STRUCTURAL PERFORMANCE EVALUATION OF DIAGRID FRAME UNDER EARTHQUAKE LOAD AS PER BNBC 2020 FOR SYLHET REGION, BANGLADESH

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ABSTRACT

The world's population is increasing nowadays, but space is limited. In this limited space, high-rise buildings are more significant than low-rise buildings. Natural disasters are a constant threat to the South Asian Region. Earthquake phenomenon is more devasting because of its unpredictability. Geographically, Bangladesh lies in the most earthquake-prone zones. For constructing high-rise buildings in the Sylhet region, special consideration should be taken to minimize the loss of structure and life. Diagrid frame buildings have inclined columns that carry lateral and vertical loads. It reduces the use of steel, making the structure stiffer and lighter than the bare frame structure. This study analyzed the (G+20) storey RC building of 6400 square feet using ETABS v16, considering earthquake and wind load conditions as per Bangladesh National Building Code (BNBC-2020). Five diagrid framed structures of different shapes (C, H, L, T, and square) are considered and analyzed against a bare frame for this study, and performance is evaluated in terms of lateral drift and displacement under an equivalent static analysis method. After analysis, it is found that all the diagrid frame imparts less displacement and storey drift ratio compared to the bare framed structure of similar height, and square shaped diagrid frame shows a minimum displacement of 7.71 inches and storey drift of 0.012 h_{sx}, which makes it less vulnerable and efficient in a replace of an RC bare frame.

Keywords: *Equivalent static analysis method, Diagrid frame, Bare frame, Inter storey drift and Displacement, Seismic performance.*

1 INTRODUCTION

The diagrid structure has become a cutting-edge construction technique that has advanced the development of tall buildings and high-rise structures in engineering and architectural fields. It makes the structure lighter and stiffer. Civil engineers mainly focus on stiffer, lighter, and new-technology structures because of our limited space and environmental conservation. Since we concentrate on seismic and wind analysis, the diagrid structure is designed and analyzed compared with the conventional building using ETABS (Extended Three-Dimensional Analysis of Building Systems). This structure provides an inclined column that carries lateral and vertical loads and uses a small amount of steel compared to a conventional building. Also, this structure reduces displacement (Tirkey & Ramesh Kumar, 2020).

In Bangladesh, earthquake zones fall into four categories. Sylhet has strong seismic activity, while Dhaka has moderate seismic activity. Seismic zone coefficient Z = 0.36 for Sylhet indicates extremely high seismic activity zone and falls under category IV. Earthquakes are among the deadliest natural disasters because of their unpredictable nature and catastrophic effects. The earthquake data demonstrate that the consequences are the loss of human lives and the destruction of property, ultimately affecting the nation's economy. On the other hand, the incidence of earthquakes cannot be foreseen or stopped, but we may build structures to resist the forces caused by earthquakes(Monish & Karuna, 2015).

Amruta K. Podar compared the diagrid construction to the standard building of G+20 storeys and 3 m floor height in terms of storey drift, lateral displacement, and diagrid angle. The diagrid model used vertical columns of 45°, 63°, 71°, 75°, and 90°. By using the ETABS program, the model was assessed and contrasted. The design parameters and load combination were the same for both building frames, and the paper found that the G+20 storey structure's diagrid angle of 63 was optimal. The diagrid design reduced shear force, axial force, lateral displacement, and storey drift. Thus, the diagrid construction is more advantageous than the conventional building frame. This paper's shortcomings are its use of space and diagrid frames(Potdar & Patil, 2017).

Nishith B. Panchal analyzed the G+20 building. ETABS software developed the G+20 building's diagrid and outside frame construction. The experiment examined the structure's top storey displacement and storey drift. The Indian Standard codebook included the load combination, earthquake, and wind characteristics. When live and dead loads were applied, the basic frame structure showed displacement 30% more than the diagrid structure, and when seismic loads were used, the frame structure was more earthquake-prone. The diagrid building balanced lateral and gravity loads and removed vertical columns, while the external braced column took the lateral load. The outer frame structure and diagrid structure were allocated wind and seismic loads. Compared to braced frame building, a diagrid structure yields better results. In braced structures, drift and displacement are bigger(Panchal & Patel, 2014).

Abhay Guleria used ETABS software to test rectangular, I, C, and L-shaped structures. Seismic analysis is calculated for each form of G+15 storey with a 3 m floor height. The paper was analyzed for drift, displacement, and maximum bending and shear force diagrams. I and L forms had comparable findings to the other two shapes. However, the rectangular shape had a significant overturning moment. Rectangular and C shape models deformed more than I shape due to their asymmetry. The paper's negativity is that asymmetrical structures look better and use less steel. According to Indian Standard code books, the asymmetrical design must be analyzed. Asymmetrical Diagrid Structures include Abu Dhabi's Capital Gate (Guleria, 2014).

Chowdhury Mohammad Shams Wahid generated a HYDE curve; the total horizontal displacement against the seismic force is now only 0.035 m rather than 0.176 m, suggesting that 80% of displacement may be reduced by applying the Hysteretic Device (HYDE) method (Wahid et al., 2022).

Five distinct architectural styles analyzed on a 21-storey (G+20) RC structure. Minimum displacement is compared and analyzed with the help of ETABS v16 software. Moreover, it checked the minimum storey drift for five diagrid building shapes and one bare frame building shape and found the building which gave the more acceptable result. Under earthquake load conditions, analyze a structural system's seismic behavior by using different building shapes and identify the most efficient and suitable lateral load-resistant building shape.

2 METHODS OF WORK

The study process outlines based on prior research are shown in Figure 1. Following BNBC 2020, a (G+20)-storeyed RC bare frame square shape and various diagrid building types, including C, H, L, T, and square shape, were prepared using ETABS v16. All building shapes were then analyzed under earthquake and wind load conditions before comparing the modeled vertical and lateral displacement structures. From the ETABS, the minimum displacement value is measured, and the storey drift value is also taken from the ETABS. Using this formula ($\delta_x = \frac{C_d \delta_{xe}}{I}$), find the actual deflection of level x at the center of the mass from the ETABS storey drift value, where C_d is the deflection amplification factor, δ_{xe} an elastic analysis determines the deflection, and I is the importance factor.

2.1 Outlines of the Study Procedure

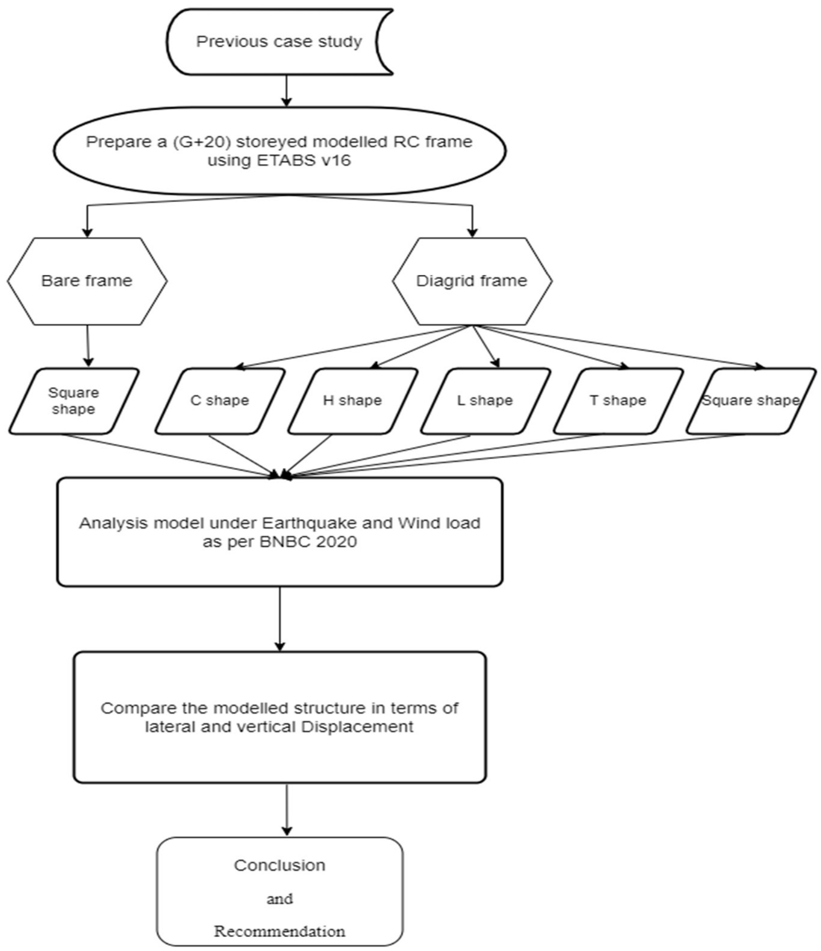

Figure 1:The methodology flowchart of the study procedure

2.2 Equivalent Static Analysis Method

This approach applies to the linear static process since the reaction of structures is believed to be linearly elastic, and it is called "linear static." The analysis is done according to IS1893:2002 (Part 1)(IS-1893-Part-1, 2002), and the total lateral design load or design base shear in any primary direction is reported based on the design horizontal seismic coefficient and the seismic weight of the structure. The zone factor of the site determines the horizontal design coefficient, the significance of the structure, the response reduction factor of the lateral force-resisting parts, and the entire natural time period of the structure(Monish & Karuna, 2015).

Since only the first mode in each direction is considered by equivalent static analysis, it is best suited for use with low to medium-height structures that do not have substantial coupled lateral-torsional modes. For example, tall structures (those above 75 meters in height), in which the second and higher modes may be essential, or buildings that include torsional effects are considerably less suited for the procedure. Applying more complicated methods when dealing with these kinds of buildings is necessary(Bagheri, 2012)(BNBC, 2020).

3 MODELLING AND ANALYSIS

The structure is 21 stories tall with a plan area of 6400 square feet. It has a 10-foot storey height. A typical layout and elevation are shown in Figures 2 and 3. A bare-frame building and a diagrid structure are the two models used for the comparative analysis. For both models, the building data remained unchanged.

3.1 Structural Modelling

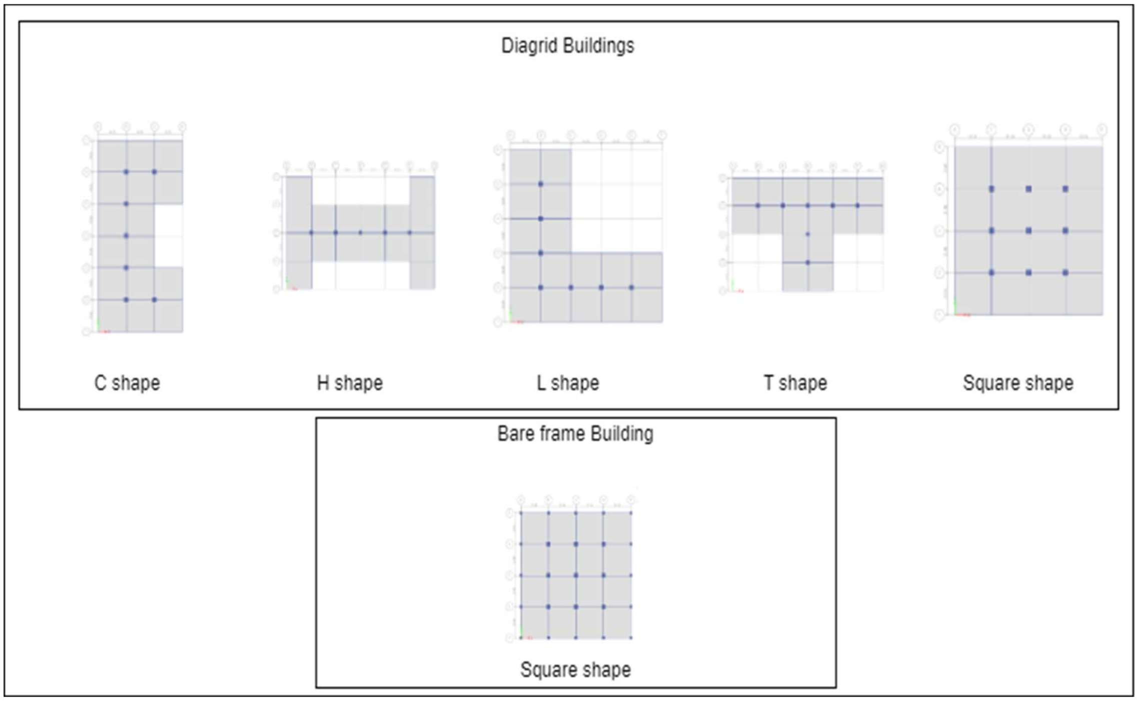

Figure 2: Plan view for diagrid and bare frame structures

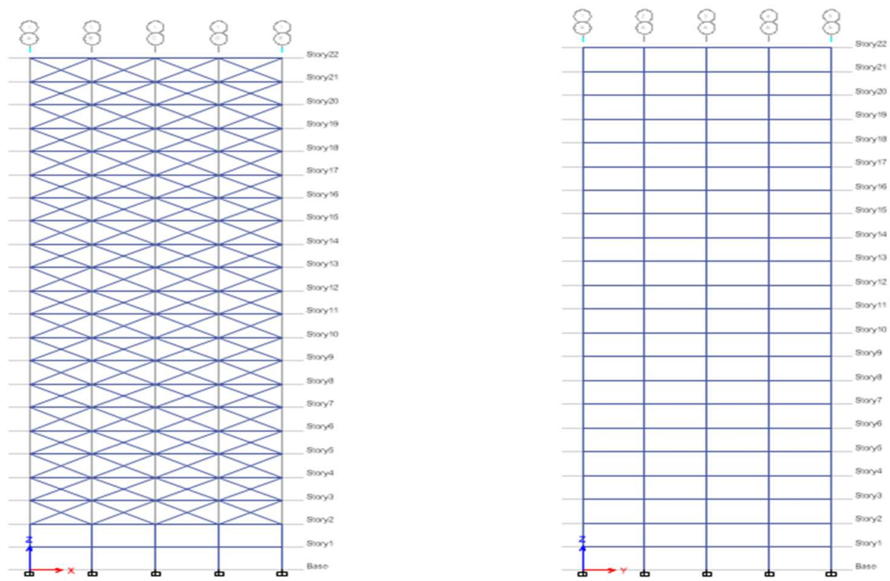

Figure 3: Elevation view for diagrid and bare frame structures

3.2 Model information

Table 1 lists the dimensions of the columns and beams. The diagrid building's internal columns are 36" by 36", while the diagrid is 15" by 24". However, C1 and C2's bare frame structures are 36" by 36" and 24" by 24", respectively. A slab thickness of six inches is considered for each.

Table 1:Model information

Column size	36 X 36 (inch)
Floor Beam	10 X 20 (inch)
Grade Beam	12 X 20 (inch)
Slab thickness	6 inches
Number of storeys	G + 20
Storey height	10 ft
Diagrid size	15 X 24 (inch)
Compressive strength of concrete section for Column (f′c)	3.5 ksi
Compressive strength of concrete section for Beam and Slab (f′c)	3 ksi
Yield stress of steel (fy)	60 ksi
Area	6400 sq.ft
Span	20 ft
Column size for bare frame	C1 = 36 X 36 (inch) C2 = 24 X 24 (inch)

3.3 Load information

Table 2 demonstrates this. The following factors are used to calculate the design seismic and wind loads of a system: exposure type C; response modification of 7; overstrength omega of 2.5; wind speed of 136.5 mph; zone coefficient of 0.36; topographical factor of 1; earthquake importance factor of 1.25; deflection amplification of 5.5; wind importance factor of 1.15. The dead and live loads are similar for the diagrid and bare frame constructions.

Table 2:Load information

Live Load	42 psf
Floor Finish	30 psf
Partition Wall	50 psf
Wind Speed	136.5 mph
Earthquake Load	ASCE 7-05
Importance Factor (Earthquake load)	1.25
Importance Factor (Wind Load)	1.15

3.4 Analysis report for modelled structures under earthquake and wind load condition as per BNBC 2020

The analysis has done by using ETABS v16. From the analytical analysis of the models, the results of various parameters like maximum storey displacement and storey drifts have been compared for 21 storeys (G+20). The lateral displacement and storey drift of the RC bare frame building structure for the seismic load cases has been analyzed in the X and Y direction. The bare frame building structure results are compared with various shapes of the diagrid building structures. It observed that the minimum displacement shows the diagrid building shape. And also detected that the best diagrid shape building shows minimum storey displacement and storey drift.

4 RESULT AND DISCUSSION

A variety of diagrid-shaped and bare-frame square-shaped building types were used to examine the seismic behavior of the structural system under wind load and earthquake conditions. In comparison to bare frame square shape buildings, the minimum displacements of diagrid square, L, T, H, and C shape buildings are 62.84%, 56.39%, 42.02%, 32.87%, and 16.48%, respectively. The diagrid square form is the most appropriate and effective lateral load-resistant shape because it provides the least displacement when compared to other diagrid shapes and bare-frame square-shaped structures.

4.1 Maximum Storey Displacement and Storey Drift for All Shape Building

Figure 4: Maximum storey displacement (all shape)

Figure 4 describes the Storey vs. Displacement graph for all shapes. It shows that the maximum displacement of a bare-frame Square shape building is 20.75 inches. In contrast, the minimum displacement shows diagrid various shapes like the C shape is 17.33 inches, and similarly, the H shape is 13.93 inches, the L shape is 9.05 inches, the T shape is 12.03 inches, and the Square shape is 7.71 inches. It observed that the Diagrid Square shape building gives minimum displacement than all other shapes.

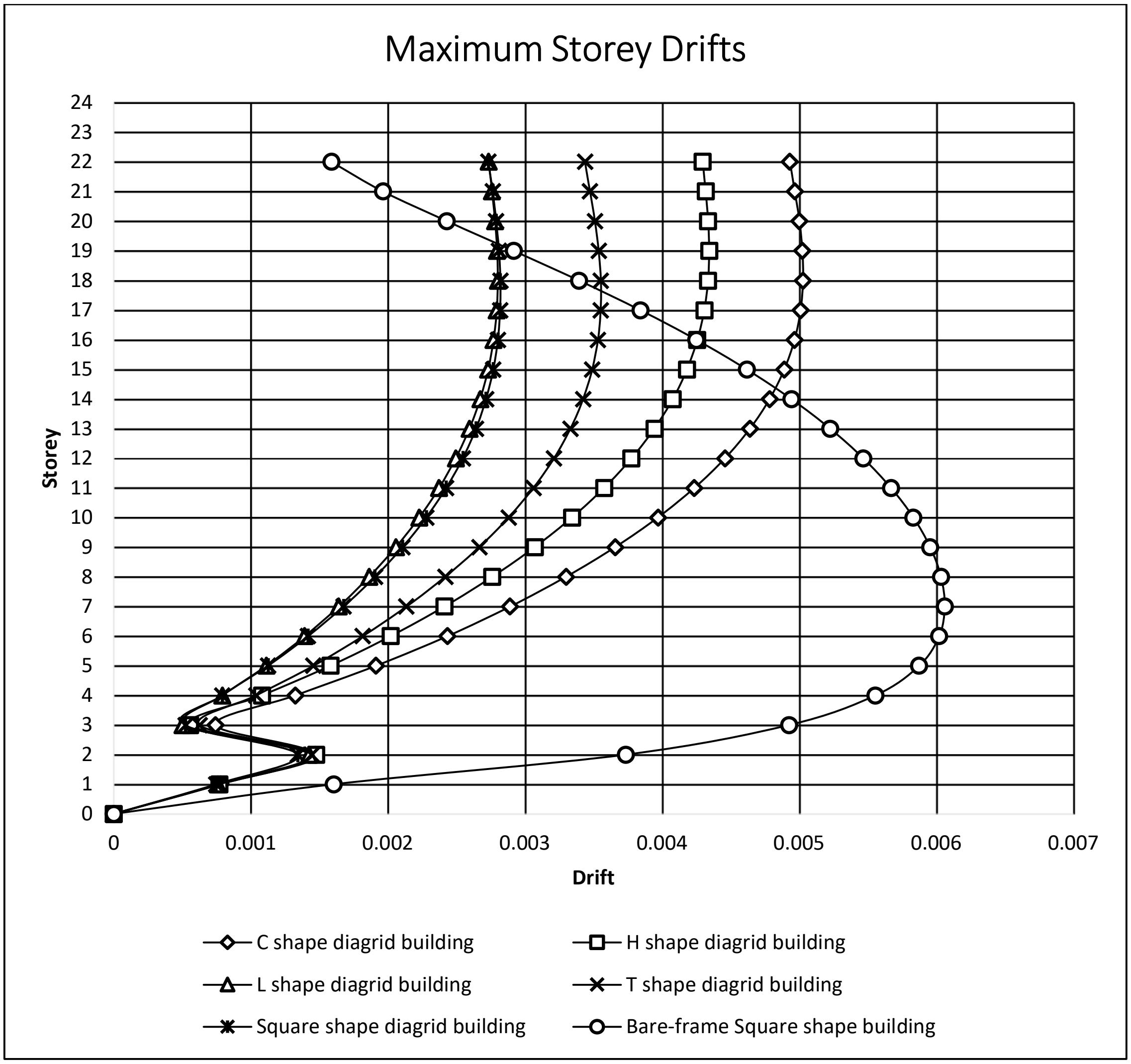

Figure 5: Maximum storey drifts (all shape)

Figure 5 explains the maximum storey drifts for all shape buildings. The maximum storey drift value taken from the graph and used this formula ($\delta_x = \frac{C_d \delta_{xe}}{I}$) finally showed the actual maximum storey drift for all shapes. It shows the maximum drift for a bare-frame Square shape building is $0.027h_{sx}$, while the various shapes of diagrid buildings show minimum drift like the C shape is $0.022h_{sx}$, and similarly, the H shape is $0.019h_{sx}$, the T shape is $0.016h_{sx}$, the L shape is $0.012h_{sx}$, and also the Square shape is $0.012h_{sx}$. Acceptable buildings from all shapes are L shape and Square shape because their result is less than $0.015h_{sx}$, which is the requirement for allowable drift for occupancy 3 in BNBC 2020.

5 CONCLUSION

This paper presents a comparative analysis and design of 21-storey diagrid frame buildings with various shapes and bare-frame square-shaped buildings. Considered an area of 6400 square feet and checked minimum storey displacement and minimum storey drift using ETABS v16 for modeling and analysis. Earthquake and wind load conditions followed the requirements for BNBC 2020.

Concluded the study that,

I. The diagrid square shape building gives less displacement, 14.82%, 35.89%, 44.64%, 55.50%, and 62.83%, respectively, than the diagrid building L, T, H, C, and building of bare-frame square shape.

II. The diagrid square-shaped building shows a similar storey drift at the diagrid L shape and gives, respectively, from the T, H, C diagrid building, and bare frame square shape building at 1.33, 1.58, 1.83, and 2.25 times less storey drift.

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