Evaluation on the Reduction Influence on the Pullout of Longitudinal Bar in a RC Column Based on E-Defense Excitation

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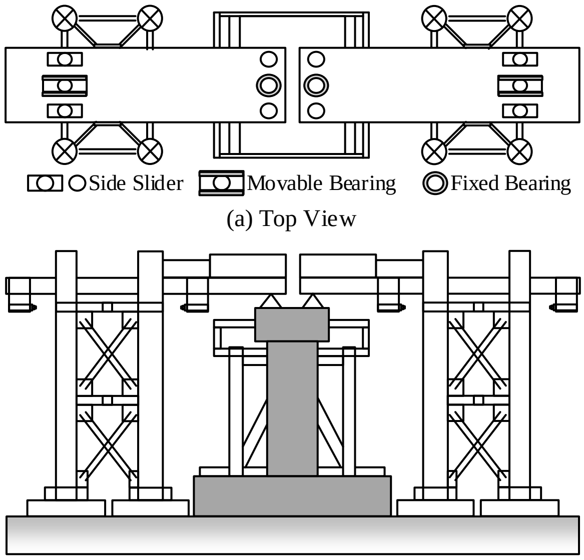
1. Introduction

A 3D shake table experiment on a large scale reinforced concrete bridge column using E-Defense has been constructed by the National Research Institute for Earth Science and Disaster Prevention. To study the mechanisms for a large scale reinforced concrete column, named C1-1 (in Fig. 1), representing typical columns of flexural failure is built in the 1970s. The first shake table experiment using E-Defense by C1-1 was conducted in Dec. 2007.

C1-1 is the specimen, as the Fig. 2 shows, constructed by 3 layers of longitudinal reinforcing bars with 29mm diameter, respectively 32, 32 and 16 at outer, middle and inner layers. Deformed circular stirrups with 13mm diameter are provided by 300mm interval. In experiment, response displacement of RC column is not only caused by flexure but also rotation induced by longitudinal bar pulling out from inside footing. Consequently, the pullout should be discussed further based on the experiment.



(a) Top View

(b) Elevation

Fig. 1 Experimental Test on C1-1 Specimen

2. Evaluation on the reduction influence from bar-to-bar

As for the experimental data by strain gauge (SG), Fig. 3 is plotted to illustrate the strain history measured by outer bar at south side as an example, including the data measured at 0 m and -0.3 m. Corresponding to the column displacement (1δy and 2δy), the measured strain is marked in the history.

Analysis is conducted to evaluate the reduction influence from bar-to-bar based on the calculated methods provided by the former research:

$$\tau / f_{ck}' = 0.73(\ln(1+5000S/\phi))^3/(1+\varepsilon\times10^5) \qquad (1)$$

$$\Delta\sigma = \pi\cdot\phi\cdot\Delta x\cdot\tau / A_s \qquad (2)$$

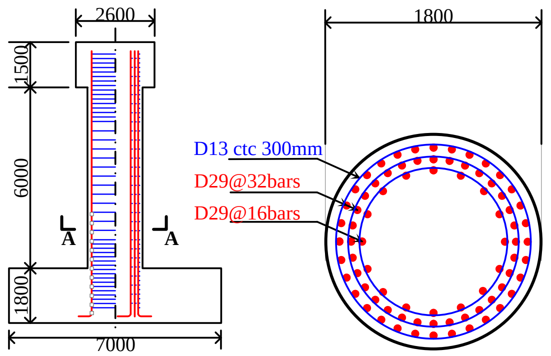
Here, τ is the bond stress; f'_{ck} is concrete strength; S is bond slip; ϕ is bar diameter; ε is strain; $\Delta\sigma$ is stress increment by interval Δx.

This kind of analysis, defined hereinafter as Case 1, has been conducted by considering a single bar inside footing, however, the C1-1 has been reinforced by tri-layer which may contribute to the reduction influence from bar-to-bar. Anotn bbn her modification [3] considering this part of reduction, defined hereinafter as Case 2, has been conducted. The calculated method for reduction coefficient for bond stress and slip relationship (τ-s) can be shown as follows:

$$K_i = 0.4 + 0.03D_i / \phi \qquad (3)$$

Here, the D_i is the distance between adjacent two bars and ϕ is the diameter of longitudinal bar.

The reduction coefficient for bond stress can be calculated based on the Fig. 3. One of the bars in outer layer is taken as an example, the maximum distance of layer spacing is 100mm and it is



(a) Side View (unit: mm) (b) Sectional View(unit: mm)

Fig. 2 C1-1 Column on E-Defense

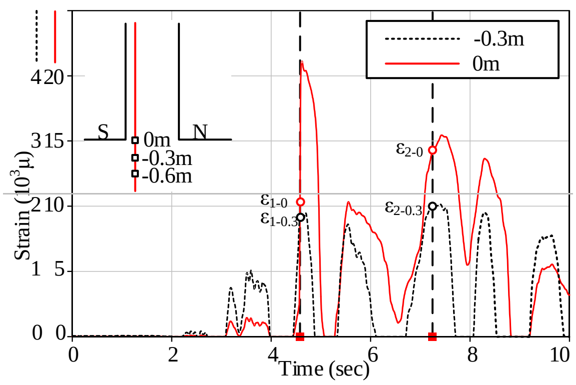


Fig.3 Strain History of Outer Bar (South)

156mm for lapped spacing. Based on Eq. (3), the component reduction coefficient can be calculated as 0.503 and 0.561 respectively. As for the reduction coefficient of bond stress, it is defined as product of calculated component value by both lapped and layer spacing which is calculated as 0.282 (0.503 × 0.561). Based on Eq. (1), analysis that bond stress multiplied by the reduction coefficient of 0.282 is conducted.

3. Analytical results

Analytical result is plotted in Fig. 4. When the column displacement reaches 1δy, shown in Fig. 4, the analytical result of strain in analysis of Case1 has reappeared the experiment better than the analysis of Case 2.

Pullout displacement at base, is integrated as 2.59 mm at 1δy in experiment, and column displacement caused by pullout takes 48% of the response column displacement. Case 1 and Case 2 analysis respectively result in 0.66 mm and 2.18 mm. Column displacement caused by pullout takes 12.6% and 40% of the response column displacement respectively for Case 1 and Case 2. By contrast, the experiment has been well reappeared by Case 2 analysis. As for the bond fracture, it is defined as beginning at when the bond slip (S) exceeds 0.014ϕ (0.406 mm). Shown in Fig. 4 (a), bond fracture occurred at - 0.465 m and -1.419 m depth respectively for Case 1 and Case 2 analysis. Based on the analysis, multi-layer of reinforcement causes the bond fracture begins deeper inside the footing and pullout displacement at base becoming greater.

Similarly, as for state of 2δy shown in Fig. 4 (b), pullout displacement is results in 3.4 mm in experiment by strain gauge which contributes to the response column displacement by 22%. In analysis, pullout is got as 1.03 mm and 3.52 mm respectively for Case 1 and Case 2 analysis. The ratio of column displacement caused by pullout reaches 7% and 23% respectively for Case 1 and Case 2.

With the pullout displacement solved by both experiment and analysis in Fig. 5, column displacement caused by pullout-induced base rotation can be obtained. Fig.6 shows the percentage that pullout-induced column displacement takes in total response displacement. It can be seen that the results of analysis Case 2 has well accorded with that of experiment, in which the pullout-induced column displacement takes about 30%. However, in analysis Case 1, the pullout-induced column displacement only takes about 10% which is relative small.

4. Conclusions

(1) Based on the analysis, considering the relative close lapped spacing and lay spacing, experiment has been well reappeared. Multi-layer of reinforcement (tri-layer in C1-1) contributes to the bar-to-bar reduction influence on bond stress. In analysis considering bar-to-bar reduction, bond fracture begins deeper, which causes the analytical pullout and column displacement caused by pullout increasing by 3.3 times than that in analysis only considering single bar.

(2) Pullout displacement is measured as 2.59 mm and 3.4 mm at south side respectively in 1δy and 2δy by strain gauge. Pullout-induced base rotation in both experiment and analysis considering bar-to-bar reduction has contributed to the column displacement by about 30%. However, in analysis without considering the reduction, pullout-induced column displacement only takes about 10%.

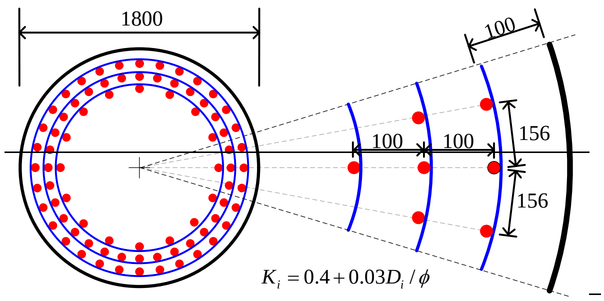


Fig. 4 Reduction Coefficient

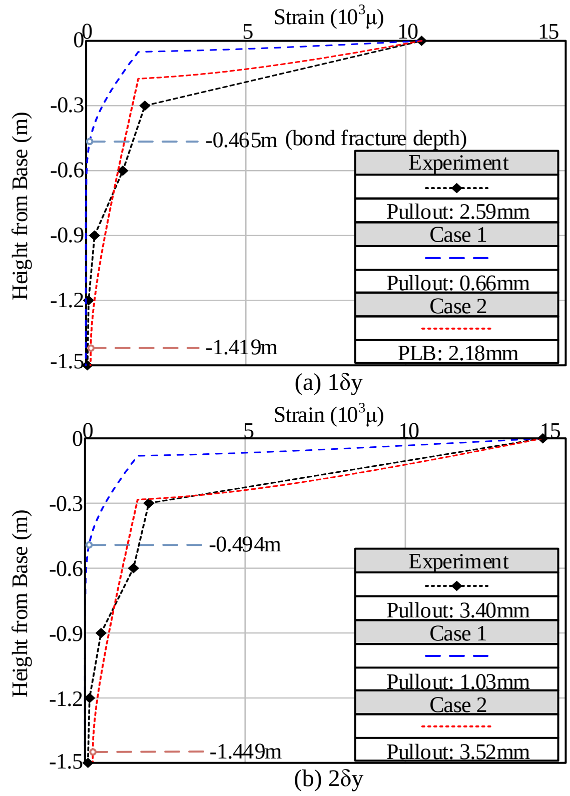


Fig. 5 Experimental and Analytical Result ($1\delta_y$)

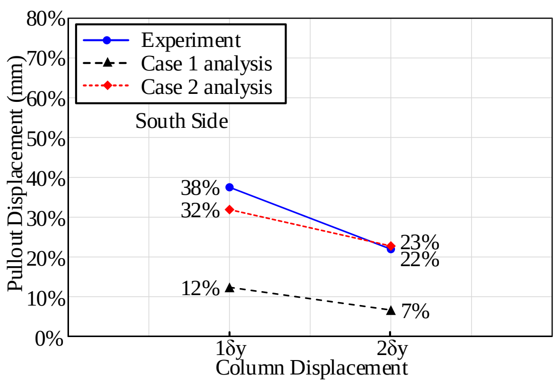


Fig.6 Strain distribution of outer bar at south side