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Full scale flexural test of jointed concrete members strengthened with post-tension tendons with internal anchorage

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ABSTRACT

A new strengthening system, which embeds a post-tensioned PC bar tendon into the wedge-shaped anchorage of an existing concrete member, was developed. Previously, the adequate load-bearing capacity of the prestressing tendon anchorage was confirmed on simple element specimens. In the present study, the developed system is applied to the addition of new concrete members to old concrete structures. The strengthening effect of the system was examined in a loading test on jointed full-scale concrete members. The saltwater permeability at the joint was also examined. The flexural properties of the jointed members were compared to those of concrete beams jointed with conventional post-installed adhesive anchors. The concrete beams jointed by the proposed system exhibited superior crack-resistance and load-carrying capacity, and their joints were strongly water-impermeable.

1. Introduction

As is well known, concrete materials are vulnerable to tensile forces and frequently crack under internal and external forces. Therefore, concrete structures are usually reinforced by post-tensioned prestressing systems. Owing to their effectiveness and reliability, prestressed concrete (PC) structures have become popularized around the world. In addition, technical papers and reports on post-tensioning techniques have been widely published. In recent years, conventional prestressed tendons have been supplemented by advanced materials such as fiber reinforced polymers (FRPs) [3,11,27,24,15,16,4,28,14,22]. Flexural tests on prestressed concrete using various prestressing-materials are often conducted for assessing the fundamental structural performance of reinforced concrete structures.

Ng and Tan [18] developed a simple "pseudo-section analysis" method for externally prestressed concrete beams subjected to flexure. In addition, Ng and Tan [19] examined the flexural behavior of the prestressed beams and confirmed applicability of the proposed analytical model. Park et al. [21] conducted flexural tests of post-tensioned girders using high-strength strands. The flexural behaviors of their girders well agreed with the predictions of current design codes, although the concrete crack widths and stresses in the reinforcements slightly exceeded the specified limits. Akiyama et al. [1] examined the flexural behaviors of cylindrical concrete pile prestressed with unbonded bars. They found that the load capacity of prestressed concrete pile was greatly increased by confining the pile between carbon fiber (CF) sheets. Kim et al. [12] developed a post-tensioning method for near-surface mounted (NSM) carbon fiber reinforced polymer (CFRP) strips, and estimated the anchorage capacity in comparative finite element simulations. Vu et al. [25] proposed a structural model of post-tensioned prestressed beams with unbonded tendons. Their model accurately predicted the deformations observed in experimental flexural tests. The structural responses of post-tensioned concrete slab/wall structures have also been extensively reported [29,7,6,5,26,2,13,8].

The existing concrete members in civil infrastructures become deteriorated by aging, and require regular strengthening and/or upgrading. Prestressing tendons and cables are generally arranged outside of the existing concrete members, demanding adequate workspace for the strengthening work. Recently, the present authors developed a new strengthening system using a conventional post-tensioning PC tendon [17]. The prestressing system uses an internal anchorage within existing concrete members. The tendon can be firmly anchored in a wedge-shaped hole filled with high strength mortar. This post-tensioning system also enables the addition of new concrete members to existing concrete structures. Whereas conventional RC jointed members are vulnerable to steel corrosion at the joints of the new and old

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concrete, the developed prestressing system may increase the durability of the jointed structure. To assess the applicability of the new system, the present studies examine concrete members joined by the developed post-tensioning method.

Previous investigations on jointed concrete members have evaluated the structural performance and durability of segmented element systems. Turmo et al. [20] predicted the structural behavior of segmental concrete elements jointed by external pre-stressing in numerical simulations. The applicability of their model was confirmed in comparisons between their predictions and experimental observations. Pillai et al. [23] studied the service reliability of segmental PC bridges in corrosive environments. They proposed a method that predicts the time-variant service reliability index, accounting for damage to PC tendons and other uncertainties.

The present study examines the workability of the post-tensioning system in full-size concrete members, and confirms the improved structural performance and durability of structures reinforced by the system. Full-scale reinforced concrete (RC) beams were connected by the developed method, and subjected to flexural tests. The results were compared against those of RC beam specimen jointed with conventional post-installed adhesive anchors. To examine their water permeability and steel corrosion resistance, jointed concrete beams were also exposed to saltwater for 5 weeks. This paper reports the cracking resistance, load-bearing capacity and saltwater permeability of the strengthened beams.

2. Strengthening method using post-tension tendons with internal anchorages

The developed strengthening system requires conventional prestressing bars, high strength mortar and a wedge-shaped hole (Fig. 1) formed by a special drilling device (see Fig. 2(a)). The drilling process of the hole is described in Fig. 2(b). Fig. 3 schematizes the strengthening process of the developed system. The prestressing tendon is firmly anchored in the internal wedge hole filled with high-strength mortar. Further details of the post-installed anchorage system are described in Mimoto et al. [17].

As shown in Fig. 3, the developed system can add new concrete members to existing concrete structures. A typical application is widening the slab width of concrete bridges (see Fig. 4). Concrete joints formed by the post-installed prestressing method may be much more durable than conventional jointed RC structures.

3. Methodology

3.1. Materials and mixture proportion

Table 1 lists the materials used in the experimental investigation. The conventional reinforcing materials were those used in previous studies. The mixture proportions of the concrete and mortar are summarized in Table 2. The mixture of concrete (A) complies with that of general RC structures in Japan. The water-to-cement ratio was reduced in concrete (B) (relative to concrete (A)) to improve its strength and durability. The specified compressive strengths of concrete mixtures (A) and (B) are 24 MPa and 30 MPa, respectively. To ensure sufficient strength and the appropriate fresh properties, the wedge-shaped anchorage was filled with commercial mortar (premix type). According to the manufacture sheet, the minimum compressive strength of mortar is 100 MPa at the age of 28 days. Detailed information about the filling material cannot be described here because of a commercial contract with the manufacturer.

This study reports the mechanical properties (compressive strength, Young's modulus and Poisson's ratio) of the concretes and mortar. Consistent with the Japanese standard and the authors' previous study [17], each test was conducted on three cylindrical concrete specimens (100 mm diameter × 200 mm height) and three cylindrical mortar specimens (50 mm diameter × 100 mm height). The mechanical properties of the concretes and the high-strength mortar are summarized in Table 3.

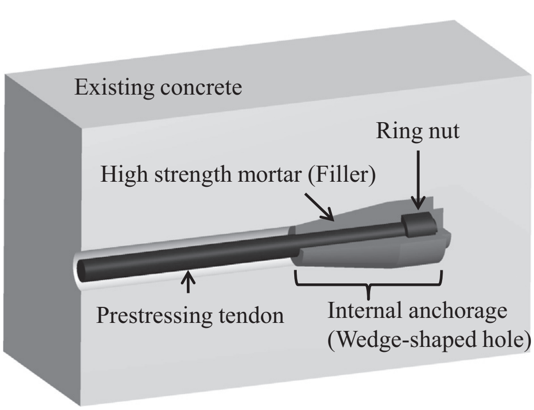
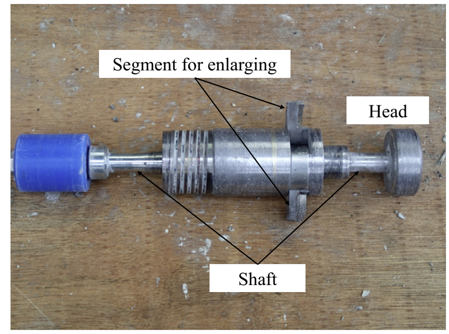
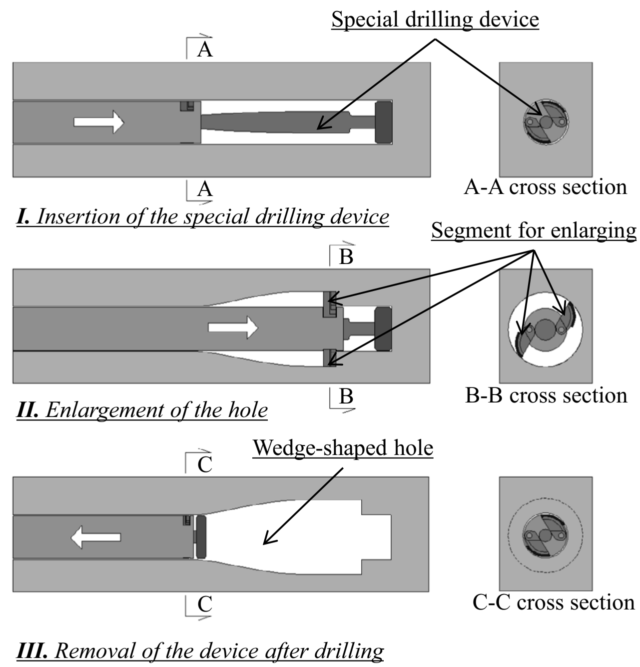


Fig. 1. Schematic of the internal anchorage system [17].



(a) Special drilling device



(b) Drilling process

Fig. 2. Drilling of the wedge-shaped hole in concrete [17]: (a) Special drilling device; (b) Drilling process.