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Bond characteristics of near-surface-mounted anchorage for prestressing

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HIGHLIGHTS

- A new grouted anchorage system is applied to the NSM strengthening technique.
- The bond behavior of anchorage for the post-tension method was investigated.
- 40 pullout tests with different fillers and diameters of the anchorage were conducted.
- Behavior and failure characteristics of tested anchorage systems were examined.
- The optimum mortar filler strength and sleeve diameters were proposed.

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ABSTRACT

The external bonds of carbon fiber reinforced polymers (CFRP) used to strengthen structures are known to be vulnerable to delamination. To prevent FRP delamination and efficiently strengthen structures, post-tension CFRP rods are installed for near-surface-mounted (NSM) strengthening. For post-tensioning, grouted anchorage systems have been applied to the NSM strengthening technique. The bond behavior between the CFRP rods and the filler in the anchorage for the post-tension rods should be investigated. This study evaluates the behavior and failure characteristics of bond-type anchorage systems based on the results of 40 pullout tests with different mortar fillers and diameters of the anchorage sleeve. The optimum mortar filler strength and sleeve diameters have been proposed to ensure proper bond behavior in NSM anchorage systems.

1. Introduction

The common methods used to strengthen deteriorated concrete bridges are bonding of steel plates, prestressing of steel tendons, external bonding of fiber reinforced polymers (FRPs), and near-surface-mounted (NSM) FRP rods. Among the various strengthening techniques, the number of projects using FRP reinforcements has increased significantly because carbon-fiber reinforced polymer (CFRP) rods have outstanding mechanical properties. CFRP rods can be protected from mechanical damage by being mounted in the concrete structure. Interest in CFRP as an alternative material to steel reinforcement has increased due to its non-corrosive and lightweight properties. In recent decades, several studies have reviewed the design of external post-tension systems for FRPs and NSM rods. Prestressing force generates a compressive force to the FRP rods. The generated compressive force in FRP rod increases the strength of concrete members. Recently, FRP rods have been used as reinforcing bars and prestressing tendons for post-tension anchorages. Because the surface treatments and properties of FRP rods differ from those of steel, introducing FRP rods into post-tension systems requires knowledge about the behavior of the FRP in the sleeve. To improve the strength of concrete structures using NSM strengthening, a post-tension anchorage and CFRP rods are mounted at the tensional surface, as shown in Fig. 1.

Several studies [1–10] have used pullout tests to examine bond behavior in the FRP strengthening method. Malvar et al. [11] experimentally analyzed the bond characteristics of four different types of CFRP rods with different surface deformations embedded in lightweight concrete. Earlier studies provided local bond stress–slip data and bond stress–radial deformation data, which are needed for interface modeling of the bond mechanics. Baena et al. [12] experimentally investigated the influence of the rod surface, rod diameter, and concrete strength on the bond stress–slip curves. Additionally, they suggested analytical models to describe the ascending branch of the bond stress–slip curves. Sharaky et al. [13] experimentally studied the effects of adhesive

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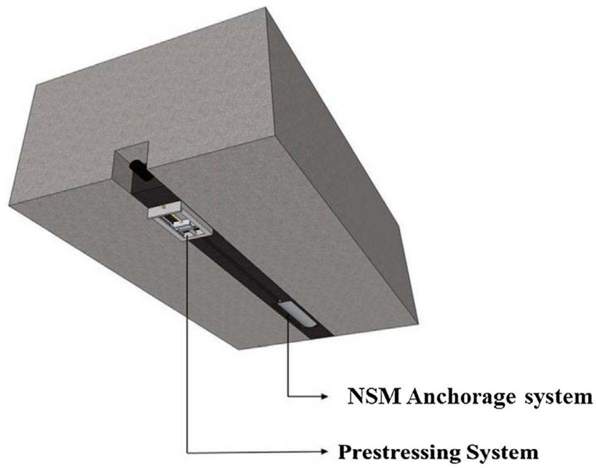
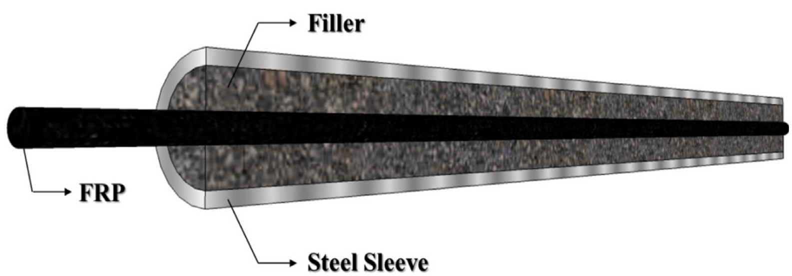


(a) Post-tension NSM strengthening technique



(b) Anchorage System

Fig. 1. Concept of near-surface-mounted strengthening technique: (a) Post-tension NSM strengthening technique and (b) Anchorage system.

properties, rod type, rod size, and FRP properties. They discussed the failure load, average bond stress, loaded end slip, free end slip, transverse strains (on adhesive and concrete), and the mode of failure for the tested joints.

Benmokrane et al. [14] performed an experimental study on the tensile characteristics, bond strength, and pullout behavior of aramid FRP (AFRP) and CFRP rods in sleeves. The pullout test program involved four types of rods, four types of cement grouts, and three bonded lengths. The surface geometry of the FRP rods, the properties of the filling grouts, and the stiffness of the anchorage sleeves influence the pullout behavior, pullout capacity, and maximum bond stress of the cement-grouted FRP anchors. Zhang and Benmokrane [15] performed pullout bond tests on four types of FRP rods, three types of grouts, and two bond lengths embedded in cement-mortar-filled steel sleeves. The experimental results showed that the material properties and surface conditioning of the FRP rods influenced the pullout behavior of the grouted rods. That study also proposed an analytical model of bond stress–slip relationships for grouted FRP rods. Zhang and Benmokrane [16] discussed an experimental study on a newly developed bond-type anchorage system using CFRP lead line 8-mm-diameter rods. The test program consisted of 9 monotonic tensile tests, two pullout tests, and two proving tests on anchorage systems with 1 or 9 rod tendons. The test results indicated that the developed anchorage system with 250-mm bond length ensured full development of the tensile strength of mono-rod tendons. Schmidt et al. [17] studied a two-piece wedge anchorage for CFRP tendons with an integrated sleeve and a differential angle between the barrel and wedge sections. They described the failure modes to highlight the importance of addressing them when testing. The developed anchorage reached the full capacity of the CFRP tendon and ensured a stable fracture load. Fang et al. [18] presented a bond type anchorage system for multi-rod CFRP tendons with a bonding medium of ultra-high performance reactive powder concrete. During the tests, the load distribution among the rods in the tendon was monitored until the bonds of the multi-rod system failed. The test results showed that the capacity reduction from inherent non-uniformities in multi-rod anchoring systems should be considered, and the authors provided the corresponding capacity reduction factor. Furthermore, they established the equations to evaluate the bond strength and critical bond length of both single and multiple CFRP rods embedded in RPC grout and showed them to be in good accordance with the test results. Schmidt et al. [19] discussed three methods of mechanical anchorage: spike, wedge, and clamping. They attributed the inconsistencies they found to the brittleness of the tendons, low strength perpendicular to the fiber direction, and insufficient stress transfer in the anchorage/-tendon interface. Thus, anchorage failure modes tend to involve excessive principal stresses, local crushing, and interfacial slippage, all of which are difficult to predict. Elrefai et al. [20] used an experimental study to examine the fatigue performance of a novel wedge-type anchorage for CFRP post-tension tendons. They considered two minimum stress levels, representing 40% and 47% of the ultimate strength of the CFRP tendon. Four stress ranges, varying between 7% and 17% of the ultimate strength of the tendon, were applied. The anchor system successfully met the Post-tension Institute provisions for cyclic loading. The fatigue test was primarily affected by the applied stress range, with little effect from the minimum stress. The fatigue limit of the CFRP tendon anchorage system was in a stress range of 10% for a maximum