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Review Paper on Structural Analysis of Diagrid Multi-Stored Building

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***Abstract*: Up to the present day, various developments have been arisen to improve the performance behavior of buildings. Diagrid system is an innovative structural system for high rise structures with its latticelike aesthetics and high-efficiency structural performance. Literally, the word "diagrid" is made of two words "diagonal" and "grid". In this system, all exterior vertical columns are eliminated in contrast to conventional structural systems such as braced frames and framed-tube systems. The diagrid frame is subdivided into repetitive modules along the height and forms a diamond-shaped structure.**

***Index Terms* – Diagrid structural system, Conventional system, Braced framed system, optimum diagonal angle.**

I INTRODUCTION:

In modern age, the decrease of available free land and increase of land prices along with the wide spread of urban area has made architects and engineers to develop the cities vertically. For vertical growth, the only option is to construct the buildings as high as possible. It is a task of a structural designer to make the desired building stand and stable throughout its life. There are various structural systems for tall buildings, among them diagrid system is one of them. Diagrid is an exterior structural system which resists the lateral forces by axial actions of diagonals provided in periphery. Statistical analysis of tall buildings in India is carried out and presented for multi-stored building. Parametric study and detailed comparison of diagrid structural system with respect to conventional frame is carried out for symmetrical buildings.

For design of high-rise buildings the major factors to be considered are wind and earthquake loads, these lateral loads are resisted by structural system. The lateral load resisting systems used widely are rigid frame, shear wall, wall-frame, braced tube system, outrigger system, diagrid system and tubular system.

Recent trend shows that the Diagrid structural system is becoming more popular in the design of tall buildings due to its inherent structural and architectural advantages. Diagrid is an exterior structural system in which all perimeter vertical columns are eliminated and consists of only inclined columns on the facade of the building.

II LITERATURE REVIEW:

Khushbu Jania & Paresh V. Patelb [1] (2012) have performed analysis and design of 36 storey diagrid steel building is presented in detail. A regular floor plan of 36 m × 36 m size is considered. ETABS software is used for modeling and analysis of structure. All structural members are designed using IS 800:2007 considering all load combinations. Load distribution in diagrid system is also studied for 36 storey building.

Also, the analysis and design results of 50, 60, 70 and 80 storey diagrid structures are presented. From the study it is observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripherial diagonal columns. So, internal columns need to be designed for vertical load only. Due to increase in lever arm of peripherial diagonal columns, diagrid structural system is more effective in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and facade of the building.

Nishith B. Panchal1 & Vinubhai R. Patel2 [2] (2014) have done comparative analysis and design of 20-storey diagrid structural system building and simple frame building is presented here. A regular floor plan of 18m x 18m size is considered. ETABS 9.7.4 software is used for modelling and analysis of structure. Analysis results like displacement, storey drift, storey shear are presented here. Also design of both structures is done and optimum member sizes are decided to satisfy the code criteria. We conclude from the study that,

1. As the lateral loads are resisted by diagonal columns, the top storey displacement is very much less in diagrid structure as compared to the simple frame building.
2. The storey drift and storey shear is very much less for diagrid structural system.
3. The design of both structures are done by using same member size but that member sizes are not satisfied to design criteria in case of simple frame structure and failure occurs with excessive top storey displacement. So the higher sizes of members are selected to prevent the failure criteria.
4. Diagrid structure system provides more economy in terms of consumption of steel and concrete as compared to simple frame building.

Nishith B. Panchal & Dr. V. R. Patel [3] (2014) have carried out analysis by considering the different angles of diagrid and also different storeys of the building. The plan of 36m x 36m is considered with four different types of angles of diagrid that is 50.2°, 67.4°, 74.5° and 82.1° and also by considering 24-storey, 36-storey, 48-storey and 60-storey building, a comparative study is carried out. We conclude from the study that,

1. Diagrid angle in the region of 65° to 75° provides more stiffness to the diagrid structural system which reflects the less top storey displacement.
2. The storey drift and storey shear results are very much lesser in the region of diagrid angle 65° to 75°. As time period is less, lesser is mass of structure and more is the stiffness, the time period is observed less in the region of diagrid angle 65° to 75° which reflects more stiffness of the structure and lesser mass of structure.
3. Diagrid angle in the region 65° to 75° provides more economy in terms of consumption of steel and concrete as compared to different angles of diagrid.
4. When number of storey increases means height of building increases, diagrid angle in the region 65° to 75° gives better results in terms of top storey displacement, storey drift, storey shear, time period and material consumptions.
5. Diagrid structural system provides more economy and more benefits when no of storey is more than 40 with the diagrid angle in the region of 65° to 75°.
6. Optimum angle of diagrid is observed in the region of 65° to 75°.

Ravish Khan & S.B. Shinde [4] (2015) have considered two structural models for this study, which is diagrid model and braced frame model. Following data are involved in the modeling of both the structures. 20-storey building with 18x18m plan dimension, having 72m of total height with 3.6m height of each storey is taken for both models. Size of diagrid is taken 350mm pipe section with 12mm thickness at an angle of 67.4°.For braced frame model, inverted V-type bracings are used which is long leg back to back double angle section of 180x180x15mm. The dead load is taken 5.5kN/m2 on terrace level and 4kN/m2 on floor level. The live load is taken 1.5kN/m2 on terrace level and 4kN/m2 on floor level of both the models. The earthquake load parameters are taken as zone factor 0.1, soil type II, Importance factor 1, Response Reduction 5 as per IS-1893-2002. Modeling, analysis and design is carried out on STAAD Pro V8isoftware and the design of columns are done by IS-456-2000 and that of beams, diagrids and bracings are done by IS 800- 2007. From the study, it is concluded that,

1. The diagrid structure resists approximately the same amount of lateral loads as compared to the exterior braced structure, despite all the vertical columns being eliminated in the periphery of the diagrid structure.
2. Less amount of storey shear is seen in diagrid structure than to the braced frame structure.
3. The top storey drift of diagrid structure is less by 30.7% than in the exterior frame structure.
4. The top storey displacement of diagrid structure is less by 46.7% than in the exterior frame structure.

Manthan I. Shah& Snehal V. Mevada [5] (2016) has carried out analysis and comparison of Seven steel buildings for different heights are modelled, analysed and designed in ETABS for two structural systems; diagrid and conventional frame.

Analysis and design are carried out for dead load, live load, lateral earthquake load and lateral wind load. For earthquake loads, both static and response spectrum analysis are done. To consider extreme conditions of lateral loads, the buildings are considered to be located in Zone V. The parameters selected for the comparison are fundamental time period, maximum top storey lateral displacement, maximum base shear, steel weight and percentage difference of weight, maximum storey displacement and maximum storey drift. Further, governing lateral force is also determined. Based on the numerical study carried out in the present research work, following major conclusions can be drawn:

1. Diagrid structural system has emerged as a better solution for lateral load resisting system in terms of lateral displacements, steel weight and stiffness. It is stiff enough to resist wind forces upto higher heights.
2. The diagrid structure provides high efficiency in terms of steel weight along with the aesthetic appearance. For 24 storey building, weight of conventional frame is 100% more than diagrid building.
3. Displacements on each storey and storey drifts are observed to be less in diagrid systems as compared to conventional frame.

Kiran Kamath & Sachin Hirannaiah [6] (2016) study the performance characteristics of diagrid structures using nonlinear static pushover analysis. The models studied are circular in plan with aspect ratio H/B (where H is total height and B is the base width of structure) varying from 2.67 to 4.26. The three different angles of external brace considered are 59◦, 71◦ and 78◦ (Kim et al., 2010). The width of the base is kept constant at 12 m and height of the structure is varied accordingly. The nonlinear behavior of the elements is modelled using plastic hinges based on moment—curvature relationship as described in FEMA 356 guidelines. Seismic response of structure in terms of base shear and roof displacement corresponding to performance point were evaluated using nonlinear static analysis and the results are compared. The following are the observations drawn from the present analysis.

1. For all the brace angles considered 59◦ brace angle structures have lower base shear at performance for all the aspect ratios considered in the present study.
2. The models with 71◦ brace angle has higher base shear at performance compared to any other brace angles considered in the study.
3. The performance of the structure is influenced by brace angle and aspect ratio.

Dr. Gopisiddappa, M. Divyashree & Sindhuja G [7] (2017) have done analysis of 30 storey linear building and diagrid systems with different diagonal angles that is 45 degree, 63 degree, 73 degree, 75 degree, 78 degree, 81 degree. The comparison between linear building and diagrid building is carried out.

ETABS software is used for modeling and analysis of structure. Analysis results like storey displacement, inter storey drift are presented here. Following are the conclusions inferred from the study.

1. Framing building without any load resisting system shows highest drift and displacement value as compared to diagrid system.
2. Top storey displacement is less for diagrid system with diagonal angle 63 degree.
3. Between the region 63 degree to 75 degree (diagonal angle) diagrid system posses better stiffness, storey drift and storey displacement are less in this region.

Snehal S. Mali [8] (2017) has interpreted seismic response of diagrid building with conventional frame structure at seismic zone IV and soil type is hard. Model is of same parameter with diagrid and conventional frame. Position of diagrid in opposite face, three faces, and all faces in model are taken. Equivalent static analysis, Response spectrum analysis and wind analysis is done using ETABS software. Result is representing in term of displacement. It is conclude that at equivalent static analysis, response spectrum analysis of diagrid structure lateral displacement significantly less 45.48% and 41.71%, 45.92%, 42.17% in X, Y direction respectively as compared to conventional structure. At wind analysis lateral displacement significantly diagrid structure compared to conventional structure is less 45.34% in X and 41.59% in Y direction.

Mohammed Abdul Rafey & M. A. Azeem [9] (2018) investigated models of diagrid structures and conventional braced frame structures with different symmetric and asymmetric plan geometries. For the purpose of analysis, two symmetric and two asymmetric structures were modeled and analyzed using linear static method for each of the two structural types. Hollow mild steel pipes were considered as exterior diagrids whereas ISA angle sections were considered for exterior bracing. It was observed that the diagrid structures' performance against the lateral loads was much better than that of the conventional braced frame structure and that the member stiffness in diagrid structures' elements were of much greater magnitude than the conventional braced structure despite the fact that all peripheral vertical columns are eliminated from the diagrid structure. The top storey displacements in the diagrid models are less compared to the conventional braced frame models. The storey shear for diagrid models is much less than that of conventional braced frame models which is because the seismic weights of diagrid structures are less than the seismic weights of the conventional braced frame structures.

Amruta K.Potdar [10] (2018) have done comparative analysis and design of 20-storey diagrid structural system building and simple frame building is presented here. A regular floor plan of 15m x 15m size is considered. Different models for different diagrid angle (45, 63, 71, 75 and conventional) are made. ETABS 15 software is used for modelling and analysis of structure. Following conclusion where found

1. Diagrid building shows less lateral displacement and drift in comparison to conventional building. Axial load on internal column is less in diagrid building as compared to conventional building. Shear force of interior beam is less in diagrid as compared to conventional building.
2. For 20 storey diagrid structure, the optimal range of diagrid angle is from about 60º to 70º.
3. In comparison to conventional building, diagrid buildings are more aesthetic in look and it becomes important for high rise building.
4. Due to diagonal columns on its periphery, diagrid shows better resistance to lateral loads and due to this, inner columns get relaxed and carry only gravity loads. While in conventional building both inner and outer column are designed for both gravity and lateral loads.

Mahdi Heshmatia , Alireza Khatamia & Hamzeh Shakiba [11] (2020) have studied diagrid structures of 36-story with a uniform story height of 4.0 m. All archetypes are symmetric and include 6 bays of 6.0 m in each direction. The uniform diagonal angles for exterior frames are considered to be 53°, 69°, 76° and 79° in which internal frames are assumed to be pin-connected and only carry gravity loads. On the other hand, diagonal slope of 69° is assumed for interior diagrid frame in tube-in tube diagrid structures. Diagrid structures are divided into 2-, 4-, 6- and 8- story modules along the height. The uniform dead load of 5

KN/m2, live load of 3 KN/m2 , and partition load of 1 KN/m2 are applied on the floors. All archetypes were designed for SDC Dmax of FEMA P695 [23] with SDS (short-period spectral acceleration) of 1.0g and SD1 (1-second spectral acceleration) of 0.6. Diagonal elements were made of steel grade 50 with Fy = 345 MPa and Fu = 450 MPa. Also steel material with Fy = 250 MPa and Fu = 400 MPa is used for beams. The response spectrum analysis is applied for seismic analysis based on ASCE/SEI 7-16 [24] requirements. Results of nonlinear static analyses demonstrated that when diagonal angles were lower than those of the core, interior tube could act as a backup load-resisting system after the yielding of perimeter tube. In addition, most diagrid structures were capable of undergoing large deformations without abrupt collapse in the whole system. Also Interior diagrid tube appropriately procrastinated occurrence of damage states and provided a safety margin for core diagrid structures. Diagrids structures performed acceptable under earthquake motions and most of the mean deformations were within the allowable range. Deformations were spread throughout the height and addition of interior diagrid tube enhanced the distribution of forces towards upper levels especially in models with higher diagonal angles. The distribution of residual drifts also confirmed that diagrid system was well-behaved under rare earthquakes.

Shith B. Panchal & Dr. V. R. Patel [12] (2020) have studied, seismic performance of 36-story diagrid structures with varying angles are evaluated using pushover and nonlinear time history analysis. Furthermore, in order to evaluate the effect of diagrid core on behavior of structures, interior gravity frames are replaced with diagrid frames. The results of pushover analyses demonstrate that diagrid core can enhance the hardening behavior of structures when the angles of perimeter panels are lower or equal than those of the core compared to the conventional diagrids. In addition, core diagrids provide safe margins between the damage states under lateral loading. Nonlinear time history analyses are then performed to assess inter story drift ratio, residual drift, energy dissipation and hinges distribution of structures. It is observed that most of the models perform well under rare ground motions and hinges are well spread throughout the height among different elements and diagrid structures are capable of undergoing large deformations under rare earthquakes Large portion of input energy are dissipated by diagonal members and as the slope of exterior diagonals exceed that of perimeter tube, diagrid core efficiently participates in dissipating energy Diagrids structures performed acceptable under earthquake motions and most of the mean deformations were within the allowable range. Deformations were spread throughout the height and addition of interior diagrid tube enhanced the distribution of forces towards upper levels especially in models with higher diagonal angles. The distribution of residual drifts also confirmed that diagrid system was well-behaved under rare earthquakes.

III. Conclusion

The above literature review shows that comparison between diagrid structure models with conventional frame model, braced frame model. Various diagrid angles are considered with different irregularities in structure. Response spectrum, time history and pushover analysis is considered by using different softwares i.e etabs, staad pro, sap2000 etc from the literature review it can be concluded that

1. Diagrid structure shows more stiffness than the simple conventional model
2. Diagrid structure resist greater lateral load than the braced framed structure.
3. Optimum angle is changes with respect to the height of the diagrid structure.
4. Optimum angles lies in a range of 60° to 75° according to the height of the structure.

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