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Structural Performance Evaluation of a Five-Storey RCC Hostel Building Under Gravity and Seismic Loads

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Abstract- The rapid growth in university enrollment has increased the demand for safe and economical student accommodation, particularly in seismically active regions. This study presents the structural modeling, analysis, and design of a five-storey reinforced concrete (RCC) hostel building located in Rahim Yar Khan, Pakistan, using ETABS software. The structure was designed in accordance with ASCE 7-16 for loading and ACI 318-14 for reinforced concrete design. Gravity loads (dead, super dead, and live loads) and lateral loads (seismic loads in X and Y directions) were applied to evaluate structural performance. Results show that the maximum story displacement occurred at the roof level with a value of 0.3299 inches, which is within permissible limits. The maximum story drift was recorded at Story 4 with a value of 0.000553, significantly lower than the allowable drift limit of 0.020 prescribed by ASCE 7-16. The highest story stiffness of 3818.72 kip/in was observed at the first storey, decreasing gradually towards the top. Base reaction results indicated a seismic base shear of -96.119 kip in the X-direction and overturning moments of - 4172.55 kip-ft and 3649.15 kip-ft about the Y and Z axes, respectively. These results confirm that the proposed RCC structural system satisfies strength, stiffness, and serviceability requirements, making it suitable for long-term student accommodation.

Keywords: RCC building, ETABS, seismic analysis, story drift, displacement, hostel building.

I. INTRODUCTION

Concrete is the most widely used construction material in modern infrastructure due to its high compressive strength, durability, availability, and cost efficiency (Mehta & Monteiro, 2014; Neville, 2011). Rapid urbanization and the continuous expansion of higher-education institutions have increased the demand for multi-storey residential buildings, particularly student hostels. These structures must accommodate large populations while maintaining structural safety, serviceability, and long-term durability under sustained gravity loads and environmental actions such as wind and earthquakes (Taranath, 2016).

Reinforced concrete (RCC) frame structures are commonly employed in residential and institutional buildings because of their structural reliability, fire resistance, and adaptability to architectural requirements (Wang et al., 2018). The inclusion of shear walls within RCC frames significantly improves lateral load resistance by increasing stiffness and reducing excessive lateral deformations (Paulay & Priestley, 1992). Previous studies indicate that buildings incorporating shear walls exhibit superior seismic performance compared to bare frame systems, particularly in mid-rise structures located in seismic regions (Chopra, 2017).

Seismic forces impose critical demands on multi-storey buildings, especially in areas classified as moderate to high seismic zones. Earthquake-induced lateral loads can result in excessive inter-story drift, cracking of structural members, and damage to non-structural components if not adequately controlled (Fardis, 2009). Modern seismic design philosophy emphasizes deformation-based performance criteria rather than strength alone, ensuring that structures remain functional and safe during seismic events (Priestley et al., 2007). Inter-story drift has been identified as a key indicator of seismic performance and directly influences occupant safety and serviceability (Krawinkler & Seneviratna, 1998).

International design standards provide explicit guidance for seismic analysis and structural design. ASCE 7-16 outlines procedures for seismic load calculation, load combinations, and drift limitations to ensure acceptable structural behavior under earthquake loading (ASCE, 2016). Compliance with these provisions ensures adequate ductility, stiffness, and energy dissipation capacity. Several researchers have emphasized that strict adherence to seismic design codes significantly reduces the risk of structural damage and collapse during strong ground motions (Clough & Penzien, 2003).

In addition to lateral loads, gravity loads play a dominant role in the design of hostel buildings. Such structures experience relatively high live loads due to continuous occupancy, furniture loads, and human movement (IS 875-2, 1987). Accurate estimation of dead loads, superimposed dead loads, and live loads is essential for realistic modeling and economical member design. Inadequate load representation may lead to unsafe designs or inefficient material usage (MacGregor & Wight, 2012).

Advancements in computational techniques have transformed structural engineering practice. Structural analysis software such as ETABS enables three-dimensional modeling, automated load combination generation, and efficient evaluation of structural response parameters (CSI, 2018). The software is widely used for analyzing multi-storey RCC buildings due to its ability to simulate real-world loading conditions and provide reliable outputs for displacement, drift, stiffness, internal forces, and base reactions (Ahmad & Sheikh, 2019). Software-based analysis has been shown to improve accuracy and reduce human error compared to conventional manual design methods (Qamar et al., 2020).

Accurate modeling of slabs, beams, columns, and shear walls is essential for obtaining realistic structural behavior. Modeling assumptions related to diaphragm action, boundary conditions, and material properties significantly influence seismic response parameters (Wilson, 2002). Story displacement and stiffness distribution provide insight into force transfer mechanisms from upper storeys to the foundation system (Taranath, 2016). Base reactions obtained from analysis are particularly important for foundation design, as they reflect the interaction between the superstructure and supporting soil during seismic events (Bowles, 1996).

Controlled deformation behavior is especially important for hostel buildings, where occupant comfort and safety are primary concerns. Excessive lateral displacement, even without structural collapse, may result in serviceability issues and long-term maintenance problems (Ghobarah, 2001). Verification of displacement and drift limits is therefore a fundamental requirement in the structural assessment of residential buildings located in seismic regions. A systematic evaluation using code-compliant software-based analysis provides a reliable framework for achieving safe, economical, and durable RCC structures throughout their service life (ACI Committee 318, 2014).

II. LITERATURE REVIEW

Reinforced concrete (RCC) has remained the dominant construction material for residential and institutional buildings due to its favorable mechanical properties, durability, and adaptability to diverse structural forms. Extensive research has highlighted the widespread application of RCC frame systems in mid-rise buildings, particularly where economic efficiency and structural reliability are primary concerns (Mehta & Monteiro, 2014; Neville, 2011). The combination of concrete and steel reinforcement provides adequate strength and ductility, making RCC structures suitable for resisting both gravity and lateral loads.

The seismic behavior of RCC buildings has been a major focus of structural engineering research, especially in earthquake-prone regions. Chopra (2017) emphasized that dynamic response characteristics such as natural period, lateral displacement, and inter-story drift govern the seismic performance of multi-storey buildings. Studies have shown that excessive lateral deformation is one of the primary causes of structural and non-structural damage during earthquakes (Fardis, 2009). Consequently, modern seismic design has shifted from purely strength-based approaches toward performance-based and deformation-controlled methodologies (Priestley et al., 2007).

The role of shear walls in improving the seismic response of RCC buildings has been extensively documented. Paulay and Priestley (1992) reported that the inclusion of shear walls significantly enhances lateral stiffness and reduces inter-story drift demands. Buildings with strategically placed shear walls demonstrate improved load distribution and reduced bending demands on frame elements when compared to bare frame systems. Similar observations were reported by Taranath (2016), who noted that shear walls are particularly effective in controlling lateral displacement in mid-rise residential buildings.

Inter-story drift has been identified as a critical parameter for evaluating seismic performance and serviceability. Krawinkler and Seneviratna (1998) demonstrated that drift-based criteria provide a more reliable measure of structural damage potential than force-based parameters alone. Excessive drift can lead to cracking of concrete members, yielding of reinforcement, and damage to non-structural components, even when collapse does not occur. Ghobarah (2001) further emphasized that limiting drift is essential to ensure post-earthquake functionality and occupant safety.

Design codes play a crucial role in regulating seismic performance of buildings. ASCE 7-16 provides detailed procedures for seismic load determination, load combinations, and drift limitations to ensure acceptable structural behavior under earthquake loading (American Society of Civil Engineers [ASCE], 2016). Research by Clough and Penzien (2003) demonstrated that adherence to codal provisions significantly improves structural resilience and reduces seismic risk. Similarly, ACI Committee 318 (2014) establishes design requirements for reinforced concrete elements to ensure adequate strength, ductility, and durability.

Gravity load considerations are equally important in the design of hostel and residential buildings. Live load estimation is particularly critical due to continuous occupancy, furniture loads, and human activity. MacGregor and Wight (2012) highlighted that inaccurate load estimation may result in either unsafe designs or uneconomical use of materials. Standards such as IS 875 (Part 2) provide guidelines for imposed loads on residential buildings, ensuring realistic representation of occupancy conditions (IS 875-2, 1987).

The adoption of structural analysis software has significantly enhanced the accuracy and efficiency of building design. ETABS has been widely used for modeling and analysis of multi-storey RCC buildings due to its ability to simulate three-dimensional structural behavior and complex loading scenarios (Computers and Structures Inc. [CSI], 2018). Wilson (2002) emphasized that three-dimensional modeling allows realistic representation of diaphragm action, load paths, and member interactions, which are difficult to capture through simplified analytical methods.

Several studies have demonstrated the reliability of ETABS in evaluating seismic performance parameters such as displacement, drift, stiffness, and base reactions. Ahmad and Sheikh (2019) reported that accurate modeling of slabs, beams, columns, and boundary conditions in ETABS leads to results that closely align with code-based expectations. Qamar et al. (2020) further observed that software-based analysis reduces human error and provides consistent results for performance evaluation of RCC buildings subjected to lateral loads.

Foundation design is directly influenced by base reactions obtained from structural analysis. Bowles (1996) emphasized that seismic base shear and overturning moments must be carefully transferred to the foundation system to prevent excessive settlement or rotational instability. Accurate estimation of these forces ensures proper soil–structure interaction and overall stability of the building during seismic events.

III. METHODOLOGY

Building Description

The proposed structure is a five-storey reinforced concrete hostel building located in Rahim Yar Khan.

The building consists of a regular RCC frame system with shear walls to enhance lateral load resistance. The ground floor height is 12 ft, and the total number of storeys is five.

Material Properties

Concrete with a compressive strength of 4000 psi was used for all structural elements. The modulus of elasticity was taken as 29,000,000 psi, with a Poisson's ratio of 0.2 and a unit weight of 150 pcf.

Structural Components

Standard reinforced concrete sections were adopted based on practical construction considerations. Beams of size 12 in × 18 in, columns of sizes 12 in × 12 in and 18 in × 18 in, and slabs with a thickness of 6 inches were used throughout the structure.

Load Considerations

Dead load, super dead load, and live load were applied according to standard design practice. A live load of 50 psf and a super dead load of 55 psf were assigned to slabs. Seismic loads in both X and Y directions were applied as per ASCE 7-16, considering the building to be located in Seismic Zone 2B.

Modeling and Analysis

The structural model was developed in ETABS using a three-dimensional approach. Fixed supports were assigned at the base of all columns. Load combinations were generated according to ASCE 7-16. Linear static analysis was performed to obtain story displacements, drifts, stiffness, internal forces, and base reactions.

IV. RESULTS AND DISCUSSION

Story Displacement

The maximum lateral displacement was observed at the roof level (Story 5) with a value of 0.3299 inches. The gradual increase in displacement from base to top indicates elastic and stable structural behavior under applied loads, each story displacement is given in figure 1.

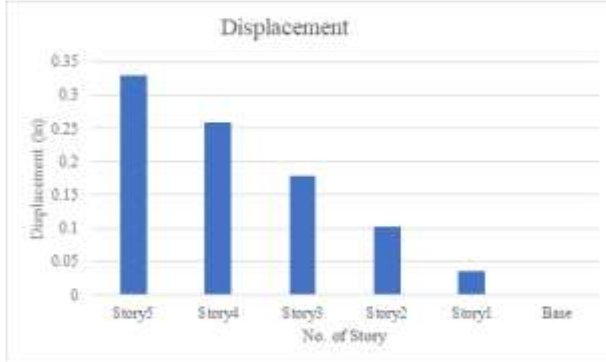

Figure. 1 Displacement of Building Storey-wise

Story Drift

The maximum story drift occurred at Story 4 with a value of 0.000553. This value is well within the allowable drift limit specified by ASCE 7-16, confirming that the structure satisfies serviceability requirements under seismic loading, each story drift is given in figure 2.

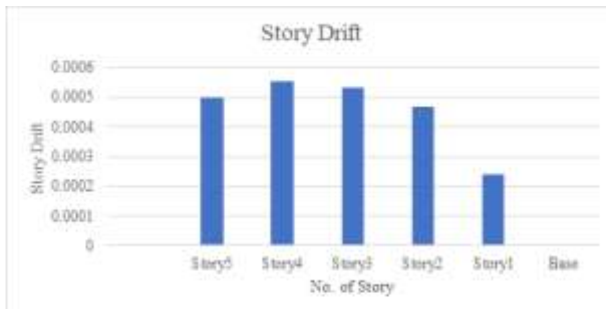

Figure. 2 Drift of Building Storey-wise

Story Stiffness

The highest stiffness was observed at Story 1, with a value of 3818.72 kip/in. A decreasing trend in stiffness toward upper storeys was noted, which is typical for multi-storey RCC buildings and beneficial for energy dissipation during seismic events further it is presented in figure.3.

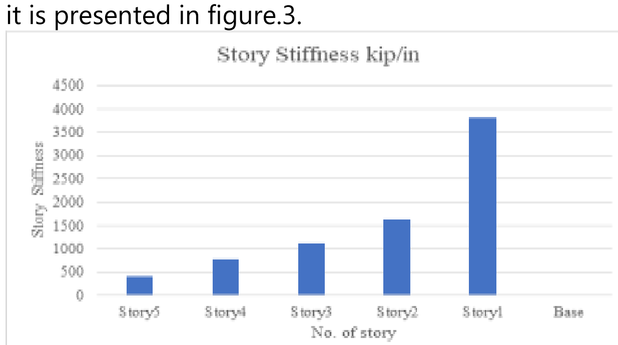

Figure. 3 Stiffness of Building Storey-wise

Internal Forces and Base Reactions

Bending moments, shear forces, and axial forces were found to be within acceptable limits. The base shear in the X-direction was calculated as -96.119 kip, while significant overturning moments were observed due to seismic loading. These forces (Shear forces, Axial Forces Diagram and Bending Moment) indicate that the structure is properly engaging with the foundation system to resist lateral loads which are given in table 1 and figure 4(a), figure 4(b). and figure 4(c).

Table. 1 Base Reaction forces

Reaction	Value	Unit
FX	-96.119	Kip
FY	0	Kip
FZ	0	Kip
MX	-0.00003086	kip-ft
MY	-4172.5491	kip-ft
MZ	3649.15	kip-ft

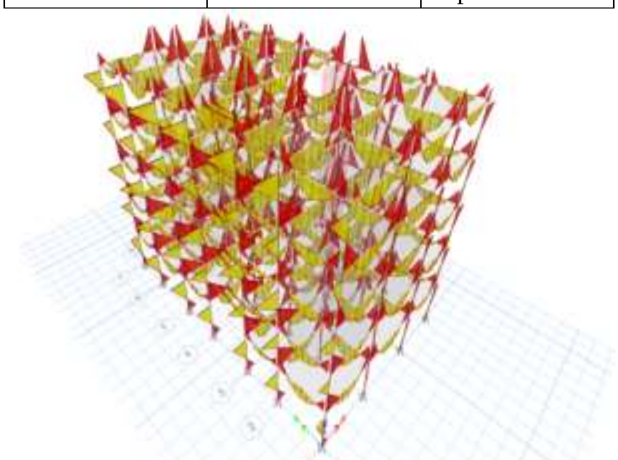

Figure 4 a) Bending Moment Diagram

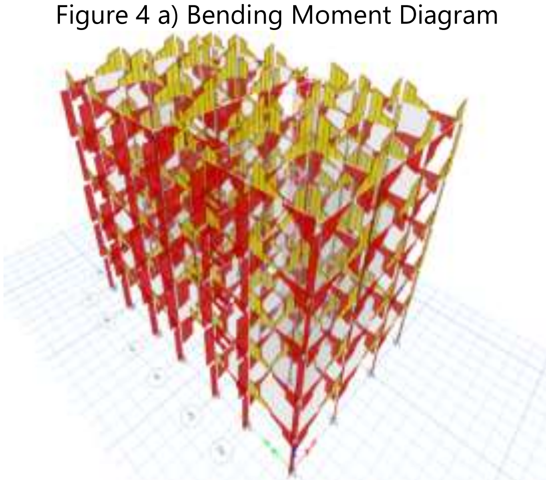

Figure 4 b) Shear Force Diagram

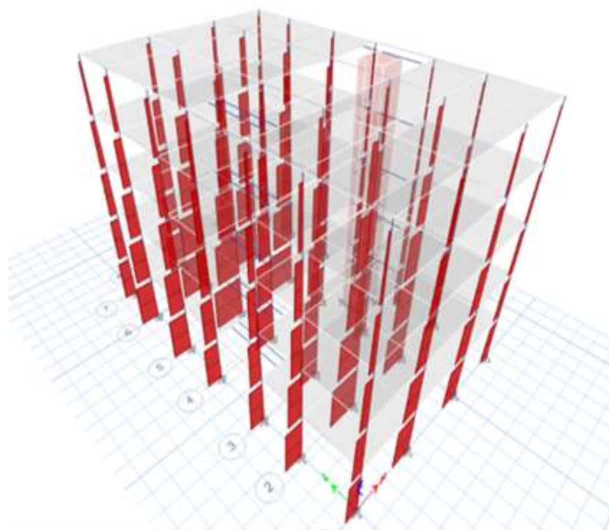

Figure 4 c) Axial Forces Diagram

V. CONCLUSION

The structural analysis and design of a five-storey reinforced concrete hostel building were successfully carried out using ETABS software. The building was designed to resist gravity and seismic loads in accordance with ASCE 7-16 and ACI 318-14 provisions. Analysis results demonstrated that story displacement, story drift, stiffness distribution, and base reactions remain within permissible limits. The study confirms that RCC frame structures with shear walls provide an efficient and safe solution for student hostel buildings. The use of ETABS proved effective in achieving a reliable and economical structural design suitable for real-world applications.

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