TENSILE LAP SPLICES
PART I: RETAINING WALL TYPE, VARYING MOMENT ZONE

By

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SUMMARY REPORT 113-2 (S)

SUMMARY OF

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The Splitting Problem

For bond on deformed bars in general, and for tension splices in particular, the most common failure is by splitting the concrete parallel to the bar axis. The bearing forces on the bar lugs, instead of being parallel to the axis of the bar, have a radial component which reacts on the surrounding concrete, like water pressure in a pipe, to cause failure by splitting on the weakest plane.

In the stem of a cantilever retaining wall the closely spaced splices accumulate these splitting forces with resulting weakness in the plane of the vertical bars.

Project Objective

The primary objective of this investigation is to study the behavior of the retaining wall type of splice and to formulate modified design requirements if found desirable.

Part A—Retaining Wall Splices

Scope of Investigation

Thirty-two beams were tested, 27 having #11 bar splices, 4 having #8 bar splices, and 1 having 9 main bars spliced to #11 dowel bars. The percentage of longitudinal steel was generally 1.67 percent of A432 steel, the beam size being varied when bar diameter or spacing was changed. Concrete strength was typically from 3000 to 4000 psi.

Various lateral spacings of splices and various arrangements of the spliced bars were used. Typically two splices were used in a test number, but some specimens had 3 or 4 splices and some splices were staggered. Five beams used the equivalent of ties or stirrups over the splices.

Test Specimens

The shape of a retaining wall section (Fig. 1b) is not convenient for testing purposes. The stem of the wall was simulated by a beam length of constant cross section. The base of the wall was replaced (Fig. 1c) by a perpendicular (stub) section projecting from both the tension and compression faces of the beam, and the beam itself was extended to form a dummy or loading section. The beam load was applied through the stub section in a manner

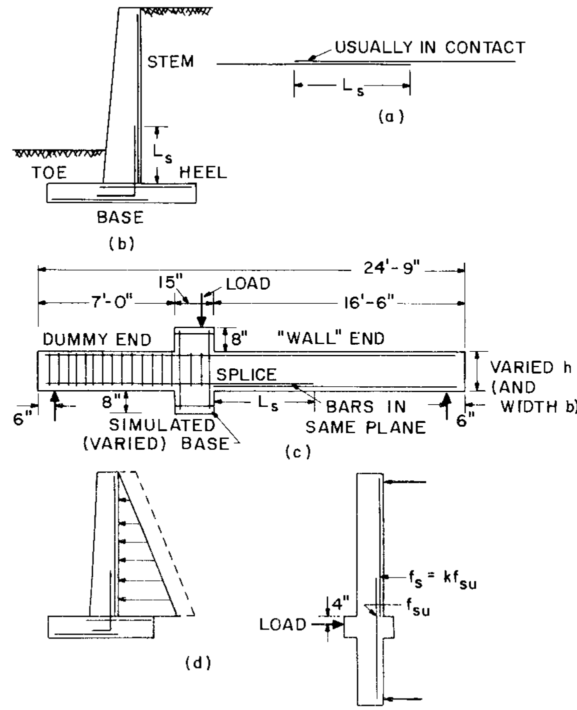

Fig. 1. Test concept. (b) Cantilever retaining wall with typical stem bar splices. (c) Test specimen to simulate wall splice. (d) Wall loading compared to test loading.

crudely simulating the flexural compression from the toe of the retaining wall (Fig. 1d). Although the test specimen is greatly different from the wall, its behavior around the splice was planned to be similar to that of the wall.

Splice Behavior

The member first cracked in flexure at the higher stressed end of the splice, adjacent to the loading stub. No appreciable tendency toward the formation of diagonal cracks near the loading stub was noted. Flexural cracking progressed along the splice as loads were increased, with the crack at the outer end of the splice appearing somewhat ahead of neighboring flexural cracks.

Splitting along the bars developed with increasing load, for closely spaced splices only on the sides of the beam, but for wider spacings first on the tension face followed by side splitting before failure. Four types of failure were observed:

1. Flexure, by yielding of steel and secondary compression failure.

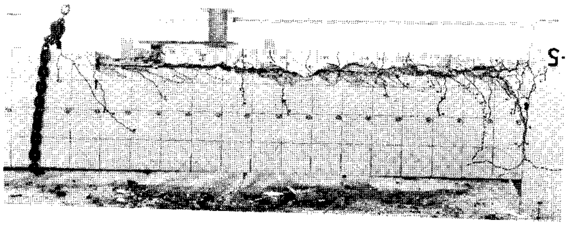

Fig. 2. Side split failure of beam No. 5.

2. Diagonal tension at the lower stressed end of the splice.
3. Side split failure, that is, bond splitting all across the plane of the bars, with little or no splitting on the tension face, as in Fig. 2.
4. Face-and-side split failure, that is, splitting first on the tension face and then all across the plane of the bars.

Flexural failure implies a splice entirely adequate for the beam in which it was used. The lowest steel stress at such a failure was 71.5 ksi.

Only three beams failed in diagonal tension. Each was a premature failure (in terms of the ACI USD allowable v_c of $2\sqrt{f'_c}$) but two were in such a stage of splitting as to be judged as near splitting failure.

Splitting failures, except with stirrups, were sudden and sharply defined, leaving a wide crack at the failure surface (Fig. 2).

General Influence of Splice Spacing

The test value of average bond stress over the splice length was considerably influenced by the lateral spacing of the splices. The ratio of half the ultimate (average) bond stress to the AASHO allowable (WSD) bond stress is plotted in Fig. 3,

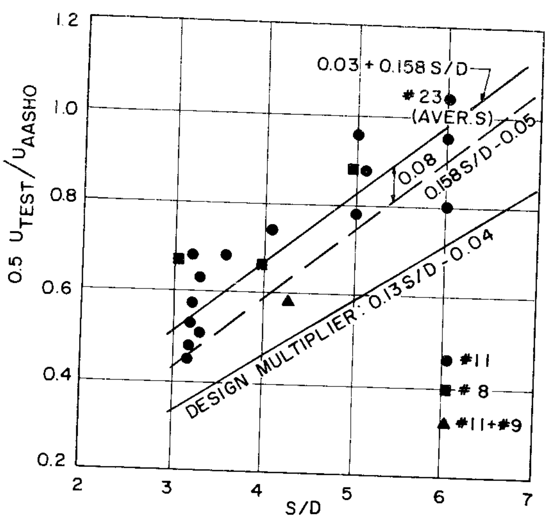

Fig. 3. Bond efficiency in terms of AASHO bond stress ($0.75 \times 0.1f'_c \leqq 0.75 \times 350$ psi).

omitting special cases and using S as the center-to-center spacing. All ratios are extremely low, less safe than desirable for #11 bars at practical spacings, and for very close spacings barely safe at service loads. The ratios plotted are defined by

$$0.5\ u_{test} / u_{AASHO} = 0.03 + 0.158\ S/D$$

Modification of AASHO Specification for Splices

The ratios above, lowered by roughly one standard deviation (0.08), become

$$0.158\ S/D - 0.05$$

If one could accept for design a brittle failure mode at the first yield of the reinforcing, the AASHO bond stress could simply be multiplied by this factor. Since good design avoids a brittle failure wherever possible, a further lowering of the permissible bond stress (and this multiplier) to 80 percent of the above is recommended:

$$0.13\ S/D - 0.4$$

It should be noted that present data stop at S/D of 6 and are based on using 2 in. of clear cover.

Alternatively, and to obtain the same end result, the splice length as currently specified by AASHO (19D at $f_y = 40$ ksi and $f'_c = 3500$ psi) might be divided by this "multiplier" to give the following lap L_s for #11 bars:

$$L_s = 19D \div (0.13\ S/D - 0.04) \geqq 19D$$

S/D	S	Reqd. Lap	Now Specified (for all size bars and spacings)
3	4.2″	54D	19D
4	5.6″	40D	19D
5	7.0″	31D	19D
6	8.5″	26D	19D
8 or over	11.2″ or over	19D	19D

For $f_y = 60$ ksi and $f'_c = 3500$ psi, 1.5 times the above laps are required.

General Comments

These tests were designed to give the necessary laps for retaining wall splices. For constant moment splices, with equal stresses at each end, more length is needed, probably 15 to 25 percent.

A single splice (one bar continuous) or a staggered splice (one starting where the other is complete) is more effective, by 25 percent or more.

In the one specimen where #11 dowels were spliced to #9 main bars with the maximum unit stresses in each about the same, the strength was

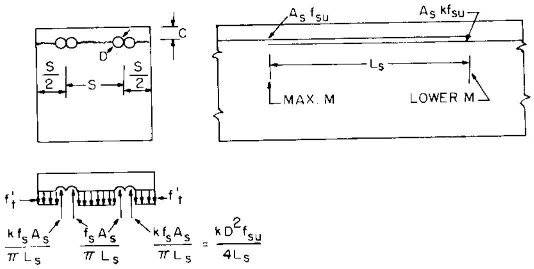

Fig. 4. Splitting forces for side split failure.

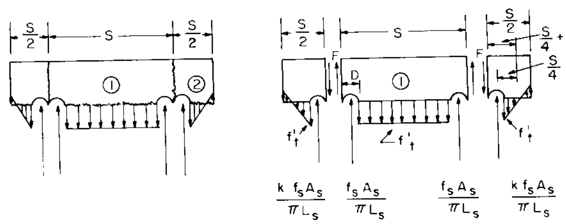

Fig. 5. Face-and-side split failure.

roughly 10 percent lower. The theory discussed in Part B indicates that a lower stress at one end of the splice is advantageous, but heavy shearing stresses may offet this when the one stress is *very* low.

At large S/D ratios a detailed study shows that the efficiency of a splice drops some with the increasing length, but this influence is less than the influence of S/D and data are not adequate to clarify this point.

Where U-stirrups around the splices are feasible, the tests indicate a possible 40 to 100 percent gain in stress transfer.

Conclusions and Recommendations

In retaining wall splices at ordinary spacings, the AASHO specification (1965, 9th Edition) is shown not to be a safe guide unless seriously modified. Based on the use of 2 in. clear cover over the bars, $f_y = 40$ ksi and $f'_c = 3500$ psi, the recommended lap splice length is increased to

$$L_s = 19D \div (0.13\ S/D - 0.04) \geqq 19D$$

which has been verified for S/D up to 6 for #11 bars and also seems to fit #8 bars. The recommended lap lengths for S, a center-to-center spacing, are:

S/D	S for #8	S for #11	L_s
3	3″	4.2″	54D
4	4″	5.6″	40D
5	5″	7.0″	31D
6	6″	8.5″	26D
≧8	≧8″	11.2″	19D

Consistent with the AASHO specification, the value of L_s must increase linearly with f_y and with the ratio $3500/f'_c$, the latter only where f'_c is *less* than 3500 psi.

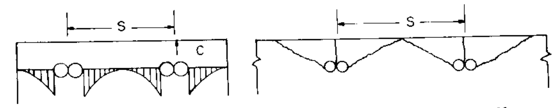

Fig. 6. V-type failure where C/S is very small.

On the basis of only 4 specimens, staggering of splices or the splicing of only half the bars at a given cross section would permit a splice length L_s to be reduced to 80 percent of the above.

The recommendations do not apply for splices in a constant moment region, which should be longer; nor do they apply for less than a 2 in. clear cover.

Part B—A Possible Theory For Splices

Recently Professor Goto in Japan has shown experimentally that at high steel stresses a tension bar embedded in a prism of concrete will not only develop transverse cracks in the prism but also internal cracks radiating from each transverse lug. These cracks are not perpendicular to the bar but in effect develop a truncated hollow cone of concrete around the bar bearing against the lug. These essentially parallel conical shells develop the change in bar tension by inclined compressive forces which are separated by the inclined cracks. This seems to be the manner by which tangential splitting stresses are developed near ultimate.

An analysis based upon the simplest possible basic assumption, namely, that the radial and longitudinal stress components in the concrete are equal*, results in splitting stresses correlating well with split cylinder test strengths. This analysis uses also a second assumption based on test data from the strain gage readings for this series of tests, that, in spite of very different initial and intermediate distributions, *at ultimate* for the splice the variation in steel stress along each splice bar is essentially linear from zero at one end to maximum at the other; and this holds in both directions even when stress at one end is much lower than at the other.

Close examination of the failed specimens indicated two splitting failure patterns and pointed toward a third for thinner cover or wider spacing than used in this investigation, as shown in Figs. 4, 5, and 6. Calculation of tensile stresses from these free bodies look very promising, but the analysis needs further study.

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*Photographs made by Professor Goto would indicate an angle of possibly 50 to 55 degrees, which would mean even a larger splitting component.