A Comparative Study of Seismic Behavior of High Rise Building With Diagrid Structure and Conventional RCC Framed Structure

Ajaya Kumar Behera [1] *and P. K. Parhi* [2]

Abstract

Construction of tall buildings with various structural systems is on the rise these days. Due to its adaptability and attractive look, the Diagrid system is a prominent technology in high-rise buildings. In this study, a structural model of 32 storey buildings is analyzed using the ETAB software, and various metrics, such as storey stiffness, storey displacement, storey shear, and storey drift in different seismic zones are derived. Comparison is done among these parameters for 36 different cases and the best of the configuration is found out.

Study of the these parameters is done by adopting Response Spectrum Method for Zone II and Zone V. This study concludes that the square shaped building with 2-storey module diagrid column shows less displacement, less storey drift and higher stiffness among all the considered cases.

Keywords : **Diagrid, Response Spectrum Method, Storey Drift, Storey Shear, Storey Displacement, Storey Stiffness, and Base Shear**

I. INTRODUCTION

A. General

Tall buildings are currently desired since there is a lack of suitable land in cities and the urban population is expanding quickly. The lateral resisting system becomes just as crucial as the gravity sustaining system as a building's height rises. The major issue with tall buildings is that lateral loads regulate the design, whereas gravity loads control low rise building. Because of this, structural techniques that produce stiffness against lateral stresses more effectively are favored for high rise building. Due to its various geometric configurations, the diagrid structural system is one of the most effective lateral resisting systems. Recently, following diagrid constructions has seen great advancement from both structural engineers and architects. The main difference between rigid frame system and diagrid system is that diagrid system eliminates the outside vertical columns. In the present day, diagrid buildings have emerged as a new, elegant design for tall structures with improved structural efficiency. The present investigation aims to study the following objectives:

- To examine the effectiveness of a diagrid structure versus a conventional structure in ETABS when subjected to seismic loading.
- To investigate the behavior of diagrid and conventional structures with regard to variables such as storey displacement, storey drift, and storey stiffness.
- To examine the variations in structural response carried on by earthquake motions in various seismic zones.

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✎ To determine the proper diagrid system configuration for different seismic zones that yield the best outcome.

B. Diagrid Structure

Diagrid structure is a distinct structural system among the various lateral structural systems that is becoming increasingly prominent in tall building design. The phrase "diagrid" is made up of the words "diagonal" and "grid". The bracing system includes a rather complex diagrid system. It evolved from the traditional bracing system. It is made up of massive diagonal bracings that sit on the building's periphery and are generally visible to the public. As a result, it becomes one of the aesthetic components used by architects. In order to withstand both compression and tension, diagrid employs diagonal bracing members.

C. ETABS Software

Buildings with multiple stories are analyzed and designed using engineering software called ETABS. Modelling tools and templates, code-based load prescriptions, analysis methods, and solution approaches all take into account the grid like geometry that is unique to this type of construction. Simple or complicated systems can be analyzed with ETABS in static or dynamic circumstances. For a sophisticated assessment of seismic performance, P-Delta and Big Displacement effects may be combined with modal and direct-integration time-history analysis.

II. LITERATURE REVIEW

Before proceeding to the seismic analysis of the RC framed diagrid buildings, a wide range of literature reviews are carried out to understand the concept and find out the gap in the research carried out till now. Several literatures, research dealing with analytical, experimental, and numerical studies conducted by many researchers and investigators in the field of diagrid building were studied and are presented next.

Panchal and Suthar made a comparative study with different structural systems of diagrids. By using E-tabs software, they analyzed a 42 m x 42 m structural plan for a 40-storey steel building subjected to seismic zones II, III, IV, and V. Response spectrum analysis and the gust factor approach for dynamic along wind response were analyzed. It was observed that flat slab diagrid structures perform better than standard slab with beam diagrid structures in terms of storey displacement in case of earthquake loading. The top storey displacement, inter storey drift, and time period are compared in the investigation. It is concluded that the optimal diagrid angle for heights between 120 and 240m is 61° to 72°. However, the diagrid angle 67.22° gives optimum result in terms of maximum displacement and drift.

Kiran and Yogesh provided a statistical approach to determine concrete diagrid structure. It is analyzed and compared with conventional concrete building. G+16 storey RCC building with a plan dimension of 24m x 16m is considered. Seismic zone V is considered for seismic analysis. A conventional structure is compared with a diagrid structure of diagrid angle 40^0 and diagrid angle of 60^0. 60^0 angled diagrid structure shows less storey displacement and storey drift as compared to conventional structure and 40^0 angled diagrid structure. 60^0 angled diagrid structure shows less axial force in inner columns as compared to conventional structure and 40^0 angled diagrid structure. This result and analysis show that 60^0 angled diagrid structure is most economical and is more stable than conventional structure and 40^0 angled diagrid structure.

Aarthi and Umamaheswari made an investigation and planned the structural performance of both conventional and diagrid structures using ETABS v.15. Linear Static Analysis (LSA) was carried out for the conventional structure and diagrid structure. Parameters like storey displacement, storey drift, and storey stiffness were found out for both the structures. Lateral displacement under seismic loading is more efficient in a diagrid structure. The storey drift in diagrid structure emerged as a better solution. The diagrid structure resists higher lateral forces as it has greater stiffness and can be preferred over conventional structure. The diagrid structure performed so well despite all the vertical columns being eliminated in the interior of the structure. The diagrid structure is more prominent than the conventional structure.

Prajapati and Hansora investigated and planned a regular square plan of 30m × 30m diagrid structure considering different storey (i.e. 4, 6, 8 & 12) module with and without a Shear Walls at core. They observed different storey (i.e. 24, 36, and 48) buildings. The comparison of analyzed results in terms of inter storey drift-ratio, storey displacement, base shear, and reduction in lateral load on diagrid are taken into consideration. Shear wall takes most of lateral loads, almost half as compared to structure without shear wall. Shear wall at core of diagrid structure, the increase in base shear is around 5 to 6% and material quantity is around 8–11% for concrete and 3–4% for steel which is considerably small. Shear wall takes 30% to 65% of lateral loads which reduces the lateral loads on diagrid at periphery which ultimately results in economical diagrid section compared to diagrid structure without shear walls at core.

Rathore and Pahwa studied various configurations of the diagrid structure and detailed comparison of diagrids with regular configuration and diagrid with varying angles. By using static and dynamic (response spectrum and time history) methods G+12 storey and G+18 storey building structures are modeled with different varying angles of diagrids. In linear static analysis, the displacement is observed to be less in 3 storey diagrid model than two other 2 storey diagrid and 4 storey diagrid. Similarly, in static analysis the maximum drift ratio is reduced to be observed in 3 storey diagrid model than two other 2 storey diagrid and 4 storey diagrid model for both G+12 and G+18 storey building model. Maximum reduction in displacement and drift ratio are reduced in 3 storey diagrid model for both G+12 stories and G+18 stories diagrid model in dynamic analysis of response spectrum. In nonlinear dynamic analysis as time history analysis, the maximum displacement and drift ratio are reduced to 4 storey diagrid model. Hence, the conclusion shows that higher angle of diagrid member gives better performance in dynamic analysis than static analysis as control to maximum displacement at the top of the building in G+18 stories building structure.

III. METHODOLOGY

Fig.1 shows steps used to analyze 32 storey and 16 storey buildings in ETabs are described in the flowchart.

A. Mathematical Formulation

An approach is made considering Response Spectrum Method (RSM) for seismic analysis of 32 storey and 16 storey building analyzed in ETABS 2019. In this investigation by changing the seismic zone II and V for two different storey height of square shape and circular shape.

Storey shear force in each mode by Response Spectrum Method (RSM) :

Storey shear force can be calculated in storey *i* in mode *k* and peak lateral force (Q_{th}) is determined by Equation (1),

$$V_{ik} = \sum\nolimits^{n}_{j=i+1} Q_{ik} \qquad (1)$$

Where,

V = storey shear force

Q = mode shape coefficient

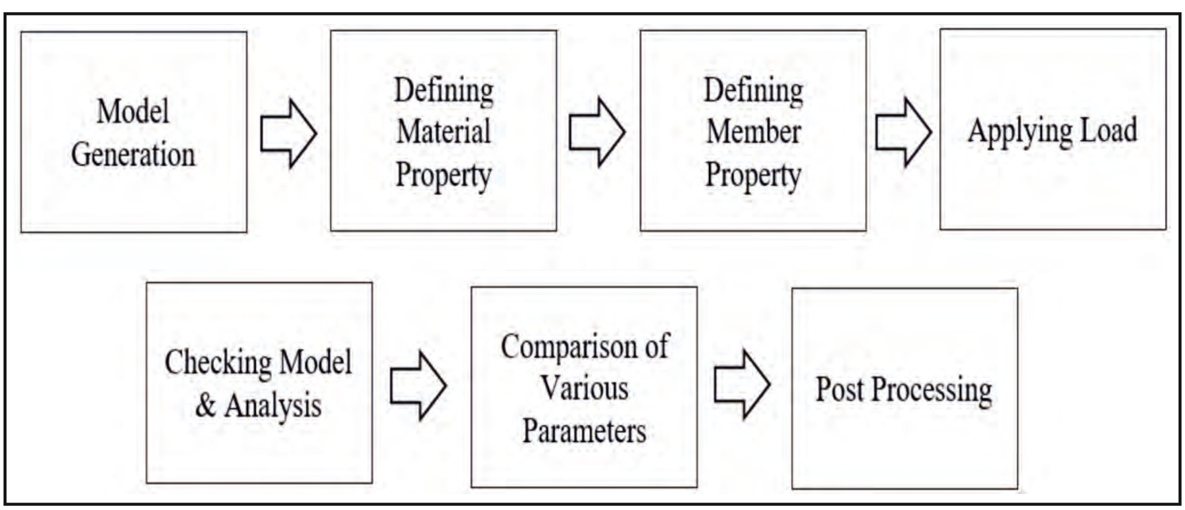

Fig. 1. Flow Chart

Limitation of Storey Drift

Storey drift should not exceed 0.004 times the storey height as per IS1893: 2016. In this analysis, the storey height is taken as 3m. So, the limited value of storey drift for this investigation is 0.384m for 32 storey and 0.192m for 16 storey.

B. System Development

In this investigation, different shapes of buildings like square shape and circular shapes are considered. The structural dimension and its properties are described next in brief. Fig. 2 and Fig. 3 shows the plan and 3D view of

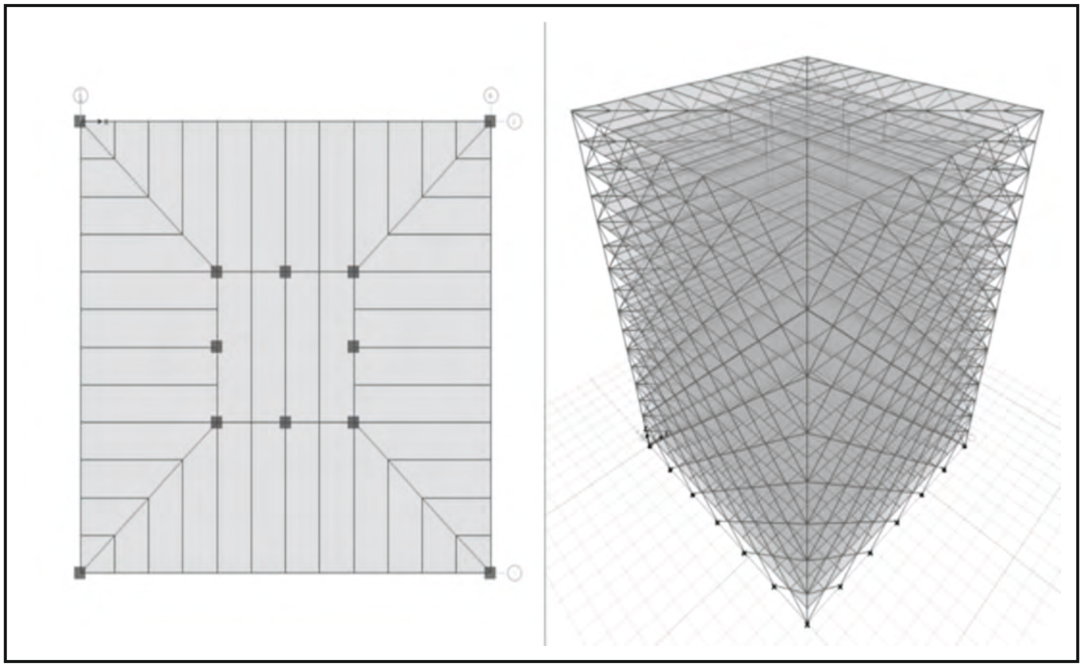

Fig. 2. Plan and 3-D view of Square Diagrid Building

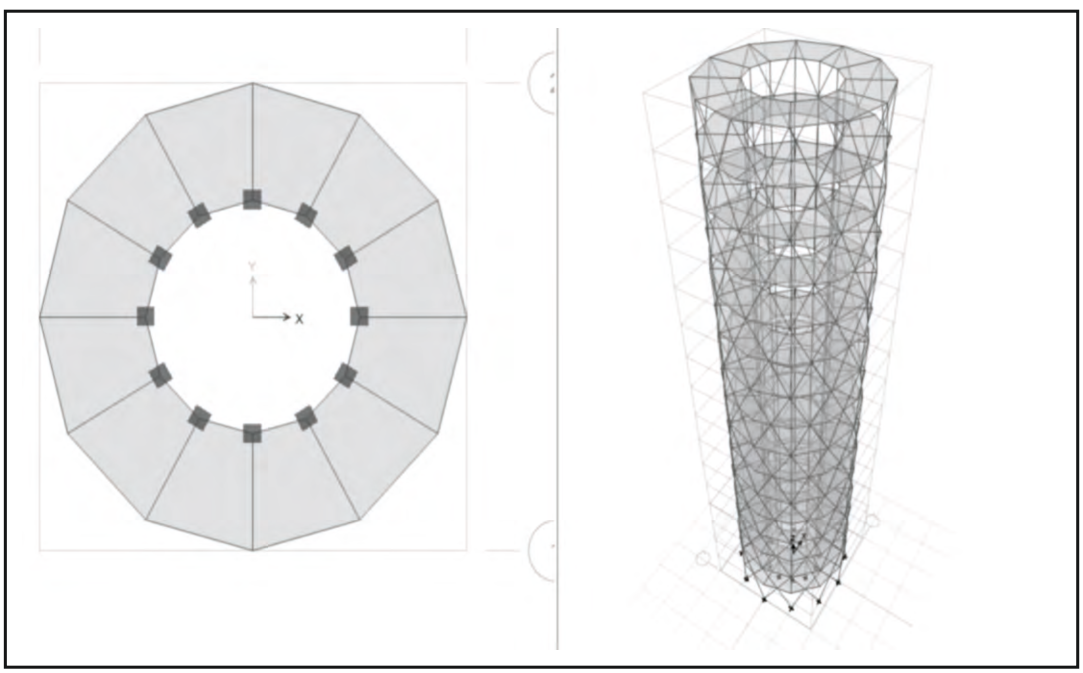

Fig. 3. Plan and 3-D view of Circular Diagrid Building

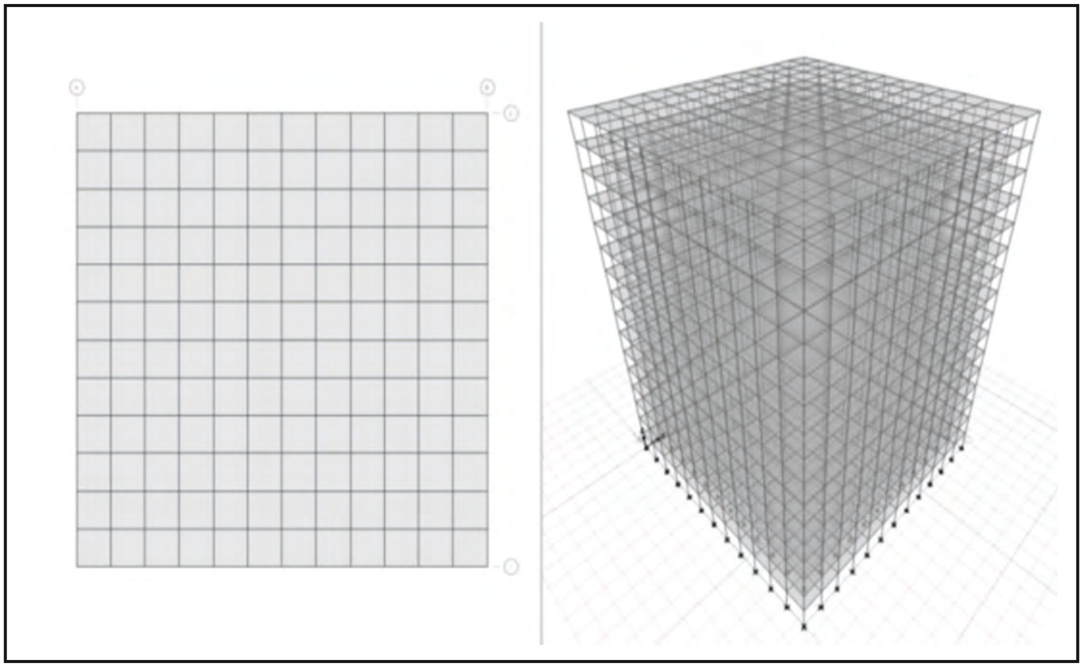

Fig. 4. Plan and 3-D view of Square Conventional Building

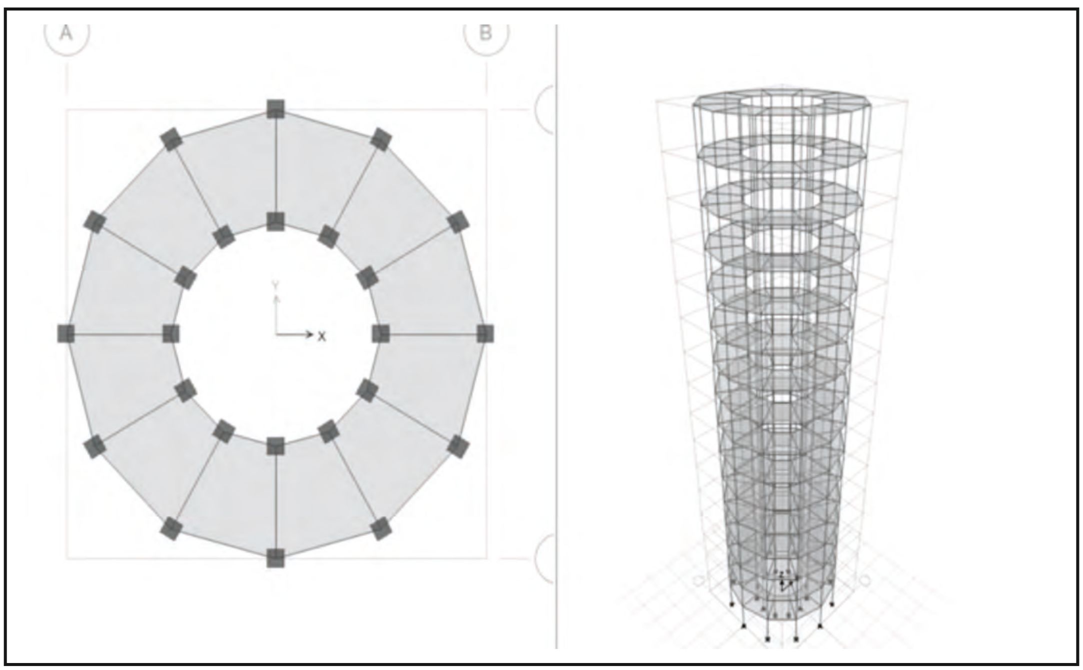

Fig. 5. Plan and 3-D view of Circular Conventional Building

square and circular Diagrid buildings. Fig. 4 and Fig. 5 show the plan and 3D view of square and circular conventional buildings. In addition, the building is compared with both RCC framed columns and Diagrid columns. Various parameters like storey displacement, storey drift, storey stiffness, and base shear are studied in both zone III and Zone V.

Further details of the building are provided in Tables I to III.

TABLE I.

SPECIFICATION OF THE BUILDING

Particulars	Details
No. of Storey	32 and 16
Storey Height	3m
Beam Size	300mm x 700mm
Column Size	1000mm x 1000mm
	500mm x 500mm
Diagrid Size	500mm x 500mm
Slab Thickness	150mm
Grade of Concrete	M30
Grade of Steel	Fe500

TABLE II.

SEISMIC DETAILS

Particulars	Details
Damping Ratio	5%
Building Type	OMRF
Importance Factor	1
Response Reduction Factor	3
Soil Type	Hard
Seismic Zone	II and V

TABLE III.

LOADING DETAILS

Particulars	Details
Dead Load	Default Value Calculated by ETABS
Live Load on Floor	2 kN/m^2
Live Load on Roof	1.5 kN/m^2
Floor Load	3.75 kN/m^2

IV. RESULTS AND DISCUSSIONS

A 32 storey and 16 storey framed model is analyzed using Response Spectrum Method (RSM). The multistoried building is provided conventional frame building and diagrid building separately and comparison is done for 32 different cases as shown in Table III. by applying the loading as per the loadings considered and explained in the previous chapter. Graphs are plotted for various parameters and conclusion is drawn for the best configuration.

A. Storey Displacement

It is an actual lateral displacement that is determined by the lateral loads to its base. The storey displacement models are presented next. Fig. 6 shows the maximum storey displacement in zone II for 32 storey building. Maximum storey displacement increases by 26% when the building zone is changed from zone III to Zone V.

For 32 storey and 16 storey height building, the minimum displacement observed for each storey in Zone III and Zone V is Square shaped 2-story Diagrid module when compared to other different cases.

TABLE IV.

CASE DETAILS

FOR ZONE II			
CASE TYPE	TYPE OF STRUCTURE	PLAN TYPE	STOREY HEIGHT
CASE 1	2-Storey Module	Square Shaped	32
CASE 2		Square Shaped	16
CASE 3	4-Storey Module	Square Shaped	32
CASE 4		Square Shaped	16
CASE 5	6-Storey Module	Square Shaped	32
CASE 6		Square Shaped	16
CASE 7	2-Storey Module	Circular Shaped	32
CASE 8		Circular Shaped	16
CASE 9	4-Storey Module	Circular Shaped	32
CASE 10		Circular Shaped	16

CASE 11	6-Storey Module	Circular Shaped	32
CASE 12		Circular Shaped	16
CASE 13	Conventional Building	Square Shaped	32
CASE 14	Conventional Building	Square Shaped	16
CASE 15	Conventional Building	Circular Shaped	32
CASE 16	Conventional Building	Circular Shaped	16
	FOR ZONE V		
CASE 17	2-Storey Module	Square Shaped	32
CASE 18		Square Shaped	16
CASE 19	4-Storey Module	Square Shaped	32
CASE 20		Square Shaped	16
CASE 21	6-Storey Module	Square Shaped	32
CASE 22		Square Shaped	16
CASE 23	2-Storey Module	Circular Shaped	32
CASE 24		Circular Shaped	16
CASE 25	4-Storey Module	Circular Shaped	32
CASE 26		Circular Shaped	16
CASE 27	6-Storey Module	Circular Shaped	32
CASE 28		Circular Shaped	16
CASE 29	Conventional Building	Square Shaped	32
CASE 30	Conventional Building	Square Shaped	16
CASE 31	Conventional Building	Circular Shaped	32
CASE 32	Conventional Building	Circular Shaped	16

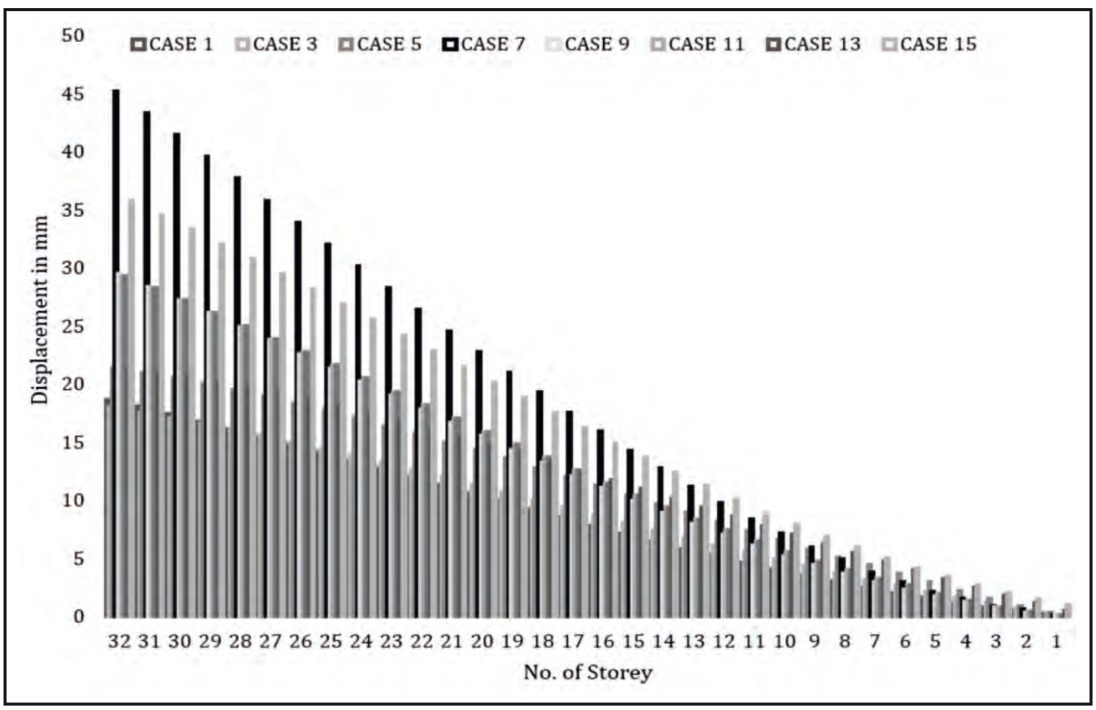

Fig. 6. Maximum top storey displacement in Zone II for 32 storey height

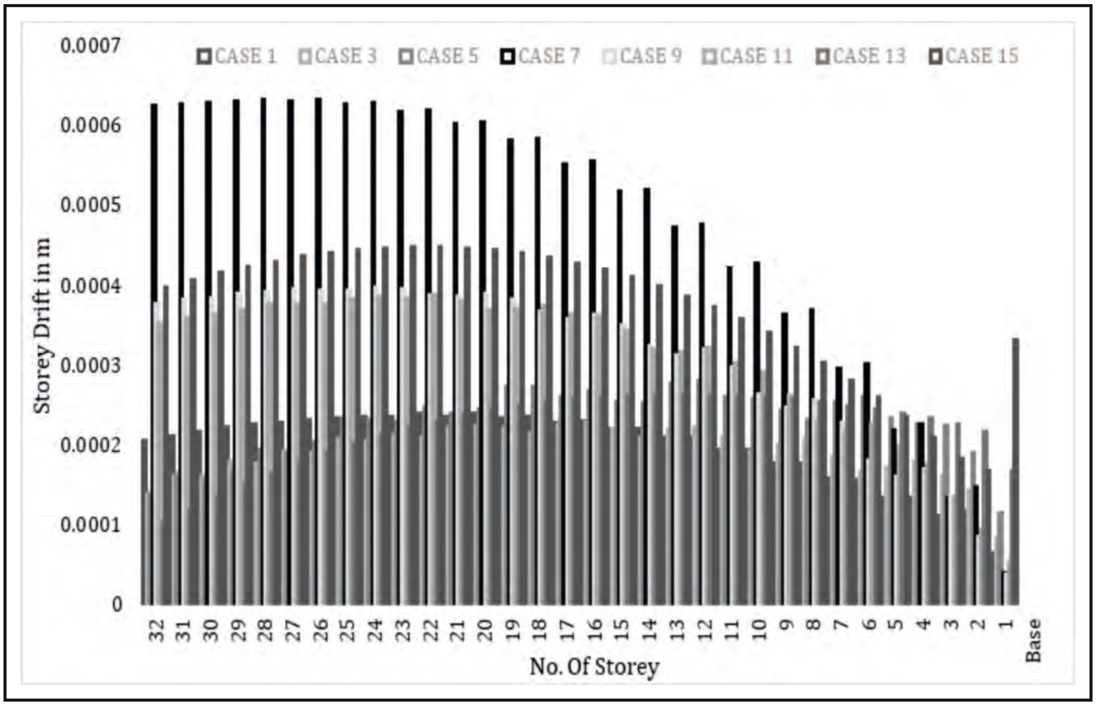

Fig. 7. Maximum storey drift in Zone II for 32 storey height

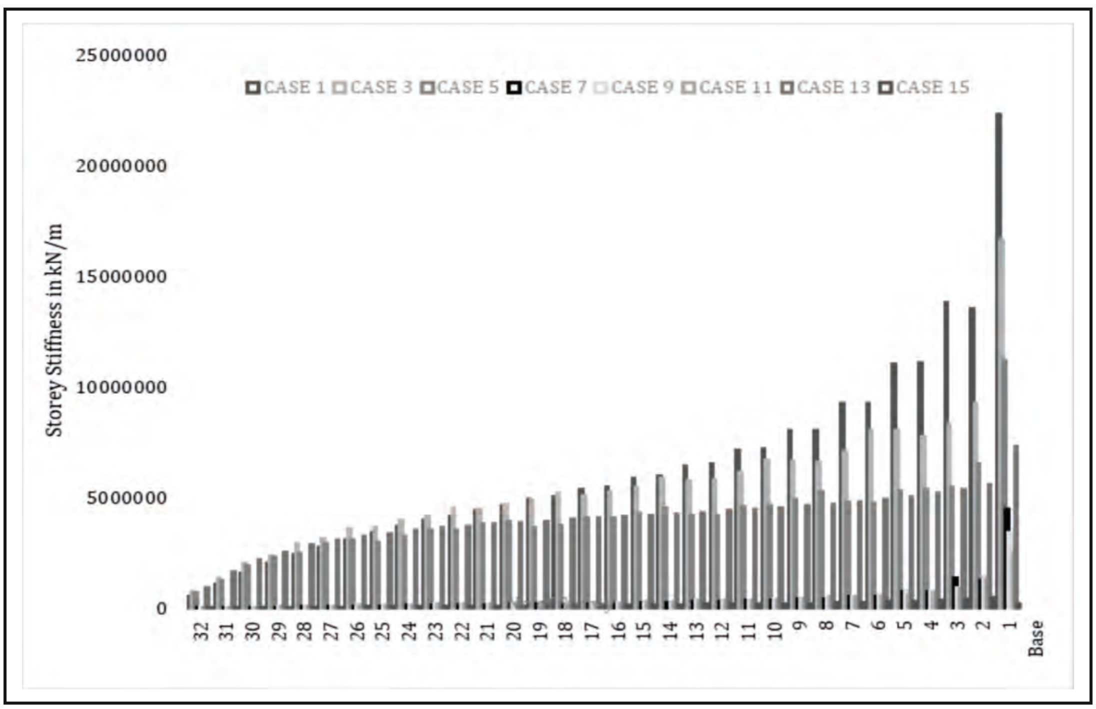

Fig. 8. Maximum storey stiffness in Zone II for 32 storey height

B. Storey Drift

Storey drift is the relative displacement of one storey relative to the other. Here the storey drifts for zone II are shown in Fig. 7. It shows the storey drift of eight different types of building plan using both diagrid column and conventional frame. All the storey drift lies within permissible limit, i.e. within 0.384m for 32 storey height and 0.192m for 16 storey height building. It is seen that maximum storey drift occurs for conventional frame

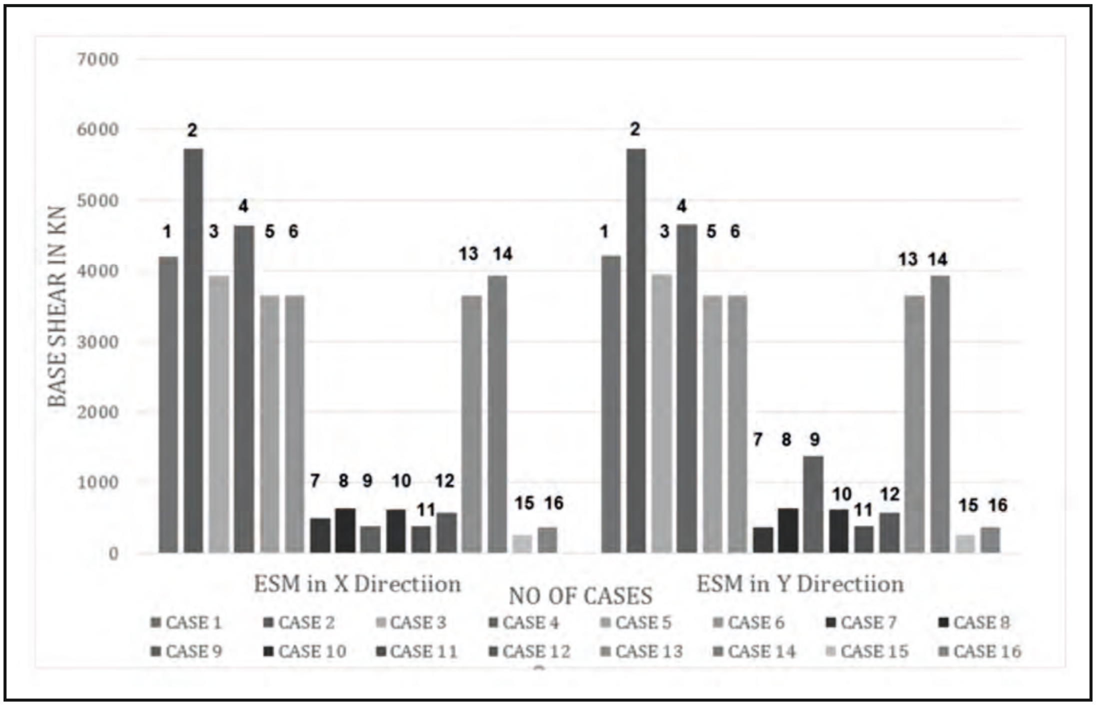

Fig. 9. Base Shear in Zone II for 32 Storey Height

building without diagrid column that indicates the structure is the least stable among all the models. Maximum storey drift increases by 26.07% when the building zone is changed from Zone III to Zone V. For 32 storey and 16 storey height building, the minimum drift observed for each storey in Zone III & Zone V is Square shaped 2-story Diagrid module when compared to other different cases.

C. Storey Stiffness

Storey stiffness is the measure of the amount of force required to displace a building by certain amount. Fig. 8 shows that the storey stiffness is maximum for square shaped plan using diagrid columns, hence it is the best combination among all. The storey stiffness is least for circular conventional frame plan, so is the least preferable.

D. Base Shear

Base shear is the maximum expected lateral force that occurs due to seismic ground motion at the base of the structure. It generally depends upon the soil condition at the site. Fig. 9 shows the base shear of 16 different building plans using diagrid frame building and conventional frame building and shows the variation of base shear in square and circular shape plan. It is seen that circular shaped building using diagrid column in zone II is the best configuration compared to conventional framed building.

V. CONCLUSION

In all the different conditions it is seen that the storey displacements are within permissible limits according to IS code IS 456–2000.

➭ All the storey drifts are within permissible limits, hence the building is safe.

➭ The use of diagrid column for multistory building gives better results when compared with conventional frame building.

➭ Storey displacement values for diagrid framed sections are almost 15% less when compared with conventional framed building.

➭ Storey drift values for diagrid column are 50% less when compared with conventional framed building.

➭ Diagrid framed structures are light weight which reduces the dead load of the structure, ultimately reducing the weight of the body on foundation. So, from this study it is concluded that diagrid framed structures are more economical.

➯ From these results, it is seen that square shaped 2-storey storey module diagrid framed structures give least displacement, drift, base shear, and provide maximum stiffness. Hence, it is the best plan for Zone III and Zone V when compared with conventional framed buildings.

AUTHORS' CONTRIBUTION

Ajaya Kumar Behera carried out all the computational investigations under the supervision of Prof. Pravat Kumar Parhi who helped him by providing the idea about the research topic and helped in review of literature and correction of the manuscript.

CONFLICT OF INTEREST

The authors certify that they have no affiliation with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter, or materials discussed in this manuscript.

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