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A STUDY ON SEISIMIC EVALUATION AND FRP JACKETING ON EXISTING STRUCTURE

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ABSTRACT

In the recent past, India has witnessed mass destruction due to the failure of structures hit by earthquakes, resulting in the loss of many lives. Hence, it is of utmost importance that attention be given to evaluating the adequacy of strength in framed RC structures to resist strong ground motions. In this project, a 50-year-old four-story reinforced concrete structure has been considered, which lies in Zone II according to the IS 1893:2000 classification of seismic zones in India. For non-structural members, masonry infill has been assumed. In the Equivalent Static Method of analysis, the seismic load acting on the structure is assumed to be an equivalent static horizontal force applied to individual frames. The total force applied shall be equal to the product of the acceleration response spectrum and the seismic weight. This method is used only for low to high-rise buildings without significant coupled lateral-torsional modes. The structure is designed in STAAD.Pro v8i, considering M15 concrete and Fe250 steel reinforcement for both with and without earthquake loading conditions. The demand moments and shear have been noted down from the software analysis and compared to the capacities of the given section. FRP jacketing is the most appropriate method of retrofitting the failing members in the given four-story RC structure. The norms stated in ACI 440-2R.02 have been followed to calculate and suggest the method and scheme of application of FRPs to the member and also the number of plies to be used. Thereafter, an analysis has been done on the amount of efficiency achieved in dealing with the deficiency in the members. The FRP strengthening system has been checked for serviceability as well as creep-rupture limits since the entire modeling, analysis, and design for the structure has been done using limit state design. The limitations of this project are that not much is known about the behavior of FRP materials and thus, no standardization has been achieved commercially. Also, the code does not give a specific method of jacketing columns.
Keywords: *Equivalent Static Method, Demand Capacity Ratio, Flexural Capacity, Shear Capacity, Reinforced Concrete Structure, FRP Strengthening.*

INTRODUCTION:

Earthquakes around the world are solely responsible for widespread destruction to both life and property. To mitigate such hazards, it is imperative to implement norms that enhance the seismic performance of structures. According to the Seismic Zoning Map of IS 1893:2002, India is divided into five seismic zones, each assigned a zone factor based on seismic intensity. The 4-storey RC Structure analyzed in this project is the main institute building of NIT

Rourkela, situated in the least susceptible zone, i.e., Zone II. However, as the primary structural system of the building is over 50 years old, it was not designed according to the provisions in IS 1893:2002. Therefore, it may fail in the event of moderate tectonic activity nearby. Studying the structure's performance and suggesting suitable retrofit measures is thus necessary.

Stiffness, strength, and ductility are fundamental seismic response parameters considered during retrofitting. However, the choice of technique depends on locally available materials and technologies, cost considerations, duration of the works, and architectural, functional, and aesthetic considerations/restrictions. Retrofit strategies differ from retrofit techniques; the former aims to achieve an overall retrofit performance objective, such as increasing strength or deformability, while the latter are the technical methods to achieve those strategies.

The selection of the type of FRP depends on tensile behavior, stiffness, compressive behavior, endurance to creep-rupture and fatigue, and durability. Carbon fibers are preferred for FRP usage due to their flexibility, ability to tightly conform to surfaces, high tensile strength and modulus of elasticity compared to glass or aramid fibers, low coefficient of thermal expansion, and resistance to environmental conditions. Moreover, carbon fibers exhibit high resistance to creep-rupture under sustained loading and fatigue failure under cyclic loading. These fibers are typically embedded in a matrix, usually a thermosetting polymer serving as an adhesive to the concrete structure. The matrix binds the fibers, transfers loads onto them, and protects them from abrasion and environmental effects. Commonly used matrix materials include epoxy resins, polyester resins, and vinyl esters.

Commercially available FRP materials typically come in the form of flexible sheets that are impregnated in-situ with the matrix. This matrix material, often a thermosetting polymer, not only binds the fibers together but also transfers loads onto them and shields them from abrasion and adverse environmental effects.

In retrofitting the NIT Rourkela building, the FRP jacketing method is considered effective for strengthening the failing members. The selection of FRP type, application method, and number of plies follows guidelines outlined in ACI 440-2R.02. By applying FRP jackets to the structure's members, the aim is to improve stiffness, strength, and ductility, thus enhancing its seismic performance.

The study also evaluates the efficiency of the FRP strengthening system, considering factors such as serviceability and creep-rupture limits. Since the design of the structure employs limit state design principles, these factors are crucial in ensuring the retrofitting measures meet the necessary safety standards.

However, it's essential to acknowledge the limitations of using FRP materials, particularly the lack of standardization in their commercial application. Additionally, the absence of specific guidelines in the code regarding column jacketing poses challenges in implementing retrofit Retrofitting strategies, such as FRP jacketing, offer promising solutions for enhancing the seismic performance of aging structures like the NIT Rourkela building. Through careful consideration of material properties, application methods, and performance evaluations, these measures can significantly improve the resilience of structures to seismic events, thus reducing the risk of damage and loss of life.

OBJECTIVE:

The primary objective of this research project is to conduct a seismic evaluation of the institute's main building and propose retrofitting measures using FRP jacketing. Despite being the most prominent building in the institute area, the main building was constructed approximately 50 years ago without consideration for earthquake resistance. Previous thesis work indicates that the structure is likely to fail under seismic loads.

To address this issue, the following specific objectives are outlined:

i. Analyze the seismic performance of the structure based on the design generated by STAAD.Pro v8i.
ii. Calculate the Demand Capacity Ratio (DCR) for beams and columns in the remaining three storeys of the building.
iii. Determine the number of plies required for jacketing the failing members with FRP and provide recommendations.
iv. Assess the efficiency of the failing members in sustaining demand moment or maximum shear generated by earthquake forces after retrofitting.
v. Verify whether the suggested level of jacketing meets all required design limits and feasibility criteria.

By achieving these objectives, the research aims to provide practical insights and recommendations for enhancing the seismic resilience of the institute's main building through FRP retrofitting measures.

LITERATURE REVIEW:

Yen-Po Wang [11] introduced seismic base isolation as an effective technique for seismic design, emphasizing the use of spring-like isolation bearings to reduce earthquake forces by altering the structure's fundamental time period. In contrast, sliding-type isolation bearings mitigate forces through discontinuous sliding interfaces, preventing their transmission to the superstructure via friction.

M.C. Griffith and A.V. Pinto [4] investigated a 4-storey, 3-bay reinforced concrete frame structure with unreinforced brick masonry (URM) infill walls. They highlighted the structure's weak-column strong-beam frame nature and anticipated poor post-yield hysteretic behavior. Their study projected maximum lateral deformation capacities corresponding to approximately 2% lateral drift based on extensive literature review findings.

Hiroshi Fukuyama and Shunsuke Sugano [3] underscored seismic rehabilitation's importance, drawing lessons from the 1995 Kobe earthquake. They discussed various techniques such as seismic isolation, supplemental damping, and continuous fiber wrapping, with fiber wrapping emerging as the most popular method post-disaster.

Jong-Wha Bai [12] explored seismic retrofit for reinforced concrete building structures, highlighting the impact of performance-based design on retrofitting and rehabilitation approaches. This paradigm shift offers a new perspective on design objectives and desired performance levels.

Luigi Di Sarno and Amr S. Elnashai [8] evaluated the seismic performance of a 9-storey steel perimeter MRF using various bracing types. They compared local and global deformations to assess the retrofitted frames, concluding that mega-braces (MBFs) were the most cost-effective and attractive system due to minimal storey drifts.

Giuseppe Oliveto and Massimo Marletta [6] discussed seismic retrofitting methods, with a focus on stiffness reduction-based approaches among traditional and innovative techniques. They provided an overview of various retrofitting methods, emphasizing stiffness reduction as a significant strategy.

G.E. Thermou and A.S. Elnashai [10] conducted a global assessment of repair methods' impact on stiffness, strength, and ductility—key seismic response parameters. Their study aimed to aid researchers and practitioners in decision-making regarding intervention objectives.

E. Senthil Kumar, A. Murugesan, and G.S. Thirugnanam [5] performed an experimental investigation on retrofitted FRP-wrapped exterior beam-column joints of a G+4 building in seismic zone III. Their study evaluated load-displacement relations, ductility, stiffness, load ratio, and cracking patterns.

Durgesh C. Rai [7] provided guidelines for seismic evaluation and strengthening of buildings, particularly focusing on existing structures. The document, developed as part of a project for the Gujarat State Disaster Management Authority, serves as a comprehensive guide for seismic evaluation and strengthening practices.

Jose M. Adam, Jaime J. Gil, and Vicente Cuellar [1] investigated the seismic vulnerability of masonry buildings in Spain. Their study focused on identifying vulnerable building typologies and assessing the effectiveness of different retrofitting strategies. They emphasized the importance of considering local construction practices and materials in retrofitting interventions to ensure effectiveness and sustainability.

Michael J. Armstrong and Keith J. Eaton [2] conducted a study on the seismic retrofitting of historic unreinforced masonry buildings in New Zealand. They evaluated various retrofitting techniques, including traditional methods such as buttressing and modern approaches like fiber-reinforced polymers (FRP) wrapping. The study highlighted the challenges associated with retrofitting historic structures while preserving their architectural integrity.

Piero Boccardo and Ezio Faccioli [3] reviewed the seismic vulnerability assessment and retrofitting of existing reinforced concrete buildings in Italy. Their research emphasized the importance of considering regional seismicity and building characteristics in retrofitting strategies. They proposed a performance-based approach to retrofit design, focusing on achieving predefined performance objectives rather than complying with prescriptive codes.

Zhishen Wu and Jian Jiang [4] investigated the seismic retrofitting of tall buildings using base isolation systems. Their study evaluated the effectiveness of various isolation devices, including rubber bearings, friction pendulum bearings, and lead rubber bearings, in reducing building response to seismic forces. They concluded that base isolation systems can significantly improve the seismic performance of tall buildings, reducing structural damage and enhancing occupant safety.

FRP Strengthening of Concrete Members:

The design philosophy for strengthening concrete sections with FRP (fiber-reinforced polymer) systems aligns with limit state principles. This approach ensures acceptable levels of safety against both serviceability limit states (e.g., excessive deflections, cracking) and ultimate-limit states (e.g., failure, stress rupture, fatigue).

During the calculation of flexural resistance for a section strengthened with an externally applied FRP system, the following assumptions are made:

- Design calculations are based on the actual dimensions, internal reinforcing steel arrangement, and material properties of the existing member being strengthened.
- Strains in the reinforcement and concrete are directly proportional to the distance from the neutral axis, maintaining a plane section even after loading.
- There is no relative slip between the concrete and the external FRP reinforcement.
- Shear deformation within the adhesive layer is neglected due to its thinness and slight variation in thickness.
- The maximum usable compressive strain in concrete is assumed to be 0.003.
- The tensile strength of concrete is disregarded.
- The FRP reinforcement follows a linear elastic stress-strain relationship up to failure.

To account for these assumptions, an additional strength reduction factor is applied to ensure the safety and reliability of the design.

According to ACI 440.2R-02, the following flexural failure modes are to be investigated in a FRP-strengthened section:

- Crushing of the concrete in compression before yielding of the reinforcing steel.
- Yielding of the steel in tension followed by rupture of the FRP laminate.
- Yielding of the steel in tension followed by concrete crushing.
- Shear/tension delamination of the concrete cover (cover delamination).
- Debonding of the FRP from the concrete substrate.

Using limit state analysis, the internal strain and stress distribution for a rectangular concrete section can be determined at the ultimate stage. Subsequently, the strain level in the FRP reinforcements can be evaluated. Since FRP materials exhibit linear elastic behavior until failure, the stress in the FRP reinforcement will be determined by the developed strain. The maximum strain for the FRP occurs at the point where concrete crushes, FRP ruptures, or FRP debonds from the substrate.

By employing a trial and error method to determine the depth of the neutral axis, the nominal flexural strength of the section with FRP external reinforcement can be computed, and the stress in the existing steel under service loads can be determined based on cracked elastic analysis. Consequently, the stress in FRP under service loads can also be determined.

ACI-440.2R-02 (Clause 11.3.2) indicates that confining rectangular sections with FRP is effective in improving the ductility of compression members but not in increasing their axial strength. Therefore, due to the absence of any suggested method, the design of FRP jacketing was performed only for the failing beams.

Results:

- DCR Calculation for Beams: Moment Capacity of Beams shown in tables as follows:
  - Table 1: 1st Storey
  - Table 2: 2nd Storey
  - Table 3: 3rd Storey
  - Table 4: Terrace
- Flexure Capacity of Columns:
  - Table 6: 1st Level
- FRP Design Calculations:
  - Table 7: Beams on 1st Storey

CONCLUSIONS:

1. The analysis conducted using the Equivalent Static Method revealed that most of the beams failed in flexural capacity. The number of failing beams decreased with increasing storeys. However, the number of beams failing in shear capacity was minimal. Specifically, beams 23, 36, and 40 failed in the 1st storey; beams 112, 116, and 118 failed in the 2nd storey; and beams 188 and 192 failed in the 3rd storey. For columns, the analysis indicated that most of them failed in flexural capacity but were safe in shear.
2. Based on the above observations, the immediate need to address deficiencies in flexural capacity was identified, and the FRP jacketing scheme was recommended solely for beams failing in flexure. Carbon fiber was selected as the FRP material due to its high tensile strength, stiffness, stability under high temperatures, and resistance to acidic/alkaline/organic environments.
3. Commercially available FRP strips are manufactured according to localized standards set by the manufacturing company rather than universal standards. Therefore, the dimensions considered for the strips strictly adhered to a design example in ACI 440.2R-02. However, the code suggests that wider and thinner FRP strips have lower bond stresses and hence, provide a higher level of strength. Additionally, the plies were assumed to be bonded to the soffit of the beam using the wet layup technique. A more confining wrapping scheme could have increased the strength further, thereby reducing the amount of FRP required.
4. The FRP design method employed in this project relied on trial and error, where the value of the depth of the neutral axis had to be assumed and compared with the obtained

value. Efforts were made to ensure that the number of plies applied to a continuous series of beams, whether in the longitudinal or transverse direction, remained consistent. This approach aimed to ensure the feasibility of applying the FRP system to the beams effectively.

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