FRP jacket assembly for retrofitting concrete structures

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Abstract
Most of the existing fibre-reinforced polymer (FRP) strengthening systems are wrapped directly to the structure creating a “2-material repair system”, i.e. the existing structure and the FRP wrapping. Recently, a new type of FRP composite jacket with an innovative mechanical joining system for repair of existing structures has been developed. This repair system works by wrapping the prefabricated FRP jacket around the damaged structure and placing a grout infill between the jacket and the damaged structure producing a cylindrical confinement and creating a “3-material repair system”. The effective assembly of the components, the existing structure, the grout infill and the FRP jacket, is the key for the effective utilisation of this repair system. This paper reviews and evaluates the important parameters that affect the behaviour of structures repaired with the novel FRP jacket to ensure its structural integrity and efficiency.

1. Introduction

The increasing problems of deteriorating reinforced concrete (RC) structures have resulted in many civil infrastructures becoming out of service due to safety concerns. These damaged structures need to be either replaced or retrofitted so they can remain in service. In most cases, it is more economical to repair the existing structures than to replace them. In year 2000 alone, the US State Department spent an estimated $5 billion to remediate corroded RC bridges [1]. Similar cost was spent by Europe and Canada to maintain their bridge infrastructure [2]. In Australia, the corrosion damage has cost the economy more than $13 billion per year due to cost of lost production and shutdowns to make repairs [3]. Adopting effective rehabilitation and strengthening techniques can be economically beneficial by minimizing the off-period time of the structure, and eventually saving a significant amount of resources. Due to the limitations of the traditional rehabilitation techniques such as concrete and steel jacketing, the introduction of fibre-reinforced polymer (FRP) composites for strengthening and rehabilitation of civil infrastructure has been essential and very versatile.

The concept of directly wrapping FRP composites to the damaged structure and creating a “2-material repair system”, has been successfully used in protecting and restoring the structural integrity of deteriorated wood piles [4] and steel structures [5]. Furthermore, researches have established that the effective utilization of FRP composites can significantly improve the strength and ductility of RC structures [6]. However, a major issue in most available prefabricated FRP repair systems is the integrity of their joints to provide structural continuity and confinement. A new type of FRP jacket with an innovative joining system was therefore developed. This paper presents the novelty of this repair system and the important parameters that need to be considered in their effective design and application.

2. Pre-fabricated jacket system with a novel joint

The prefabricated FRP jacket for pile repair and concrete formwork has an innovative joining system as shown in Fig. 1a. This repair system is quick and safe to install due to the easy-fit and self-locking mechanical joints as depicted in Fig. 1b. This joining system comprises of two interlocked edges that can easily fit into each other like the teeth of zipper. This “3 material repair systems” is comprised of the (1) existing damaged structure, (2) prefabricated composite jacket, and (3) grout as infill to the annulus between the structure and the jacket. This system works by wrapping the FRP jacket around the damaged pile and placing the joint key vertically along the seam to lock the jacket producing a cylindrical confinement. This simple assembly process can be carried out underwater or alternatively above waterline. The finished assembly is then lowered in the water up to the required depth. The annulus is then filled with water displacing grout. Compared to other composite repairs, the effective assembly of this novel FRP jacket highly depends on the three elements that comprise this repair system which is discussed in the next sections.

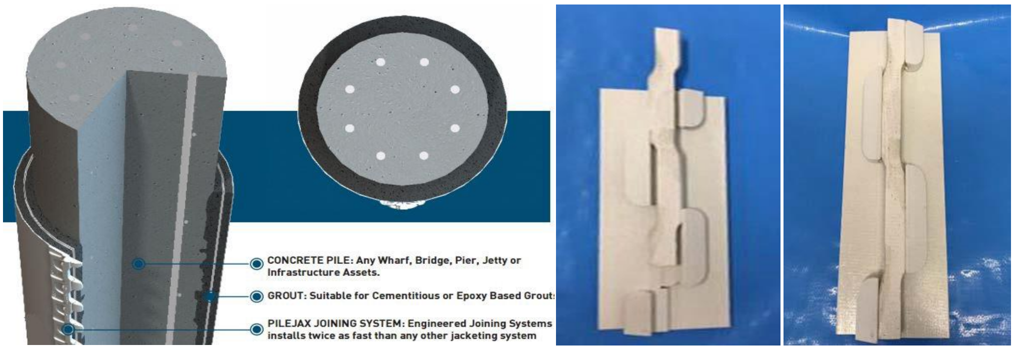

Figure 1. (a) Repair system [7], (b) Jointing system.

3. Factors affecting the effectiveness of the FRP jacket system

3.1. Existing structure

- ***Level of corrosion***

Corrosion of steel reinforcement leads to cracking, reduction of bond strength, reduction of steel cross section, and loss of serviceability and structural integrity [8]. The results of an experimental study conducted by Ma, Che [9] showed that a 15% of steel reinforcement corrosion damage resulted in more sever strength, stiffness and ductility degradation.

- ***Loss of concrete cover***

The concrete cover spalling and reinforcements exposure change the structural behaviour of the degraded member because the reinforcement can no longer act compositely with the concrete. An experimental study conducted by Cairns and Zhao [10] noted that a 50% loss in strength was found for a rectangular beam with 1.5% reinforcement when over 90% of the span lost its concrete cover.

- ***Cross sectional shape of the core***

The confinement mechanism of externally bonded FRP jackets is less effective for square and rectangular columns compared to circular columns [11]. Thus, in most cases, the cross section of square and rectangular columns are modified into a circular shape before applying the confinement.

3.2. Grouting system

- ***Stiffness***

Efficient load transfer between the components of the repair system is strongly associated with the stiffness of the grout. With stiffer grout, the strain of the core will be less as the FRP jacket is acting compositely with repair system by taking more strain and producing larger confining pressure [12].

- ***Flowability***

The presence of voids within the grout and/or core and FRP jacket causes discontinuity in the system. The voids can be resulted from either flowability issues or because of shrinkage cracks during the curing process of grout. Therefore, a non-shrinkage or expansive grout is preferable to avoid the gap effect and create a small post-tensioning effect, which confines the concrete column better.

- ***Compressive strength***

The strength gain of the repair system diminishes slightly with the increase of core's compressive strength [13]. Similarly, the hoop strain or stress in the FRP jacket decreases as the compressive strength of the core increases. These changes are attributed to the increase in the material brittleness as it is increased with the compressive strength and that changes the micro-cracks development patterns from heterogeneous to localised pattern which is considered the main reason for this deficiency [14].

3.3. FRP jacket

- ***Thickness of the jacket***

Increasing the thickness of FRP wraps increases the strength and ductility of RC columns considerably [15]. The analysis conducted by Hajsadeghi, Alaee [15] for RC columns wrapped with one, three and five FRP layers showed that the columns with five layers exhibited the highest carrying capacity in terms of axial stress and axial strain compared to other columns due to the increase in the lateral confining pressure.

- ***Fibre type***

The tensile strength depends mainly on the types of fibres that form the jacket. The carbon fibres have superior properties than glass fibres, but the latter are cost competitive, while aramid fibres have inadequate capacity in terms of compressive loads comparing with other fibre types [6].

- ***Fibre orientation***

The direction of placing the fibres can dramatically influence the load carrying capacity of the FRP jacket, hence, they are usually oriented along the load direction. For example, in FRP confining applications, fibres are oriented in the hoop direction to produce higher lateral pressure [15].

- ***Joint***

The traditional joining techniques, such as tongue and groove, laps/straps joints, and screws and fasteners, are difficult to install and does not share the same properties with FRP jacket to withstand the various weathering conditions. While the novel joining technique of the proposed system comprise of two FRP interlocked edges that can easily fit into each other and continues the cylindrical confinement that produced by the FRP jacket.

4. Discussion

The prefabricated jacket with a novel joint offers an effective repair system to enhance the strength and ductility of deteriorating structures. Its novelty is its innovative joining system which makes the installation much easier and safer than the other traditional repair systems. The efficiency of this system relies on the effective assembly of its components, i.e. the existing structure, the grout infill and the FRP jacket. Moreover, important factors such as the level of corrosion, loss of concrete cover, shape, type and properties of the infill, thickness of the jacket, and the integrity of the joint should be considered in the design and construction of this repair system. However, the low cost-to-performance benefits of this FRP jacket are not yet fully explored and its contribution in the structural capacity of the repaired structure is still undefined. An investigation of the actual performance of the concrete structure repaired with this repair system is now being planned to provide engineers and end users an assurance on the efficiency and structural reliability of this composite repair method.

6. Conclusion

A new type of FRP jacket for pile rehabilitation and concrete formwork is presented in this paper. The following are the novelty and the major factors to be considered in this “3 material repair system”:

- The novelty of the FRP jacket is the innovative joining system comprising of two interlocked edges that can easily fit into each other providing structural continuity and confinement.
- The level of corrosion damage, loss of concrete cover and cross-sectional geometry of the existing structure need to be considered in designing the appropriate composite repair system.
- The stiffness, flowability and compressive strength of the grout are the most important factors to effectively transfer the stress from the existing structure to the repair system.
- The increase in strength and ductility of the repaired structure highly depends on the thickness, fibres type and orientation of the FRP jacket, and the continuity provided by its joining system.

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