Non-Linear Time History Analysis and Design of Grid Shell Structure

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Abstract — Grid shell structures, which are lightweight, double-curved frames known for their structural efficiency and architectural beauty, are the subject of this project's nonlinear time history study and design. One dynamic analysis method used to assess the grid shell's performance under real-time seismic excitations is nonlinear time history analysis. The reaction of the structure to seismic loads is simulated using sophisticated computational methods, paying particular attention to significant deformations and possible instabilities. contributes to sustainable, effective architectural solutions for seismically vulnerable areas, improves our understanding of grid shell behavior under dynamic settings, and offers design insights for resilience.

Keywords: Non-linear, time history analysis, grid shell structures, dynamic analysis, ETABS, story drift, base shear

I. INTRODUCTION

A. General

Compared to former eras, technological advancements have made our lives more pleasant and easy, but they have also increased the need for living space due to the expanding population. The need for multistory buildings is growing daily. In terms of building method, material, system type, analysis, and design, various new technologies have emerged. The city's residential development has been significantly impacted by the fast urban population increase and the resulting strain on available space. The need to maintain significant agricultural output, the high cost of land, and the need to prevent unrelenting urban sprawl have all fueled the upward trend of residential construction. The city's residential development has been significantly impacted by the fast urban population increase and the resulting strain on available space.

Numerous studies on grid shells, also known as diagrid buildings, have been conducted throughout the last ten years. Since the significance of diagrid structures has been acknowledged, scholars and professionals have created sophisticated design techniques to make diagrid structural systems cost-effective and efficient. Numerous studies have outlined the design technique that should be used, and investigations of the joint connections have also been conducted. A diagrid system's efficiency and design minimize the number of structural elements needed on a building's façade, which lessens the barrier to the exterior view. The diagrid system's structural effectiveness also aids in avoiding corner and interior columns, giving the floor layout a great deal of flexibility.

B. Diagrid Structures

A framework created by the intersections of diagonal components composed of various materials used in construction, such as concrete, steel, metal, or wooden beams, is known as a grid shell structure, or diagrid structural system. Skyscraper construction is done with Diagrid. Steel is typically employed as a construction material for these structures. . However, diagrids are being utilized for high-rise structures with greater spans and heights. Diagrid is a cutting-edge structural solution for tall structures because of its structural effectiveness and architectural planning flexibility. Because of the sturdy skeleton, diagrids are typically not used, giving the building more glazing and architectural planning flexibility. In order to regulate the torsional effects, lateral buckling, and static force, more members have been added to the robust skeletal framework.

Time History Analysis

Analysing the dynamic reaction of a building over time when its base is subjected to particular ground motions is known as time history analysis. To determine the structure's response for a given time history, time history analysis is done. To determine the structure's response for a given time history, time history analysis is done. It must be carried out using recognized principles of earthquake structural dynamics and be predicated on a suitable ground motion (compatible with the design acceleration spectrum in the intended range of natural periods).

II. REVIEW OF LITERATURE

Garlan Ramadhan, (2018) researched about the buildings analyzed were subjected to an equal number of crustal and subduction motions (in total 14 motions). the TMD system was most effective if the mass damper is extended over four floors. This allows for optimal load transfer to the exterior diagrid structure**.**

M.eeri, (2020) A relatively simple nonlinear method for the seismic analysis of structures (the N2 method) is presented. It combines the pushover analysis of a multi-degree-of-freedom (MDOF) model with the response spectrum analysis of an equivalent single-degree-of-freedom (SDOF) system. The method is formulated in the acceleration-displacement format, which enables the visual interpretation of the procedure and of the relations between the basic quantities controlling the seismic response

Michael Banbrook, (2022) With the emergence of nonlinear dynamical systems analysis over recent years it has become clear that conventional time domain and frequency domain approaches to speech synthesis may be far from optimal. Using state space reconstructions of the time domain speech signal it is, at least in theory, The synthesis technique, which is based on ideas taken from nonlinear dynamics theory is detailed and demonstrated showing that it is capable of high quality natural sounding speech

III. OBJECTIVES AND METHODOLOGY

A. *Objective of the Project*

1. To model the grid shell structure
2. To conduct nonlinear time history analysis of grid shell structure using ETABS software
3. To design the diagrid structure

B. *Steps Involved in Earthquake Resistant Design*

1. Defined standard code & start model initialization
2. Assigned dimensions and story data in ETABS
3. Defined material properties
4. Defined sectional properties
5. Defined load patterns
6. Defined the required functions
7. Defined load cases
8. Defined load combinations
9. Analyzed the check model
10. Selected load cases to run
11. Run analysis
12. Check the required analysis results

IV. STRUCTURAL MODELING AND ANALYSIS

For the purpose of evaluating the seismic response of different lateral force resisting systems, the present study analyses, using ETABS, of B+G+12+T diagrid commercial building.
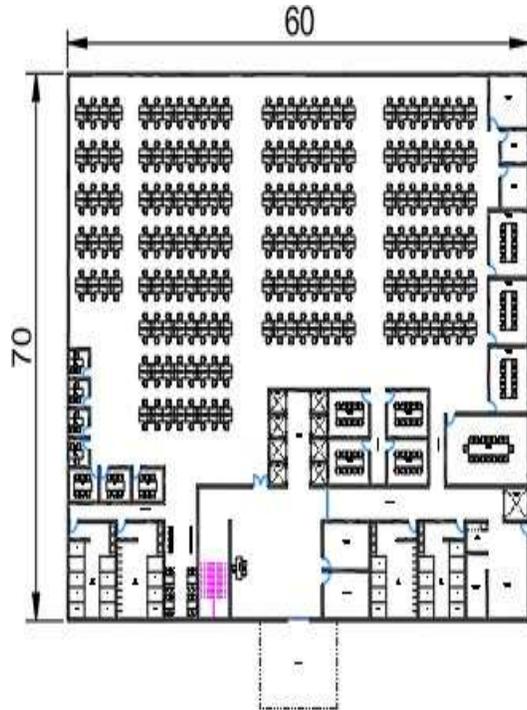
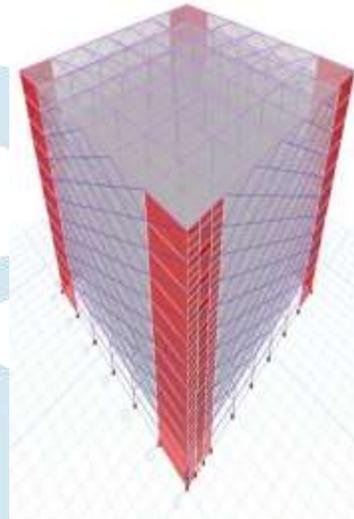Figure 1: Plan of (G+12) commercial Building, size of building is 60mmX70mm
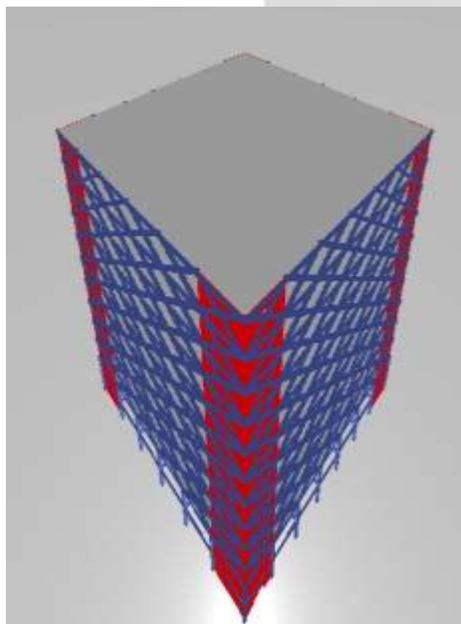

Figure 2: Rendered view of diagrid building

Figure 3: 3D View of diagrid building

A. Structural Details of Model

- Number of Stories – G+12
- Storey Height – 3.0m
- Seismic Zone Factor, Z – V (0.36)
- Structure Type – RC buildings with special moment-resisting frame (SMRF)
- Response Reduction Factor, R – 5.0
- Importance Factor, I – 1
- Soil Type – Ideal soil-dense gravel

B. Material Properties

The material used in the structure is concrete for beam and column members and slab respectively. Fe500 grade of steel and M30 grade of concrete are used for all the models used in this study. Parameters considered for this study is given below.

C. Sectional Properties

The structural elements of the building are specified with the following dimensions: The slab has a thickness of 180 mm. Beams are provided in two sizes—300 mm x 600 mm and 230 mm x 750 mm. Columns come in four different sizes: 600 mm x 600 mm, 700mm x 900 mm, 600 mm x 500 mm, and 450

mm x 600 mm. The walls have a uniform thickness of 230 mm.

D. Gravity Loads

The self-weight of the structural elements such as beams, columns, and slabs is automatically computed by the software used for analysis and design. Additional loads, such as wall loads, have been calculated separately and assigned as uniformly distributed loads on the beams. The wall load applied on all the floors is 14.50 kN/m², while the wall load on the terrace is considered as 4.0 kN/m.

E. Live Loads

Live loads, as defined by IS: 875 (Part 2) – 1987, are dynamic vertical forces from occupancy and use, including people, furniture, and equipment. For this project, classified under business and office buildings, live loads are applied as uniform area loads on slabs. The loads considered are: 1.5 kN/m² for water closets, general slab, lobby and balcony is 1.5 kN/m², for terrace is 1.0 kN/m².

F. Load Combination

The load combinations shall be considered as specified in respective standards due to all load effects mentioned there in IS : 875 (Part 5) – 1987. In addition, those specified in the IS 1893 (Part 1): 2016 code shall be applicable, which include earthquake effects.

V. RESULTS AND DISCUSSIONS

A. Comparison of bending moment results of diagrid building and building without diagrids

Structural element	Diagrid building	Irregular building
Ground floor	50.44	110.06
Mid span beam	40	95.56
Roof beam	30	70
Diagrid member	60	190
Story overturning moment	9,000	12,500

The table showing the bending moment values of diagrid building and building without diagrids. From the observations ,

1. Diagrid building has significantly lower bending moments in beams and columns due to force being carried axially through diagonal members
2. Irregular building shows higher moments, especially at the locations with stiffness irregularities
3. Interior columns in irregular structures carry more moment due to the lack of uniform load paths.

B. Time history analysis

Time history analysis examines the dynamic reaction of a structure at each time increment when its base is subjected to specific ground motion. Time history analysis is used to determine the structure's response to a specific time history.

- It must be based on adequate ground motion (compatible with the design acceleration spectrum over the intended range of natural periods) and carried out in accordance with known earthquake structural dynamics principles
- The Nonlinear time history analysis indicates a strong intensity shaking, of peak ground acceleration is 2.4m/s^2 . The diagonal members transfer loads efficiently and resistance to torsion during the seismic events

C. Modal mass participation

Modal analysis determines the natural resonance periods of a structure based on its overall mass and stiffness. These intervals of vibration are highly crucial to consider in earthquake engineering

- The rotation mode in the z direction has a maximum time period of 5.351 sec and a natural frequency of 0.18 HZ.
- The second and third modes are translation in the X and Y directions, respectively.
- Total modal mass involvement on the x and y directions is 99%, exceeding 90%

C. Story drift

The peak drift occurs, with values of around 0.004395 and 0.000664 based on THA on the X axis. The drift progressively increases from bottom to top, peaked at

story 11, and then decreased little at the tallest story. This is routine and appropriate seismic behavior, indicating no unexpected weakness or soft tale. The reported maximum drift values are well below permissible limits, indicating safe and efficient seismic performance based on the applied time history analysis. The drift curve is smooth, with no sharp leaps between two consecutive stories, showing that stiffness does not alter irregularly.

D. Story displacement

The topmost story (story 14) has a maximum displacement of 2.4567mm, whereas story 12 has a value of 0.4563mm. The curve has a gentle slope up to roughly story 4, indicating increased flexibility in the top half of the construction. The displacement grows gradually and linearly from the bottom to the top, indicating stable and elastic structural behaviour. There are no abrupt shifts, indicating a homogeneous lateral stiffness distribution across the height. Overall, the structure demonstrates adequate seismic displacement performance in the X axis, confirming steady lateral behaviour and energy dissipation.

E. Structural behaviour of beam

The maximum negative bending moment at the supports is -227.34 kNm, whereas the maximum positive bending moment at the middle span is 262.19 kNm. To withstand these moments, a top reinforcement of 962 mm2 near the supports and a bottom reinforcement of 936 mm2 at the midspan have been given. The maximum shear force is 179.57 kN on the left and right supports, with the minimum shear at the midspan being 74.34 kN. The design meets the strength and serviceability requirements, and the beam section is structurally safe.

VII. CONCLUSION

This study focuses on Non linear time history analysis of diagrid (grid shell) structure of a building having (B+G+12) stories. Based on the objectives carried out, the following conclusions are found

- After modelling the building with diagrid and without diagrids , found out that the diagrid building has significantly lower bending moments in beams and columns due to force being carried axially through diagonal members,

- The diagrid members carried 60 kN-m of moment whereas irregular reached 190kN-m
- The story overturning moment was also lower in diagrid structure as 9000kN-m compared to the irregular one as 12,500kN-m.
- Thus the results shown that diagrid structures are more efficient, leading to lower bending moment and improved seismic performance.
- The Nonlinear time history analysis indicates a strong intensity shaking, of peak ground acceleration is 2.4m/s^2 . The diagonal members transfer loads efficiently and resistance to torsion during the seismic events.
- The diagrid structure has a cumulative mass participation of 99.6% in X-direction (sumUX), 99.9% in Y-direction (sumUY), and 99.9% in Z-direction (sumUZ), indicating its dynamic accuracy and dependability for earthquake analysis.
- During the design check ,the maximum displacement occured 2.4567mm and at the story 12 with a value of 0.4563mm, the curve shows a gradual slope up to about story 4, shows greater flexibility in the upper portion of the structure
- The moment capacities vary up to 193.08kNm and the shear capacities reach up to 290.55kN. Ast values ranging from 1166 mm^2 to 2867.4 mm^2 The spacing of stirrups at 150mm and 200 mm at midspan. The provided design ensures the strength, ductility, and serviceability of the diagrid structure

Overall, the diagrid system is technically sound and economically viable solution for modern seismic resistant building design

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