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論文 A Study on the Joint Strength of Lap Splices for Precast Concrete Structures

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ABSTRACT: Forty eight pullout specimens were tested in an objective to determine the changes in the joint strength of the lap splices while varying the lapping lengths. The results obtained are compared with calculated values from existing bond strength equations. It is also the aim of the experimental program to evaluate the effect of the presence of voids in the grout on the efficiency of the sheath-grout-main bar system in precast concrete structures. It was concluded that the presence of 20% void in the grout reduced the strength of the connection by about 12-16 percent.

KEYWORDS : joint strength, pullout tests, lap splice, sheath, grout

1. INTRODUCTION

The post-insertion method in precast concrete connections is utilized in this study. Providing both seismic resistance and construction efficiency, this method allows for the jointing of the main bars at the center of the members where seismic forces are small, and for the construction of simple precast members such as beams and columns. In this method, a simple and economical bar joint system is proposed wherein in the casting of the precast members, instead of main bars, metallic corrugated sheaths and lapping bars are embedded at the position of the main bars together with the lateral reinforcement. At the construction site, the main bars are then inserted into the sheaths to which high-strength mortar is later grouted, effectively fixing the main bars in the sheaths.

This investigation is a continuation of the series of tests done by Yanez [1] where the influences of sheath lug, thickness of cover concrete, lateral reinforcement ratio, loading history, splice type and splice position on the joint strength of lap splices were studied. The effect of the said parameters on the joint strength of the proposed connection were determined. However, no definitive trend was developed for the behavior of the connection while varying the lapping length since the lapping length was made constant at 20 times the lapping bar diameter for all the tests. This led to the idea of further investigating the joint strength of lapped splices at different lapping lengths. Also, the main bar was changed from D25 (SD390) to D25 (SD490). Such increase in the steel strength was made to insure failure before yielding since for most of the connections in previous tests, failure took place after yielding of the main bars. This study therefore aims to further investigate the joint strength of lap splices using the proposed sheath-grout-main bar connection technique. It is also the aim of this study to examine the effect of the presence of voids in the grout on the efficiency of the proposed technique.

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2. OUTLINE OF SPECIMENS

A total of 48 pullout specimens, designed to represent a confined section of precast beams, were tested. These specimens were divided into 6 groups indicating 6 lapping lengths: 10d, 15d, 20d, 25d, 30d and 35d, where d is the diameter of the lapping bar. In each group, four variations on the type of bar connection used were made: main bar without sheath, and with sheath having 0%, 10% and 20% void in the grout.

Table 1 Material Properties

a) Steel

SIZE (GRADE)	σ_Y tf/cm^2	σ_R tf/cm^2	E tf/cm^2	REMARKS
D10(SD295A)	3.82	5.24	1890	stirrup
D25(SD490)	5.36	7.29	1900	main and lapping bar
D13(SD295A)	not tested			top bar

b) Concrete

COMPRESSIVE STRENGTH(kgf/cm^2)	REMARKS	
	TYPE	LAPPING LENGTH
350	without sheath 0% grout void	10d,15d
368		20d
367		25d,30d,35d
337	10% and 20% grout void	10d,15d
338		20d
368		25d,30d,35d

*Spec. Comp. Strength = 300kgf/cm^2

c) Grout

DAYS	7	22	28
STRENGTH (kgf/cm^2)	491	706	725

*Spec. Comp. Strength = 600kgf/cm^2

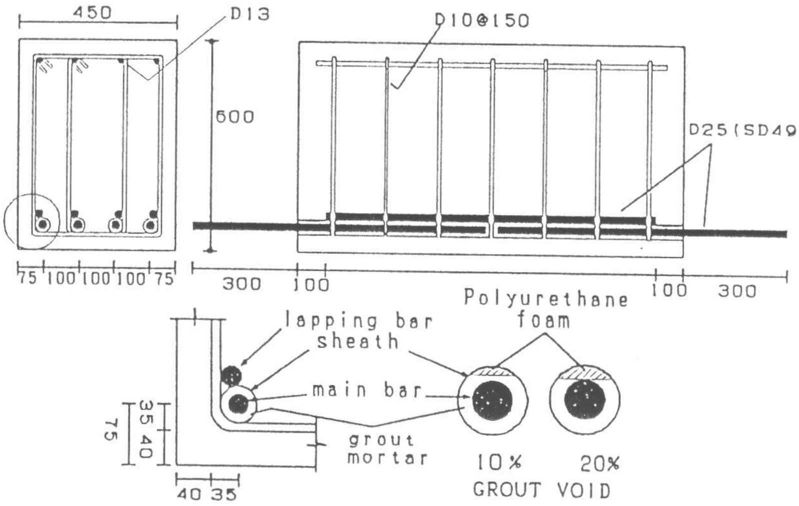


Fig.1 Specimen Cross Section and Longitudinal Details

The concrete of the specimens was cast horizontally. For the specimens with sheath, the sheaths were first set in a vertical position. Then from both ends of each sheath, two main bars were inserted until their ends meet at mid-height. Rubber caps was placed at the lower end of the sheaths to prevent mortar leakage. High-strength mortar was then grouted from the top end filling the space between the sheath and the main bar. In the actual construction of precast beams utilizing sheaths however, the mortar is grouted with the sheaths in a horizontal position. This horizontal grouting may cause the formation of a void space in the sheath when the grout settles. This case is represented by 10 and 20% voids in the grout parameters. For the specimens with grout voids, the voids were accomplished by an appropriate amount of polyurethane foam inserted in the sheaths before the mortar is grouted as shown in Fig. 1. Two specimens were constructed for each variation totalling to 48 specimens.

Main bars of size D25 with a specified yield strength of 5000kgf/cm^2 (SD490) were used. Although D25 with a specified yield strength of 4000kgf/cm^2 (SD390) is commonly used in actual design, steel with a higher strength was chosen to insure bond failure before yielding of the main bars. Screw-type bars are used for main bars in this system for convenience although in ordinary constructions, bamboo-type main bars are commonly used in Japan. A single lapping bar of the same diameter as the main bar was chosen. A cross section of 600mm x 450mm and a side and bottom concrete cover of 40mm was typical for all specimens. 4-D10 (SD295A) stirrups spaced at 150mm on centers were used as lateral reinforcements. Bending for anchorage (135^0 hook) was done at the top bars where there were no sheaths. The specimen cross section and longitudinal details are shown in Fig. 1. A sheath diameter of 42mm with a lug height of 2mm and a pitch of 28mm was used. The specified compressive strength for concrete and grout mortar was 300kgf/cm^2 and 600kgf/cm^2, respectively. Properties of materials obtained from tests are listed in Table 1.

3. TEST SET-UP

A schematic view of the test set-up is shown in Fig. 2. The specimens were inverted at the time of testing. Tensile load P was gradually applied to each of the four bottom main bars by oil jacks controlled by a load cell in 1.0 ton increments until bond failure occurred. At each load stage, the deformation of the two main bars were measured. The measurement was done by linear voltage displacement transducers (LVDT) attached to both ends of two main bars by means of a steel frame. The actual deformation of the main bars were obtained by extrapolation of the values measured by the transducers. The test was halted after the ultimate load was reached.

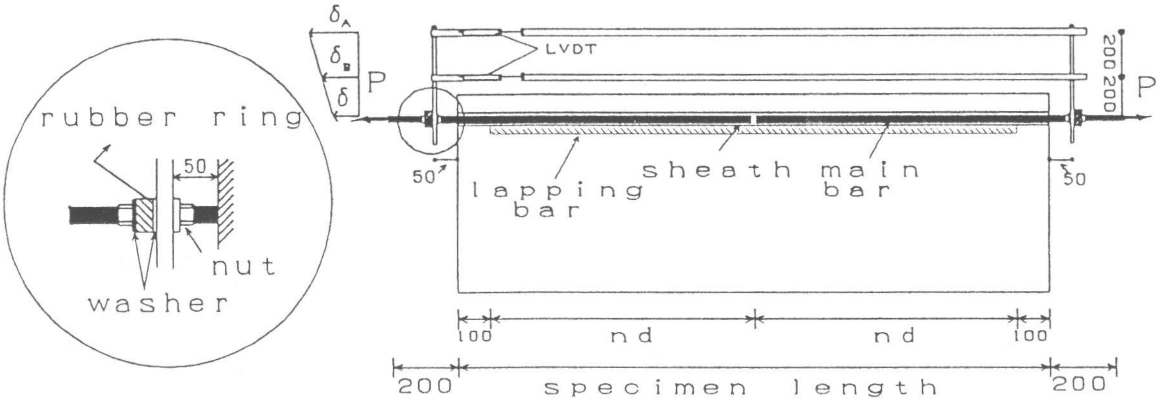


Fig. 2 Schematic View of Test Set-Up

4. RESULTS AND DISCUSSION

4.1 Failure mode

Schematic illustrations of the typical cracking patterns for specimens with different lapping lengths are shown in Fig. 3. All specimens with a lapping length of 10d, 15d and 20d exhibited side splitting mode of failure. Failure took place before yielding of the main bars. At the early stage of loading, cracks perpendicular to the main bar occurred at the mid-portion of the cover, where the main bars abutted. As loading continued, more cracks occurred at distances from the middle initiating longitudinal splitting cracks in the side cover adjacent to the bars. Failure occurred just after side splitting cracks started forming along the splices at the mid-portion of the specimen towards the loaded ends. Also, diagonal cracks were severe at the loaded ends impending spalling off of the corner concrete at failure.

The final mode of failure for specimens with lapping length of 25d, 30d and 35d was a face-side split failure. Failure took place before yielding of the main bars for specimens with a lapping length of 25d and for those with a lapping length of 30d with sheath and 0% grout void. For the rest, failure occurred after yielding of the main bars. The first cracks occurred at mid-length of the specimens. With the increase of load, more cracks appeared and longitudinal splitting cracks started forming. The longitudinal cracks appeared in the bottom cover directly below the splices and in the side cover adjacent to the bars inducing a face-side split failure at the final stage. At failure, concrete was cracked throughout its full length and a corner main bar or sheath (for specimens with sheaths) was pulled out together with a lump of concrete.

Specimens with 10 and 20% void in the grout exhibited similar cracking patterns as those without sheaths and with 0% grout void. The cracks however, are more pronounced and with heavier density. Also, no direct pullout of main bars from the sheaths occurred in any of the specimens indicating still adequate grout confinement up to a grout void of 20%.

4.2 Load displacement relationship

Load-displacement relations of main bars which are transformed into average stress-strain diagrams for different lapping lengths are shown in Fig. 4. Replicates of all specimens gave comparable results indicating validity of the test data. For specimens with a lapping length of 10d, 15d and 20d, the stiffness of the load-displacement curves of bars with 0% grout void were slightly less but the behavior is comparable to that of the bars without sheath. The ultimate load at failure is almost the same for these specimens. The specimens with 10 and 20% grout void, on the other hand, showed a less load-displacement curve performance. There was a reduction of strength of about 12 to 16 percent for these specimens.

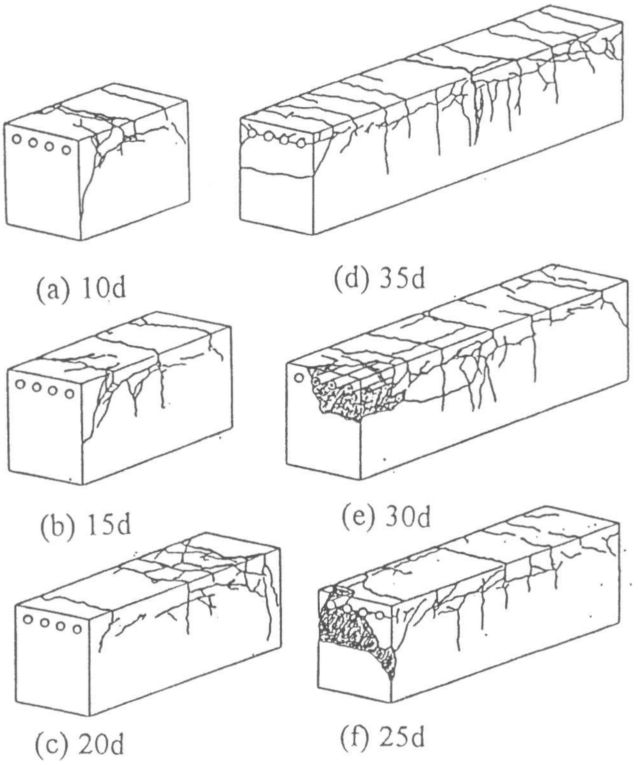

(a) 10d
(d) 35d
(b) 15d
(e) 30d
(c) 20d
(f) 25d

Fig. 3 Typical Cracking Patterns
(0% grout void specimens)

Load-displacement curves of bars with lapping lengths of 25d and 30d indicated the same pattern of behavior. The ultimate load at failure of the bars with voids in the sheath are almost identical to that of the bars without sheath and with 0% void. Strength reduction ranging from a negligible amount to 10 percent are noted for these specimens. Load-deformation curves of specimens with a lapping length of 35d, which failed after yielding, showed large displacements before ultimate failure occurred.

The ultimate loads sustained by the specimens with different lapping lengths and the corresponding deformations of the connection are shown in Fig. 5. The ultimate load and deformations are expressed

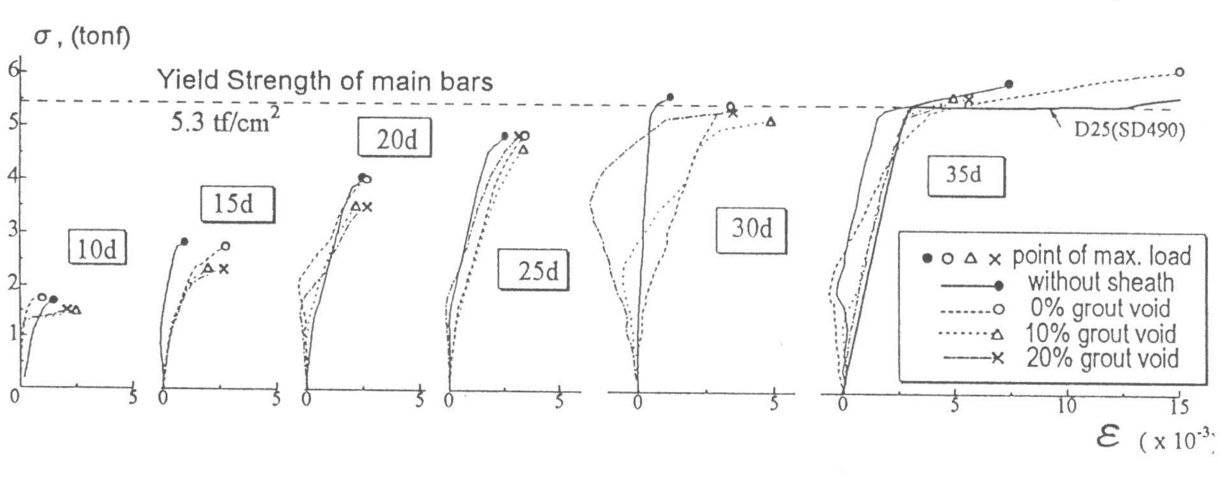
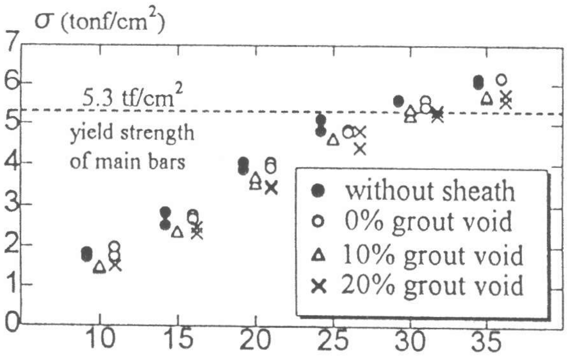


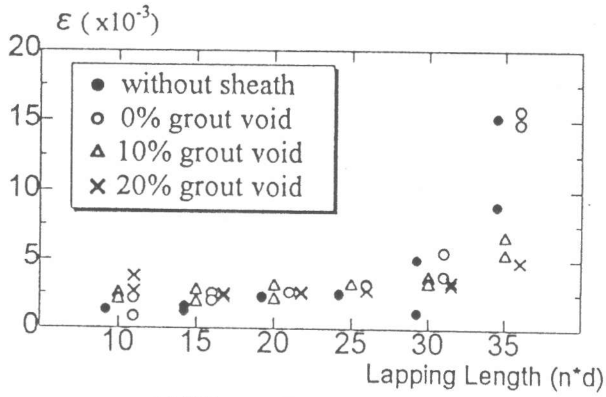
Fig. 4 Load-Displacement Curves

in terms of tensile stress and average strain, respectively. It can be seen from Fig. 5(a) that the ultimate strengths reached by specimens with lapping lengths of 20d and 30d are about 4 tf/cm^2 and 5 tf/cm^2, respectively. This suggests that there is no significant strength improvement with such an increase in the lapping length. Also, there is not much difference between the ultimate strength sustained by the specimens without sheath to those with 0% grout void. The specimens with grout void exhibited a similar behavior but with a decreased strength.

It can be observed from Fig. 5(b) that the increase in deformation is small up to a lapping length of 25d. Beyond this, deformation increases considerably due to the yielding of the main bars at failure. Figure 6, on the other hand, shows that tensile strengths and average strains follow the stress-strain curve of the continuous main bar but is stiffer and with a higher yield strength. This can be attributed to the combined confinement provided by the surrounding concrete and lapping bar on the jointed connection.



a) Ultimate Strengths



b) Ultimate Deformations

Fig. 5 Relationship between Lapping Length and Ultimate Strength and Deformation

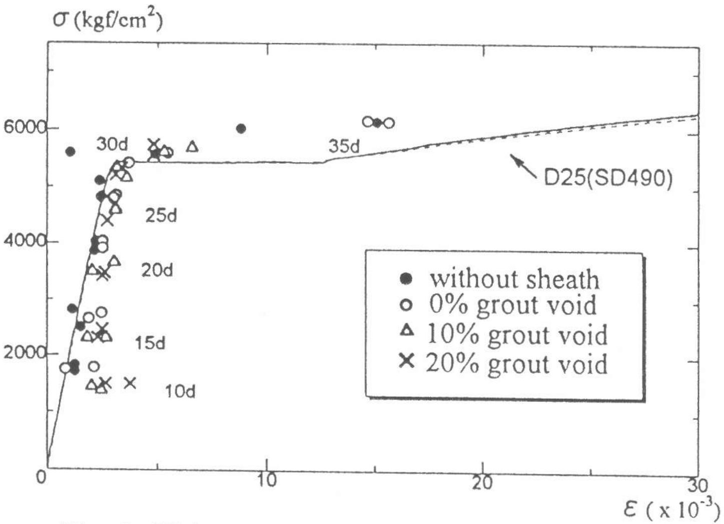


Fig. 6 Ultimate Loads and Deformations Plotted in the Stress-Strain Curve of Main Bar

4.3 Joint strength

Figure 7 shows the bond stresses of the main bar, sheath and lapping bar plotted at different lapping lengths. Separate graphs are drawn for specimens without sheath and with 0, 10 and 20% grout voids. The values obtained are compared with values calculated from bond strength equations proposed by Fujii-Morita [2], Orangun-Jirsa-Breen [3], and Jimenez-White-Gergely [4]. It is worthy of noting that the Fujii-Morita equation was developed for continuous bars while the Orangun and Jimenez equations were derived for bars with lap splices. The calculated bond strengths were obtained by assuming splitting failure at the perimeter of the lapping bar. The same assumption was done by Yanez [1] in a related experiment.

An excellent agreement existing between experimental bond strengths and those calculated from the equations of Orangun and Jimenez can be observed from the graph for specimens without sheath and 0% grout void in the sheath. This holds true for lapping lengths greater than 15d with the Orangun equation predicting a slightly higher value than the experimental results for specimens with lapping length of 35d. Specimens with 10 and 20% grout voids exhibited the same pattern of behavior with increasing lapping lengths but with expected lower strengths than the calculated values. The Orangun and Jimenez equations, however, overpredict the ultimate bond strength for smaller lapping lengths (10d and 15d). Although, for these specimens, the calculated values obtained from Fujii-Morita equation seems to be in good agreement, the sample is small and may not be significant. Further investigation is needed to clarify the behavior of smaller lapping lengths.

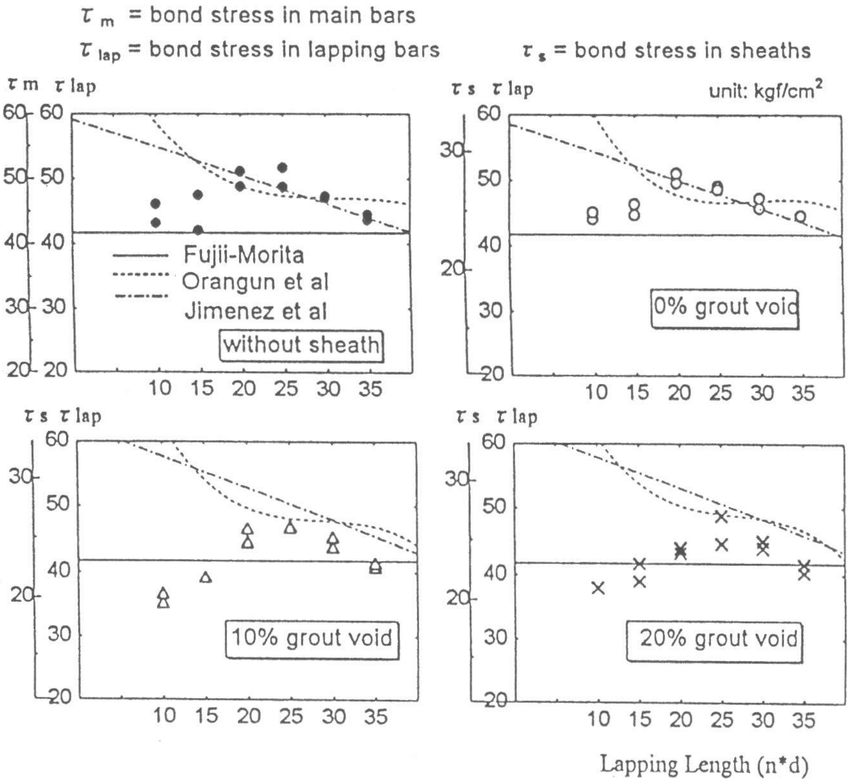


Fig. 7 Relationship between Lapping Lengths and Bond Strengths

5. CONCLUSIONS

Based on the analysis and comparison of the test results of 48 pullout specimens, the following conclusions were made:

1. The strength of the splice joint with 0% grout void in the sheath is almost identical to the strength of the conventional lapping joint .
2. The presence of the void in the grout reduced the strength of the connection by about 12-16 percent for lapping lengths of 15d and 20d and by about 10% for longer lapping lengths.
3. There was no direct pull out of the main bars from the sheaths. This indicates that even with an allowance of up to 20% void in the grout , the sheath-grout-main bar system can act effectively as a unit.
4. The Orangun-Breen-Jirsa and the Jimenez-White-Gergley equations can be used to estimate the bond strength of the proposed bar joint for lapping lengths in the range of 20-30 times the diameter of the lapping bar.

REFERENCES

1. Yanez, R., Castro, J.J., Yamaguchi, T. and Imai, H., "An Experimental Study on Joint Strength of Spliced Bars using Spiral Sheaths for Precast Concrete Structures", Journal of Structural and Construction Engineering of AIJ, No.469, March 1995, pp. 91-104.
2. Fujii, S., Morita, S., "Splitting Bond Capacity of Deformed Bars(Part 2), A Proposed Ultimate Strength Equation for Splitting Bond Failure (in Japanese)", Transactions of AIJ, No. 324, February 1983, pp. 45-53.
3. Orangun, C.O., Jirsa, J.O., Breen, J.E., "A Re-evaluation of Test Data on Development Length and Splices", ACI Journal, Vol. 74, March 1977, pp.114-122.
4. Jimenez, R., White, N., Gergely, P., "Bond Dowel Capacities of Reinforced Concrete", ACI Journal, Vol. 76, No. 1, January 1979, pp. 73-92.