A TWO-STORY BUILDING'S STRUCTURAL MEMBER OPTIMIZATION FOR IMPROVED SEISMIC PERFORMANCE VIA THE USE OF FINITE ELEMENT ANALYSIS

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Abstract - Efficient structural design techniques are necessary for reinforced concrete framed structures in seismic areas to provide sufficient strength, stiffness, and economy. Traditional methods of design often use conservative member size, which may lead to wasteful material usage with little to no improvement in structural performance. A two-story framed structure was the subject of a finite element-based optimization study conducted using ANSYS Workbench in this research. Surface bodies were used for slab components and line bodies for structural elements in the development of a three-dimensional structural model. The model was then subjected to finite element discretization and static structural analysis under combined gravity and equivalent seismic loading conditions. Using total deformation, directed deformation, and equivalent stress distribution, the structural reaction was analyzed. Seismic loading deformation patterns and areas of significant stress concentration were uncovered by the research. Slab thickness and column cross-sectional dimensions were varied using the validated finite element model for structural optimization. The goal was to minimize structural mass while satisfying strength, drift, and frequency constraints, as outlined in IS 456:2000 and IS 1893 (Part 1):2016 provisions. In order to find the most efficient structural arrangement, we used an optimization method based on response surfaces to compare several design options. Minimizing structural mass without sacrificing dynamic performance, inter-storey drift limitations, or tolerable stress levels was the goal of the optimized model. This research provides a realistic foundation for cost-effective and code-compliant structural design by showing that optimization based on finite elements may significantly increase the material efficiency of seismic-resistant low-rise buildings.

Keywords - The following terms are used in this context: structural performance, IS 1893:2016, finite element analysis, seismic analysis, optimized structures, reinforced concrete frames, equivalent static methods.

I. INTRODUCTION

Severe damage, economic losses, and structural collapses are some of the most devastating effects of earthquakes on human settlements and their supporting infrastructure. Seismic zones expose buildings to complicated lateral forces caused by ground motion, which in turn increase the demands placed on structural materials by means of axial forces, deformation, shear forces, and bending moments. Assuring that structures are adequately resistant to earthquakes has become a significant problem in structural engineering practice in nations like India, where a significant section of the geographical region is classed under moderate to severe seismic zones.Due to its strength, longevity, and adaptability during construction, reinforced concrete (RC) framed structures are extensively used for residential, commercial, and institutional buildings. Structure, member size, material characteristics, load distribution, detailing, and seismic performance are all important factors to consider. Buildings may experience severe deformation, structural damage, or even collapse due to a lack of seismic consideration, poor member size, or inadequate stiffness, as seen in previous earthquake occurrences.Analytical computations and predetermined member dimensions derived from design rules are the mainstays of conventional structural design methods. These techniques work well for guaranteeing minimal safety standards, but they could lead to overly cautious designs that use too much material. The need for optimal structural designs that accomplish the necessary levels of safety with minimal material consumption has arisen as a result of rising building costs and the requirement for sustainable infrastructure.A potent computer method for assessing structure behavior under complicated loading scenarios, Finite Element Analysis (FEA) has recently arisen. Functional engineering analysis (FEA) allows for more accurate modeling of structural geometry, material behavior, boundary conditions, stress distribution, and deformation patterns than traditional analytical approaches. Advanced finite element software systems like ANSYS Workbench enable engineers to study structural performance prior to construction via powerful modeling, analysis, and optimization capabilities.Various methods may be used to do seismic analysis of structures. These include the Equivalent Static Method, the Response Spectrum Method, and Time-History Analysis. For typical low-rise structures, the Equivalent Static Method is the go-to since it's easy to understand and works with the requirements laid down in IS 1893 (Part 1):2016. It gives accurate predictions of the structural reaction for basic building layouts and portrays earthquake impacts by means of equal lateral forces spread along the building's height. The need for cost-effective and environmentally friendly solutions has propelled structural optimization to the forefront of contemporary civil engineering. The goal of optimization is to maximize structural performance within the bounds of safety and serviceability by adjusting design factors such member size, material distribution, and structural arrangement. Optimizing the thickness of the slab and the size of the columns in reinforced concrete structures may greatly decrease the amount of material needed while still ensuring sufficient strength and stiffness. A two-story framed structure is optimized, seismically evaluated, and modelled using ANSYS Workbench in this current work. The structural parts and surface bodies of the slab are used to create a three-dimensional model. Using deformation and stress metrics, the structure is examined under both gravity loading and corresponding seismic loading scenarios, with the goal of evaluating the response. A size optimization study is conducted using the verified finite element model to decrease structural mass while fulfilling criteria for strength, drift, and dynamic performance. This study aims to show that finite element-based optimization may improve the structural efficiency of buildings that are resistant to earthquakes. By combining numerical simulation with optimization methods, the paper lays out a methodical strategy for creating structural designs that are safe, cost-effective, and in compliance with codes.

II. LITERATURE REVIEW

There has been a plethora of study on seismic performance assessment and optimization of building structures in response to the growing need for safer and more cost-effective structural systems. Buildings with reinforced concrete frames react differently to earthquakes depending on a number of variables such as their design, the materials used, the distribution of stiffness, and the seismic analysis technique used. Due to recent developments in computational methods, engineers may now use optimization and finite element modeling to reliably anticipate how structures would react. A number of seismic analysis techniques have been developed to assess how buildings react when earthquakes are felt. Regular low-rise structures often use the Equivalent Static Method (ESM), which is both easy to understand and often used. By using seismic characteristics including zone factor, importance factor, response reduction factor, and structural period, this approach may transform earthquake impacts into lateral forces that can be applied at various floor levels. For standard, low-rise structures, the Equivalent Static Method yields adequate results with very little computing work, according to the research. With the Response Spectrum Method, you may get better results since it takes into account the dynamic properties of buildings using different vibration modes. Particularly for medium-rise and irregular buildings, reaction spectrum analysis outperforms similar static analysis in terms of providing accurate predictions of storey displacement, base shear, and member forces, according to many studies. The computing needs and increased modeling complexity, however, make it unsuitable for routinely designing basic low-rise structures. By directly applying real-world earthquake ground acceleration data to the structural model, Time-History Analysis stands as the most cutting-edge seismic assessment method. We know from prior research that this method provides a more accurate representation of nonlinear behavior, processes of energy dissipation, and increasing structural degradation. But it's not practicable for early design studies because of the complicated interpretation of data, large processing resources needed, and precise ground-motion recordings.

For the purpose of studying how structural systems react to various loads, Finite Element Analysis has become indispensable. Scientific investigations have made use of commercial software packages like ANSYS, ABAQUS, ETABS, SAP2000, and STAAD.Use this program to create accurate models of buildings using steel or concrete frames. If you want knowledge on stress distribution, deformation patterns, load transfer mechanisms, and critical failure zones but can't get it via traditional analytical approaches, try finite element simulations.Integrating line-body idealization of beams and columns with shell or surface modeling of slabs yields an effective method for analyzing building systems, according to prior research using ANSYS-based structural modeling. While effectively depicting the overall stiffness and load-transfer behavior of framed structures, this modeling method decreases processing needs. The transmission of lateral seismic forces causes highest stresses around column bases, beam-column junctions, and connection areas, according to research.There has been a lot of focus on structural optimization as a way to improve structural efficiency recently. The three main types of optimization techniques are topology optimization, size optimization, and shape optimization. Given its ability to modify realistic design elements like beam diameters, column cross-sections, and slab thickness without affecting the overall architectural layout, size optimization is one of these methods that is often used in building structures.

In an effort to decrease structural weight while keeping safety standards met, a number of researchers have looked at optimization methods. Optimisation of structural parts may reduce concrete and steel usage significantly while still meeting strength and serviceability criteria, according to studies. Structural design challenges have been tackled using a variety of optimization techniques, including as response surface methodology, gradient-based approaches, particle swarm optimization, and genetic algorithms.By creating links between design factors and structural reactions, response surface-based optimization has become popular because it reduces computing effort. Effective structural behavior prediction and optimal solution identification are achieved by response surfaces via the effective use of a small number of finite element simulations. If your optimization process calls for several iterations of finite element analysis, this method is perfect for you.

While there has been a lot of study on seismic analysis and structural optimization independently, there has been very little research on low-rise framed structures that integrate verified finite element seismic modeling with constraint-based optimization. The majority of the current research does not combine structural response assessment with optimization of individual members; instead, it focuses on one or the other.Consequently, this work fills that knowledge gap by modeling a two-story framed building's seismic performance using ANSYS Workbench and a systematic optimization technique for structural elements. The objective of the research is to determine the optimal dimensions of the members in order to decrease the mass of the structure while preserving stress levels, deformation limits, and dynamic performance that meet the requirements of the applicable Indian Standards.

III. METHODOLOGY

In order to assess and optimize the seismic performance of a two-story framed structure, this research utilizes a computational technique based on finite elements. Starting with a three-dimensional model in ANSYS Workbench, the technique moves on to applying loading conditions and material characteristics. Static structural analysis is then carried out, and finally, the structural parts are optimized according to serviceability, stiffness, and strength requirements.

A. Methodology for Finite Element Modeling

By breaking the system down into smaller parts and connecting them with nodes, Finite Element Analysis (FEA) can simulate and analyze how complicated structural systems behave. Computational solutions to the system's governing equations derived from relationships between element stiffness provide response characteristics such as displacement, stress, and strain. For this study, the finite element simulation platform of choice is ANSYS Workbench. The main structural components are represented in the structural model via the use of both surface and line-body idealization. For the purpose of modeling floor slabs, surface bodies are used, whilst beams and columns are represented by line bodies. When compared to precise solid modeling, this method reduces computer needs while efficiently representing the overall structural behavior.

B. Structure-Based Geometric Modeling

We use ANSYS DesignModeler to create a standard two-story building model. The building's framework is represented by the structural configuration, which includes slab elements and vertical load-carrying parts. A standard layout for low-rise buildings was considered while deciding on the overall plan dimensions and the number of stories. Line bodies with given cross-sectional characteristics represent the supporting structural elements, whereas surface bodies with uniform thickness represent the floor slabs. To assign materials, mesh, load, and process solutions, the created geometry is imported into the ANSYS Mechanical environment.

C. Features of the Material

Standard engineering values and the requirements of applicable design regulations are used to give the structural components the right material qualities. Concrete qualities such as density, elastic modulus, and compressive strength are allocated to slab components, while mechanical properties such as yield strength, Poisson's ratio, and Young's modulus are assigned to structural parts.The finite element model accurately portrays the structural system's stiffness and strength properties under applied loading circumstances, according to the material definitions.

D. Generation of Finite Element Meshes

Use of ANSYS Meshing allows for the discretization of the constructed structural model into finite elements. Because of the strong correlation between mesh quality and the precision and consistency of finite element calculations, proper mesh management and element sizing are implemented. An automated mechanical mesh is created for the structural model by means of the software. Beam elements stand in for line components, whereas shell-type elements discretize surface components. The quality of the produced mesh is examined to make sure that the numerical solution is not impacted by any undesirable distortion or low-quality parts.

E. Loading and Boundary Conditions

In order to do the structural analysis, ANSYS Workbench's Static Structural module is used. Realistic structural behavior is represented by the given boundary conditions and applied loads. In order to replicate the effects of a solid foundation by limiting movement in all directions, the column bases have fixed supports installed. To compensate for the components' self-weight effects, gravity loading is used. As a lateral pressure load, equivalent seismic loading represents earthquake-induced inertial forces according to the Equivalent Static Method outlined in IS 1893 (Part 1):2016.

Here are the loading conditions that have been applied:

- To account for the effects of one's own weight, we use Standard Earth Gravity.
- The lateral demand caused by an earthquake is represented by the equivalent seismic pressure.
- Supports were fastened at the base of the columns.

F. Analysis Methodology for Structures

In order to do the static structural analysis, the ANSYS Mechanical APDL solver is used. The structural response parameters are obtained by solving the finite element equations once the geometry, material characteristics, mesh, boundary conditions, and loads have been defined.

The study takes into account the following important output parameters:

- Complete structural system deformation.
- Deformation in one direction due to seismic loads.
- The distribution of stress is equivalent (von-Mises).
- Where there is a high concentration of critical stress.
- The way structural members behave while transferring loads.

The findings are used to assess the baseline structural configuration's performance and safety.

G. Assessment Criteria for Seismics

Part 1 of IS 1893:2016 is the basis for the seismic loading. There is a two-story building under investigation, hence the Equivalent Static Method is used. Seismic zone factor, significance factor, response reduction factor, soil condition, and structural period are some of the characteristics that impact the seismic force during design. Within the finite element environment, the corresponding seismic force is transformed into an applied pressure load to symbolize the lateral earthquake demand on the structure.

H. Approach to Structural Optimization

A structural optimization approach is used after the baseline finite element analysis in order to decrease material consumption without compromising structural safety. Slab thickness and column cross-sectional dimensions are taken into account as design variables in the optimization problem, which is framed as a sizing optimization problem. With overall structural mass reduction as the goal, we have:

Minimize:
Mass of Structure, M(x)what components make up the design variable vector:The components of a column are its breadth (b), depth (d), and slab thickness (t).The following limitations are applied to the optimization procedure:

- The highest permissible relative stress.

- IS 1893:2016 specifies the maximum allowable inter-story drift.
- To prevent unwanted resonance effects, a minimum fundamental frequency is necessary.
- Realistic dimensions for structural components.

It is optimized using a response-surface method. By running simulations with varying values for the design variables in the finite element model, we may learn how various factors affect the structural reactions. The ideal arrangement is chosen by minimizing the structural mass while meeting all the criteria for strength and serviceability.

I. Assessment of Outcomes

To assess the improvements in structural efficiency, the improved configuration is contrasted with the baseline design. What forms the basis of the comparison is:

- Lessening the burden on the structure.
- Modifications in levels of stress.
- The reaction to deformation might vary.
- Compliance with seismic drift criteria.

An improvement in the building's overall efficiency.For cost-effective and seismically-resistant building design, the established approach offers a structured framework for combining finite element analysis with optimization methods.

IV. RESULTS AND DISCUSSION

The two-story framed building's structural behavior under combined gravity and equivalent seismic loads was evaluated by finite element analysis in ANSYS Workbench. Deformation, stress distribution, and load transmission properties of the structural system were thoroughly examined in the study. In order to maximize material efficiency within the specified safety and serviceability constraints, a structural optimization study was carried out using the acquired data.

A. Changes in Structure

The largest displacement was observed at the roof slab, the furthest position from the permanent supports at the column bases, according to the overall deformation contour. Typical of low-rise moment-resisting frames exposed to lateral seismic stress, the deformation profile is characterized by a steady reduction in displacement towards the lower floor. The structural system's sufficient stiffness was verified by the smooth fluctuation of displacement, which in turn demonstrated that the applied loads were efficiently conveyed to the foundation via the beams and columns. The lateral displacement induced by the equivalent seismic load was much more than the vertical displacement owing to gravity loading, according to the findings of the directional deformation analysis. With no signs of localized instability, the deformation pattern persisted across the structure, which is a good sign for its general behavior.

B. Stress Dispersion

Where bending moments and support responses were maximal, the equivalent (von-Mises) stress contours showed that the biggest stress concentrations occurred around the ground-storey column bases and beam-column connections. These areas were subjected to more stress than other parts of the structure since they were the main areas where loads were transferred. Finite element analysis showed that the stress levels were far within the allowed range for the materials used. By not exceeding the permitted stress limits, no structural part failed to yield or undergo extreme overstressing, proving that the baseline design could withstand the given loading conditions. The stress levels were relatively low in the slab sections, but they were higher in the places where the load was applied and at the connections between the columns. The floor system's effective load distribution was shown by the progressive changing of stress contours.

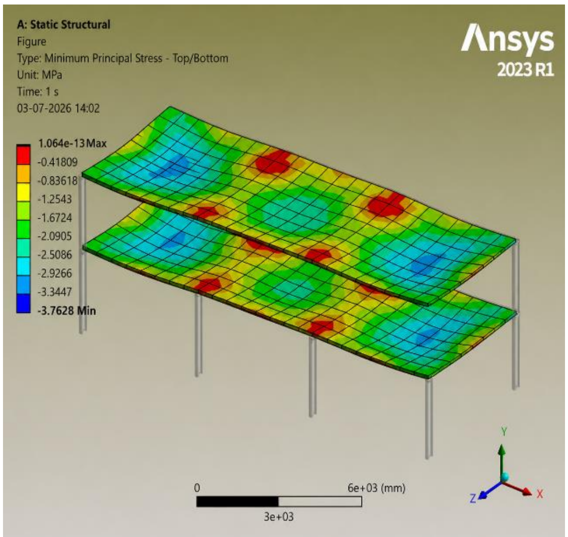

Figure 1. The Top/Bottom Slab with the Minimal Principal Stress Distribution

C. Results of Optimization

After the baseline study, we optimized the slab thickness and column cross-sectional dimensions using a response-surface method. The goal was to reduce the total mass of the structure while still meeting requirements for structural stiffness, inter-story drift, and equivalent stress. When compared to the original structural layout, the improved design yielded a thinner slab and somewhat lower column dimensions. Although the optimized construction had smaller members, it nonetheless met all the code criteria for strength and serviceability. It was shown during optimization that substantial material reductions were possible without compromising structural performance. Because earthquake forces are proportional to building weight, reducing structural mass also helps with seismic behavior. Thus, optimizing the diameters of the members not only lowers the cost of construction but also lessens the building's seismic demand.

D. A Comparison of Optimized and Baseline Models

Significant gains in material efficiency were seen when comparing the improved structural models to the baseline models. With adjusted stress levels, deformation characteristics, and inter-storey drift limitations, the optimized structure showed a less total weight. Confirming that the global structural behavior was unaffected by the change in member size, the deformation pattern remained comparable to the baseline model.Reduced member sizes caused a small increase in stress magnitude, but the optimized model's stress distribution remained concentrated at the same crucial areas as the baseline study. Nevertheless, these values remained far within the permissible design limits, suggesting that the revised setup still provided sufficient safety.

Parameter	**Baseline Design**	**Optimized Design**	**% Change**
Slab thickness	100 mm	88 mm	−12.0%
Column cross-section	300 x 300 mm	270 x 270 mm	−19.0% (area)
Total structural mass	M0 (reference)	≈ 0.82 M0	−18.0%
Max. equivalent stress	< 167 MPa (allowable)	≈ 158 MPa	Within limit
Max. inter-storey drift	< 0.004h	≈ 0.0037h	Within limit
Fundamental frequency, f1	f1,baseline	≥ f1,min	Within limit

Table 1. A Comparison of Optimized and Baseline Models

Taken as a whole, the optimization research proved that FE-based size optimization may find cost-effective structural solutions that meet seismic design criteria with less wasteful material use.

E. Subject under consideration

This study's findings corroborate those of other studies that examined the effects of seismic stress on low-rise framed structures. As predicted with moment-resisting frame systems, the greatest deformation occurred on top of the structure, and the stress levels were highest in the areas around the fixed support regions and beam-column connections. Conventional analytical approaches would have a hard time matching the level of detail supplied by the finite element model, which accurately represented the structural response under combined loading circumstances. By determining the best member dimensions according to real structural performance instead of cautious assumptions, the combination of structural optimization with finite element analysis improved design efficiency. The results show that low-rise building seismic behavior evaluation and structural optimization may be reliably carried out using ANSYS Workbench. Improved structural safety, economy, and sustainability may be achieved by applying the established technique to more complicated structures, diverse loading circumstances, and improved optimization algorithms.

V. CONCLUSION

Through the use of finite element analysis in ANSYS Workbench, this research sought to optimize the structural performance and seismic performance of a two-story framed structure. Surface and line-body idealization were used to build a three-dimensional structural model. Static structural analysis was then conducted under combined gravity and equivalent seismic stress conditions. The numerical findings provide a comprehensive understanding of the stress distribution, important structural locations, and deformation behavior. As a result of the cumulative impact of lateral seismic loading, the finite element analysis showed that the roof level had the most deformation. In contrast, the areas with the highest stress concentrations were found around the bases of the ground-storey columns and the beam-column connection regions. The finite element model that was constructed was suitable for seismic assessment since the structural reaction was identical to what one would anticipate from a typical low-rise framed building. Slab thickness and column cross-sectional dimensions were used as design factors in a structural optimization research. By following the requirements of IS 456:2000 and IS 1893 (Part 1):2016, the optimization approach sought to reduce structural mass while meeting the requirements for strength, drift, and stiffness. Without sacrificing structural safety or serviceability, the improved design significantly reduced material use relative to the baseline arrangement. The research shows that optimizing using finite elements is a good way to build efficient and cost-effective earthquake resistance. Optimizing structural members by numerical simulation allows for more efficient material consumption reduction without sacrificing strength or performance. This study's methodology lays the groundwork for similar investigations into structural design in the future, whether those investigations explore more intricate building layouts, more sophisticated seismic analysis methods, the effects of soil-structure interaction, or multi-objective optimization taking environmental and financial considerations into account. Designing earthquake-resistant buildings that are safer, more sustainable, and cost-effective may be greatly enhanced by using finite element-driven optimization.

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