Evaluation of Various Anchorage Methods For Externally Bonded FRP

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Introduction

Carbon Fiber Reinforced Polymers have been a popular method used by the Florida Department of Transportation (FDOT) to repair and retrofit concrete structural members on bridges. This includes damages caused by over-height vehicles, corrosion damage, and severe cracking that would lead to a need for load strengthening. This load strengthening includes increasing flexural and shear capacities. Simply bonding the CFRP to the member successfully achieves this goal but doesn't maximize the full strength of the CFRP due to a common failure mode, debonding. Full wrapping the CFRP around the member is the preferred method for shear strengthening and to achieve the desired failure modes such as CFRP fracture and strain, as opposed to debonding. However, this reinforcement method isn't always available due to limited access to the top of the member of interest. Therefore, wrapping three (U-wrap) or two faces is introduced and in tern debonding or peel off failure mode occurs. To combat these failure modes anchorage methods are utilized to maximize the FRP sheets. Currently the most popular anchorage methods include spike anchors, U-wrap anchors and mechanical fasteners. The most popular method being spike anchor due to its proven effectiveness despite concrete invasiveness and installation complexity. The goal of this research is to determine the definitive best option for anchoring FRP for concrete bridge repairs, taking into consideration structural effectiveness, cost, concrete invasiveness, level of complexity and maintenance.

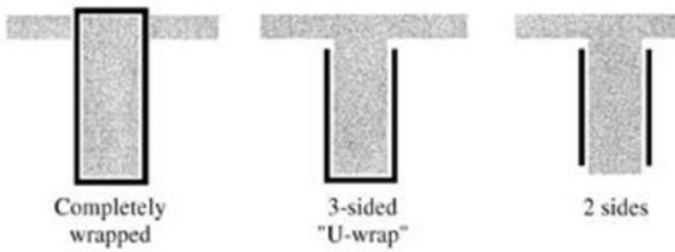

Fig 1. Different FRP wrapping techniques

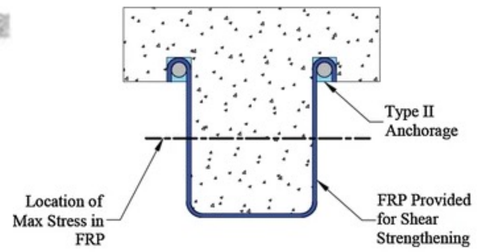

Fig 2. U-wrap anchorage

Anchorage Methods

There are many different types of CFRP anchorages which are usually chosen for a project based off their complexity of installation, invasiveness to the concrete and of course it's structural effectiveness. Different method include spike anchors, U-wrap/anchor, staple anchor, FRP strip and sheet, mechanical and metallic, and longitudinal chase. Spike anchors are constructed when taking a bundle of fibers, soaking them in epoxy, and then inserting into predrilled holes in the concrete. U-wrap method is when bonding the CFRP sheet to three faces of the member and is occasionally combined with anchors grooves into the member called U-wrap anchors. This method is very common in repairs of concrete bridge girders damaged by passing vehicles. Mechanical and metallic anchors involve using drilling a metal bolt into the concrete typically with a metal plate for more coverage in holding the FRP. This method has a high strength increase but is not a preferred method.

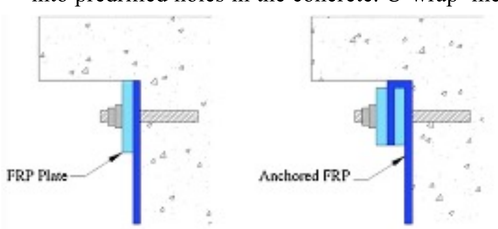

Fig 3. Mechanical and metallic anchors

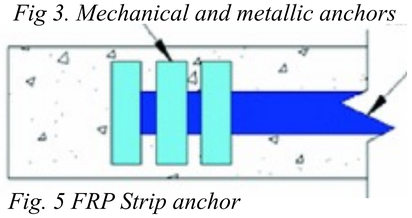

Fig. 5 FRP Strip anchor

Fig 4. Cross section of spike anchor

Fig 5. Spike anchor fanned in place

Structural Effectiveness

Using spike anchors is an effective way to maximize the load capacity generated from the CFRP. If sufficient embedment depth is reached, concrete breakout can be reached translating to a successful anchorage. As shown in the two tables below, the spike reinforcement increased the capacity across the board for both experiments, and when combined with a U-wrap, increased the capacity even more. The mechanical anchor was more effective at increasing the ultimate load the member can withstand before failure. Full wrapping allows for very high load capacities to be reached however very few real-world application will be possible due to the need for bonding to 4 faces. A study shown in the International Journal of Civil Engineering had U-wrap anchorage successfully attaining up to 180% ultimate load capacity over a control sample. If the FRP sheet can reach the soffit of the beam, a high bond force can be achieved but the failure mode remains to be debonding. Combining this method with strategically placed spike anchors will limit the holes drilled into concrete while also securing FRP against debonding.

Specimen	Cacking Load (kN)	Yielding Load (kN)	Average Ultimate Load (kN)
Control Sample	13.6	33.4	44.5
Full Wrap	18.5	37.9	50.2
Spike with U-wrap	17.8	37.4	46.7
Additional Spikes with U-wrap	23	47.5	54
Full Wrap with Spike	20	47.9	58.8

Table 1: Comparing load capacities of various anchorages.

Item	Girder 1	Girder 2	Girder 3	Girder 4	Girder 5
Type of anchor	Control	No-anchor	Spike anchor (fanned)	Mechanical-anchor	U-wrap
Ultimate load (kips)	175.06	186.7	182.6	187.7	168.7
Maximum Deflection (in)	2.42	3.4	4	3.8	2.04
Maximum tensile strain for CFRP	-	6173	5772	6443	2336

Table 2: Comparing results of different anchorage methods

Invasiveness of Anchorage

Limiting invasiveness is important as in it decreases the structural integrity of an already damaged section. The goal is to ensure debonding of FRP doesn't occur, however the methods which don't present debonding as a primary failure mode are also the most invasive. An alternative to spike anchor and mechanical anchors are being investigated for this exact reason. Spike anchors are successful at stopping debonding but involve drilling into the concrete, which is also an issue found in mechanical anchors. U-wrap and FRP strip/sheet method involve no invading of the concrete as they rely solely on the exterior bonding agent to hold onto the surface. As a result, the full strength of the FRP can't be attained debonding is the primary failure mode. Different levels of invasiveness are may include:

- No alteration; zero interior reinforcement needed.
- Minor alteration to surface; roughing surface.
- Alteration of substrate; grinding or shallow cutting.
- Penetrate beyond cover; Drilling holes for anchors.
- Major alteration; Cutting channels for embedment of foreign materials.

Summary and Conclusion

- The goal of this research is to determine the best FRP anchorage method for concrete bridge repairs.
- The purpose of FRP anchorage is to maximize the load strengthening repair capacity by limiting debonding failure and promoting FRP fracture and strain as the desired failure method.
- Concrete breakout is a preferred failure mode as it's not the CFRP failing. When debonding occurs, the full strength of the concrete and CFRP were not achieved
- Popular methods include spike anchors, U-wrap/U-wrap anchors and mechanical fasteners.
- Some methods such as mechanical anchors are very effective increasing load capacities and limiting debonding but have the draw back of being very invasive while also inviting corrosion.
- Weighing the pros and cons of invasiveness and debonding is a debate which can lead to the desired method.
- Increasing the number of anchors present and placing in high stress areas limits the debonding of CFRP.
- Combining spike anchors and U-wraps increases the load capacities significantly by decreasing debonding drastically

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