Outline of “Development of Estimation Method for Residual Prestressing Force of PC Girders Based on Measurement of Concrete Surface Strain”

「コンクリート表面のひずみ計測に基づく PC 桁の残存緊張力の推定手法の開発」の概要


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1. Introduction

An accident in December 2012 involving the collapse of ceiling panels in the Sasago Tunnel is an example showing that the deterioration of infrastructure in Japan is becoming a serious problem. This paper discusses the deterioration of the prestressing force of prestressed concrete (PC) girders and proposes a method for estimating the residual prestressing force in a PC beam with cracks orthogonal to the beam length. Measurements of concrete surface strain and crack width were used for the estimation, and laboratory loading tests were carried out to verify the proposed method. The test specimens were small-scale specimens with rectangular cross sections and a full-scale specimen with an I-shaped cross section.

The paper was honored with the Outstanding Paper Award of JPCI in 2022.

2. Estimation Method [1]

(1) Estimation of Cracking Moment

Assuming that the prestress in an extreme tension fiber is zero during crack opening, the residual prestressing force can be calculated as follows:

$$\sigma_{ce} = 0 = \left(\frac{P_e}{A_c} + \frac{P_e \cdot e_p}{W_c} \right) - \frac{M_d}{W_e} - \frac{M_o}{W_e} \quad (1)$$

$$P_e = \frac{M_d + M_0}{\dfrac{W_e}{A_c} + \dfrac{W_e \cdot e_p}{W_c}} \quad (2)$$

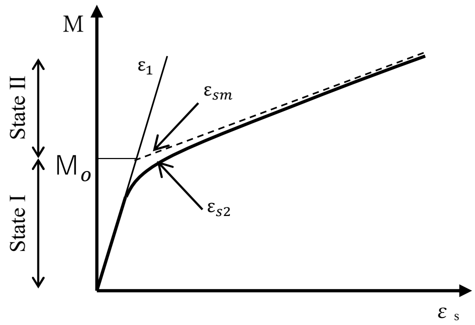


Fig. 1 Relationship between working moment and strain of reinforcement bar

where σ_{ce} (N/mm^2) is the prestress in the extreme tension fiber, W_c (m^3) is the section modulus of the concrete, W_e (m^3) is the reduced section modulus of the cross section, e_p (m) is the distance between the centroid of the cross section and that of the prestressing steel group, M_d (N·m) is the working bending moment due to dead load, M_o (N·m) is the cracking moment, and P_e (N) is the prestressing force.

The relation between the strain of a tensile reinforcement bar at a cracked section and the working moment at the same section is shown in **Fig. 1**. In this figure, the tensile reinforcement bar of a hypothetical reinforced concrete (RC) section under axial force is also shown as a dashed line. Under a higher working moment, the strain ε_2 is closer to the strain ε_{sm} of the aforementioned RC [2], and the cracking moment M_0 can be obtained as the intersection of ε_1 in state I and ε_{sm} in state II.

(2) Outline of Measurements

The proposed measurements for calculating the cracking moment are outlined in **Fig. 2**. Two methods are proposed: (i) using strain gauges and a pi-shaped displacement meter, and (ii) using optical fiber sensors and a strain gauge. In the proposed method, the strain of the tensile reinforcement bar before crack opening is equal to the average strain between the cracks.

(3) Loading Test for Verification

To verify the proposed method, laboratory loading tests were carried out. The accuracy of the estimation method was evaluated by comparing its results with those of tests on 3000-mm simply supported specimens in which prestressing force had been introduced. Those test specimens were small-scale concrete beams with a rectangular cross section. In addition, a full-scale beam specimen with an I-shaped cross section was also tested.

The cross section and loading conditions of the small-scale specimens are shown in **Figs. 3** and **4**, respectively. Three prestressing forces were applied, namely, 95 kN, 76 kN, and 57 kN; 95 kN was used for the case of no deterioration, while 76 kN and 57 kN were used to simulate the deterioration. Two-point loading with a distance between loading points of 1000 mm was statically applied by a hydraulic jack to each specimen.

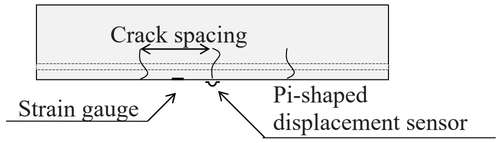
The cross section and loading conditions of the full-scale specimen are shown in **Figs. 5** and **6**, respectively. The full-scale specimen was 17,040 mm long, and two-point cyclic loading with a distance between loading points of 2,000 mm was applied statically by an actuator operated under load control.

3. Conclusion

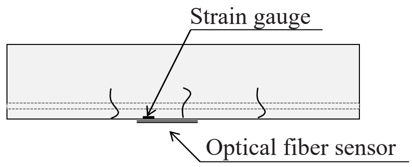
This paper proposed a method for estimating the residual prestressing force in a PC beam with cracks orthogonal to the beam length. Laboratory loading tests were carried out to verify the proposed method.

The research mentioned above revealed the following.

- The proposed method for estimating of the prestressing force of a PC beam with flexural cracks was verified based on laboratory loading tests.
- The estimation error was less than 2% for the three levels of prestressing force in loading tests on small-scale specimens.
- The estimation error was 1.7% for a full-scale specimen and thus almost the same level of accuracy was obtained compared with the small-scale specimens.



(a) Measurement using strain gauges and pi-shaped displacement sensor



(b) Measurement using optical fiber sensors and a strain gauge

Fig. 2 Outline of measurements

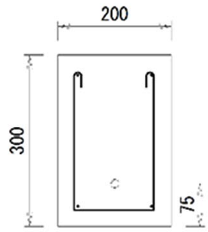


Fig. 3 Cross section of a small-scale specimen (unit: mm)

Fig. 4 Setup for loading test of a small-scale specimen

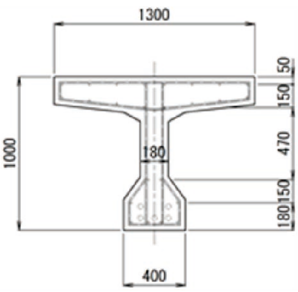


Fig. 5 Cross section of full-scale specimen (unit: mm)

Fig. 6 Situation in loading test of full-scale specimen

References

[1] Tsunekuni, M., Kato, Y., Uomoto, T.: *Investigation for Structural Degradation Diagnosis of Existing PC Girder*, Proceedings of the Japan Concrete Institute, Vol.28, No.1, JCI, Tokyo, pp.1967-1972, 2006 (in Japanese).

[2] Kakuta, Y.: *On Cracking and Deformation of Flexural Concrete Members*, Proceedings of the Japan Society of Civil Engineers, Vol.384/V-7, JSCE, Tokyo, pp.21-32, Aug. 1987. doi: 10.2208/jscej.1987.384_21