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Effect of creep induction at an early age on subsequent prestress loss and structural response of prestressed concrete beam

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HIGHLIGHTS

- The creep induction at an early age reduces subsequent prestress loss in a PC beam.
- The early age creep within the elastic range does not reduce the concrete strength.
- The flexural behaviour of a PC beam is not affected by the early age creep.
- The large creep induction under severe conditions may alter the structural response.

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ABSTRACT

The authors investigated a technique to inhibit subsequent prestress loss in a concrete beam by effective creep induction at an early age, and examined the structural performances of beams with the creep at an early age. Consistent experimental results suggested that a more progressive creep induced by a higher first prestressing force or under an elevated temperature (45 °C) at an early age was likely to reduce the prestress loss after another prestressing at seven days of age. The creep tended to increase the compressive strength and Young's modulus of the concrete, and the tensile strength was not decreased when the sustained stress was within the elastic range. The flexural behaviour of a prestressed concrete beam with the creep at an early age was observed to be almost the same as that of a beam without the creep, although the maximum flexural crack width was slightly increased by the early age creep. It was found that the shear crack propagation was more progressive when the creep was significantly accelerated at an early age under severe conditions that applied a high sustained stress beyond the elastic range or at the elevated temperature. It was thus concluded that a larger creep induction at an early age impeded subsequent prestress loss in concrete beams more significantly, although its acceleration under the above severe conditions may lead to reduction of the structural performance.

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1. Introduction

Concrete creep is significantly larger than those of other construction materials such as steel, and an extremely long time is required for its convergence. Long-term continuous creep deformation is a major cause of the loss of prestressing force in pre-tensioned or post-tensioned concrete beams, and might lead to excessive deflection, which can be related to bridge collapse [1,2]. Although a number of experimental and numerical studies have been conducted, there is still no practical model for the reasonable prediction of long-term creep [3]. This is because creep deformation is essentially due to a combination of various complicated chemico-physical phenomena [4].

However, excessive beam deflection resulting from the loss of prestressing force can be prevented by in-service reduction of concrete creep. Because creep is well known to be more progressive at earlier ages [5] and its ultimate magnitude may be limited, the authors conceived the idea of intentionally promoting creep by prestressing at a very early age to reduce the long-term creep due to future prestressing. Hereafter, the intentional creep induction at an early age (before an age of seven days) for the inhibition of the subsequent creep is referred as to "creep promotion" in this paper.

This concept of effective creep promotion at an early age for the purpose of impeding prestress loss after subsequent prestressing was investigated by changing the prestressing force and ambient temperature of beams during the promotion. The strength and stiffness of the concrete in which creep was induced at an early age were also examined. Furthermore, the structural performances

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of beams subjected to various creep histories were studied. Although the application of the creep promotion technique proposed in this paper is currently limited to precast concrete members with post-tensioning, the authors believe that it has the potential for other applications. The present study is also of academic interest regarding the effect of continuous creep progress from an early age on the mechanical properties of concrete and the structural behaviour of prestressed concrete (PC) beams.

2. Experimental program

2.1. Materials and beam specimens

The concrete comprised ordinary Portland cement (specific surface area = 3580 cm^2/g, density = 3.15 g/cm^3), fine aggregate (river sand; fineness modulus = 2.60, density in saturated surface-dry condition = 2.60 g/cm^3), and coarse aggregate (crushed sandstone; maximum size = 15 mm, density in saturated surface-dry condition = 2.66 g/cm^3). The mix proportion is listed in Table 1. The unit water content was intentionally made to be high to increase the creep and facilitate clear examination of the effect of its promotion on the subsequent prestress loss during the limited test period. The design compressive strength of the concrete was 45 MPa and the water-to-cement ratio was 0.4.

Fig. 1 shows the setup and dimensions of the PC beam specimens. For the purpose of investigating the effect of creep promotion at an early age on the flexural and shear behaviour of the PC beams, two series of the beam specimens were designed, namely, those designed to fail by flexural tension (A series) and those designed to fail by diagonal tension (B series). The JSCE standard specifications for concrete structures [6] were used for the designs. Both types of beams were 1500 mm long and had rectangular cross sections measuring 100 mm × 200 mm. The A series beams had a uniform bending moment distribution zone of 400 mm to observe their flexural cracking, and had sufficient stirrup reinforcement in their shear span. The B series beams, however, had no stirrup reinforcement. The values of the shear span-to-depth ratio (a/d) of the A and B series beams were 3.2 and 3.5, respectively. The yield stress and Young's modulus of the 13-mm-diameter PC tendon of the beams were 1220 N/mm^2 and 200 kN/mm^2, respectively. Reinforcements of diameter 6 mm, yield stress 351 N/mm^2, and Young's modulus 200 kN/mm^2 were used as stirrups and the longitudinal bars for supporting the stirrup assembly.

2.2. Creep promotion in beam specimens at an early age

To examine the effective creep promotion in the beams at an early age, prestressing forces with various stress levels were applied to the above-mentioned PC beams from an age of one day after removing the form until an age of seven days.

Table 1
Mix proportion of concrete (kg/m^3).

Water	Cement	Fine aggregate	Coarse aggregate	AE agent
200	500	605	873	0.05

Table 2
Ratio of prestress to compressive strength of concrete at each age.

Series	Beam	Ratio of prestress to compressive strength of concrete at ages of one day and seven days	
		1 day	7 days
A series	A-1	0%	0%
	A-2	0%	20%
	A-3	20%	20%
	A-4	30%	20%
B series	B-1	0%	0%
	B-2	0%	20%
	B-3	20%	20%
	B-4	30%	20%
	B-5	40%	20%
	B-6	20% at 45 °C temperature	20%

The effect of the creep promotion at an elevated temperature was also studied. The second prestressing force was then applied to all the PC beams at an age of seven days to investigate the subsequent creep.

The prestressing programs for the A and B series beams are summarised in Table 2. The ratio of prestress in the table is the ratio of the compressive stress applied to the full cross section of the concrete in the beam to the compressive strength (at ages of one day and seven days, respectively). Because identical prestressing forces were applied to all the beams before the loading test at about four months of age, grouting was not done until the loading test which is be explained in Section 2.4. Beams A-1 and B-1 were the reference ones that had no creep before the test. To enable significant creep promotion, only beam B-6 was heated by wrapping an electrical carpet around it until seven days of age after application of the first prestressing force at one day of age. The temperature of the beam was maintained at about 45 °C.

During the prestressing, all the beams were stored in a temperature-controlled room at 20 ± 1 °C and RH of 60 ± 20% for about four months. The free shrinkages of the two series were also measured using the reference beams A-1 and B-1, respectively. The concrete strains on the bottom surface of the beams were measured at the mid-span and the two shear span centres of the beams to determine their compressive time-dependent deformations. The prestressing force was monitored using a centre-hole-type load cell. The measurement interval was a day.

2.3. Compression and direct tension tests

To examine the effect of the creep promotion at an early age on the mechanical properties of the concrete, compression and direct tension tests were conducted using cylindrical specimens measuring diameter 100 mm and height 200 mm to induce the compressive creep at an early age. The mix proportion was the same as those for the PC beams. As in the case of the beams, based on the compressive strength at each age, a sustained compressive load was applied to the cylindrical specimens at an age of one day after demoulding, and a greater load was again applied at an age of seven days. The load was simultaneously applied to tandemly-arranged three specimens by tightening the bolts of the thick PC tendons on both sides of the frame as shown in Fig. 2. The load was measured by the load

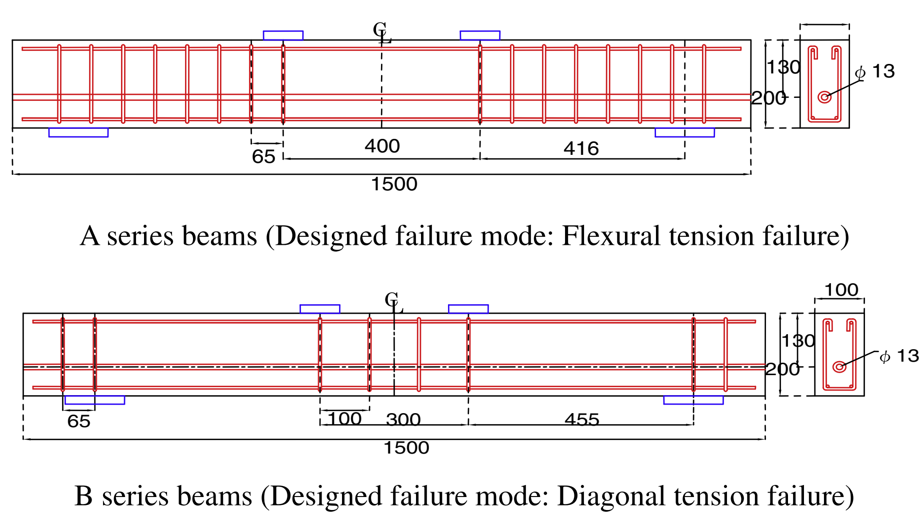

Fig. 1. Setup and dimensions of prestressed concrete beams (unit: mm).

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