International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-13 Issue-6, May 2024

Analysing the Impact of Simulation-Based Design Processes on Structural Performance Optimization: A Research Inquiry

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Abstract: With the recent advancement of several technologies and software, the simulation-based design processes for optimizing the structural strength of various erections have become extraordinarily effortless. This software is an advanced version of the human mind, designed to provide solutions for complex problems in real-time. However, this software lacks the creativity, broader understanding, and intuition that characterize the human mind. This paper presents a research study on computer-aided software and its efficiency in determining the structural strength of complex residential buildings. This software reduces the need for time-consuming and costly physical testing. This paper also provides compiled information on issues related to simulation software, trends in optimisation studies, and the effectiveness of these tools. Factors such as model simplification, material property calibration, and validation against real-world performance data are critically processed to ensure the reliability and applicability of the proposed design solutions. In addition to these, this paper presents a holistic approach to structural optimisation using a Building Information Modelling platform within the context of the entire building lifecycle. Emphasizing sustainability and environmental considerations, the study examines how simulation-based design processes can contribute to reducing energy consumption, minimizing environmental impact, and achieving compliance with green building standards. Primarily, this research inquiry provides insights and recommendations that can inform the development of best practices for optimising the structural strength of complex residential buildings.

Keywords: STAAD Pro, Analysis, Modelling, Plan, Design, BIM

I. INTRODUCTION

According to the Oxford Dictionary, a floor plan is defined as a scale diagram of the arrangement of rooms in one story of a building. The process of creating floor plans involves gathering information and creating a blueprint that incorporates the available options.

Manuscript received on 05 May 2024 | Revised Manuscript received on 12 May 2024 | Manuscript Accepted on 15 May 2024 | Manuscript published on 30 May 2024.
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In ancient times, these drawings were prepared manually with pen and paper by individual architects or civil engineers. Due to the advancement of technology, architects and civil tech experts collaborate to create specialised rules for computers to generate floor plans, considering factors such as room sizes, layouts, and movement. This technology helps gather feedback from clients about the layouts and compiles it to create a floor plan, ensuring everything is in order. Computer programs enable easy modifications and learning from existing plans.

The final design is checked for compliance with rules and requirements, ensuring efficiency and cost-effectiveness. This approach saves time and ensures the final design is perfect for the intended users.

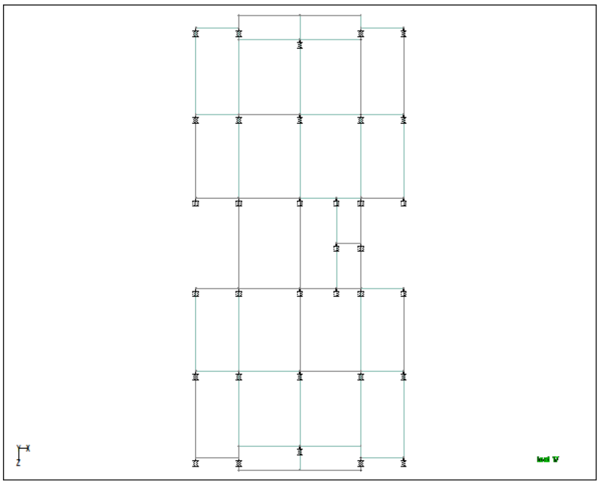

Fig.1. Top View STAAD Pro Model

The growing demand for urban housing necessitates the development of efficient and well-designed residential complexes. Designing and building complexes of high quality with efficient energy performance and durability requires aggregation and iterative processes of various technical aspects such as site preparation, foundation design, structural design, building envelope design, and building system design [18]. The introduction of computer-aided software in the building industry has made remarkable progress in terms of variety in design, quality of the final product, and efficiency in the process of design [17]. With the use of this software, the process of technical aspects has become very facile due to the fusion of both human creativity and computer processing power. Designers interact with the software to explore ideas, iterate on designs, and visualize concepts in 2D and 3D.

Retrieval Number: 100.1/ijitee.G989613070624
DOI: 10.35940/ijitee.G9896.13060524
Journal Website: www.ijitee.org

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This paper focuses on the structural design of a G+8 multi-dwelling building using computer-aided design software, with this concept in mind. This project utilizes STAAD Pro software for efficient 3D geometric modeling, load analysis, and initial member design [9]. The outline is followed by Advanced Concrete Design software for detailed design and reinforcement detailing of beams, columns, and slabs [8].

The chosen architectural plan prioritizes aesthetics by strategically placing columns to achieve a "flushed-out look" while maintaining structural integrity. The design process considers various load scenarios, including seismic loads as per IS 1893 (Part 1) for Lucknow (Zone 3) and wind loads as per IS 875 (Part 3), considering the city's specific wind pattern [6]. The load conditions also include Live load considerations for floor finishes, imposed floor loads as per IS 875 Part 1 for residential buildings, and a separate DPC floor load for the terrace [4]. Following the design process, the project meticulously documents each stage with photos, culminating in structural drawings for all building members. This comprehensive documentation ensures clear communication and facilitates the construction process. This project demonstrates the effectiveness of using computer-aided design software for structural analysis and design of residential complexes [14]. The chosen approach optimises design efficiency while adhering to essential safety standards to ensure a sustainable and well-built structure.

II. METHODOLOGY

This CAD-based project underwent meticulous execution across multiple phases, characterised by its intricate nature and extensive utilisation of diverse resources. Leveraging a breadth of knowledge spanning various realms within civil engineering, the endeavour navigated through complex challenges, requiring adeptness in diverse fields and concepts within the discipline. The project encompasses the following sequential steps:

A. Architectural Plan Selection and Integration:

The architectural design for the G+8 building was meticulously crafted, with a pre-designed blueprint serving as the foundation [9]. The layout was carefully planned to align columns with walls, creating a visually appealing and structurally sound structure [1]. This strategic positioning not only enhances the overall aesthetics of the building but also ensures its optimal structural integrity.

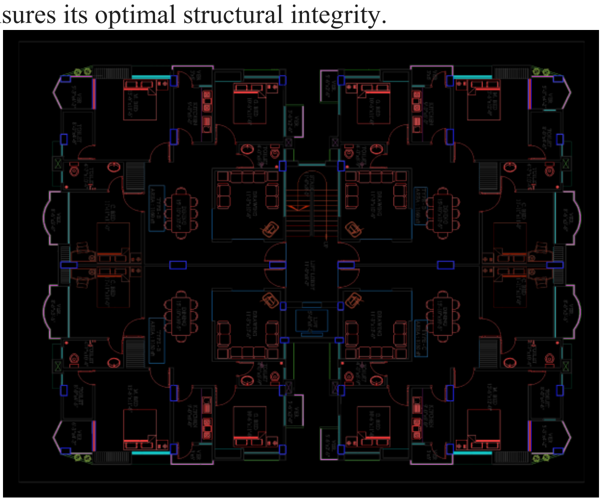

Fig.2. Architectural Floor Plan

B. Geometric Modelling in STAAD Pro:

The geometric model of the G+8 building was expertly designed using STAAD Pro software, a sophisticated tool in the field of structural engineering [9]. The software facilitated the efficient placement of nodes at the intersection points of columns and beams, leveraging the translational repeat functions to ensure accuracy and consistency. Beams were then systematically generated by connecting these nodes, forming the skeletal framework of the structure.

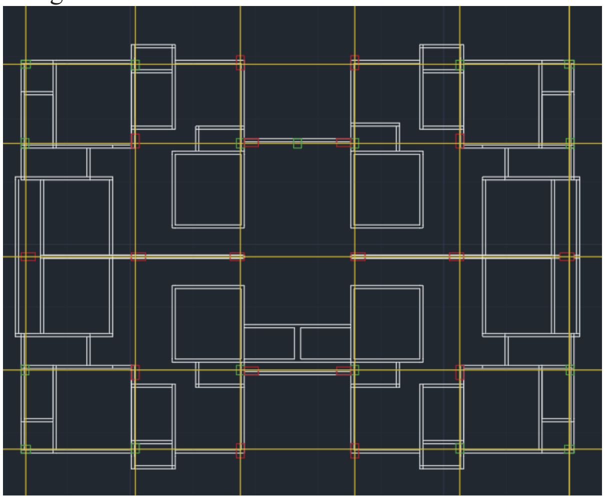

Fig.3. Skeletal Framework of Floor Plan

To replicate the floors, the completed floor plan was duplicated vertically eight times, with each floor having a height of 3.6 meters, thereby maintaining uniformity throughout the building's elevation. For the foundation-level modeling, the column nodes were duplicated downwards by 2 meters to establish a solid base for the structure.

The versatility of STAAD Pro was further demonstrated in the detailed crafting of the terrace, water tank, and slab geometries. Each element was designed with precision, adhering to the specific requirements of the project [13]. The software's comprehensive toolkit enabled the creation of a detailed and accurate structural model, serving as a reliable blueprint for the construction phase.

C. Material Properties and Section Assignment:

In the structural design of the G+8 building, material properties were meticulously assigned to beams, columns, and slabs according to industry standards and established guidelines. The beams were designated a section size of 250mm x 450mm to ensure optimal load-bearing capacity and structural stability. Similarly, columns were assigned a section size of 450 mm x 600 mm, providing the necessary strength to support the building's vertical load.

The slabs, crucial for distributing loads evenly across the structure, were assigned a thickness of 150mm to meet structural requirements and ensure durability. These material specifications were carefully selected to meet safety standards and structural integrity criteria.

a. Support Conditions:

Fixed supports were applied to all base nodes representing the building's foundation.

b. *Load Definition and Cases:*

In the structural analysis of the G+8 building, seismic loads were defined according to IS 1893 (Part 1) for Lucknow, categorized as Zone 3 [6]. This ensured that the structure could withstand seismic forces prevalent in the region [10]. Wind loads were determined using IS 875 (Part 3), taking into account the specific wind patterns of Lucknow to ensure structural stability against wind-induced forces. Various load cases were created to simulate different loading scenarios on the building:

- Seismic load case was considered to evaluate the structure's response to seismic forces [7].
- Wind load cases in both X and Z directions were analyzed to assess the building's resistance to wind pressures.
- Dead load case accounted for the self-weight of the structure.
- Live load case included:

Floor finish load of 1.1 kN/m²

An imposed floor load of 1.5 kN/m² as per IS 875 Part 1 for multi-dwelling residential buildings

Damp proof course (DPC) floor load on the terrace of 0.6 kN/m² [4]

Live loads were assigned to beams supporting specific walls (exterior, interior, parapet) based on their calculated weights using material densities and plaster thickness [5]. By considering these load cases and assigning appropriate loads to different structural elements, the design of the G+8 building was optimised to withstand a range of potential loading conditions effectively.

c. *Load Combination Generation:*

Load combinations were generated by IS 456:2000, Table 18. (You can list a few examples or reference the table itself).

d. *Analysis and Design:*

The structural model of the G+8 building underwent a comprehensive analysis using STAAD.Pro software, which involved determining member forces and stresses, applying various loading conditions, defining boundary constraints, and incorporating material properties [11]. Through iterative computations, the analysis aimed to ensure the structural integrity of the building and compliance with safety standards. The design process for beams, columns, and slabs was carried out using both STAAD.Pro and Advanced Concrete Design software, with strict adherence to relevant Indian Standards such as IS 456 [3].

In specifying material properties, a yield strength (Fy) of 500 N/mm² and a characteristic compressive strength of concrete (Fck) of 35 N/mm² were utilized to model the behaviour of the structural elements accurately [2]. Following the initial automated design process, the beams were manually reviewed to fine-tune the reinforcement details, and then grouped automatically in STAAD.Pro for efficient analysis [14].

For detailed column design, the Advanced Concrete Design software played a crucial role, especially in the redesign of columns that did not meet the requirements of the initial auto-design phase [8]. Columns requiring adjustments were meticulously redesigned, and those with similar reinforcement details were grouped to streamline the design process and ensure consistency in structural performance. This meticulous approach to beam and column design, combined with the use of advanced software tools, significantly contributed to the robustness and safety of the structural design of the G+8 building.

III. RESULTS

The simulation results were obtained from STAAD.Pro software for the structural analysis of the G+8 building provided valuable insights into the behaviour and performance of the designed structure [11]. The analysis revealed detailed member forces and stresses acting on beams, columns, and slabs under various loading conditions, including seismic and wind loads specific to the region of Lucknow (Zone 3) [7]. By applying accurate material properties, boundary conditions, and loading scenarios, the simulation ensured that the building's design met safety standards and structural integrity requirements.

Through the iterative computations performed during the simulation, critical aspects of the structural design were evaluated to verify compliance with Indian Standards (IS 456) and optimize the overall performance of the building [2]. The results of the simulation enabled engineers to make informed decisions regarding reinforcement details, member sizing, and load distribution, ensuring that the structure could effectively withstand anticipated loads and environmental forces [16].

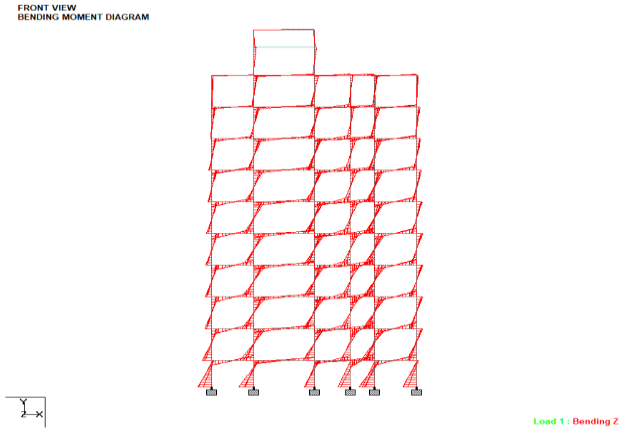

Fig.4. Bending Moment (Front View) STAAD Pro Model

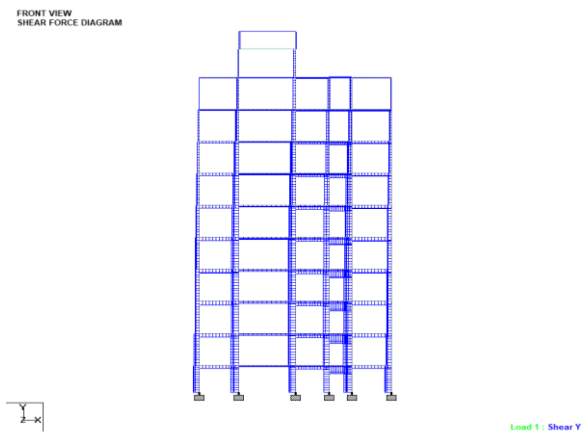

Fig.5. Shear Force Diagram (Front View) STAAD Pro Model

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A. Load Combinations

Shear force and bending moment were obtained for each element of the structure from the simulation. These were studied for various load combinations by IS 875 Part 5. The following load combinations were designed

COMB1 - 1.5 DEAD + 1.5 LIVE
COMB2 - 1.2 DEAD + 1.2 LIVE + 1.2 WIND (1)
COMB3 - 1.2 DEAD +1.2 LIVE +1.2 WIND (2)
COMB4 - 1.2 DEAD +1.2 LIVE +-1.2 WIND (1)
COMB5 - 1.2 DEAD +1.2 LIVE +-1.2 WIND (2)
COMB6 - 1.2 DEAD + 1.2 LIVE+ 1.2 SEISMIC-H (1)
COMB7 - 1.2 DEAD + 1.2 LIVE+ 1.2 SEISMIC-H (2)
COMB8 - 1.2 DEAD + 1.2 LIVE +-1.2 SEISMIC-H (1)
COMB9 - 1.2 DEAD +1.2 LIVE +-1.2 SEISMIC-H (2)
COMB10 - 1.5 DEAD + 1.5 WIND (1)
COMB11 - 1.5 DEAD + 1.5 WIND (2)
COMB12 - 1.5 DEAD + -1.5 WIND (1)
COMB13 - 1.5 DEAD + -1.5 WIND (2)
COMB14 - 1.5 DEAD + 1.5 SEISMIC-H (1)
COMB15 - 1.5 DEAD +1.5 SEISMIC-H (2)
COMB16 - 1.5 DEAD +-1.5 SEISMIC-H (1)
COMB17 - 1.5 DEAD +-1.5 SEISMIC-H (2)
COMB18 - 0.9 DEAD + 1.5 WIND (1)
COMB19 - 0.9 DEAD + 1.5 WIND (2)
COMB20 - 0.9 DEAD + -1.5 WIND (1)
COMB21 - 0.9 DEAD + -1.5 WIND (2)
COMB22 - 0.9 DEAD +1.5 SEISMIC-H (1)
COMB23 - 0.9 DEAD + 1.5 SEISMIC-H (2)
COMB24 - 0.9 DEAD +-1.5 SEISMIC-H (1)
COMB25 - 0.9 DEAD +-1.5 SEISMIC-H (2)
COMB26 - 1 DEAD + 1 LIVE
COMB27 - 1 DEAD +1 LIVE+1 SEISMIC-H(1)+2 SEISMIC-H(2)

After studying all of the critical members for all load combinations of Bending moment diagrams, RCC members were designed.

B. Beam and Column Design

Designing beams and columns according to the Indian Concrete Design Code (IS 456:2000) using software like RCDC involves a systematic approach to ensure structural integrity and safety. The design process begins with analyzing various load combinations specified by the code, including dead loads (self-weight of structural members and finishes), live loads (imposed loads due to occupancy) [5], wind loads, and seismic forces as per IS 1893:2016. By evaluating the internal forces such as bending moments, shear forces, torsional effects, and axial loads along the length of beams and columns, engineers can determine the required dimensions and reinforcement details [6].

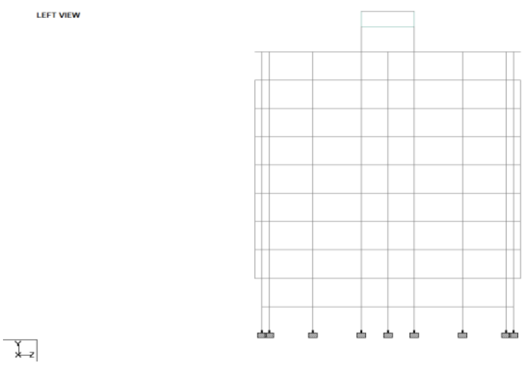

Fig.6. Left View STAAD Pro Model

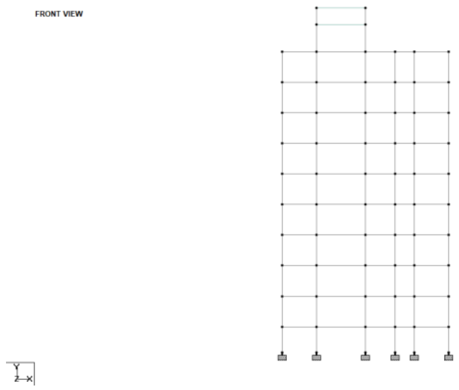

Fig.7. Front View STAAD Pro Model

For beam design, the software calculates the required area of tensile reinforcement (steel) based on the design bending moments, ensuring that the beam can resist these moments without exceeding permissible stresses in concrete and steel [12]. Shear reinforcement (such as stirrups) is provided to resist the shear forces at critical sections, with spacing and detailing conforming to IS 456 requirements [2]. Development lengths are specified to ensure proper anchorage of reinforcement within the concrete member, preventing premature failure due to bond stress.

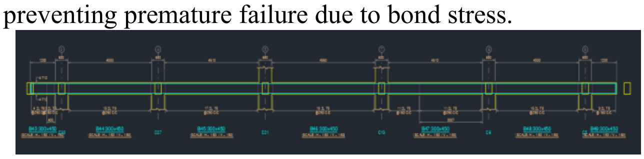

Fig.8. Beam Design

Column design involves analyzing axial loads and moments to determine the column size and reinforcement requirements. The design ensures that the column can safely carry the applied loads without excessive deflection or instability. Longitudinal reinforcement details are specified based on axial and bending demands, while lateral ties or spirals are provided to enhance confinement and ductility, as per IS 13920:2016.

C. Slab Design

Based on structural analysis, the required slab thickness was determined to meet the minimum requirements specified in IS 456, taking into account span, support conditions, and applied loads. The software calculated the area of tensile reinforcement (bottom bars) necessary to resist bending moments induced by the loads. Shear forces were checked, and appropriate shear reinforcement (stirrups) was provided according to IS 456 requirements to enhance structural stability and safety [2]. Detailed reinforcement layouts were specified within the software, outlining the arrangement of primary reinforcement (bottom bars) and distribution reinforcement (top bars) throughout the slab. Bar bending schedules were automatically generated, providing precise details on bar sizes, lengths, and bending shapes for construction purposes. Concrete cover over reinforcement bars was defined based on exposure conditions to ensure durability as per IS 456 recommendations [2].

Retrieval Number: 100.1/ijitee.G989613070624
DOI: 10.35940/ijitee.G9896.13060524
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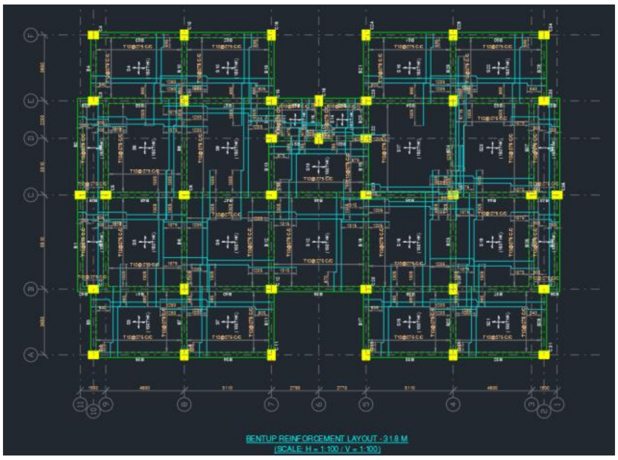

Fig. 9. Slab Design

To verify the slab design, an Excel sheet was created by the specifications outlined in IS 465:2000. Every detail of the slab was taken into consideration, including the type of slab, load, and end conditions.

D. Foundation Design

The foundation design process using RCDC software is integral to ensuring the stability and structural integrity of buildings in accordance with Indian design standards, particularly IS 456:2000 for reinforced concrete and IS 2950:2011 for the design and construction of shallow foundations. The design begins with a comprehensive analysis of the site's soil conditions and load requirements based on relevant code provisions [19].

RCDC software streamlines the foundation design process by enabling engineers to input site-specific parameters, including soil properties, building loads, and foundation type, as per IS 2950:2011. The software performs structural analysis and checks for compliance with Indian design codes, ensuring that the foundation design meets safety and performance criteria [14].

Comprehensive design reports, drawings, and schedules are generated automatically within RCDC, providing detailed documentation for construction teams to implement the foundation design accurately and efficiently. Through adherence to Indian design standards and careful consideration of soil-structure interaction, RCDC facilitates the development of robust and stable foundations for construction projects in India, ensuring the long-term durability and safety of structures.

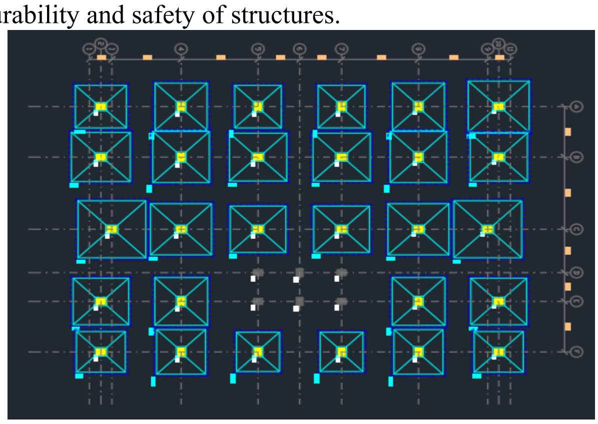

Fig.10. Foundation Design

Overall, the simulation results from STAAD.Pro provided a comprehensive assessment of the G+8 building's structural response, confirming its ability to meet safety regulations, resist seismic and wind forces, and maintain stability and durability throughout its intended lifespan [7]. The detailed analysis facilitated by the software contributed to the successful design and engineering of a structurally sound and reliable building for its occupants.

IV. CONCLUSION

The research study explores computer-aided software for optimizing the structural strength of complex residential buildings. While these tools offer efficiency and reduce the need for physical testing, they lack the creativity and intuition inherent in the human mind. The paper critically examines issues related to simulation software, trends in optimization studies, and the effectiveness of these tools. It emphasises factors such as model simplification, material property calibration, and validation against real-world data [20][21]. Additionally, the study takes a holistic approach by integrating Building Information Modelling (BIM) within the entire building lifecycle. By emphasizing sustainability and environmental considerations, simulation-based design processes can contribute to energy reduction, minimize environmental impact, and achieve compliance with green building standards [15]. The research provides valuable insights and recommendations for optimizing the structural strength of complex residential buildings.

DECLARATION STATEMENT

Funding	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence.
Availability of Data and Materials	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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methodology, vibration control/damping, material characterization for innovative use in earthquake-resistant design, performance-based design, forensic analysis, structural pathology, rehabilitation, and repair/strengthening are welcome
11. "Analysis and Design of G+3 Building Using ETABS." This study presents structural analysis and design ideas for a planned residential building. All analyses and criteria for structural design input are included in this document
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AUTHORS PROFILE

Arpit Singh is a final-year student pursuing a Bachelor of Technology degree in Civil Engineering at Vellore Institute of Technology (VIT), Vellore. My passion for construction and structural design led me to pursue a career in this field. Proficient in tools like AutoCAD, Revit, STAAD Pro, and Excel, I've explored various aspects of civil engineering, fueling my interest in practical applications and simulation work. My focus is on creating efficient solutions to address diverse challenges in civil engineering, demonstrating my commitment to advancing the field and promoting sustainable infrastructure development. Outside of engineering, I enjoy cooking, working out, and video games. Let's connect and share insights on engineering and creativity!

Darsh Uday Maru, a third-year B.Tech student in Civil Engineering at VIT Vellore, is passionate about structural design and sustainable construction. Throughout my studies, I have developed a keen interest in project management, structural analysis, and environmental sustainability. I am committed to applying my skills and knowledge to real-world projects, contributing to innovative and efficient engineering solutions that drive progress. My academic journey has equipped me with a solid understanding of engineering principles and hands-on experience through various laboratory work and internships, enhancing my technical skills, problem-solving abilities, and teamwork capabilities. I am enthusiastic about the prospect of working on challenging projects that positively impact society and the environment, and I continuously seek opportunities to expand my expertise and stay at the forefront of advancements in civil engineering.

Roshan Shivaji Rathod is a third-year B.Tech Civil Engineering student with a passion for modern technology in civil engineering. My interests span various subfields, including structural and geotechnical engineering. I strongly believe in gaining hands-on experience to complement my academic learning. I am particularly interested in innovation and the use of modern software in the civil engineering field, including proficiency in STAAD Pro, AutoCAD, and Primavera. Additionally, I am eager to develop my project management skills. With strong critical thinking and problem-solving abilities, I strive to integrate cutting-edge technology with traditional engineering principles, driving my approach to tackling complex challenges in the field.

Sakshi is a final-year student pursuing a Bachelor of Technology degree in Civil Engineering at Vellore Institute of Technology (VIT), Vellore. My fascination with buildings and bridges from a young age inspired me to choose this field for my undergraduate studies. Throughout my academic journey, I have explored various aspects of civil engineering, which fueled my interest in research and simulation work. My research and design focus on developing and mapping out efficient solutions to address diverse challenges within civil engineering, demonstrating my commitment to advancing the field and contributing to the development of sustainable infrastructure.

Dr. A.S. Santhil, Working as Professor in the Structural and Geotechnical Engineering department, under the School of Civil Engineering at VIT, Vellore (Tamil Nadu), India.