Use of FRP composite for strengthening of concrete structures

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ABSTRACT: This paper focuses on the use of emerging technologies for the strengthening of RCC structures. A number of structures like Bridges, building, jetties, silos etc. has been strengthened for various load requirements that were not incorporated during the original designs. Strengthening of concrete members with externally bonded fiber reinforced polymer (FRP) system received remarkable attention. The design and construction principles for use in practice have been finalized by the American Concrete Institute (ACI). On the application side, FRP materials have been used in some multi-million dollar projects for strengthening bridges, parking garages, multi-purpose convention centers, office buildings and silos etc. The drivers for this technology are several, but perhaps the most relevant ones are the ease and speed of installation. In the repair/upgrade arena, one of the most important unresolved questions remains that of durability. Addressing this issue will increase the degree of confidence in the technology and allow for its full exploitation.

1 INTRODUCTION

Cement Concrete reinforced with steel is the most widely used construction material. However, due to the reactive nature of its components, it behaves differently when it is exposed to different environmental conditions. Since concrete is hydrophilic in nature, percolation of moisture is the most common problem. It is this single biggest factor responsible for age related damage to concrete or corrosion of steel in concrete. This results in reduction in concrete strength, rusting of embedded steel reinforcements and an eventual cracking and spalling of concrete.

In old structures, while the steel rusts and the concrete cracks and spalls, the load carrying capacity of the RCC element comes down. However, the earlier perceived notion that only old structure requires strengthening is long gone. In fact new structures in India are being strengthened more frequently; of course the reasons are different. Bad construction practices, poor design mix leading to reduced onsite strength of concrete, missing steel reinforcement, adding more floors not accounted for in the original design, functional changes on floors leading change in loading requirement, seismic upgradation are some of the most common examples of strengthening needs in new construction.

2 CONVENTIONAL METHODS FOR STRENGTHENING

In the last couple of decades the attempts to strengthen the RCC structures have been mainly concentrated around the following methods:

i. Sectional Enlargement by using Micro-concrete.
ii. External Post Tensioning of steel bars.
iii. Strengthening by steel plate bonding

All the above methods have been well experiment and widely used and are found to be very effective for strengthening purposes. However, the main obstacle or rather limitations faced in these methods are,

i. Destructive in nature as lot of drilling to fix anchor bars is required.
ii. Bulky methods increasing self-load on the structural members
iii. Labor intensive requires more labor for execution.
iv. Time Consuming takes more time to complete execution.
v. Member Size increase reduces commercial space.
vi. Complex arrangement bulky set up requiring complex formwork arrangement.

An alternative to the above methods of strengthening is the use of epoxy bonded fiber reinforcement polymer composite system for strengthening applications. Although the technology was originally developed for aero-space industry but its use for the purpose of strengthening of RCC structures has been increasingly pursued in the recent past due to its lite weight, ease of handling and rapid implementation.

3 FIBRE REINFORCED POLYMER COMPOSITE MATERIAL FOR STRENGTHENING

Fiber Reinforced Polymer (FRP) materials are composites consisting of high strength fibers embedded in a polymeric resin (Figure 1). Fibers in an FRP composite are the primary load–carrying elements, while the resin maintains the fibers alignment and protects them against the environment and possible damage and acts as an important medium of load transfer in the matrix. Among all the commercially available fibers, carbon exhibits the highest strength and stiffness when compared with steel. The type of fiber is selected based on mechanical properties and the strengthening needs while the type of resin depends upon environmental and constructability needs, however most commonly used adhesive for bonding FRP systems are based on epoxy resins. Perhaps the most relevant property of carbon FRP (CFRP) composites for construction use is their resistance to corrosion that allows having them installed on the concrete surface.

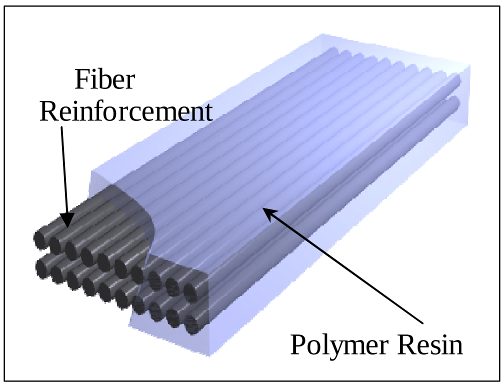

Figure 1. High strength fibers embedded in a polymeric resin

FRP laminates have been used worldwide to strengthen, repair or add ductility to existing concrete bridges and buildings in the last couple of years. Currently, not only internationally but even in India lot of activities related to the increased use of FRP is underway and institutes like IITs are taking up many research assignments for better understanding of the FRP system for use in strengthening applications.

In recent years, the technology of strengthening reinforced concrete (RC) and members with externally bonded FRP system has been widely investigated and reported. Similar to steel plate bonding, FRP laminate bonding involves adhering thin flexible fiber plies to the concrete surface with an epoxy resin. This technique, known as manual lay-up, is used to increase the shear and flexural capacity of beams and slabs and to provide confinement in columns. The advantages of this technology include speed and ease of installation, durability of the material system, its light weight, and performance.

The upgrade approach used for the structures is available in a technical document published by the American Concrete Institute (ACI) (ACI Committee 440, 2002), which provides guidance for the selection, design, and installation of FRP systems for external strengthening of concrete structures as an emerging technology. This document can be used to select an FRP system for increasing the strength and stiffness of RC and PC beams or the ductility of wrapped columns. Conditions are also identified where FRP strengthening is beneficial and where its use may be limited.

4 DESIGN PRINCIPALS

According to ACI 440 (2002), it is recommended that the increase in load-carrying capacity of RC members strengthened with an FRP system be limited. The philosophy is that a loss of FRP reinforcement should leave a member with sufficient capacity to resist at least 1.2 times the design dead load and 0.85 times the design live load. Design recommendations are based on limit-states-design principles. This approach sets acceptable levels of safety against the occurrence of both serviceability and ultimate limit states (e.g., deflections, cracking, stress rupture, and fatigue). In determining the ultimate strength of a member, all possible failure modes and resulting strains and stresses in each material should be assessed. For evaluating the serviceability of an element, engineering principles, such as modular ratios and transformed sections, can be used. In addition to conventional strength-reduction factors required by code for conventional materials, other reduction factors applied to the contribution of the FRP reinforcement are recommended to reflect the limited body of knowledge of FRP systems compared with steel RC. For the design of FRP systems for the seismic retrofit of a structure, it may be appropriate to use established capacity design principles, which assume a structure should develop its full elastic capacity and require that members be capable of resisting the associated shear demands. The guaranteed tensile strength of FRP is defined as the mean tensile strength of a sample of test specimens minus three times the standard deviation. The design tensile strength that should be used in all design equations is given by the guaranteed value multiplied by a knock down factor to account for the service environment and is dependent on fiber type and exposure conditions of the structure. The design rupture strain should be determined similarly, whereas the design modulus of elasticity is the same as the value reported by the manufacturer.

For both flexural and shear strengthening, it is recognized that the FRP cannot attain its design rupture strain as a result of potential debonding. For this, the strain level in the FRP reinforcement at the ultimate-limit state needs to be determined and limited to an upper value to prevent debonding or delamination. This term recognizes that laminates with greater stiffness are more prone to delamination.

To avoid plastic deformations, the existing steel reinforcement should be prevented from yielding at service load levels. The stress in the steel at service should be limited to 80% of the yield stress. Similarly, to avoid failure of an FRP-reinforced member due to creep rupture of the FRP, stress limits for these conditions should be imposed on the FRP reinforcement. In the case of shear strengthening, the effective strain cannot be larger than 0.4% to avoid the loss of aggregate interlock of the section before FRP delamination or rupture. Several of the unresolved issues remain the objective of on-going research, for example: durability (including fire) and test methods. Further research into the mechanics of bond of FRP reinforcement is of critical importance. New experimental evidence and analytical tools should yield more accurate methods for predicting delamination at the interface and in the concrete. Further developments will likely account for the stiffness of the laminate, the stiffness of the member to which the laminate is bonded, and the influence of the adhesive thickness and properties. The interim recommendations to limit the strain in the FRP to prevent delamination need to be revisited and confirmed. In addition to the above, efforts need be made to allow for other forms of FRP strengthening.

FRP bars as a new type of reinforcement has also been used for increasing flexural strength of deficient RC. The advantages of FRP bars compared with external FRP laminates are the possibility of anchoring the reinforcement into adjacent RC members, and minimal surface preparation work and installation time. For installation, a groove is cut in the desired direction into the concrete surface, the groove is then filled half-way with adhesive paste and the FRP bar is placed in the groove and lightly pressed. This forces the paste to flow around the bar and fill completely between the bar and the sides of the groove. Finally, the groove is filled with more paste and the surface is levelled.

4.1 *Case Study I*

Project: Rail Over Bridge (ROB), Chaltan Surat
Structure Type: RCC Bridge supported on I-Girders
Project Scope: Strengthening of Bridge Girders
Client: National Highway Authority of India

Project Description

The rail over bridge at Chaltan, Surat on NH8 (Figure 2) connecting Mumbai to Delhi was identified to be deficient in flexure and shear for the vehicular traffic. The four lane Bridge has eight girders in the longitudinal direction and is divided into three spans, end spans being 12m each. Girders are approximately 0.5m width and 1.2m depth. The scope of the work was to strengthen the flexural and shear demand to meet the current and future loading requirement.

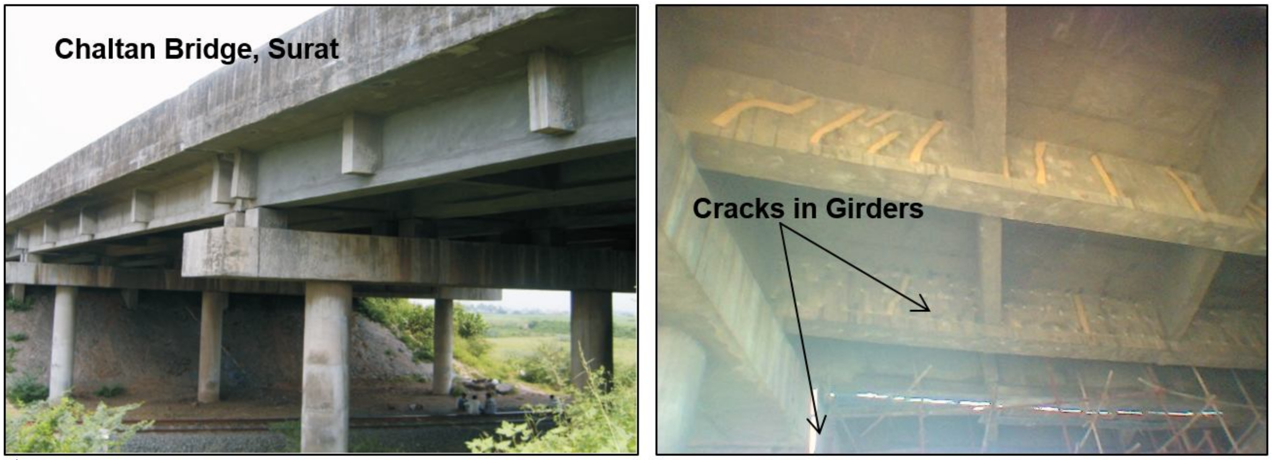

Figure 2 Chaltan bridge

Design and analysis

The existing capacity of the girders was determined using the basic design principles of Reinforced concrete design theory and the additional flexural and shear capacity for single section was computed. This included review of the bridge construction details to the extent possible, use of established and necessary codal provisions and Visual inspection of the Bridge. This revealed no significant deterioration of the parent concrete material however the girders reported cracking along the span and were found to be deficient for flexure and shear for the designed load.

Solution Proposed and Executed

National Highway Authority of India after being convinced with FRP technology accepted the proposal by the consultant to strengthen the bridge girders using Fiber composites. The solution proposed included,

i. Sealing and Injection of cracks in concrete girders.
ii. Preparation and levelling of the concrete surface to receive FRP reinforcement.
iii. Application of FRP reinforcement by Wet-Layup process.

Figure 3. Application of FRP composite on Chaltan Bridge

5 CONCLUSIONS

It can be concluded that the use of FRP for strengthening application shall allow for a change in the way strengthening approach has been adopted for decades. With the increase in the number of strengthening requirement due to various reasons and the availability ACI Guidelines for the design and construction of FRP systems, the use of FRP reinforcement for strengthening application shall allow the construction Industry to take full advantage of this new technology in future.

REFERENCE

ACI440.2R-02, “Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures”