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EXPERIMENT ON SHEAR OF POST-TENSIONED CONNECTION BETWEEN CONCRETE AND CAST IRON PLATE HAVING SHEAR-KEY

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In this paper, post-tensioned connection between concrete and cast iron plate having shear-key was adopted. Frictional resistance acts when there is no displacement between concrete and cast iron plate, shear-key also act to transmit stress to RC beam at the same time as the frictional resistance when the displacement occurs. Each specimen consists of RC beam and plate simulating post-tensioned connection. Ten specimens were tested. The parameter are type of plate, with or without the shear-key, the height of the shear-key, amount of the shear-key, difference between the post-tensioned force and whether or not applying vertical tensile force. In conclusion, it was needless to think their displacement by post-tensioned connection. And the strength of specimens with shear-key is presented by the sum of friction resistance and bearing resistance by using anamnestic formula.

Keywords: Reinforced concrete, Gusset plate, PC bar, Adhesion resistance, Friction resistance, Bearing resistance.

1 INTRODUCTION

In recent years, the vibration dampers, such as buckling restrained braces (BRBs), have been studied to attach to reinforced concrete (RC) flames in Japan. Steel plate with shear connectors has been used to transmit stress from damper to RC flames in the connection, adopting the plate with stud bolts (Kukita et al, 2000), and embedding Gusset plate (G.PL) to RC beam-column joints distribution muscle enters. However, the methods cause difficulty in design and construction. Then, in this paper, post-tensioned connection between concrete and cast iron plate with shear-key was adopted. When there is no displacement between concrete and cast iron plate frictional resistance acts, when the displacement occurs shear-key also acts. In addition manufacturing cast iron plate is easier than steel. In this paper, the purpose is to study the strength equation of the post-tensioned connection between concrete and cast iron plate with shear-key.

2 SPECIMENS AND TEST CONTROL

2.1 Specimens

The details of specimen are in Figure 1, the placements of shear-key are in Figure 2 and the material properties of concrete and rebar are in Table 1. About mortar, the strength was 87MPa. About cast iron (FCD400), it was not tested. In the specification, the yield strength is more than 250MPa, tensile strength is more than 400MPa and extension is more than 18%. In this test, cast iron was elastic state at all time. Each specimen consists of RC beam and plate simulating post-tensioned connection. Ten specimens were tested. The list of specimens is in Table 2. The parameter are type of plate, with or without the shear-key, the height of the shear-key h_d, amount of the shear-key, difference between the post-tensioned force and whether or not applying vertical tensile force.

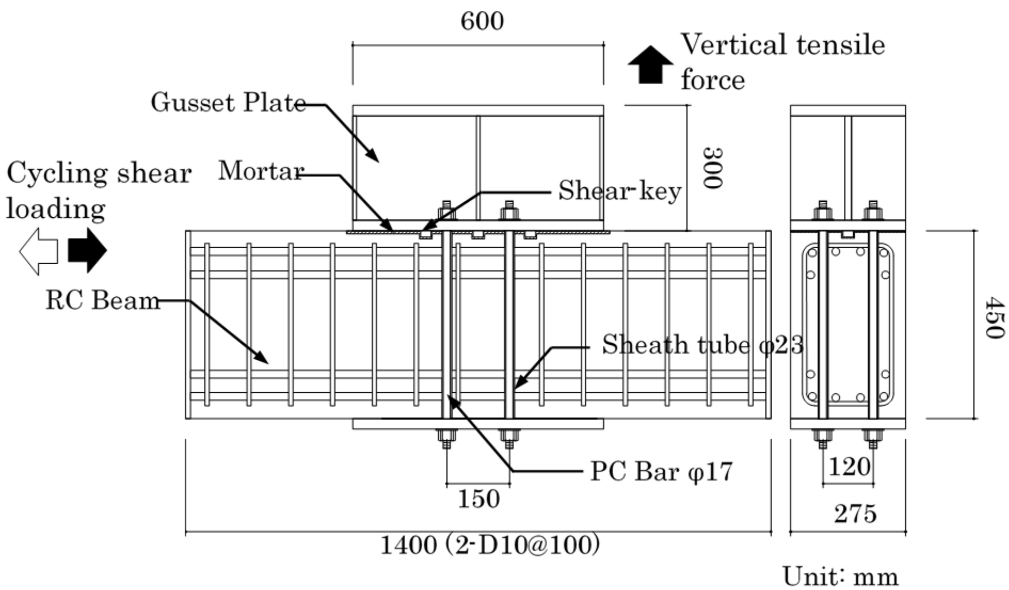

Figure 1. Specimen.

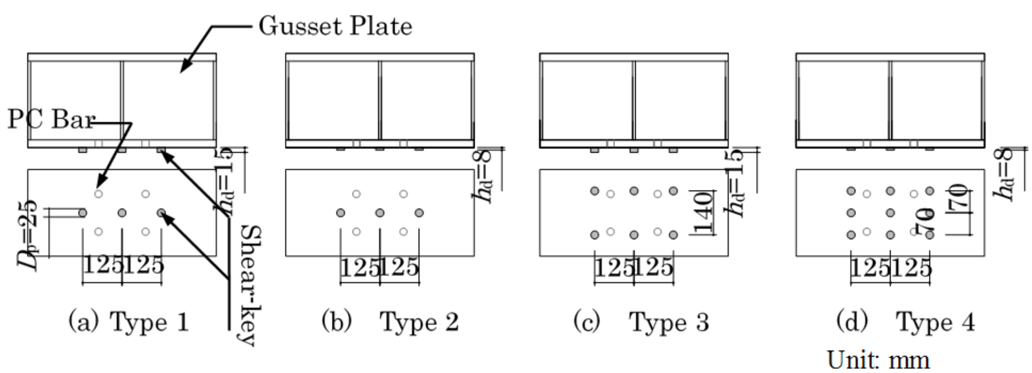

Figure 2. Gusset Plate.

Table 1. Material properties of concrete and rebar.

Main reinforcement D19 (SD345)				Stirrups D10 (SD295A)				Concrete		
Yield strength (MPa)	Tensile strength (MPa)	Elastic modulus (MPa)	Extension (%)	Yield strength (MPa)	Tensile strength (MPa)	Elastic modulus (MPa)	Extension (%)	Concrete strength (MPa)	Tensile strength (MPa)	Elastic modulus (MPa)
402	577	1.89×10^5	22.0	352	482	1.74×10^5	21.9	40.5	3.4	3.06×10^4

Table 2. List of specimens.

<table>
<tr><th rowspan="2">Object</th><th colspan="4">Beam</th><th rowspan="2">Plate</th><th colspan="2">Shear-key</th><th rowspan="2">Post-tentioned force (kN)</th><th rowspan="2">Vertical tensile force (kN)</th><th rowspan="2">Estimated strength (kN)</th></tr>
<tr><th>Section (mm)</th><th>Concrete strength (MPa)</th><th>Beam Bars</th><th>Stirrup</th><th>Amount</th><th>Height (mm)</th></tr>
<tr><td>S0-0-0H</td><td rowspan="10">275×450</td><td rowspan="10">40.5</td><td rowspan="10">6-D19 (SD345)</td><td rowspan="10">2-D10@100 (SD295A) Pw=0.52%</td><td>SS400</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">535</td><td rowspan="5">-</td><td rowspan="2">214</td></tr>
<tr><td>F0-0-0H</td><td rowspan="9">FCD400</td></tr>
<tr><td>F3-15-0H</td><td rowspan="6">3</td><td rowspan="5">15</td><td>20</td><td>141</td></tr>
<tr><td>F3-15-5H</td><td>535</td><td>355</td></tr>
<tr><td>F3-15-7H</td><td>763</td><td>446</td></tr>
<tr><td>F3-15-5H+lV</td><td rowspan="5">535</td><td>210</td><td>271</td></tr>
<tr><td>F3-15-5H+hV</td><td>535</td><td>141</td></tr>
<tr><td>F3-8-5H</td><td>8</td><td rowspan="3">-</td><td>289</td></tr>
<tr><td>F6-15-5H</td><td>6</td><td rowspan="2">15</td><td>495</td></tr>
<tr><td>F9-8-5H</td><td>9</td><td>439</td></tr>
</table>

2.2 The Estimated Strength

In this paper, BRBs of yield strength 250kN was adopted. It is assumed that the frictional resistance acts until BRBs is to yielding, then the bearing resistance by shear-key acts to design strength. The BRB's specifications to assume are the core LY225, the core plastic unit section area 1111mm^2 and mounting angle 31° (span 6m × floor height 3.6m). Considering variations in the actual yield point 225+20N/mm^2 and strength increase rate 1.5 times in the plastic unit strain 2.0%, the connection design strength is $N_{y\_BRB\_J}$=(225+20)×1.5×1111=408kN. If it could be shown that 250kN is by frictional resistance and 158kN is by bearing resistance, the design strength is each of 214kN and 135kN of their horizontal components when G.PL is put on the RC beam. Therefore, four ϕ17 PC bars were pretensioned to 2/3 the nominal yield strength, 134kN per PC bar, to provide an overall pretensioning force P_0=535kN to fasten the gusset plate. The estimated strength of each specimen is set to the sum of friction and bearing resistance before test, then the coefficient friction between concrete and steel and cast iron plate was 0.4 (AIJ, 2012), and bearing resistance force was calculated (Takase et al, 2014).

2.3 Load Control

All specimens were tested cycling shear loading three times followed by 20kN at beginning, 1/3, 2/3, 1, 1.5 and 2 times of estimated strength. In addition, only F3-15-5H+lV and F3-15-5H+hV were tested vertical tensile force at constant.

3 TEST RESULTS

The test results are in Figure 3 that are liner envelope. The vertical axis shows a load and the horizontal axis shows the relative displacement between the plate and the RC beam. The numbers of the top in Figure 3 are the strength of each specimen (kN). For F0-0-5H, the strength was 486kN and it was than twice strength of the estimated strength because of post-tensioned force. The specimen with steel plate showed little higher strength than that with cast iron because it showed smaller post-tensioned force than that of cast-iron in specimen with cast iron plate. For F3-15-5H, the strength was 647kN and it was 160kN higher than F0-0-5H. For F6-15-5H, the strength was 740kN and it was 90kN higher than F3-15-5H. The each force acting to PC bar of each F3-15-5H+lV and F3-15-5H+hV rose 4kN, 23kN higher at applying vertical tensile force. For F3-15-5H+lV, the strength was 541kN and it was 151kN lower than F3-15-5H.

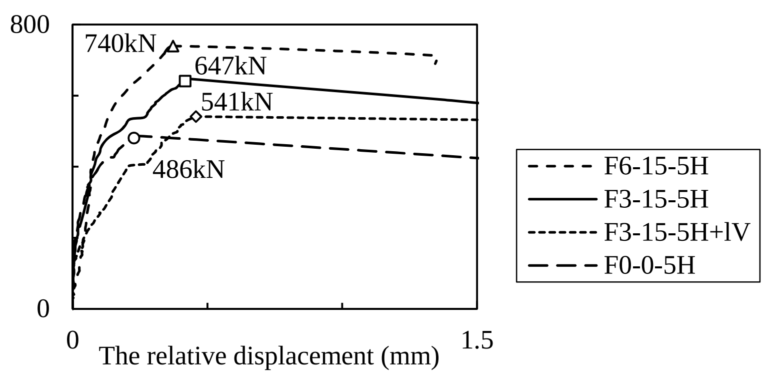

Figure 3. Test results.

4 BEARING RESISTANCE FOMULA

The shear resistance behavior with shear-key were caused by the friction and bearing resistance.

4.1 Adhesion Resistance and Friction Resistance

The test result of F0-0-5H is in Figure 4. The specimens without shear-key slipped sharply after strength. The time of strength was considered as adhesion destruction, and the load after the time was considered as friction resistance. The friction coefficient between cast iron and concrete is obtained by diving the friction resistance force of F0-0-5H (=375kN) by the post-tensioned force (=531kN), then the coefficient is 0.71. In this paper, the friction resistance force of each specimen is assessed by multiplying the post-tensioned force to the coefficient of friction 0.71.

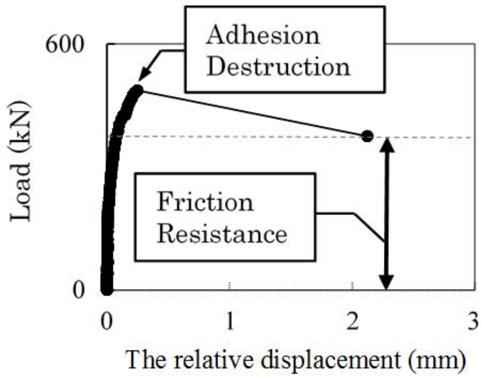

Figure 4. Specimen without shear-key.

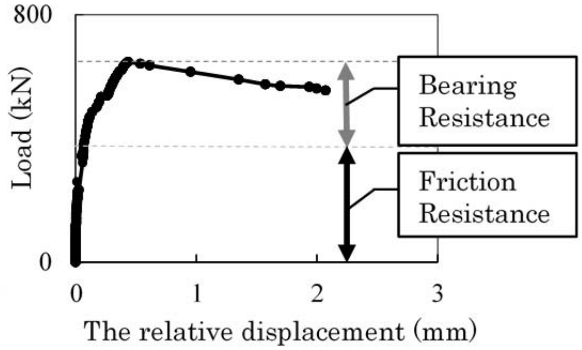

Figure 5. Specimen with shear-key.

4.3 Bearing Resistance

This paper presents the bearing resistance formula of each shear-key q_p in Equation (1) by using anamnestic formula. Anamnestic formula shows smaller value than that in this experience. Therefore, in this paper the coefficient, α (Takase et al, 2014), is obtained by the bearing resistance of F3-15-5H (=254kN), then the coefficient is 0.263. K_1 is coefficient of influence of edge distance in Equation (2), A_B is area to receive the bearing resistance in Equation (3). The relationship between bearing resistance and the edge distance is shown as Figure 6.

$$q_p = 0.263 \cdot K_1 \cdot A_B \cdot \sqrt{E_C \cdot \sigma_B} \quad (1)$$

$$K_1 = \begin{cases} e/e_e & (e < e_e) \\ 1 & (e_e \leq e) \end{cases} \quad (2)$$

$$A_B = \int_R dA_B = \int_{-\frac{\pi}{4}}^{\frac{\pi}{4}} h_d \cdot \frac{D_p}{2} d\theta = \frac{\pi \cdot D_p \cdot h_d}{4} \quad (3)$$

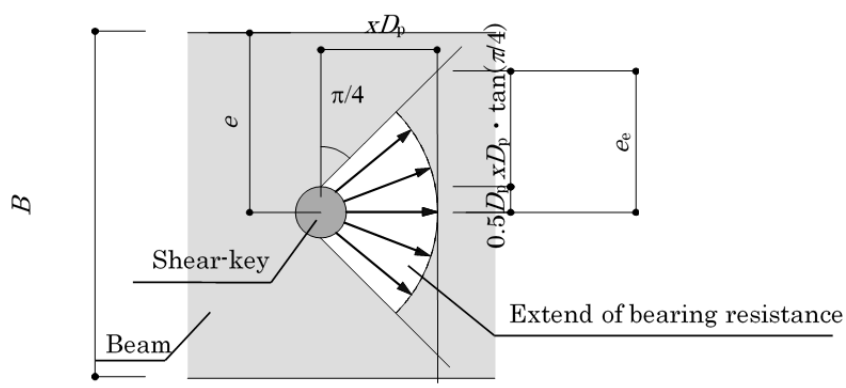

Figure 6. Extend of bearing resistance.

Where, E_C is elastic modulus of concrete (MPa), e is edge distance, e_e is distance bearing resistance reaching to, θ is angle to shear direction and D_p is diameter of shear-key, h_d is height of shear-key. F6-15-5H and F9-8-5H was multiplied by reduction coefficient 4/6 and 7/9 in Formula (1).

4.4 Strength Equation

The strength is expressed the sum of friction resistance force Q_{fr} and bearing resistance force Q_p in Formula (4). The experimental values are almost equal to the calculated values as shown in Figure 7.

$$Q = Q_{fr} + Q_p \tag{4}$$

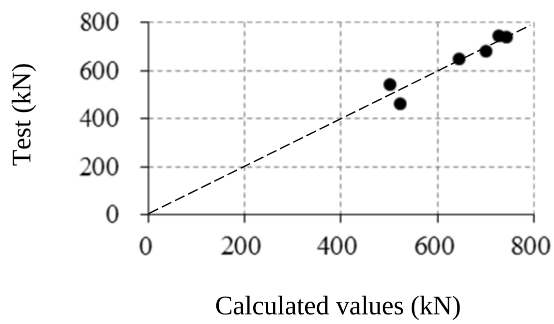

Figure 7. The comparison of test and calculated values.

5 CONCLUSIONS

In this paper, post-tensioned connection between concrete and cast iron plate having shear key was adopted and the shear resistance behavior observed. The time of strength was considered as adhesion destruction and the load after the strength was considered as friction resistance. And it is concluded that the friction coefficient between cast iron and concrete is 0.71 by diving the load by post-tensioned force of the specimen. The strength of each specimen with shear-key was the sum of friction and bearing resistance force. The frictional resistance force was calculated by multiplying 0.71 to the post-tensioned force and the bearing resistance force was calculated by using formula in this paper. In this paper, the experimental values are almost equal to the calculated values.

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