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論 文

[2130] 鉄筋と鋼板の重ね継手による応力伝達性能

THE CAPACITY OF LAPPED SPLICE CONNECTION BETWEEN DEFORMED BARS AND STEEL PLATE (SIDE SPLITTING FAILURE MODE)

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1.INTRODUCTION

Since demand for structures recently requires very complicated performance, only one type of structures, for instance, steel structure or reinforced concrete structure, may not able to meet the requirement of structures. The structural system, therefore, trends to be formed as a system of mixed structures. This system leads to the unavoidable connection joints of different types of structures, which is one of the problems arising in structural design method. One of these typical connection joints is the joint between the member in which structural steel plate is employed and the member in which reinforcing bars is utilized such as the connection joint between open-sandwich member and reinforced concrete member. Due to simplicity and flexibility in construction method, lapped splice connection is considered as a possible approach to treat this kind of connection joint. The way of splicing is to overlap between reinforcing bar and steel plate with welded rib and to make concrete responsible for flow of force in lapped splice. With the aim to develop the design method for this type of connection joint, performance of lapped splice between deformed bar and steel plate designated as " composite lapped splice" was investigated in this study.

2. TEST PROGRAM

The experiments of the lapped splice between deformed bars and steel plate in concrete medium were conducted by using beam specimen as shown in Fig.1. Testing beams were the simply supported beams loaded by two symmetrical loading points. At a constant moment region, two 13 mm diameter of deformed bars were lapped to steel plate. The specimens were cast with mortar having maximum size aggregate of 5 mm. The casting direction is also shown in Fig.1. Four test series with different parameter investigation given in Table 1. were included in the test program. The study parameters cover the effects of rib shape (plate shape, T-shape, L-shape), rib spacing (s), bottom covering (c_b), side covering (c_s), plate thickness (t), and lapped length (l_s).

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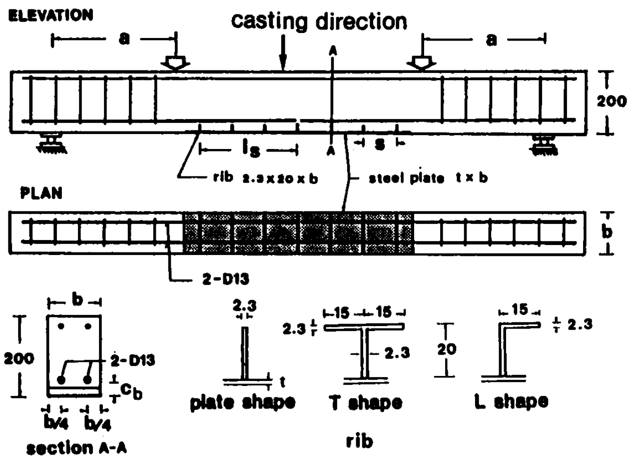


Fig.1 Detail of specimen.

TABLE 1. DETAILS OF SPECIMENS

SPECIMEN	rib shape	b mm	t mm	s mm	c_b mm	l_s mm
SC 6-2	P	150	2.3	64	20	350
SC14-2	P	150	2.3	140	20	350
SC23-2	P	150	2.3	233	20	350
SC35-2	P	150	2.3	350	20	350
SC 6-5	P	150	2.3	64	50	350
SC10-3	P	150	2.3	100	33	350
SL-10	P	150	2.3	100	30	100
SL-20	P	150	2.3	100	30	200
SL-30	P	150	2.3	100	30	300
SL-40	P	150	2.3	100	30	400
SL-45	P	150	2.3	100	33	450
SL-50	P	150	2.3	100	30	500
SL-60	P	150	2.3	100	30	600
SST	T	150	2.3	100	30	300
SSL	L	150	2.3	100	30	300
SB-7	P	70	4.5	100	30	300
SB-10	P	100	3.2	100	30	300
SB-152	P	150	2.3	100	30	300
SB-154	P	150	3.2	100	30	300
SB-20	P	200	1.6	100	30	300

P : plate shape T : T-shape L : L-shape

3.CRACK PATTERN AND FAILURE MODE

Fig.2a shows the observed crack pattern occurred in composite lapped splice. Two types of cracks which are flexural cracks and side splitting cracks existed in the splice. The flexural cracks were firstly developed and likely initiated from rib position. The side splitting cracks were following cracks which also propagated from rib positions and directed to the bar end. Bond stress deterioration of bar due to side splitting cracks was extended from the ends of splice to the center portion of splice, which is similar to lapped splice of reinforcing bar. No bottom crack was observed in spite of less bottom covering than side covering.

According to the geometrical arrangement of deformed bars in composite lapped splice, two failure modes, side splitting failure mode and rib failure mode, were distinguished. With sufficient rib shear connectors arranged in the splice, failure of all tested specimens was due to the side splitting failure mode. The failure was sudden and concrete was split at the plane where the steel bars were located as shown in Fig.2b. This mode of failure is similar to splitting mode of bond failure. The rib failure mode was found in the specimen with large spacing of rib. The forces transferred to the rib exceeds the capacity of rib, causing the large deformation and delamination of steel plate from concrete, then the transferring mechanism is destroyed. This type of failure was found only in specimen SC35-2 as shown in Fig.2d.

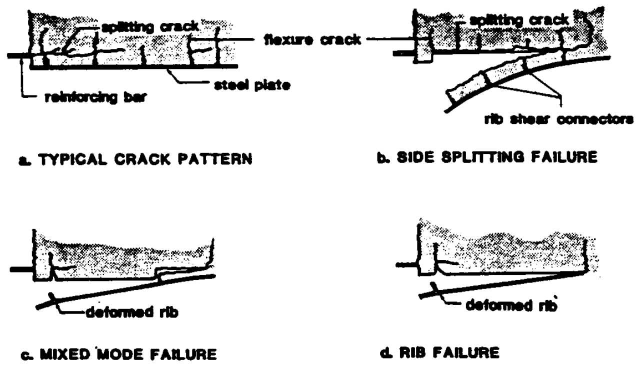


Fig.2 Crack pattern and failure mode.

4. CAPACITY OF LAPPED SPLICE UNDER SIDE SPLITTING FAILURE MODE

4.1 Parameters Affecting Capacity of Lapped Splice

The results of ultimate capacity of lapped splice in term of bar bond strength are given in Table 2. Various parameters affecting capacity of splice are as follows.

Under the side splitting failure mode, no effect of plate thickness, rib shape and rib spacing on capacity of lapped splice was observed.

TABLE 2. COMPARISON OF ULTIMATE BOND STRENGTH BETWEEN TEST RESULTS AND CALCULATED VALUES

SPECIMEN	f_c MPa	τ ult(test) MPa	τ ult(cal) MPa	FAILURE MODE
SC6-2	28.44	2.45	2.76	S
SC14-2	32.55	2.66	2.92	S
SC23-2	32.75	2.57	-	M
SC35-2	34.61	1.99	-	R
SC6-5	30.40	2.79	2.84	S
SC10-3	33.44	2.98	2.96	S
SL-10	27.45	4.33	4.11	S
SL-20	27.75	3.32	3.28	S
SL-30	25.10	3.08	2.76	S
SL-40	25.10	2.78	2.51	S
SL-45	27.46	2.59	2.50	S
SL-50	27.75	2.16	2.43	S
SL-60	27.45	1.96*	2.23	S
SB-7	28.73	1.67	1.72	S
SB-10	29.42	2.40	2.12	S
SB-152	28.73	3.34	2.92	S
SB-154	29.42	3.31	2.94	S
SB-20	28.73	4.03*	3.66	S
SST	21.67	2.66	2.60	S
SSL	21.67	2.43	2.60	S

NOTE * : bond strength at yielding of reinforcement
S : side splitting failure mode
M : mix mode of failure
R : rib failure mode

Effect of clear distance between rib and bar (s_b) : This effect represents the degree of disturbance from rib. The farther this distance (s_b) implies the less degree of disturbance. At approaching zero degree of disturbance, bond strength of steel bar becomes equal to strength of bar anchorage. The results of splice capacity in specimens SC6-5 and SC6-2 may reflect this effect. The difference in the capacities, however, is not much, compared with this difference in the clear distance. This distance is practically not much varied, so that the effect of this clear distance can be considered as a constant effect.

Effect of side covering (c_s) : According to the splitting failure mode for lapped splice and anchorage of bar, side covering can provide the resisting capability of splitting action which enable capacity of lapped splice and anchorage to be increased. The same characteristics were observed in SB series of composite lapped splice. As shown in Fig.3, the similar linear effect of side covering on capacity of lapped splice was disclosed for composite lapped splice and bar anchorage of Chamberlin.[1] However, at nearly same l_s/d_b, the capacity of composite lapped splice is less than capacity of bar anchorage. This is because of the disturbance effect from steel plate as discussed above.

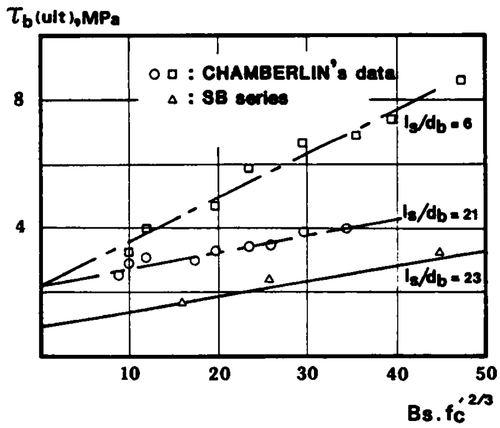


Fig.3 Effect of side covering on capacity of lapped splice.

Effect of lapped length (l_s) : From the test results of SL series as shown in Fig.4., it was found that increasing of lapped length trends to decrease capacity of lapped splice. It is revealed that at failure, percentage of bond deterioration zone in lapped splice is the greater, the longer lapped length is. These test results are compared with those of bar anchorage[1] and bar lapped splice [2] as shown in Fig.5. The similar effect of lapped length is observed.

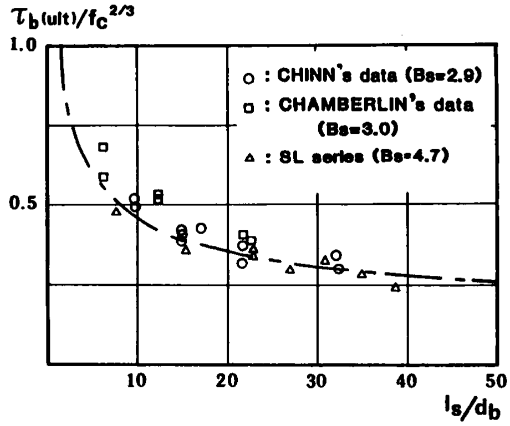


Fig.4 Effect of lapped length on capacity of composite lapped splice.

Effect of bottom covering (c_b) : In spite of less bottom covering than side covering as shown in specimens SC6-2 and SC14-2, it was found that capacity of composite lapped splice was still governed by side splitting failure mode which was different from lapped splice of bar. The reason is that existing rib can provide the role of transverse reinforcement preventing bottom crack by friction behavior along the rib face and steel plate. Therefore, failure of this lapped splice is mainly due to side splitting failure mode. Practically, this bottom covering effect is believed to be negligible

Although the similar behavior to reinforcing bar lapped splice and anchorage was observed in composite lapped splice, capacity of composite lapped splice is 30-50% less than that of lapped splice and anchorage of bar evaluated from available equations.[3,4] The reason is explained by comparing mechanism between reinforcing bar lapped splice and composite lapped splice as shown in Fig.5. According to Beeby's suggestion,[5] the possible bond stress and bursting stress distribution around the bar lapped splice are prescribed in Fig.5. Force transferring mechanism for bar is three dimensional, but, for steel plate with rib on it, the mechanism is more like two dimensional. Therefore, for bar, bursting stress which develops around its circumference will produce the resultant forces in the orthogonal direction (X,Y-direction) while for steel plate, total bursting forces are concentrated only Y-direction. As the results, larger splitting forces than in reinforcement lapped splice appear along side splitting failure plane for composite lapped splice. The increased bursting force ($\nu \sigma_p d_b$) in composite lapped splice in fact is the bursting force ($\sigma_p d_b$) in X-direction of reinforcement lapped splice multiplied by factor ν which converts three dimensional behavior into two dimensional behavior. It can be seen that the capacity of composite lapped splice is less than

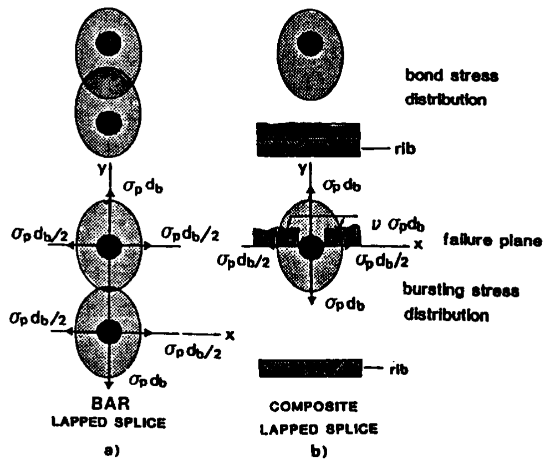


Fig.5 Bond stress and bursting stress in lapped splice.

capacity of reinforcement lapped splice by a constant reduction factor relating with factor ν.

4.2 Proposed Equation for composite lapped splice

Since the effect of plate disturbance on capacity of lapped splice is a constant effect, it is convenient to consider the capacity of composite lapped splice in terms of bar bond strength. Semi-empirical approach was introduced. By estimating the capability of concrete to resist splitting force in an assumed failure plane and cooperating with bond mechanism,[6] Eq.1 is derived

$$\tau_b = K(Ls,Bs)\ Bs\ f_t + C(Ls) \qquad (1)$$

where
- τ_b : average bond strength, $= \sigma_s/4Ls$
- $K(Ls,Bs)$: parameter taking into account of fracture area and uniformity of tension stresses along plane of failure,
- $C(Ls)$: bond stress at zero side covering,
- Ls : normalized lapped length $= l_s/d_b$,
- Bs : normalized effective width of concrete area, $= (b-n.d_b)/n.d_b$
- f_t : tensile strength of concrete, $= 0.269\ fc^{2/3}$
- n : number of bar arrange within width b,
- σ_s : bar stress at the end of plate,
- b : beam width,
- d_b : bar diameter.

Parameters K and C are empirically evaluated by assuming the similar effect of Ls on the parameter K and C. This leads to equation for the capacity of composite lapped splice as follows

$$\tau_{bult} = (0.45\ Bs\ f_t + 3.0\ )/\ Ls^{1/3} \qquad (2)$$

Fig.6 shows the comparison between the test results and calculated values from Eq.2. The equation for the capacity of composite lapped splice was also compared with equations for the capacity of ordinary lapped splice and anchorage[3,4,7,8] as shown in Fig.7. Similar parameter effects on their capacities were observed.

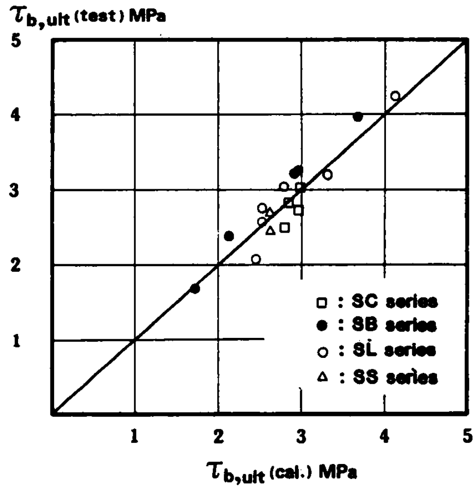
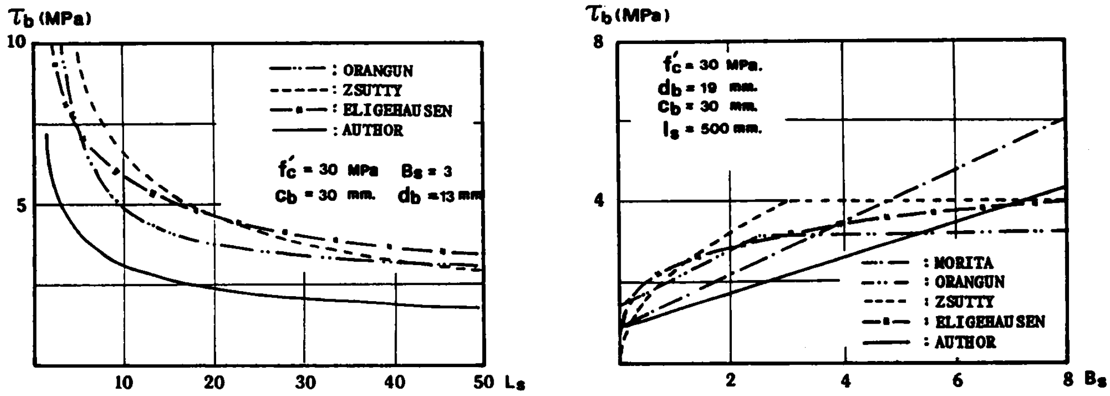


Fig.6 Comparison of capacity of composite lapped splice between test results and calculated values.

5.CONCLUSIONS

1) Connection joint between deformed bars and steel plate in concrete medium can be treated as lapped splice connection. The formula for capacity of composite lapped splice was proposed.



a) Effect of lapped length

b) Effect of side covering

Fig.7 Comparison of equation for capacity of lapped splice and bar anchorage.

2) The capacity of composite lapped splice is less than the capacity of ordinary lapped splice splice and anchorage because of difference in dimensional mechanism. Its effect can be practically considered by introducing constant reduction factor.

3) Effect of bottom covering on the capacity of composite lapped splice is less significant than in the case of ordinary lapped splice because steel plate and rib can behave as transverse reinforcement.

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