Effect due to 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.

2. Experimental Data

Based on the experimental data by LVDT (located at 80 mm height from base), Fig. 3 makes a general summary about the pullout displacement at the just point ($n\delta_y$, n=1, 2, 3) of response column displacement. Measured data at north, south and east side are summarized in Fig. 3, except west side which is unreasonable.

Response displacement of column top is strongly related to the pullout which causes the base rotation, and it is necessary to distinguish the part of pullout induced column displacement. With the measured pullout displacement (u), calculated location of neutral axis (X_0) and height of column (H), pullout induced column displacement can be solved ($u/X_0 \cdot H$). Fig. 4 reveals the actual effect of the pullout at base by plotting the ratio it induced displacement takes in response column displacement. Shown in Fig. 4, ignoring the data by east side at 1δy which is much greater, pullout at base has contributed 33.6% of the top displacement averagely.

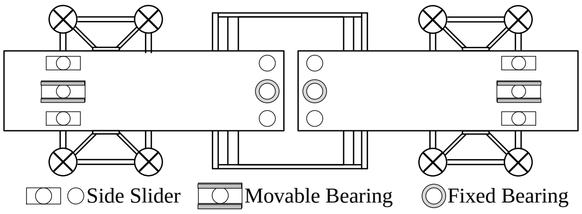
As for the experimental data by strain gauge (SG), Fig. 5 is plotted to illustrate the strain history measured by outer bar at south side as an example, including the data measured at 0 m and -0.3 m. Corresponding to the column displacement ($1\delta_y$ and $2\delta_y$), the measured strain is marked in the history.

3. Analysis on Pullout and General Result

Analysis is conducted based on the calculated methods provided by the former research:

$$\tau / f_{ck}' = 0.73(\ln(1+5000S/\phi))^3/(1+\varepsilon \times 10^5) \quad (1)$$

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



(a) Top View

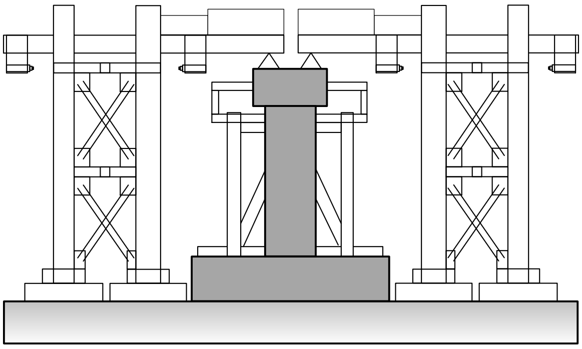
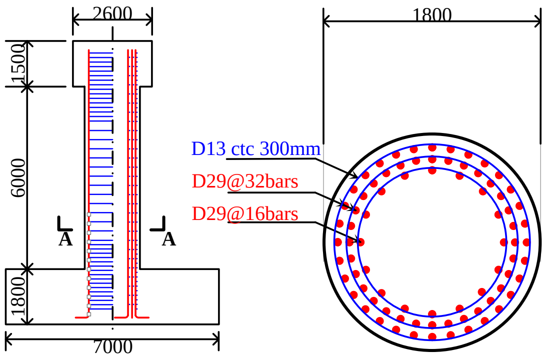

(b) Elevation

Fig. 1 Experimental Test on C1-1 Specimen



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

Fig. 2 C1-1 Column on E-Defense

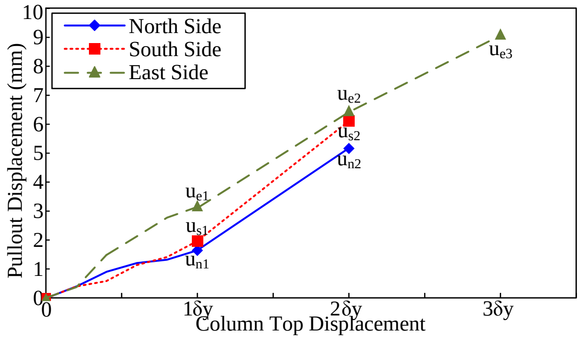


Fig. 3 Pullout Displacement at Base

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 bar-to-bar reduction influence. Another modification considering this part of reduction, defined hereinafter as Case 2, has been conducted by solving the reduction coefficient:

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

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

One of the reinforcing bars in outer layer is taken as an example, shown in Fig. 6. The lapped spacing in outer layer is 100mm and layer spacing is 156mm so that component reduction coefficient is calculated as 0.503 and 0.561 respectively by Eq. (3). Considering reinforced lapped and layer spacing, reduction coefficient on bond stress is defined as product of component values which is calculated as 0.282 (0.503×0.561).

Analytical result is plotted in Fig. 7. When the column displacement reaches 1δy, shown in Fig. 7, 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. 7, 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.

4. Conclusions

(1) By the displacement meter at base, pullout displacement is measured as 1.95 mm and 6.05 mm at south side respectively in 1δy and 2δy. Pullout displacement keeps increasing along the column displacement increase. Pullout-induced base rotation has contributed to the column displacement by 33.6% which is relative great and cannot be neglected. Pullout displacement integrated by data of strain gauge has caused a relative high ratio of 48%.

(2) 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.

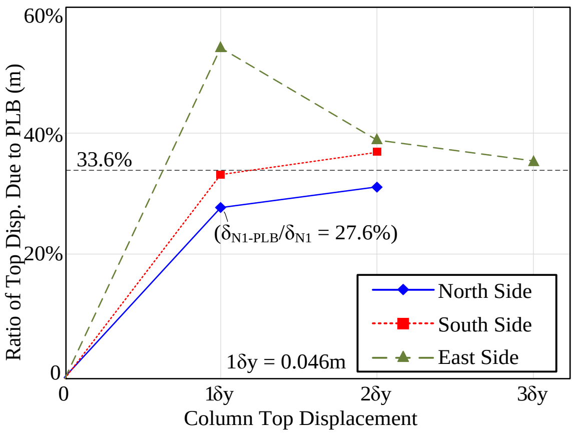


Fig.4 Ratio of Top Displacement due to pullout

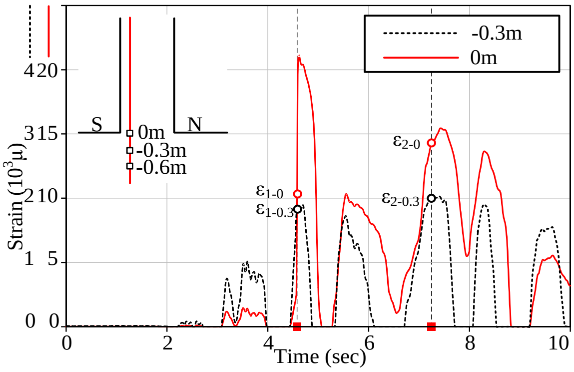


Fig.5 Strain History of Outer Bar (South)

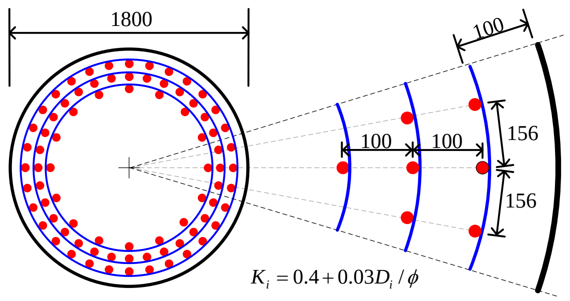


Fig. 6 Reduction Coefficient

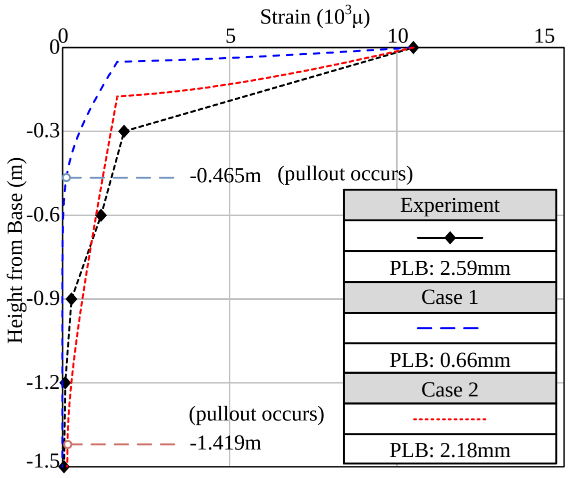


Fig. 7 Experimental and Analytical Result ($1\delta_y$)