Earthquake Resistant Building Using Seismic Retrofitting

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Abstract — This study investigates the seismic performance of reinforced concrete structures and evaluates the effectiveness of seismic retrofitting techniques combined with advanced material modifications. Many existing buildings are vulnerable to earthquake forces due to inadequate design provisions, making retrofitting a necessary solution for structural safety. In this research, a three-storey building model was analyzed using STAAD.Pro to compare structural behavior before and after retrofitting. Key parameters such as base shear, nodal displacement, storey displacement, support reactions, bending moment, and shear force were evaluated. The retrofitting techniques considered include shear walls and base isolation, while material enhancement was explored using rubberized concrete and graphene oxide. Experimental results indicated that rubberized concrete improves ductility and energy absorption, whereas graphene oxide enhances strength and durability. However, analytical results showed an increase in displacement and internal forces after retrofitting due to increased seismic mass. The study concludes that while retrofitting improves structural capacity, improper balance between stiffness and mass can lead to increased seismic demand. Optimized design strategies are essential for achieving effective earthquake-resistant structures.

Keywords: Rubber Aggregate, Rubberized Concrete, Conventional Concrete, Sustainable Construction

I. INTRODUCTION

Earthquakes are among the most destructive natural disasters, causing extensive damage to infrastructure and posing significant risks to human life. The severity of structural damage during earthquakes depends on various factors, including ground motion intensity, soil conditions, and most importantly, the structural design and construction quality of buildings. Many existing structures, especially those constructed before the enforcement of modern seismic design codes, are highly vulnerable to earthquake forces. As discussed by T. Cosgun et al. (2023) and S. Sankhwal and N. Patel (2018), such structures often lack adequate seismic resistance and are prone to significant damage or collapse under earthquake loading.

To address this issue, the concept of earthquake-resistant design has become a fundamental aspect of civil engineering. Earthquake-resistant buildings are designed to withstand seismic forces by absorbing and dissipating energy, thereby reducing the likelihood of structural failure. However, constructing new earthquake-resistant buildings for all existing structures is not economically feasible. Therefore, seismic retrofitting has emerged as an effective solution to enhance the performance of existing buildings. According to M. M. More et al. (2024), retrofitting provides a cost-effective and practical approach to improving the seismic resilience of aging infrastructure.

Seismic retrofitting refers to the process of strengthening and upgrading existing structures to improve their resistance to seismic forces. It involves modifications to structural components such as beams, columns, slabs, and foundations to enhance their strength, stiffness, and ductility. Various retrofitting techniques are widely used in practice, including the addition of shear walls, steel bracing systems, base isolation devices, and column jacketing. Studies by K. Singh and A. Uniyal (2020) and X. Y. Cao et al. (2022) emphasize the importance of selecting appropriate retrofitting methods based on structural conditions and performance requirements.

Shear walls are among the most commonly used retrofitting techniques due to their ability to resist lateral loads effectively. They provide additional stiffness and strength to the structure, reducing lateral displacement and inter-storey drift. Steel bracing systems are another effective method that enhances structural stability by redistributing forces and improving load-carrying capacity, as highlighted by A. Badalia and S. P. Singh (2025). Column jacketing increases the cross-sectional area and confinement of columns, thereby improving strength and ductility, making it suitable for damaged or weak structures. This approach has been further validated by B. Talahmeh et al. (2025) through finite element modeling studies.

Base isolation represents an advanced retrofitting technique that reduces the transfer of seismic energy from the ground to the structure. Unlike conventional methods that resist seismic forces, base isolation works by decoupling the structure from ground motion, allowing controlled movement at the base. This significantly reduces acceleration and structural damage, making it suitable for critical structures such as hospitals and heritage buildings. The effectiveness of base isolation systems has been extensively discussed by W. A. Ghafar et al. (2025), who demonstrated its ability to significantly reduce seismic forces.

In addition to structural retrofitting techniques, the use of advanced construction materials has gained attention in recent years. Materials such as rubberized concrete and graphene oxide have shown promising results in improving seismic performance. Rubberized concrete, which incorporates recycled rubber particles, exhibits high damping properties and improved energy absorption capacity. This helps in reducing vibrations and enhancing ductility during seismic events. On the other hand, graphene oxide improves the mechanical properties of concrete by enhancing strength, bonding, and durability. As discussed by G. Markou (2023), such material innovations play a crucial role in improving the overall effectiveness of retrofitting strategies.

The integration of retrofitting techniques with advanced materials offers a comprehensive approach to improving earthquake resistance. While structural modifications enhance stiffness and strength, material innovations improve energy dissipation and crack resistance. However, achieving an optimal balance between these factors is critical, as excessive increase in mass can lead to higher seismic forces. The dynamic response behavior of structures under seismic loading has been studied in detail by C. Michel et al., highlighting the importance of balancing stiffness and mass in structural design.

This study aims to evaluate the effectiveness of seismic retrofitting techniques combined with material modifications in improving structural performance. A comparative analysis is carried out using a three-storey building model to assess parameters such as displacement, base shear, and internal forces. The findings of this study provide insights into the challenges and considerations involved in designing effective retrofitting strategies.

II. METHODOLOGY

The methodology adopted in this study involves the analysis of a three-storey reinforced concrete building model using STAAD.Pro software. The objective is to evaluate and compare the seismic performance of the structure before and after retrofitting.

Two structural models were developed:

1) Pre-retrofitted model representing the original building without any strengthening measures
2) Post-retrofitted model incorporating seismic retrofitting techniques

The building model was designed with a regular grid layout and standard structural components, including beams, columns, and slabs. The geometry and dimensions were defined based on a scaled model, ensuring consistency in both cases.

The retrofitting techniques applied in this study include:

- Shear wall addition at the rear side of the structure to enhance lateral stiffness and reduce displacement
- Base isolation system at the foundation level to reduce seismic force transmission

Seismic loads were applied using the Equivalent Static Method as per IS 1893 provisions. The following loads were considered:

- Dead load
- Live load
- Seismic load

Key parameters such as zone factor, importance factor, response reduction factor, and soil type were incorporated in the analysis.

The performance of the structure was evaluated based on:

- Base shear
- Nodal displacement
- Storey displacement
- Support reactions
- Bending moment
- Shear force

Additionally, experimental analysis was conducted on concrete specimens with modified materials. Different mixes incorporating rubber aggregates and graphene oxide were prepared and tested. The following tests were performed:

- Compressive strength test
- Split tensile strength test
- Flexural strength test

The results from structural analysis and material testing were combined to assess the effectiveness of retrofitting techniques and material modifications.

III. RESULTS AND DISCUSSION

The results obtained from the STAAD.Pro analysis indicate significant changes in structural behavior after retrofitting.

The base shear increased from 172.30 kN to 219.11 kN, indicating an increase in seismic demand due to the added structural elements. This increase is primarily attributed to the additional mass introduced by retrofitting components such as shear walls.

The maximum nodal displacement increased from 336.01 mm (Node 20) to 501.86 mm (Node 36). This result suggests that the increase in stiffness was not sufficient to counterbalance the increase in seismic mass. Ideally, retrofitting should reduce displacement; however, improper distribution of stiffness or excessive mass can lead to increased deformation.

Storey displacement analysis showed that the maximum displacement shifted to the top storey after retrofitting. This indicates a change in deformation pattern and suggests that higher levels of the structure experienced greater flexibility.

Support reactions increased from 391.55 kN to 587.77 kN, indicating higher load transfer to the foundation. This highlights the need for foundation strengthening when retrofitting is applied.The beam end force analysis revealed an increase in bending moment from 86.82 kNm to 135.90 kNm and shear force from 50.71 kN to 182.70 kN. This indicates increased internal. force demand on structural members, which may require additional reinforcement

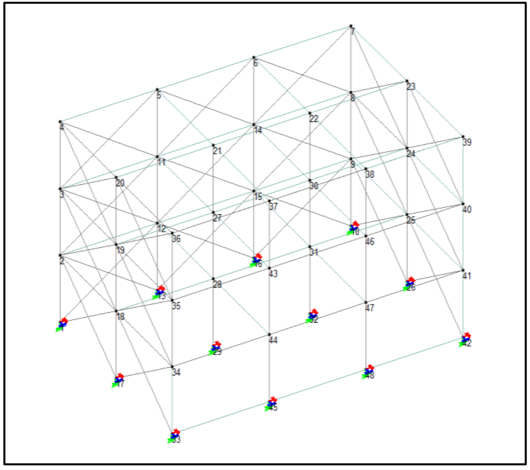

Fig. 1: Analytical Model of Retrofitted Structure with Bracing System

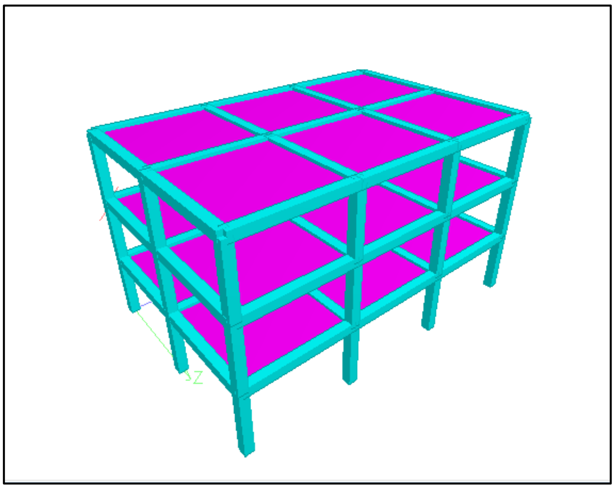

Fig. 2: Reinforced Concrete Building Model in STAAD.Pro

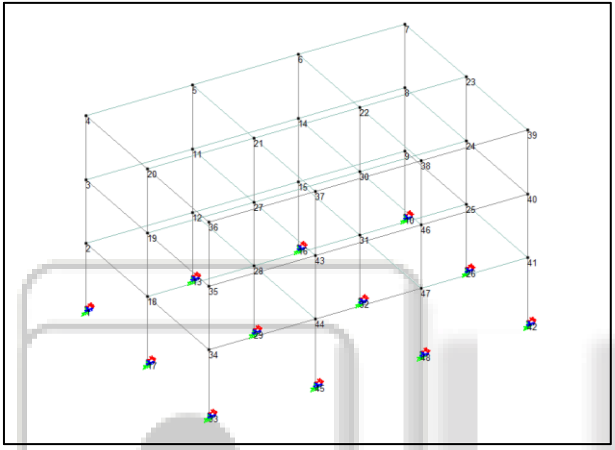

Fig. 3: Analytical Model of Reinforced Concrete Frame Structure

Experimental results showed that rubberized concrete improved ductility and energy absorption, while graphene oxide enhanced strength and bonding properties. The combination of these materials improved overall concrete performance.

Overall, the results indicate that while retrofitting enhances structural capacity, it also increases seismic demand. Proper optimization is required to achieve effective performance.

IV. CONCLUSION

The present study evaluated the seismic performance of a reinforced concrete building before and after retrofitting using STAAD.Pro. The analysis focused on key structural parameters such as base shear, displacement, support reactions, and internal forces.

The results indicate that retrofitting increased the seismic demand due to additional mass, leading to higher base shear, displacement, and internal forces. Although structural elements such as shear walls improved stiffness, the increase in mass outweighed the benefits, resulting in higher deformation.

The study highlights the importance of achieving a balance between stiffness and mass in retrofitting design. Simply adding structural elements without considering their impact on seismic weight can lead to undesirable performance.

Material modifications using rubberized concrete and graphene oxide showed promising results in improving ductility, strength, and durability. These materials can play a significant role in enhancing seismic resistance when used appropriately.

Overall, the study concludes that seismic retrofitting is an effective strategy for improving structural safety, but it must be carefully designed and optimized. Future work should focus on reducing displacement, improving stiffness distribution, and minimizing additional mass to achieve better performance

The study demonstrates that effective seismic retrofitting is not solely dependent on increasing structural strength, but on achieving a well-balanced design that controls displacement, minimizes forces, and ensures overall structural safety.

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