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# Analysis of Different Types of FRP Strengthening for RC Beam Column Joint and RC Shear Wall: A State of Art

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**ABSTRACT:** The global awareness of sustainability initiated human innovativeness for identifying and implementing more environmental solutions such as the use of fibre-reinforced polymers (FRP) to reduce greenhouse gas emissions and energy consumption associated with unnecessary structural labor. The use of fibre-reinforced polymers gained popularity because of their advantageous properties such as lightweight, high strength and corrosion resistance. Reinforced concrete beam-column joints are generally recognized as critical zones which experience severe deformations during earthquakes as well as Reinforced concrete shear walls are widely used in medium to high rise buildings to provide the lateral strength, stiffness, and energy dissipation capacity required to resist lateral loads caused by wind or earthquakes. Due to bad effect of Environmental changes, pollution, carbonation, and corrosion in a structural part cause the structure to collapse. This paper aims to introduce the retrofitting of different types of FRP strengthening for RC Beam Column joint and RC Shear Wall under axial and cyclic loading to determine which will be more effective in the field of construction.

**KEYWORDS:** Beam column joint, shear wall, finite element analysis, cyclic loading, FRP

## I. INTRODUCTION

Earthquakes are a natural phenomenon that can happen anywhere, at any time, and they have destroyed a lot of infrastructure and taken many lives. As a result, the buildings must be constructed in a way that ensures their safety in the event of such an incident. To prevent partial or complete collapse during earthquakes, the majority of reinforced concrete structures will require significant repairs soon. One of the biggest problems that civil engineers nowadays are dealing with is retrofitting old structures. New retrofitting solutions have had to be developed as a result of the upgrading of many cities and towns in the nation to higher seismic zones. To provide a ductile response of reinforced concrete structures during earthquakes, careful reinforcing details is of the utmost importance. The detailing is done to make sure that, even under the worst conditions that an earthquake may bring about, the entire strength of the reinforcing bars acting as either the major flexural reinforcement or the transverse reinforcement can be developed.

The use of Fibre Reinforced Polymer (FRP) materials in civil engineering field has continuously expanded since their initial notable debut in practice approximately three decades ago. Despite the fact that many academics and professionals have shown that FRP systems offer a great deal of potential for a variety of civil engineering applications, they have largely risen to the top among the alternatives for the refit and rehabilitation of reinforced concrete structures. FRP material outperforms other traditional materials in strengthening applications due to its clearly defined material properties, high strength-to-weight and stiffness-to-weight ratios, resistance to electrochemical corrosion, and ease of handling.

### FRP strengthening in RC beam column joint

RC Beam-column joints are regarded as one of the most vulnerable and critical structural elements. According to research, the inadequacy of existing structures has often been brought to light by severe damage or complete collapse brought on by earthquakes. In actuality, many RC structures were only intended to withstand the effects of static gravity loads, with no attention paid to the lateral strength needed to withstand the inertial forces generated by the structure's

mass. Additionally, poor seismic performance is typically the result of a lack of ductility, which is a result of two significant design process flaws, inadequate reinforcement details and a lack of design philosophy. As a result, several techniques for strengthening have been adopted, including jacketing, shotcrete, post-tensioning, etc., all of which have some drawbacks and restrictions. FRP is one of them and is currently frequently utilised because of its attributes and availability.

### FRP strengthening in RC Shear Wall

Reinforced concrete (RC) shear walls are the most common systems resisting lateral loads in concrete buildings. Because they lessen floor movement in large concrete buildings, RC shear walls are crucial in decreasing the severity of seismic damage during an earthquake. The RC shear walls' easy construction and inexpensive cost are additional benefits that make them a popular lateral load resisting solution. In order to prevent brittle failure when subjected to heavy lateral loads, RC shear walls must be properly built to have not only enough strength but also enough flexibility. Many RC shear walls all around the world are in urgent need of rehabilitation because they have been damaged by prior earthquakes, have inadequate design detailing, or have construction flaws. Many designed shear walls include flaws such insufficient stiffness, insufficient reinforcements, and unfavorable wall dimensions, which impacts how well RC walls operate when subjected to lateral loading. In order to prevent brittle shear failure of RC walls, appropriate ductility must be given in addition to sufficient stiffness. Investigating strengthening techniques while taking into account different factors is crucial for retrofitting existing RC shear walls. Both experimental observations and numerical studies can be used to examine strengthening techniques. These days, steel components and fibre reinforced polymer (FRP) layers are widely used as effective methods for boosting the performance of concrete structures.

### Fibre-Reinforced Polymer (FRP)

Fibre-Reinforced Polymer (FRP) materials are composite materials that typically have strong fibres embedded in a resin matrix. The fibres give the composite material strength and stiffness and typically support the majority of the applied loads. The matrix functions to bind and safeguard the fibres and to enable the passage of stress from fibre to fibre through shear stresses. Glass, carbon, and synthetic fibres are the most prevalent types. FRP composites are nonconductive, noncorrosive, and lightweight materials with exceptionally high strength properties. These materials have advantageous electrical, magnetic, and thermal properties, a high strength-to-density ratio, outstanding corrosion resistance, and all-around usefulness. They are fragile, though, and the rate of loading, temperature, and environmental factors can all have an impact on their mechanical characteristics.

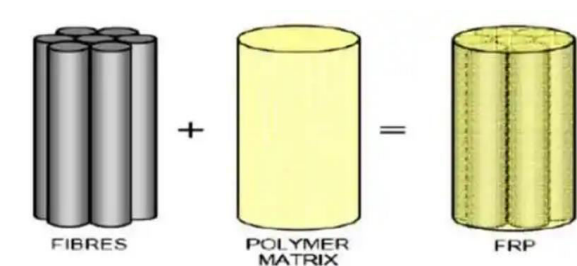


Fig.1. fibre reinforced polymer

### Types of Fiber Reinforced Polymer used in this study

- Carbon Fiber Reinforced Polymer
- Glass Fiber Reinforced Polymer
- Basalt Fiber Reinforced Polymer
- Aramid Fiber Reinforced Polymer

## II. LITERATURE SURVEY

T. El-Amoury, A. Ghobarah [1] Analysed Glass fibre-reinforced polymer (GFRP) sheets are wrapped around the joint to prevent the joint shear failure. GFRP sheets are attached to the bottom beam face to replace the inadequately anchored steel bars. Three beam-column joints are tested; namely, a control specimen and two rehabilitated specimens. The specimens are tested under quasi-static load to failure. The control specimen showed combined brittle joint shear and bond failure modes while the rehabilitated specimens showed a more ductile failure mode. A simple design methodology for the rehabilitation scheme is proposed.

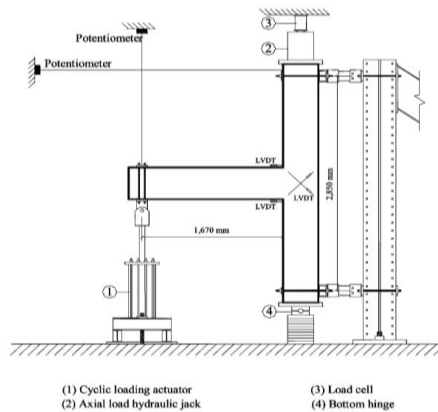


Fig.2. Test Set-up [1]

Reyes Garcia, Yaser Jemaa, Yasser Helal, Maurizio Guadagnini and Kypros Pilakouta [2] Investigates the seismic behavior of three full-scale exterior reinforced concrete (RC) beam-column joints rehabilitated and strengthened with externally bonded carbon fiber-reinforced polymers (CFRP). The specimens had inadequate detailing in the core zone and replicated joints of a real substandard building tested as part of the EU-funded project BANDIT. Seven tests were performed in two successive phases. The bare joints were first subjected to reversed cyclic loading tests to assess their basic seismic performance. As these initial tests produced severe damage in the core, the damaged concrete was replaced with new high-strength concrete. The specimens were subsequently strengthened with CFRP sheets and the cyclic tests were repeated. The results indicate that the core replacement with new concrete enhanced the shear strength of the substandard joints by up to 44% over the bare counterparts. ASCE guidelines predict accurately the shear strength of the bare and rehabilitated joints. The CFRP strengthening enhanced further the joint strength by up to 69%, achieving a shear strength comparable to that of joints designed according to modern seismic provisions. Therefore, the rehabilitation/strengthening method is very effective for post-earthquake strengthening of typical substandard structures of developing countries.

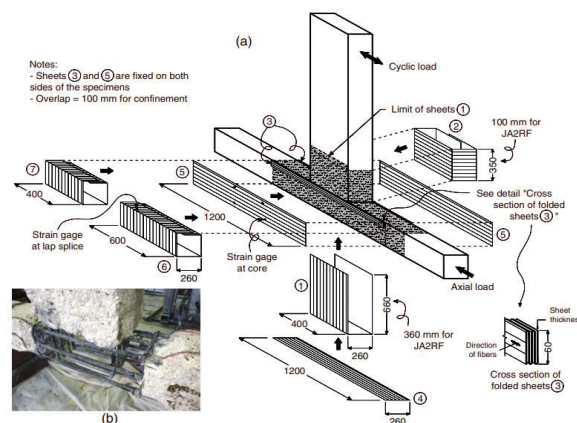
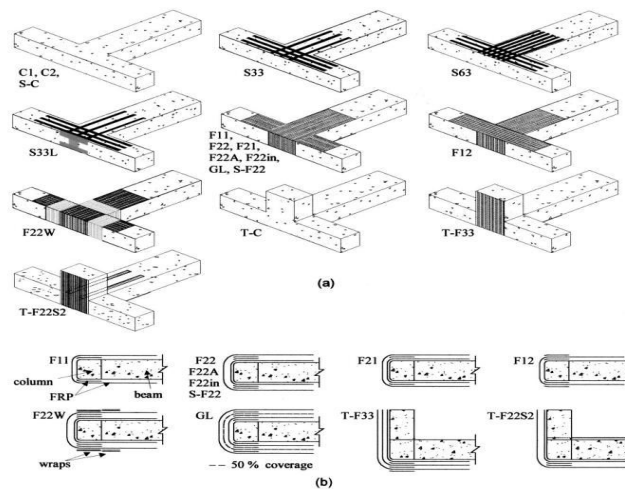


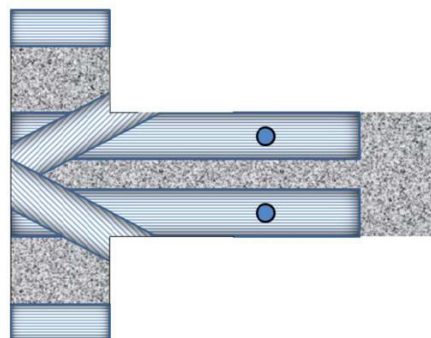
Fig.3. (a) CFRP strengthening strategy and (b) removal of CFRP and core replacement in joint JB2RF (units: mm) [2]

Costas P. Antonopoulos and Thanasis C. Triantafillou [3] Conducted experimental program, aimed at providing a fundamental understanding of the behavior of shear-critical exterior reinforced concrete (RC) joints strengthened with fiber reinforced polymers (FRP) under simulated seismic load, are presented in this study. The role of various parameters on the effectiveness of FRP is examined through 2/3-scale testing of 18 exterior RC joints. Conclusions are drawn on the basis of certain load versus imposed displacement response characteristics, comprising the strength (maximum lateral load) the stiffness, and the cumulative energy dissipation capacity. The results demonstrate the important role of mechanical anchorages in limiting premature debonding, and they provide important information on the role of various parameters, including: area fraction of FRP; distribution of FRP between the beam and the column; column axial load; internal joint (steel) reinforcement; initial damage; carbon versus glass fibers; sheets versus strips; and effect of transverse beams.



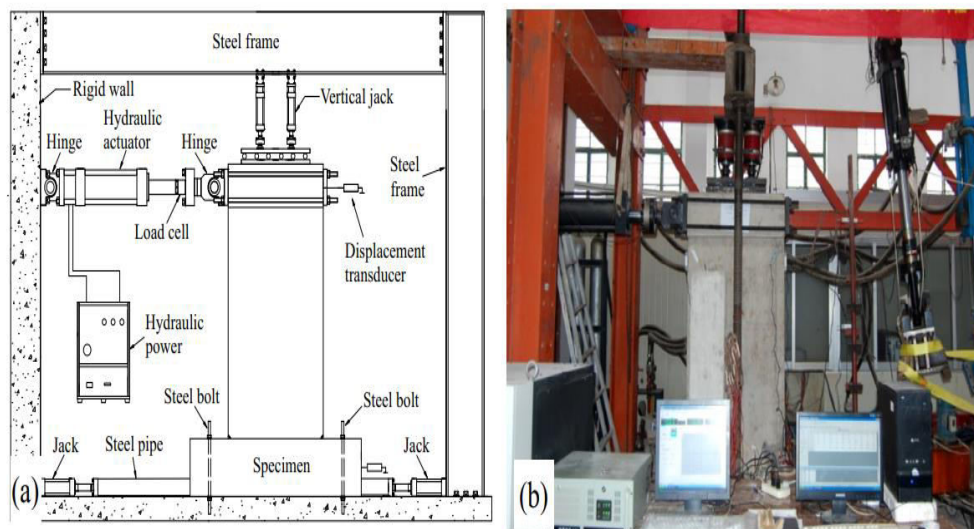
**Fig.4.** (a) Description of specimens and strengthening alternatives; (b) layout of FRP layers [3]

Halil Sezen [4] Tested Three exterior reinforced concrete beam-column joint specimens under reverse cyclic loading. The joint region of these specimens suffered significant damage, whereas limited damage was observed in the beams. The damaged specimens were repaired and strengthened to prevent shear damage and strength deterioration inside the joint region and to achieve more ductile response. First, the damaged loose concrete was removed and replaced by high-strength non shrink mortar. Then, fiber-reinforced polymer (FRP) strips were diagonally wrapped over the joint region, and longitudinal FRP strips were applied and anchored on the beams. The original strength was restored in all strengthened specimens under the application of the same loading history. Deformation capacities of the strengthened specimens were much larger than those of the original specimens.



**Fig. 5.** FRP-strengthening scheme [4]

Dejian Shen, Qun Yang, Yang Jiao, Zhenghua Cui, Jinyang Zhang [5] Investigated on the RC shear walls strengthened with basalt FRP (BFRP) are relatively limited compared with RC shear walls strengthened with carbon FRP or glass FRP. Six RC shear wall specimens with an aspect ratio of 1.6, characterized as medium-rise, were subjected to cyclic load to investigate failure modes, displacement ductility ratio, stiffness characteristic, energy dissipation capacity, and load carrying capacity. One of them was tested without any strengthening as a reference specimen and the other five specimens were strengthened using BFRP strips with different configurations. The theoretical load carrying capacity was also calculated and compared with the test results.



**Fig.6.** Test setup layout: (a) schematic drawing; (b) photo. [5]

Nayera Mohamed, Ahmed Sabry Farghaly, Brahim Benmokrane, and Kenneth W. Neale [6] studied the applicability of reinforced concrete shear walls totally reinforced with glass fiber-reinforced polymer (GFRP) bars to attain reasonable strength and drift requirements as specified in different codes. Four large-scale shear walls one reinforced with steel bars (as reference specimen) and three totally reinforced with GFRP bars were constructed and tested to failure under quasistatic reversed cyclic lateral loading. The GFRP-reinforced walls have different aspect ratios covering the range of medium-rise walls. The reported test results clearly show that properly designed and detailed GFRP-reinforced walls could reach their flexural capacities with no strength degradation and that shear, sliding shear, and anchorage failures were not major problems and can be effectively controlled. The results also show recoverable and self-centering behavior up to allowable drift limits before moderate damage occurs and achieving a maximum drift meeting the limitation of most building codes. Acceptable levels of energy dissipation accompanied by relatively small residual forces, compared to the steel-reinforced wall, were observed. The promising results can provide impetus for constructing shear walls reinforced with GFRP and constitute a step toward using GFRP reinforcement in such lateral-resisting systems.

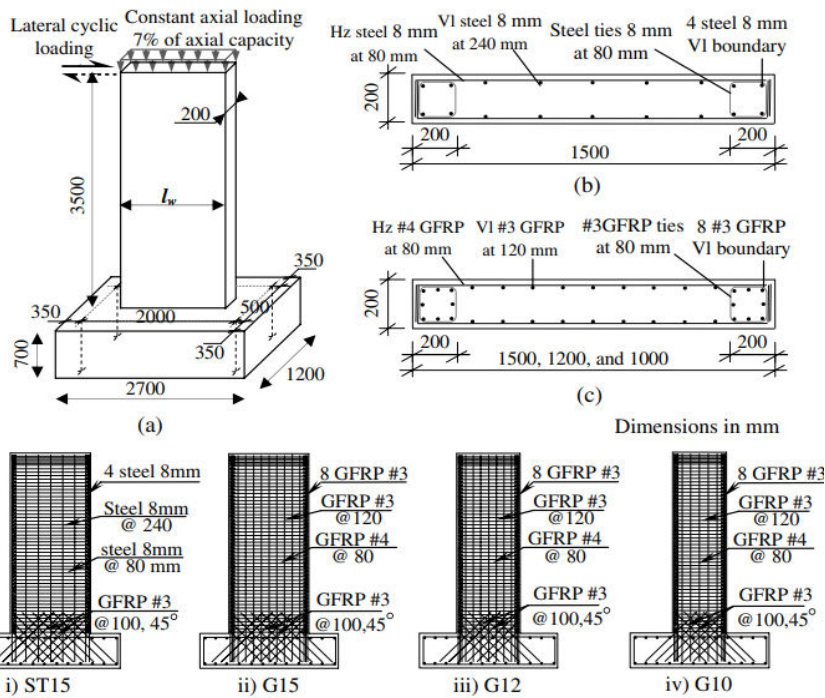


Fig.7. Concrete dimensions and details of reinforcement configuration [6]

W. Leonardo Cortes-Puentes and Dan Palermo [7] studied Nonlinear analyses to provide modeling procedures that can satisfactorily replicate the response of retrofitted RC shear walls. The retrofitting strategies included bolting of steel plates, bonding of external steel plates and fiber-reinforced polymer (FRP) sheets, and addition of steel plates with delay mechanisms. The modeling used simple rectangular and triangular membrane elements for concrete with smeared internal reinforcement, truss bar elements for external steel and FRP retrofitting materials, and bond-link elements for the bonding interface between steel and FRP to concrete. Critical to the success of the analyses was the development of constitutive bond-slip models for the link elements to simulate slotted steel connections, which function as a delay mechanism, and for anchorage of FRP sheets to concrete foundations. The analyses satisfactorily simulated seismic behavior, including lateral load capacity, displacement capacity, energy dissipation, hysteretic response, slip between the retrofitting material and the concrete structure, and failure mode.

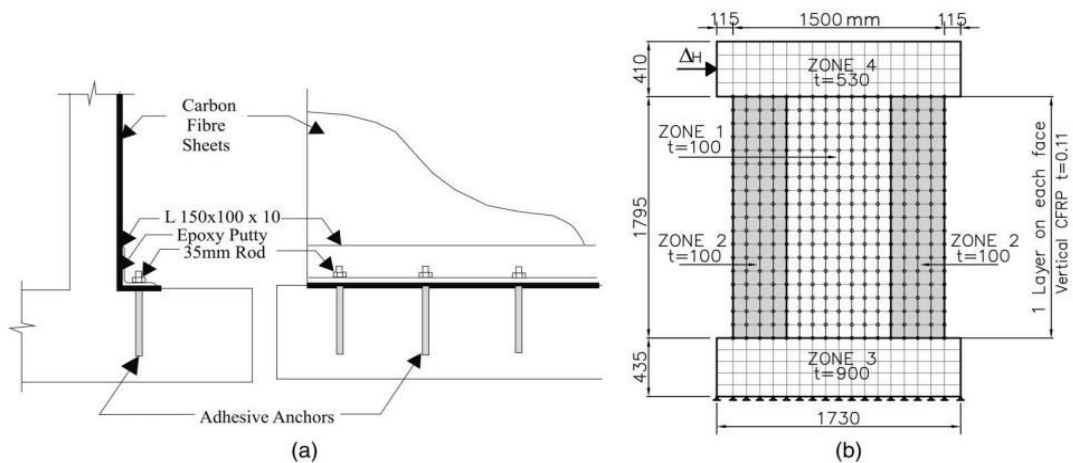


Fig.8. Wall SSW1: (a) anchorage system for CFRP (Lombard et al. 2000; with permission from New Zealand Society for Earthquake Engineering); (b) numerical model [7]

Hamed Layssi, William D. Cook and Denis Mitchell [8] designed and detailed wall specimen to simulate nonductile reinforced concrete construction of the 1960s, having lap splices of the longitudinal reinforcement in the potential plastic hinge region, and having inadequate confinement of the boundary regions. The lap splices in these walls failed in a brittle manner before yielding occurred in the main flexural reinforcement. The use and effectiveness of carbon fiber-reinforced polymer (CFRP) wrap for improving the lap splice behavior and the shear strength of the walls were investigated. The walls were tested under reversed cyclic loading with loading applied near the top of the walls. The retrofit technique improved the displacement ductility, energy dissipation, and prevented premature failure of the lap splices. The target ductility level of 2.0 was achieved with this CFRP retrofit.

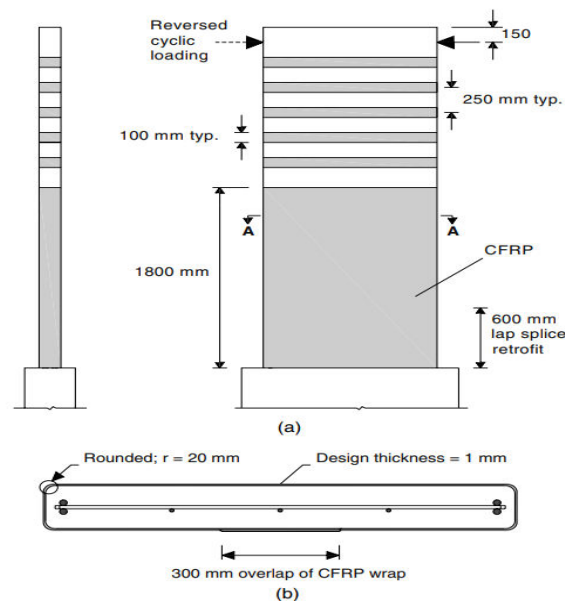


Fig.9. Details of retrofit using CFRP wrap [8]

### III. CONCLUSION

From the research it can be concluded that strengthening the structural elements using FRP composites, it has been proved that it gives an increase in strength but the % of increase varies from 5% to 70% which depends on parameters considered like width of wrap, length of wrap, size of substrate, available reinforcement, size of specimen considered for testing, grade of concrete, grade of reinforcement steel used in the structural member.

Different types of FRPs have different modulus of elasticity and different Poisson's ratio. Therefore, the variation is observed.

By going through the research, it is observed that, there is not any procedural data or standard code available in India for application of FRP. That is why research and application is followed by literature available on FRP.

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