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# Strengthening of Beams Using Fibre Reinforced Polymer (FRP)

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**Abstract:** *Retrofitting of structures became popular in the field of civil engineering for repairing and rehabilitation of existing damaged and new buildings which are inadequate to bear the loads acting on them. The concrete structures can also be damaged due to aging, excessive loads, accidental loads, temperature, corrosion, chemicals, and other conditions. Demolishing and reconstructing those structures need more time and uneconomical hence strengthening was done. Using FRP for strengthening concrete structures is one of the effective methods of strengthening due to its advantages like lightweight, highly resistant to corrosion and chemicals, high tensile strength, high stiffness and also it is easily applied to structures. The most commonly used fibers were steel, carbon, glass, aramid, basalt, polypropylene, nylon, etc. Nowadays natural fibers like jute, kenaf, flax, hemp, etc. were also used. Numerous studies were conducted to find its effectiveness in various conditions like marine, fire, corrosive and other aggressive conditions. In this paper, experimental works on FRP were reviewed and their conclusions were discussed briefly.*

**Keywords:** Concrete structures, Confinement, Debonding, Fire, FRP, Marine, Retrofitting, Strengthening

## I. INTRODUCTION

Demolishing and reconstructing a structure were considered to be an uneconomical and time-consuming process. Hence strengthening of new and existing structures had become popular in the construction field [1]. One of the most commonly used methods for repair and rehabilitation of structures is Retrofitting. Retrofitting is the modification of the existing structure by the addition of a new component for restoring the original capacities in the structure [2]. Strengthening old structures is necessary as old structures were constructed with old design codes that do not consider the post elastic behavior of the structure [3, 4]. Other reasons to strengthen a structure include faulty design or execution, aging of structure, various environmental conditions like corrosion, change in climate, inadequate maintenance, natural calamities like earthquakes and so on [1]. Jacketing is one of the easiest and effective techniques in retrofitting of structures. There is various type of jacketing is available to enhance the strength in structures such as Concrete jacketing, Steel jacketing, Ferrocement jacketing and Fiber Reinforced Polymer (FRP) jacketing [2]. Concrete jacketing is the first method to strengthen the damaged structures. A new layer of reinforced concrete is constructed around the existing concrete for achieving strength. Steel connectors, roughening of the surface and applying epoxy resin are used to make the bond between existing and new concrete material [2]. Steel jacket helps to restore the strength, ductility, and energy absorption capacity of columns thus it seems to be effective in retrofitting columns [5]. And also, the steel jacket helps to increase the flexural strength and ductile behavior of the lap-spliced column thus increasing the lateral performance of columns [81]. The steel jacket helps to increase the performance of RC structures in the seismic region effectively. But corrosion is the only disadvantage [6, 7]. Ferrocement is a low cost thin composite material, easily manufactured, easily adaptable and durable. Hence requires no fire and corrosion protection. With the addition to expanded steel mesh, it is used to strengthen the shear deficient columns [3]. One of the most commonly used methods for retrofitting is Fiber Reinforced Polymer (FRP) jacketing [8]. FRP is widely used for its properties such as high strength to weight ratio, stiffness, good impact properties, high resistance to corrosion in harsh environmental and chemical condition, and also it causes only a minimum alteration to the geometry of structural elements than other methods [1, 9, 10]. In this paper behavior of FRP strengthened structures such as beams, columns were discussed.

## II. BEHAVIOR OF STRENGTHENED COLUMNS

### 2.1 Rectangular Column

2.1 Rectangular Columns Many researchers conducted the experimental study to analyze the behavior of columns strengthened with FRP considering various factors such as a number of confining layers, FRP schemes, etc. Some of the results were discussed in this paper. Polyethylene terephthalate FRP is used to strengthen the corroded rectangular columns considering different levels of corrosion and various volumetric ratios and the test results indicate that shear resistance of FRP and column increases with the increase in volumetric ratio and decreases with increase in different levels of corrosion. And also, if shear resistance of FRP decreases bond between the column and FRP is reduced which leads to failure of the column [11]. Corner radius is considered to be one of the factors which affect the confinement of rectangular and square columns [12]. If the corner radius and thickness of FRP increase ultimate axial strain and compressive strength of column increases [13]. CFRP and BFRP confined rectangular columns with varying aspect ratios were constructed and tested under axial compression to analyze whether aspect ratio influences the columns. Results indicate that aspect ratio has no ductility but it has a significant effect on the strength of the column [14]. The cross-section aspect ratio decreases the axial strain [15]. If the CFRP confined columns were prestressed, the strength of column increases than the normal FRP confined columns [15].

### 2.2 Square Column

In square columns ductility increases when CFRP is partially confined with one layer whereas in fully CFRP confined columns ductility increases when the diameter of transverse reinforcement increases [16]. Intermittent CFRP strips in FRP increase the strength and ductility of square columns but when eccentricity increases it decreases the load-carrying capacity and ductility [17]. To increase the efficiency of square columns, a new technique namely Externally Bonded Reinforcement on Grooves (EBROG) and Externally Bonded Reinforcement in Grooves (EBRIG) were developed. The technique shows more effectiveness than the externally bonded reinforcement in improving strength and ductility. And also, it postpones the buckling of columns [18]. The technique was analyzed in comparison with Near Surface Mount (NSM) technique for both circular and square columns. The result indicates that buckling and debonding of FRP is delayed and is more effective in circular columns than square columns [19]. By increasing the no. of layers, stiffness of the column increases thus helps in improving load-carrying capacity and ductility of eccentrically loaded square columns [20]. Providing corner radius equal to cover increases the load-carrying capacity and smoothening the edges of the square column delay the rupture of FRP from the surface of the column [21].

### 2.3 Circular Columns

if the stiffness of FRP increases the buckling of columns is resisted as effective confinement is obtained [12]. In addition to longitudinal CFRP confinement, CFRP hoop wraps were provided in which longitudinal confinement helps to increase the load-carrying capacity and hoop wraps provide lateral support to longitudinal CFRP wraps [22]. Various studies were done to examine the effect of eccentricity in columns [23, 24]. When eccentricity increases load-carrying capacity and ductility of column decreases [24]. Stress-Strain relationship of concentrically loaded columns will not apply to eccentrically loaded columns as error increases with an increase in eccentricity. The ultimate failure strain of the eccentrically loaded column is 50% higher than the concentrically loaded column [23]. At low confinement ratio plastic hinge length of circular column increases [25]. Using artificial neural networks, an analysis was conducted to predict the factors affecting the compressive strength FRP confined columns. The thickness of FRP, elastic modulus of FRP, diameter, height and unconfined strength of concrete were some of the factors affecting the compressive strength of columns [26]. Aramid Fiber Reinforced Polymer (AFRP) improves the strength, ductility, and energy absorption characteristics. In wet/dry conditions no strength is reduced and in freeze/thaw conditions the only a little amount of reduction of strength is noted [27]. If horizontal stirrups were added to fiber-reinforced jacket strength and ductility increases than the conventional concrete [28]. If the slenderness ratio of columns increases strength, ductility, toughness and deformation capacities decrease and vice versa [29]. CFRP and GFRP wrapped columns slow down the rate of corrosion and epoxy are more responsible for resisting the corrosion [30]. If an externally bonded CFRP sheet is provided in addition to near-surface mounted technique in the form of spiral grooves stiffness, strength, ductility, and energy absorption characteristics were improved [82].

## III. BEHAVIOR OF FRP STRENGTHENED STRUCTURAL MEMBERS IN FIRE EXPOSURE

When exposed to fire, concrete offers good resistance to fire as it has low thermal conductivity. But if exposed to fire for a long time, the structure gets damaged as it loses its strength and stiffness [8]. Mechanical behavior of fire-damaged concrete varies depending on many factors such as age, duration of exposure, max. The temperature of the fire, properties, and material of concrete, etc. [8]. The deteriorated structure can easily be strengthened [76]. FRP is the most commonly used material for strengthening as it possesses good stiffness, strength, good resistance to corrosion, etc. But these properties were reduced when exposed to high temperature as it was bonded to the concrete surface by polymeric resin [10]. Epoxy is the matrix normally used to bond FRP on the structure. Epoxy provides good bonding because of its rigid characteristics. At elevated temperature i.e., when the temperature exceeds glass transition temperature, epoxy changes its rigid character to a soft one. Hence the bonding between FRP and the concrete surface reduced [77]. To overcome this, proper fire insulation materials are laid over them [10]. Many pieces of researches had been done to strengthen to investigate the fire-damaged concrete structure using various materials. Some of them were discussed in this paper. Wrapping GFRP or CFRP seems effective in strengthening the fire-damaged columns as it increases the strength and ductility of columns [76]. FRP hoop wraps are effective in enhancing the strength of fire-damaged concrete but fail to increase stiffness. The increase of strength depends upon the fundamental characteristics of the concrete [8]. As already stated, above the glass transition temperature, epoxy cannot provide an effective bond between concrete and FRP. Hence CFRP or GFRP wrapping fails to increase strength, strength may be increased by providing insulation for fire protection [78, 77]. Another material namely Textile Reinforced Mortar (TRM) was effective in increasing strength and flexural capacity of beams. If TRM is coated with adhesives such as epoxy or if no. of confining layers is increased, then it will be more effective in increasing the performance of fire-damaged beams [1]. Debonding of FRP from the structure can be prevented by providing insulation. Cooling anchorages were used to increase the performance of the beam and it shows good results [9]. A new supplementary insulation technique was developed, a cement-based mortar was applied in spray type for protection. And the develop insulation helps to increase the strength, stiffness, and ductility of columns [10]. CFRP strengthening system helps to bear the load until it fails under high temperature. If the thickness of CFRP is increased, the system may bear the load for more time. Vermiculite perlite, a sprayed fire protection material of low thermal conductivity is used for preventing the FRP [79]. Epoxy resin bonded FRP confined beams showed better fire resistance than the geopolymer resin bonded FRP confined beams and if the primer is applied performance of them was improved [80].

## IV. CONCLUSION

From the experimental works reviewed in this paper the following conclusions were made:

- FRP strengthening improves the flexural, shear and compressive strength of RC elements. It is preferred for its advantages like easy application, lightweight, stiffness, high tensile strength, etc.
- FRP exhibits good bonds with concrete by the use of epoxy resin. The bond gets failed when only the temperature exceeds the glass transition temperature. Nowadays bio-based resins were also developed to bond FRP on the surface of the damaged structures.
- Different types of wraps were followed. Partial wrapping shows better performance than full wrapping and is economical.
- FRP commonly fails due to debonding from the concrete surface. Its anchorage devices are provided to them, the concrete elements showed better performance than the unanchored.
- If no. of confining layers were increased the performance of the RC elements was also increased.
- FRP was also used in the form of rods which is placed at the distance less than the cover of reinforcement. This method increases both load-carrying capacity and ductility. Their failure mode is the separation of concrete cover with the crushing of concrete.

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