LOAD BEARING CAPACITY OF 35-YEAR-OLD PRESTRESSED CONCRETE BEAMS DUE TO COMBINED EFFECTS OF CARBONATION AND CHLORIDE ATTACK

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1. Introduction

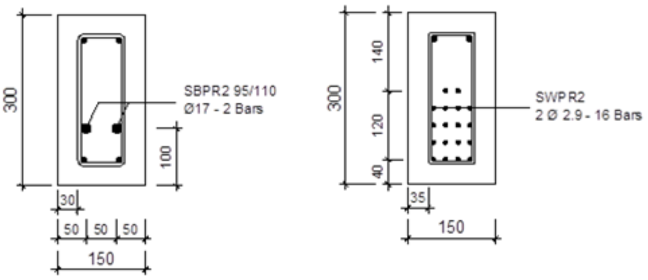
Corrosion of steel reinforcement is one of the important factors affecting long-term durability. Corrosion usually occurs due to either carbonation or chloride attacks. However, evaluation of prestressed concrete beams (pretensioned and post tensioned type) subjected to both carbonation and chloride ingress has not been clarified well so far. This paper discusses the load bearing capacity of 35-year-old prestressed concrete beams due to combined effects of carbonation and chloride attack.

2. Experimental Program

2.1 Beam details and materials

A total of four prestressed concrete (PC) beams were tested. They are post-tensioned type (herein after abbreviated as PC-O) and pretensioned type (PC-R). All beams have the identical cross-section of 150 x 300 mm and length of 2400 mm, but bar arrangements and cover depth are varied according to the type, with strength target of 50 MPa. Cross-section of the beams is described in **Fig.1**. High early strength Portland cement was used, and properties of aggregate are presented in **Table 1**. Mix proportion of concrete was designed with w/c and s/a of 40.7% and 37.0% respectively. The composition of material in kg/m^3 for water, cement, sand and gravel was 167, 410, 640 and 1175 respectively.

Prestressing tendons were round wires of 2Ø2.9 mm for PC-R beams, and round bars of Ø17 mm for PC-O beams. Yield strength was 1148 and 1795 MPa for wire and bar respectively. Deform bars of Ø10 mm were embedded as stirrups with spacing of 100 mm.



a. Post-tensioned beam (PC-O) b. Pretensioned beam (PC-R)

Fig. 1 Cross-section of PC beams

Table 1. Properties of aggregate

Aggregate	Density, g/cm^3	Fineness Modulus
River sand	2.25	2.84
Crushed stone	2.75	6.63

2.2 Curing and exposure condition

After concrete placing, the beams were moisture cured for one day and demoulded. Then PC beams were steam cured (max. temperature 60^{o}C) for about 10 hours, followed by curing in air until the start of exposure. All beams have been exposed to the actual marine tidal environments at Sakata port for 20 years, then transferred to the laboratory and stored at a constant temperature over 15 years.

2.3 Method of evaluation

Bending tests were conducted by simply supported with span of 2100 mm. Load was applied symmetrically at two points 700 mm apart. Each beam was tested in three separate phases. In the first phase, load was applied to create and locate a series of flexural cracks to set strain gauges and π gauge at the location of cracking. The second phase was loaded to determine the decompression load based on strain and displacement measurements of crack openings. The third phase of each test involved loading until ultimate failure. After completion of bending test, several cores of 50 mm in diameter were taken in the area that was predicted un-cracked during the test for compressive strength and modulus of elasticity test.

3. Results and Discussion

3.1 Compressive strength and elastic modulus

The compressive strength and elastic modulus of concrete in 35-year-old PC beams are presented in **Table 2.** Compared to the 20 years' data, the average elastic modulus loss of specimens was about 10.33%. The variation of the data is expected due to the use of small cores for 35-year test, while for 20-year test, cylindrical specimens of Ø150 x 300 mm were used. The results suggest that strength and modulus of elasticity data clearly indicate that deterioration of beams was affected by the exposure condition.

Table 2. Compressive strength and elastic modulus

Description	Compressive Strength, MPa		Modulus of Elasticity, GPa	
Exposure time	20 years	35 years	20 years	35 years
PC-O	40 - 74	62 - 77	25.0-35.0	25.6-30.9
PC-R		42 - 52		21.6-27.0

Table 3. Summary of several points during loading procedure

Name	Applied Load, kN			Neutral Axis, mm	Effective Prestressing Force, kN	Prestress Loss, %	Effective Prestress, MPa
	Decompression Load	First Crack	Ultimate Load				
PC-O-1	80	92	215	195	342	22.80	7.61
PC-O-2	82	90	236	190	334	24.64	7.43
PC-R-1	89	90	193	195	403	22.17	8.95
PC-R-2	100	50	228	186	441	14.66	9.81

3.2 Decompression loads and prestress loss

Plot of applied load vs. strain to determine the decompression load is presented in **Fig. 2** for strain gauge installed adjacent to crack on each beam. Using the decompression load values at each crack location, a simple elastic analysis were carried out to compute the effective prestressing force (P_e) in each beam. In addition, by comparing with the initial prestressing force (P_i), prestress loss was calculated. A summary of results for each strain gauge and prestress loss is described in **Table 3**. Prestress loss up to 25% is supposed to be due to increment in the corrosion ratio of strand/tendons, caused by a combination of chloride attack and carbonation.

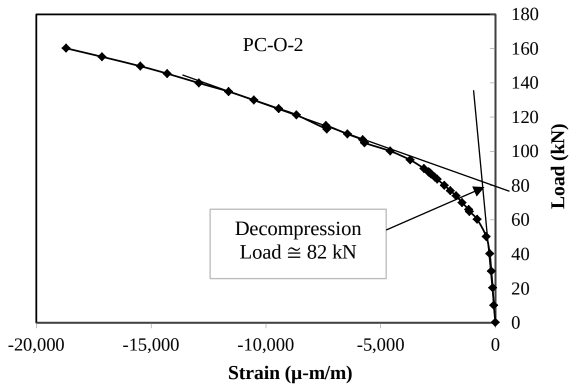


Fig. 2 Decompression load from load-strain data

3.3 Ultimate strength test

The ultimate loads are shown in **Table 3**. During the loading, the failure of strands could be detected by using AE sensor. At the times of strand failure, high sound sould be heard by ears. However, there was no sign of tendon failure during loading procedure in PC-O beams because there was no sound heard, while in PC-R beams, a half of total strands failed. In addition, flexural cracks appeared in the tension zone and failure occurred by crushing of the concrete in the compression zone in all beams. Thus, the failure mode of beams was a tension failure. During the test, midspan deflection, strain of the concrete, and the width of cracks were monitored and recorded.

In 20 years test, up to the ultimate load, a small residual displacement was observed, indicating elastic behavior. That is, PC strands/tendon had not yielded and PC-O type showed less residual displacement. Similar results were also found for 35 years test in PC-O beams, except in PC-R beams. Some PC strands in PC-R beams failed, which indicate that strands have yielded.

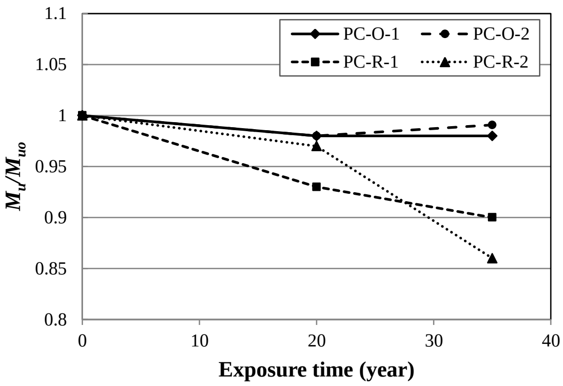


Fig. 3 Changes in ultimate flexural moment

Fig. 3 shows the changes in ultimate flexural moment against exposure time. The ultimate flexural moment (M_u) is expressed as the ratio to the initial (before exposure) flexural moment (M_{uo}). After 15 years stored in a constant temperature, the ratio decreased for PC-R beams and constant for PC-O beams. The large ultimate load reduction is not due to the prestress loss, but due to the compressive strength of concrete reduction.

4. Conclusion

From the above description, it can be concluded that prestress loss is affected by corrosion, however, load bearing capacity is not affected by corrosion and dropped by 10% for PC-R beams due to the compressive strength reduction.

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References

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