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Research Article

Retrofitting of Deteriorated Concrete Structures using Composite Materials for Rehabilitation and Service Life Enhancement

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Abstract

Retrofitting of deteriorated concrete structure using composite materials is rather a new technique that is used to make structures more stable to withstand tensile load. The composite materials used are mostly Fibre Reinforced Plastics / Polymers (FRP). This technique is used for all types of structural elements viz. Column, beam, bridge, slab, span etc. This technique provides reinforcement against all types of external loads viz. axial load, flexural load, shear load, torsional load and also for impact loads. There are various types of Fibre Reinforced Plastics / Polymers (FRP) commercially available for wrapping of structures for reinforcement. Further there are various wrapping methods used. There is need for standardization of the material as well as the different wrapping schemes. This requires rigorous stress analysis of the reinforcement material as well as wrapping methods adopted.

Keywords: *Concrete structures; Rehabilitation; Service Life enhancement; Composite material; Fibre Reinforced Polymer (FRP); GFRP; CFRP; AFRP; Retrofitting;*

1. Introduction

1.1 Rehabilitation of Reinforced Cement Concrete (RCC) structures

Steel plates have been widely used for rehabilitation of Reinforced Cement Concrete Structures. Bonding of thin steel plates to structural members leads to enhanced structural performance. (Azadeh Parvin et al) There are inherent difficulties in wrapping of structural members using steel plates viz.

(a) Corrosion
(b) Handling difficulties owing to heavy weight of steel
(c) Difficulty in shaping steel plate to suit the structural element to be repaired. This is more pronounced when wrapping is required around tapered members.

Retrofitting of Reinforced Cement Concrete (RCC) by wrapping of Fibre Reinforced Plastics / Polymers (FRP) is a very effective and relatively new technique. FRP is a composite material.

1.2 Composite materials, properties and applications

Composite materials are defined as combination of two or a lot of dissimilar materials that once combined are having stronger or unique characteristics than the individual materials. Some of the properties that can be improved by forming a composite material are

- Strength
- Stiffness
- Corrosion resistance
- Wear resistance
- Weight
- Attractiveness
- Fatigue life
- Thermal insulation
- Thermal conductivity
- Temperature-dependent behaviour
- Acoustical insulation

Not all the properties are improved at the same time nor is there usually any requirement to do so. The objective is merely to create a material that has only the characteristics needed to perform the design task.

There are four commonly accepted types of composite materials viz.

(i) **Fibrous composite materials**: This consists of fibres in a matrix
(ii) **Laminated composite materials**: It consists of layers of different materials

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(iii) **Particulate composite materials**: These are composed of particles in a matrix
(iv) Combinations of some or all of above three types

FRP materials contain high strength fibres with a polymer resin (Fig. 1). The fibres act as the key reinforcing elements, whereas the polymer resin (or the matrix) works as a binder which transfer loads between fibres and also protects fibres.(Chandran Hanu et al) The most commonly used fibres for FRP materials are carbon, glass, aramid while the most common matrix are vinyl ester, epoxy or polyester thermosetting plastic.

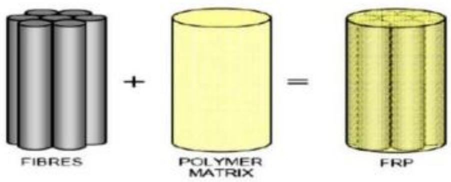

Fig 1: Fiber + Matrix produce FRP

1.3 Standardization and specification of composite materials for reinforcement of concrete structures

Desired properties of composite materials used for wrapping of concrete structures are

(i) Strength
(ii) Durability
(iii) Stiffness
(iv) Light weight
(v) Resistance to corrosion
(vi) Resistance to fire
(vii) Flexible enough for ease in wrapping on the structural member; Tailor ability of the material.

Fibrous composite materials consist of long fibres inherently stiffer and stronger than the same material in bulk form (Fig. 2). For example, ordinary glass plate fractures at stresses of order of 20 MPa but glass fibres have strengths of the range 2800 to 4800 MPa. Fibres are bonded together to take the form of a structural element that can carry load. The binder material is usually called a matrix.

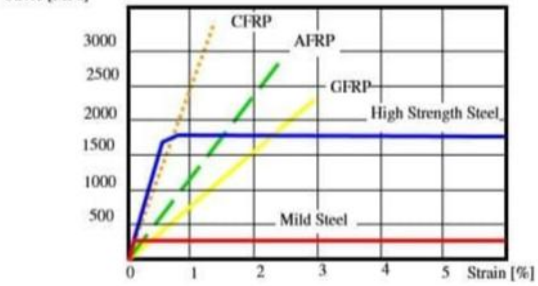

Fig 2: Properties of different FRP's as compared to steel

The purpose of matrix is to support the fibres, protect the fibres, stress transfer between broken fibres. (Hashmat Parvez et al) (John P Busel et al) The matrix is typically of considerably low density, low stiffness and much lower strength than the fibres. However the combination of fibres and a matrix can have very high strength and stiffness, yet still have low density. Fibrous composite materials are suitable for wrapping on concrete structures for reinforcement.

Commercially available FRP materials for reinforcement-wrapping of concrete structures are the following.

(v) Glass Fibre Reinforced Polymer (GFRP)
(vi) Carbon Fibre Reinforced Polymer (CFRP)
(vii) Aramid Fibre Reinforced Polymer (AFRP)

2. Rehabilitation of concrete structures using composite materials

1.2 FRP wrapping technique for reinforcement of concrete structures

Civil engineering structures need upgrading due to various reasons viz.

- Deterioration due to aging
- Weak design
- Weak construction
- Shortage of maintenance
- Environmental effects
- Earthquakes
- Accidental happenings

FRP wrapping is found suitable for rehabilitation (strengthening) concrete structures due to the following reasons.

(i) High strength: FRP materials can be designed to meet specific strength requirements tailored for an application.
(ii) Light weight: FRP's are used to produce the highest strength to weight ratio structures.
(iii) Corrosion resistance: FRP materials provide long term resistance to severe chemical temperatures requirements. They have ability to bear outdoor exposure, chemical handling applications and severe environment service.
(iv) Design flexibility (Tailor ability): FRP's have an advantage over other materials because they can be moulded into complex shapes at relatively low cost. The flexibility (Tailor ability) of creating complex shapes offers designers a freedom that steers FRP's achievement.
(v) Durability: FRP material have long life span. Maintenance requirement is also pretty low.

2.2 Various modes of loading of concrete structures

Rehabilitation of concrete structures calls for reinforcement against all sorts of external loads. The various modes of external loads are Axial loads (Tensile and compressive), Shear load, bending moment, torsion (Fig. 3).

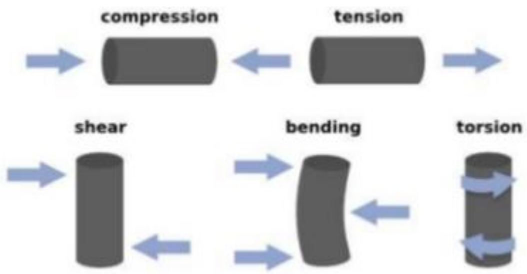

Fig 3: Modes of loads application

2.3 Flexure strengthening applications

Externally bonded FRP plates of strips on RC beams enhances flexure on the tension zone of the structural member. (Tumialan Gustavo et al) The direction of FRP fibres is kept parallel to the direction of high tensile stresses in the axial direction of the beam (Fig. 4 & Fig 5). Resin based adhesives are used for bonding of FRP plates and the concrete.

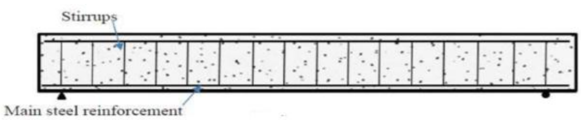

Fig 4: RCC beam

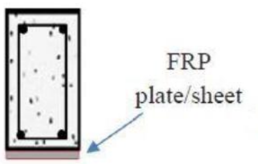

Fig 5: FRP reinforcement of RCC beam against flexural failure

2.4 Shear strengthening applications

FRP plates or strips, when bonded on RC beams, boost its shear capacity. The directions of bonded fibres need to be in transverse direction as shown in the Fig. 6. Wrapping of FRP can be done in different fashions. There can be wrapping schemes viz. Full wrapping (Fig. 7), U-wrapping (Fig. 8) and Side bonded (Fig. 9).

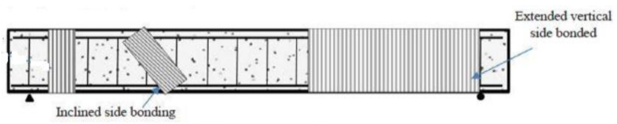

Fig 6: FRP strengthened beam

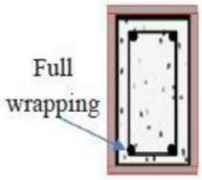

Fig 7: Strengthening using Full wrapping of FRP

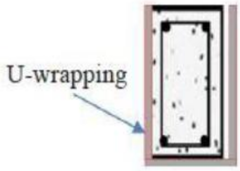

Fig 8: Strengthening using U-wrapping of FRP

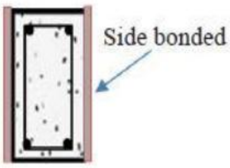

Fig 9: Strengthening using Side bonded FRP

2.5 Axial strengthening applications

To strengthen column and bridge piers to prevent them from failure during earthquake due to seismic loads. FRP plates or sheets are bonded externally. Here the nature of loading is predominantly uni-axial stresses. (Fig. 10). FRP is bonded externally as externally bonded sheets (Fig. 11) or NSM strengthening.

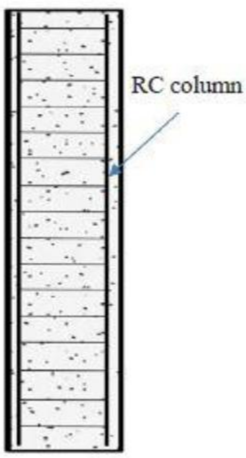

Fig 10: RC column

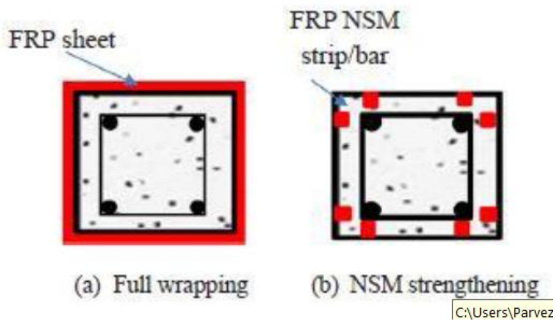

Fig 11: Full wrapping of column and NSM strip for axial strengthening

2.6 Torsion strengthening applications

FRP strengthening by bonding it on RC beams with fibres in longitudinal direction as well as transverse direction. (Fig 12)

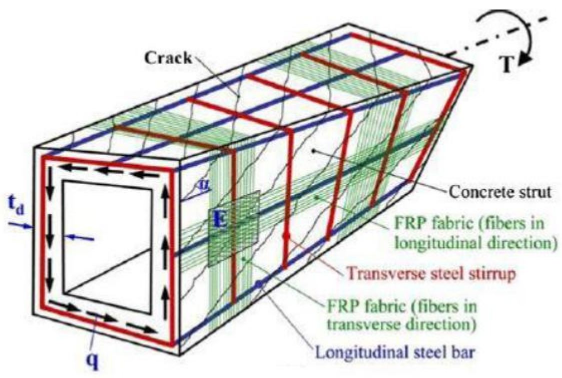

Fig 12: FRP strengthening of beams against torsional loads

2.7 Rehabilitation of walls

FRP laminates when epoxy bonded to walls serve as tensile reinforcement. It provides seismic strengthening of masonry structures. (Yousef A et al) This technique is found effective for in-plane and out-of-plane testing of masonry wall under cyclic loads. (Fig. 13 & Fig. 14)

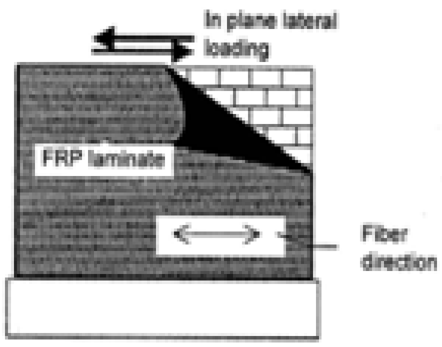

Fig 13: Reinforcement with FRP laminates for lateral loading of wall

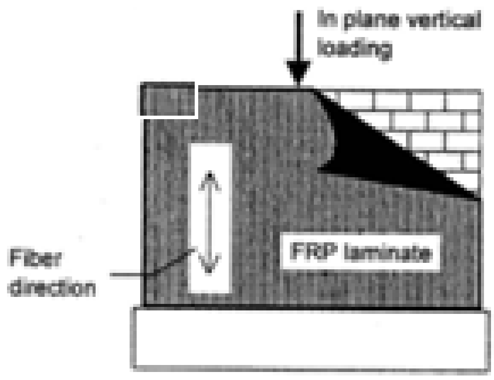

Fig 14: Reinforcement with FRP laminates for vertical loading of wall

3. FRP wrapping and installation methods

3.1 Surface preparation for FRP reinforcement

Surface preparation is the key to achieve the strength of the FRP system to concrete members. Lots of problems like flaking and deboning of FRP fibres occur due to faulty or unwell surface preparation of the member.

3.2 FRP reinforcement techniques- EB and NSM

For strengthening of RC and masonry structures, laminates and plates are externally bonded whereas bars may be near surface mounted (NSM). The externally bonded reinforcement is placed by manual lay-up in the case of laminates or adhered to the surface in the case of pre-cured plates.

Externally Bonded (EB) technique, as the name suggests, is essentially a externally bonded technique. The FRP panel is pasted on the surface of the element. Lot of care is required in surface preparation for proper pasting of FRP panels. To attach FRP on the surface of elements bonding agents or adhesives are required. The bonding agents are mostly epoxy resins. (Fig. 15)

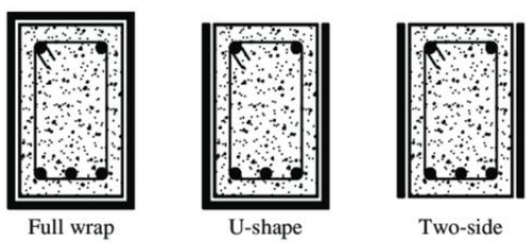

Fig 15: Typical FRP bonding schemes for externally Bonded (EB) systems

Reinforcement by Near Surface Mounted (NSM) method (Fig. 16) is achieved in the following steps.

- Cutting grooves with a diamond saw on the cover of the member laterally on the tension zone.

- Grooves are dried using brushes and pressed air
- Resin or epoxy grout is stuffed in the groove as binder
- FRP reinforcement bar is placed into the groove
- Finally extra resin is filled to fill any vacant space remaining in the groove

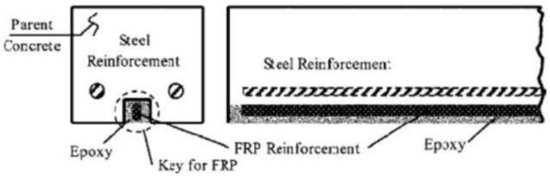

Fig 16: FRP strengthening by Near Surface Mounted (NSM) method

4. Status of FRP wrapping reinforcement technology

FRP composite reinforcement technology is a state-of-the-art technology in United States. Until a few years ago, the application of these materials to concrete and masonry strictures was only the subject of research. Nowadays, many companies are involved in the manufacturing, design, and installation of these systems throughout the country. Hundreds of projects have been completed accounting for millions of square meters of FRP laminates.

Design guidelines or acceptance criteria from the American Concrete Institute ACI Committee 440 and the International Building Code Officials (ICBO) for the use of composite materials have been drafted. These documents have increased the confidence of practitioners in the use of FRP strengthening systems.

However, FRP strengthening technology is yet to attain wide acceptance. It is not widely used due to various reasons viz.

- less awareness about this technology
- lack of standardised products
- lack of skilled man power
- lack of design engineers

Conclusions

FRP strengthening technology is still in its inception phase. The acceptance as well as awareness of FRP strengthening technology is too low. Though research studies and field projects have demonstrated the genuineness of this technology, the practitioners still do not have thorough knowledge of efficacy of this technology and its implementation. The following efforts can help to promote FRP strengthening technology into a mainstream technology.

- Training of skilled manpower
- Availability of design engineers
- Introducing this concept in graduate and under graduate curriculum
- Availability of raw materials

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