論 文

[2173] An Experimental Study on the Strength of a Proposed Bar Joint for Precast Concrete Columns

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1. INTRODUCTION

One of the most important parts in the design of Precast Concrete (PCa) structures is the connection details. Connections between precast members must effectively integrate the individual structural members in full continuity with each other so that the overall building structure behaves monolithically. Hitherto, in the conventional PCa methods, the main bars are placed inside of the PCa members and jointed at the same place where the PCa members are jointed too. This method generated a problem between the construction of precast members and the seismic performance because the main bars are jointed where the stresses due to seismic forces are large. A new concept was proposed by Imai [1], based on that the main bars are not placed when the precast members are prefabricated and also that the bar joints are located at the middle part of each member, where the stresses due to the seismic forces are small. A test to study the behavior of the main bar-mortar-sheath-lapping bars system, as stated above, was carried out by conducting a pullout test.

In this paper, the influences of the height of sheath lug, thickness of cover concrete, lateral reinforcement ratio, lapping length, and loading history are investigated.

2. SPECIMENS

The test specimens were designed to represent a confined section of PCa columns. Figure 1 shows the detailed section of precast specimens and Table I shows the differences among the test specimens. The specified concrete strength for the PCa and the RC specimens were Fc= 300 kgf/cm^2 and 240 kgf/cm^2, respectively. Also the specified compressive strength of the grout mortar was 600 kgf/cm^2. For main bars D25 with specified yield strength of 4000 kgf/cm^2 (SD390), and as lapped bars two bars of D19 (SD390) were chosen for this investigation. Tables II, III and IV show the properties of the materials. The specimens were cast horizontally. That

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position was the basis of naming the upper bars as "top bars" and the lower ones as "bottom bars".

Depending on the parameters, the specimens were divided into five cases: lug height of sheath, thickness of cover concrete, amount of lateral reinforcement, lapping length, and loading history.

Table I Differences Among Specimens

Parameter	Specimen	Height of Lug (mm)	Lateral Reinf.	Cover of Concrete (mm)	Specified Fc (kgf/cm^2)	Lapping Length
Height of Sheath Lug	PS15 PS20 PS30	1.5 2.0 3.0	4-D10	40	300	20 d
Lateral Reinf.	PH210 PH410 PH413 PH416	2.0	2-D10 4-D10 4-D13 4-D16			
Cover of Concrete	PL20 PL30 PL40		4-D10	20 30 40		
Loading History	PR11 PR13 PR15			40		
Lapping Length	RC20 RC25 RC30	Without sheath			240	20 d 25 d 30 d

Sheath Diameter: 44 mm
Main Bars: D25 (SD390)
Lapped Bars: 2-D19 (SD390)
Hoop: welded close type at every 100 mm
d: lapping bar diameter

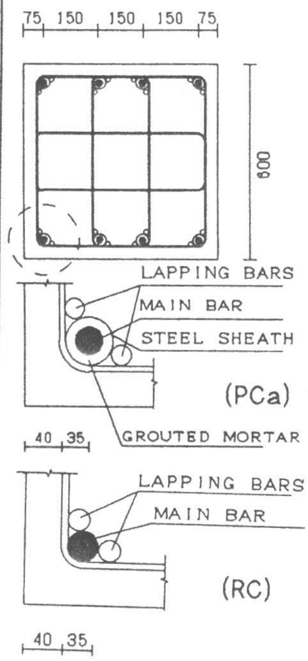


Fig. 1 Section of Specimen

A steel spiral sheath of 44 mm diameter with lug height of 2 mm was used for all specimens except when the lug height was the parameter. Also, a concrete cover of 40 mm from the surface to the lateral reinforcement was considered for all specimens, except when the influence of the cover thickness of concrete was investigated. Each specimen had 4-D10 (SD295A) as lateral reinforcement, except when its influence on the joint was tested. As lapping length, 20 times the diameter of the lapping bar was considered for all the PCa specimens. For the RC specimens three different lapping lengths were considered: 20, 25 30 times the diameter of the lapping bar.

Table II Properties of Steel

Size	Grade	σ_y (tf/cm^2)	σ_b (tf/cm^2)	E (tf/cm^2)
D10	SD295A	3.799	5.132	1914
D13		3.677	5.105	1835
D16		3.661	5.226	1919
D19	SD390	4.251	5.967	1890
D25		4.296	6.086	1972

Table III Properties of Mortar

Specified Strength (kgf/cm^2)	Grouting Day	Specimen Strength 7 Days (kgf/cm^2)	4 Weeks (kgf/cm^2)	13 Weeks (kgf/cm^2)
600	11/3/91	548	668	748
	18/3/91	517	638	715

3. TEST APPARATUS AND LOADING HISTORY

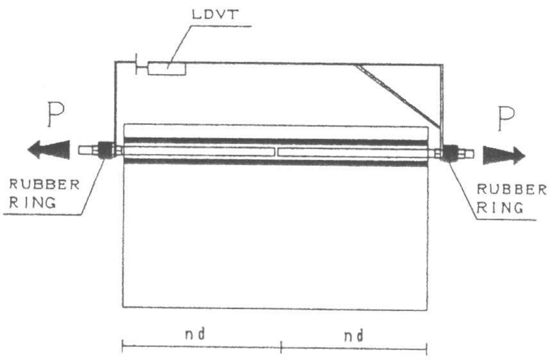
The loading arrangement is shown in Fig. 2. Tension load P was applied horizontally to the both ends of the main bars by oil jacks controlled by a load cell. Displacements between both ends of the main bars were also measured.

In order to obtain the maximum load, load was applied monotonically with incrementals of 1 tonf up to failure. In case of the bottom bars, the maximum load was obtained after the bars yielded. The top bars did not yield because of bond failure. Six specimens were tested under repeated loading. First, the specimens were loaded with increments of 1 tonf until it reached 2/3 of the level of 1.1, 1.3, and 1.5 times the value of the specified yield strength of the main bars. The reason for multiplying the value of 2/3, is because a lapping length of 20d was tested, while the design lapping length is 30d. Then, after 10 cycles of repeated load with same level in each case, the maximum load was obtained. Same as in the monotonic loading, the bottom bars yielded before the bond failure happened, while the top bars failed in bond before the bars yielded.

The following testing pattern was adopted for two specimens with the same parameters: first, the top bar was tested until the specimen was close to failure. Then, the bottom bar was tested until it failed. The bottom bar of the second specimen was tested until the load was close to the maximum load. After that, the top bar was tested until failure. By this testing pattern the authors got good results with the limited number of specimens in each case.

Table IV Properties of Concrete

Specimen	Specified Strength (kgf/cm^2)	Specimen Strength	
		4 Weeks (kgf/cm^2)	Exp. day (kgf/cm^2)
PS15 PS20 PS30 PH413 PH416	300	311	317
PH210 PC20 PC30		311	326
RC20 RC25 RC30	240	300	296
PR11 PR13 PR15	300	311	326



d: diameter of lapping bars
n: 20, 25, 30

Fig. 2 Loading System

4. TEST RESULTS

4.1 INFLUENCE OF THE HEIGHT OF LUG

First transverse cracks appeared at the 1/3 of the specimen length at 6 tonf in/ all cases. The first cracking loads for the bottom bars were 1.3 times those for the top bars. At 9 tonf transverse cracks developed at the center, at 12 tonf cracks developed in the longitudinal direction at the both ends. Cracks spread with the increment of load and before the maximum load a concentration of cracks at the corners was observed.

The load-displacement (P-δ) relationship for the lug height of 2 mm is shown in Fig. 3. The maximum loads for the bottom bars were 1.38 times bigger than for the top bars.

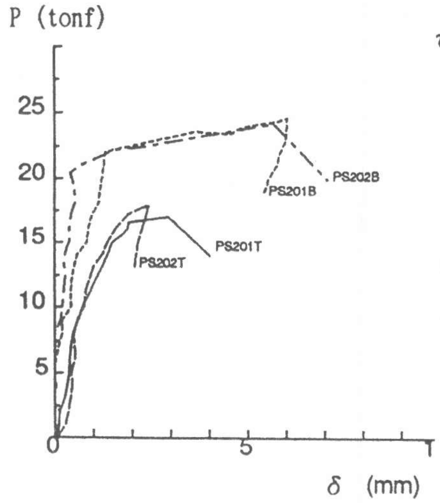


Fig. 3 P-δ Relationship for a Lug Height of 2 mm

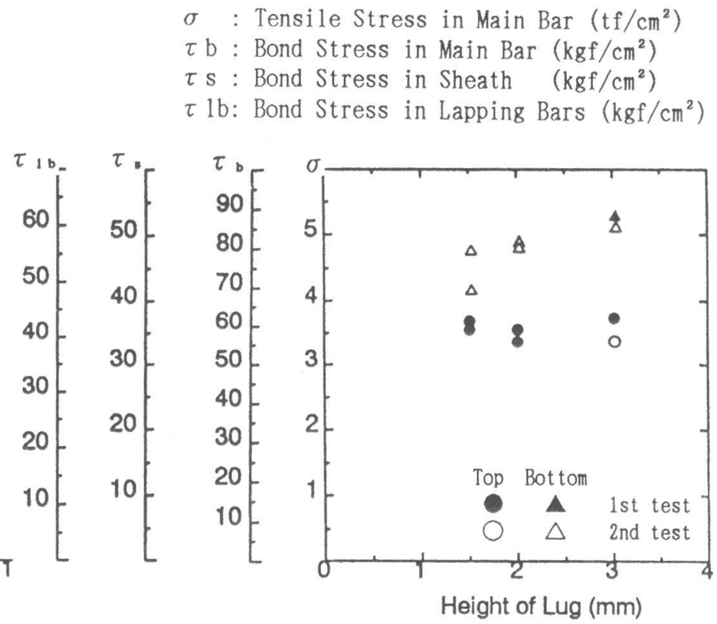


Fig. 4 Relationship Between Joint Strengths and Lug Height of Sheath

Figure 4 shows the relation between the tensile stress in main bar, average bond stresses in main bar, sheath, lapping bar at the maximum load and the lug height. The bond strength was calculated using equation (1) :

$$\tau = \frac{P_{max}}{\phi \cdot l} \quad (1)$$

where: Pmax = maximum applied force to the main bar
ϕ = perimeter of main bar, sheath or lapped bars
l = lapped length

It can be noticed that when the height of the sheath lug is increased , the stress of the bottom bars increases while that of the top bars, which failed in bond, remains almost constant.

4.2 THICKNESS OF THE COVER CONCRETE

The first cracks appeared at 4 tonf and 6 tonf for the top and bottom bars, respectively. It was observed that there were more cracks in the specimens with lower concrete cover. For specimens with cover concrete of 40 mm transverse cracks were distributed at 1/3 the length of the specimens. Specimens with cover concrete of 30 mm had a similar crack pattern to that with cover concrete of 40 mm, except that the transverse cracks were distributed at 1/4 of the specimens length. No differences of the crack patterns between the top and bottom bars were observed.

A typical P-δ relationships are shown in Fig. 5. All the specimens showed almost similar curves. The maximum loads were 1.44 times bigger for the bottom bars than for the top bars.

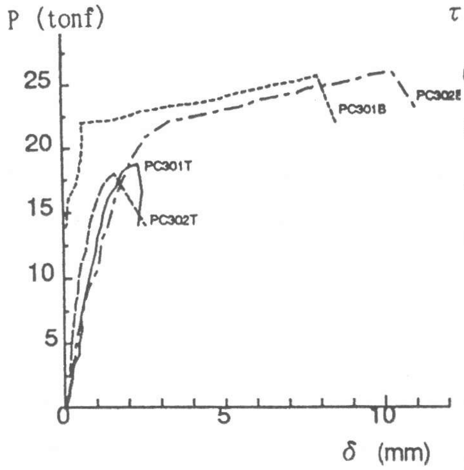


Fig. 5 P-δ Relationship for Cover of 30 mm

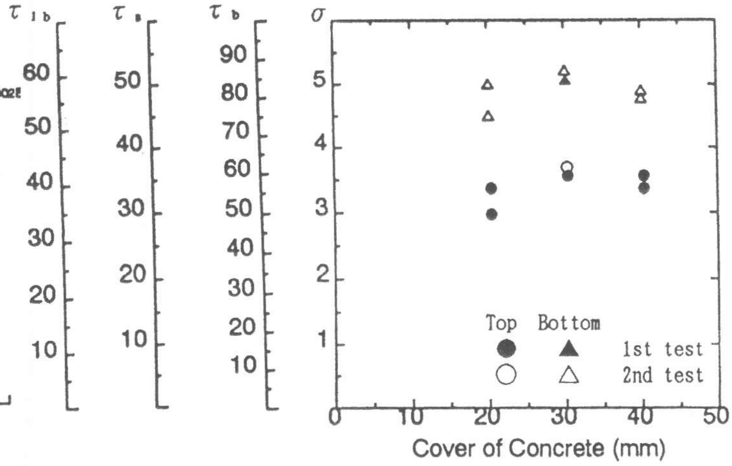


Fig. 6 Relationship Between Joint Strengths and the Cover Concrete

Figure 6 shows the relation between the lapping joint strengths and the cover thickness of concrete. From this figure, it can be observed that when the concrete cover is changed from 20 mm to 30 mm, the strength increases, but when it was changed to 40 mm that strength decreases.

4. 3 LATERAL REINFORCEMENT

When the top bars were being tested, the first crack occured at the central part of the specimen when the load was 5 tonf. On the other hand, as the bottom bars were being pulled the crack initiated at one of the middle thirds of the specimen when the load was 7 tonf. For the specimens with 2-D10 as lateral reinforcement, just before failure a transverse crack appeared at the end of the lapping length. For specimens with 4-D10 and 4-D13, the crack pattern was almost similar to each other and failure was due to the corner bar split. During the test of the top bars of specimens with lateral reinforcement of 4-D16 the specimens broke at the center where the main bars are abutted. There were less cracks in these specimens compared to the others. No damage was observed for the bottom bars.

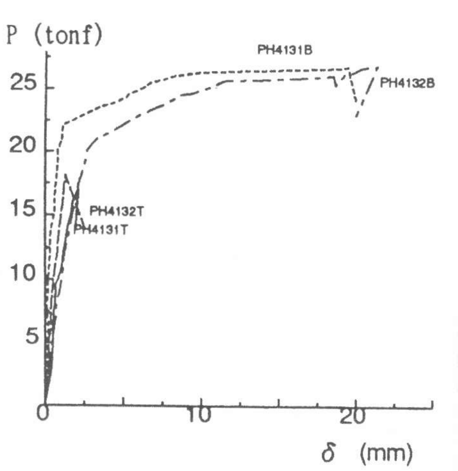


Fig. 7 P-δ Relationship for Lateral Reinf. of 4-D13

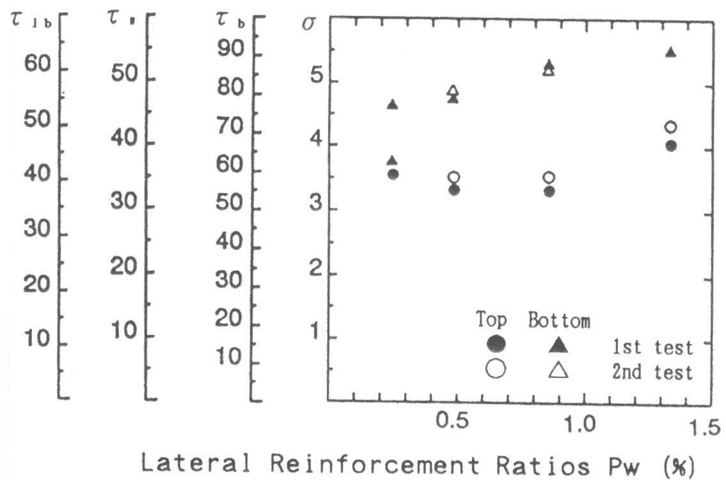


Fig. 8 Relationship Between Joint Strengths and the Lateral Reinforcement Ratios Pw

A typical P-δ relationships are shown in Fig. 7. The maximum loads for the bottom bars were 1.38 times bigger than the top bars. Figure 8 shows the relation between the joint strengths and the lateral reinforcement ratios. As the lateral reinforcement ratio of the bottom bars increases, the strength increases, but in the case of the top bars, an increase in the lateral reinforcement gives a slight decrease and a subsequent increase in the strength.

4.4 LAPPING LENGTH

Figure 9 shows the relationship between the lapping length and the tensile stress in the main bar, average bond strengths at the maximum load. This figure shows a good performance for the bottom bars, and for the top bars, the experimental values were close to the specified yield strength for lapping length of 30d. It can be noticed that the greater the lapping length is the lower the average bond stress at the maximum load.

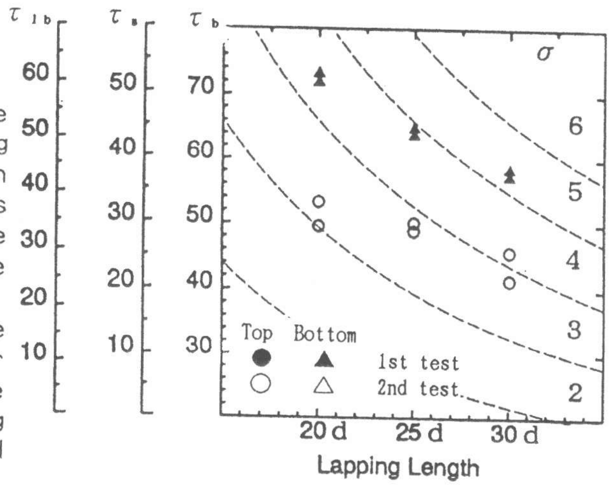


Fig. 9 Relationship of Bond Strengths and Lapping Length in RC Specimens

4.5 LOADING HISTORY

No difference was appreciated concerning the variation of the repeated loads, where either the top or bottom bars showed a similar behavior to the specimens under the monotonic loading.

5. CONCLUSIONS

From the foregoing discussions, the following conclusions can be obtained.

1) With the same lapping length, a difference of the lapping joint strength for the top and bottom bars was recognized.
2) An improvement in the bond strength was recognized with the increment of the lug height of the sheath.
3) No remarkable influence of the cover concrete thickness was recognized.
4) As the lateral reinforcement ratio of the bottom bars increases, the strength increases, but in the case of the top bars, an increase in the lateral reinforcement gives a slight decrease and a subsequent increase in the strength.
5) The greater the lapping length is the lower the average bond stress at the maximum load.

REFERENCES

1) Imai, H.; Yamaguchi, T.; Yanez, R., "Bond Performance of a Lapping Joint Developed for Precast Concrete Columns", Proceedings of The Japan Concrete Institute, Vol. 13, No 2, 1991, pp. 1063-1068.