論 文

[2181] BOND PERFORMANCE OF A LAPPING JOINT DEVELOPED FOR PRECAST CONCRETE COLUMNS

Hiroshi Imai*, Teruaki YAMAGUCHI** and Rodolfo YANEZ***

ABSTRACT

An experimental investigation was carried out in order to predict the bond behavior of a newly developed lapping joint for Precast Concrete (PCa) Columns. Pull out test on 27 specimens was carried out. Each one of the specimens represented the confined section of PCa columns, where steel sheaths were placed at the main bar positions and lapped with two bars each, and then, the main bars were inserted from the both sides of the sheath, so each main bar abutted at the middle height of the column specimens and high strength mortar was grouted inside. The influences of the following parameters were studied: loading history, diameter of main bars, lapping bar length, and concrete strength. The test results showed a good performance for developing the full strengths of main bars D25 (SD390) for concrete strength Fc= 400 kgf/cm^2 and D22 (SD390) for Fc= 300 kgf/cm^2, under the condition that the lapped length of 30 times the diameter of the lapping bars was used.

1. INTRODUCTION

At the present mortar grouted bar joints are commonly used in PCa columns in Japan, but they need special devices and technicians, and are located at the ends of members where the stresses due to seismic forces are large. A cheaper and simple joint method for PCa columns has been developed, which is used at the middle part of the members where the stresses are small. At the position of main bars, a sheath is placed and lapped with two bars each, then at the construction site the main bars are inserted into the sheaths, so the end of each bar abuts at the center of columns, and high strength mortar is grouted inside of the sheath. The stress transfer mechanism of the lapping joint method is that the stress of main bar is transferred progressively to the mortar and then to the half part of the lapping bars through the sheath by bond stresses, and from the other half part of lapping bars to the other main bar, reversely.

* Institute of Engineering Mechanics, University of Tsukuba
** Technical Research Institute, Kabuki Construction Co. Ltd.
*** Doctoral Degree Program, University of Tsukuba

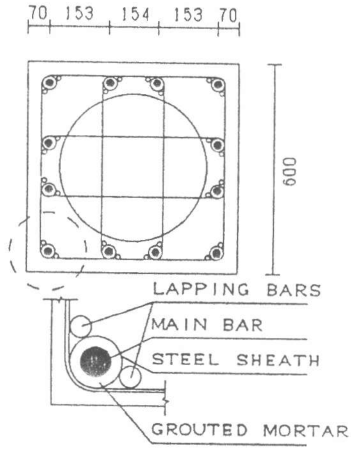
2. SPECIMEN

The test specimens were designed to represent a confined section of PCa columns with newly developed joints. Figure 1 shows the detailed section of typical specimens and Table I shows the differences among the test specimens. The specified concrete strength for centrifuged and ordinary PCa columns were Fc= 400 kgf/cm^2 and 300 kgf/cm^2, respectively. The specified strength for the core concrete of the centrifuged specimens were 240 kgf/cm^2. Also the specified compressive strength of the grouted mortar was 600 kgf/cm^2. Cover concrete from the surface to the lateral reinforcement was 40 mm thick.

Three different lapping lengths were chosen as 30, 25, and 20 times the diameter of the lapping bars. Depending on the tested main bars, the experiments were divided into Cases C, S, and F. Case C was defined as the test on the bars located at the corners, as well as Case S on the bars located at the side, and Case F on four bars tested at the same time.

Table I Differences Among Specimens

	Type of Specimen	Lapping Length (*d)	Specimen Length mm	Main Bar SD395	Lapping Bar SD395	Concrete Strength kgf/cm²
1	Centri-fuged	30	1200	D25	2-D19	400
2		25	1000			
3		20	800			
4		30	1000	D22	2-D16	
5		25	850			
6		20	700			
7	Monoli-thic	30	1000			300
8		25	850			
9		20	700			



Hoop: welded closed type

Fig. 1 Section of Specimen

A sheath of 38 mm outside diameter with lug height of 2 mm and pitch of 28 mm was selected in order to represent similar characteristics of deformed bars.

For main bars D25 and D22 with specified yield strength of 4000 kgf/cm^2 (SD390) were chosen. All the main bars were confined with hoops of D10 (SD295A) at 100 mm pitch .

For lapping bars, two bars of D19 and two D16 were used in the case of main bars D25 and D22, respectively. Therefore, the sectional area of two lapping bars was larger than the single main bar. The main bars were inserted into the sheaths from the bottom and high strength mortar was grouted inside, after the core concrete was cast.

Tables II and III show the properties of materials.

Table II Prop. of Materials

Specimen	Lapping Length	Specifi. kgf/cm²	Experim. kgf/cm²
1 - C S F	30d	400	348 435 437
2 - C S F	25d		381 379 454
3 - C S F	20d		408 379 454
4 - C S F	30d		467 363 392
5 - C S F	25d		462 365 392
6 - C S F	20d		390 419 453
7 - C S F	30d	300	301 290 292
8 - C S F	25d		326 271 226
9 - C S F	20d		299 310 307
Core Concrete		240	242 4 weeks
Mortar		600	729

2. TEST APPARATUS AND INSTRUMENTATION

The loading arrangement is shown in Fig.

2. Tension was applied horizontally to both ends of the main bars by oil jacks. Displacement between both ends of the main bars was measured. Also, strains at the center of lapping bars were measured.

3. LOADING HISTORY

Two types of loadings were applied to the specimens: monotonic and repeated loadings. For each specimen in Cases C and S, three bars were tested independently under monotonic loading, and the rest one under repeated loading. For Case F, four bars of each side were tested under repeated loading.

In the monotonic loadings, incremental loads of 1 ton were applied until yielding. Thereafter, the tests were continued under displacement control until the bars were pulled out. Until the first crack appeared, the load was applied slowly.

In the repeated loading, after applying the same loading as in the monotonic loading, the specimens were loaded to the level of 1.1 times the specified yield strength of main bars. Then loads of ten cycles were applied at each prescribed load. Thereafter the loading history was switched to the displacement control.

4. TEST RESULTS

4.1 CRACK PATTERNS

Figure 3 (a) shows schematically the typical crack patterns at the peak loads of specimens with the condition of D25 and 30d of Cases C, S, and F, where 30d means 30 times the lapping bar diameter.

For Specimen 1C-1 under monotonic loading, at 12 tons longitudinal cracks ① started at both ends. Also transverse cracks ② were initiated at 12 tons and ③ at 16 tons. These cracks propagated with the increments of loads. Before the peak load, transversal crack ④ at the middle part of the specimen and Y-shaped cracks suddenly appeared at both ends. At the peak load of 30 tons, the concrete of the side face spalled because the system bar-mortar-sheath split out. The

Table III Properties of Steel

Size	Grade	σ_y (tf/cm²)	σ_b (tf/cm²)	E (tf/cm²)
D10	SD295A	3.50	4.65	1810
D16	SD390	4.60	6.20	1840
D19		4.90	6.80	1840
D22		4.40	6.00	—
D25		4.50	6.20	1890

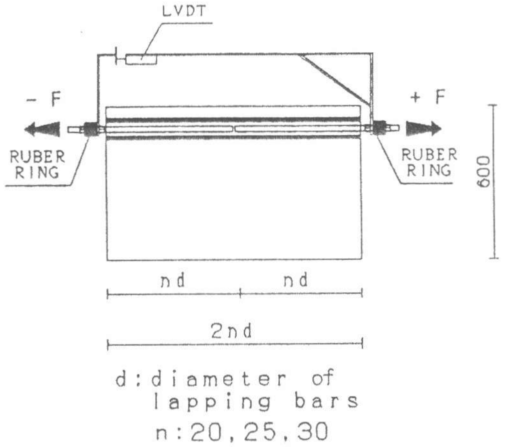
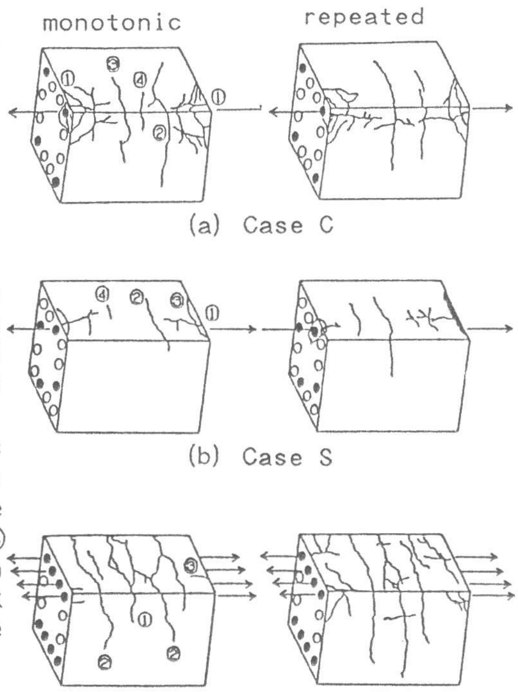


Fig. 2 Loading Arrangement



(a) Case C

(b) Case S

(c) Case F

Fig. 3 Crack Patterns

failure pattern was predominant over almost all specimens in Case C. The crack pattern of Specimen 1C-4 under repeated loading was similar to that of the specimen under monotonic loading.

For Specimen 1S-4 under monotonic loading as shown in Fig. 3 (b), at 10 tons longitudinal cracks ① appeared at both ends and propagated with the increments of loads. At 23 tons, just before the peak load, transverse cracks ② initiated at the location of 1/3 of the specimen length, and at the peak load the transverse cracks ③ at both ends and ④ at the center initiated. This was also a predominant crack pattern over almost all test specimens in Case S.

The crack pattern of Specimen 1S-1 under repeated loading was quite similar to that of the specimens under monotonic loading.

For Specimen 1F-1 under monotonic loading, Fig. 3 (c) shows that at 7 tons the transverse cracks ① appear at the center, and at 9 tons transverse cracks ② initiated at the location of 1/3 of the specimen length, at 12 tons longitudinal crack ③ initiated at right side. All cracks were propagated with the increments of load.

For Specimen 1F-2 under repeated loading, the crack pattern was similar to the monotonic one with the difference that Y-shaped cracks spread at both ends.

For main bars D22 with lapped length of 20d, concrete spalling was a common failure type for all the cases, especially with the bars at the corners.

4.2 LOAD-DISPLACEMENT RELATIONSHIPS

Figures 4 (a), (b) and (c) show the load-displacement relationships for Cases C, S, and F, respectively. The uppers and the lowers correspond to the test results under monotonic and repeated loadings, respectively. In almost all cases, when the bond failure was caused by splitting the bond resistance dropped suddenly to zero. Repeated loads were applied carefully, because the bond strength depended on the maximum loads reached previously.

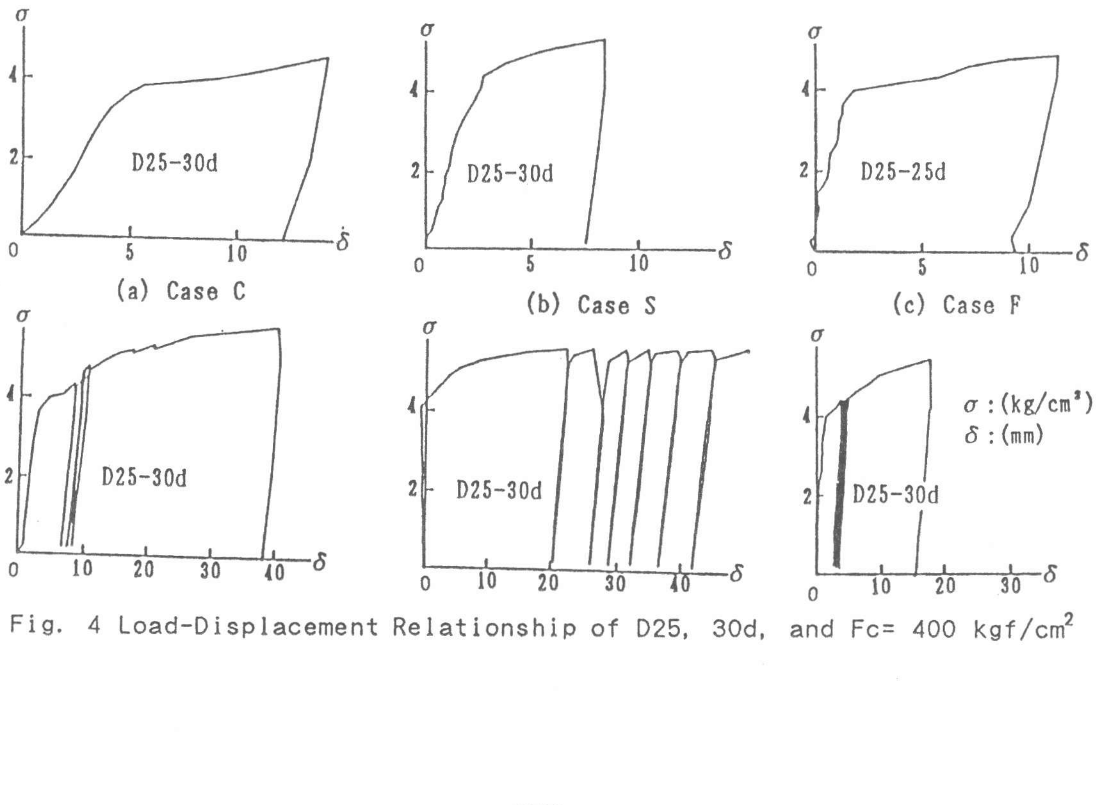


Fig. 4 Load-Displacement Relationship of D25, 30d, and Fc= 400 kgf/cm^2

4. 3 STRESS TRANSFER CAPACITY

Relations for all test specimens between lapping lengths, bond stresses, and main stresses at the maximum loads are illustrated in Fig. 5. These diagrams were deduced by converting applied maximum forces into bond stresses using Eq. (1) :

$$\tau = \frac{F}{\phi \cdot l} \qquad (1)$$

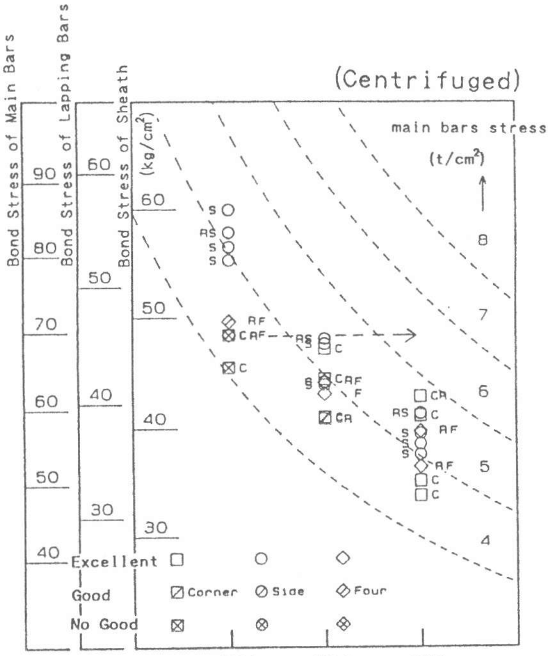
where

F = maximum applied force

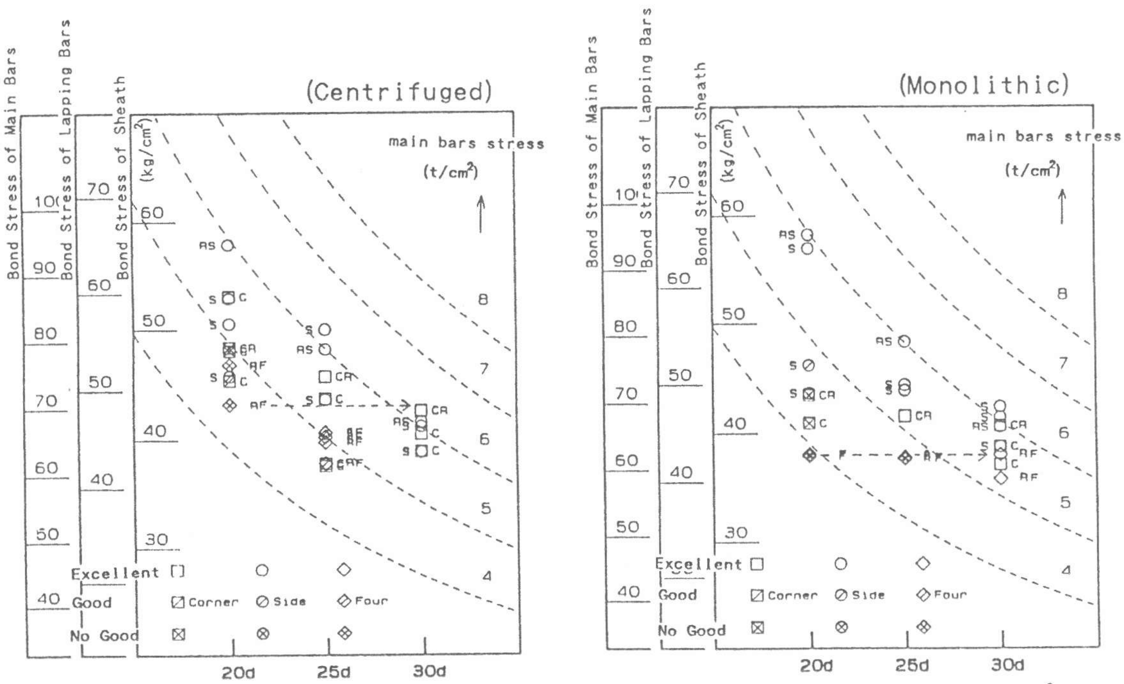
ϕ = perimeter of main bar, two lapping bars, or sheath

l = lapped length (=nd)

The marks □ , ○ , and ◇ denote the cases C, S, and F, respectively. R means test results under repeated loading. x, /, and blank inside of those marks mean the failure patterns during the tests. In case of blanks the ultimate bond strength was not reached and the main bar elongated into the range of strain hardening, having a good bond performance, especially for lapped length of 30d. For /, the



(a) D25 and Fc= 400 kgf/cm²



(b) D22 and Fc= 400 kgf/cm²

(c) D22 and Fc= 300 kgf/cm²

Fig. 5 Relations Between Lapped Lengths, Bond Stresses and Main Stresses bond performance was good enough for main bars to reach the ultimate stress after yielding, but finally main bars were sometimes pulled out. In case of x, the failure pattern was not good enough to transfer the full strength of main bars. The most of cases of x were for lapped length of 20d.

Case S showed better bond performances than Cases C and F. Since the stress condition of main bars in Case F is similar to the actual one under bending stresses, hereafter the results in Case F are focussed.

For bars D25 and concrete strength of Fc= 400 kgf/cm^2, Fig. 5(a) shows a good behavior at the lapped lengths of 20d, 25d, and 30d, where d is the lapping bar diameter, with all the experimental values over the specified yield stress of main bars of 4 ton/cm^2.

Figure 5(b) and 5(c) illustrate the experimental results of the centrifuged and monolithic concrete specimens with different concrete strengths and main bars D22 with different lapped lengths. Both of them have a good behavior for lapped length of 25d and 30d.

Developed stresses of main bars for lapped lengths of 30d were in the range of strain hardening without concrete failure. If the bond strength for the lapped length of 20d is assumed to be equal to the bond strength of 30d, the main bar stress becomes 6.5 t/cm^2 as is shown in Fig 5(a), by drawing a horizontal line from the test result for Case F at 20d.

5. CONCLUSIONS

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

1) If the bond failure is caused by splitting of concrete, the bond resistance drops rapidly to zero after the occurrence of splitting cracks.
2) During repeated loading the degradation of bond strength and bond stiffness depended on the maximum load reached previously.
3) The stress transfer capacity of the lapping joint located at the side of the column section is larger than that at the corner.
4) Joints with lapped length of 30d and concrete strength of 400 kgf/cm^2 can transfer the full strength of main bars D25 (SD395) and D22 (SD395) respectively, even if the four bars with distance of 150 mm between bars are stressed at the same time.

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