FRP Retrofit Solutions

Critical Issues for Peer Review

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Structural strengthening using Fiber Reinforced Polymers (FRP) has become a viable alternative to conventional strengthening techniques for reinforced concrete structures. FRP composites have been successfully applied to both new and existing structures to increase the as-built capacity, and/or address deterioration-related damage. Since FRP is still an emerging technology with some design and application uncertainty, structural engineers often issue performance specifications for the FRP design option. However, in such cases, the Engineer of Record (EOR) is required to review design calculations performed by others. This article provides general guidelines for peer reviewing FRP strengthened solutions, focusing on the use of FRP fabric for retrofits.

What is FRP?

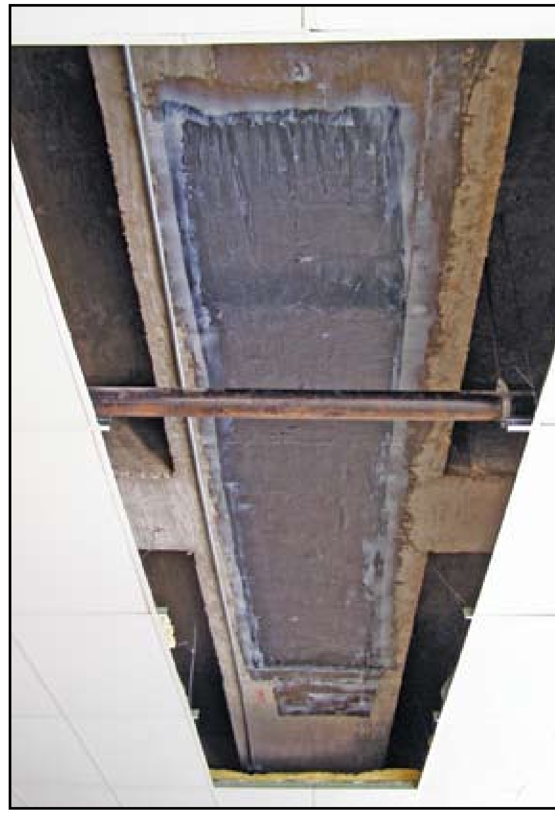
FRP materials are composites consisting of high-strength fibers encapsulated in a polymeric resin to form a laminate. Fibers in FRP composite materials carry the load, while the resin protects the fibers and keeps them in alignment. In addition to encapsulating the fibers, the resin acts as an adhesive to bond the laminate to the concrete substrate. Commonly available fibers are manufactured of carbon, glass, and aramid. The fibers are typically provided in a woven sheet matrix, pre-cured laminates, or solid bars.

Why use FRP?

FRP strengthening offers several advantages over conventional strengthening for existing reinforced concrete structures. FRP materials are relatively thin in their application and hence ideal for areas with limited access, such as applications above drop ceilings or within floor slabs. They are relatively easy to install with minimal invasive modifications to the existing structures. FRP materials are also lightweight, so increases in dead loads from the strengthening solution are negligible. It should be noted that FRP composites provide only a nominal increase in stiffness, so they are generally useful for increased structural strength, rather than deflection control.

FRP Design Methodology

In 2002, the American Concrete Institute (ACI) Committee 440 produced design guidelines (ACI 440.2) for FRP strengthening of reinforced concrete structures. While ACI 440.2 primarily addresses FRP applications to buildings, the technology can be applied to other structures such as bridges and dams. The ACI guidelines continue to evolve with changes in materials, research, and new laboratory test findings. As this document currently represents the standard of care for FRP applications to reinforced concrete, a peer review effort should evaluate the solution for compliance with ACI 440.2. Some of its key requirements include:



Carbon-based FRP installation on the soffit of an existing beam. Courtesy of Walter P Moore.

1) **Strengthening Limit** – Prior to strengthening a concrete structure with FRP, the un-strengthened structure must have a reasonable level of existing load capacity in the event that the proposed FRP retrofit is damaged by fire, vandalized, or negated by other causes. The current strengthening limit requires that the existing structure have sufficient capacity to resist service loads. ACI 440.2, which is based on the load and strength reduction factors of ACI 318-99, defines this service load level as 1.2D + 0.85L. If the structure does not satisfy this criteria, then FRP strengthening is probably not a viable option. It is the responsibility of the EOR to verify adherence to this criteria prior to specifying FRP as a repair solution.
2) **Environmental Exposure** – Environmental conditions should be verified to determine whether the FRP application could be damaged by exposure to detrimental factors such as ultraviolet light, salt water, chemicals, high temperatures, high humidity, or freeze/thaw. ACI 440.2 provides FRP strength reduction factors depending on the application exposure conditions – interior, exterior, or aggressive environmental exposures. A UV-resistant top coating can be applied in an exterior application to extend the service life of the retrofit.
3) **Failure Modes** – Several failure modes should be considered in the design calculation for the FRP retrofit solution, since the failure of the applied FRP material may not control the design capacity. Examples include concrete crushing prior to steel yielding, steel yielding followed by rupture of the FRP, steel yielding followed by concrete crushing, cover delamination, and FRP debonding.
4) **Strength Reduction for Multiple Plies** – Multiple-ply FRP applications have a greater stiffness and are subject to a strength reduction since they are more prone to peeling/delamination or FRP debonding. Increasing the number of plies does not necessarily equate to a better performing strengthening option. The maximum ply limit is typically 4 to 5 plies, due to the diminishing strength gain from additional plies.
5) **Development Length** – FRP laminates must be adequately bonded

to a concrete element over a prescribed length, just as with the development lengths of reinforcing steel.

FRP Constructability

The proposed FRP strengthening solution needs to be constructible. Plans and details should be reviewed to determine if the FRP can be installed as designed. Site visits should be conducted to review field conditions prior to launching into the construction phase of the strengthening. The following issues should be reviewed with great attention:

1) **Interference of existing members** – Member interference may prevent a proper installation of the FRP. Interference is common at beam-column and beam-beam intersections.
2) **Negative moment continuity** – Continuity is often difficult to achieve when strengthening beams due to column obstructions. Negative moment applications may require careful drilling and installation of FRP through existing structural members. There also may be a need to apply the FRP plies to the sides of the beams.
3) **Protection from damage after installation** – FRP can be recessed below the floor level to hide the application. Depending on the installation, the FRP may need to be protected by grout or steel plates in order to prevent damage from normal use of the facility.
4) **Bond issues with corners** – It is difficult to obtain sufficient bond when the FRP is applied at inside corners. If required due to application constraints, the corner should first be rounded-off or transitioned with a fillet prior to the FRP application. Similarly, columns need to be chamfered to accommodate the FRP wrap. The performance for circular columns tends to be better.
5) **Bond critical applications** – Ideally, no live loads should be allowed near the strengthened structural component until the FRP application has been given time to cure.

An example of a carbon-based FRP witness panel prepared in the field for laboratory tensile testing. Courtesy of Walter P Moore.

FRP Installation

The success of FRP strengthening is highly dependent on the installation of the FRP. The following items should be reviewed during construction to help ensure a successful FRP application:

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1) **Contractor qualifications** – The FRP installation contractor should demonstrate competency for surface preparation and application of FRP systems, and should be certified as an applicator by the FRP manufacturer. Some contractors are only trained on certain FRP systems, so it is prudent to check the credentials of the applicator prior to awarding the construction contract. The EOR should specify the minimum qualifications required.
2) **Surface preparation** – Proper preparation of the substrate to receive the FRP is critical to developing the necessary bond between the FRP and concrete surface. The concrete surface must be sound and free of delaminations prior to the FRP application. Damaged concrete must first be repaired before proceeding. Even on non-bond-critical applications, appropriate surface preparation of the substrate will improve the overall performance of the FRP material.
3) **Galvanic Corrosion** – If a carbon-based FRP solution is being used to strengthen a concrete structure with steel embed plates, appropriate care needs to be taken to prevent galvanic corrosion. This can be achieved by using an insulating layer of glass-based FRP to insulate the carbon-based FRP from steel plates.
4) **Pull tests to check bond** – Test patches should be installed for each application day and batch of resin used. These patches should be pulled after curing to ensure that the FRP application has sufficient bond with the concrete being strengthened.
5) **Witness panels/laboratory testing to check laminate strength** – Witness panels should be constructed for each application day and batch of resin used in order to ensure quality control. Fully cured witness panels should be sent to a qualified testing laboratory to validate the FRP material properties with those specified in the design.
6) **Testing laboratory personnel experience** – Since FRP is an emerging technology, most testing laboratories do not have the necessary equipment or qualified personnel to perform the required tests. It is incumbent upon the EOR to help the laboratory personnel develop an understanding of the FRP materials and testing requirements. The EOR should be present for the field tests and the panel preparation.

Conclusion

FRP strengthening techniques, when implemented correctly, can offer significant performance enhancement for existing reinforced concrete structures. However, FRP strengthening is not appropriate for all types of structural strengthening projects. Careful consideration and review must be given to the proposed strengthening objectives prior to implementation. When reviewing the proposed FRP procedures, it is important to ascertain whether the design, constructability, and installation guidelines discussed can be met.▪

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