論文 Shear Transfer of Precast Reinforced Concrete Connection under Large Dowel Displacement

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ABSTRACT: The mechanism of shear transfer across the connection interface of precast reinforced structure was summarized on kinking effect of dowel reinforcement, produced by a couple moment in the dowel reinforcement. A theoretical expression based upon Von Mises's yield criterion was formulated to predict shear transfer capacity in large dowel displacement. And, 19 specimens were applied to study this mechanism and the results were compared with the theoretical model. It was concluded that the proposed formula gave a good prediction for shear transfer capacity, and kinking effect enhanced shear capacity up to about 60 percent.
KEYWORDS: kinking effect, shear transfer capacity, connection interface, dowel reinforcement, plastic hinge

1. INTRODUCTION

In the case of reinforced concrete slabs, it has been shown that considerably large kinking (neck) effect advances in the steel reinforcement crossing cracks[1]. Based on the direct shear test of precast reinforced concrete structures, the presence of the kinking effect was also proven in the characteristic of shear transfer across connection interfaces of PCa structures[2]. This effect enhanced shear transfer capacity with increasing slip displacement and especially, improved distinctly the shear transfer capacity after the concrete was crushed acting underneath dowel reinforcement.

In this analysis, a theoretical expansion formula of shear transfer capacity was described on the combination of shear forces (kinking of reinforcement) due to couple moment in a dowel steel bar, within the dowel zone between two plastic hinges formed in dowel reinforcement due to large slip displacement along connection interface of PCa structures. This couple moment was induced by bending capacity and distorted deformation of dowel reinforcement satisfying the condition of yield criterion. Such a new theoretical model for kinking effect has not be seen till now. It was confirmed that the analytical results calculated according to the proposed theory formula given in this paper appeared to be coincided with direct shear experimental results.

2. THE CHARACTERISTIC OF SHEAR TRANSFER DUE TO KINKING EFFECT

When dowel reinforcement across connection interface is applied by shear force in connection face, as shown in Fig.1, a plastic hinge is formed at the cross-section of the

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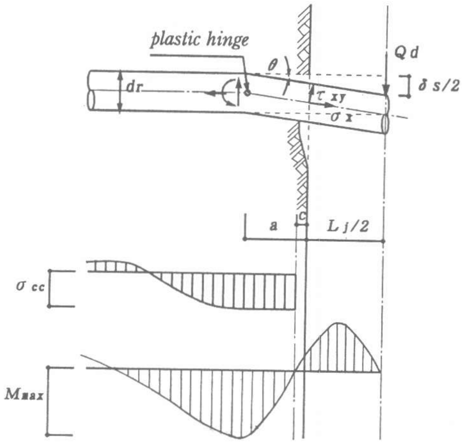
maximum bending moment (at a distance a from the connection interface) in the dowel reinforcement. In the meantime, the effect of bearing pressure of concrete underneath the dowel reinforcement from connection interface up to the plastic hinge occurrs because of local compressive stress σ_{cc} of concrete. Shear transfer capacity Q_{dc} due to ultimate capacity of bearing pressure is written by following expression[2]:

$$Q_{dc} = 3\sigma_B \times a \times \sum d_r \tag{1}$$

where σ_B=compressive strength of concrete (kgf/cm^2); d_r= diameter of dowel reinforcement (cm); a=the distance from the connection interface to the plastic hinge (cm), it is expressed as[4]:

$$a = \frac{1}{\beta}\tan^{-1}\left(\frac{1}{1+\beta L_j}\right) \tag{2}$$



(Precast Reinforced Concrete) (Connection)

Fig.1 The Mechanism of Concrete Failure and Stress Distribution at δ sl

where L_j= connection width; β = relative stiffness between concrete and dowel reinforcement, $\beta = (k/4E_s I_s)^{1/4}$; k = bearing stiffness of concrete; E_s, I_s= Young's modulus and second moment of area of dowel reinforcement, respectively.

As bearing pressure capacity of concrete increase, the concrete acting under the dowel reinforcement close to the connection interface starts to deteriorate. Thereafter, the concrete is crushed at ultimate capacity of bearing pressure. Assuming the length of the crushed concrete zone as locating the distance c from connection interface, the shear transfer must be resisted by tensile force of dowel reinforcement in the zone of distance c for the sake of loss of bearing pressure effect of concrete acting underneath the dowel reinforcement. And, if M_r and M_j are defined by the bending moment acting upon the dowel reinforcement around the edge of crushed zone and the one at connection interface respectively (Fig.2), the corresponding shear force capacity due to these bending moments is given by $Q_{dr}=(M_j+M_r)/c$. It is rewritten in terms of yield bending moment on the plastic hinge in the follows:

$$Q_{ds} = c_k \frac{\pi \times \sigma_y \times d_r^{\,3}}{32c} \tag{3}$$

where c_k is a decreasing coefficient and σ_y stands for yield strength of dowel reinforcement.

Considering the equilibrum of capacities with respect to shear transfer capacity developed in a dowel reinforcement and bearing pressure of concrete, the expression for the length of the crushed concrete is derived by substitution from equation (2) and (3):

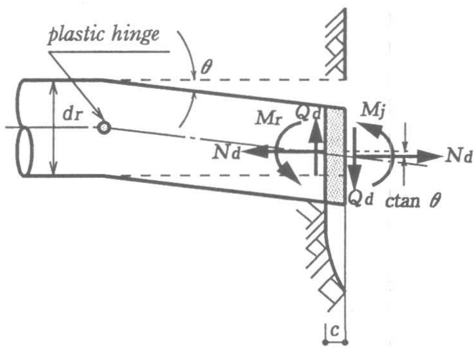


Fig.2 Equivalent Stress of a Dowel in Concrete Crushed Zone

$$c = \frac{c_k \times \pi}{96\bar{a}} \cdot \frac{\sigma_y \times d_r}{\sigma_B} \tag{4}$$

where the symbol $\bar{a}$ is the ratio of a/d_r.

The relationship between shear transfer and slip displacement of dowel reinforcement is shown in Fig.3, in which δ_{sl} is defined as critical slip displacement of bearing pressure under the condition when concrete begins to crush acting underneath dowel reinforcement. When relative slip displacement δ_s exceeds the critical slip displacement δ_{sl} of bearing pressure, couple moment of $N_d \times \text{ctan}\,\theta$ occurrs due to horizontal component of tensile force N_d in dowel reinforcement besides shear transfer capacity Q_{ds}. This couple moment induced by relative slip displacement between two plastic hinges at an angle θ to dowel's axis contributes to shear transfer capacity. This contribution is written as:

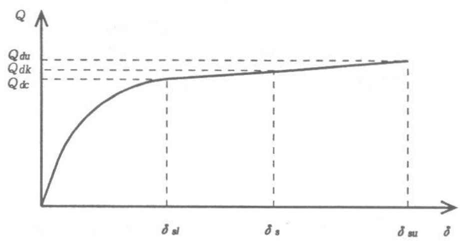


Fig.3 Shear Transfer Capacity – Slip Displacement for Dowel Reinforcement

$$Q_{dn} = N_d \times \tan\theta \qquad (5)$$

where Q_{dn} is given by a definition of kinking effect of dowel reinforcement.

Depending upon above illustration, shear transfer capacity Q_{dk} after critical slip displacement δ_{sl} is resisted by the combination of Q_{ds} and Q_{dn}. From equations (3), (4) and (5), expression (6) is obtained:

$$\begin{aligned} Q_{dk} &= Q_{ds} + Q_{dn} \\ &= 3\sigma_B \times a \times \sum d_r + N_d \times \tan\theta \end{aligned} \qquad (6)$$

It is shown in Fig.3 that shear transfer capacity beyond δ_{sl}[2] increases linearly with slip displacement δ_s owing to kinking effect of dowel reinforcement, and increases until ultimate strain ε_u of dowel reinforcement. If the deformation of the dowel reinforcement between two plastic hinges approximates to distort linearly, the relationship between the ultimate slip displacement δ_{su} and the ultimate strain ε_u at cross-section of reinforcement is conducted on the basis of geometrical equivalent:

$L_j \leqq 2.37/\beta$

$$\varepsilon_u = \sqrt{1 + \frac{1}{4}\left[\frac{\delta_{su}}{a + L_j/2}\right]^2} - 1 \qquad (7a)$$

$L_j > 2.37/\beta$

$$\varepsilon_u = \sqrt{1 + \frac{\delta_{su}^{\,2}}{16a^2}} - 1 \qquad (7b)$$

Then

$L_j \leqq 2.37/\beta$

$$\delta_{su} = 2\sqrt{(\varepsilon_u + 1)^2 - 1} \times \left(a + L_j/2\right) \qquad (8a)$$

$L_j > 2.37/\beta$

$$\delta_{su} = 4a\sqrt{(\varepsilon_u + 1)^2 - 1} \qquad (8b)$$

Where $L_j \leqq 2.37/\beta$ indicates the case with small width of connection and $L_j > 2.37/\beta$ the case with large width of connection[3].

3. THE STRESS OF DOWEL REINFORCEMENT BASED ON STRAIN COMPATIBILITY

The deformation of dowel reinforcement between two plastic hinges makes an angle θ

with reinforcement axis due to relative slip displacement δ_s of two PCa elements. Consequently, as Fig.1 shows, axial stress σ_x and shear stress τ_{xy} occur along cross-section of dowel reinforcement. Then σ_x and τ_{xy} are described as follows on the elastic deformation of reinforcement[5].

$$\tau_{xy} = \frac{G}{E}\sigma_x \tan\theta \tag{9}$$

where E and G indicate Young's modulus and shear modulus for reinforcement, respectively.

If normal stress σ_x is taken to be uniformly distributed throughout the cross-sectional area of the dowel steel, the axial force N_d acting perpendicular to dowel's cross section at connection interface is given as:

$$N_d = a_j\left(\sigma_x \cos^2\theta + \tau_{xy}\sin\theta\cos\theta\right) \tag{10}$$

where $\boldsymbol{a}_j$ is entire cross sectional area of dowel reinforcement crossing connection interface.

Because the dowel reinforcement locating at crushed portion of concrete is in the state of plasticity, the normal and shear stresses satisfy Von Mises's criterion in the following way:

$$\sigma_x^{\ 2} + 3\tau_{xy}^{\ 2} = \sigma_y^{\ 2} \tag{11}$$

By substitution from equation (9),

$$\sigma_x = \frac{\sigma_y}{\sqrt{1+3\left(\frac{G}{E}\right)^2\tan^2\theta}} \qquad \tau_{xy} = \frac{\sigma_y \tan\theta}{\sqrt{1+3\left(\frac{G}{E}\right)^2\tan^2\theta}}\cdot\frac{G}{E}$$

Replacing equation (10) by σ_x and τ_{xy}, the following expression for horizontal component of normal force in the dowel reinforcement which satisfies yield criterion is:

$$N_d = \frac{a_j\sigma_y}{\sqrt{1+3\left(\frac{G}{E}\right)^2\tan^2\theta}}\cdot\left(\cos^2\theta + \frac{G}{E}\sin^2\theta\right) \tag{12}$$

where

$$\sin\theta = \frac{\delta_s}{\sqrt{(2a+L_j)^2+\delta_s^{\ 2}}} \qquad \cos\theta = \frac{2a+L_j}{\sqrt{(2a+L_j)^2+\delta_s^{\ 2}}}$$

Depending upon above illustration, it is known that the shear transfer capacity Q_{dk} due to kinking effect in reinforcement is affected by slip displacement δ_s, the distance $\boldsymbol{a}$ and connection width L_j.

4. THE VERIFICATION OF KINKING EFFECT

4.1 THE OUTLINE OF SHEAR TEST

As shown in Fig.4, the test specimens modelling the joint connection of precast reinforced concrete structures consisted of two precast reinforced concrete elements, plane concrete joint without cotter and dowel reinforcement.The two-element were in (165～210)mm wide, 450mm long and 210mm high. 19 test specimens under monotonic action were investigated by following parameters[2,4]:

1) Connection width (L_j= 30, 60, 90 and 120mm)

2) Diameter of dowel reinforcement (d_r= 16, 19, 22 and 25mm)

3) Steel strength (σ_y= 5000kgf/cm^2 only for D19 and σ_y= 7000kgf/cm^2 for all dowel reinforcements; or SD490 only for D19 and SD685 for all dowel reinforcements)

4) Concrete compressive strength (Fc=300kgf/cm^2 and Fc=360kgf/cm^2)

The details for all 19 specimens were listed in Table 1 .

The loading was applied monotonically by a 100 tonf -oil jack and in displacement -controlled conditions. The direct shear force along connection interface was transmitted by load applying through PC steel bars placed in the concrete elements. The relative slip displacement and opening of two precast reinforced concrete elements were measured by high sensitive displacement meters. The strains of dowel reinforcement were measured by wire strain gauges.In order to keep apparatus in allowable range, the maximum relative slip displacement was controlled within 48mm.

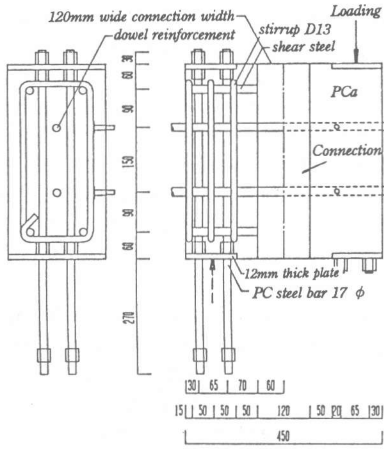


Fig.4 Test Specimen and Loading (for Lj=120mm)

4.2 THE COMPARISION OF EXPERIMENTAL AND THEORETICAL RESULTS

The typical load-slip displacement diagrams for test specimens of JPC60-16M, JPC120-19M and JPC30-360-500M, observed in the direct tests, were plotted in Fig.5 by solid lines. This figure also presented the relationships of theoretical predictions of shear transfer capacity derived in equation (6) after slip displacement exceeding δ_{sl} with broken lines for the sake of comparision.A observation in this figure was that the theoretical values appeared to be a little larger than experimental results for JPC30-360-500M test specimen, since high strength concrete was used. However, the analytical results was confirmed to be consistent with experimental ones with respect to test specimens of JPC60-16M and JPC120-19M.

Table 1 compared experimental load with theoretical predicted shear transfer capacity at slip displacement of δ_s=4mm, as well as at maximum slip displacement. Also, the distance of plastic hinge from connection interface in the reinforcement and critical slip displacement δ_{s1} of bearing pressure were listed in the same table.The comparision between test and theory at maximum slip displacement was reasonable with the ratio of the theoretical to experimental values being from 0.80 to 1.20 as shown in Fig.6.And,kinking effect Q_{dk} of reinforcement seemed to contribute to about 52 to 67 precent of the total shear transfer capacity. The dowel reinforcement in JPC30-360-700M test specimen was broken when slip displacement δ_{sl} reached up to 30mm.

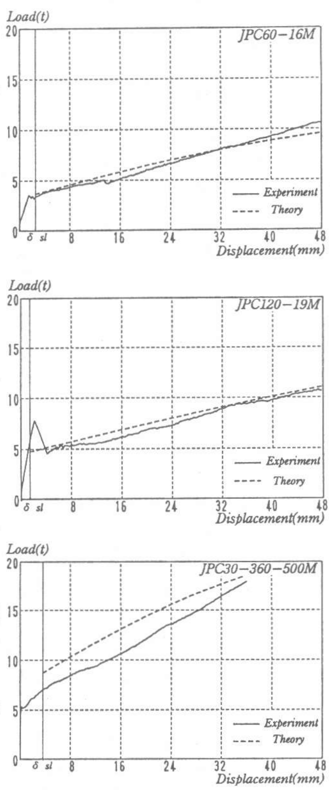


Fig.5 Load — displacement Curves

5. CONCLUSIONS

The kinking action of dowel reinforcement was appraised as dowel effect regarding shear transfer capacity along connetion interface of precast reinforced concrete. The following conclusions were obtained from theoretical analysis and direct shear tests:

1) It was identified that both experimental and theoretical shear transfer capacities at connection interface of PCa structures improved with increasing slip displacement due to kinking action of dowel reinforcement, after the concrete underneath a reinforcement was crushed.

2) Theoretical shear transfer capacity taking into account kinking effect was in good agreement with the experimental load at maximum slip displacement.

3) Kinking effect from 36mm to 48mm of slip displacement was advanced up to approximately 60 percent of total shear transfer capacity.

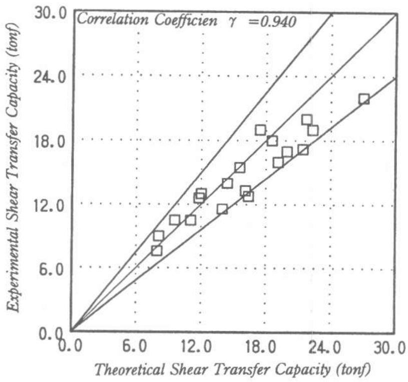


Fig.6 Comparison of Experimental and Theoretical Results for Shear Capacitv

Fig. 1 The Comparision of Experimental and Analytical Results for Shear Transfer Capacity

No.	Specimen	Connection Width (mm)	Concrete Strength (kgf/cm^2)	Steel Yield Strength (kgf/cm^2)	Distance a of Plastic hinge (cm)	Critical Slip Displace-ment δ sl (cm)	Shear Transfer Capacity Qdk at δ s=24mm (kgf)			Shear Transfer Capacity Qdk (kgf)			
							Test	Theory	Test/Theory	δ s (mm)	Test	Theory	Test/Theory
1	JPC 30-16M	30	408	3543	1.77	0.35	8400	9165	0.92	48	12600	11808	1.07
2	JPC 30-19M	30	408	3850	2.22	0.45	12000	13275	0.90	48	19000	17450	1.09
3	JPC 30-22M	30	408	3821	2.68	0.48	14000	17326	0.81	42	20000	21727	0.92
4	JPC 30-25M	30	408	3519	3.14	0.56	16000	21227	0.75	45	22000	27029	0.81
5	JPC 60-16M	60	474	3543	1.28	0.25	6700	6969	0.96	48	10500	9579	1.10
6	JPC 60-19M	60	474	3850	1.67	0.35	8800	10430	0.84	48	14000	14416	0.97
7	JPC 60-22M	60	474	3821	2.08	0.36	11000	13954	0.79	48	16000	19116	0.84
8	JPC 60-25M	60	474	3519	2.50	0.45	13400	17428	0.77	39	17200	21409	0.80
9	JPC 90-16M	90	456	3543	1.13	0.10	5900	5771	1.02	48	9000	8113	1.11
10	JPC 90-19M	90	456	3850	1.33	0.12	9200	8412	1.09	48	13000	12014	1.08
11	JPC 90-22M	90	456	3821	1.68	0.15	8600	11445	0.75	48	13300	16105	0.83
12	JPC 90-25M	90	456	3519	2.05	0.18	10700	14509	0.74	48	17000	19931	0.85
13	JPC120-16M	120	458	3543	1.50	0.14	5000	6025	0.83	48	7600	7978	0.95
14	JPC120-19M	120	458	3850	1.50	0.14	7200	7994	0.90	48	10500	11055	0.95
15	JPC120-22M	120	439	3821	1.50	0.14	8400	9880	0.85	48	11600	13977	0.83
16	JPC120-25M	120	439	3519	1.73	0.16	9200	12307	0.75	44	12800	16397	0.78
17	JPC30-360-300M	30	375	3480	2.18	0.40	11700	13347	0.88	36	15500	15549	1.00
18	JPC30-360-500M	30	375	4760	2.18	0.36	13600	15551	0.87	36	18000	18562	0.97
19	JPC30-360-700M	30	375	6910	2.18	0.36	15800	19252	0.82	36	19000	22310	0.85

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