FRICTION LOSS AND ELONGATION OF PRESTRESSING STEEL IN POST-TENSIONED FLAT SLAB

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ABSTRACT

This study was to evaluate the friction loss and elongation of prestressing tendon in post-tensioned flat slab. The typical layout of the carpark building was selected in this study. A comparison between the calculated elongation and the measured value was conducted for the tendon. The designed elongation was calculated from the tendon profiles indicated in the construction drawing. The site deviation which was the deviation of the tendon profiles measured in the installation process was collected to calculate of the deviation of friction loss and elongation. The calculated elongations were compared with the collected data measured from the ram after stressing. It was revealed that the calculated elongation and the measured elongation was deviated up to 11.10%, which was greater than the allowable limit of 7.00%. This deviation was due to the discrepancy between the design tendon profile and the actual construction, which contributed up to 40% of the total deviation. The effect of site deviation played an important role on the elongation which should be taken into account in the design.

Keywords: Friction loss, Elongation, Post-tensioned, Prestressing tendon, Flat slab.

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PREFACE

During the prestressing installation of the post-tensioned concrete, the friction loss along the prestressing tendon is often developed due to the curvature friction of the vertical and horizontal profiles. To evaluate the friction loss, the elongation of the steel is used to determine the loss of prestressing force in the tendon. The friction loss along the tendon profile can be calculated using the empirical formula recommended by the codes. The resulting force at the end of stressing operation is normally dropped due to the friction loss and the wedge seating. When the force is applied to the tendon and the wedge is seated, the elongation of the tendon is measured to calculate the force in the tendon. To ensure the design force, it is expected that the measured elongation at the site is close to the calculated elongation of the design stage with the deviation in the tolerance limit of 5-7% (ACI Committee 318, 2019, p. 545). The deviation normally arises due to the uncertainty of the parameters used in the calculation. The friction factors, i.e., the wobble friction and the curvature friction coefficients are varied in a wide range recommended in the codes (ACI Committee 423, 2016, p. 18). Recently, Yuan et al. (2020, pp. 1-10) investigated the friction coefficient by testing full-scale specimen and adopting Bayesian quantile regression method. The proposed method was effective in the estimation of friction coefficient. Current researches have investigated the elongation tolerance of the post-tensioned tendons. Hayek and Kang (2017, pp. 795-802) investigated the elongation deviation of single strands and tendons in post-tensioned building structures. It was proposed that the deviation should be considered from the larger value of 7% and the percentage corresponding to 3/8 in. difference between the measured and the calculated elongation. Choi, Woods, Hrynyk and Bayrak (Online, 2018, pp. 1-20) reported that the anticipated friction losses with the curvature coefficient of 0.25 were approximately 33 %, and the average friction losses were varied from 40-60 %, which are larger than the anticipated friction losses estimated on the current codes. Cao et al. (2018, pp. 1-9) proposed an alternative method to calculate the elongation of the prestressed strand by combining with the practical precaution and the accurate measurement. The calculated elongation was closed to the actual measurement.

RESEARCH OBJECTIVES

This study was to evaluate the friction loss and elongation of prestressing tendon in post-tensioned flat slab.

RESEARCH METHODS

The typical layout of the carpark building was selected in this study. The 32 sets of tendon profiles were investigated to compare the calculated elongation and the measured values. The tendon profiles indicated in the construction drawing were employed to calculate the friction loss and elongation of the prestressing tendon. To investigate the site deviation, the tendon profiles measured in the installation process were collected to calculate of the deviation of friction loss and elongation. The calculated elongations were compared with the collected data measured from the ram after stressing. The site deviation resulting from the elongation discrepancy between the calculated values from the drawing and the installation process was investigated.

FRICTION LOSS AND ELONGATION

The force in the prestressing steel along the tendon profile is calculated according to Eq. 1 (ACI, 2016, p. 18). Where, P_o is the jacking force of the prestressing steel, P_x is the prestressing force at the distance x from the jacking end, k is the wobble friction coefficient due to unintentional curvature, μ is the curvature friction coefficient for intentional vertical and horizontal profile, as shown in Figure 1.

$$P_x = P_o e^{-(kx+\mu\alpha)} \tag{1}$$

The elongation of the prestressing steel can be calculated at the jacking end of the tendon length L as shown in Eq. 2. Where, A_{ps} is the area of the prestressing steel, E_{ps} is the modulus of elasticity of prestressing steel, typically 195,000 Mpa, Δ_A is anchor set or wedge seating of the anchorage.

$$\Delta = \int_0^L \frac{P_x}{A_{ps}E_{ps}} dx - \Delta_A \qquad (2)$$

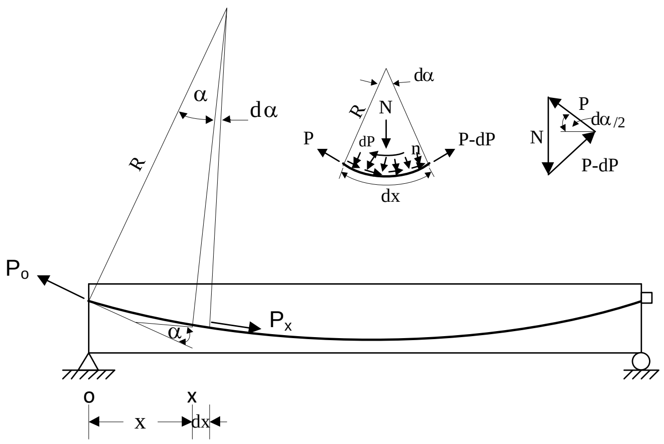

Figure 1. Friction loss due to the curvature effect (Nawy, 2000, p. 86)

SELECTED POST-TENSIONED FLAT SLAB

The posted-tensioned flat slab was selected from the typical layout of the car-park building. Details of the floor slab are as follows: the main span of slab was 8.0 m with 0.25 m thickness and drop panel of 0.40 m thickness. The compressive strength of concrete was 50 Mpa. The prestressing steel was the low relaxation 7-wire strand with diameter 12.7 mm. The number of strands in each tendon was varied between 1-5 strands. The ultimate tensile strength of each strand was 183.6 kN. The modulus of elasticity was 195,000 MPa. The friction curvature coefficient, μ was 0.20/radian, and the friction wobble coefficient, k was 0.0035/m. The jacking force of each prestressing strand was 137.7 kN.

DATA COLLECTION

The layout plan of the building was divided into four zones, i.e., Zone 1, 2, 3, 4. The actual field data of 8 tendons were collected for the longitudinal and the transverse direction of each zone. Therefore, the total 32 sets of tendon profile were collected from bonded post-tensioned tendons by measuring with a hand tape. The tendons were stressed from one end and the field measurement of the stressing strand under the multi strand stressing jack was collected from the stressing report. These data included the elongation and the anchor set or the wedge slip of each tendon.

CALCULATION OF FRICTION LOSS AND ELONGATION

The design tendon profile was recorded from the drawing and the actual tendon profile were measured in the site at each specified interval. Then, the friction loss of post-tensioned tendon was calculated for each segment by using Eq. 1. The stress of prestressing steel along the distance from the jacking end to the wedge end was calculated in terms of prestressing force ratio (P_x/P_o) which is the ratio of the force P_x at the distance x and the jacking force P_o. The elongation of the tendon was calculated for the entire length by using Eq. 2. The design tendon profiles indicated in the construction drawing were employed to calculate the friction loss and the force ratio. The resulting elongation calculated from the force ratio of the design tendon profile was represented for the design elongation. The actual tendon profiles measured in the installation process were calculated for the friction loss and the force ratio. The elongation resulting from the actual tendon profile was the actual calculated elongation. The elongation discrepancy between the design and the actual calculated elongation was represented for the site tolerance. The design elongation was compared with the measured elongation from the ram after stressing to determine the deviation between the design and the field measurement.

RESEARCH RESULT

The prestressing force ratio (P_x/P_o) of the 32 sets of post-tensioned tendon (T1A-T1H, T2A-T2H, T3A-T3H, T4A-T4H) were compared between the design and the actual values, as shown in Figures 2, 3, 4, 5, respectively. It was observed that the force ratio decreased along the tendon length. The prestressing loss was varied between 10-15% and 20-35% for short tendon length of 7-15 m and long tendon length of 25-35 m, respectively. In the overview, the force ratios of the actual profile were lower than the design values, which means that the prestressing loss of the actual profile was greater than the design value. This was due to the large curvature profile in the construction process.

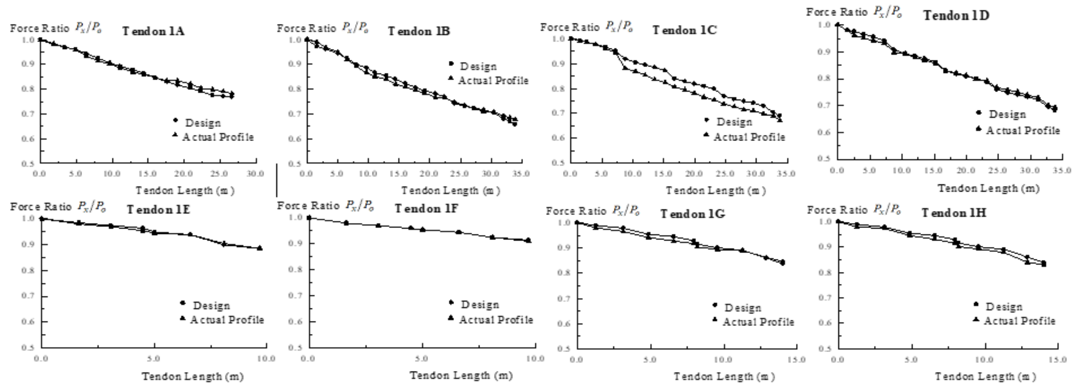

Figure 2. Force ratio of the design and the actual profile for Zone 1

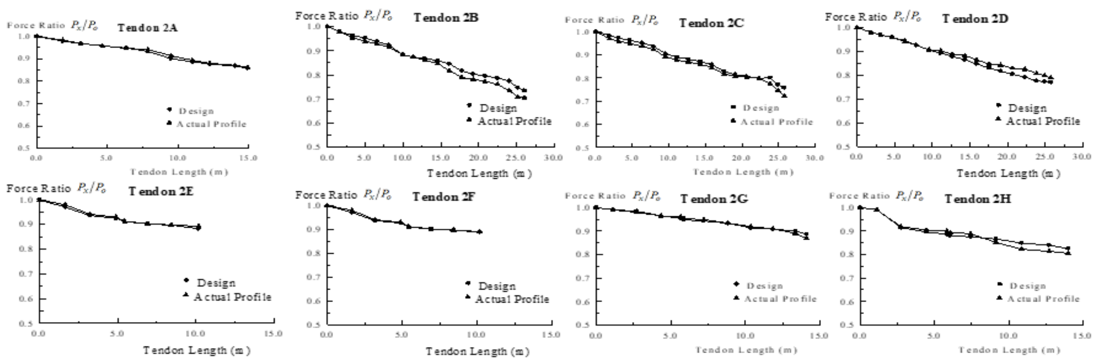

Figure 3. Force ratio of the design and the actual profile for Zone 2

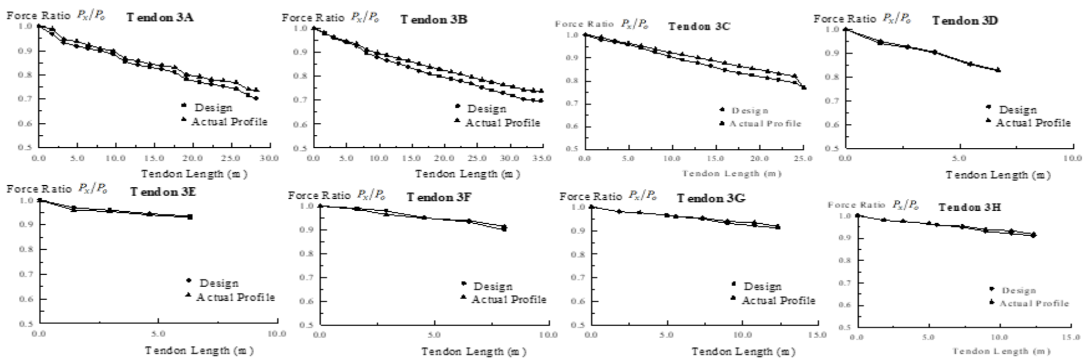

Figure 4. Force ratio of the design and the actual profile for Zone 3

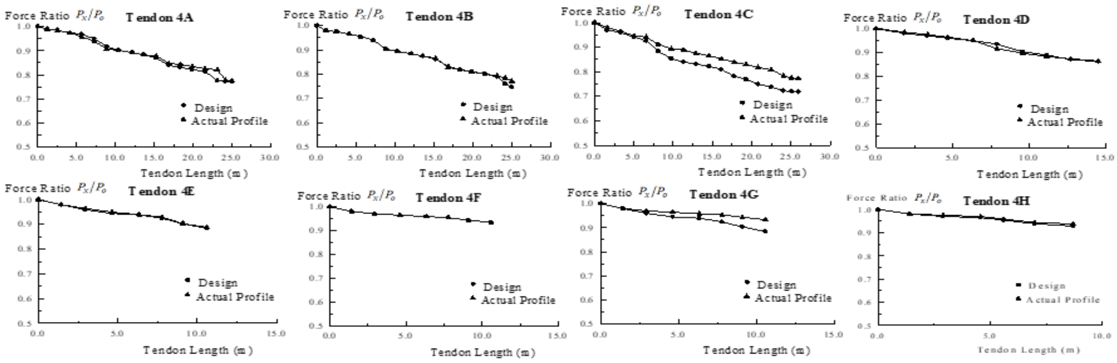

Figure 5. Force ratio of the design and the actual profile for Zone 4

However, the force ratios of several actual profiles, i.e., T3A, T3B, T3C and T4C, T4G were slightly greater than the design values indicating that the prestressing losses of these tendons were lower than the design values. The design elongations of the prestressing tendons were compared with the measurement and the calculated elongation of the actual profile as shown in Figure 6. The deviation among the measurement, the actual profile and the design elongation are presented in Figure 7.

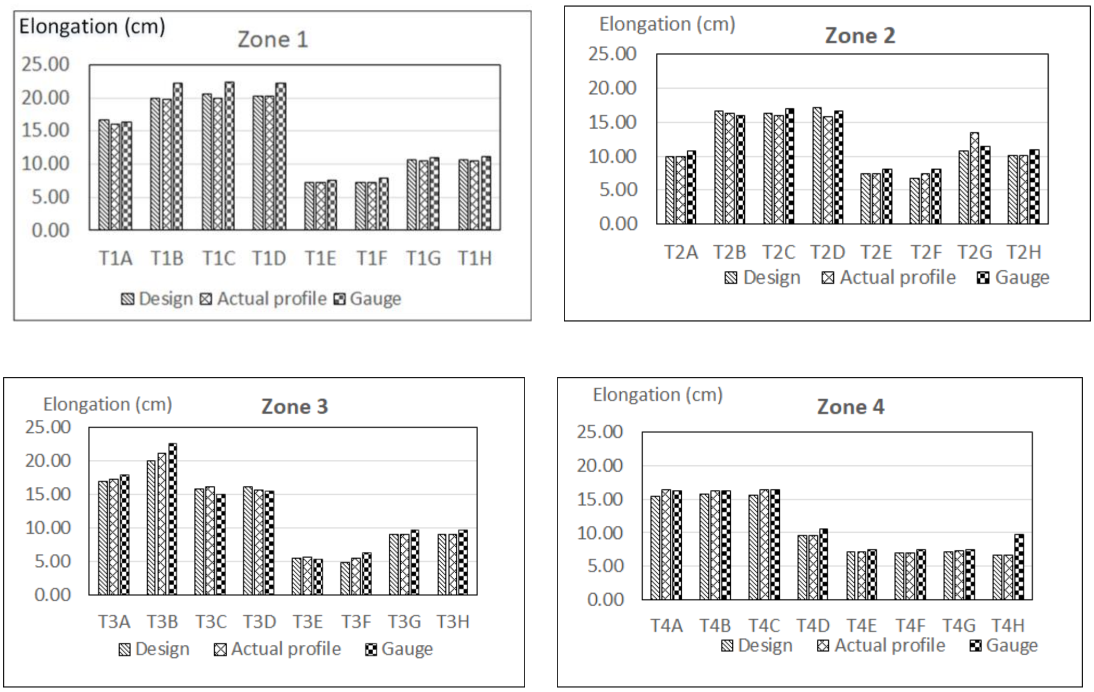

Figure 6. Elongation of the design, actual profile and gauge

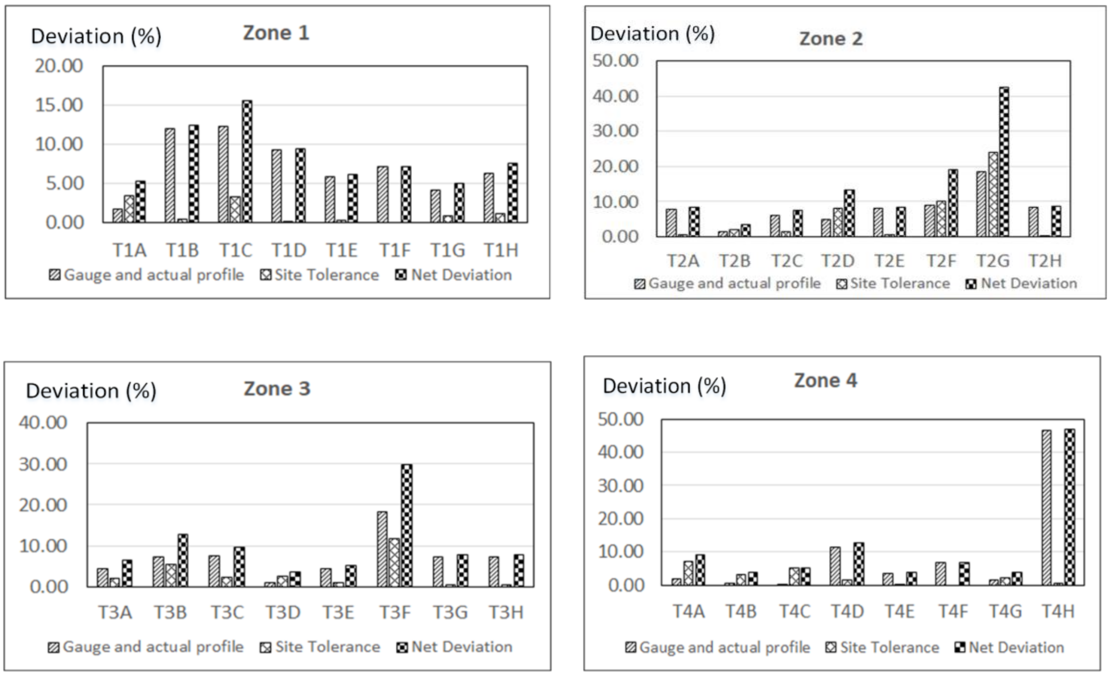

Figure 7. Deviation of the design, actual profile and gauge

DISCUSSIONS

It was found that the deviation between the measured elongation and the actual profile elongation was varied between 0.19-46.54% with an average value of 7.90%. The site tolerance resulting from the elongation discrepancy between the design and the actual elongation was varied between 0.00-23.88% with an average value of 3.20%. The average total deviation which is the sum of deviation between measurement and design including the site tolerance was 11.10%. It was found that the additional site tolerance could enhance the total deviation up to 40%. The average deviations exceeded the tolerance elongation of 7% according to ACI 318-19. This was due to the deviation from site tolerance which contributed about 40% of the total deviation. The result can be compared with the previous research. The average site tolerance of this study is 3.95 mm which is greater than the measurement tolerance of 3.175 mm reported by the previous research (Hayek & Kang, 2017, p. 796). Therefore, the excessive site tolerance plays an important role that significantly affected to the elongation.

CONCLUSIONS

The elongation of prestressing tendon in post-tensioned flat slab was investigated. The conclusions are as follows:

a) The average deviation between the measured elongation and the actual profile elongation was 7.90%. The average site tolerance resulting from the elongation discrepancy between the design and the actual profile in the installation process was 3.20%.

b) The total deviation (11.10%) exceeded the tolerance elongation of 7% due to the deviation from site tolerance which contributed up to 40% of the total deviation. The site tolerance significantly affected to the elongation.

SUGGESTIONS

It is recommended that the tendon profile should be carefully installed in the construction process to reduce the effect of site tolerance.

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