Structural Analysis and Design of Multi-Storey Symmetric and Asymmetric Shape Building Using Conventional Slab and Grid Slab in Etabs

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Abstract:

The objective of the project is to investigate and compare the structural effectiveness of two categories of floor structures in multi-story constructions: traditional slabs and grid slabs. Utilizing the ETABS software, an in-depth analysis and design procedure will be executed to evaluate their operational efficiency. The study will encompass both symmetric and asymmetric building configurations to examine the response of these slabs under diverse structural conditions. Essential elements such as gravitational forces, lateral loads, and seismic forces will be meticulously taken into account during the building's design phase. ETABS offers robust tools for simulating and assessing building performance under these forces. The project involves the creation of a multi-story building model in ETABS, with a comprehensive examination and comparison of deflections, moments, shears, and stresses for both types of slabs. The primary focus is on appraising their structural efficacy and effectiveness. Various loading scenarios will be taken into consideration to assess the performance of each slab type. Additionally, the design of structural elements will adhere to building codes and standards to guarantee safety and stability.

Keywords: Asymmetric; Conventional Slab (C.S.); Grid Slab (G.S.); Symmetric; Storey Displacement; Storey Drift; Storey Shear.

1. Introduction:

The research project, titled "Investigation and Comparative Analysis of Multi-Storey Building Structures using Conventional Slabs and Grid Slabs in ETABS," aims to explore and contrast the structural behaviour of two distinct slab types—conventional and grid slabs—in the context of multi-storey buildings. Employing the ETABS software for analysis and design, the primary goal is to evaluate the efficiency of these slabs within both symmetric and asymmetric building layouts. The assessment encompasses a thorough examination of floor slab performance under various structural conditions, considering gravitational forces, lateral forces, seismic activity, and wind forces. The design of multi-storey buildings takes into account factors such as dead loads, live loads, wind loads, and seismic forces to understand their impact on structural elements. The project involves creating a detailed multi-storey building model in ETABS, exploring symmetric and asymmetric configurations, and subjecting the structure to diverse loads for testing. The analysis covers key structural aspects, including displacements, bending moments, shear forces, and internal stresses. A comparative study is conducted between conventional slabs, known for their simplicity and cost-effectiveness, and grid slabs, which enhance structural efficiency through the use of a grid of beams. Grid slabs offer advantages such as reduced material usage, longer spans, and improved load-bearing capacity. The primary objective is to assess and compare the structural performance of conventional and grid slabs, with a specific focus on displacements, member forces, and overall structural efficiency. The research also extends to evaluating each slab type's performance under varying loading scenarios. Based on the analysis results, the project proceeds to design structural elements like columns, beams, and slabs in compliance with relevant building codes and standards, ensuring structural integrity and safety. In conclusion, the project's findings aim to provide valuable insights into the comparative performance of conventional slabs and grid slabs in multi-storey buildings. This information is intended to assist engineers and architects in making informed decisions when selecting suitable slab systems for diverse building layouts.

The literature is reviewed from various sources includes books, journals, notes, video lectures, codes etc. The standards are established by the Bureau of Indian Standards (BIS) are fundamental in the assessment of the forces acting upon structures. In our research, we have utilized the Indian standards (IS 456-2000)[1], (IS 1893-1, 2016)[2], (IS 875-1, 1987)[3] and (IS 875-2, 1987)[4] as key references when considering factors associated with static and dynamic loads. Latha M.S, Pratibha K(2020)[5] paper help me to understand through there paper that the conventional slab experiences the highest deflection in a regular structure, while in irregular structures, the grid slab demonstrates the greatest deflection. Additionally, in both regular and irregular structures, story displacement is maximized in the grid slab system and minimized in the conventional slab. Maulin Patel and Abbas Jamani(2022)[6] generally investigate on the Analysis and Design of a multi-storey building for various slab configurations to analyze the structural behavior of the building across different seismic zones where they focused on evaluating parameters such as Story Displacement, Story Drift, and Shear Force using the ETABS software. Mr. K. Prabin kumar, R. Sanjaynath(2018)[7] provides the basic scenario on how to carry out the detail study of multi-storey residential building in detail. In-depth research on Grid Slabs and Flat Slabs is conducted by Mr. Y.K.Nikam and Dr.H.S.Jadhav(2022)[8], their study provides valuable guidance on how to appropriately employ these slab types with respect to spans and structural necessities, thus facilitating slab design alignment with these crucial factors. Mr.Chintha Santosh, Mr. Vankatesh Wadki(2016)[9] provides an extensive examination of the utilization of grid slabs in multi-story buildings. These grid floor systems comprise beams arranged regularly in perpendicular orientations, creating a monolithic structure with the slab. Usually, the dimensions of the perpendicular beams remain constant. In our project, we have opted for a diagonal beam grid layout, and we will present a comprehensive insight into our project's execution. Investigating the Dynamic Performance of Reinforced Concrete Structures, Mahek H. Dholu, Pintu R. Senghani, and Narendra R. Pokar(2020)[10] have explore Flat, Conventional, and Grid Slabs under various plan configurations, including Regular and Irregular layouts. The study employes Response Spectrum and Time History analysis to evaluate the influence of bracing. The primary focus of Syed Abdul Qavi, Syed Khaleelullah Shah Quadri, and Syed Farrukh Anwar(2019)[11] lies in conducting Comparative Analysis and Design for Flat and Grid Slab Systems, in contrast to the standard slab system. Their research involves varying column spacing and grid sizes to determine the most cost-effective approach to slab design. A thorough investigation into flat, grid, and conventional slabs is done by Abhijit K Sawwalakhe and Prabodh D Pachpor(2021)[12], with the primary goal of identifying the most budget-friendly option among the grid slab, flat slab with a drop, and standard slab. Anitha.K ,R.J Rinu Isah(2017)[13] priories detail study on grid slab which help us in understanding the slab design in detail. Mrunal .C. Lonare and Dr. P. Nagarik(2022)[14] provides analysis under seismic condition for flat slab and grid slab design consideration

The assessment of how constructions respond to dynamic forces such as earthquakes, wind pressures, or vibrations induced by human activity is conducted through the linear dynamic analysis of structures. The goal is to assess the response of the structure concerning movements, accelerations, and internal stresses. Engineers create a mathematical model of the structure, considering its dimensions, material properties, and limitations, often utilizing finite element analysis.

where they analyses that the Storey shear and drift is maximum at the bottom and minimum at the top of the building. Anghan Jaimis, Mitan Kathrotiva(2012)[15] have done study on comparison between Flat slab and Grid slab where I am able to understand detail considerations of parameters to be considered in the study. Aradhna ganvir(2021)[16] study of flat slab with finite element analysis by considering the factors associated with the openings and without openings which compared the results. Amit Sathawane and R.S. Deotale(2021)[17] helps to understand the detail design procedure to be followed while designing the flat and grid slab along with the cost that is to be required for the design.

2. Methods of analysis:

2.1. Static analysis: Static analysis is a crucial technique within the realm of structural engineering, aimed at evaluating how structures perform and remain stable under different circumstances and applied forces. Its primary goal is to verify that structures can withstand gravitational forces, wind pressures, seismic activities, and other external loads without experiencing excessive stress or deformation. This evaluation is based on the principles of equilibrium, where the total sum of forces and moments acting on the structure must be zero to maintain a static balance. Furthermore, static analysis considers various loads such as dead loads, live loads, wind loads, seismic forces, and temperature-induced effects to calculate internal forces and structural deformations.

2.2. Response spectrum analysis: Nonlinear dynamic analysis stands as a crucial technique in evaluating how a structure reacts to dynamic forces such as earthquakes or powerful winds. In contrast to linear analysis, which presupposes linear and elastic responses, this method takes into account the nonlinear properties of materials and structural components. The procedure encompasses several pivotal stages. Initially, a three-dimensional structural model is formulated through specialized software, accurately capturing the geometry and characteristics of the building.

2.3. Dynamic Analysis:

3. Objectives:

The primary objectives of this project can be succinctly delineated as follows:

• Develop designs for two multi-storey buildings (G+5) employing two different plan configurations, encompassing:

- Symmetrical multi-storey building design

- Asymmetrical multi-storey building design

• Conduct a thorough analysis and design for the buildings, considering two distinct reinforced slab options.

• Devise a design for Grid Slabs: Investigate and formulate designs for grid slabs on specific floors within the building. The project seeks to explore the feasibility and advantages of incorporating grid slabs in the proposed building design.

• Formulate a design for Conventional Slabs: Create a design for standard floor structures in the multi-story building, incorporating the findings from the analysis. This involves determining the necessary reinforcement, floor thickness, and other design parameters to ensure that the floors can adequately withstand applied loads.

• Undertake Response Spectrum Analysis and compare design aspects and configurations for all four building models. Understand the positive and negative attributes that guide the appropriate way of designing the structure for different slab systems.

• Conduct a Comparative Study: Compare the structural behaviour, construction feasibility, material requirements, and cost implications of conventional slab and grid slab systems. Analyse the pros and cons of each system to ascertain their suitability for the given project.

• Evaluate Structural Performance: Examine the structural integrity of the building under various loading conditions, including gravitational and seismic forces. Assess parameters such as story displacement, stress distribution, story drift, and story shear to ensure compliance with prescribed performance standards and code requirements.

3.1. Software's used in analysis:

ETABS 2019: The formidable software ETABS 2019, developed by Computers and Structures, Inc. (CSI), is dedicated to the examination and planning of structures. ETABS, its abbreviation, represents "Extended Three-dimensional Analysis of Building Systems." Structural engineers extensively employ ETABS to assess, design, and analyse diverse categories of buildings and structures.

AutoCAD 2017: Autodesk's AutoCAD 2017, a product in the field of computer-aided design (CAD), is extensively employed across diverse industries such as architecture, engineering, construction, and manufacturing. This software introduces numerous advancements and improvements aimed at boosting design efficiency and productivity. AutoCAD 2017 specifically focuses on enhancing 2D drafting and documentation capabilities, bringing forth significant improvements in these aspects.

3.2. Types of Slab considerations:

Conventional Slab: A commonly used method for constructing floors in the building industry is the Conventional slab. This particular type of flooring comprises reinforced concrete, providing a level and secure surface for occupants while effectively supporting the loads from the structure above. Essentially, the Conventional slab is a vital element in a building's structural framework, typically extending over supporting beams or walls. Its main role is to adeptly transfer various loads, including the inherent weight of the slab (dead loads) and the fluctuating loads resulting from occupancy, furniture, and other influences (live loads), to the supporting elements beneath.

Grid Slab: A grid slab, also referred to as a waffle slab, constitutes a specially engineered flooring or roofing system crafted from reinforced concrete. Comprising an arrangement of slender beams or ribs in a grid configuration, this structural design serves the purpose of efficiently distributing loads, offering a robust yet lightweight framework with minimal utilization of concrete and reinforcement. To put it simply, these grids are architectural elements employed in spaces such as theatres, auditoriums, lobbies, and showrooms that require expansive open areas. Typically adopting square or rectangular shapes on the ceiling, they are utilized for installing various architectural lighting fixtures and fulfilling other purposes. Engineered to cover extensive areas without the need for additional columns, such grid structures have found application in numerous locations across India and other countries. When external forces are exerted onto the grid's surface, it manifests as an interconnected network of beams or bars forming the structural grid.

4. Methodology:

4.1. Pathway followed for the analysis: The objective of this study is to assess the performance of multi-story reinforced concrete (R.C) frame structures, investigating both symmetric and asymmetric floor layouts. The ground floor has a height of 4m, while the subsequent 1st to 5th storeys have a height of 3m for both Symmetrical and Asymmetrical buildings. Four distinct models will be generated based on the chosen slab design type:

- Symmetrical building design with Conventional slab.

- Symmetrical building design with Grid slab.

- Asymmetrical building design with Conventional slab.

- Asymmetrical building design with Grid slab.

The frame structures underwent characterization, and models were developed using E-tabs software. Various load scenarios were considered during the analysis. The static behaviour was determined by IS 875 Part I, specifying the dead load, while IS 875 Part III dictated the live load. Lateral forces were assessed following the provisions of IS 1893 (Part 1) 2016.

Using Response Spectrum Analysis in E-tabs software, three-dimensional reinforced concrete structures with G+5 stories were analysed. The analysis focused on studying the structural aspects of the buildings, including Storey Shear, Storey Drift, Storey Displacement, and Storey Shear.

4.2. Problem Statement of Symmetric & Asymmetric shape Building Analysis:

The purpose of this project is to investigate two structures comprising five stories each, characterized by symmetrical and asymmetrical designs employing both Conventional and Grid slab design approaches. In accordance with section 5.1, four design models are currently in preparation. The focal point of the analysis revolves around evaluating Multi-storey R.C.C Buildings utilizing E-tabs software in seismic zones II. The chosen designs feature both symmetric and asymmetric forms. While these designs do not represent an existing or planned construction, they function as architectural blueprints. The structure has undergone analysis to evaluate its response to both static and dynamic seismic forces.

4.3. 3D Model Views of Structure:

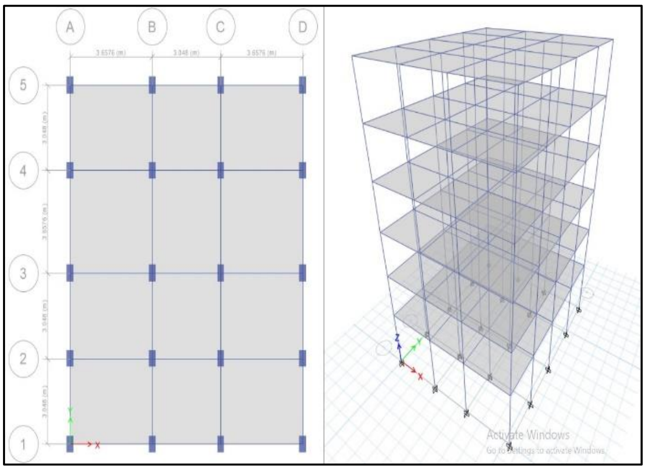


Fig.1. Symmetric shape of building using C.S.

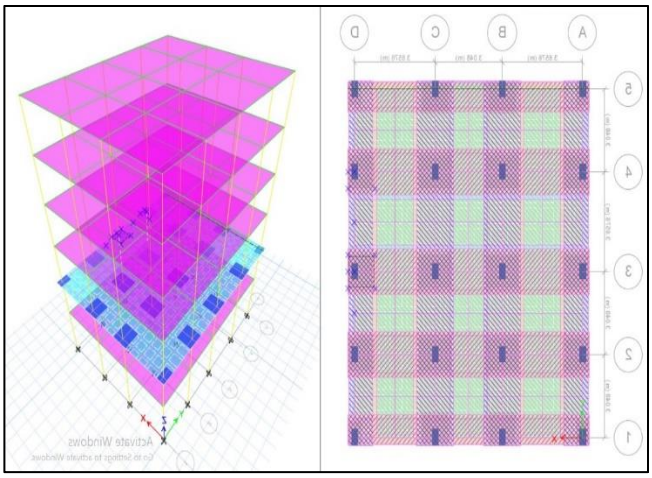


Fig.2. Symmetric shape of building using G.S.

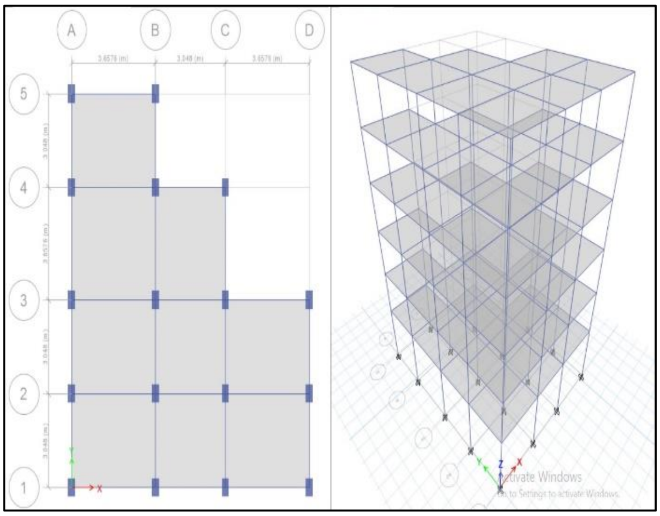


Fig.3. Asymmetric shape of building using C.S.

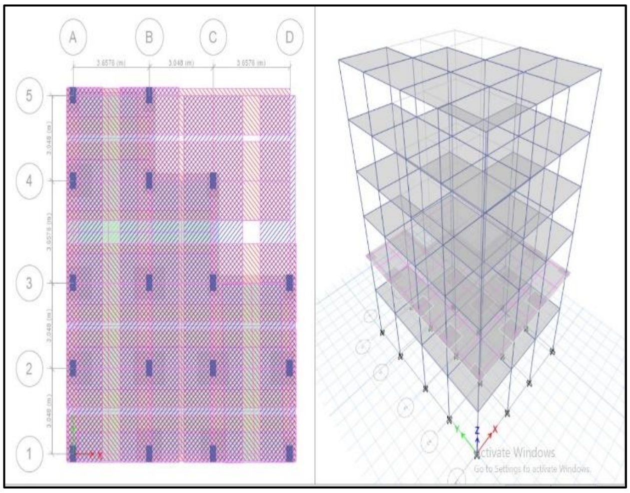


Fig.4. Asymmetric shape of building using G.S.

5. Results and discussions:

5.1. Shear Force Displacement visualization due to Earthquake load:

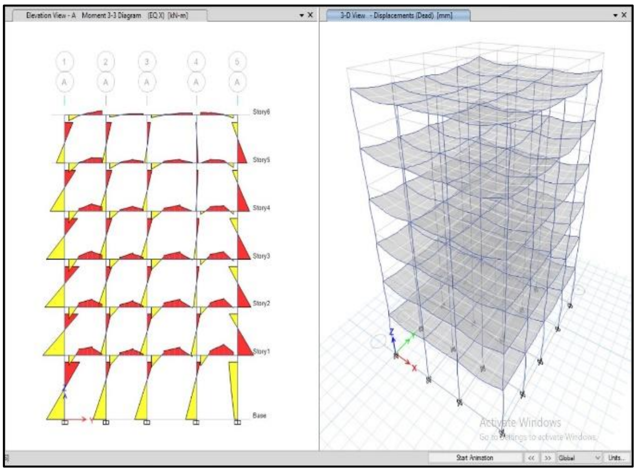


Fig.5. Symmetric shape building using C.S.

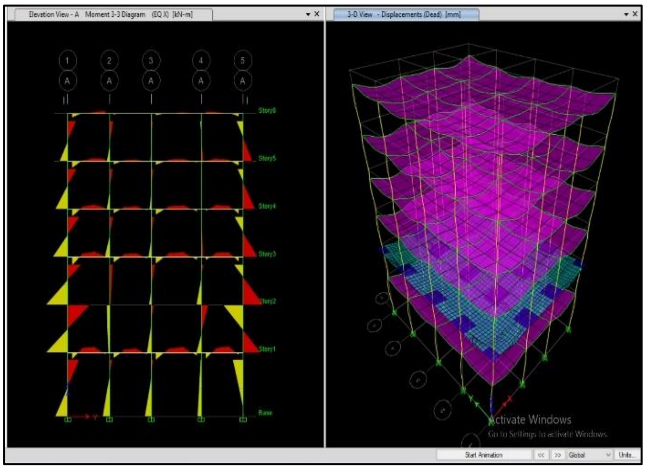


Fig.6. Symmetric shape building using G.S.

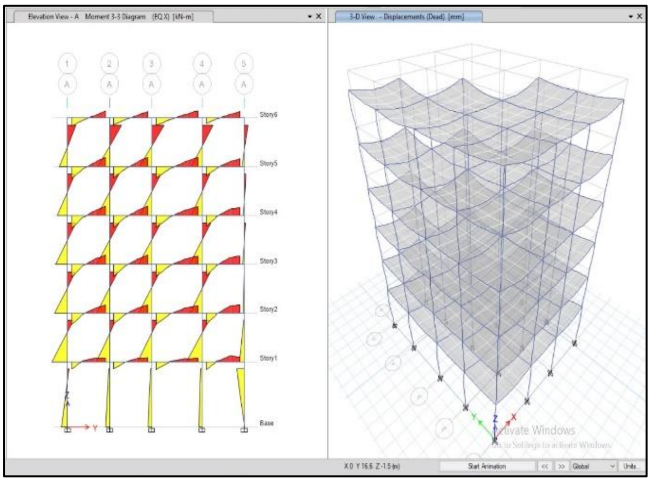


Fig.7. Asymmetric shape building using C.S.

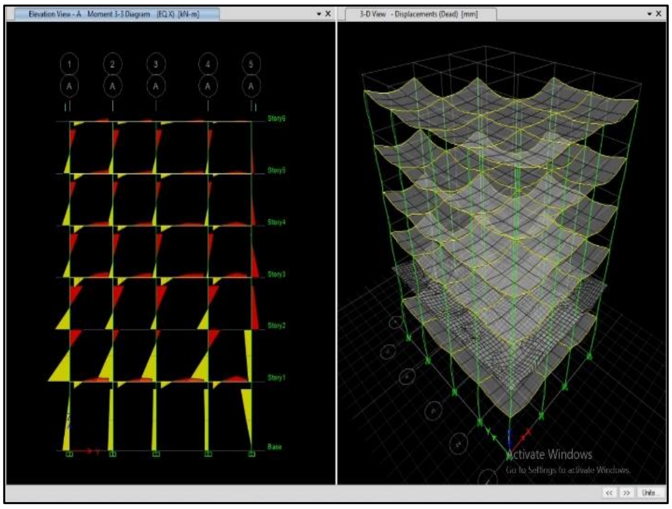


Fig.8. Asymmetric shape building using G.S.

5.1. Deflection diagram visualization due to Earthquake load:

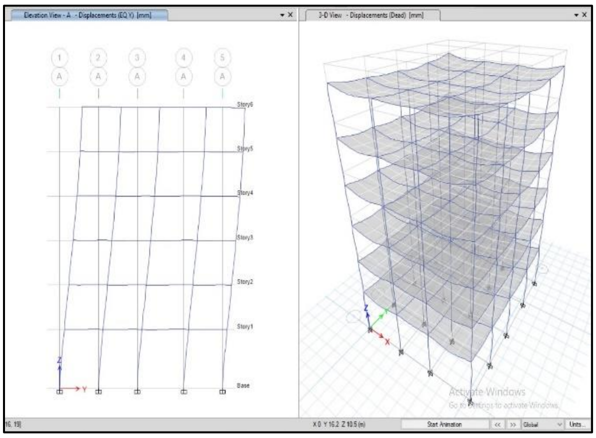


Fig.9. Symmetric shape building using C.S.

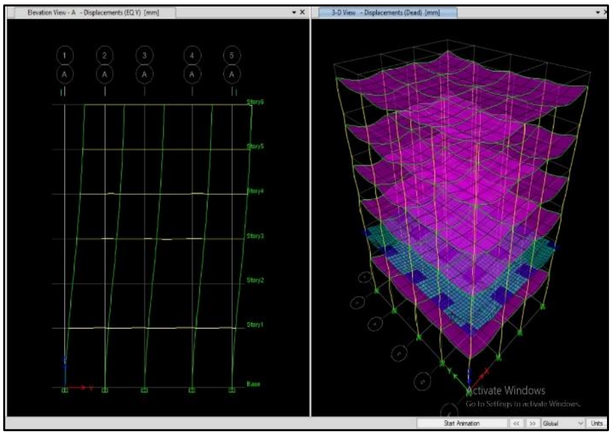


Fig.10. Asymmetric shape building using C.S.

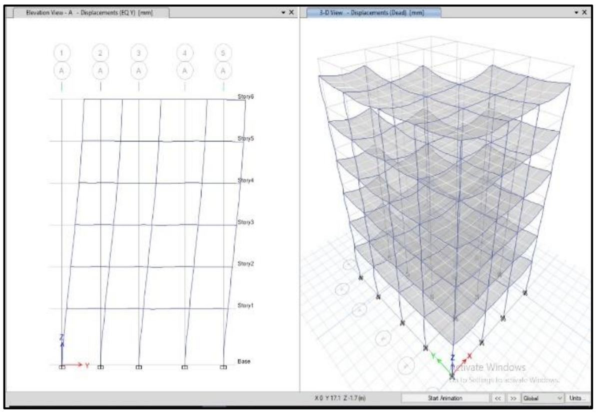


Fig.11. Symmetric shape building using G.S.

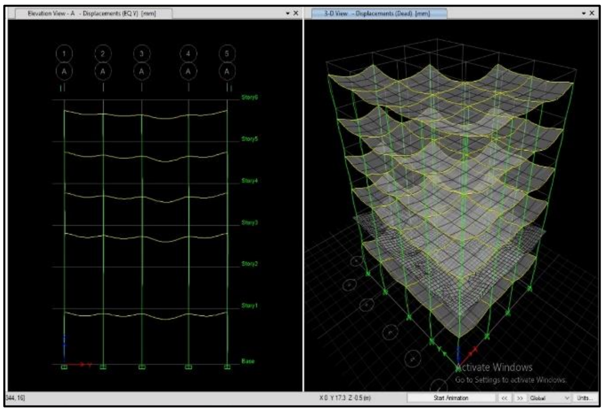
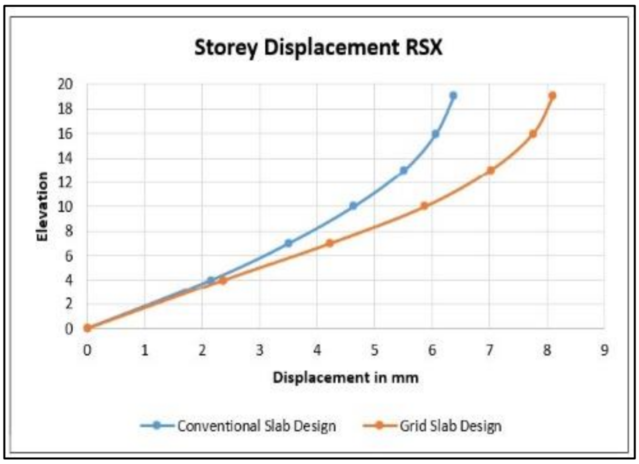


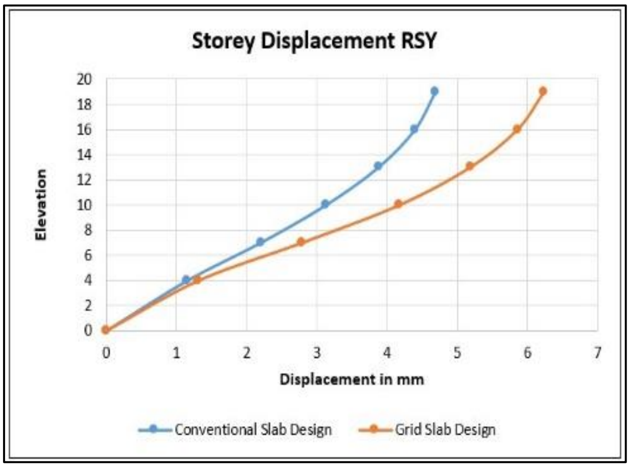
Fig.12. Asymmetric shape building using G.S.

5.3. Storey Displacement:

- **Comparison for Storey Dispacement RSX & RSY between Conventional Slab design VS Grid Slab design of Symmetrical shape multistorey building model :**



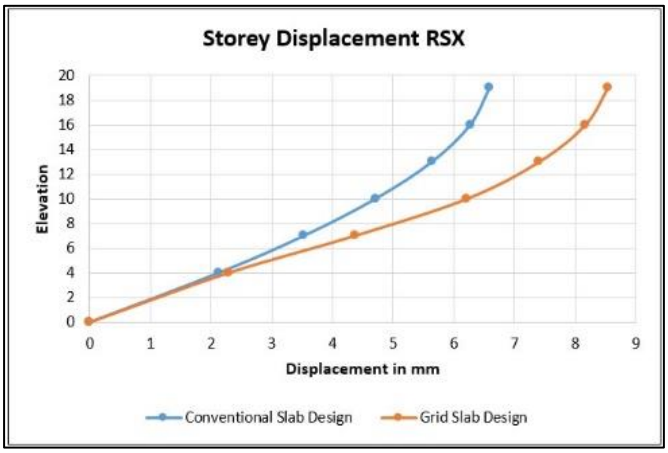
Graph.1. Storey Displacement RSX



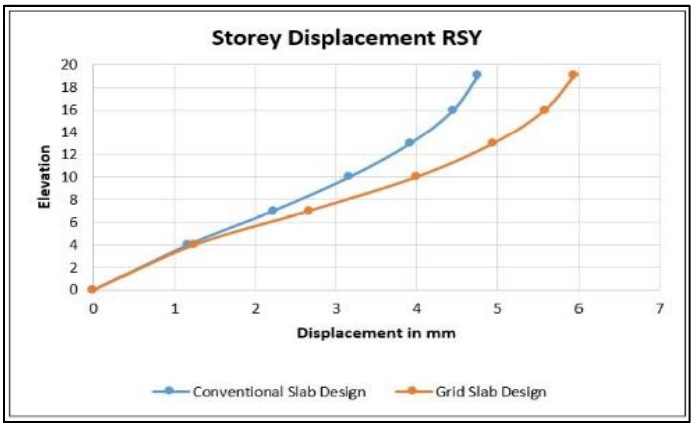
Graph.2. Storey Displacement RSY

The visual depictions indicate that there is a lesser percentage variation in Storey Displacement RSX and RSY when dealing with a Symmetrical building in the traditional slab design framework compared to the grid slab design approach. To be specific, the difference is around 20-25% (about 23.86%) for RSX and 25-30% (roughly 28.26%) for RSY during the transition from the conventional to the grid slab design.

- **Comparison for Storey Dispacement RSX & RSY between conventional slab design VS grid slab design of Asymmetrical shape multistorey building model :**



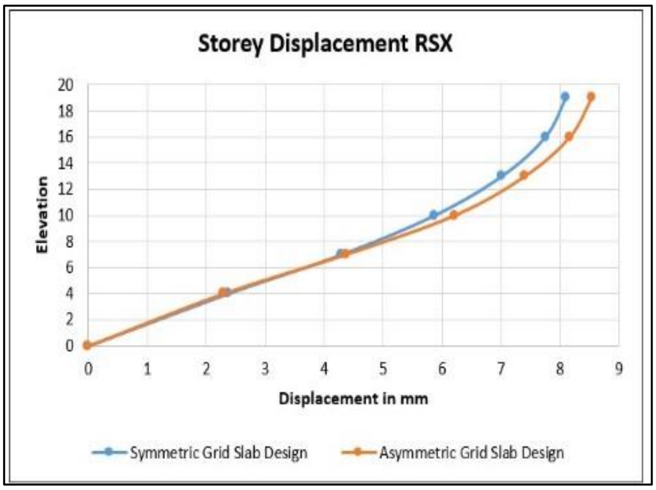
Graph.3. Storey Displacement RSX



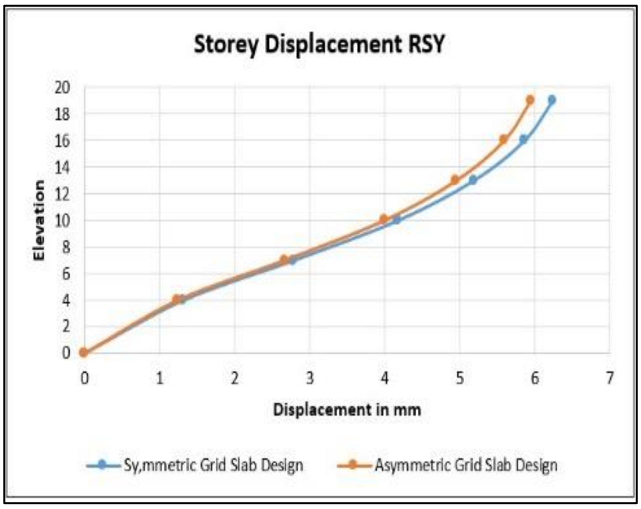
Graph.4. Storey Displacement RSY

In the previously shown charts, it is clear that the change in percentage for Storey Displacement RSX and RSY in an Asymmetrical building is less in the traditional slab design model than in the grid slab design model. To be more precise, there is a variation of around 20-30% (roughly 25.81%) for RSX and 20-25% (approximately 22.25%) for RSY when moving from the conventional to the grid slab design model.

- **Comparison for Storey Dispacement RSX & RSY between grid slab design of Symmetric building model VS grid slab design of Asymmetrical shape multistorey building model :**



Graph.5. Storey Displacement RSX

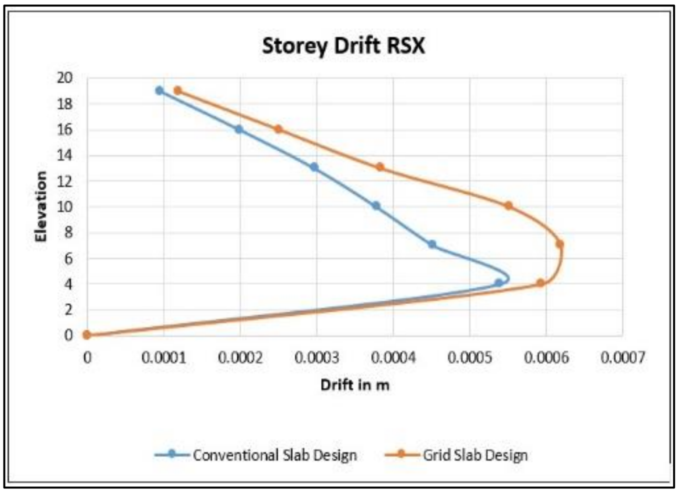


Graph.6. Storey Displacement RSY

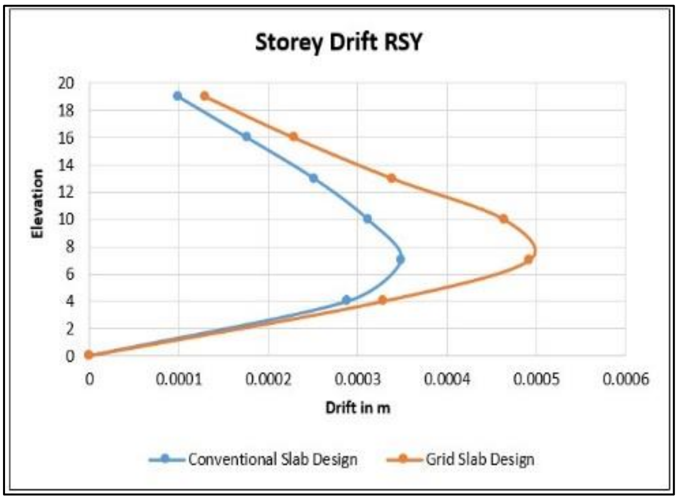
Examining the information provided in the table and graph, it is clear that there is a noticeable decrease in the percentage alteration of Storey Displacement RSX and RSY when considering the Symmetric Grid slab design model in contrast to the Asymmetric Grid slab design model. More precisely, the fluctuation ranges from 1% to 10%, with RSX demonstrating an approximate change of 5.31%, and RSY exhibiting an approximate alteration of 4.76% when moving from the Symmetric Grid to the Asymmetric Grid slab design model.

5.4. Storey Drift:

- **Comparison for Storey Drift RSX & RSY between conventional slab design VS grid slab design of Symmetrical shape multistorey building model :**



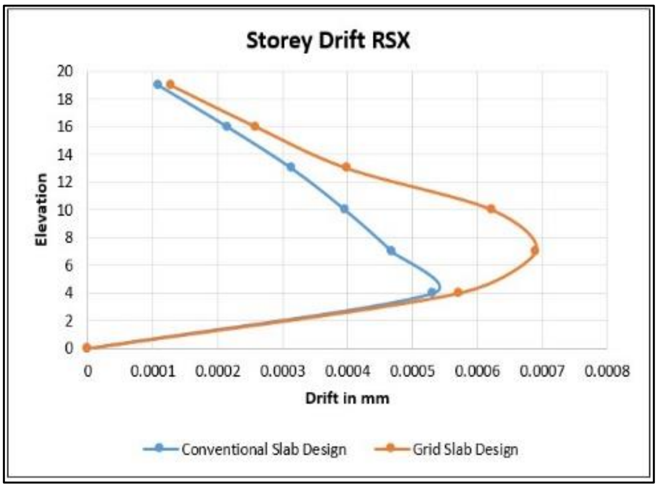
Graph.7. Storey Drift RSX



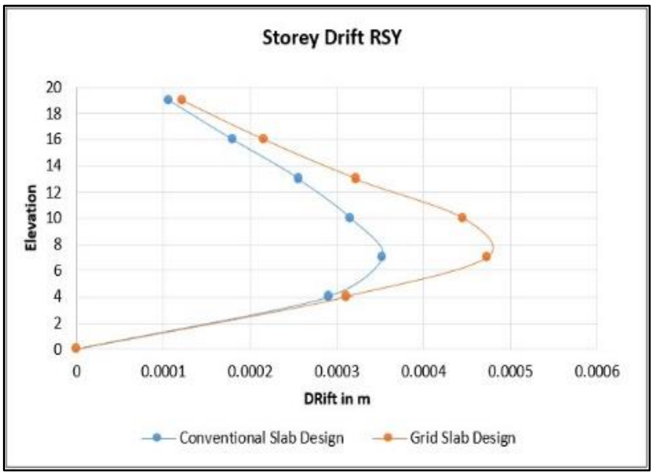
Graph.8. Storey Drift RSY

The charts depict a diminished percentage fluctuation in Storey Drift RSX and RSY for the symmetrical structure when employing the traditional slab design model compared to the grid slab design model. The difference is approximately 30-40% (around 32%) for RSX and 30-40% (about 34%) for RSY when moving from the conventional to the grid slab design.

- **Comparison for Storey Drift RSX & RSY between conventional slab design VS grid slab design of Asymmetrical shape multistorey building model :**



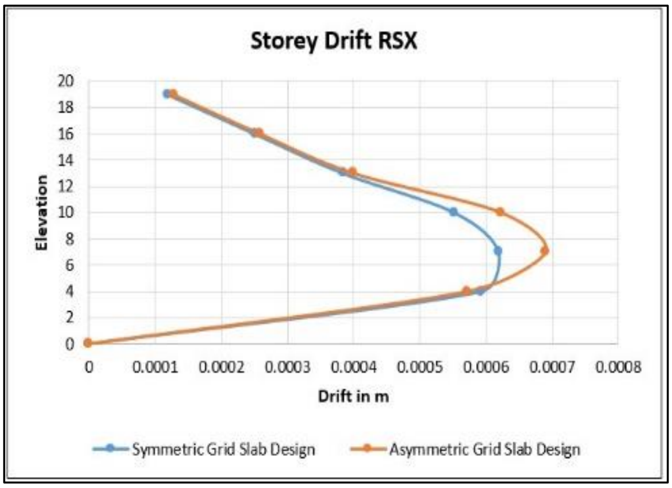
Graph.9. Storey Drift RSX



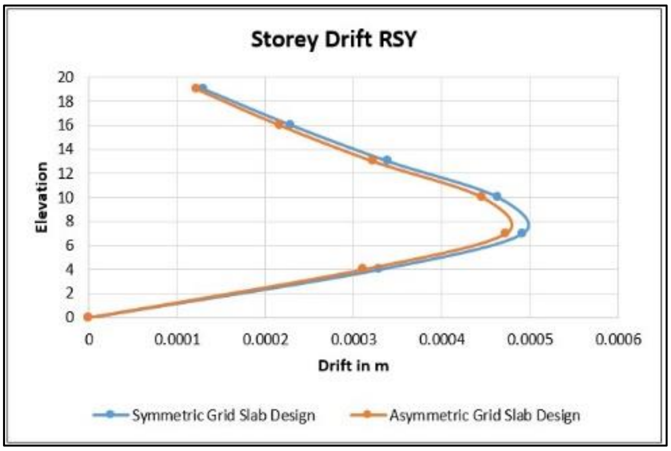
Graph.10. Storey Drift RSY

Analysing the charts presented earlier reveals that there is a noticeable decrease in the percentage alteration of Storey Drift RSX and RSY in the case of the Asymmetrical building when using the traditional slab design model compared to the grid slab design model. This difference is approximately 8% for RSX and around 29% for RSY when transitioning from the conventional to the grid slab design model.

- **Comparison for Storey Drift RSX & RSY between grid slab design of Symmetric building model VS grid slab design of Asymmetrical shape multistorey building model :**



Graph.11. Storey Drift RSX

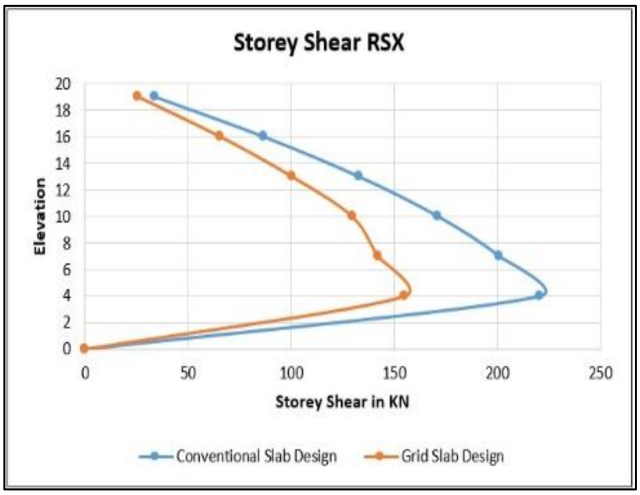


Graph.12. Storey Drift RSY

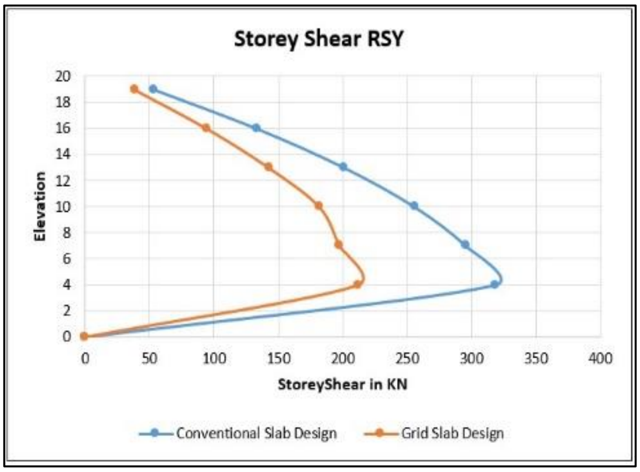
Based on the table and chart presented earlier, it is evident that the percentage change in Storey Drift RSX and RSY is lower in the Symmetric Grid slab design model compared to the Asymmetric Grid slab design model. The observed difference is approximately 7.28% for RSX and 6.35% for RSY when comparing the Symmetric Grid slab design model with the Asymmetric Grid slab design model.

5.5. Storey Shear:

- **Comparison for Storey Shear RSX & RSY between conventional slab design VS grid slab design of Symmetrical shape multistorey building model :**



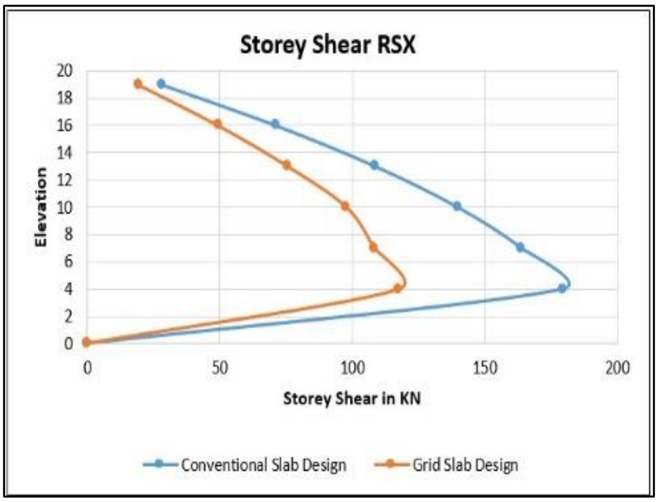
Graph.13. Storey Shear RSX



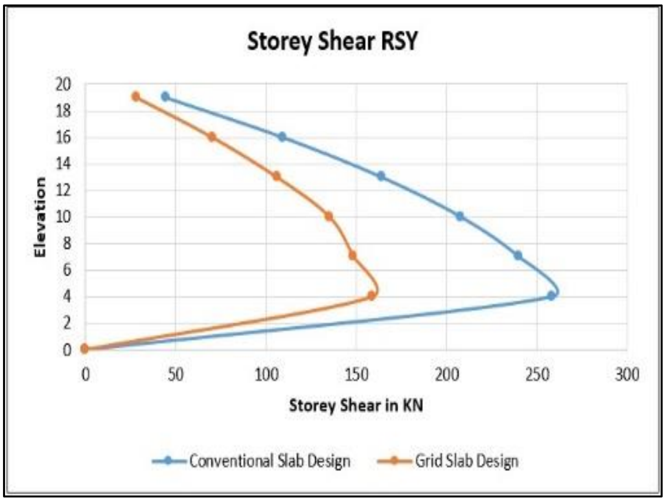
Graph.14. Storey Shear RSY

The visual depictions unmistakably show that the variation in Storey Shear RSX and RSY percentages is more conspicuous in a symmetrical building's conventional slab design model as opposed to the grid slab design model. Precisely, there is an alteration of about 34% in RSX and roughly 40% in RSY when shifting from the conventional to the grid slab design model.

- **Comparison for Storey Shear RSX & RSY between conventional slab design VS grid slab design of Asymmetrical shape multistorey building model :**



Graph.15. Storey Shear RSX.



Graph.16. Storey Shear RSY.

Based on the visual depiction above, it is evident that the percentage difference in Storey Shear RSX and RSY for an Asymmetrical building is higher in the conventional slab design model compared to the grid slab design model. The observed fluctuation is approximately 40-50% (around 42%) for RSX and 40-50% (approximately 44%) for RSY when transitioning from a conventional to a grid slab design model.

5.6. Moments on beams:

• Analysis of moment distribution on beams in a building with a Symmetric shape and a Conventional slab (G+5) reveals that the maximum moment for this structural configuration is approximately 14.587 kilonewton-meters.

• Evaluating moment distribution on beams in a Symmetric shape building with a Grid slab (G+5) indicates that the maximum moment for this type of structure is approximately 10.40 kilonewton-meters.

• Investigation into moment distribution on beams in an Asymmetric shape building with a Conventional slab (G+5) demonstrates that the maximum moment for this architectural design is approximately 12.08 kilonewton-meters.

• Examining moment distribution on beams in an Asymmetric shape building with a Grid slab (G+5) illustrates that the maximum moment for this specific structure is approximately 7.22 kilonewton-meters.

6. Summary:

- The research project titled 'Analysis and Design of Multi-Storey Buildings with Conventional and rid Slab Systems in ETABS' provides a comprehensive overview of key elements for multi-storey structures. This encompasses the integration of both conventional and grid slab methodologies, facilitated through the use of the ETABS software.

- Outlined the study's objectives, underscoring the importance of structural analysis and design in the context of multi-storey buildings. Emphasized the pivotal role played by the ETABS software throughout the entire process.

- Conducted an in-depth examination of existing literature and research on structural analysis and design techniques applicable to multi-storey buildings, with a specific focus on conventional and grid slab systems. Evaluated the pros and cons of each system, referencing prior studies leveraging the capabilities of ETABS.

- Clarified the study's methodology, delineating the criteria for selecting multi-storey buildings, factors taken into account, and the procedural aspects of the analysis and design process. Expounded on the involvement of the ETABS software in modeling, analyzing, and designing.

- Provided a step-by-step account of creating the structural model for multi-storey buildings in ETABS, encompassing tasks like defining structural geometry, assigning material properties, specifying loading conditions, and applying constraints.

- Utilized ETABS for structural analysis, considering diverse load scenarios such as dead loads, live loads, wind loads, and seismic loads. Evaluated structural performance with a focus on deflections, internal forces, and stability.

- Executed the design phase for chosen slab systems (conventional and grid slabs) based on analysis results from ETABS. This involved determining necessary reinforcement for each slab component, including beams and columns, while adhering to applicable design codes and standards.

- Scrutinized the study's outcomes, evaluating the efficacy of ETABS in the structural analysis and design of multi-storey buildings utilizing conventional and grid slab systems. Additionally, presented detailed findings, drew conclusions, and proposed potential avenues for future research or enhancements in the design process.

associated with structural analysis and design

7. Conclusion:

In the conclusion, it is evident that static analysis alone is insufficient for high-rise building structures, necessitating dynamic analysis. Proportional static assessments often lead to economically unfavorable results due to higher displacement estimates compared to dynamic investigations. The study's key findings can be summarized as follows:

1. Storey Displacement:

Comparison between conventional slab and grid slab designs for Symmetrical and Asymmetrical building models reveals that the conventional slab design model exhibits lower storey displacement than the grid slab design model. Further analysis of grid slab design shows that Symmetrical building models experience less storey displacement than their Asymmetrical counterparts.

2. Storey Drift:

When comparing conventional slab and grid slab designs for Symmetrical and Asymmetrical building models, it is evident that the conventional slab design model has less storey drift than the grid slab design model. Additionally, the study highlights that Symmetrical building models using grid slab design have less storey drift than their Asymmetrical counterparts.

3. Storey Shear:

Comparative analysis between conventional slab and grid slab designs for Symmetrical and Asymmetrical building models demonstrates that the conventional slab design model has less storey shear than the grid slab design model. Examining grid slab design further reveals that Symmetrical building models experience less storey shear than their Asymmetrical counterparts. Compliance with earthquake-resistant design standards (IS 1893(Part 1): 2016) favours the conventional slab design approach over the grid slab design method for both symmetrically and asymmetrically shaped buildings.

4. Additional Insights:

Grid slabs require a significantly larger amount of concrete and steel compared to traditional slab construction. Concrete volume increases with the span or grid size of structures, even with the same slab system. Conventional slabs are preferable for residential and compact span constructions, while grid slabs are chosen for larger span structures like shopping malls, auditoriums, and grand halls to enhance architectural elegance. Future research directions involve implementing structural optimization algorithms to improve cost-efficiency in structural engineering, considering slab properties regardless of symmetry or asymmetry.

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Author's contribution:

The A has done research on the project and have written the research paper under the guidance of B and reviewed by B.

Declaration:

Declaration of No Conflicts of Interest: As far as the authors are aware, the work was carried out with equal input from each of them. Consequently, we assert that there are no conflicts of interest among the authors.

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