

Performance-Based Structural Analysis and Design of a G+4 Residential Reinforced Concrete Building Under Gravity and Lateral Loads

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Abstract- Rapid urbanization and population growth have increased the demand for multi-storeyed residential buildings, especially in urban and semi-urban regions where land availability is limited. The present project deals with the analysis and design of a G+4 residential building using both manual calculations and STAAD.Pro V8i software. The building is a reinforced cement concrete (RCC) framed structure consisting of four residential floors above ground level, designed as per the provisions of IS 456:2000, IS 875 (Part 1 & 2), and other relevant Indian Standard Codes. The planning and drafting of the building were carried out using AutoCAD, ensuring compliance with National Building Code (NBC-2016) requirements related to setbacks, ventilation, room dimensions, and safety provisions. The structural elements such as slabs, beams, columns, and isolated footings were designed using the Limit State Method. Loads considered in the analysis include dead loads, live loads, and floor loads as per codal specifications. The modeling of the structure was performed in STAAD.Pro by defining geometry, assigning material properties (M30 concrete and Fe500 steel), applying support conditions, and generating load combinations. The analysis results such as bending moments, shear forces, axial loads, and deflections were obtained through the post-processing mode. These results were compared with manual design calculations to evaluate accuracy and efficiency. The comparison shows that the analysis results from STAAD.Pro and manual calculations are nearly similar, with slight variations in reinforcement detailing. The use of software significantly reduces computation time and minimizes human errors while ensuring safe and economical design. The project concludes that STAAD.Pro provides reliable and efficient structural analysis and design results for multi-storeyed residential buildings.

Keywords: Multi-storeyed Residential Building, G+4 Structure, RCC Framed Structure, Structural Analysis, Limit State Method, STAAD.Pro V8i, AutoCAD, IS 456:2000, IS 875, Load Combinations, Beam Design, Column Design, Slab Design, Footing Design, Estimation and Costing.

I. INTRODUCTION

The construction of multi-storeyed residential buildings has become a necessity due to rapid population growth and increasing urbanization [12]. In many developing regions, especially in India, the availability of land is limited while the demand for housing is continuously rising. This situation has led to the adoption of vertical construction systems such as G+4 and higher residential structures [7], [8]. Reinforced Cement Concrete (RCC) framed structures are widely used in modern construction because of their strength, durability, fire resistance,

and adaptability to different architectural layouts [1], [7]. In framed structures, loads are transferred through beams and columns to the foundation, ensuring uniform load distribution and structural stability [9], [10]. Compared to conventional load-bearing structures, RCC framed buildings are more economical and efficient for multi-storeyed construction [8].

Structural analysis and design play a crucial role in ensuring that a building can safely resist various types of loads such as dead load, live load, wind load, and seismic load [2], [3], [4]. Dead loads are calculated as per IS 875 (Part 1):1987, and live loads

are considered as per IS 875 (Part 2):1987 [2], [3]. For seismic analysis, IS 1893 (Part 1):2002 provides guidelines for evaluating earthquake forces acting on buildings [4], [11]. The design of reinforced concrete members is carried out using the Limit State Method in accordance with IS 456:2000, which ensures safety against collapse and serviceability under working loads [1], [5]. Proper structural planning also requires compliance with foundation design standards such as IS 1904:1986 [6].

Traditionally, structural design was carried out manually using classical structural analysis principles [9], [10]. However, manual calculations for multi-storeyed three-dimensional structures are time-consuming and prone to computational errors. With advancements in structural engineering software, tools such as STAAD.Pro have significantly improved the accuracy and efficiency of structural analysis and design [13]. STAAD.Pro enables engineers to model three-dimensional framed structures, apply load combinations, and evaluate bending moments, shear forces, axial forces, and deflections using finite element analysis techniques [13]. Drafting and planning of structural layouts are performed using AutoCAD, ensuring compliance with architectural and dimensional requirements [14].

The design of structural components such as slabs, beams, columns, and foundations is carried out using codal provisions and standard design aids such as SP-16 [5], [7]. Reinforcement detailing and structural checks for deflection, shear stress, punching shear, and development length are performed to ensure structural safety and durability [1], [8]. In addition to structural analysis, estimation and costing are prepared using Standard Schedule of Rates (SSR) to evaluate the economic feasibility of the project [15].

II. LITERATURE REVIEW

1 Ibrahim et al. (2019) – Design and Analysis of Residential Building (G+4)

Ibrahim et al. (2019) carried out the design and analysis of a G+4 residential building by considering various loading conditions such as dead load, live load, wind load, and seismic load. The study

emphasized the importance of accurate load calculations and proper assignment of member dimensions for beams, columns, and slabs. AutoCAD was used for preparing detailed structural drawings, while STAAD.Pro was used for structural analysis and design as per IS 456:2000. The authors concluded that STAAD.Pro effectively calculates reinforcement requirements and provides detailed design outputs including bar spacing and detailing. The research highlighted that software-based analysis reduces time consumption and improves accuracy compared to manual methods. This study supports the use of STAAD.Pro in the present project for safe and economical design of G+4 residential buildings.

2 Dunnala Lakshmi Anuja et al. (2019) – Planning, Analysis and Design of Residential Building (G+5)

Dunnala Lakshmi Anuja et al. (2019) focused on the planning, structural analysis, and design of a G+5 residential building using STAAD.Pro. The structural elements such as slabs, beams, columns, staircases, and footings were designed using the Limit State Method as per IS 456:2000 and SP-16 design charts. The study examined shear forces, bending moments, deflection limits, and torsional effects in structural members. The results obtained from software analysis were compared with manual design calculations to validate accuracy. The authors observed that the results from STAAD.Pro closely matched manual results, with minor variations due to rounding and modeling assumptions. This literature provides a strong foundation for comparing manual and software-based design approaches in the present project.

K. Prabin Kumar et al. (2018) – Study on Design of Multi-Storey Residential Building

K. Prabin Kumar et al. (2018) conducted a detailed study on the structural analysis and design of a multi-storey residential building using STAAD.Pro. The research mainly focused on analyzing structural members under axial load, bending, shear, and torsion. Columns were designed considering biaxial bending effects, while beams were designed for flexure and shear as per IS 456:2000. The study emphasized the importance of accurate modeling and proper load combinations for achieving structural safety. The authors concluded that

software tools provide efficient and precise reinforcement detailing and reduce design complexity in high-rise structures. The study reinforces the significance of structural software in modern engineering practices and supports the methodology adopted in this project.

R.D. Deshpande et al. (2017) – Structural Analysis of Multi-Storeyed Buildings

R.D. Deshpande et al. (2017) discussed structural analysis as a critical process for predicting the behavior of buildings under various loads. Their research included analysis of a basement + G+2 building using Indian Standard codes. Dead loads were calculated based on material properties, and live loads were considered as per IS 875 (Part 2). The authors applied the Limit State Method for designing beams and columns. The study concluded that structural analysis ensures safety, stability, and durability of buildings by evaluating internal forces and deflections. It also highlighted the need for careful design of foundations based on soil bearing capacity. This literature is relevant to the present project as it emphasizes systematic structural planning and analysis before design implementation.

Sreesha K.S. (2016) – Analysis and Design of G+4 Apartment Building

Sreesha K.S. (2016) analyzed and designed a G+4 apartment building using STAAD.Pro software. The study was divided into three stages: modeling and analysis of the building, design of structural elements, and detailing of reinforcement. Dead and live loads were considered as per IS 875 (Part 1 & 2). Structural components such as slabs, beams, columns, staircases, and foundations were designed following IS 456:2000 provisions. The author concluded that STAAD.Pro significantly simplifies the analysis of complex structures and provides accurate bending moment, shear force, and deflection results. The research demonstrated that software-based design ensures compliance with codal provisions and enhances efficiency. This study directly relates to the present project, which also involves the analysis and design of a G+4 residential building using similar methodologies.

III. WORKING METHODOLOGY

The working methodology adopted for the analysis and design of the G+4 residential building follows a systematic and organized procedure to ensure structural safety, accuracy, and economy. The methodology begins with data collection and planning of the building layout. The plot dimensions, setbacks as per National Building Code (NBC 2016), room requirements, ventilation standards, and circulation spaces are first finalized. After confirming the architectural plan, drafting is carried out using AutoCAD software.

The plan includes details such as room dimensions, wall thickness, staircase position, column locations, and lift provision. The structural planning stage involves deciding the position and orientation of columns, beam layout, slab spanning direction, and type of foundation. The building is planned as a reinforced cement concrete (RCC) framed structure where loads are transferred through beams and columns to the foundation.

The next stage involves calculation of loads acting on the structure. The loads considered in this project include dead loads, live loads, floor finish loads, and self-weight of structural members. Dead loads are calculated based on material unit weights as per IS 875 (Part 1), while live loads are taken as per IS 875 (Part 2). The self-weight of beams and columns is automatically generated in STAAD.Pro. After load calculation, the structural model is developed in STAAD.Pro V8i.

The geometry of the building is created by defining nodal coordinates and connecting them with beam and column members. Material properties such as M30 grade concrete and Fe500 grade steel are assigned. Fixed supports are provided at the base of columns. Load cases and load combinations are generated according to IS 456:2000 guidelines. The structure is then analyzed using the finite element method to obtain bending moments, shear forces, axial forces, and deflection values.

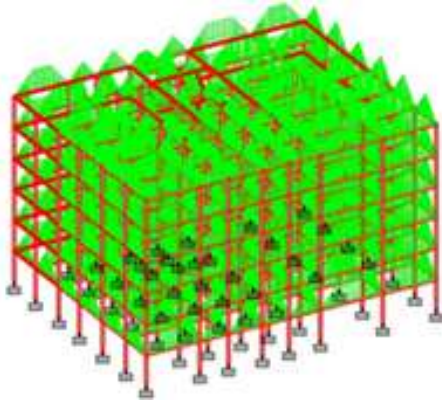


Fig 1– Load Combinations Acting on the Structure

This fig1 represents the different load combinations considered in the analysis of the G+6 RCC shear wall structure. In STAAD.Pro, load combinations are created as per IS 456:2000 and IS 1893:2002 to ensure structural safety under worst possible loading conditions. The structure is subjected to Dead Load (DL), Live Load (LL), and Seismic Load (EQX and EQZ). These loads are combined using factored combinations such as $1.5(DL + LL)$, $1.2(DL + LL \pm EQ)$, and $1.5(DL \pm EQ)$. The purpose of load combinations is to simulate realistic scenarios where gravity and earthquake loads act simultaneously. These combinations help in determining maximum bending moments, shear forces, and axial forces in beams, columns, and shear walls. Proper load combination ensures that the structure remains safe against collapse and excessive deformation under critical loading conditions.

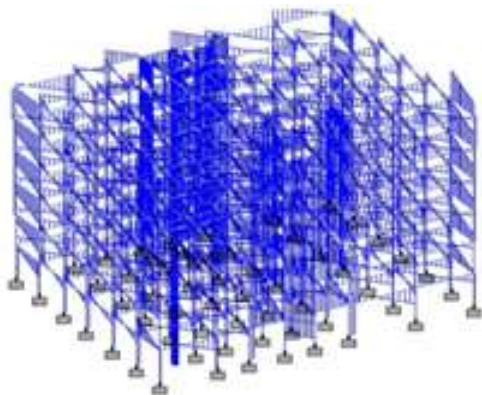


Fig 2– Shear Force Diagram of the Structure

The shear force diagram shows in fig2 the distribution of shear forces in beams, columns, and shear walls due to applied load combinations. Shear

force is generally maximum near supports and column-beam junctions and decreases towards mid-span in beams. In the multi-storeyed RCC structure, higher shear forces are observed in lower storey columns because they carry cumulative loads from upper floors. The diagram indicates that shear forces are significantly influenced by seismic loads, especially in the lateral load-resisting elements such as shear walls. Proper interpretation of this diagram ensures adequate shear reinforcement (stirrups) is provided to prevent brittle shear failure. The shear values obtained are within permissible limits as per IS 456:2000, confirming structural safety.

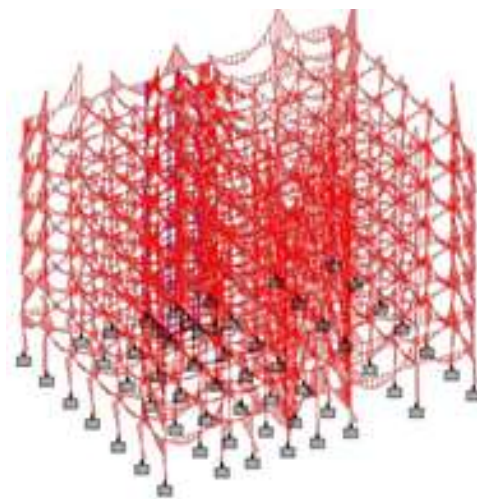


Fig3– Bending Moment Diagram of the Structure

The bending moment diagram Fig 3 illustrates the variation of bending moments in structural members under the applied load combinations. Maximum positive bending moments are typically observed at mid-spans of beams, while negative bending moments occur near supports. In columns, bending moments increase towards the base due to the effect of lateral seismic forces. Shear walls also experience significant bending moments, particularly at the lower storeys, where overturning effects are maximum. The diagram confirms that the structure behaves as a moment-resisting frame combined with shear wall action. These bending moment values are used for designing longitudinal reinforcement in beams, columns, and shear walls as per Limit State Method. The results show that the moments are within safe limits and properly resisted by the assigned member sections.

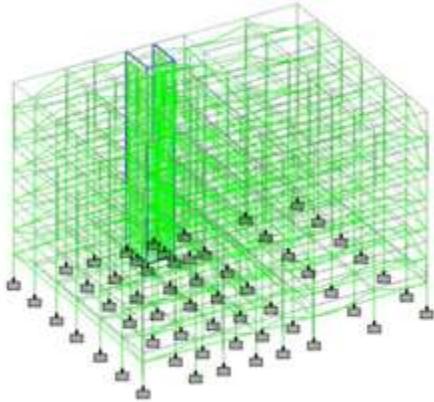


Fig4 – Displacement Diagram of the Structure

The displacement diagram Fig 4 represents the lateral and vertical deflections of the structure under seismic loading. It shows that maximum displacement occurs at the top storey, which is expected due to the cantilever-like behavior of multi-storeyed buildings. The displacement gradually decreases toward the base where fixed supports are provided. The presence of shear walls significantly reduces lateral displacement and improves stiffness of the structure. The storey drift values are within the permissible limits specified in IS 1893 (Part 1): 2002, ensuring serviceability and occupant safety during earthquake conditions. The diagram confirms that the building has adequate stiffness and stability against lateral forces.

IV. CONCLUSION

The present project on Analysis and Design of (G+4) Residential Building successfully demonstrates the systematic planning, structural analysis, and design of a reinforced cement concrete framed structure. The building was planned according to the provisions of the National Building Code (NBC 2016), ensuring proper setbacks, ventilation, lighting, and safety requirements. Structural elements such as slabs, beams, columns, and isolated footings were designed using the Limit State Method in accordance with IS 456:2000. Loads including dead loads, live loads, and floor loads were calculated as per IS 875 specifications. Both manual calculations and STAAD.Pro V8i software were used for analysis and design.

The analysis results such as bending moments, shear forces, axial loads, and deflections obtained from STAAD.Pro were compared with manual calculations. It was observed that the analytical results were almost similar, with minor variations in reinforcement detailing. Manual design generally resulted in slightly higher reinforcement due to conservative assumptions. However, STAAD.Pro provided faster results, accurate load distribution, and efficient reinforcement detailing. The software significantly reduced computational time and minimized human errors compared to manual methods.

The structural safety of beams, columns, slabs, and footings was verified by checking shear stresses, bending moments, deflection limits, and punching shear. The foundation design satisfied soil bearing capacity requirements. Estimation and costing were also prepared to evaluate the overall construction cost. From the overall study, it is concluded that STAAD.Pro is a reliable and efficient tool for structural analysis and design of multi-storeyed residential buildings. The project ensures safety, serviceability, durability, and economy of the proposed G+4 residential structure.

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