

FRP Material for the Performance of Bridge Components Reinforcement and Improvement

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Abstract. Most bridges today suffer from ageing as a result of increased uses and the erosion of the natural environment. Engineers often need to focus on the actual strengthening needs in the projects they design, as each method has its own limitations and applicability, and there are gaps in the strengthening and improvement methods for various bridge elements. This paper provides a synthesis of some methods of strengthening bridge elements to facilitate comparison and discussion during construction. The application of Fiber Reinforced Polymer (FRP) materials in bridge engineering is then explored and the different types of FRP materials are compared. The results show that the strengthening methods are more suitable for each bridge member. For bridge decks, the analysis of various FRP reinforcement test results and crack extensions lead to the conclusion that the FRP reinforcement is closer to the modulus of elasticity of concrete and has better coordination of deformation, making it a splitting of concrete. However, when discussing the strengthening of bridge girders and pier members, the type of damage that occurs under different damage and loads is different. Therefore, there are different options and methods for different types of FRP materials.

Keywords: Bridge Reinforcement, Fiber Reinforced Polymer, Bridge Components.

1. Introduction

Fiber Reinforced Polymer (FRP) materials are widely used in bridge construction and strengthening reinforcement today, and quite a few researchers have proposed various methods of strengthening reinforcement and different types of FRP materials applicable on this basis. However, the strengthening and improvement methods for various bridge components are often discussed separately in separate papers. Dividing the different components of a bridge into smaller sections and bringing them together as an overview can provide easier advice and guidance for some of the more miscellaneous and specific construction conditions.

Main reinforcement techniques: (1) Surface adhesive FRP reinforcement technology: This reinforcement method has two cases, which is the curing and field curing laminate. The latter one is to use primer on the concrete surface, and the purpose of this is to fill the micro-cavity, waiting for the primer to cure, then fill the surface cavity. After that, apply the mixed resin evenly on the concrete surface, and finally use the roller to press the cut board on concrete [1]. (2) Surface embedded FRP reinforcement concrete deck technology: Compared with the traditional FRP reinforcement method embedded with FRP reinforcement method, the built-in method can improve the durability, and greatly improve the work efficiency. Using the NSM (Near Surface Mounted) rod, you need to scratch the surface of the concrete, cleaning the groove, filling the part with a high viscosity adhesive. Then gently press the FRP rod into the groove and finally fill the groove with the same adhesive [1]. This reinforcement method of strengthening the concrete deck slab can very effectively improve the bearing capacity of the bridge deck [2].

Reinforcement of the main parts of the bridge: (1) FRP reinforced concrete deck reinforcement method: The surface bonding method and the surface embedding method have limitations; it has the disadvantage of being difficult to handle and easily damaged by humans. An emerging method (ETS-Embedded Through-Section) of reinforcing concrete bridge decks for shear reinforcement with penetrating FRP reinforcement is a method of pouring adhesive into the members and then adding reinforcement. It avoids the direct contact between the reinforcement material and the external environment and improves the durability of the steel bar. In addition, this construction method is simpler, which greatly improves the construction efficiency [3]. (2) In the structure of a bridge, the beam is one of the components. After years of use, different traffic lines have different damage to beams. Increasing the beam section was a way to strengthen the beam, but because its long construction period, it had a great impact on service life. Taking advantage of the differences in material properties, some researchers have proposed a double-layer carbon-glass fiber composite system and used it to reinforce the main beams of bridges. The experiment result showed that the flexural strength of the beam was increased by 114%. The flexural ductility and stiffness of the reinforced beams decrease when the FRP reinforced material exhibits tensile fracture and damage. This article will discuss the application and applicability of FRP materials in terms of Flexural strengthening, Compressive and impact strengths and Shear strengthening. (3) Large Rupture Strain Fiber Reinforced Polymer (LRS-FRP) hybrid reinforced pier method: Compared to traditional FRP, LRS FRP mixture are cheaper and more environmentally friendly. In recent years, this mixture has gradually replaced traditional FRP composite, it has become a method of reinforcement piers. [4].

The purpose of this paper is to use bridge components as the division standard to describe the application of some FRP materials in bridge reinforcement. This division method can more clearly understand the impact of different use environments and bridge reinforcement and reconstruction projects.

2. Performance improvement of bridge deck

2.1 Component analysis

As shown in Figure 1, three mainly failure modes forms of concrete bridge panels: bending failure, punching failure and shear failure. The traditional methods of bridge deck reinforcement include increasing section, sticking steel plate, prestressed reinforcement and sticking external FRP [2]. However, the existing structures or methods of steel bridge deck reinforcement have limitations and high maintenance cost that cannot meet the reinforcement requirements of the steel bridge deck fatigue cracking. Moreover, the bridge deck reinforced with external FRP sheet is prone to peel damage [2]. Therefore, the research of using FRP to strengthen the bridge deck is still in progress.

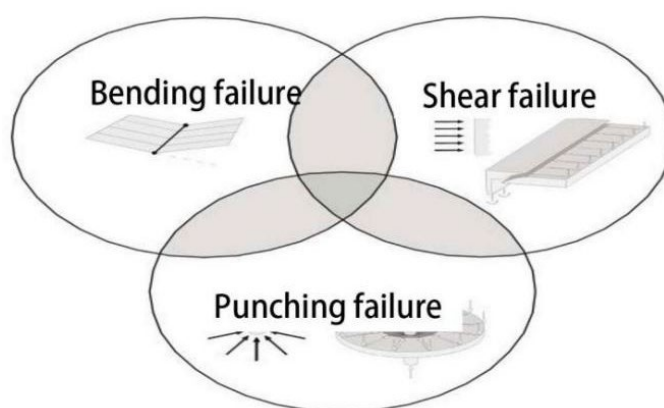


Figure 1. Three failure modes for bridge panels [5]

2.2 Bridge deck reinforcement method of FRP

2.2.1 Flexural strengthening

Current research into bridge deck strengthening has focused on improving the flexural performance of bridge decks. Externally Bonded (EB) PRP and Near Surface Mounted (NSM) are the common reinforcement methods to increase bending resistance. Comparing the two reinforcement methods, the latter has better durability due to the built-in reinforcement can better resist wear, collision and other unexpected effects. It also has better bonding effect with concrete in the groove. NSM method is convenient for the reinforcement to anchor with adjacent members, reduces the processing workload on the surface of members and improves the construction efficiency [2, 6-7]. Table.1 is the results of the loading test result of reinforced traditional beam-slab bridge panel structure model with 1:3 scale, which use the NSM reinforcement method with different reinforcement materials Carbon Fiber Reinforced Plastics (CFRP), Basalt Fiber Reinforced Plastics (BFRP), Glass Fiber Reinforced Plastic (GFRP) [2]. According to Table.1, the bearing capacity of the reinforced specimens is increased by about 40%, which indicated that the reinforcement method can effectively improve the ultimate working performance of the panel structure.

Table.1. Loading test results of NSM method [2]

Specimen number	CB-Con	CB-C100	CB-B100	CB-G100
Reinforcement material	-	CFRP	BFRP	GFRP
Cracking load of plate bottom PDCr / kN	50	55	60	50
Cracking load of plate roof PTCr / kN	50	55	55	50
Ultimate load Pu / kN	108	155	140	134
Hardened/unhardened	1	1.43	1.29	1.24
Failure mode	Bending+share	Bending	Bending	Bending

When using CPRP material and NSM method to strengthen cantilever concrete slab, the fatigue durability of bridge slab is also improved obviously. In an 11-months experiment [7], a cantilever RC slab specimen with embedded CFRP rods with high moduli was built on a moving-wheel load tester, and the deck of the bridge was repeatedly loaded. The test results show that when the initial load is 60 kN, the specimens of CFRP reinforced plates bear about 3.56 million cycles, which is 32% higher than the design expectation. The final failure of the bridge panel in this experiment is the punching shear failure caused by the fracture of CFRP bars, which further proves the feasibility of NSM technology [7].

2.2.2 Shear strengthening

As heavy vehicles are driven close to the support, the plate ends bear a large shear force. It is necessary to further study the problem of shear reinforcement at the end of the bridge deck [3]. However, EB method and NSM method are not suitable for the shear reinforcement of bridge deck. In order to overcome the shortcomings of EB method and NSM method, a new ETS (Embedded Through-Section) reinforcement technology emerged at the right moment. According to the preliminary study of domestic and foreign scholars, ETS technology has the characteristics of good reinforcement effect, simple construction, good bond with concrete, etc., especially suitable for the shear reinforcement of bridge deck [3, 8]. Table.2 and Table.3 are the result of tensile test and loading test of concrete strip reinforced with perforated FRP bars, which comes out of Wang Xugang. In order to study the shear performance of specimens and simulate the force state of heavy vehicles driving near the end during the working process of bridge deck, three-point asymmetric linear loading scheme was adopted in loading test [3].

Table.2. Tensile test result of ETS method [3]

Reinforcement material	Diameter (mm)	Failure mode	Breaking load (kN)
Steel	10	Adhesive failure	36.75
BFRP	9	Concrete splitting	41.86
GFRP	9	Concrete splitting	44.04
CFRP	9	Concrete splitting	43.48

Table.3. Loading test of ETS method [3]

Reinforcement material	Cracking load P _{cr} (kN)	Ultimate load P _u (kN)	P _{cr} / P _u (%)	Failure mode
Steel	30	142	21.13	Bending
BFRP	30	144	20.83	Bending
GFRP	30	138	21.74	Bending + shear
CFRP	25	138	18.14	Bending + shear

Through the analysis of the experimental results and crack propagation, it can be concluded that the elastic modulus between FRP bars and concrete is close, which makes it better to become the deformation coordinated decomposition failure mode of concrete rather than adhesive failure. Therefore, strengthening and FRP reinforced materials injected into the type of materials can effectively avoid damage and reinforce the peeled structure. In addition, the existence of ETS bars limits the development of shear fracture. In particular, the critical shear fracture which directly causes the workpiece shear fracture is avoided. Thus, the failure modes of specimens from shear failure to bending failure or bending-shear combined failure are changed. The ductility and stress can be improved while the performance of the material can be fully developed [3].

3. Performance improvement of bridge beam

3.1 Component analysis

The beam is one of the main components of the bridge. During the use process, the beam bears the vertical load. After many years of use of various beams on different traffic lines, the damage of beams is not the same. In the past, increasing beam section is a way to strengthen the beam, but because of its long construction period has a great impact on production and life. Not only that, the effect of this reinforcement method largely depends on the quality of the construction team. The other traditional method is the outer steel reinforcement method, which has the disadvantage of high cost. FRP has various types and flexible application methods. It is a good choice to use FRP to strengthen them. In recent years, a large number of studies on FRP strengthened beams have been carried out and draw some conclusions.

3.2 Performance improvement

3.2.1 Flexural strengthening

Among the types of damage to beams, flexural failure is the most common one. In order to extend the use time of beams, most of them need flexural reinforcement. The reinforcement materials, reinforcement techniques, loads and environmental conditions all influence the performance of the reinforced beam. In terms of reinforcement technology, EB and NSM FRP systems are common [9]. Mounting FRP laminates on the drawn side of a beam has also been shown to improve its flexural strength [10-11]. In addition, U-wrapped and fully wrapped beams are improved on flexural strength and stiffness, but this technology is too complex in construction. The ductility of GFRP is higher than that of CFRP. Some researchers apply this difference in properties to propose a twin layer carbon-glass fiber composite system and use it to reinforce the main beam of the bridge [12]. The experimental results show that the flexural strength of the beam is increased by 114%. If the FRP material used for reinforcement exhibits tensile fracture and damage, the flexural ductility and

stiffness of the reinforced beam decrease. On the other hand, the flexural strength of beams reinforced with three, two and one layers of CFRP sheets is increased by 38.86%, 46.6% and 15.5%, respectively [13], the results vary with the type of FRP. After a single layer of GFRP sheet is used for reinforcement, the performance of this type is improved by 45%, and when it is replaced by BFRP sheet, it will be improved by 27% [14-15]. Therefore, the use of FRP for flexural reinforcement of beams is effective and reliable.

3.2.2 Compressive and impact strengths

Vehicles, hail, tornadoes, and even accidental explosions can have an impact on a bridge's beams. Consequently, it is necessary to strengthen the compressive strength and impact strength of the beam. Beams are often invalidated under impact loads, when they are invalidated under static loads [16-17]. Reinforced concrete beams will also increase their impact strength by 5% to 15% after bending reinforcement [18-19]. The improvement of beam compressive strength can be achieved by using FRP. One study showed that the beam's compressive strength could be 115 percent higher than ultra-high performance concrete by adding excellent fibers [20]. Mastali and Dalvand [21] used jacketing/U wrapping method to reinforce the cylindrical and cubic beams containing 0.25%, 0.75% and 1.25% recycled carbon fiber, and their compressive strength increased by 31.10%, 47.07% and 65.10%, respectively. Two layers CFRP and one CFRP strip also adopts the U wrapped method to strengthen the beam, its impact bearing capacity is increased by 1.5%, and if the beam is reinforced with seven U wrapped strips, its performance is increased by about 9% [17]. Aramid fiber-reinforced polymer (AFRP) is recommended to improve the toughness of the beam due to its superior impact resistance and energy absorption [22], so that it can cope with the free swing effect of the beam after the impact effect. In addition, the experimental results show that the compressive strength of beams reinforced with CFRP sheet can be increased by 24.68% [23]. According to the mentioned research, AFRP and CFRP play an important role in compressive and impact strengths.

3.2.3 Shear strengthening

Some beams need to be improved the shear bearing capacity due to lack of shear reinforcement or cracks. It must be pointed out that the EB FRP system plays an important role in the improvement of the shear strength of the beam, and the shear strength of the reinforced beam is related to the type of FRP reinforcements. Researchers [24] have found that the shear reinforcement effect is improved after adjusting the shear-span-to-depth ratio and reducing the FRP spacing [25]. Various FRPs have been applied to the external reinforcement of beams, The reinforcing effect of unidirectional FRP system is not as good as that of hybrid FRP system [26]. The shear strength of beams wrapped by single-layer [27] and double-layer FRP [23] sheets was increased by 50% and 92%, respectively. Accordingly, a variety of FRP and reinforcement processes can improve the shear bearing capacity of the beam.

4. Performance improvement of bridge pier

4.1 Component analysis

The piers are the substructures to support the bridge span structure and transfer the dead and vehicle live loads to the foundation, which is located on both sides of the bridge. The bridge pier is located between the two abutments for supporting the bridge span structure. This is because the abutment bearing not only supports the bridge span structure, but also it can be connected with the embankment, preventing the embankment from slipping. In bridge pier design, brittleness, flexural shear failure and environmental corrosion are the most important aspects to consider.

4.2 Large Rupture Strain Fiber Reinforced Polymer (LRS-FRP)

LRS-FRP composites are normally made of Polyethylene Naphthalate (PEN) or polyethylene terephthalate (PET) fibers. They have relatively lower elastic modulus but much larger rupture strains

(usually greater than 5%) compared to conventional FRP composites (i.e. Carbon FRP, Glass FRP and Aramid FRP), which provides us with a cheaper but more effective solution for the seismic retrofit of reinforced concrete (RC) columns [28].

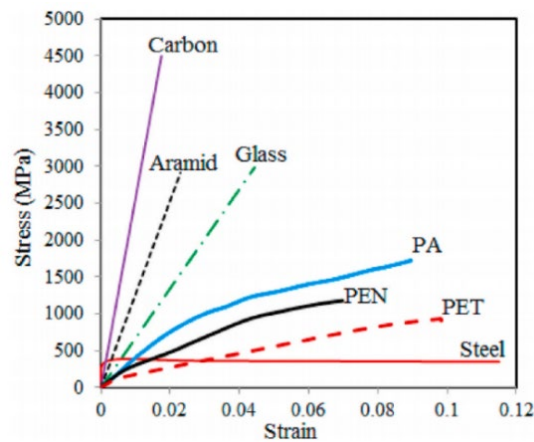


Figure 2. Comparison of typical tensile stress-strain responses between conventional FRP composites and LRS FRP composites [29]

As shown in the Figure.2, the secant tensile modulus of LRS-FRP composite is much smaller than those of conventional FRP composite and steel, while the tensile strength of LRS-FRP composite is much larger than that of the conventional strength steel. PET fibers are usually produced from recycled PET bottles or plastic waste, so they are cheaper and more environmentally friendly. Compared with PET fiber, PEN fiber has better properties in terms of strength, thermal stability, radiation resistance, etc. due to its unique naphthenic ring, but its price is more expensive than PET fiber [301]. Fiber-reinforced polymer (FRP) composites have been widely used in civil engineering to reinforce existing metamorphic reinforced concrete (RC) structures or build new ones [31]. It is worth noting that the mechanical properties of LRS-FRP composites are different from those of conventional FRP composites. LRS composites generally exhibit approximately bilinear tensile stress-strain behavior, high elongation (up to 8%) and low elastic modulus [32]. Similar to conventional FRP composites, LRS FRP composites are also fabricated by embedding continuous fibers such as PA, PEN and PET in a resin matrix. The fiber is an important component that carries the applied load, and the matrix protects the fiber from the attack of the external environment and ensures the joint action of the fiber under various loads. The properties of LRS composites depend on the properties of the reinforcing fibers, the type of polymer matrix, fiber orientation, fiber content, and fiber-matrix bonding properties [31].

4.3 LRS-FRP differs from the influence of some common materials on bridge piers

4.3.1 Material properties

Compared with unconfined concrete, the deformation capacity of LRS-FRP confined concrete is significantly improved, but the improvement in compressive strength is smaller. The stress-strain response of LRS-FRP constrained high-strength and ultra-high-strength concrete is strain-hardening-softening-hardening, while the strain-softening behavior of LRS-FRP constrained ordinary-strength concrete is not significant [29]. It should be noted that for seismic strengthening applications, FRP jackets with larger fracture strains are generally beneficial because FRP jackets have greater ductility and greater energy for the same degree of strength enhancement absorptive capacity [4]. Two main issues need to be considered in the seismic reinforcement of reinforced concrete piers: one is the enhancement of shear force, and the other is the enhancement of ductility. The LRS-FRP jacketing provides additional shear resistance, reducing the risk of brittle shear damage and also increasing the strain capacity of the concrete under compression, thus significantly improving the ductility of the above-mentioned elements [33].

4.3.2 Application in bridge pier reinforcement

LRS-FRP jacketing is adopted for the reinforcement of bridge piers. Combining the advantages of traditional FRP composites and LRS composites, a hybrid sheathing system exists for the seismic reinforcement of reinforced concrete piers. Two types of FRP composites were used in this system: a conventional FRP composite for shear reinforcement outside the plastic hinge zone, and an LRS FRP composite for shear reinforcement within the plastic hinge zone [4]. LRS FRP composites have lower elastic modulus. Large amounts of fibers may be required to meet shearing needs. Therefore, shear reinforcement with LRS FRP composites may not be very effective. On the other hand, using LRS FRP composites to reinforce concrete piers can improve the inelastic deformation capacity of the buckling plastic hinge region of concrete piers. The limit state of traditional FRP concrete bridge piers is usually caused by fiber fracture in its plastic hinge zone, especially at the corners of the rectangular section, leading to the explosive failure of traditional FRP composites. Therefore, LRS FRP composite material is a good substitute material as a protective material for the plastic hinge area of reinforced concrete piers, which can avoid this explosive failure [4].

5. Discussion and conclusion

This paper mainly makes a general description of the improvement of FRP material reinforcement for different parts of the bridge. At the same time, a certain degree of advice is given for the selection of materials and directions in the reinforcement project. The summaries of the individual materials and components are shown as follows:

(1) In order to meet the relatively larger and more concentrated vehicle load of modern Bridges, it is necessary to improve the flexure and shear capacity of bridge deck. According to the analysis of the experimental data, among the existing FRP reinforced bridge deck methods, NSM technology is suitable for enhancing the bending performance of bridge deck, while ETS technology is more suitable for improving the shear performance. Reasonable selection of reinforcement methods and materials can shorten construction periods and reduce costs.

(2) Using LRS FRP composite material to reinforce the piers, it can achieve green and no pollution, reduce the construction cost, and has the advantages of non-corrosion and easy to construct. The reinforcement method of FRP reinforcement makes the reinforcement not easy to wear and easy to reinforce, which is conducive to reducing workload and improving work efficiency. The use of LRS FRP composites allows the gradual expansion of longitudinal reinforcement while maintaining the integrity of the concrete cover, thus avoiding a sudden loss of bearing capacity. This progressive and ductile failure mode is highly desirable for structures during earthquakes. Under the same ductility properties, using PET FRP sheet instead of AFRP sheet can reduce the construction cost by about 70%, which indicates that LRS FRP composite material is a more economical and effective seismic retrofit solution for reinforced concrete piers.

(3) In terms of reinforcing beams, the use of FRP and some reinforcement techniques have significant effects on improving flexural strength, compressive and impact strength, and shear strength. In bend reinforcement, EB and NSMFRP systems are widely used, and the combination of CFRP and GFRP has achieved excellent results. U wrapped beams perform well in compressive and impact-resistant reinforcement, and AFRP can be used to cope with the free vibration effects of beams. EBFRP system reinforcement can also be used in shear reinforcement.

FRP materials have good performance both in terms of environmental protection and application. We believe that the prospect of adopting FRP reinforcement technology: (1) In the future construction, the construction party needs to pay attention to the mixing of different types of high-performance FRP composites and the modification caused by the composites. (2) In future construction, engineers will need to emphasize prestressing methods and use them for structural strengthening. (3) The localization of FRP materials might reduce the cost of local construction and reduce the energy consumption caused by the transport of materials. (4) The relevant government departments should expedite the development of relevant technical standards, which will be beneficial to construction.

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