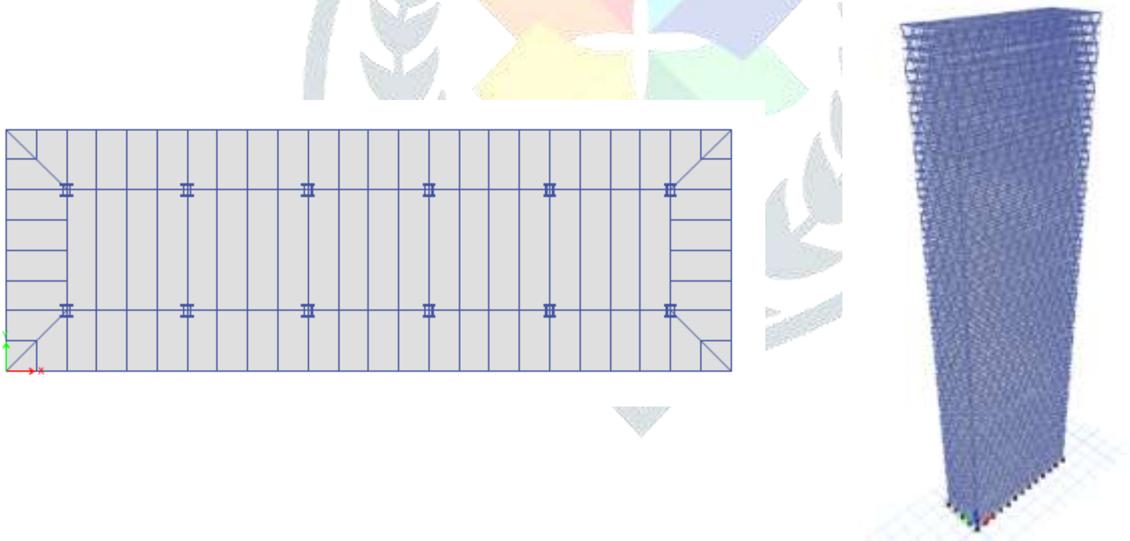


FIG 6: RECTANGLE GEOMETRY 2 & 3D VIEW OF STRUCTURE

V. LOAD DATA

Referring to IS 800:2007 specifies the various loads and forces that has to be considered while performing the design of steel structures. The design dead load and live loads on floor slab are 3.75 kN/m^2 and 2.5 kN/m^2 respectively. For lateral load calculation Ahmedabad location is selected. The dynamic wind loading is computed based on the basic wind speed of 39 m/sec and terrain category III as per IS:875 (III)-1987 (Gust factor method). The design earthquake load is computed based on the zone III, medium soil, importance factor of 1 and response reduction factor of 5.

VI. COMPARISION OF ANALYSIS RESULT

TABLE 2 LOAD DISTRIBUTION IN MODEL M1

Loading	**Total load on diagrid system (kN)**	**Loading on perimeter diagonals (kN)**	**Loading on internal columns (kN)**
Gravity loading	252175.28	111154.09	141021.19
Lateral loading	8181.11	7794.72	386.39

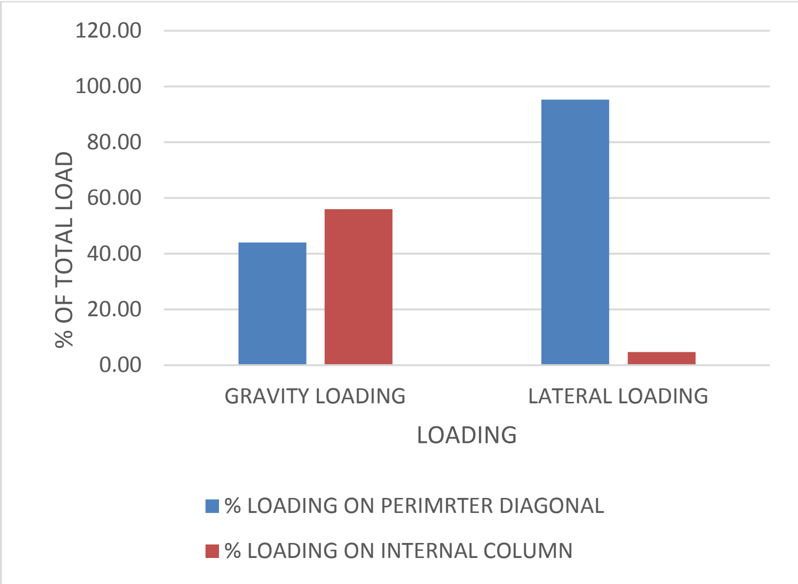


FIG 7: LOAD DISTRIBUTION IN EXTERIOR AND INTERIOR FRAME

Lateral load is mainly resisted by exterior frame (Diagonal Columns) and gravity load is resisted by both the exterior frame (Diagonal Columns) and interior frame. From the results, it can be observed that interior frame is mainly resisting gravity loading.

TABLE 3 LATERAL LOAD IN MODEL M1

LATERAL LOAD	WL X	WL Y
	3984.75 kN	3984.75 kN
LATERAL LOAD	EQ X	EQ Y
	1075.60 kN	1075.60 kN

From the results, Wind load is more governing compared to Earthquake load.

TABLE 4 COMPARISON OF DISPLACEMENT, TIME PERIOD AND STEEL MASS

PLAN	MODEL	MAXIMUM DISPLACEMENT (mm)	DISP. %	FIRST MODE TIME PERIOD (sec)	TIME PERIOD %	STEEL MASS (TONNE)	STEEL MASS %
PLAN - 1	M1	642.52	100	5.774	100	7361	100
	M2	597.38	92.97	5.864	101.56	9163	124.48
	M3	670.1	104.29	6.248	108.21	8998	122.24
PLAN - 2	M4	604.72	100	6.613	100	16905	100
	M5	604.12	99.90	6.676	100.95	16969	100.38
	M6	725.75	120.01	7.299	110.37	15938	94.28
PLAN - 3	M7	551.16	100	7.091	100	24690	100
	M8	664.89	120.63	7.252	102.27	24680	99.96
	M9	647.46	117.47	7.823	110.32	24447	99.02
PLAN - 4	M10	90.66	100	3.959	100	43054	100
	M11	102.98	113.59	4.274	107.96	42894	99.63
	M12	123.40	136.11	4.75	120.01	42535	98.79
PLAN - 5	M13	103.77	100	4.818	100	88641	100
	M14	131.94	127.15	5.507	114.30	88394	99.72
	M15	160.87	155.03	6.149	127.63	87853	99.11
PLAN - 6	M16	164.1	100	5.521	100	134223	100
	M17	240	146.25	6.621	119.92	133893	99.75
	M18	301.03	183.44	7.193	130.28	133172	99.22

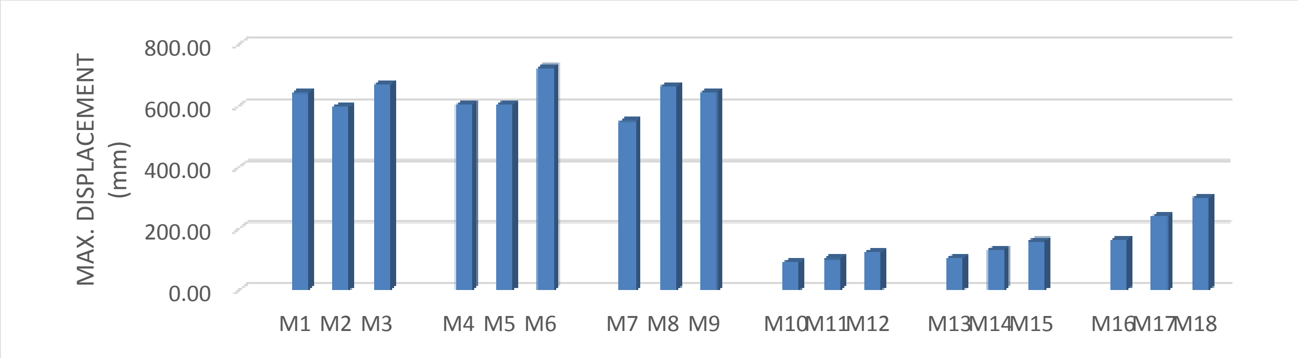


FIG 8: COMPARISION OF MAXIMUM. DISPLACEMENT

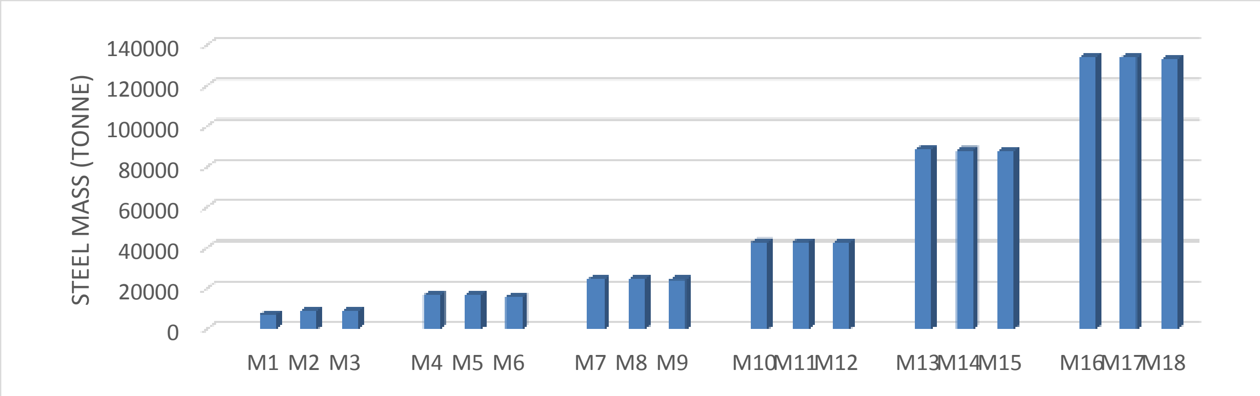


FIG 9: COMPARISION OF STEEL MASS

TABLE 5 COMPARISON OF STOREY DRIFT

STOREY DRIFT					
PLAN	**MODEL**	**MAX. STOREY DRIFT**	**PLAN**	**MODEL**	**MAX. STOREY DRIFT**
PLAN - 1	M1	0.004160	**PLAN - 4**	M10	0.000513
	M2	0.003734		M11	0.000577
	M3	0.004159		M12	0.000688
PLAN - 2	M4	0.003806	**PLAN - 5**	M13	0.000582
	M5	0.003650		M14	0.000736
	M6	0.004333		M15	0.000924
PLAN - 3	M7	0.003385	**PLAN - 6**	M16	0.001058
	M8	0.003379		M17	0.001494
	M9	0.003813		M18	0.001891

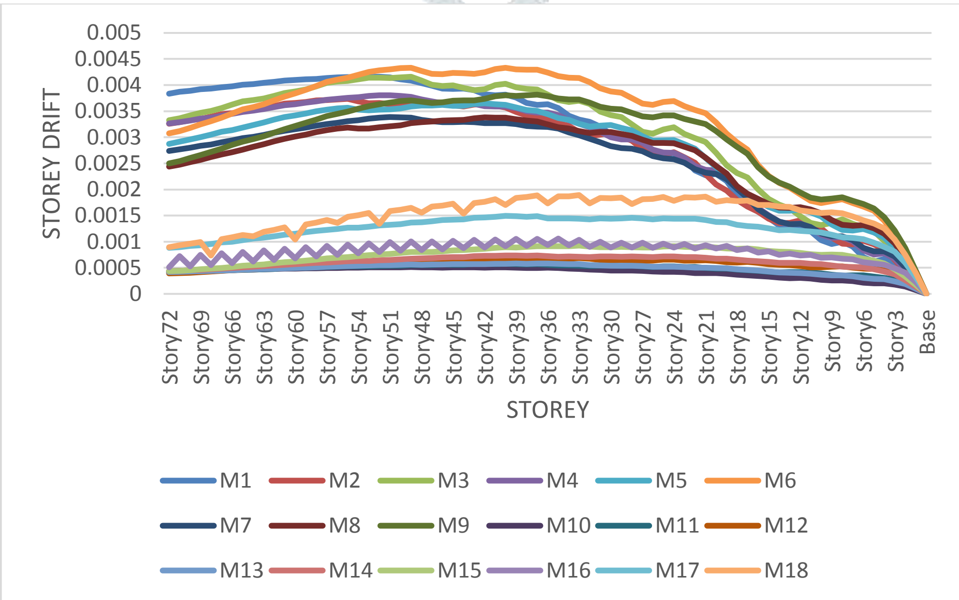


FIG 10: COMPARISION OF STOREY DRIFT

VII. DESIGN OF DIAGRID STRUCTURAL SYSTEM

The gravity load and lateral load are combined and assigned to structure in ETABS software. From the analysis results design of diagonal members, floor beams and interior columns is carried out as per IS:800-2007. The yield strength of steel is considered as 345 N/mm^2. The sizes of typical members of diagrid structure are shown below.

TABLE 6 MEMBER SIZES OF DIAGRID STRUCTURE

MODEL	DIAGONAL MEMBER		INTERIOR COLUMN	BEAM (SAME FOR ALL STOREY)
	STOREY	SECTION SIZE		
M1, M3, M4, M6, M7, M9	1-16	550 mm Pipe section with 50 mm thickness	COLUMN C1 1000 x 1000	BEAM B1 = ISWB 500 with Top and Bottom Cover Plate of 220 × 75 mm
	17-32	450 mm Pipe section with 25 mm thickness		
	33-48	350 mm Pipe section with 25 mm thickness		
	49-72	250 mm Pipe section with 25 mm thickness		BEAM B2 = ISWB 500 with Top and Bottom Cover Plate of 220 × 50 mm
M2, M5, M8	1-18	550 mm Pipe section with 50 mm thickness		
	19-36	450 mm Pipe section with 25 mm thickness		BEAM B3 = ISMB 500
	37-54	350 mm Pipe section with 25 mm thickness		
	55-72	250 mm Pipe section with 25 mm thickness		
M10, M12, M13, M15, M16, M18	1-16	7000 mm Pipe section with 50 mm thickness	COLUMN C1 2300 x 2300	BEAM B1 = 2ISWB 600 with Top and Bottom Cover Plate of 550 × 75 mm
	17-32	600 mm Pipe section with 50 mm thickness		
	33-48	500 mm Pipe section with 50 mm thickness		BEAM B2 = ISWB 600 with Top and Bottom Cover Plate of 220 × 50 mm
	49-72	450 mm Pipe section with 50 mm thickness		
M11, M14, M17	1-18	7000 mm Pipe section with 50 mm thickness	COLUMN C2 3000 x 2300	
	19-36	600 mm Pipe section with 50 mm thickness		BEAM B3 = ISMB 600
	37-54	500 mm Pipe section with 50 mm thickness		
	55-72	450 mm Pipe section with 50 mm thickness		

VIII. CONCLUSION

- Lateral load is mainly resisted by exterior frame (Diagonal Columns) and gravity load is resisted by both the exterior frame (Diagonal Columns) and interior frame. From the results, it can be observed that interior frame is mainly resisting gravity loading.
- Mainly two type of loading act on the building i.e. gravity load and lateral load due to earthquake or wind. The base shear of wind load is higher compared to earthquake load for 72 storey diagrid structure considered in this study. Thus, wind load is governing for the design of structure.
- Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure.
- From the study it is observed that, for Square Geometry, 4 Storey Module is more effective but with increase in Square Geometry, 8 Storey Module is effective while for Rectangle Geometry, 8 Storey Module is more effective in terms of steel mass.

REFERENCES

[1] Khushbu Jani, Paresh V. Patel, "Analysis and Design of Diagrid Structural System for High Rise Steel Buildings", Elsevier – 2013
[2] Nishith B. Panchal, Vinubhai R. Patel, "Diagrid Structural System: Strategies to Reduce Lateral Forces on High-Rise Buildings", IJRET: International Journal of Research in Engineering and Technology – 2014
[3] Jatin B Tank, Ashwin G Hansora, "Analysis of Varying Angle Diagrid Structural System for High-Rise Steel Building", NCERTE – 2016
[4] Sarvaswini H.C, Ranjith A, Sanjith J, "A Comparative Study on The Performance of Tall Structures with Diagrid Systems and Exterior Braced Frame Systems Subjected to Seismic Loading", International Journal for Research Trends and Innovation - 2017
[5] Kyoung Sun Moon, "Optimal grid geometry of diagrid structures for tall buildings", Architectural Science Review - 2008
[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.