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LONG TERM BEHAVIOR OF CONCRETE MEMBER STRENGTHENED WITH INTERNAL PRESTRESSING SYSTEM

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To maintain and retrofit appropriately concrete structures, various strengthening materials and methods have been developed and applied. One of the effective and reliable strengthening method for concrete is an application of the prestressing system. The present study focuses on a strengthening system using an internal anchorage and a prestressing tendon. The strengthening system is acceptable even in relatively narrow workspaces, and also applicable for joints between existing and additional concrete members. In our previous investigations, a static push-out and pull-out tests were performed to examine the load-bearing capacity of the prestressing tendon embedded in the wedge anchor. The test confirmed that the prestressing tendon can be anchored firmly in an internal wedge hole filled with high-strength mortar. Long-term behavior of the strengthened member should be examined to confirm the applicability of the system. The load and deformation of a concrete member subjected to sustained force by the prestressing bar were measured for 1 year. This paper reports the long-term loading test, and discusses the time-dependent properties of the strengthened concrete member. The test result confirms that the loss of prestressing force is negligible for actual applications.

Keywords: Strengthening, Loss of prestress, Internal anchor, Prestressing bar, Time-dependent behavior.

1 INTRODUCTION

Numerous concrete structures for civil infrastructure, such as bridges and so on, have been constructed for decades in Japan. Civil engineers have to maintain and retrofit appropriately these structures to sustain the modern infrastructures. Various strengthening materials and methods have been developed and applied to concrete members. The most effective and reliable method for concrete structures is an application of a prestressing system. The strengthening system has been investigated in previous studies. Kim *et al*. (2010) examined the strengthening effect of prestress by using a carbon fiber-reinforced polymer (CFRP) laminate. Michels *et al*. (2013) developed an anchorage system for prestressing CFRP strips to strengthen concrete members.

The anchorage system is a key to ensure the strengthening effect using a prestressing bar. The anchor system for reinforcing materials has been discussed in various previous studies. Kim *et al.* (2013) conducted a pull-out test of post-installed anchorage systems drilled in concrete members. Marti-Vargas *et al*. (2013) focused on and examined the anchor length of pre-tensioned prestressed concrete members. Yilmaz *et al*. (2013) investigated tensile behavior of post-installed chemical anchors embedded in low-strength concrete blocks.

The study focuses on a strengthening system using an internal wedge-shaped anchorage for a prestressing bar (Fig.1). The prestressing bar can be firmly anchored in the wedge hole filled with high-strength mortar. The strengthening system is acceptable even in relatively narrow workspaces, and also applicable for joints between existing and additional concrete members. Mimoto *et al.* (2015) conducted a push-out test to examine the load-bearing capacity of the wedge hole, and Sakaki *et al.* (2015) performed a pull-out test to confirm the yielding and ultimate loads of the prestressing bar embedded in the wedge anchor of full-size concrete member. These tests indicated the adequate strength of the anchor system for strengthening concrete members.

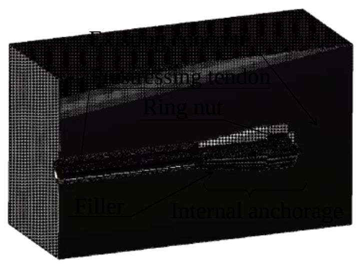

Figure 1. Internal anchorage system.

It should be noted that the tensile load in the pull-out test was statically increased up to the ultimate strength of the prestressing bar. Long-term behavior of the concrete member under a sustained load should be examined to confirm the applicability of the system. An objective of the experimental investigation is to examine the time-dependent properties of the concrete member strengthened with this system. The loss of prestressing force and deformation of the concrete member subjected to the tensile load (design load for strengthening) for 1 year are reported in this paper.

2 STRENGTHENING SYSTEM USING AN INTERNAL ANCHORAGE

This section outlines the strengthening system developed in the previous studies (Mimoto *et al.* 2015; Sakaki *et al*. 2015). Figure 2 shows the strengthening process of the post-installed anchorage system. To create a wedge-shaped hole (wedge anchor), a tip of hole drilled in concrete member is enlarged by using a special drilling device (Fig.3). The wedge anchor is filled with high-strength mortar after installing a prestressing bar as shown in Fig.1. The strengthening work is implemented as follows: Step 1: Core-drill into existing concrete and enlarge the hole tip; Step 2: Install a prestressing tendon (bar) and grout a filler (high-strength mortar) into the enlarged hole tip; Step 3: Place new concrete to increase size if necessary. Pull the tendon for prestressing; Step 4: Grout mortar into the hole.

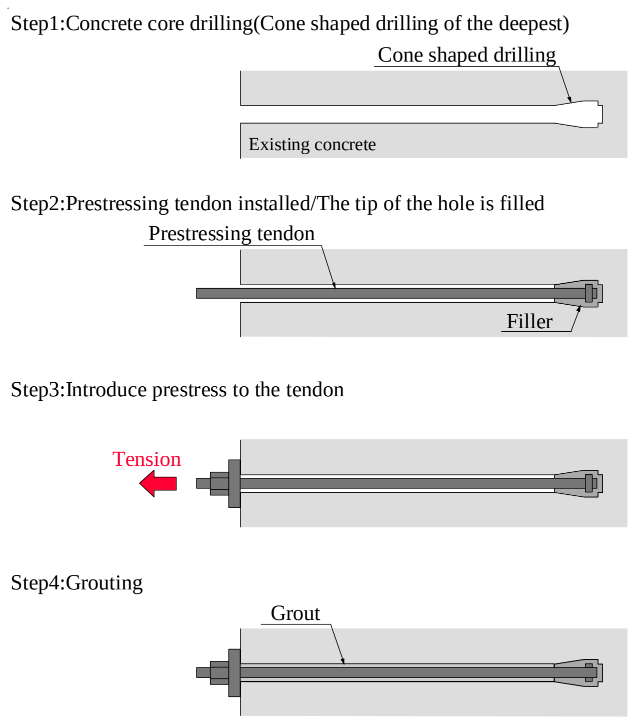

Figure 2. Process of the strengthening system.

Figure 3. Special drilling device.

Table 1. Mixture proportion of concrete and properties of reinforcing materials.

w/cm	Water	Cement	Fine agg.	Coarse agg.	Admixture	Air
0.53	175 kg/m^3	330 kg/m^3	887 kg/m^3	978 kg/m^3	1.16 kg/m^3	4.5 %
Reinforcing bar		Bar diameter: 13 mm; Yield strength: 345 MPa; Young's mod.: 206 GPa				
Prestressing tendon		Bar diameter: 23 mm; Yield strength: 1080 MPa; Young's mod.: 202 GPa				

3 EXPERIMENTAL PROGRAM

3.1 Materials

Table 1 summarizes a mixture proportion of concrete and properties of strengthening materials. The specified strengths of concrete were 35.9 MPa (Comp.), 2.6 MPa (Split. tens.) and 34.5 GPa (Young's mod.). In addition, the mechanical properties of filling mortar were 90.2 MPa (Comp.), 4.4 MPa (Split. tens.) and 39.8 GPa (Young's mod.). The detail of used materials is described in the previous report (Sakaki *et al.* 2015).

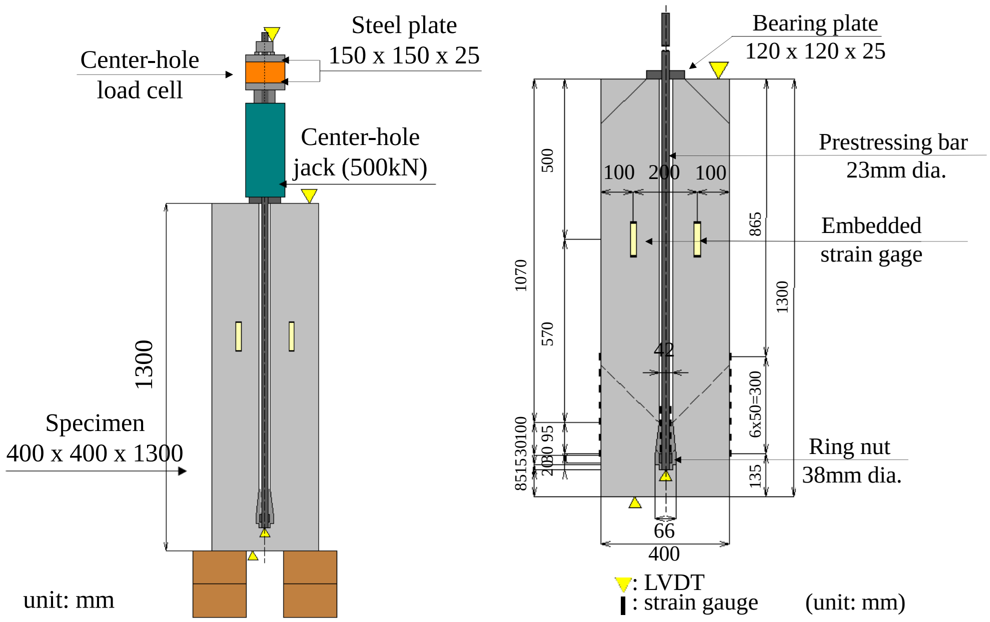

Figure 4. Schematic of test specimen.

Figure 5. Test specimen covered with drying prevention and thermal insulating sheets.

3.2 Test Specimens

Figure 4 presents the schematic of specimen for the sustained loading test. The concrete specimen was full-size concrete for actual strengthening work, and was same to concrete specimens for static loading test (Sakaki *et al*. 2015). The initial load of 314.1 kN was applied to the test specimen at the concrete age of 92 days. The day after tensioning, the hole in concrete was filled with cement grout to ensure a solid connection between the prestressing bar and the concrete. The applied load was determined as 70 % of the ultimate tensile force (448.7 kN) of prestressing tendon. It should be noted that the maximum loads (489.6 kN, 490.9 kN, 490.5 kN) observed in the static test achieved the ultimate force (Sakaki *et al*. 2015).

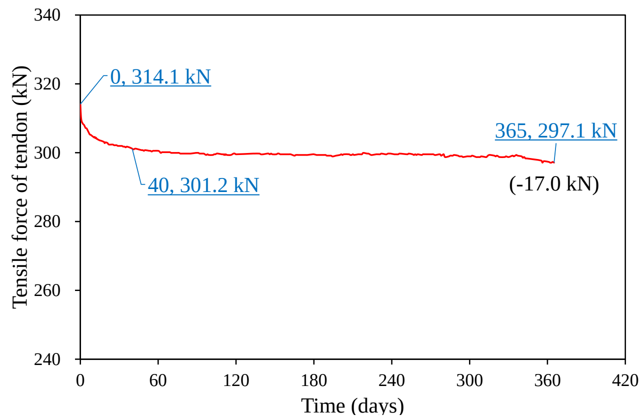

Figure 6. Loss of prestressing force.

This study uses the superposition principle to estimate time-dependent strain due to the sustained load. Hence, a full-size concrete block made at the same time was placed in the laboratory to determine concrete shrinkage and thermal strain, as well as the loaded specimen. Both specimens were covered with drying prevention and thermal insulating sheets to prevent volume change of concrete. Figure 5 demonstrates test specimens placed in the laboratory. The load of prestressing bar and deformation were measured by using a data acquisition system up to 1 year-loading.

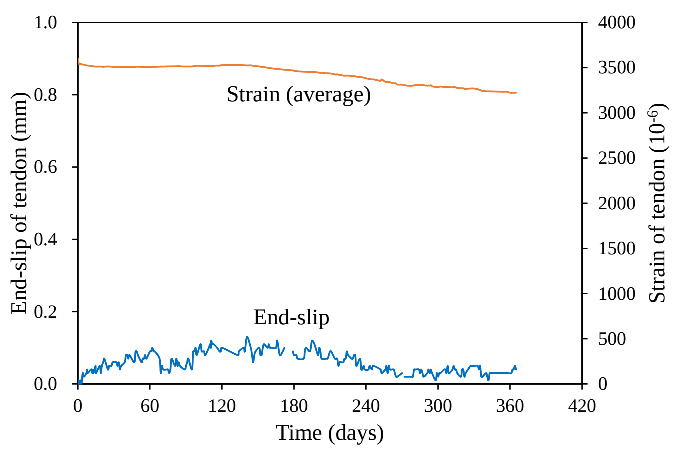

Figure 7. End-slip and strain of prestressing tendon.

4 TEST RESULTS AND DISCUSSION

Figure 6 illustrates the tensile force of prestressing tendon in the sustained loading test. The tensile force gradually decreased with time, but stabilized in around 300 kN after 40 days approximately. The loss of prestressing force was -17.0 kN (5.4 %) during 365 days. The observation implies that the loss of prestressing force is almost equal to or lower than the loss in conventional prestressed concrete structures. End-slip and averaged strain of prestressing tendon were presented in Fig.7. The end slip hardly increased while the strain gradually decreased due to shrinkage and creep of concrete. The test results confirm the prestressing bar was anchored firmly in the internal wedge hole filled with mortar even under the sustained loading. Further research should be conducted to examine durability of the strengthened member, such as fatigue.

5 CONCLUSIONS

This investigation focused on the long-term behavior of the prestressing tendon anchored into the wedge hole embedded in full-size concrete specimen. A 1-year loading test was conducted to measure loss of prestress and deformation of concrete. The conclusions of this experimental investigation are as follows:

- The prestressing force decreased from 314.1 kN to 297.1 kN in the 1-year loading test. The loss of prestressing force (5.4 %) was equal to or lower than the loss in conventional prestressed concrete structures.
- The test confirms that the end slip hardly increased with time and the maximum slip was negligible for practical application.

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