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論 文

[2139] The Dowel Action of Steel Bars in the Joint Connection of Precast Reinforced Concrete

Shuang XIE*, Eiji MAKITANI**, and Shouhei OGAWA***

1 INTRODUCTION

For the connection of precast reinforced concrete which is located at beam-column interface, the shear transfer of steel bars across the connection face is researched on the basis of the dowel action of steel bars. This dowel action idealizes the flexural ridigity of steel bars and spring constant coefficient of concrete under the bars as elastic support model. Its behaviour is not only influenced by the flexural rigidity and spring constant coefficient, but is also influenced greatly by joint connection.

The object of this study is to investigate the behaviour of the dowel action. Two blocks of precast reinforced concrete members are connected by steel bars and joint connection as a test specimen.The relationship between dowel action feature and connection width is investigated on the basis of the theory of elastic support model. Especially, in order to solve the resistance mechanism of dowel action, the relation among the distance from connection face to the point of maximum bending moment, connection width and steel bar diameter is chiefly analysed. The results of test and analytical studies are described as follows.

2 THE DOWEL ACTION OF STEEL BARS

The two blocks of precast reinforced members are connected by the steel bars of dowel with the diameter of d_r and the joint connection which is L_j wide and made by mortar. When the members are subjected to shear force Q_d, the slipping shear deformation at the connection face generates and hence the compressive stress distribution occurs on the precast reinforced concrete under the steel bars of dowel. Fig.1 shows the compressive stress and the deflection of the steel bars in the precast concrete. With the elastic support model, the compressive stress distribution is the function of the dowel deflection v of the steel bars . The elastic equation is expressed as :

$$E_s I_s \frac{d^4 v}{dx^4} = -kv \tag{1}$$

in which E_s — the modulus of elasticity of steel bars ; I_s — the moment of intertia of steel bars ; k — the constant coefficient of elastic support in precast reinforced concrete. The general equation for the deflection of the equation (1) is expressed by the following equation:

$$v = e^{\beta x}(A\cos\beta x + B\sin\beta x) + e^{-\beta x}(C\cos\beta x + D\sin\beta x) \tag{2a}$$

in which e — the base Naperian logarithms; x — distances from the connection face; β — the relative stiffness of precast reinforced concrete(1/cm), it can be expressed as:

* Doctor course student, Dept. of Architecture, Kanto Gakuin University, M.Eng., Yokohama Japan , Member of JCI
** Prof., Dept. of Architecture, Faculty of Engineering, Kanto Gakuin University, Dr. Eng., Yokohama Japan , Member of JCI
*** Daiwa House Industry Co. LTD., M.Eng, Tokyo Japan, Member of JCI

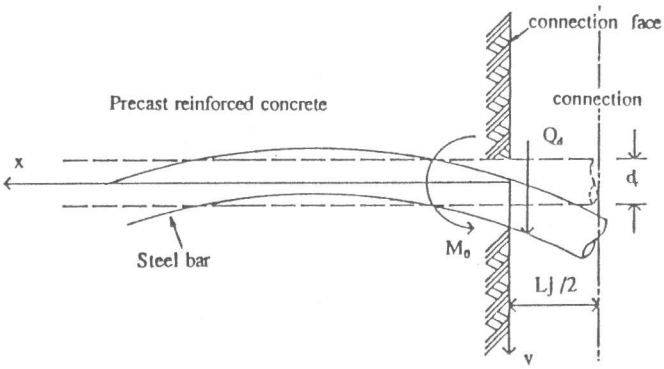

Fig.1 The compressive stress and the deflection of the dowel bar in the precast concrete

$$\beta = \sqrt[4]{\frac{k}{4E_S I_S}} \tag{3}$$

Supposing the deflection v of the steel bar which extends an infinite distance in the positive direction from its boundary surface being zero, the deflection v becomes

$$v = e^{-\beta x}(C\cos\beta x + D\sin\beta x) \tag{2b}$$

The integral constants C and D in the above equation are determined by the independent boundary conditions: $E_S I_S(d^2v/dx^2)_{x=0} = -M_0$, $E_S I_S(d^3v/dx^3)_{x=0} = Q_d$, in which M_0 and Q_d are the applied moment and the applied shear force respectively subjected by the steel bar at the face of the connection where x=0. Hence, the general equation for the deflection v is represented:

$$v = \frac{e^{-\beta x}}{2\beta^3 E_S I_S}\{Q_d\cos\beta x + \beta M_0(\cos\beta x + \sin\beta x)\} \tag{4}$$

The bending moment of the steel bar is established by taking the second derivative of equation (4):

$$M = -\frac{e^{-\beta x}}{\beta}\{Q_d\sin\beta x - \beta M_0(\sin\beta x - \cos\beta x)\} \tag{5}$$

Furthermore, the commpressive pressure q in concrete under steel bar is established by taking the fourth derivative of equation (4):

$$q = 2\beta e^{-\beta x}\{\beta M_0\sin\beta x + (P - \beta M_0)\cos\beta x\} \tag{6}$$

3 THE OUTLINE OF SHEAR TEST

3.1 TEST SPECIMEN

The s-type specimens tested in this study simulate the dowel behaviour of beam longitudinal bars.They consisted of two precast reinforced concrete blocks.These two blocks are connected together by dowel bars and mortar connection. The aggregate interlock between the block face and connection is eliminated by placing 0.3mm Teflon-sheet at the constact surfaces. Each of concrete blocks has a width of 225mm, a length of 450mm and a height of (165～225)mm. In order to investigate the relation among the distance a, connection width L_j and steel bar diameter d_t, the shear tests in this paper are classified into two groups. In the first group, the connection widthes are 0, 15, 30, 60 and 120mm, respectively and the steel bars are 4-D19 of the

hoop shape. In the other group, the connections are all 30mm wide and steel bars are 2-D16, 2-D19, 2-D22 and 2-D25, respectively. The details of steel arrangement are shown in Fig.2. Table 1 shows 9 test specimens of two-group tests.

3.2 THE METHOD OF LOADING AND MEASURING

The loading installation plan is that test specimen is placed vertically and force is applied through the PC steel bars along the joint connection by oil jack. The displacement of the precast concrete, the relative slip displacement of two blocks and the relative opening of the connection are measured by high sensitive displacement meters. The strains of dowel steel bars at different points are by wire strain gauges which are at the bottoms of two side channels.

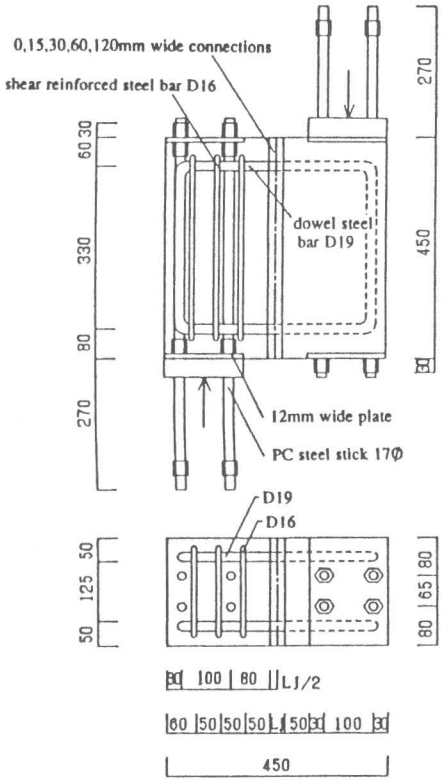

Fig.2 Steel arrangment drawing

Table 1 Test specimens

Name of Test Specimen	Connection Width (mm)	Dowel Steel Bar SD-345 (Ratio of Steel)	Compression Strength of Concrete (kgf/cm²)	Tension Strength of Concrete (kgf/cm²)	Young's Coefficient (10^3kgf/cm²)
JPC 0-000	0	4-D19 (1.14)	276	24	2.09
JPC 15-000	15	4-D19 (1.14)	233	17	2.11
JPC 30-000	30	4-D19 (1.14)	243	17	2.63
JPC60-000	60	4-D19 (1.14)	260	22	2.54
JPC120-000	120	4-D19 (1.14)	241	17	2.46
JPC 30-16M	30	2-D16 (0.39)	265	23	2.20
JPC 30-19M	30	2-D19 (0.57)	265	23	2.20
JPC 30-22M	30	2-D22 (0.76)	265	23	2.20
JPC 30-25M	30	2-D22 (1.00)	265	23	2.20

3.2 THE METHOD OF LOADING AND MEASURING

The loading installation plan is that test specimen is placed vertically and force is loaded through the PC steel bars along the joint connection by oil jack by monotonous loading method. The displacement of the precast concrete,the relative slip displacement of two blocks and the relative opening of the connection are measured by high sensitive displacement meters. The strains of dowel steel bars at different points are measured by wire strain gauges which are at the bottoms of two side channels.

4 COMPARISION OF TEST RESULTS AND THEORETICAL STUDIES

4.1 CALCULATION OF MEASURED BENDING MOMENT OF DOWEL ACTION

When steel bars of dowel transmit shear force from one block to the other side, the steel is applied by both bending stress of dowel action and tensile stress. From wire strain gauges, bending strain ε can be derived as $\varepsilon=(\varepsilon_1+\varepsilon_2)/2$, in which ε_1 and ε_2 are strains of steel bars measured by gauges. The measured bending moment M of dowel action can be calculated by $M = E_S \cdot \varepsilon \cdot Z$.

4.2 RELATIVE STIFFNESS OF PRECAST REINFORCED CONCRETE

Suppose that the spring constant coefficient k of elastic support in precast reinforced concrete is dependent on Young's coefficient of concrete[6], that is $k = \alpha E_c$, the equation (3) is rewritten as $\beta=\gamma/dr$, in which $\gamma=1.50(\alpha E_C/E_S)^{1/4}$. From the direct test result of dowel steel, the coefficient γ is equal to 0.53.[7] Therefore, β can be determined as:

$$\beta = \frac{0.53}{d_r} \tag{7}$$

in which d_r — the diameter of steel bar (cm). Fig.3 shows the comparision between calculated and measured bending moments in case of JPC30-19C. It is said that the formula (7) gives predicition for the relative stiffness β of precast reinforced concrete. Fig.4 shows β versus d_r curve.

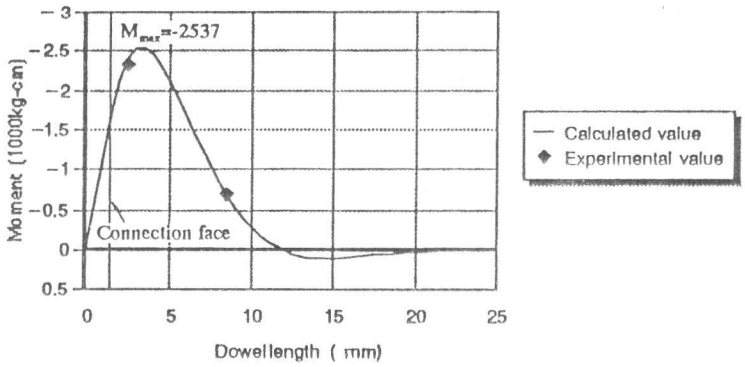

Fig.3 The comparsion of calculated and measured moment

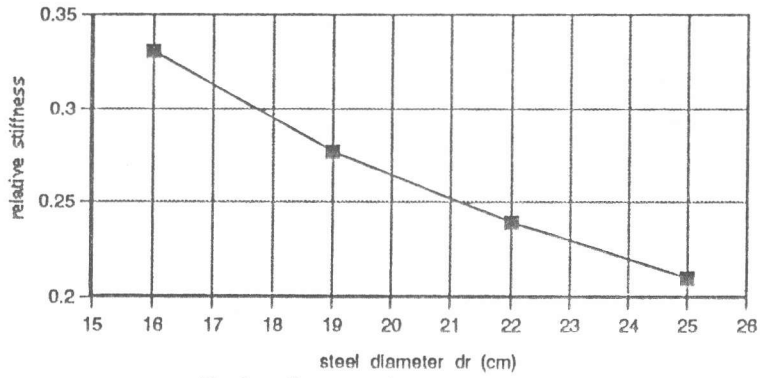

Fig4. β versus d_r curve

4.3 DISTANCE OF MAXIMUM BENDING MOMENT FROM CONNECTION FACE

Fig.5 shows the curves of q versus x and M versus x in the case of β =0.279. It is clear that the compressive pressure mainly occurs at the distance from the connection face to the point of maximum bending moment which is also the location of plastic hinge when the steel bar reaches the state of plasticity. In order to obtain the value of a, the moment boundary condition M_0 have been determined before. From the direct test results,[3] the moment boundary condition is classified into 3 types: (a) when the joint connection L_j is small; (b) when L_j=0; (c) when L_j is large. When L_j is small, assuming that a contraflexure point in the steel bar be located at the center of the joint connection, the distance a of the maximum bending moment from the connection face can be obtained from dM/dx=0:

$$a = \frac{1}{\beta}\tan^{-1}\left(\frac{1}{1+\beta L_j}\right) \tag{8}$$

When L_j=0, a is expressed by a=0.785/β. It is seen that the value of a is mainly influenced by the diameter

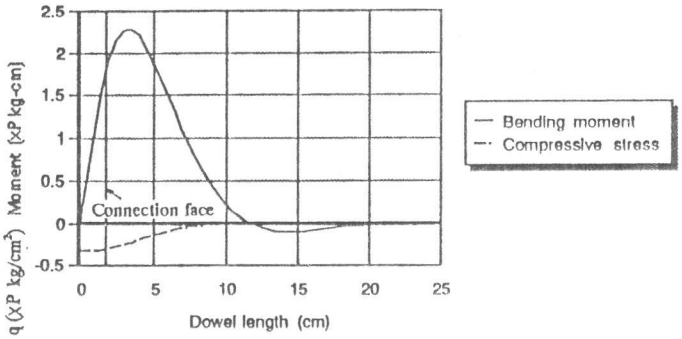

Fig.5 Moment and compressive pressure curves

of steel bars, the modulus of elasticity of the steel bars of dowel and the width of joint connection. If the connection width increases, the maximum bending moment of steel bar occurs both in the joint connection and in the precast reinforced concrete. In the meantime, the bending moment at the face of the connection is equal to zero.[3] By substituting $M_0=0$ in equation (5), the bending moment along the steel bar of dowel is obtained:

$$M = -\frac{e^{-\beta x}}{\beta} Q_d \sin \beta x \tag{9}$$

The distance a of the maximum bending moment from the face of connection can be written as $a=L_j/4\beta$. If we suppose that the bending moment at $x=L_j/2$ in the connection is zero, we arrive $\beta=2\pi/L_j$. Substituting $\beta=2\pi/L_j$ in the above equation, the equation for calculating a can be represented as:

$$a = \frac{L_j}{8} \tag{10}$$

The boundary between equation (8) and (10) is $L_j = 2.37/\beta$. When $L_j \leq 2.37/\beta$, the distance a of the maximum bending moment is calculated by equation (8); otherwise, distance a is by equation (10). The comparsions between calculated and measured bending moments in the case of JPC30-000 and JPC120-000 are given in Fig.6. Fig.7 shows the L_j versus a/d_r curves.

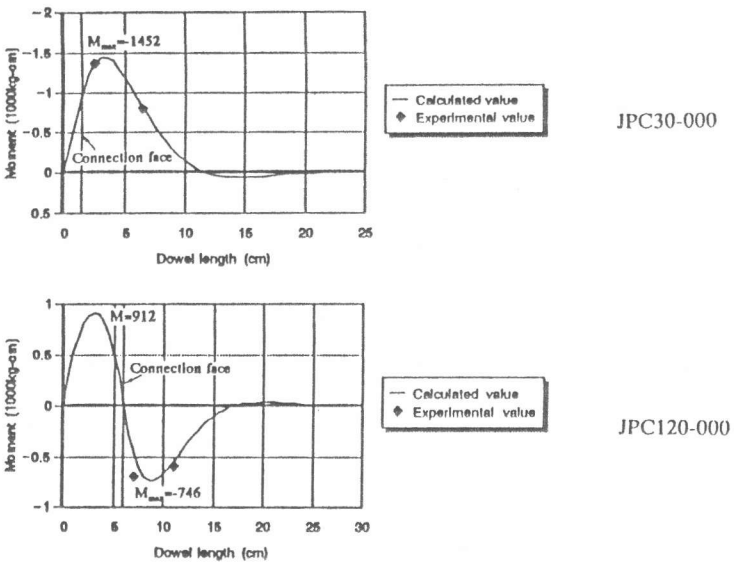

Fig.6 The moment M versus dowel length curves

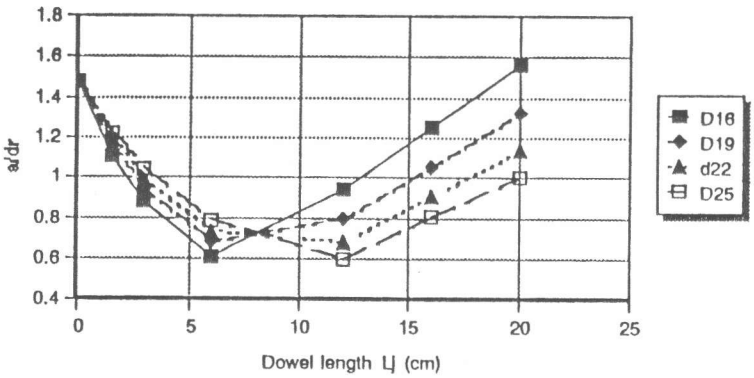

Fig.7 The curves of L_j versus a/d_r

5. CONCLUSION

Based on the beam theory on an elastic foundation, tests are performed on specimens simulating the dowel action of steel bars at the precast reinforced concrete beam-column interfaces. The following conclusions are obtained.

1) When steel bars transfer shear force from one concrete member to the another, the compressive stress mainly distributes in the area where is from the connection face (x=0) to the position of maximum bending moment of steel bars (x=a) and its value is the function of the deflection v of steel bars.

2) From the tests, the relative stiffness β of precast reinforced concrete is inversely proportional to the diameter of dowel steel bars .

3) When the width of connection $L_j \leqq 2.37/\beta$, the distance a of the maximum bending moment from the face of connection is calculated by equation (8); otherwise, a is calculated by equation (10).

4) The model in which the dowel steel bar is idealized as a beam on an elastic foundation successfully predicts the experimental test values.

5) The location of the maximum bending moment of dowel steel bars which is aslo the location of plastic hinge is the basic materials for the analysis of shear transfer behaviour of dowel steel bars in the joint connection of precast reinforced concrete.

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