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Development of the biaxially prestressed specimen for prediction of prestress loss in containment buildings

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1. Introduction

Prestressed concrete is widely used for various structures including the containment building of nuclear power plant. It is important to predict the prestress loss because the prestressing system directly affects the integrity of the containment building [1]. Prestress loss caused by immediate factors such as elastic shortening, friction, and anchorage slip is beyond the scope of this research. Prestress loss due to the time-dependent factors such as creep and shrinkage of concrete and relaxation of tendon is the main subject of this paper. Prediction of this prestress loss is not simple because the long-term deformation of concrete is affected by various factors. Therefore, a new test method with biaxial prestressing condition is herein suggested as an improved form of prestressed beam test which is often used to evaluate the prestress loss in containment building.

2. Methods and Results

In this section, experimental method and the results are described, and analytical method to predict prestress loss through the experiment is also suggested.

2.1 Experimental program

The specimen is designed from the wall of containment building as shown in Fig. 1. It represents a small portion of the wall which has both horizontal and vertical tendon and reinforcement. The curvature is neglected and the specimen is scaled down by a factor of 1/2. The final specimen is a cuboid whose vertical and horizontal cross-sections are modelled as shown in Fig. 2.

Two specimens are tested as shown in Fig. 3. The liner plate is located between the specimens. In order to have enough length for prestressing tendons, the bearing plates around the specimen are placed as shown in Fig. 3. Anchor heads and load cells are place on top of the bearing plate. The sheaths are located in the concrete and the prestressing tendons are passing through the sheaths and bearing plates.

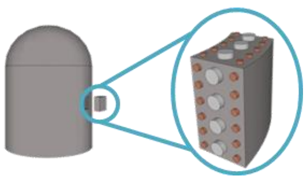
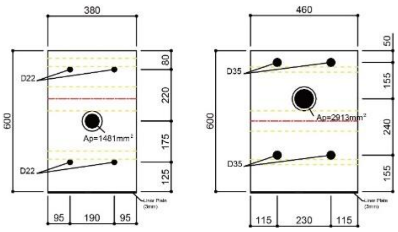


Fig. 1. Modeling of test specimen



(a) (b)

Fig. 2. Cross-sections of the specimen: (a) Vertical section (b) Horizontal section

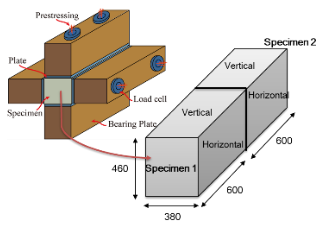
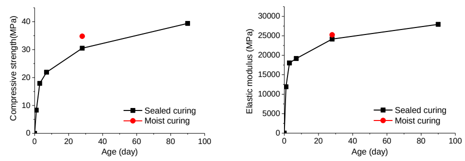


Fig. 3. Test setup

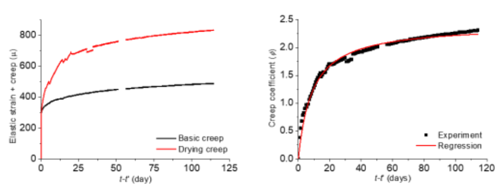
Material properties used for the test are as follows. Concrete with water-binder ratio of 0.4 is placed and its compressive strength and elastic modulus are as shown in Fig. 4.



(a) (b)

Fig. 4. Mechanical properties of concrete (a) Compressive strength (b) Elastic modulus

Creep is also tested by cylindrical specimens of $\phi\, 150 \times 300$ mm. Ambient temperature and relative humidity are fixed as 20 ℃ and 60%. Experimental results and the creep coefficient are as shown in Fig. 5.



(a) (b)

Fig. 5. Creep of concrete (a) Experimental results (b) Creep coefficient

Rebars, 'D22' and 'D35' in Fig. 2 are specified in Korean Industrial Standards(KS) [2]. Their elastic modulus, yield strength, and ultimate strength are 200,000 MPa, 400 MPa, and 560 MPa, respectively.

Tendons are low relaxation strands called 'SWPC7BL 15.2mm' specified in KS [3]. Loss of stress due to relaxation of this tendon when the strain is restrained can be calculated by Eq. (1) [4,5].

$$f_r = f_p(t')\rho_1\left(\frac{t}{\lambda_1}\right)^k \qquad \text{for } \varepsilon\text{=constant} \tag{1}$$

where f_r is loss of stress, $f_p(t')$ is initial stress applied to tendon, $\lambda_1 = 1000$ h, and the parameter ρ_1 has different values for three classes of prestressing steel. Ultimate strength of the tendon used for the specimen is 1860MPa and the yield strength is 1580MPa which is 85% of the ultimate strength.

2.2 Prediction method

Because of the experimental limitation, there are bearing plates which are not in real containment building. It is required to consider these bearing plates in analysis of the experimental results but they should not be included for analysis of containment building.

The bearing plates and reinforcing bars are made of steel and compressive behaviour can be assumed to be elastic. Concrete shows time-dependent deformation called creep and prestressing force also decreases with the time called relaxation.

Step-by-step method is used to consider the time-dependent properties of concrete. Eq. (2) represents the compatibility condition in x and y direction of i^{th} time step by considering the characteristics of the materials such as rebar, concrete, bearing plate and tendon.

$$\begin{bmatrix} \dfrac{\overline{f_{rx}(i)} - f_r(i)}{E_p} \\ \dfrac{\overline{f_{ry}(i)} - f_r(i)}{E_p} \end{bmatrix} = \frac{1}{E_c(1)}\begin{bmatrix} 1 & -\nu \\ -\nu & 1 \end{bmatrix}\begin{bmatrix} f_{cx}(1) \\ f_{cy}(1) \end{bmatrix}\phi(i,1) + \sum_{j=1}^{i-1}\frac{1}{E_c(j)}\begin{bmatrix} 1 & -\nu \\ -\nu & 1 \end{bmatrix}\begin{bmatrix} \Delta f_{cx}(j) \\ \Delta f_{cy}(j) \end{bmatrix}(1+\phi(i,j)) + \begin{bmatrix} \varepsilon_{shx}(i) \\ \varepsilon_{shy}(i) \end{bmatrix} + \frac{1}{E_b}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \Delta f_{bx}(i) \\ \Delta f_{by}(i) \end{bmatrix}$$
$$= \frac{1}{E_s}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \Delta f_{sx}(i) \\ \Delta f_{sy}(i) \end{bmatrix} + \frac{1}{E_b}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \Delta f_{bx}(i) \\ \Delta f_{by}(i) \end{bmatrix} \tag{2}$$

where f, E, ε, and ν are stress, elastic modulus, strain, and Poisson's ratio of concrete, respectively. The subscripts p, c, s, and b are the prestressed tendon, concrete, rebar, and bearing plate, respectively. $\overline{f_r}$ and f_r are the final loss of stress and the loss of stress of tendon itself calculated by Eq. (1).

Force equilibrium in x and y direction can be formulated as shown in Eq. (3).

$$\sum_{j=1}^{i-1}\begin{bmatrix} A_{cx} & 0 \\ 0 & A_{cy} \end{bmatrix}\begin{bmatrix} \Delta f_{cx}(j) \\ \Delta f_{cy}(j) \end{bmatrix} + \begin{bmatrix} A_{sx} & 0 \\ 0 & A_{sy} \end{bmatrix}\begin{bmatrix} \Delta f_{sx}(i) \\ \Delta f_{sy}(i) \end{bmatrix} = \begin{bmatrix} A_{bx} & 0 \\ 0 & A_{by} \end{bmatrix}\begin{bmatrix} \Delta f_{bx}(i) \\ \Delta f_{by}(i) \end{bmatrix} = \begin{bmatrix} -A_{px} & 0 \\ 0 & -A_{py} \end{bmatrix}\begin{bmatrix} \overline{f_{rx}}(i) \\ \overline{f_{ry}}(i) \end{bmatrix} \tag{3}$$

where A is the area and the meaning of subscripts are same as Eq. (2).

Unknown variables $\overline{f_r(\iota)}$, $\Delta f_c(i-1)$, $\Delta f_s(i)$, and $\Delta f_b(i)$ are determined by solving the Eq. (2) and Eq. (3).

The final stress of prestressed tendon can be calculated by Eq. (4).

$$f_p(i) = f_p(1) - \overline{f_r(\iota)} \tag{4}$$

2.3 Results

Fig. 6 shows the comparison of the prediction and experiment. The analytical results are affected by the models related to the long-term deformation of concrete and relaxation of tendon. Therefore, careful examinations of those models are required. If the experimental results of the specimens are reasonably predicted by the models chosen, then it is possible to predict prestressing force in the real containment building by using the same models with proper modification of the parameters related with the size and initial prestressing force.

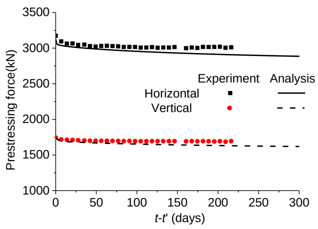


Fig. 6. Comparison of experimental results and prediction

3. Conclusions

The experimental and analytical method using the biaxially prestressed specimen are suggested in this research. This test can be an additional option along with the beam test for more reasonable prediction of prestress loss in containment buildings.

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