EFFECT OF GROUTING CONDITION ON THE DETERIORATION OF PC BEAMS

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1. ABSTRACT

Chloride-induced corrosions of a sheath and a prestressing tendon in post-tensioned prestressed concrete (PC) beams are investigated under different grouting conditions. A series of PC beams were tested by the electrically accelerated corrosion to determine the influence of grouted ratios in a sheath on the corrosion of the sheath and the prestressing tendon. After the accelerated corrosion tests, the mechanical behavior of the deteriorated PC beams was investigated under flexural loading.

2. EXPERIMENTAL PROGRAM

2.1 Detail of specimens and test variables

Nine PC beams were tested in this study to clarify the influence of ratios of grout filling in a steel sheath on the corrosion of the sheath and prestressing tendon. The overall length of the beams was 2000 mm with the cross-section of 100 x 200 mm. All of test beams were cast in a laboratory using high-early-strength Portland cement with a maximum aggregate size of 20 mm and a slump ranging from 100 to 140 mm. The design strength of concrete was specified as 40 MPa which is usually used for actual PC bridges. All the test beams were prestressed with a 53.3 kN force, which corresponds to approximately 60% of the tensile strength of the tendon. After stressing, the tendon was anchored through the steel plate using wedge-type anchorages at each end of the test beam. To prevent corrosion of the steel plate, the area extending 50 mm from each end of the test beam was coated with epoxy resin and a rubber pad was inserted between the steel plate and the beam. After the tendon was stressed and anchored, grout was injected into the sheath. Table 1 lists the details of test specimens and the experimental variables for all beams. Beams A0 (no current) and A1 (no chloride) were the control specimens, while chloride ions at a concentration of 3 kg/m3 were added to the concrete used for the other beams to accelerate corrosion. The grout filling level was varied from 0% (A2) to 33% (A3), 66% (A4) and 100% (A5) to clarify the influence of grouted ratios inside the sheath on the corrosion of sheath and prestressing tendon**.** The sheaths of beams A6, A7, and A8 were filled with water after being grouted in order to investigate the influence of water on the corrosion process.

Table 1 Specimens and test variables

<table>
<tr><th>No.</th><th>Specimen identifier</th><th>Accelerated time</th><th>Level of grout (%)</th><th>Water in sheath</th><th>Initial Cl^- (kg/m^3)</th></tr>
<tr><td>A0</td><td>Control beam 1 (no current)</td><td>0</td><td rowspan="2">100</td><td rowspan="2">No</td><td rowspan="2">0</td></tr>
<tr><td>A1</td><td>Control beam 2 (no chloride)</td><td>1</td></tr>
<tr><td>A2</td><td>G0-P60</td><td rowspan="7">1</td><td>0</td><td rowspan="4">No</td><td rowspan="7">3</td></tr>
<tr><td>A3</td><td>G33-P60</td><td>33</td></tr>
<tr><td>A4</td><td>G66-P60</td><td>66</td></tr>
<tr><td>A5</td><td>G100-P60</td><td>100</td></tr>
<tr><td>A6</td><td>G0-W-P60</td><td>0</td><td rowspan="3">Yes</td></tr>
<tr><td>A7</td><td>G33-W-P60</td><td>33</td></tr>
<tr><td>A8</td><td>G66-W-P60</td><td>66</td></tr>
</table>

2.2 Accelerated Corrosion Test

To simulate the deterioration of PC beams in a short duration, ACT method was adopted. To have galvanic accelerated corrosion, the specimen was reversed and immersed into an acrylic tank with 5% sodium chloride solution that acts as an electrolyte. In this method, the prestressing steel of the specimen was made anode while titanium mesh in the bottom of acrylic tank was used as cathode. The test setup using ACT method is shown in Fig.1. The current was supplied through a current supplier to accelerate the corrosion process. The current supplier had one end connected to the prestressing steel in the specimen and the other connected to the titanium mesh. The electric current was kept constant at 0.7 A throughout the test. All the accelerated corrosion tests were carried out in the controlled room with temperature of 20°C and relative humidity of 60%. Crack pattern and crack width were measured during the tests.

2.3 Loading test

After finishing accelerated corrosion tests, all the beams were tested under four-point loading over the span of 1700 mm. Load was applied monotonically to the test beams until failure. The strains, deflection and applied load were recorded. Crack initiation and propagation were monitored by visual inspection during the tests.

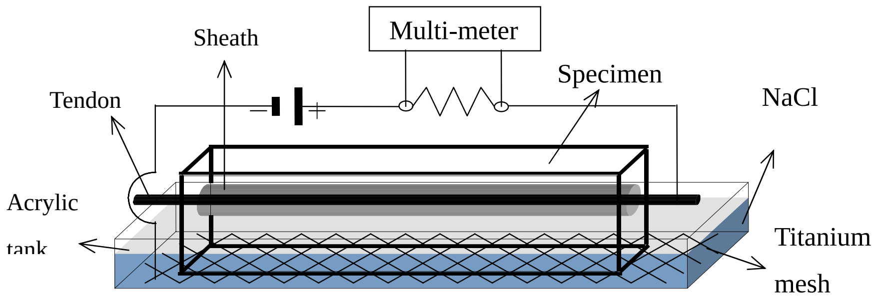

Fig.1 Test setup for accelerated corrosion testing method

Keywords: chloride-induced corrosion, grout, PC beams, prestressing tendon, steel sheath

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3. RESULTS OF EXPERIMENTS AND DISCUSSION

3.1 Influence of grouted ratio in sheath on corrosion cracking

During ACTM, cracks were observed in all but two of the beams in series-A. Exceptions were beam A1, which did not contain chloride ions, and beam A2, which was not bonded. Fig. 2 shows a relationship between the average crack width and the accelerated period for beams A2 (G0), A7 (G33-W), A8 (G66-W) and A5 (G100) with different grouted ratios in the sheath. Corrosion-induced cracks in the fully-grouted beam occur earlier than those in the insufficiently-grouted beams. The crack width increases as the grouted ratio inside the sheath increases. As the sheath corrodes, the volume of corrosion products rises to 2.5 to 3 times the original sheath volume. This increase in volume generates radial expansive pressure on the surrounding concrete and causes cracking. With more grouting-filling inside the sheath, the expansive pressure becomes larger. In other words, the radial expansive pressure in an insufficiently-grouted beam is lower than that in a fully-grouted beam, because the voids are present in the sheath. Therefore, cracks are observed in a fully-grouted beam earlier than insufficiently-grouted beams. This is also the reason why the crack width increases as the grouting level inside the sheath increases.

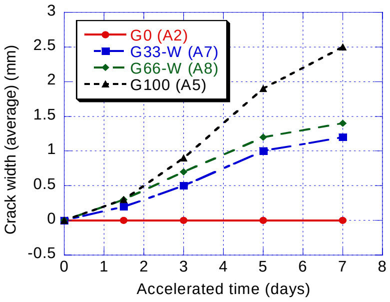

Fig.2 Average crack width

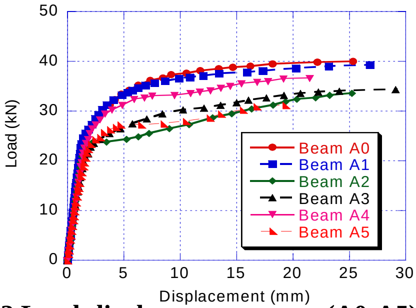

Fig.3 Load-displacement curves (A0-A5)

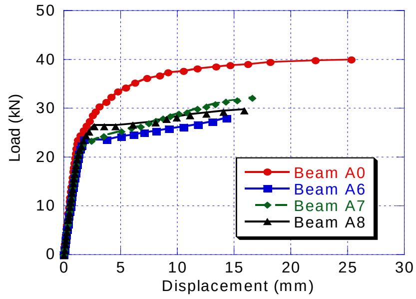

Fig.4 Load-displacement curves (A6-A8)

3.2Influence of corrosion on load-carrying capacity of PC beams

Results of the loading tests and weight loss of prestressing tendons for all beams are summarized in Table 2. Fig. 3 and 4 show the load-displacement relationships for the test beams. All the beams failed in flexural failure mode and concrete was crushed between the loading points. The control beam, A0, failed at 40 kN. Beam A1 failed at almost the same load because there was no corrosion in the prestressing tendon. All the other beams failed at loads lower than that of the control beam. The prestressing tendon loses little weight as only a little rust was observed in the prestressing tendons. The steel, however, were severely corroded except the sheath in beam A1, indicating that the decrease in the load-carrying capacity of the beams of Series A resulted mostly from bond deterioration due to sheath corrosion. The prestressing tendon of the fully-grouted beam shows less weight loss than those of the insufficiently-grouted. This implies that the prestressing tendons are better protected by sufficient levels of grouting in the sheath, even through the crack induced due to corrosion of the steel sheath is wider than that in insufficiently-grouted beams. The failure loads of the beams A6 (G0-W-P60), A7 (G33-W-P60), and A8 (G66-W-P60) were lower than those of the beams A2 (G0-P60), A3 (G33-P60), and A4 (G66-P60). The maximum reduction in the load-carrying capacity observed was 30% in the case of beam A6, where the prestressing tendon loses very little weight (0.76 %). This confirms that corrosion of the sheath causes bond deterioration, resulting in a decrease in the load-carrying capacity of the PC beam.

Table 2 Results of loading test and weight loss of prestressing tendon

No.	Ultimate failure load (kN)	Relative strength	Weight loss (g)	Weight loss (%)
A0	40.0	1.0	0	0
A1	39.3	0.98	0	0
A2	33.6	0.84	0	0
A3	34.4	0.86	3.0	0.38
A4	36.7	0.92	0	0
A5	31.3	0.78	0	0
A6	28.0	0.70	6.1	0.76
A7	32.2	0.81	3.0	0.38
A8	29.8	0.75	0	0

4. CONCLUSIONS

1. Corrosion-induced cracking tends to occur earlier in fully-grouted beams than in insufficiently-grouted beams. As the grouted ratio in the sheath increases, the corrosion cracks along the sheath propagate earlier during the accelerated corrosion. The width of cracks also increases as the grouted ratio inside the sheath increases. Even though the width of cracks become larger in a fully-grouted beam, the prestressing tendon is better protected finally by grouting.
2. The presence of water inside the sheath leads to earlier corrosion of the sheath and the prestressing tendon, resulting in lower load-carrying capacity of the PC beam.
3. Corrosion of the sheath deteriorates the bonds with concrete, resulting in a reduced load-carrying capacity of the PC beam. .
4. The experimental methodology presented in this study can be considered to be an effective means to investigate the deterioration of PC beams due to chloride-induced corrosion in a short period.

REFERENCES

1. Minh, H., Mutsuyoshi, H., and Niitani, K. Influence of Grouting Condition on Crack and Load-Carrying Capacity of Post-Tensioned Concrete Beams due to Chloride-Induced Corrosion, Journal of Construction and Building Materials, ELSEVIER, 2007 (in press).