

Optimization of Geometrical Characteristics of Building by Using Diagrid System against Lateral Forces

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Abstract: In this present era of population growth and scarcity of available land, engineers and architects are bound to construct high-rise buildings. Lateral loads are considered as most dominant factor in the construction of high-rise buildings. To improve the efficiency of high-rise buildings, new structural systems like diagrid and hexa-grid are introduced. A Diagrid structural system resists lateral load by presence of inclined columns in the periphery of the building. In this study, various diagrid models with different diagrid angles were analyzed through pushover analysis by using FEMA 356 & ATC 40 and the results were compared with a conventional frame building of same dimension. Pushover analysis is a good way of accessing the sequence of failure by indicating hinges. The method can be used where the structure needs to be fine-tuned or it needs to be retrofitted. In this study it was found that diagrid performs well against lateral forces in comparison to conventional frame building. The hinge results of test beam showed that the 1-story diagrid module gave around 70% lower values of moment at plastic stage in comparison to simple frame structure. The performance point of all the diagrids were also better than simple frame with around 70% plus values. The story displacement value for all the diagrid modules was efficient in relation to simple frame structure with almost 70% lower displacement values. This study suggests that the usage of diagrids in building helps in improving performance of tall structures and also helps in reducing the overall cost of the structure.

Key Word: Diagrid Structures, Storey Drift, Plastic Hinge, FEMA 356, Stability

I.INTRODUCTION

1.1 General

A diagrid is a frame of transversely intersecting metal, concrete, or wooden beams that is used in the construction of structure and roofs. It requires lower structural steel than a conventional steel frame. Hearst Tower in New York City, designed by Norman Foster, uses 21 percent lower steel than a standard design. The diagrid structural system can be defined as diagonal element formed as a framework made by the intersection of different materials like metals, concrete or wooden shafts which is used in the construction of structures and roofs. Diagrid structures of the steel members are efficient in furnishing results both in terms of strength and stiffness. But currently a wide operation of diagrid is used in the large span and high-rise buildings, particularly when they are complex shapes and twisted shapes.

1.2 Diagrid Structures

The diagrid structural system is often outlined as diagonal members shaped as a framework created by the intersection of various materials like metals, concrete or wood beams that is employed within the construction of buildings and roofs. Diagrid structures of the steel members result in most economical case each in terms of strength and stiffness. However today a widespread application of diagrid is employed within the massive span and high rise buildings.

Module Geometry of Diagrid Structural System:

i. Diagrid Best Angle

The diagonal member of the diagrid carries shear force and moment. The best angle for putting the diagonals relies on building height. The best angle of the columns for optimum bending rigidity within the traditional building is ninety degrees and for the diagonals for shear rigidity is thirty-five degrees. It's assumed that the best angle of the diagrid falls in between these values. Typically adopted angle is 60-70 degrees.

ii. Diagrid Module Dimensions

The module dimensions depends on majorly two things:

Height: the peak of the diagrid depends on the number of floors stacked in one module of the diagrid. The common range of floors stacked for modules of the diagrids square measure two to six.

Base of the module: the bottom on which the diagrid is created typically depends on the peak and also the best angle of the diagrid.

Types of Diagrid System and Materials of Construction. The materials used in diagrid depends upon several factors:

- a) Availability of fabric
- b) Erection time
- c) Flexibility
- d) Durability
- e) Unit weight of the fabric
- f) Labor cost
- g) Lead time
- h) Fire-electric resistance

II.OBJECTIVE

- i. The main objective of the study is to find the performance of diagrid structure with varying angles of 82° , 78° , 67° & 50° in comparison to a simple frame building for the seismic characteristics and soil properties pertaining to Pune region of Maharashtra.
- ii. To determine the formation of hinges in the diagrid structure and to plot M- θ curve to establish a comparison between simple frame structure and a diagrid structure regarding the performance in plastic zone of lateral loading.
- iii. To determine the story displacement of diagrid node points, so that an efficient comment can be made on whether the diagrids are efficient for tall structures in comparison to simple frame structures.

III.LITERATURE REVIEW

The brief literature review related to present study is as follows:

1. Kiran Kamath [1], An analytical study on performance of a diagrid structure using nonlinear static pushover analysis. In this article, an endeavor has been made to consider the execution characteristics of diagrid structures utilizing nonlinear static pushover investigation. The models examined are circular in arrange with aspect ratio H/B (where H is total height and B is the base width of structure) shifting from 2.67 to 4.26. The three diverse angle of the outside brace considered are 59° , 71° and 78° . The width of the base is kept same at 12 m and height of the structure is varied accordingly. The nonlinear behavior of the components is displayed utilizing plastic hinge based on moment-curvature relationship as portrayed in FEMA 356 rules. The seismic reaction of structure in terms of base shear and roof displacement comparing to execution focuses were assessed utilizing nonlinear static analysis and the results are compared. For 71° brace angle show base shear at execution appears an increment in all the aspect ratio considered in the study. The execution of the structure is affected by brace angle and aspect ratio. For all the brace angle considered 59° brace angle structures have lower base shear at execution for all the aspect ratio considered in the study. The models with 71-degree brace angle has higher base shear at performance compared to any other brace points considered in the study. The execution of the structure is impacted by brace angle and aspect ratio.
2. G. Lecidogna [15], Impact of the geometrical shape on the auxiliary behavior of diagrid tall buildings beneath lateral and torque actions. Four distinctive height of the building were taken under consideration, specifically 126 m, 168 m, 210 m and 252 m, which compare to four diverse numbers of floors, i.e. 36, 48, 60 and 72 individually (Table 1). For each building height, four distinctive floor plan shapes were explored, specifically square, hexagonal, octagonal and circular. Six diverse diagonal inclination were adopted. The diagonal inclination is the most geometrical parameter influencing the basic behavior of the building. For the explored diagrid structures, its ideal values are found to lie within the extend of 64° - 72° to minimize lateral displacements and these increase when the aspect ratio of the building increases, due to the competition between shear and bending inflexibility. Contrariwise, the diagonal inclinations which provide the most noteworthy torsional stiffness are continuously found within the run 35° - 38° and don't depend on the total height of the building, since torsional behavior is as it were influenced by the shear unbending nature of the diagrid modules. It is observed that the particular arrange geometry does not influence significantly the structural response, when the diagonal inclination is within the ideal extend for restricting the lateral displacements.
3. Sivapalan Gajan [2], Application and Validation of Practical Tools for Nonlinear Soil-Foundation Interaction Analysis. The potential benefits and results of nonlinear foundation-soil interaction for shallow foundations are well reported within the literature. Modeling methods that account for this nonlinear behavior are required for use in practice. In this paper, an audit of two numerical models for simulating soil foundation interaction, archive the input parameters and parameter choice conventions for those models, compare show expectations to each other for theoretical building structures on clay, and compare model predictions to centrifuge data for a diverse set of experiments. The two models considered are referred to as a beam-on-nonlinear Winkler-foundation demonstrate and a contact interface show (CIM).
4. George Gazetas [3], Nonlinear Soil-Structure Interaction: Foundation Uplifting and Soil Yielding, The study found the monotonic behavior of an elevating foundation of a generally tall structure is influenced by: (i) the P- Δ wonder, (ii) the adaptability of the soil, and (iii) the greatness of the ordinary constrain compared with the vertical bearing capacity of the foundation (i.e., the static factor of safety. Beneath seismic loading, toppling might not occur even when the instantaneous factor of safety against overturning (with bearing capacity exceedance) is well underneath solidarity. The nature of seismic excitation (particularly its frequency composition and, especially, the presence of a sequence of long-duration impulsive cycles) is the controlling figure of the reaction of a particular framework. Too the start of uplifting and the mobilization of bearing capacity "failure" can be very advantageous for the superstructure, beneath certain conditions related with the elemental period of the structure and characteristics of ground shaking.

5. Iman Dabbaghchian [4], Comparison of seismic behavior of the eccentric and conventional diagrid system. The diagrid could be an effective load-bearing framework that gives aesthetical and structural benefits. In spite of the fact that due to failing of its post-yield behavior, the auxiliary benefits of EDS are presented. This inquire about compared the seismic execution of eccentric systems with customary diagrid quantitatively through a arrangement of numerical models. Results appear that in eccentric diagrid archetypes, post-structural behavior is essentially progressed. The collapse point is shifted relative to conventional framework, as well as the ratio of extreme resistance over plan base shear, which stands for ductility and over strength factors.
6. Mr. Anirudha [5], Nonlinear seismic analysis of normal structure with diagrid structure using Etabs. The comparative study has been effectively executed for distinctive diagrid structures utilizing ETABS computer program to discover the stiffness and adaptability of the tall raised structures additionally for an asymmetrical structure through basic system. The lateral load resisting framework is way better at standing up to the gravity loads than the basic framework when the structure tallness gets expanded. The configuration and efficiency of the diagrid framework has decreased the number of structural components. The ETABS program is utilized to design and analyze the result such as axial, shear and bending moment. The possibility of failure is much lesser for diagrid structure when compared to the conventional structure by heavy vibrations amid a seismic tremor.
7. Valentina Tomei [6], Optimization of structural patterns for tall buildings: The case of Diagrid, Engineering Structures. The optimized basic arrangements are continuously characterized by comparable or lower weight than the arrangements planned according to procedures recommended in past investigation, but the dispersion of corner to corner cross areas along rise is by and large very distinctive; this gives rise to a predominant execution of the optimized arrangements, and, thus, to an increment of basic productivity. The examination of the strength request to capacity ratio calculated for the diagonal individuals show that a better exploitation of the member strength capacity is obtained in the optimized arrangements with regard to the ordinarily conventionally arrangements.
8. Sepideh Korsavi [7], The Evolutionary Process of Diagrid Structure towards Architectural, Structural and Sustainability Concepts: Looking into Case. The paper points at finding the developmental prepare of diagrid structures and their advance which leads to major breakthroughs in architectural, structural and sustainability concepts. Without a doubt, these later propels are examined and detailed by designers and engineers. The result, based on case thinks about, appear that these structures have been able to address most of the plane requirements. They have too been utilized in numerous ventures with completely distinctive height, regions and capacities, recommending diamond modules can be connected not as it were for high-rises but for a wide range of projects. Rahul Leslie [8], The Pushover Examination, clarified in its Straightforwardness. The require for a straightforward strategy to anticipate the non-linear behavior of a structure under seismic loads saw light in what is presently popularly known as the Pushover Examination (PA). It can offer assistance illustrate how dynamic failure in buildings truly happens, and recognize the mode of final failure. Here, what the author has expecting is to clarify the method of Pushover analysis step by step, in terms basic and simple, to be reasonable to anybody recognizable with the conventional seismic analysis.
9. Neha Tirkey [14], Analysis on the diagrid structure with the conventional building frame using ETABS, This article outlines the case study on diagonal perimeter often known as the diagrid structure using software ETABS. The diagrid structure is designed, analyzed and compared with the conventional building using ETABS software mainly focusing on seismic and wind analysis parameters. As per IS 456:2000 and the Linear Static Method all the structural members of the diagrid model are designed and IS 1893 (PART 1): 2002 is considered for load combination of seismic analysis.
10. Sindhu Nachiar [16]. A Comparative Study on Seismic Analysis of Diagrid and Hexagrid Structural framework. In this paper a normal square floor arrange of 48x48 m and unpredictable floor plans like C and L sort base arrange of diagrid and hexa-grid are examined. All structural steel individuals are outlined as per IS 800:2007. The design earthquake load is computed based on the zone factor and their soil types, significance factor and response reduction factor as per IS: 1893-2016. All models are having same 40-story height and they are compared based on the parameters like displacement, maximum story drift, story shear, maximum base shear and steel consumed are considered in this study.
11. Kamil Ashraf Bhat [17], Analyzing diverse arrangements of variable angle diagrid structures. This paper gives an investigation of diverse arrangements of the variable angle diagrid structures. For this reason, the parameters of variable point diagrid structures such as point of slant of diagrids and the proportion of height for which point of slant of diagrids are shifted to think about its impact on the structure. Distinctive designs of variable point diagrid structures are created for a 60-storied building which are demonstrated and analyzed in ETABS beneath gravity and wind loads. The ideal arrangement is chosen from these diagrid setups based on the auxiliary weights of diagrids and exhibitions of the building.
12. Mahdi Heshmatia [19], Seismic performance assessment of tubular diagrid structures with varying angles in tall steel buildings. In this consider, seismic execution of 36-story diagrid structures with changing angles are evaluated utilizing pushover and nonlinear time history analysis. Besides, to evaluate the impact of diagrid core on behavior of structures, insides gravity frames are supplanted with diagrid frames. The result of pushover analysis illustrate that diagrid core can improve the solidifying behavior of structures when the angles of perimeter panels are lower or rise to those of the core

compared to the conventional diagrids. In expansion, core diagrids give secure edges between the damage states beneath horizontal loading. Nonlinear time history analysis are at that angle performed to assess inter-story drift ratio, residual drift, energy dissipation and hinges distribution of structures. It is watched that most of the models perform well beneath rare ground movements and hinges are well spread all through the height among diverse components and diagrid structures are able of experiencing huge distortions beneath rare seismic tremors. Huge portion of energy is dissipated by diagonal element and as the slope of outside diagonals surpass that of perimeter tube, diagrid core efficiently participates in dissipating enter.

IV.METHODOLOGY

Methodology for comparison of seismic resistance of diagrid structure with different soil profiles can be studied. A detailed capacity spectrum can be generated with the help of FEMA-356 and other standard codes. The failure of members can be predicted with the help of simulation software such as Etabs/Sap2000/StaadPro. Analysis with varying angles of diagrid and soil parameters can be studied and its relevance in future planning of high-rise building can be accessed.

1. Capacity Spectrum Generation: Create a detailed capacity spectrum using FEMA-356 and other relevant standards to understand the structural capacity of the diagrid.
2. Predicting Member Failure: Utilize simulation software such as Sap2000 to predict member failures under seismic loads, enabling the assessment of structural performance.
3. Analyzing Varying Diagrid Angles and Soil Parameters: Perform analyses with different diagrid angles and soil parameters to study their impact on structural behavior, with implications for future high-rise building planning.
4. Methodology of Analyzing Structure: Analyze the structure through FEMA 356, ATC 40 as follows:
 - Define load cases for pushover nonlinear static analysis in both X and Y directions.
 - Consider mass sources with 100% dead load and 25% live load.
 - Apply specific displacements to nodes.
 - Utilize Capacity Spectrum Method (CSM) and Displacement Coefficient Method (DCM).
 - Define hinge locations on beams and columns.
 - Plot capacity spectra per ATC 40 and access displacement coefficients through FEMA 356.

The diagrid models are analyzed using SAP 2000, with member sizes and configurations defined. Different modules are modeled with varying angles to study their behavior. MAT foundations and settings for equivalent static methods are used. Soil parameters are based on site-specific data, considering the region's properties. Settlement calculations and the sub-grade modulus (K value) are determined. This comprehensive methodology enables the comparative assessment of diagrid structures' seismic performance under different soil profiles and angles, contributing to improved understanding and future planning of high-rise buildings.

As per IS 1893:2002

Seismic Zone: Zone IV

Seismic Factor: 0.24

Seismic Analysis Method (For initial analysis): Equivalent static method

Soil Type: Type I (Rocky Hard Soil)

Importance Factor: 1

Response Reduction Factor: $R = 5$ (SMRF)

Load Combinations:

As per IS 875:1987 (Part-1 & Part-2) [10]

Loads for building taken as:

Dead Load on Slab = 2.5 kN/m^2

Live Load on Slab = 3.5 kN/m^2

As per FEMA 356 [11]

Pushover Analysis with Displacement Coefficient Method is consider.

As per ATC 40 [12]

CSM (Capacity Spectrum Method) can be carried out. Performance points can be accessed.

Table 1: Load Combinations as per IS 456:2000, IS 1893-2002

Factors for Serviceability	Factors for Collapse
DL+LL	1.5(DL+LL)
DL±EQX	1.5(DL±EQX)
DL±EQY	1.5(DL±EQY)
DL+0.8LL±EQX	1.2(DL+LL±EQX)
DL+0.8LL±EQY	1.2(DL+LL±EQY)

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