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PERFORMANCE EVALUATION OF TALL BUILDINGS WITH STEEL DIAGRID SYSTEM

Femy Mariya Thomas[1], Binu M. Issac[2], Jessymol George[3]

[1]M Tech student, Department of Civil Engineering, Amal Jyothi College of Engineering Kottayam, Kerala, (India)

[2]Structural Engineer, Aalaya, Kottayam, Kerala, (India)

[3]Assistant Professor, Department of Civil Engineering of Organization, Amal Jyothi College of Engineering, Kottayam, Kerala, (India)

ABSTRACT

Construction of multi-storey building is rapidly increasing throughout the world. The diagrid structural system has been widely used for recent tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system. Diagrid is a system of triangulated beams, straight or curved, and horizontal rings that together make up a structural system for a skyscraper. Diagrid structures use a lesser amount of structural material in general than conventional structural systems composed of orthogonal members. The structural efficiency of the diagrid system makes the number of interior columns decrease, therefore allowing much flexibility on the plan design. In this journal the concept of steel diagrid structural system is studied by conducting literature review, then optimum configuration for buildings and optimum angle for diagrid is found out by comparing square, rectangular and circular buildings with same plan area using ETABS software.

Keywords: Diagrids; Tall Buildings; Storey Displacement; Inter Storey Drift

I. INTRODUCTION

The rapid growth in population, scarcity and high cost of land has greatly influenced the construction industry. This has led to the construction of buildings upwards. Advances in construction technology, materials, structural systems, analysis and design software facilitated the growth of tall buildings. As the height of buildings increases lateral load resisting system becomes more important than the structural system that resists gravity loads.

The lateral load resisting systems that are widely used are: rigid frame, shear wall, wall-frame, braced tube system, outrigger system and tubular system. Recently the diagrid structural system has been widely used for tall buildings due to the structural efficiency and aesthetic potential provided by the unique geometric configuration of the system.

1.1 Diagrid System

Diagrid refers to diagonal grid and is a structural system that can carry gravity loads as well as lateral forces due to their triangulated configuration. Diagrid is formed by intersecting the diagonal and horizontal components as shown in Fig 1.

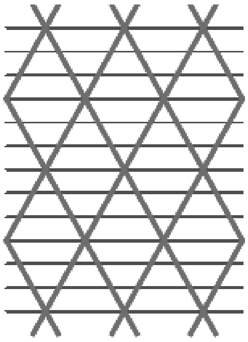

Fig. 1: Diagrid Structural System

The height of building is divided into modules. The diamond shaped modules typically span 6 to 8 floors, tip to tip. Floor edge beams frame into the module to create triangulation. Some famous examples of diagrid structure are the Swiss Re London and Hearst Tower in New York as shown in Fig 2.

Fig. 2: Hearst Tower in New York and Swiss Re in London

In this paper the performance of buildings with Square, Rectangular and Circular plan is compared by varying number of storeys per diagrid module and diagrid density and analysis results in terms of storey displacement and inter-storey drift are discussed.

1.2 Merits of Diagrid Structural System

1. Increased stability due to triangulation
2. Combination of the gravity and lateral load-bearing systems, potentially providing more efficiency.
3. Provision of alternate load paths (redundancy) in the event of a structural failure (which lacks in case of conventional framed building).
4. Reduced weight of the superstructure can translate into a reduced load on the foundations.
5. By adopting this system we can save upto about 20% ofstructural steel in high rise buildings compared to framed structures.

1.3 Scope of Diagrid Structural System

1. Column free structures can be constructed
2. Natural day lighting saves energy consumption
3. Free and clear, unique floor plans are possible
4. Aesthetically dominate and expressive

II. OBJECTIVES OF THE STUDY

1. To study the concept of diagrid structural system
2. To determine the optimum configuration for buildings –square, circular, rectangular in plan, with steel diagrid system using ETABS Software
3. To determine the optimum angle for diagrid system

III. BUILDING CONFIGURATION

A 36 storey tall building is considered. The storey height is 3.6 m. The diagrids are provided at six meter spacing along the perimeter. The live load and floor finish load on floor slab are 5 kN/m^2 and $1kN/m^2$ respectively .The design earthquake load is computed based on the zone factor of 0.16, medium soil, importance factor of 1 and response reduction factor of 5 as per IS-1893-2002. The steel used is of grade YST 310.

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. Some of the details of the structural members are taken from the journal 'Analysis and Design of Diagrid Structural System for High Rise Steel Buildings' by Khushbu Jani and Paresh V. Patel (2013). The building details are given in Table 1.

Table 1: Details of Building

Sl No	**Building Details**	
1	Plan Area	$1296m^2$
2	Height of Floors	3.6m
3	Total Height of Building	129.6m
3	Number of Storeys	36
4	Beam	ISMB550, 1SWB600
5	Column – Built- up	1.5m x1.5m
6	Diagrid	Circular- 450 mm dia, 25mm thick, YST 310 grade Steel
7	No. of storeys per Module	2,4,6,8,12
8	Slab	150 mm thick, M30 grade concrete

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3.1 Modeling

The entire work consists of 33 models. The typical plan of Square building (36m x 36m) is shown in Fig 3. Rectangular (54m x 24m) and Circular buildings (40.62m dia) are prepared by keeping the area constant 1296m^2 as shown in Fig 4 and Fig 5.

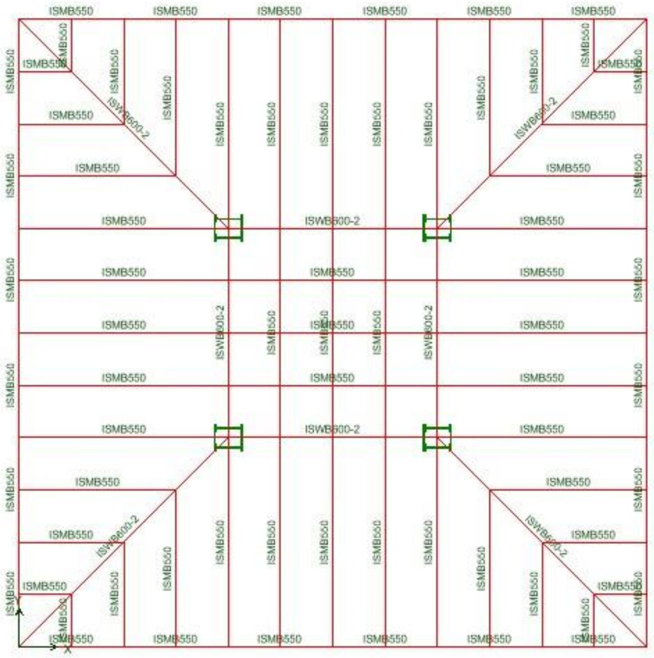


Fig. 3: Plan of Square Building

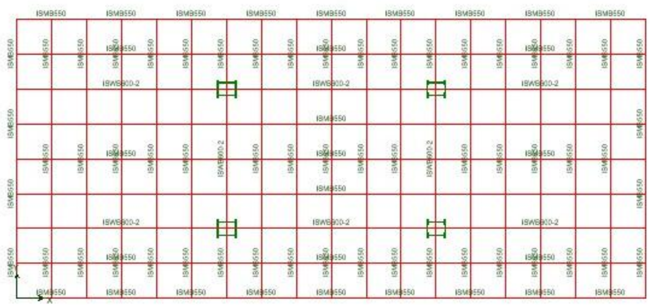


Fig. 4: Plan of Rectangular Building

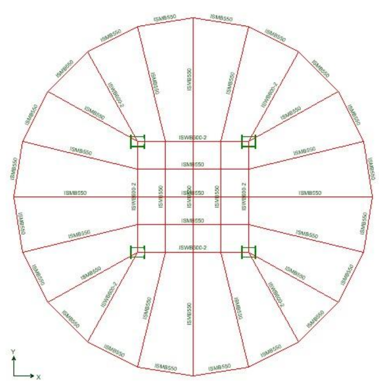
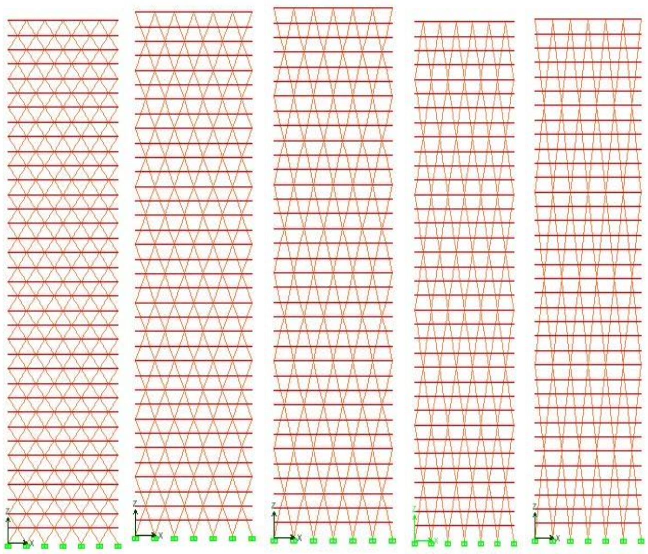


Fig. 5: Plan of Circular Building

Five primary models are considered each for square, rectangular and circular buildings by varying number of storeys per module (2,4,6,8,12). Also another six secondary models are modeled from square, rectangular and circular buildings with 2,4,6 storey diagrid module by varying diagrid density aong the height of the building. The present study is done by using ETABS 9.5. It is finite element based structural program for the analysis and design of civil structures. Fig. 6 shows the elevations of the primary models taken for the study. The dead load, live load, floor finish load, earthquake load are defined and assigned to the various models.



Model 1 Model 2 Model 3 Model 4 Model 5

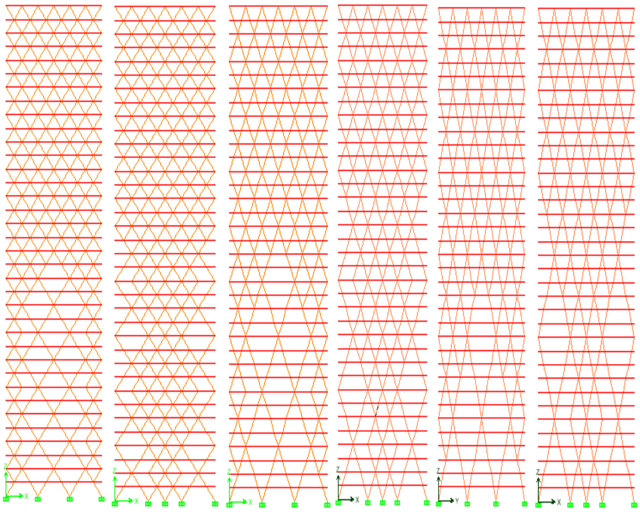
Fig. 6: Elevations of Primary Models

The diagrid angle for 5 models are tabulated in Table 2.

Table 2: Diagrid Angle for 5 Models

Model	Diagrid Module	Angle
1	2 Storey	50.20°
2	4 Storey	67.38°
3	6 Storey	74.48°
4	8 Storey	78.23°
5	12 Storey	82.09°

The elevation of 6 secondary models with varying diagrid density are shown in Fig 7.



Model 6 Model 7 Model 8 Model 9 Model 10 Model 11

Fig. 7: Elevations of Secondary Models

IV. ANALYSIS –LINEAR STATIC ANALYSIS

Linear Static Analysis of the models are conducted and the results are presented in terms of storey displacement and inter- storey drift

V. RESULTS

The present study is to compare the performance of square, rectangular and circular buildings with steel diagrid structural system . The analysis were carried out for diferent models and the results in the form of graphs are presented here.

5.1 Square Model - Storey Displacement

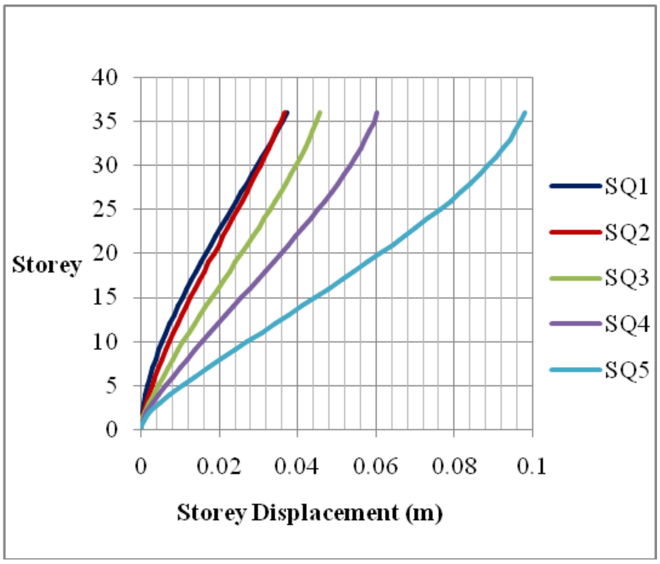


Fig. 7: Storey Displacement Vs Storey for Square Models 1 to 5

5.2 Square Model - Inter - Storey Drift

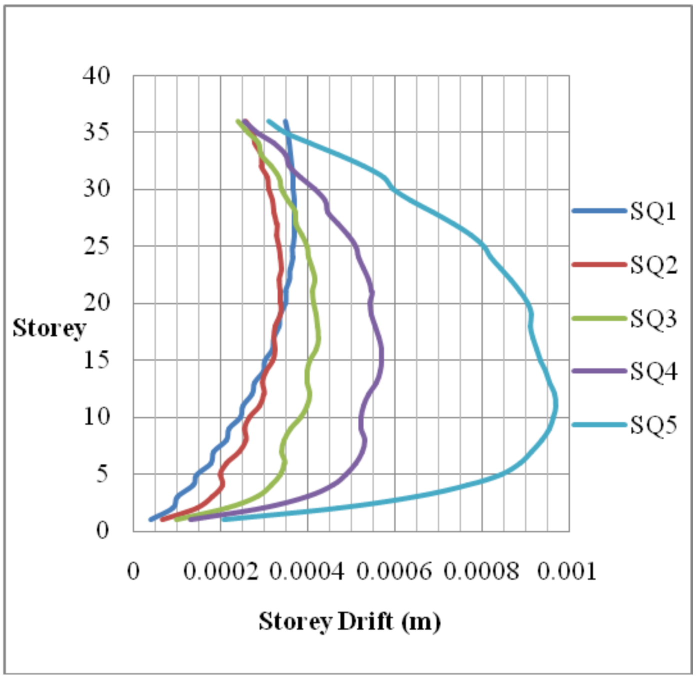


Fig. 8: Inter-Storey Drift Vs Storey for Square Models 1 to 5

5.3 SRectangular Model – Storey Displacement

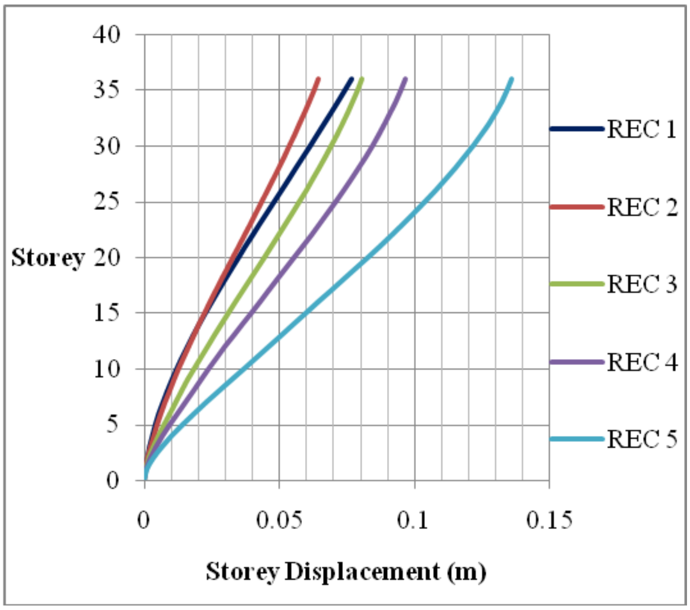


Fig. 9: Storey Displacement Vs Storey for Rectangular Models 1 to 5

5.4 Rectangular Model – Inter Storey Drift

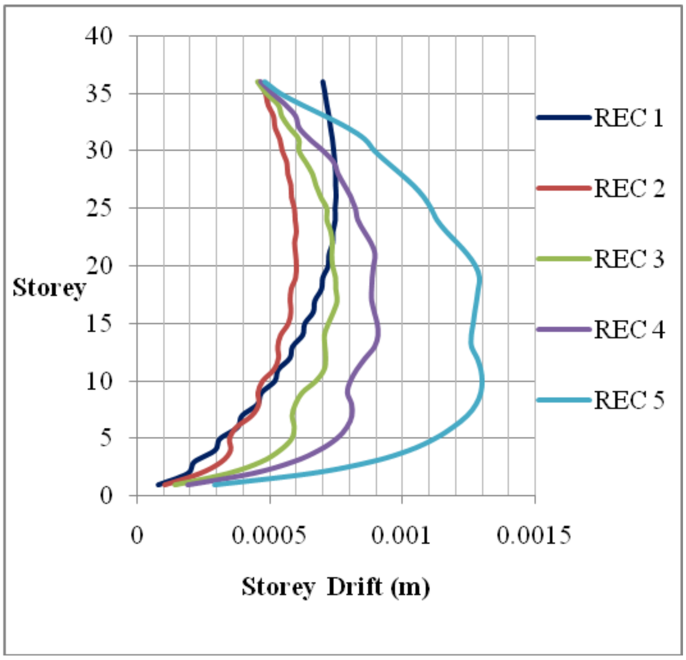


Fig. 10: Inter-Storey Drift Vs Storey for Rectangular Models 1 to 5

5.5 Circular Model – Storey Displacement

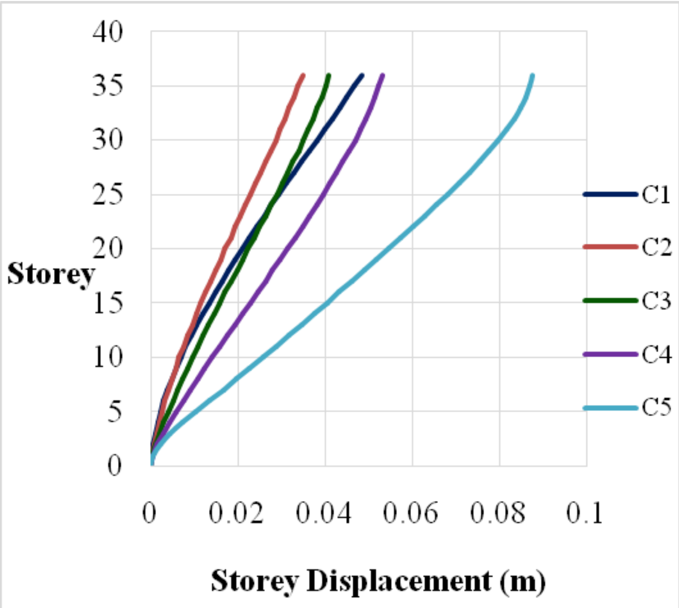


Fig. 11: Storey Displacement Vs Storey for Circular Models 1 to 5

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5.6 Circular Model – Inter Storey Drift

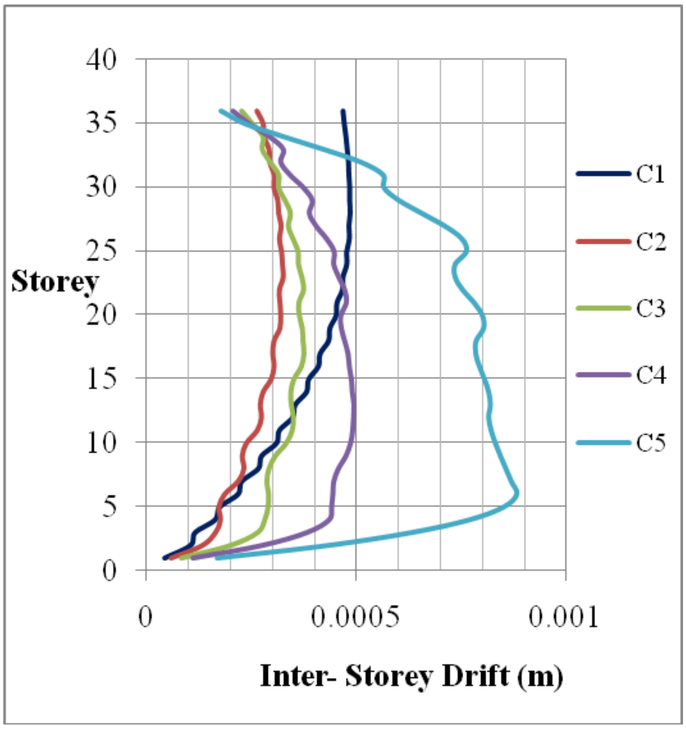

Fig. 12: Inter-Storey Drift Vs Storey for Circular Models 1 to 5

5.7 Secondary Models- Varying Diagrid Density

Square Model – Varying Density- Storey Displacement

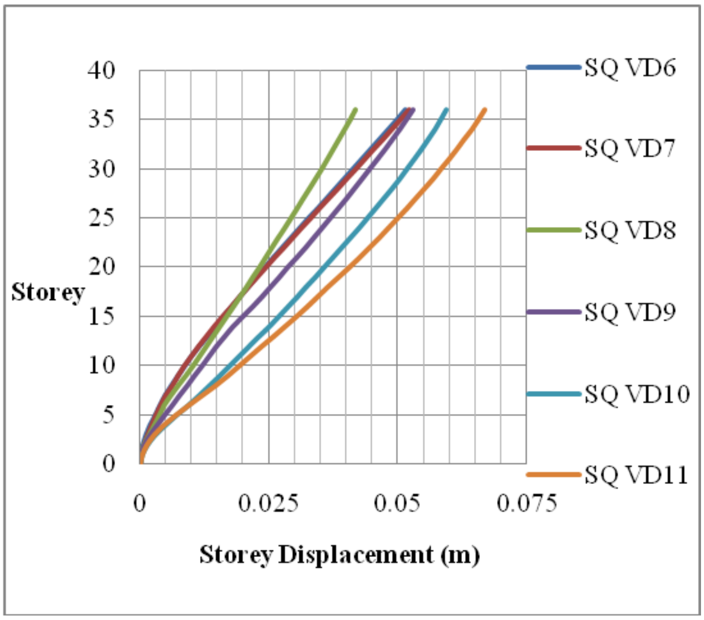

Fig. 13: Storey Displacement Vs Storey for Square Models 6 to 11 with Varying density

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5.8 Square Model -varying density - Inter Storey Drift

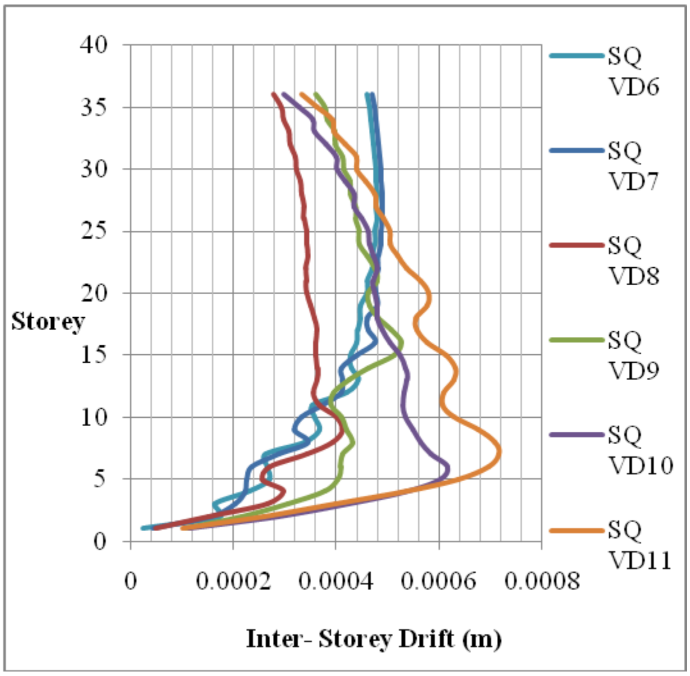

Fig. 14: Inter Storey Drift Vs Storey for Square Models 6 to 11 with Varying density

5.9 Rectangular Model – varying density- Storey Displacement

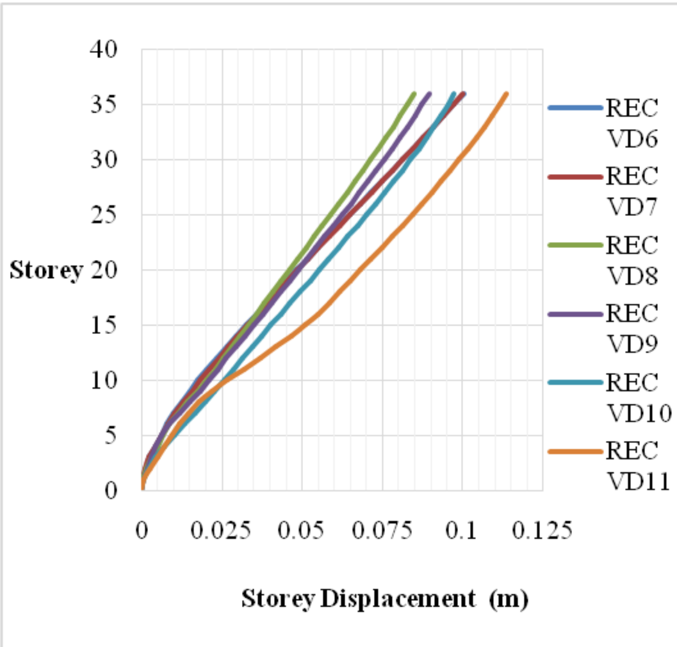

Fig. 15: Storey Displacement Vs Storey for Rectangular Models 6 to 11 with Varying density

5.10 Rectangular Model – VARYING DENSITY- Inter STOREY DRIFT

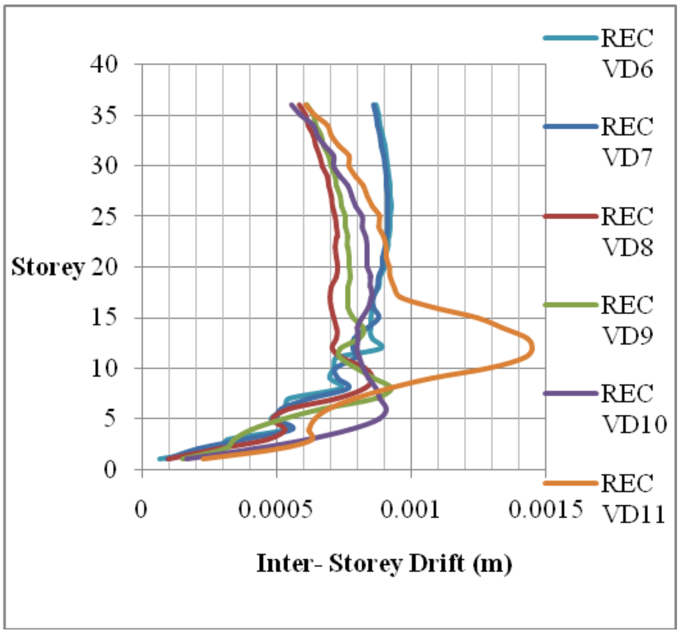

Fig. 16: Inter Storey Drift Vs Storey for Rectangular Models 6 to 11 with Varying density

5.11 Circular Model – varying density- Storey Displacement

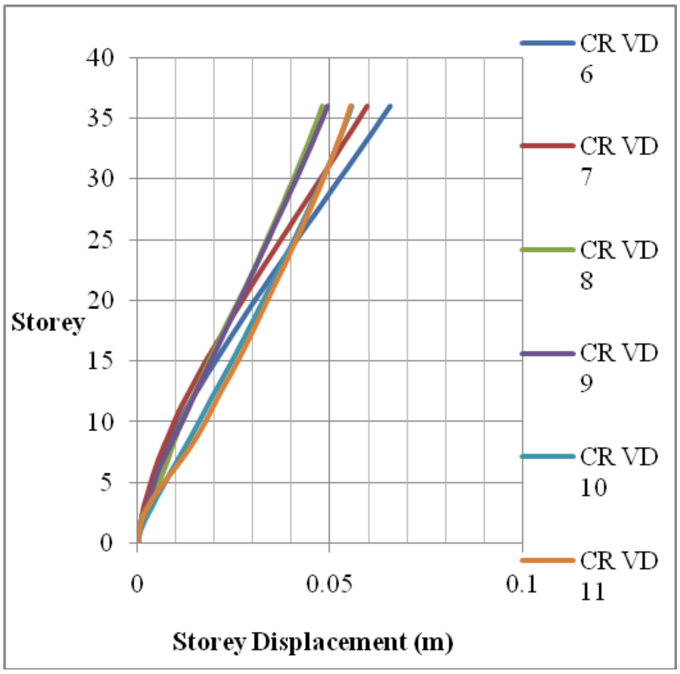

Fig. 17: Storey Displacement Vs Storey for Circular Models 6 to 11 with Varying density

5.12 Circular Model - varying density– Inter Storey

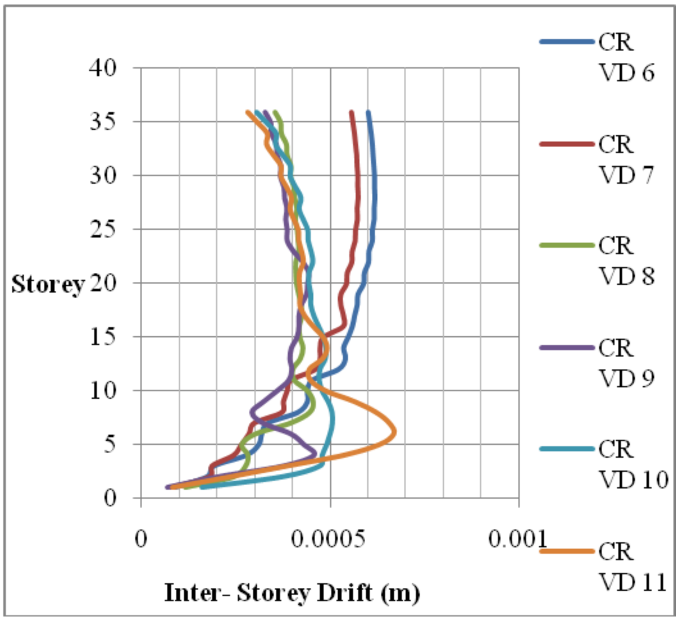

Fig. 18: Inter Storey Drift Vs Storey for Circular Models 6 to 11 with Varying density

VI. COMPARISON OF RESULTS

Table 3 : Maximum Storey Displacement values for Square, Rectangular and Circular Building

Model	Diagrid Module	Maximum Storey Displacement Storey 36 (m)		
		Square Building	Rectangular Building	Circular Building
1	2 Storey	0.0374	0.0768	0.0484
2	4 Storey	0.0367	0.0646	0.0348
3	6 Storey	0.0458	0.0807	0.0409
4	8 Storey	0.0604	0.0968	0.0531
5	12 Storey	0.0980	0.1361	0.0876
6	Varying Density	0.0514	0.1005	0.0655
7		0.0521	0.1002	0.0597
8	Varying Density	0.0417	0.0848	0.0478
9		0.0530	0.0896	0.0494
10	Varying Density	0.0593	0.0974	0.0555
11		0.0669	0.1137	0.0552

Table 4 : Maximum Inter Storey Drift values for Square, Rectangular and Circular Building

Model	Diagrid Module	Maximum Inter Storey Drift (m)		
		Square Building	Rectangular Building	Circular Building
1	2 Storey	0.000369	0.000747	0.000484
2	4 Storey	0.000341	0.000600	0.000327
3	6 Storey	0.000424	0.000753	0.000375
4	8 Storey	0.000570	0.000905	0.000495
5	12 Storey	0.000970	0.001300	0.000883
6	Varying Density	0.000479	0.000923	0.000619
7		0.000489	0.000912	0.000573
8	Varying Density	0.000411	0.000852	0.000456
9		0.000526	0.000925	0.000458
10	Varying Density	0.000615	0.000904	0.000504
11		0.000715	0.001448	0.000667

VII. PERMISSIBLE VALUES

Maximum Storey Displacement is limited to H/ 500, Where H is the height of the building. For 36 storey building of 129.6m height,

Permissible Maximum Storey Displacement =

= 0.2592m

As per IS 1893 (Part 1): 2002, Clause 7.11.1, the Storey Drift in any storey shall not exceed 0.004 times the storey height (h). The storey height of the models under study is 3.6m.

Permissible Storey Drift = 0.004h

= 0.0144 m

IX. . CONCLUSIONS

In this paper, comparative analysis of 36-storey diagrid structural system- Square, Rectangular and Circular in plan are presented. ETABS 9.5 software is used for modelling and analysis of structure. Analysis results like storey displacement, inter storey drift are presented here. Following are the conclusions inferred from the study:

1. For all the 33 models considered for the study the storey displacement and storey drift values are within the permissible limit.
2. Optimum Diagrid Angle:

- For Square, Rectangular and Circular buildings, 4 storey diagrid module (Model 2) building with diagrid angle 67.38° has the least Maximum Storey Displacement and Storey Drift value compared to 2, 6, 8, 12 storey diagrid module buildings.
- In case of 4 storey diagrid module (Model 2), Circular buildings have least Maximum Storey Displacement and Storey Drift compared to Square and Rectangular buildings.

3. Optimum Building Configuration:

- Square and Circular Diagrid Buildings have lower Maximum Storey Displacement and Inter Storey Drift values compared to Rectangular Diagrid Buildings.
- Circular Diagrid Buildings have lower Maximum Storey Displacement and Inter Storey Drift values compared to Square Diagrid Buildings.

4. Maximum Storey Displacement and Inter Storey Drift values of diagrid buildings with varying Diagrid Density are higher compared to their parent models.
5. Square and Circular Diagrid Buildings perform almost equally better than Rectangular Diagrid Buildings.
6. Circular Diagrid buildings perform better than Square Diagrid Buildings.

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