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Seismic Repair to Exposed Column Base -Residual Strength after Cone Failure-

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Abstract—**This paper focuses on the residual strength of exposed column bases after the cone failure. It was found that the residual strength depends on the restrain force of the hoop reinforcement crossing the fracture surface.**

INTRODUCTION

Since corner columns of buildings is difficult to ensure the horizontal projection surface of cone failure, cone fracture has been reported in the recent earthquake disasters. The cone fracture is a brittle fracture and it does not make buildings available. In addition, the seismic repair to exposed column base with strength deterioration due to cone fracture has not been establish. The final goal of this study is to create the seismic repair to the damaged exposed column base. In this paper, the experiment of the exposed column base with different length of anchor bolts was conducted in order to make clear the residual strength after cone failure.

I. EXPERIMENTAL PLAN

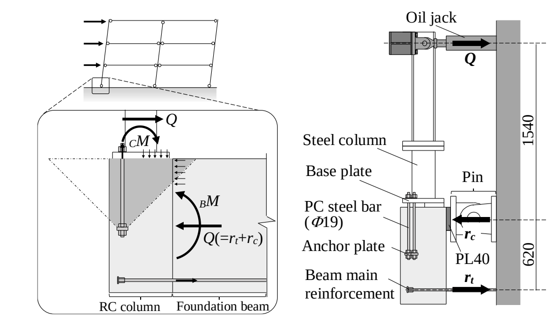
A. Experimental method

The specimens are consisted of steel column, exposed column base (hereinafter, RC column) and foundation reinforced concrete column (hereinafter, foundation beam). Oil jack was connected to the upper part of the steel column. Only the stress (Q+${}_{B}M$) as reaction forces is reproduced in the foundation beams. In the RC column, the beam main reinforcement is inserted into the bending tension side of the foundation beam and fixed to the reaction jig. On the other hand, compression side is supported on the pin. In addition, for the exposed column base, an anchor bolt is inserted on the bending tension side and fixed to the base plate, and PL40 is put on the bending compression side. Shear force is applied to the steel column by oil jack to generate column moment (${}_{C}M$) on the column base. As reaction forces, a compression reaction force (r_c) is generated on the pin and a tensile reaction force (r_t) is generated on the beam main reinforcement. They reproduce the stress of the foundation beam.

B. Specimens

The RC column is consisted of hoop reinforces(11-D6(SD295)), column main reinforcements (4-D6 (SD295)), beam main reinforcements (3-D19 (SD390)) and anchor bolts (PC steel bar, 4-F19). Cold roll-framed steel column 200x200x12(BCR295) and PL40x360x360 (SS490) are used for the steel column.

The experimental parameter is the length of anchor bolt. Three specimens were prepared with lengths of 10, 20, and 39 times the diameter (= 19 mm) of the anchor bolt (L_a = 200, 400, 770 mm). Hereinafter, the specimens are call as 10D, 20D, and 39D.



(a)Stress state in corner column (b)Setup

Fig.1 Method of experiment

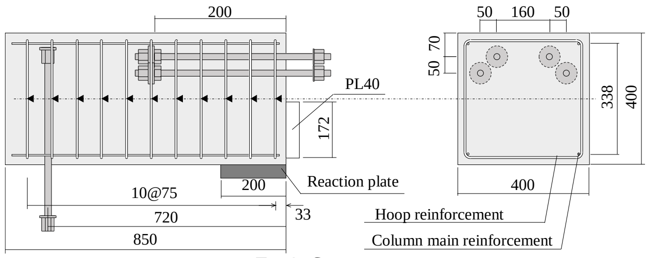


Fig.2 Specimen

II. TEST RESULT

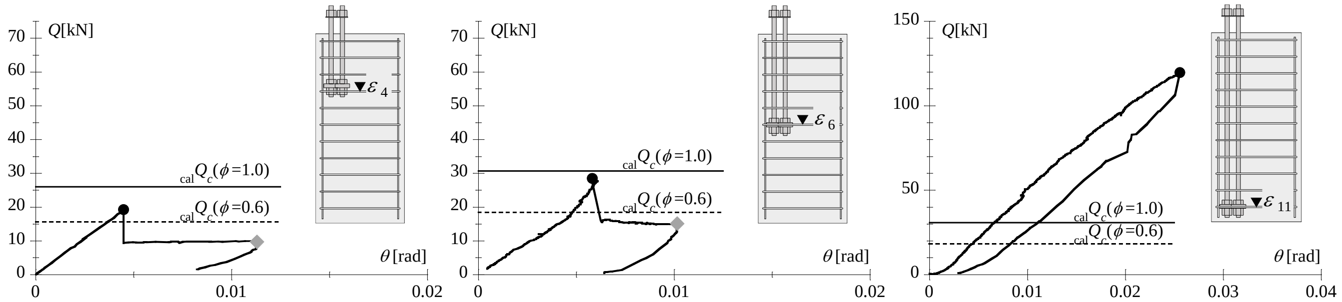
The relationship between the shear force (Q) and the rotation angle (θ) is shown in Fig. 4. In the figure, ● represents the maximum strength (${}_{exp}Q_{max}$), and ◆ represents the residual strength (${}_{exp}Q_{res}$). Also, the calculated value of the cone failure (${}_{cal}Q_C$) in "Design Recommendations for Composite Constructions"[1] expressed by the following equation.

$$ {}_{cal}Q_C = 0.31\sqrt{\sigma_C}\cdot\phi\cdot A_c \qquad (1) $$

It distinguishes the reduction coefficient by a horizontal solid line (ϕ = 1.0) and a broken one (ϕ = 0.6).

In the hysteresis obtained from the experiment, the shear force (Q) at the initial loading increased linearly. In addition, the specimens 10D and 20D reached the maximum strength, and then cone cracks occurred and the shear force was rapidly lost. However, although the width of cracks increases, it can be seen that the rotation angle is increasing while maintaining constant the shear force.

Focusing on the maximum strength, the maximum strength (●${}_{exp}Q_{max}$) increases, as the anchor bolt length is longer. For the specimens 10D and 20D, which led to cone failure, the maximum strength was between the calculated values with the reduction factor of 0.6 and 1.0. On the other hand, for the specimen 39D with the longest anchor bolt, the strength did not decrease due to cone failure.



(a)10D (b)20D (c)39D

Fig.3 Shear force Q – Rotation angle θ

Next, looking at the residual strength (◆$_{exp}Q_{res}$). It is clear that the residual strength is larger as the anchor bolt is longer. It is considered that the longer the anchor bolt, the longer the cone failure crack. As a result, the residual strength is increase due to increasing the number of hoops that restrain RC column.

III. Experimental Plan

A. The model of the residual strength

Here, the method of estimating the residual strength (◆$_{exp}Q_{res}$) is considered. The model of the residual strength is shown in Fig.4. After the reduction of strength due to cone failure, only the restrain force (T) occurs. In addition, the crack starts at the anchor plates and ends at the left of the reaction plate. Further, it is assumed that when cone failure occurs, the hoop reinforcement near the anchor plates has reached the yield strain (ε_y). Based on the above assumptions, the strain (ε_i) of the i-th hoop reinforcement from left of the reaction plate is obtained from the following equation.

$$\varepsilon_i = (l_i / l_y)\varepsilon_y \tag{2}$$

When the length of the anchor bolts is within the range of the reaction plate (L_a ≦ 200 mm), the restrain force (T) is obtained from one hoop bar. In other cases, the restrain force T after the cone failure is the sum of the tensile force (t_i) of each hoop reinforcements. The restrain force (T) can be expressed by the following equation.

$$\begin{cases} T = 2\sigma_y \cdot {}_f a_t & (L_a < 200) \\ T = 2\left(1+\sum l_i / l_y\right)\sigma_y \cdot {}_f a_t & (L_a \geq 200) \end{cases} \tag{3}$$

Further, since the tensile reaction force (r_t) is equal to the restrain force (T), the relationship between the shear force and the restrain force can be expressed by the following equation.

$$Q = \alpha T \tag{4}$$

α is the ratio of the shear force to the tensile reaction force r_t, which is determined from the geometric conditions of the specimen, and here $\alpha = 620/1540$. From the above equations, the following equations are obtained by organizing the equations (2) to (4).

$$\begin{cases} {}_{cal}Q_{res} = 2\alpha \cdot \sigma_y \cdot {}_f a_t & (L_a < 200) \\ {}_{cal}Q_{res} = 2\alpha\left(1+\sum l_i / l_y\right)\sigma_y \cdot {}_f a_t & (L_a \geq 200) \end{cases} \tag{5}$$

B. Compare experimental value and calculated value

Finally, the calculated values of the residual strength determined by equation (5) and the experimental values are compared. The relationship between the shear force and the length of the anchor bolt (L_a) is shows in Fig.5. The calculated value of cone failure ($_{cal}Q_C$) and residual strength ($_{cal}Q_{res}$) are classified by line type.

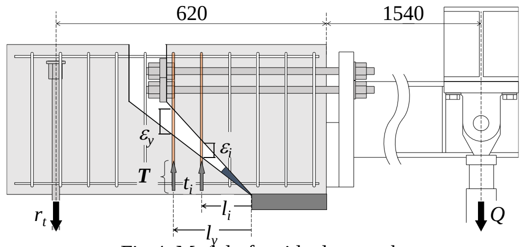


Fig.4 Model of residual strength

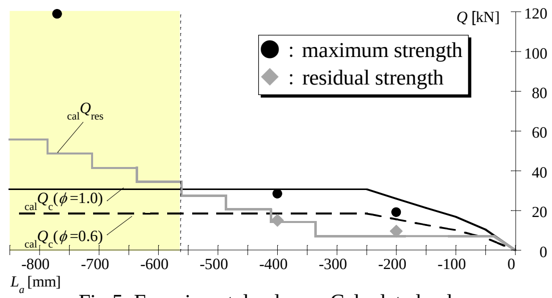


Fig.5 Experimental value vs Calculated value

Focusing on the calculated value of cone failure ($_{cal}Q_C$). As the anchor bolt L_a is longer, the calculated value of the cone failure ($_{cal}Q_C$) increases. Further, when the horizontal projection surface of cone failure exceeds the top surface of the RC column, the value becomes constant regardless of the length of the anchor bolts. The experimental values of specimen 10D and 20D corresponded to the calculated values.

Next, looking at the calculated value of residual strength (◆$_{exp}Q_{res}$). As the length of the anchor bolts increases, the number of hoop reinforcements that restrain the RC column increases. That is, the calculated value of the residual strength ($_{cal}Q_{res}$) increases stepwise. The experimental value of residual strength (◆$_{exp}Q_{res}$) corresponded to the calculated value, it is said that equation (5) is reasonable. In addition, in the range where the length of the anchor bolt (L_a) is longer than 553[mm], the calculated value of the residual strength ($_{cal}Q_{res}$) exceeds the calculated value of the cone failure ($_{cal}Q_C$). It is means that the load of cone failure can all be transmitted by the restrain force of hoop reinforcements. In other words, if the length of the anchor bolts is designed so that residual strength ($_{cal}Q_{res}$) exceeds strength of cone failure ($_{cal}Q_C$), it can be said that cone failure can be prevented.

IV. Conclusion

In this paper, the residual strength after cone failure is evaluated by the formula based on the restrain force of hoop reinforcements.

V. References

[1] Architectural Institute of Japan: Design Recommendations for Composite Constructions, p.p36-38, 2010.11 (in Japanese)