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Influence of transverse reinforcement on bond strength of tensile splices

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Abstract

The influence of transverse reinforcement on bond strength of tensile splices is investigated. An equation to calculate the bond strength of splices confined and not confined by transverse reinforcement is presented. The equation which covers all grades of concrete shows good correlation with test results. For instance for 138 normal strength concrete test results reported in the literature the mean value of test/calculated bond strength is 1.00 with a standard deviation of 0.10. These values indicate a significant improvement in the prediction of the bond strength when compared to the values obtained from other models. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Bond strength; Concrete; High strength concrete; Reinforcing bars; Relative rib area; Splice; Transverse reinforcement

Notation

A_t	area of bar making the transverse reinforcement
A_{tr}	area of transverse reinforcement normal to the plane of splitting through the spliced bars (Fig. 1)
C	minimum of $[C_x, C_y, \text{and } (C_s+d_b)/2]$
C_{med}	median of $[C_x, C_y, \text{and } (C_s+d_b)/2]$
C_x	side cover
C_y	bottom cover
C_s	spacing between spliced bars
d_b	bar diameter
f'_c	compressive strength of concrete
f_{ct}	$=0.55\sqrt{f'_c}$ tensile strength of concrete
f_{yt}	yield strength of transverse reinforcement
L	splice length
s	spacing of transverse reinforcement
u or u_p	predicted splice strength
u_c	local bond strength
u_t	measured splice strength
u_{tr}	splice strength contributed by transverse reinforcement

1. Introduction

Test results have shown that the presence of transverse reinforcement increases the bond strength of splices [1]. To account for the influence of transverse reinforcement on the splice strength, Orangun et al. [1] proposed the following equation:

$$\frac{u_{tr}}{\sqrt{f'_c}} = \frac{A_{tr} f_{yt}}{500\, s d_b} \leqslant 3 \quad \text{(English units)}. \tag{1}$$

Eq. (1) was added to the bond strength contributed by the concrete surrounding the bar and the total bond strength was given by

$$\frac{u}{\sqrt{f'_c}} = 1.2 + \frac{3C}{d_b} + \frac{50\, d_b}{L} + \frac{A_{tr} f_{yt}}{500\, s d_b} \quad \text{(English units)}. \tag{2}$$

In Eqs. (1) and (2), u_{tr} is the portion of strength contributed by transverse reinforcement, A_{tr} the area of transverse reinforcement normal to the plane of splitting through the spliced bars (Fig. 1). f_{yt} is the yield strength of transverse reinforcement, and s is the spacing between transverse reinforcement.

In Eqs. (1) and (2), it was assumed that the transverse reinforcement yielded before failure. Recent studies [2–4] have shown that the increase in splice strength does

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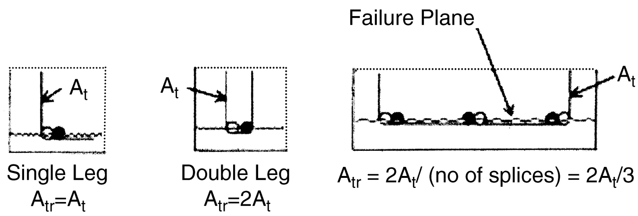

Fig. 1. Transverse reinforcement; definitions given by Orangun et al. [1].

not generally depend on the yield strength of transverse reinforcement. Tests carried out by Reynolds and Beeby [2] and Morita and Fujii [3] showed very low stress in the transverse reinforcing bar at failure. It appears, therefore, that f_y, need not be a parameter in the calculation of bond strength of splices. Darwin et al. [4] used NA_{tr}/n, instead of $A_{tr}.f_{yt}/500\ sd_b$, as a parameter, where N is the number of transverse reinforcing bars crossing splice length, A_{tr} the area of each stirrup or tie crossing the potential plane of splitting adjacent to the reinforcement being developed or spliced and n the number of bars being developed or spliced along the plane of splitting. It is seen that A_{tr} as defined by Orangun et al. is the same as A_{tr}/n as defined by Darwin et al.

In a previous study on bond [5–7], local bond and the bond strength of tensile splices were studied and an analytical equation to calculate the splice strength in beams was presented. The correlation between the calculated values and test results showed that the equation proposed in that study predicted the splice strength with a good accuracy. That study did not cover the results of tensile splices confined by transverse reinforcement. In this paper, the test data of tensile splices confined by transverse reinforcement are used to modify the equation proposed in order to cover both cases of confined and not confined splices.

2. Tensile splice strength

2.1. Tensile splices not confined by transverse reinforcement

Earlier [5–7], in an analytical study on bond, an equation (Eq. 3) to calculate the bond strength of tensile splices was proposed. The equation was compared with 66 test results of the splices not confined by transverse reinforcement, the mean value of test/calculated bond strengths being 1.00 with a standard deviation of 0.08. Accordingly, the bond strength u_c in SI units is given by

$$u = u_c \frac{1 + 1/M}{0.85 + 0.024\sqrt{M}} \left(0.88 + 0.12 \frac{C_{med}}{C} \right), \tag{3}$$

where

$$u_c = 4.9 \frac{C/d_b + 0.5}{C/d_b + 3.6} f_{ct} \tag{4}$$

for normal strength concrete, and

$$u_c = 8.6 \frac{C/d_b + 0.5}{C/d_b + 5.5} f_{ct} \tag{5}$$

for high strength concrete. Also

$$M = \cosh\left(0.0022\ L \sqrt{3 \frac{f'_c}{d_b}} \right). \tag{6}$$

u_c is the local bond strength, L the splice length, d_b the bar diameter, and $f_{ct} = 0.55(f'_c)^{0.5}$ the tensile strength of concrete, C_{med} the median of C_x, C_y, and $(C_s+d_b)/2$, and C the minimum of C_x, C_y, and $(C_s+d_b)/2$. For other symbols, see Notation.

2.2. Tension splices confined by transverse reinforcement

The test data of the splices confined by transverse reinforcement were collected from the literature [4,8–10] subject to the following limitations:

- $C/d_b \geqslant 1$;
- tests with two or more splices and all reinforcing bars spliced at the same section;
- splices located close to the bottom of the beam;
- tensile stress in the reinforcing bar at failure was less than the yield stress;
- failure was due to bond.

The effect of transverse reinforcement on splice strength could not be evaluated from the test data alone due to variations in test variables between different groups of test specimens. Instead, the bond strength of tensile splices confined by transverse reinforcement was calculated by Eq. (3). As was to be expected, for splices confined by transverse reinforcement, the value of test/calculated bond strength u_t/u_p was generally larger than that for similar splices not confined by transverse reinforcement. To account for the effect of transverse reinforcement on bond strength an appropriate variable is needed. As discussed earlier, the tensile stress in the transverse reinforcement is significantly less than the yield stress f_{yt}, and the splice strength does not generally depend on f_{yt}. By removing f_{yt} from the variable $A_{tr}f_{yt}/sd_b$ used by Orangun et al. [1] we have A_{tr}/sd_b. The variable proposed by Darwin et al. [4] does not include parameter d_b. Therefore, we may also remove d_b from A_{tr}/sd_b and use A_{tr}/s as a variable. According to the definition of A_{tr} (Fig. 1), the value of A_{tr} decreases from A_t to $2A_t/3$ when the bottom cover C_y is greater than C_x and $C_s/2$. In practical cases, the value of C_y is only slightly different to C_x or $C_s/2$, and the bond strength is not sensitive to small variations in C_y or C_x. Therefore, for all practical purposes, A_{tr} may be replaced by A_t in the variables of A_{tr}/sd_b and A_{tr}/s. To evaluate the effect of transverse reinforcement, the values of u_t/u_p were plotted against four different variables A_t/s, A_t/sd_b, A_{tr}/s and A_{tr}/sd_b, where A_t is the area of transverse reinforcing bar in mm^2, s is the spacing of transverse reinforcement in mm, and A_{tr} (mm^2) is the effective area of transverse reinforcement normal to the plane of splitting through the spliced bars as illustrated in Fig. 1 and d_b is the bar diameter in mm. These four plots of data are shown in Figs. 2–5. It can be seen that the simple parameter A_t/s (Fig. 2) gives the best fit to the data and yields the following expression:

$$\frac{u_t}{u_p} = 1 + 0.28\frac{A_t}{s}. \tag{7}$$

In Eq. 7, A_t/s is in mm. Inserting u, from Eq. 3, into Eq. 7 as u_p, we obtain the bond strength of tensile splices with transverse reinforcement as

$$u = u_c \frac{1 + 1/M}{0.85 + 0.024\sqrt{M}}\left(0.88 + 0.12\frac{C_{med}}{C}\right) \times \left(1 + 0.28\frac{A_t}{s}\right), \tag{8}$$

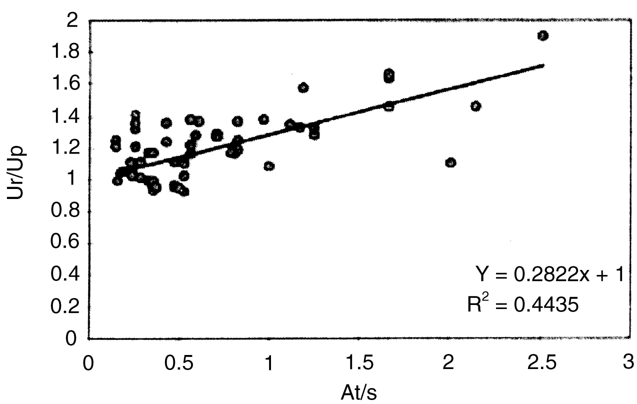

Fig. 2. u_t/u_p – versus – A_t/s relationship for Eq. (3).

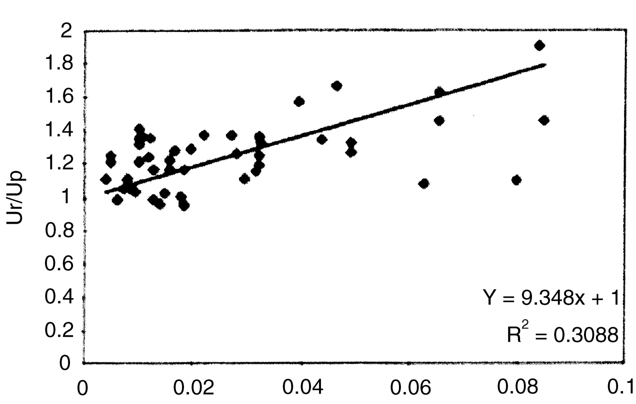

Fig. 3. u_t/u_p – versus – A_t/sd_b relationship for Eq. (3).

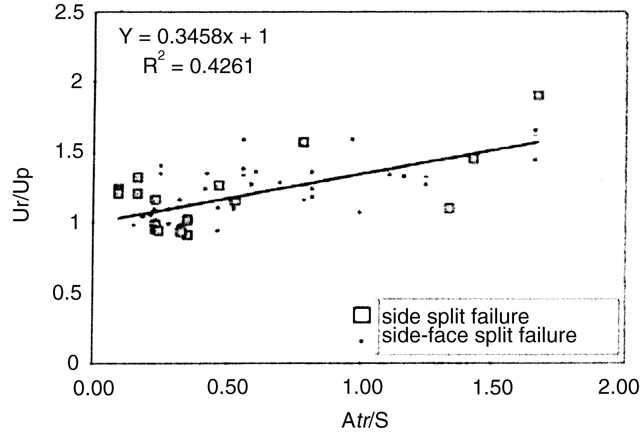

Fig. 4. u_t/u_p – versus – A_{tr}/s relationship for Eq. (3).

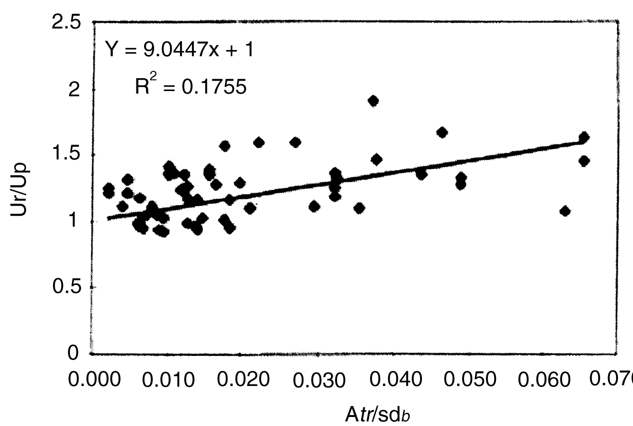

Fig. 5. u_t/u_p – versus – A_{tr}/sd_b relationship for Eq. (3).

where u_c and M are given by Eqs. 4 (or (5)) and 6, respectively.

3. Correlation with test results

3.1. Normal strength concrete

In all, 138 test results of tensile splices, 57 confined and 81 not confined by transverse reinforcement were considered. The bond strengths of these splices were calculated by Eq. (8). The results are summarised in Table 1. The mean value of test/calculated value is 1.00 with a standard deviation of 0.10. These values indicate that Eq. (8) can accurately predict the bond strength of tensile splices for both the cases.

3.2. High strength concrete (HSC)

The correlation of results of eight tests in the case of HSC given by Hwang et al. [13] is also presented in

Table 1
Comparison of test and calculated bond strength for splices confined and not confined by transverse reinforcement

	Test series	No of tests	Mean (u_t/u_p), Eq. (8)	SD (u_t/u_p), Eq. (8)
Not confined splices	All [4,5]	81	1.00	0.08
Confined splices	[8]	5	1.03	0.11
	[9]	3	1.05	0.09
	[10]	4	1.08	0.07
	[11]	10	0.89	0.07
	[4]	24	0.99	0.09
	[12]	11	1.12	0.17
	All confined splices	57	1.01	0.13
All tests (NSC)	All test results	138	1.00	0.10
(HSC) tests	[13]	8	1.01	0.11

Table 1. For these tests, the mean value of test/calculated bond strengths is 1.01 with a standard deviation of 0.11. Once again, these values are extremely satisfactory.

3.3. Bars with high relative rib area

Recently, Darwin et al. [4] reported tests on 49 tensile splices of bars with high relative rib area R. Thirty six of these specimens contained transverse reinforcement and 13 specimens did not. For splices not confined by transverse reinforcement, the value of test/calculated bond strength, using Eq. (8), does not seem to be influenced by the value of R. For these splices, the mean value of test/calculated strengths is 1.00 with a standard deviation of 0.06. The test results of splices confined by transverse reinforcement are influenced by the relative rib area R of the reinforcing bars. Fig. 6 shows the relationship between the mean of u_t/u_p value versus R. It is seen that the test/calculated ratio slightly increases with the relative rib area R.

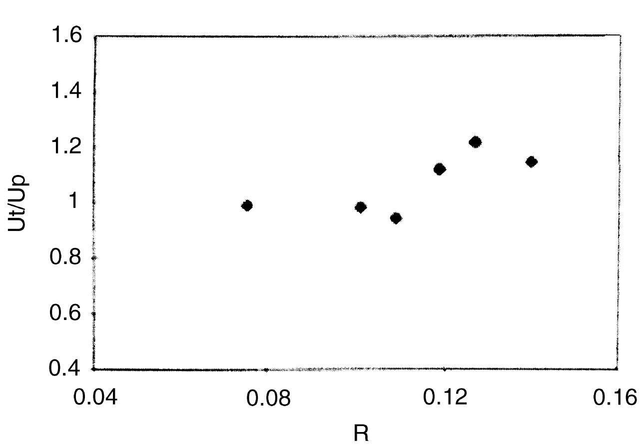

Fig. 6. Test/calculated bond strength – versus – relative Rib area relationship.

4. Conclusions

Based on the analysis of the test data and the equation presented, the following conclusions are drawn:

1. Analysis of data obtained from numerous tensile splice tests shows that the parameter A_t/s appropriately accounts for the effect of transverse reinforcement on the splice strength.
2. The predictions by Eq. (8) correlate extremely well with the bond strength of numerous tensile splices reported in the literature for both cases of splices confined and not confined by transverse reinforcement (Table 1).
3. The splice strength of reinforcing bars with higher relative rib areas R are slightly higher than the splice strengths calculated by Eq. (8) (Fig. 6).

Acknowledgements

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