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論 文

[2107] Effect of Confining Reinforcement on the Behavior of Lapped Splice Connection between Steel Bar and Steel Plate

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1. INTRODUCTION

The trend of utilizing mixed structure system has led to the need of establishing rational design method for connection of different structural types. One of the basic problem for design is the tensile connection between steel bar and steel plate in concrete medium. Such a connection can be the connection between reinforced concrete member and open-sandwich member. Although it has been revealed[1)] that lapped splice method is one of the possible ways dealing with this connection. However its capacity is quite low and the failure is brittle. To improve its behavior, the confinement of splice is considered in this study.

2. EXPERIMENTAL WORKS

The experiments of lapped splice connection between open-sandwich member and reinforced concrete member were conducted by using beam specimen as shown in Fig.1. The specimens were loaded by two symmetrical point loads. Lapped splice was placed in the constant moment region. Concrete with the maximum size aggregate of 5 mm was cast in the direction as shown in Fig.1. Steel plate having 4.3 mm thick was lapped to 19 mm diameter of deformed bar. 2.3 mm thick by 20 mm high steel plates used as shear connector were welded on base plate with 100 mm constant spacing. The bottom covering of 30 mm were kept constant for lapped bar of all specimens. Reinforcing bars were used to confine the lapped splice. The mechanical properties of reinforcing bars are given in Table 1. The degree of confining ($A_{st}\ n\ f_y/\ s_{st}$) which varied the number of confining

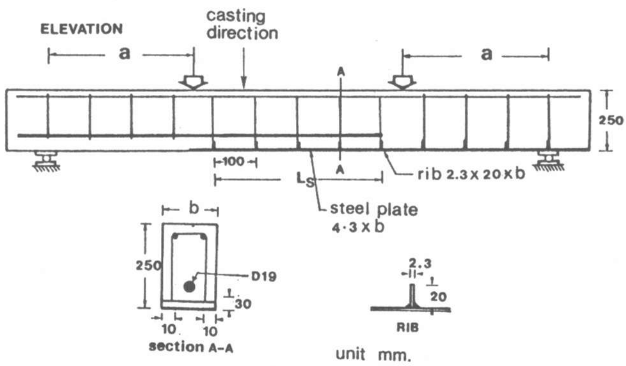

Fig.1 Details of specimens

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reinforcing bars (n) welded diameter (3 mm, 6 mm, 10 mm) and their spacing (s_{st}) was mainly the studying parameter. The details of each specimen are given in Table 2. The lapped length was also varied in this test from 200 to 400 mm. In the test, the applied load, deflection at the middle span of beam and strains at each confining reinforcement and along the lapped bar were measured.

at the position of shear connector, their

Table 1. Mechanical properties of reinforcing bar

BAR	YOUNG'S MODULUS E_s, GPa	YIELD STRENGTH f_y, MPa
D3	195	301
D6	187	343
D10	187	364
D19	189	358

Table 2. Details of specimen

SPECIMEN	b mm	d_b mm	l_s mm	A_{st} mm^2	S_{st} mm
CONF-0	100	19.1	400	-	-
CONF-1				14.1	200
CONF-2				14.1	100
CONF-3				63.3	100
CONF-4				142.7	100
CONF-5			400	14.1	100
CONF-6	80		300	14.1	100
CONF-7			200	14.1	100
CONF-8			200	28.2	100
CONF-9				42.3	100
CONF-10				63.3	100
CONF-11				142.7	100
CONF-12	100	22.2	400	14.1	200

Note A_{st} : an effective area of confine reinforcement
= 2n x cross-sectional area of confine bar
n : number of bars welded on each rib
S_{st} : spacing of confine reinforcement

3. BEHAVIOR OF LAPPED SPLICE

From the test results, effect of confinement on behavior of lapped splice was discussed below.

3.1 Crack pattern and failure mode

The similar flexural cracks and side splitting cracks to lapped splice without confinement were also found in lapped splice with confinement. However, more inclined cracks initiated from rib shear connector were developed as shown in Fig.2. Large flexural crack was concentrated at the end of plate after the specimen

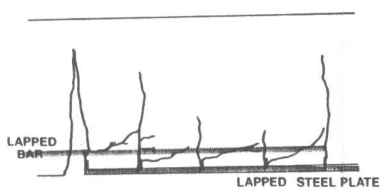


Fig.2 Crack pattern

reached its ultimate load. The failure of specimens was mostly failed in lapped splice which was characterized by side splitting failure mode as shown in Table 3. The failure occurred when side splitting crack generated along the lapped bar. Then the load was decreased and the lapped bar was pullout. Some specimens (CONF-3, CONF-4, CONF-11) which were highly confined in lapped splice were failed by flexural failure of adjoining reinforced concrete member initiated by yielding of lapped bar.

Table 3. Test results of capacity of lapped splice and failure mode

SPECIMEN	f'c MPa	Pult kN	FAILURE MODE
CONF-0	24.5	61	S
CONF-1	24.5	79	S
CONF-2	33.5	102	S
CONF-3	24.5	-	Y
CONF-4	24.5	-	Y
CONF-5	37.3	108	S
CONF-6	33.1	71	S
CONF-7	23.1	41	S
CONF-8	30.5	61	S
CONF-9	30.5	70	S
CONF-10	23.1	72	S
CONF-11	33.1	-	Y
CONF-12	33.5	90	S

NOTE : Y = yielding of lapped bar
S = side splitting failure

3.2 Confining behavior

It is known that the failure of lapped splice is mainly governed by splitting capacity of concrete at the plane through the lapped bar. To strengthen this failure plane, confining reinforcement is considered. Fig.3 shows the strain behavior of confining reinforcement at the different positions along lapped splice. As the load which was applied to lapped bar was increased, the strains of confining reinforcements was also increased. The increment of strain for confining reinforcement were slow at the beginning and rapid when the splitting crack began to propagate from the end of plate. At the failure of the splice, almost confining reinforcement strains of specimens associated with side splitting failure reached the yield value. This shows that confinement by reinforcement can be fully utilized. In lapped splice between reinforcing bars, the confining reinforcement can not be effectively utilized as the lapped splice between steel bars and steel plate. Many studies[2,3] related to lapped splice between reinforcing bars had been reported that the transverse reinforcement strain at failure of splice still remained within the elastic limit. The different behavior is due to the difference of confining condition as shown in Fig.4. In lapped splice between reinforcing bars, transverse reinforcement can confine lapped splice by bearing behavior of transverse reinforcement below lapped bar. The confined situation is

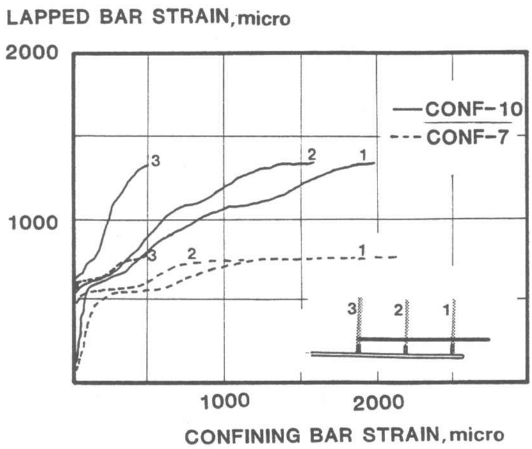
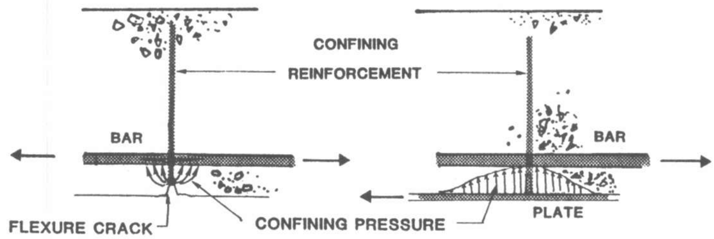


Fig.3 Confine reinforcement strain behavior in lapped splice

similar to hoop reinforcement in the column.



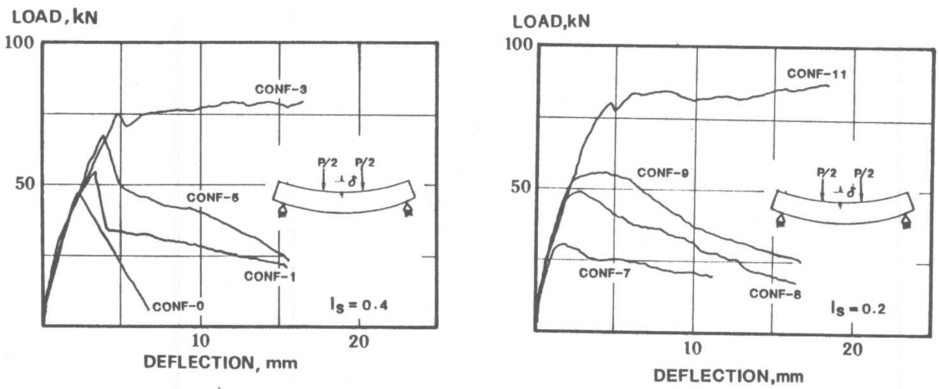
a) bar-bar b) bar-plate

Fig.4 Confining mechanism in lapped splice

Comparing to lapped splice between steel bars and steel plate, the confinement was accomplished by bearing of steel plate. The bearing of steel plate can confine lapped splice more uniformly like the pressure and is not affected by flexural cracks. However, the flexural cracks usually developed at the location of transverse reinforcement will affect the loss of bearing mechanism of bar as shown in Fig.4a. Therefore, better confining behavior can be found for lapped splice between steel bars and steel plate than ordinary reinforcement lapped splice.

3.3 Ductility of lapped splice

Concerning ductility behavior of lapped splice, the load-deflection curve of tested specimen measured at the center of specimen was considered. Fig.5a and Fig.5b show the load-deflection curve of tested specimens having different lapped length of 400 mm and 200 mm respectively. Both figures indicate that brittle behavior was found for specimens failed in lapped splice which is side splitting failure. For the specimens failed by flexural failure of adjoining reinforced concrete member, however, showed the ductile behavior.



a) b)

Fig.5 Load-deflection curve

It is noted that under the failure of splice, ductility behavior of splice can not be improved much by additional confinement. This reveals that in the structural design consideration, the failure of splice should be avoided.

3.4 Local bond behavior along lapped bar

The separation of concrete from lapped bar caused by splitting will reduce the bond force of bar along lapped length. The existence of confining reinforcement can restrain the separation of splitting crack leading to the improvement of bond behavior. Fig. 6 shows the strain distribution of lapped bar along lapped length at the load step just before the failure. From the strain distribution curve, the local bond stress behavior along lapped bar can be observed by its slope. The test results reveals that the local bond stress, especially near the end of plate where the splitting crack is exist, becomes increased and uniformly distributed as the degree of confinement is increased.

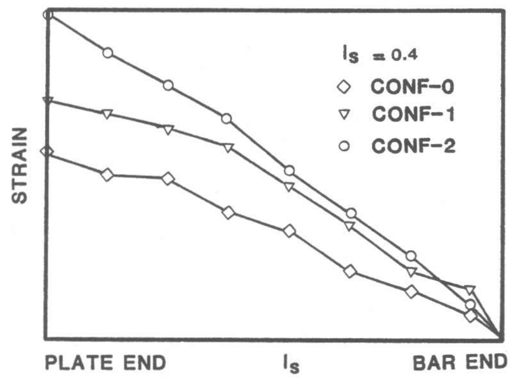


Fig.6 Strain distribution along lapped splice

3.5 Capacity of lapped splice

The test results of capacity of confined lapped splice given in Table 2. had been compared to the equation for predicting the capacity of lapped splice without confinement. Increasing capacity of lapped splice was found for lapped splice with confinement. For sake of the simplicity, the effect of confinement on capacity of lapped splice was considered as the additional capacity to the capacity of lapped splice without confinement leading to the following equation.

$$P_s = P_{ult}\,(\text{test}) - P_c \qquad (1)$$

where P_s : the additional bar force of confined lapped splice (MN),

P_{ult} (test) : the test results of ultimate bar force at end of plate for lapped splice with confinement(MN),

P_c : ultimate bar force for lapped splice without confinement[1)] (MN),

$$= (0.08\ B_s\ f_t + 0.5)\ (d_b\ l_s)^{2/3} \qquad (2)$$

B_s : normalized effective width of concrete area, $= (b-n_b . d_b)/n_b . d_b$

b : beam width(m),

n_b : number of lapped bars arranged within "b"

d_b : lapped bar diameter(m),

f_t : tensile strength of concrete (MPa),

l_s : lapped length (m).

Based on above definition (Eq.1), the additional capacity of lapped splice (P_s) can be evaluated. Since the confinement was fully utilized in lapped splice, therefore, the relationship between the value P_s and degree of confinement ($A_{st}\ n\ f_y / s_{st}$) was considered to represent the effect of confinement as shown in Fig.7. Although there was an deviating error for predicting ultimate bar force of unconfined lapped splice (P_c) causing an intercept value shown in Fig.7, the effect of confinement can be found to be a linearly increased of P_s as the degree of confinement was increased for each lapped length. This increasing behavior is also found to be larger than lapped splice between reinforcing bars[2]. This is because of the different confining mechanism as explained in section 3.2

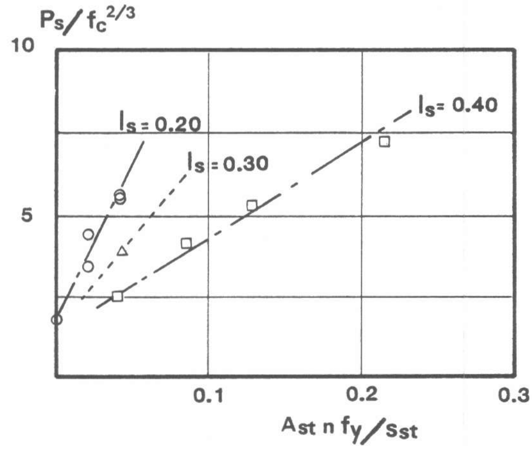


Fig.7 Effect of degree of confinement on capacity of lapped splice

4. CONCLUDING REMARKS

Based on the test results, the significant findings relating to confined behavior of lapped splice can be concluded as follows :

1) Brittle failure of lapped splice is not significantly improved by confinement in lapped splice,

2) The increasing capacity of confined lapped splice seems to be linearly related to degree of confinement,

3) The additional capacity of lapped splice due to confining reiforcement for the lapped splice between steel bar and steel plate is more effective than for lapped splice between reinforcing bars.

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