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Performance-Based Analysis of A G+6 Reinforced Concrete Shear Wall Structure under Earthquake Loads

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ABSTRACT

The principle objective of this project is to analyse and design a multi-storeyed residential building [G + 6 (3 dimensional frame)] using STAAD Pro. The design involves load calculations manually and analyzing the whole structure by STAAD Pro. The design methods used in STAAD-Pro analysis are Limit State Design conforming to Indian Standard Code of Practice. STAAD.Pro features a state-of-the-art user interface, visualization tools, powerful analysis and design engines with advanced finite element and dynamic analysis capabilities. From model generation, analysis and design to visualization and result verification, STAAD.Pro is the professional's choice.We considered a 3-D RCC frame with plan dimensions of 38.39 meter in x-direction and 11.78 meter in z-direction. The y-axis consisted of G + 6 floors. The ground floor height was 2.45 meter and rest of the 6 floors had a height of 3 meter. The structure was subjected to self weight, dead load, live load and seismic loads under the load case details of STAAD.Pro. Seismic load calculations were done following IS 1893-2000. The materials were specified and cross-sections of the beam and column members were assigned. The supports at the base of the structure were also specified as fixed. The codes of practise to be followed were also specified for design purpose with other important details. Then STAAD.Pro was used to analyse the structure and design the members. In the post-processing mode, after completion of the design, we can work on the structure and study the bending moment and shear force values with the generated diagrams. We may also check the deflection of various members under the given loading combinations. The design of the building is dependent upon the minimum requirements as prescribed in the Indian Standard Codes. The minimum requirements pertaining to the structural safety of buildings are being covered by way of laying down minimum design loads which have to be assumed for dead loads, imposed loads, and other external loads, the structure would be required to bear. Strict conformity to loading standards recommended in this code, it is hoped, will ensure the structural safety of the buildings which are being designed. Structure and structural elements were normally designed by Limit State Method.

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I. INTRODUCTION

The rapid growth of urbanization and population has significantly increased the demand for multi-storeyed residential buildings in metropolitan and semi-urban areas [3], [4]. The structural design of such buildings requires careful analysis to ensure safety, stability, serviceability, and economy [5], [7]. Reinforced Cement Concrete (RCC) framed structures are widely used in modern construction due to their durability, strength, and adaptability to different architectural configurations [1], [2], [6]. RCC combines the compressive strength of concrete with the tensile strength of steel reinforcement, making it suitable for beams, slabs, columns, and shear walls in multi-storeyed buildings [7], [15].

In multi-storeyed structures, structural members must be designed to safely resist gravity loads such as dead load and live load, along with lateral loads caused by wind and earthquakes [9], [10], [11]. Dead load includes the self-weight of structural components and permanent finishes, while live load accounts for occupancy and movable loads as specified in IS 875 (Part 1 & 2):1987 [10]. Seismic forces are particularly critical in earthquake-prone regions and must be evaluated carefully using codal guidelines such as IS 1893 (Part 1):2002 [11]. The design philosophy adopted in Indian practice is the Limit State Method, which ensures safety against collapse and acceptable serviceability under working loads as per IS 456:2000 [9].

Manual analysis of complex three-dimensional structures is time-consuming and prone to computational errors, especially for multi-storeyed buildings subjected to multiple load combinations [4], [15]. Therefore, modern structural engineering practice relies heavily on computational tools such as STAAD.Pro for accurate modeling, analysis, and design [13], [14]. STAAD.Pro incorporates advanced finite element analysis (FEA) capabilities and allows engineers to simulate realistic structural behavior under various loading scenarios [13]. The software enables efficient generation of 3D structural models, assignment of material properties, application of load combinations, and interpretation of results through graphical post-processing tools [14].

Structural analysis is a fundamental step in the design process, as it determines internal forces such as bending moments, shear forces, axial forces, and deflections in structural members [3], [15]. In seismic analysis, the building must resist horizontal inertia forces proportional to its mass and dynamic characteristics [8], [11]. The behavior of a multi-storeyed building under seismic loading depends on parameters such as building height, mass distribution, stiffness, damping, and natural period of vibration [8]. IS 1893 (Part 1):2002 provides procedures for determining design base shear, load combinations, and lateral force distribution along the height of the building [11]. For regular buildings like the present G+6 structure, the equivalent static method is recommended for seismic analysis [11].

Shear walls are effective lateral load-resisting elements that significantly enhance stiffness and reduce lateral displacement in multi-storeyed buildings [8]. The inclusion of shear walls improves structural performance during earthquakes by reducing storey drift and increasing overall stability [8], [12]. Proper ductile detailing as per IS 13920:1993 ensures energy dissipation and prevents brittle failure during seismic events [12]. Ductility plays a crucial role in maintaining structural integrity under cyclic loading conditions [6], [8].

In this project, a G+6 RCC framed structure with shear walls is modeled and analyzed using STAAD.Pro [13], [14]. The modeling includes defining nodal coordinates, assigning cross-sectional properties to beams and columns, specifying material properties such as modulus of elasticity and density, and applying boundary conditions in the form of fixed supports at the base [9], [13]. Load cases considered include self-weight, dead load, live load, and seismic load as per relevant Indian Standard codes [9], [10], [11]. Load combinations are generated to determine critical design forces in structural members [9].

The results obtained from the software include bending moment diagrams, shear force diagrams, axial force values, and displacement profiles [13], [15]. These outputs are used for designing beams, columns, and shear walls according to IS 456:2000 provisions [9]. Column interaction ratios and reinforcement requirements are verified to ensure structural safety [2], [6]. The integration of software-based analysis with codal provisions enhances accuracy, efficiency, and reliability in structural design [1], [14].

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Thus, the present study demonstrates a performance-based structural analysis approach for a G+6 RCC shear wall building under earthquake loading, combining theoretical principles of structural engineering [3], [15], codal compliance [9], [11], and modern computational tools [13], [14] to ensure safe, economical, and structurally efficient building design.

II.LITERATURE REVIEW

a. Reinforced Concrete Design – Dr. S.R. Karve & Dr. V.L. Shah

Dr. S.R. Karve and Dr. V.L. Shah, in their book *Illustrated Design of Reinforced Concrete Buildings*, provide a comprehensive explanation of reinforced concrete design principles based on the Limit State Method as per Indian Standard codes. The authors emphasize the importance of understanding load transfer mechanisms in beams, columns, slabs, and foundations. Their work discusses detailed procedures for calculating bending moments, shear forces, and axial loads in multi-storeyed buildings. The book also highlights ductile detailing provisions to improve seismic resistance of RCC structures. The authors explain the codal requirements of IS 456:2000 and IS 13920:1993 with illustrative examples, making it easier to understand structural behavior under different loading conditions. Their contribution forms the theoretical foundation for analyzing RCC framed structures manually before validating them using software tools like STAAD.Pro. The present project adopts the Limit State Design approach and reinforcement detailing principles discussed in this literature for the design of beams and columns in the G+6 building.

b. Advanced Reinforced Concrete Design – N. Krishna Raju

N. Krishna Raju, in his book *Advanced Reinforced Concrete Design*, presents detailed discussions on the behavior of RCC structures subjected to combined axial load and bending. The book provides insights into the design of columns under biaxial bending, shear design of beams, and serviceability checks such as deflection control and crack width limitation. Special emphasis is given to high-rise buildings and the effect of lateral loads such as wind and earthquakes. The interaction curves for columns under axial load and moment are discussed extensively, which are crucial for multi-storeyed structures. The book also discusses slenderness effects in columns and moment redistribution concepts. These principles are essential in the design of G+6 RCC framed buildings, where columns experience significant axial loads and moments. The present project incorporates these design concepts while interpreting the output generated from STAAD.Pro for beam and column design.

c. IS 456:2000 – Plain and Reinforced Concrete Code of Practice

IS 456:2000, published by the Bureau of Indian Standards, serves as the fundamental code for the design of plain and reinforced concrete structures in India. It outlines the requirements for material properties, load combinations, safety factors, durability, and serviceability criteria. The code introduces the Limit State Method as the standard design philosophy, ensuring safety against collapse and satisfactory performance under working loads. It specifies design procedures for flexure, shear, torsion, and axial compression members. The codal provisions also include guidelines for minimum and maximum reinforcement, spacing of stirrups, and cover requirements. This standard forms the backbone of RCC structural design in the present project. All beams and columns in the G+6 building are designed as per IS 456:2000 guidelines using STAAD.Pro software to ensure structural adequacy and safety.

d. IS 1893 (Part 1): 2002 – Criteria for Earthquake Resistant Design of Structures

IS 1893 (Part 1): 2002 provides the guidelines for seismic analysis and design of buildings in India. The code defines seismic zones, importance factors, response reduction factors, and soil conditions to determine the design base shear. It recommends the equivalent static method for regular buildings and dynamic analysis methods for complex structures. The vertical distribution of base shear along the height of the building is specified in the code. It also provides empirical formulas for estimating the fundamental natural period of vibration. In multi-storeyed RCC buildings, seismic forces significantly influence member design. The present project follows IS 1893 provisions for calculating seismic loads using the seismic load generator available in STAAD.Pro. The base shear and lateral force distribution are determined as per codal requirements to ensure earthquake resistance.

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III.WORKING METHODOLOGY

The working methodology adopted for the analysis and design of the G+6 RCC framed building using STAAD.Pro follows a systematic and structured approach in accordance with Indian Standard Codes. The process begins with the collection of preliminary data such as plan dimensions, storey heights, slab thickness, beam and column sizes, material grades, and seismic zone details. The building considered has plan dimensions of 38.79 m × 12.38 m and a total height of 20.45 m including the ground and six upper floors. The grades of materials selected are M20 concrete and Fe500 steel. These parameters are essential for accurate modeling and load estimation. After gathering the necessary data, the structure is modeled as a three-dimensional space frame in STAAD.Pro. The geometry is created by defining nodal coordinates in the X, Y, and Z directions, and members are generated by connecting these nodes to form beams and columns. Material properties such as modulus of elasticity, density, and Poisson's ratio are defined as per IS 456:2000.

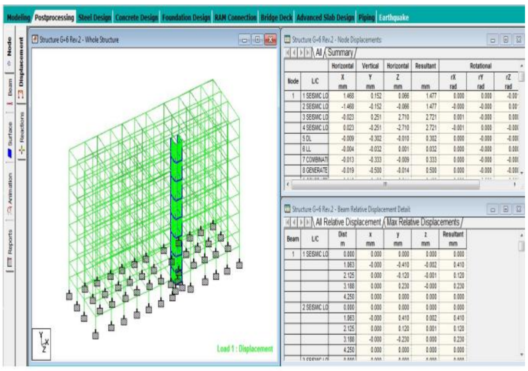

Fig.1 – Post Processing Mode in STAAD.Pro

Fig.1 shows the structure in post-processing mode after completion of analysis in STAAD.Pro. The 3D model of the G+6 building is displayed along with node displacement results. The displacement table on the right side provides numerical values of translational displacements (X, Y, Z) and rotations (RX, RY, RZ) for different load cases. The highlighted vertical element in the center indicates the critical region selected for displacement review. Post-processing mode allows engineers to examine structural response such as maximum displacement, storey drift, support reactions, and internal forces. This stage is crucial for verifying serviceability criteria and ensuring that deflection limits are within permissible values as per codal provisions.

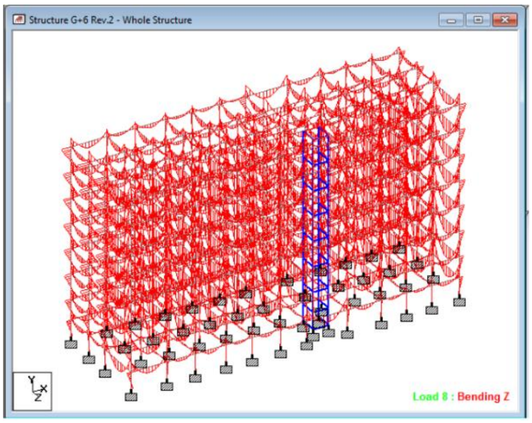

Fig.2 – Bending in Z Direction for Load Combination (1.5DL + 1.5LL)

Fig.2 illustrates the bending moment diagram in the Z-direction for the load combination 1.5DL + 1.5LL. The red contour lines represent bending deformation of beams and columns under factored gravity loading. The curved shape of the members indicates flexural behavior, with maximum bending typically occurring at mid-span of beams and near supports. The lower storey columns show higher bending effects due to accumulation of loads from upper floors. This diagram helps in identifying critical sections for reinforcement design and ensures that the moment capacity of members is adequate under ultimate load combinations.

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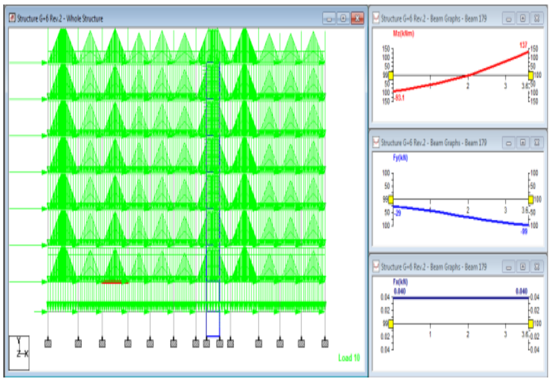

Fig.3 – Graph for Shear Force and Bending Moment of a Beam (1.2DL + 1.2LL + 1.2EQ+X)

Fig.3 presents detailed beam force graphs in post-processing mode for the load combination 1.2DL + 1.2LL + 1.2EQ+X. The top graph shows the bending moment variation along the beam length, the middle graph indicates shear force distribution, and the bottom graph represents axial force variation. The bending moment diagram generally shows maximum positive moment near mid-span and negative moment near supports. Shear force is maximum at beam ends and reduces toward the center. These graphical results are essential for calculating required tensile reinforcement and shear stirrup spacing in beam design as per Limit State Method.

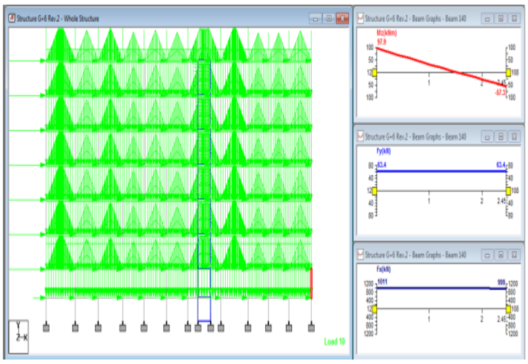

Fig.4 – Graph for Shear Force and Bending Moment of Column in Post Processing Mode

Fig.4 shows the force diagrams for a column in post-processing mode. The bending moment diagram indicates variation of moment along the column height due to combined gravity and seismic loading. The shear force diagram reflects lateral force effects, especially under seismic load combinations. Columns in lower storeys exhibit higher bending and shear values because they resist cumulative loads from upper floors. These graphs are used to verify axial load-moment interaction and ensure column safety under combined loading conditions. Proper interpretation of these diagrams is essential for designing longitudinal reinforcement and lateral ties in columns.

IV.CONCLUSION

The analysis and design of the G+6 RCC framed building using STAAD.Pro has demonstrated the effectiveness of modern structural analysis software in handling complex multi-storeyed structures. The building was modeled as a three-dimensional space frame and analyzed under various loading conditions including dead load, live load, and seismic load. The seismic forces were calculated using the equivalent static method as per IS 1893 (Part 1): 2002, and the design was carried out using the Limit State Method in accordance with IS 456:2000 and IS 13920:1993. The structural members such as beams and columns were designed to resist bending moments, shear forces, axial loads, and torsional effects generated from different load combinations. The results obtained from the analysis confirmed that the structure performs satisfactorily under both gravity and lateral loads.

From the analysis results, it was observed that the structure is comparatively more flexible in the shorter (Z) direction than in the longer (X) direction, which is consistent with the building geometry. Reinforcement detailing provided by STAAD.Pro ensured compliance with ductile detailing provisions for seismic resistance. Interaction ratios for columns

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were found to be within permissible limits, confirming structural safety. Shear reinforcement spacing and flexural reinforcement requirements were checked and found adequate as per codal provisions. Post-processing tools such as bending moment diagrams, shear force diagrams, and deflection profiles helped in verifying structural behavior effectively.

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