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Investigation into fibre composites jacket with an innovative joining system

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HIGHLIGHTS

- A new type of FRP jacket with an innovative mechanical joining system was developed.
- The materials used in the joint have a significant effect on the capacity of the FRP jacket.
- An interlocking key with GFRP rod has a better joint performance.
- Theoretical evaluation showed a good agreement with full-scale experimental results.
- The performance of jacket exceeds the industry standard for a permanent concrete formwork.

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ABSTRACT

The effectiveness of fibre reinforced polymer (FRP) composites jacket for pile rehabilitation relies mostly on the continuity of repair system. This paper presents the development of a new type of FRP jacket with an innovative, easy-fit and self-locking mechanical joining system and the evaluation of the suitability of this composite repair system for pile rehabilitation and concrete formwork. An intensive characterisation of the mechanical properties of the composite resin for the interlocking teeth and locking key of the jacket was conducted. Similarly, finite element (FE) simulation on the behaviour of the FRP jacket subjected to internal pressure was performed and verified through full-scale experimental testing. The results showed that the use of a microfibre composite resin provide the highest capacity joint. Further, the embedment of an FRP rod in the locking key resulted in an FRP jacket with a better joint performance. The results of the FE simulations showed a good agreement with the experimental results in predicting the lateral expansion in the elastic stage, capacity and failure behaviour of the FRP jacket.

1. Introduction

Retrofitting, strengthening, and repairing of aging infrastructures are becoming a major task and complex problem faced by engineers and researchers nowadays [1]. In most cases, it is more economical to rehabilitate these existing infrastructures than to replace and/or rebuild new ones. For example, the incurred costs in repairing bridges due to delay in transporting goods and services will be minimized if rehabilitation is an option. Thus, engineers and researchers yearn for a repair system that can restore the structural integrity and install easily to allow continuous operation or with only minimal disruption during the repair. Most importantly, the selected repair system should offer a long-term repair solution and low-cost maintenance infrastructure.

Prior to fibre reinforced polymer (FRP) composite materials, the rehabilitation of existing structures is performed using the same materials (wood, concrete, and steel) used in the original construction. This is not advisable since the structure will be subjected to the same forces and environmental conditions that caused its deterioration and the repair cycle will be unending [2]. In the last 20 years, FRP composites have become an extremely versatile option to strengthen or rehabilitate existing structures especially in harsh marine environment. This material has been a preferred option because of their superior properties such as high strength, corrosion resistance, lightweight, high fatigue resistance, nonmagnetic, high impact resistance, and durability [3]. In fact, reinforcing and strengthening of civil infrastructures using fibre composites has been a topic of research and development for years [1]. Further, practical applications and implementations on using FRP composites in strengthening works are now counted in hundreds [4].

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In rehabilitation works using FRP jacket, confinement is the key aspect that strengthens the columns or piles. This confinement effect of FRP wraps has been observed in numerous investigations to date, e.g. Smith et al. [5]. Columns wrapped with FRP composites exhibited enhanced ductility, load carrying capacity, and lateral deflection capability [6]. Also, the hoop strength, longitudinal strength, and shear resistance of the wrapped piles are increased [7]. Aside from meeting the strength requirements, the light weight characteristic of FRP makes it easy to install. It also serves as a shield that prevents deterioration due to environmental attacks such as marine borers, chloride penetration and water waves.

This paper presents the development of a new type of FRP jacket with an easy-fit and self-locking mechanical jointing system and the preliminary evaluation to demonstrate the application of this pre-fabricated composite repair system for pile rehabilitation and concrete formwork. This paper focuses on the investigation of the interlocking teeth and joint key of the FRP jacket including the characterisation of the mechanical properties of the composite materials used in the joint. An assessment of the capacity and behaviour of the FRP jacket subjected to internal pressure using Strand7 finite element software [8] combined with experimental verification was conducted to simulate the expansion due to the confinement effect and determine the viability of this new rehabilitation technique.

2. Background

Deterioration of reinforced concrete (RC) piles in marine environment is mainly due to the heavy loads it carries and corrosion of reinforcing bars. In the former cause, when the internal main longitudinal reinforcement bars have yielded and the concrete reached its unconfined compressive strength due to load, the concrete will experience lateral (radial) expansion. In the latter, the large volume of corroded steel induces lateral forces in the surrounding concrete. When these lateral forces are greater than the tensile strength of the concrete, cracking and spalling of concrete would occur. Among the possible upgrading strategies, the use of FRP wraps or jackets to prevent this expansion through its induced lateral resistive forces, is gaining widespread acceptance [4]. Considerable research has been reported in the last decade on the mechanical behaviour and failure of FRP wrapped RC columns. These are studies on FRP confinement of column structures not in marine environment which include repairing and retrofitting of damaged columns using FRP system [9–12] and strengthening of columns using FRP composites [13–15].

The fabrication of externally bonded FRP confining system can be categorized into two methods, the wet lay-up and the pre-fabricated system. In the wet lay-up system, FRP composite jacket is prepared on site where trained workers are essential. This repair system requires a smooth surface and rounded corners of the column before the FRP wrapping is applied. Liquid resins are then prepared on-site which are then impregnated into the fibre and rolled evenly to ensure a balanced distribution and to remove the bubbles. After curing, the jacket is installed in the structural member. Fyfe's Tyfo® SEH-51A [16] and Aqua-Advanced-FRP [17] are some examples of fibre composite repair technologies using the wet lay-up method. While this repair system is ideal when immediate rehabilitation is necessary, it requires high quality of work in terms of resin preparation and composite jacket installation to achieve the desired strength. If done underwater, the impregnation of the fibre is difficult to execute and monitor, and a proper curing of the resin may not be achieved. Another is the health and safety issue due to styrene emission which limits the full utilization of the system. Thus, pre-fabricated system is most of the times the preferred option in repairing structures using fibre composites located underwater.

In the pre-fabricated system, the FRP composite jackets are produced in the manufacturing plants to achieve a high quality and uniform product. Moulded fibre glass (MFG-CP) pile jacket [18], PileMedic™ "Seamless" jacket [19] and FRP shells by SCRIMP™ [20] are some examples of this system. A single seam MFG-CP pile jacket made up of chop strand and woven mat impregnated with epoxy resin was utilized in the rehabilitation of water front structures in New York City. These slip-joint/tongue-and-groove jackets are light weight and relatively easy to install with good abrasion and chemical resistant properties. However, divers are necessary to do an underwater assembly. Another example of this type of repair system is the "Seamless" jacket under the trade name PileMedic™. This system is made up of sheets of carbon or glass fabric up to 1.5 m wide that are saturated with resin and passed through a press that applies uniform heat and pressure to produce the jacket laminate. The repair of piles using this jacket does not require divers to work underwater, but it lacks the ability to be used as formwork in the construction of column structures. The licensed Seemann Composites Resin Infusion Process (SCRIMP) was used to fabricate FRP composite shells to repair wood piles. The system requires a minimum of two FRP composite shells to achieve the needs for structural restoration and held together with circumferential metal straps or temporary bands. Lopez-Anido et al. [20] mentioned that for this type of repair system, the metal straps are usually damaged and severed which lead to opening of the composite shells and losing the effectiveness of the repair. Thus, the ability of the pre-fabricated composite repair system to provide structural continuity and confinement in the circumferential direction is always a concern. In a study conducted by Smith et al. [12], they compared the confinement effect of a discontinuous and continuous fibre composite wrap on concrete cylinders. They found that the discontinuous sheets were easier to install than continuous wraps but failed at the lower load due to ineffective confinement. There is a need therefore to develop an innovative and effective jointing system for an FRP jacket which can provide continuity and confinement.

3. Description of the repair system

The PileJax™ is a new type of a pile repair system and concrete formwork jacket manufactured from fibre composite materials with an innovative mechanical joining system (Fig. 1). The novelty of this repair system is that it is quick and safe to install due to the easy-fit and self-locking mechanical jointing system developed and patented by Joinlox™ Pty Ltd [21]. This joint system involves two interlocked edges that quickly mesh together like the teeth of a zipper. A locking key is placed between the interlocking teeth and slid or levered only one pitch length into place, wedging the joint edges together with a uniformly loaded force along the entire length or circumference of the joint. This makes it more reliable than strapped/lap joints. This joint design was inspired by the way clams and other seashells attach themselves to rock ledges using anchors through hundreds of small filaments. These filaments can produce a very strong hold when their strength is added together.

The repair system works by wrapping the prefabricated and flexible FRP jacket around the pile above or below the waterline and placing the joint key vertically along the seam to lock the jacket producing a cylindrical confinement. Adhesive is then applied between the teeth of the jacket and the joint key to hold the key in place thereby improving its locking mechanism. The finished assembly is then lowered in the water up to the depth where repair is required. A standard hose is fitted at the bottom of the