PRESSURE BAGGING FOR REPAIRING CORRODING PILES FRP

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Introduction

Corrosion of reinforced or prestressed piles supporting structures in coastal regions is a world-wide problem. Traditional chip and patch repairs are costly but have been found to be largely ineffective [1]. As a result, there is increasing interest in alternative repair methods such as the use of lightweight, high strength, corrosion resistant, fiber reinforced polymers (FRP). Since chloride-induced corrosion is an electro-chemical process it cannot be stopped by FRP. It can at best slow down the ingress of deleterious materials such as oxygen and chlorides required for sustaining electro-chemical reactions [2]. Nonetheless, FRP can significantly extend repair life.

The effectiveness of FRP as a barrier is contingent on its bond with the concrete substrate. Good bond is critically dependent on surface preparation. However, even if all requirements for surface preparation are met, bond can still be poor if continuous, intimate contact of the FRP material and the concrete is lost while the resin is curing. This can occur when gravity effects cause separation of the resin-saturated FRP from its substrate. This scenario is common in vertical repairs, e.g. columns and piles, and in repairs performed on the bottom surface of slabs.

Gravity effects can only be countered if the frictional resistance to slipping is increased. In field repairs of columns, a plastic sheet referred to as a “shrink wrap” is tightly wound over the FRP after it has been installed. While this system may be adequate when FRP is applied to a dry surface, tests have shown that it is not as effective when the surface is wet [3]. This is a common situation in pile repair where corrosion is concentrated in the zone subjected to periodic wetting and drying due to tidal fluctuations, commonly referred to as the “splash zone”. Thus, the ability of the FRP to bond to a wet surface is crucial in pile repair.

This paper provides an outline of an experimental study conducted to ensure good FRP-concrete bond for both wet and dry surfaces. In the study, “pressure bagging” was used to apply uniform pressure to the FRP repair to ensure that intimate contact was maintained throughout the curing process. The system is simple to use and was successfully implemented in the field.

Experimental Program

Pressure bagging was developed by the composites industry for fabricating complex parts. Its use in infrastructure applications is relatively new [4]. In principle, a pressure bag can consist of just an inflatable bladder that is wrapped around the FRP after it is installed. However, it is more efficient to have the bladder inside an outer bag constructed with all the necessary fasteners, e.g. zipper, straps, etc., to facilitate easy application. This was the system that was developed. More details may be found elsewhere [5].

Prototype pressure bagging systems were developed and their effectiveness evaluated through pullout testing carried out in accordance with ASTM C1583. In the study, six full-sized piles (30 cm x 30 cm x 1.5 m) were used and the bond obtained from pressure bagging compared against those for regular repairs using a shrink wrap. These are referred to as “controls”.

Two different FRP systems were evaluated; a urethane-based system (System 1) and an epoxy-based system (System 2). In both cases, two fiberglass layers were applied using two different schemes. In “scheme 1”, the first FRP layer was positioned longitudinally and the second layer wrapped transversely over it; in “scheme 2”, both layers were placed transversely.

Since the corroded region in the pile is restricted to the splash zone this was also simulated. All test specimens were placed vertically inside a tank in which the water level was adjusted so that exactly half the wrapped region was completely under water and the remaining half dry. A total wrap length of 92 cm was used for the laboratory study, resulting 46 cm being dry, and 46 cm submerged. After the resin had completely cured, the specimens were removed from the tank and pullout tests conducted at node points on a 75 mm x 75 mm grid drawn on the FRP surface. Thus, a total of 36 tests could be conducted on a particular surface - 18 related to the submerged section and 18 for completely dry section. With six specimens, it was therefore possible to conduct a maximum of 216 specimens; however the actual number was fewer because the wrap surface near its bottom was uneven in some instances. As a result, a total of 210 tests were conducted.

Results and Discussion

The results from all of the pullout tests are summarized in Figs. 1 and 2. These provide bond values corresponding to locations both above and below the waterline. Percentage changes relative to controls are indicated within the figures. Recommendations for acceptable bond stipulated by ACI 546 are also shown in the same plots [6].

Fig. 1 shows that although both systems 1 and 2 had significantly improved bond for the dry region (111% and 194% respectively), the urethane-based system only had a 5% increase below the waterline, compared to the 545% increase for the epoxy-based system.
Fig. 2 shows that the application of pressure has a less dramatic effect on bond in the dry region (17% for the urethane system and 42% for the epoxy system) for scheme 2 in which both layers are applied transversely. However, both systems have sizeable improvements in the underwater bond (42% for the urethane and 31% for the epoxy-based system).
Thus, the extent of improvement is dependent on both the type of resin and the fiber architecture. Urethane resins (System 1) discharge carbon dioxide during curing; the application of pressure displaces the gas but cannot remove it. As a result, air pockets develop that reduce bond. This is not an issue for the epoxy-based system which does not emit gases and therefore suffers no similar adverse effects from pressure.
An unexpected finding from the study was the noticeably better bond achieved using scheme 2 in which successive FRP layers are applied transversely. This is because it is easier to exert pressure during manual installation for this scheme. Thus, if external pressure cannot be used, it is best to place the FRP material in the transverse direction. In such cases, bi-directional material must be used if longitudinal strengthening is required.

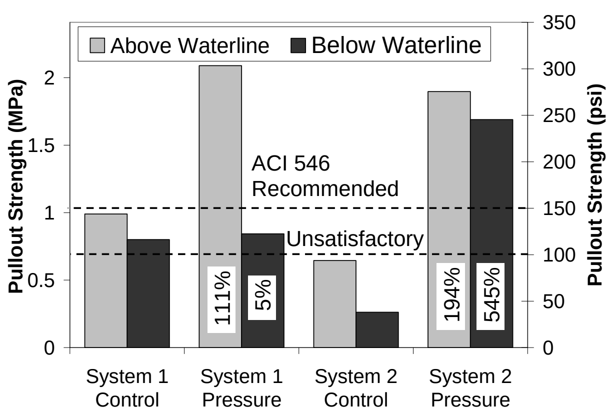

Fig. 1 Bond values from pullout tests for Scheme 1.

Conclusions

This study shows that the techniques used by the composites industry can be readily adapted for infrastructure repair.
The results of the laboratory testing confirm that external pressure significantly enhances the bond between FRP and concrete both above and below the waterline. The system developed in the laboratory is simple and was successfully implemented in the field repair of piles supporting the Friendship Trail Bridge located in tidal waters of the Gulf of Mexico.

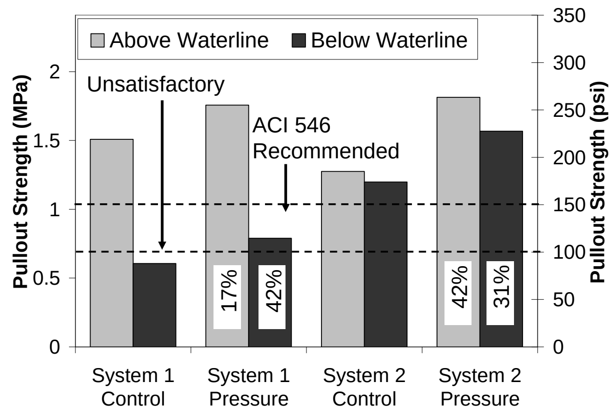

Fig. 2 Bond values from pullout tests for Scheme 2.

The pressure bagging system developed provides the construction industry with a simple, practical method for improving the concrete-FRP bond for the repair of piles and columns both above and below the waterline. Recently, Hillsborough County have stipulated the need for using pressure in conducting FRP pile repairs. This is a welcome development that is likely to promote its use in the future.

Acknowledgements

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