BOND OF EPOXY-COATED REINFORCEMENT TO CONCRETE: SPLICES

BY

CYNTHIA J. HESTER
SHAHIN SALAMIZAVAREGH
DAVID DARWIN
STEVEN L. McCABE

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ABSTRACT

The effects of epoxy coating and transverse reinforcement on the splice strength of reinforcing bars in concrete are described. Tests included 65 beam and slab splice specimens for members containing No. 6 and No. 8 bars. The average coating thickness ranged from 6 to 11 mls. Three deformation patterns were used in the study. All but one group of specimens contained Class B ACI/Class C AASHTO splices. The results of the current study are analyzed, along with the results of 48 specimens from earlier studies and used to develop improved development length modification factors for use with epoxy-coated bars. Epoxy coatings are found to significantly reduce splice strength. However, the extent of the reduction is less than used to select the development length modification factors in the 1989 AASHTO Bridge Specifications and 1989 ACI Building Code. The percentage decrease in splice strength caused by epoxy coating is independent of the degree of confining reinforcement, which provides approximately the same percentage increase in the strength of splices of both coated and uncoated reinforcement. A development length modification factor of 1.35 is applicable for design with epoxy-coated reinforcement. An alternate factor of 1.20 is applicable for epoxy-coated bars with a minimum amount of transverse reinforcement, if the positive effects of that transverse reinforcement are not already taken into account in the design provisions. The 1.20 factor is, thus, not applicable to the ACI Building Code but is applicable to the AASHTO Bridge Specifications. This report is the third in a continuing series describing research at the University of Kansas to gain a better understanding and develop accurate design procedures that reflect the changes in bond strength caused by the use of epoxy coating on reinforcing bars.

INTRODUCTION

The 1989 AASHTO Bridge Specification and 1989 ACI Building Code (ACI 318-89) provisions for development length require the use of considerably longer development lengths for epoxy-coated reinforcement than for uncoated steel. The newly adopted development length modification factors are 1.5 for coated bars with less than 3 bar diameters of concrete cover or less than 6 bar diameters of clear spacing between bars and 1.15 (AASHTO 1989) or 1.2 (ACI 1989) for bars with 3 bar diameters or more of concrete cover and 6 bar diameters or more of clear spacing between bars. Therefore, for a 2 in. cover, No. 6 and larger coated bars require a 50 percent increase in development length compared to uncoated bars. This requirement impacts both cost and constructability. The new provisions include no recommendation to account for the effects of transverse reinforcement on the bond strength reduction caused by epoxy coating.

The test results, upon which the 1.5 development length modification factor is based, consist of only 21 specimens, of which 12 contained epoxy-coated reinforcement and none contained transverse steel (Treece and Jirsa 1987, 1989). The pattern used for these tests is no longer used for epoxy-coated bars because of difficulties in coating application[1]. More recent tests at the University of Kansas using beam-end specimens (Darwin, McCabe, Choi, and Hadje-Ghaffari 1990a) indicate that epoxy-coated bars with transverse steel have a higher bond strength than epoxy-coated bars without transverse steel. A higher bond strength means that a lower increase in development length may be needed if transverse steel is present.

This report is the third in a continuing series describing research at the University of Kansas to gain a better understanding and develop accurate design procedures that reflect the changes in bond strength caused by the use of epoxy coating on reinforcing bars. Earlier research elsewhere (Johnston and Zia 1982, Treece and Jirsa 1987, 1989) and at the University of Kansas (Choi et al. 1990a, 1990b, 1991, Darwin et al. 1990a, 1990b) have demonstrated that epoxy coatings significantly reduce bond strength. Work at the University of Kansas has shown that the

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[1] Florida Steel Corporation, personal communication.

extent of the reduction is less than that reflected by the development length modification factors in the ACI Building Code (1989) and the AASHTO Bridge Specifications (1989). Coating thickness has been shown to have little effect on the amount of bond reduction for No. 6 bars and larger. However for smaller bars, bond strength reduction appears to increase with coating thickness. For No. 5 bars and larger, the reduction in bond strength caused by epoxy coating increases with bar size. The magnitude of the reduction depends on the deformation pattern: bars with relatively large rib bearing areas are affected less by the coating than bars with smaller bearing areas. Increased concrete cover reduces the effect of the epoxy coating, but not to the extent reflected in the design provisions.

This report describes research to characterize the strength of splices in members containing epoxy-coated reinforcement. The key test parameters are the bar surface condition and the degree of confinement provided by transverse reinforcement. The tests used two bar sizes and three deformation patterns, but the study was not extensive enough to evaluate the effects of either deformation pattern or bar size on splice strength. New development length modification factors for epoxy-coated bars are recommended.

EXPERIMENTAL PROGRAM

The experimental program described in this report consisted of 65 beam and slab splice specimens. The specimens were cast and tested in 15 groups, of two to six specimens each. The key test parameters were the bar surface condition (epoxy-coated or uncoated) and the degree of confinement provided by transverse reinforcement.

The specimens contained No. 6 or No. 8 reinforcing bars. The epoxy-coated bars had average coating thicknesses within the splice regions ranging from 6.1 to 11.4 mils (1 mil = 0.001 in.). All but one group of specimens contained Class B ACI/Class C AASHTO splices (ACI 1989, AASHTO 1989). Three deformation patterns, shown in Fig. 1, were used.

As part of the study, a single group of beam-end specimens containing No. 3 bars was tested. The results of those tests are reported in Appendix A.

Test Specimens

Two types of test specimens, beam and slab splice specimens, were used. The specimens were simply supported and loaded to produce a 4 ft constant moment region, as illustrated in Figs. 2 and 3. All specimens were 13 ft long and contained splices that were centered in the constant moment region.

Beam specimens–The beam specimens, shown in Fig. 2, were similar to those tested by Treece and Jirsa (1987, 1989) and Choi et al. (1990a, 1991). The beams were 16 in. wide by 15 or 16 in. deep and contained 2 or 3 No. 8 bar splices. Actual member dimensions are given in Table B1. A splice length of 16-in. was used, except in group B6 which used a $22^3/_4$ in. splice length. All bars were bottom cast with a 2 in. nominal concrete cover, except for two specimens in group B3 which had a 1 in. cover. The clear spacing between splices was equal to 3 in., except in the group B7 beams which contained two splices and had a clear spacing of 8 in. The side cover on the longitudinal bars was equal to 2 in. for all beam specimens. Specimens contained 0, 1, 2, 3, or 4 No. 3 bar stirrups within the splice region. In groups B1-B3, the stirrups were placed closer to the center of the splice (Fig. 2), while in groups B4-B7, the outer stirrups were centered $1^1/_4$ in. from the ends of the splice. As will be noted later, stirrup placement did not appear to have an effect on splice strength.

Slab specimens–The slab specimens were similar to those tested by Cleary and Ramirez (1989, 1991). The slabs were 24 in. wide by 8 in. deep and had a nominal cover of 2 in. (Fig. 3). Actual member dimensions are given in Table B2. The specimens contained top-cast No. 6 (groups S1-S4, S7, S8) or No. 8 (groups S5 and S6) bars and used No. 3 (groups S1-S3) or No. 5 (groups S4-S8) bars as transverse reinforcement. Zero, 2 or 4 closed stirrups were used within the splice regions. The outer stirrups were placed 1 or 2 in. from the ends of the splices, as shown in Fig. 3. Splice lengths were 10 in. for No. 6 bars and 16 in. for No. 8 bars. Groups S1 through S6 contained three splices. Group S7 contained a single splice with two continuous bars through the splice region. Group S8 contained two splices with a single continuous bar through the splice region. Specimens with No. 6 bars had a side cover of 3 1/4 in. and a clear spacing of 6 1/2 in. between splices. Specimens with No. 8 bars had a side cover of 3 in. with a clear spacing of 6 in. between splices. The vertical legs of the stirrups had a side cover of 1 in. As illustrated in Fig. 3, the specimens were detailed so that the transverse reinforcement provided confinement only for vertical, not horizontal, splitting.

Materials

Reinforcing Steel–ASTM A 615 (1989), Grade 60, No. 6 and No. 8 bars were used. Grade 40 and Grade 60 No. 3 bars and Grade 60 No. 5 bars were used for transverse reinforcement. Bars with three deformation patterns, designated S, C, and N, were tested (Fig. 1). Deformation pattern S consisted of ribs perpendicular to the axis of the bar. Deformation pattern C consisted of diagonal ribs inclined at an angle of 60° with respect to the axis of the bar. Deformation pattern N consisted of diagonal ribs inclined at an angle of 70° with respect to the axis of the bar. Bars of each size and deformation pattern were taken from the same heat of steel. All reinforcement, longitudinal and transverse, within a specimen had the same deformation pattern and surface properties. Yield strengths and deformation properties are shown in Table 1.

Epoxy coatings were applied in accordance with ASTM A 775 (1989) and ranged in thickness from 7.5 to 11.4 mils for the beam specimens and from 6.1 to 10.9 mils for the slab specimens, as measured by a pull-off type thickness gauge. Readings were taken at 6 points around the circumference of the bar between each set of deformations within the splice length. Average readings within the splice length are reported.

Concrete–Non-air-entrained concrete was supplied by a local ready mix plant. Air-entrained concrete was not used, to reduce the number of variables in the concrete placement and because no evidence exists to show that the use of entrained air effects bond strength. Evidence does exist (De Vries, Moehle and Hester 1991) that limiting the amount of bleeding (one of the advantages of air-entrained concrete) does not effect bond strength. Type I portland cement and $^3/_4$ in. nominal maximum size coarse aggregate were used. Water-cement ratios ranged from 0.37 to 0.46 and produced concretes with nominal strengths of 5500 or 6000 psi. Mix proportions are shown in Table 2. Concrete properties for the individual test groups are given in Table 3.

Placement Procedure

The concrete was placed in two lifts in the beam specimens The first lift was placed in all specimens in a group before any specimen received a second lift. The splice region of the beams was placed last during the first lift and first during the second lift to insure that all test regions would receive similar concrete. Each lift was vibrated on each side of the beams at staggered 1 ft intervals.

The slab specimens were cast and consolidated in a single lift. The splice regions were cast from the middle portion of the concrete batch. The specimens were vibrated at 3 points across the width, 6 in. into the slab from each side and in the middle of the section, at 1 ft intervals.

Standard 6 x 12 in. test cylinders were cast in steel molds and cured in the same manner as the test specimens. Forms were stripped after the concrete had reached a compressive strength of about 4000 psi. The specimens were covered with plastic until the forms were stripped and then allowed to dry.

Test Procedure

The specimens were tested at nominal concrete compressive strengths of 5500 or 6000 psi. The beam specimens were inverted, and both types of specimens were tested as inverted simply supported beams, as illustrated in Figs. 2 and 3 . Loads were placed on the ends of the cantilever regions, resulting in a constant moment region between the two supports. Specimens were loaded monotonically. Crack locations and widths were recorded during the tests of beams in groups B1 and B2. Crack measurement ceased at a load below the expected failure load to insure that the balance of the test would not be interrupted and would provide a consistent measure of member strength. These tests lasted 20 to 25 minutes. Crack locations and widths were not recorded on the remaining beams. The balance of the beam tests were completed in 3 to 5 minutes. Slab specimens were loaded at about 1 kip per minute, resulting in tests that lasted from 10 to 20 minutes.

Results and Observations

Load-deflection curves for the specimens are shown in Figs. 4 through 18. With a single exception (see Fig. 9), the load-deflection curves for all beams within a test group were virtually identical up to the point of failure. Most slabs exhibited similar behavior. However, in three cases the slabs containing epoxy-coated bars exhibited a lower cracking load than the slabs with uncoated steel (see Figs. 11 and 16). Specimens containing epoxy-coated bars consistently failed at a lower load than those containing uncoated bars. As a general rule, splices confined by transverse reinforcement exhibited higher strengths than splices without transverse reinforcement. However, this was not universal.

Specimens without stirrups failed in a brittle manner, with the load dropping immediately after the specimen attained the peak load. In contrast, beams with stirrups behaved in a ductile manner, with the load dropping slowly as additional deflection was applied.

For the beams in groups B1 and B2, crack widths were measured at working loads within a region spanning 12 in. on each side of the splice. The maximum crack widths and the number of cracks are summarized in Table 4. As a general observation, the number of cracks increased and the crack widths decreased as the degree of confinement increased. However, the beam with epoxy-coated bars and stirrups in group B2 had fewer cracks than the matching specimen without stirrups. As observed by Choi et al. (1990a, 1991), the width and number of cracks showed no clear dependence on the presence or absence of epoxy coating.

The ratio of the strength of specimens containing epoxy-coated bars to similar specimens containing uncoated bars, C/U, ranged from 0.61 to 0.86 for the beam specimens and from 0.64 to 0.93 for the slab specimens. All of the tests in the current study resulted in a splitting failure. However, the nature of the failure was different in the beam and slab specimens.

In the beam specimens, failure was accompanied by extensive longitudinal and transverse cracking in the region of the splices. Following failure, a horizontal crack through the plane of the spliced bars, extending the length of the splice region, was evident, as shown schematically in Fig. 19a. The concrete cover was easily removed with a hammer, exposing a nearly horizontal crack running the full width of the beam in the plane of the splices, as observed in earlier tests (Treece and Jirsa 1987, 1989, Choi et al., 1990a, 1991). Transverse cracking occurred at the end of the splices, when no stirrups were included within the splice region, and at the end of the splices and at the stirrup locations, when transverse reinforcement was used.

In the slab specimens, where the bars were separated by a minimum of 6 bar diameters, little horizontal cracking was evident. Rather, cracks propagated from the spliced bars at about 45° with the horizontal, as shown schematically in Fig. 19b. For specimens without transverse reinforcement, this resulted in intact regions of concrete between the splices, i.e., little cover was lost between the splices. For specimens with transverse reinforcement, these regions of intact concrete were more shallow; that is, more cover concrete was lost. Like the beam specimens without transverse reinforcement, transverse cracking occurred mainly at the ends of the splices for the slab specimens without transverse reinforcement. For specimens with transverse reinforcement, transverse cracking occurred both at the ends of the splices and at the stirrup locations.

On all specimens, the test bars appeared to pivot within the splice region at failure, causing the ends of the bars to lift up. This was most evident in specimens without transverse reinforcement and in specimens with transverse reinforcement in groups B1-B3, which had the stirrups located significantly away from the ends of the splices (Fig. 2). Moving the stirrups toward the ends of the splices helped reduce the degree of uplift in the ends of the bars, but did not appear to have an effect on splice strength.

As observed in earlier studies (Johnston and Zia 1982, Treece and Jirsa 1987, 1989, Choi et al. 1990a, 1990b, 1991), concrete exhibited good adhesion to the uncoated bars and virtually no adhesion to the epoxy-coated bars. The epoxy-coated bars were clean, with no concrete residue left on the bars, while the concrete in contact with the epoxy-coated bars had a smooth, glassy surface. This is in contrast to the uncoated bars which had particles of cement paste and mortar on the shaft and side of the deformations following failure. In a few cases, bars in beam specimens showed signs of the epoxy coating being crushed against the concrete, but, in general, the epoxy was undamaged. For the slab specimens, no damage to the epoxy was observed.

EVALUATION OF EXPERIMENTAL RESULTS

The principal goals of this project are to evaluate the effects of transverse reinforcement on the strength of spliced epoxy-coated reinforcement and to develop suitable development length modification factors for use in design to account for the effects of epoxy coating.

To help compare the test results obtained from the different groups of specimens, the test results are expressed in terms of steel stress at failure, f_s. The steel stresses are normalized with respect to a nominal concrete strength of 5500 psi using the assumption that, within the concrete strength range used, splice strength is proportional to the square root of the concrete compressive strength. Thus, steel stresses at failure are multiplied by $(5500/f'_c)^{1/2}$ to obtain the final modified values. Both the original and modified values of steel stress are summarized in Tables 5 and 6.

In addition to the 65 specimens tested in the current study, the results of the 21 beam splice tests by Treece and Jirsa (1987, 1989), 15 splice tests by Choi et al. (1990a, 1991), and 12 splice tests by Hamad and Jirsa (1990) are used for the overall evaluation (see Table 7). Recent tests by DeVries et al. (1991) also could have been included, but were not, because uncoated stirrups were used for specimens containing coated, as well as uncoated, longitudinal bars. Coated and uncoated bars should not be combined in practice, placing the usefulness of the De Vries test data in doubt.

In the following sections, the points of specific interest include the effect of transverse reinforcement on the relative strengths of similar specimens containing coated and uncoated reinforcement, C/U; the relative strength of members with coated bars and transverse reinforcement compared to members with coated bars without transverse reinforcement, C/C_n; the relative strength of members with uncoated bars and transverse reinforcement compared to members with uncoated bars without transverse reinforcement, U/U_n; and the relative strength of members with coated bars, both with and without transverse reinforcement, compared to members with uncoated bars without transverse reinforcement, C/U_n. In addition to these comparisons, some comments will be made on the effect of the number of bars spliced in a region and the effect of splice length on the reduction in strength caused by epoxy coating.

Effect of Transverse Reinforcement on Splice Strength of Coated Bars Relative to Uncoated Bars

The first comparisons involve the effect of transverse reinforcement on the value of C/U for specimens that, except for the surface of the reinforcement, are essentially identical. The values of C/U are listed in Tables 5 and 6 and plotted in Fig. 20 as a function of the size, yield strength and spacing of the transverse reinforcement, expressed as the variable K_{tr} (Orangun, Jirsa and Breen 1977).

$$K_{tr} = \frac{A_{tr}\, f_{yt}}{500\, s\, d_b} \qquad (1)$$

in which

A_{tr} = area of transverse reinforcement normal to the plane of splitting per developed/spliced bar (see Fig. 19), sq. in.;

f_{yt} = yield strength of transverse reinforcement, psi;

s = spacing of transverse reinforcement, center to center; or development/splice length divided by the number of stirrups, in.;

d_b = diameter of developed/spliced bars, in.

Fig. 20 includes the results obtained from the beams and slabs tested in the current study. Each data point represents the ratio of the bar stress at failure for a member containing epoxy-coated bars to the bar stress in a similar member in the same test group with uncoated bars. Values of C/U from the same test group are connected by straight line segments. As illustrated, C/U increases with increasing transverse reinforcement for some test groups and decreases for others.

To obtain a better picture of the overall effect of K_{tr} on C/U, the technique of dummy variables (Draper and Smith 1981) is used to establish best fit lines for the data. Using the technique, the best fit lines for each test group are obtained (Fig. 21) using the assumptions that there may be differences in the value of C/U due to deformation pattern and member configuration, but that the change in C/U due to transverse reinforcement is the same in all cases.

Fig. 21 illustrates that, for the current study, the value of C/U is nearly independent of transverse reinforcement. The slope of the best fit lines is – 0.002, resulting in a change in the value of C/U of only –0.02 as K_{tr} increases from 0 to 10. This insensitivity is expected based on the finite element analyses of Choi, Darwin, and McCabe (1990b) and the experimental bond study of bars subjected to a confining force by Hamad and Jirsa (1990). However, the results illustrated in Fig. 21 differ from the splice tests of Hamad and Jirsa (1990) which show a marked increase in C/U with increasing K_{tr}. However, when the six data points from Hamad and Jirsa are added to the current data, the slope, at – 0.001, remains quite flat, as illustrated in Fig. 22.

In the original formulation by Orangun, Jirsa and Breen (1977), the maximum effective value of K_{tr} was set at 3.0. If the results illustrated in Fig. 22 are analyzed for members with $K_{tr} \leq 3$, the slope remains flat at 0.001.

This analysis strongly suggests that a single epoxy-coated bar development length modification factor could be used, whether transverse reinforcement is used or not, if other aspects affecting bond are accounted for properly. The mean value of the intercepts of the best fit lines at $K_{tr} = 0$ is 0.74 in Figs. 20-22. The results of the dummy variable analyses for this and the following sections are summarized in Table 8.

Effect of Transverse Reinforcement on Splice Strength of Bars with Same-Surface Properties

Fig. 23 illustrates the effect of transverse reinforcement on the strength of splices for bars that have the same surface properties. In this figure, each data point represents the ratio of a specimen with transverse reinforcement to a similar specimen from the same test group without transverse reinforcement (C/C_n for coated bar specimens and U/U_n for uncoated bar specimens). The plots include the results of Hamad and Jirsa (1990). The data is quite scattered. However, overall trends can be obtained using best fit lines passing through the point 1.0 at a value of $K_{tr} = 0$. Fig. 23 illustrates that transverse reinforcement has a significant effect on the strength of the bars. The slopes of the C/C_n and U/U_n lines are within 10 percent of each other, at 0.0181 and 0.0204, respectively. Fig. 24 shows the results for members with $K_{tr} \leq 3$. Here, the slopes of the C/C_n and U/U_n lines are nearly identical, at 0.0655 and 0.0654, respectively. The higher slope for the specimens with lower values of K_{tr} supports the observations by Orangun et al. (1977) that, above $K_{tr} = 3.0$, additional transverse reinforcement is not particularly effective. The similarity in the effect of transverse reinforcement on the splice strength of coated and uncoated reinforcement is expected, based on the insensitivity of C/U to K_{tr} observed in Figs. 20-22. Thus, the percentage increase in splice strength with the addition of transverse reinforcement is about the same for coated and uncoated bars.

Effect of Transverse Reinforcement on Splice Strength of Coated Bars Relative to Uncoated Bars without Transverse Reinforcement

The ratios of the splice strengths of specimens containing epoxy-coated bars, both with and without transverse reinforcement, to the splice strengths of specimens with uncoated reinforcement and no transverse reinforcement in the same test group, C/U_n, are compared to K_{tr} in Figs. 25 and

26 using the technique of dummy variables. Both figures include the results of Hamad and Jirsa (1990). Fig. 25 covers all values of K_{tr}, while Fig. 26 covers members with $K_{tr} \leq 3$. The figures illustrate, as does Fig. 24, that transverse reinforcement can have a significant effect on the useful splice capacity of epoxy-coated bars. For the specimens without transverse reinforcement ($K_{tr} = 0$), the average value of C/U_n is 0.75 in Fig. 25 and 0.74 in Fig. 26 (see Table 8 for a tabulation of C/U_n as a function of K_{tr}). These ratios match the average value of 0.74 at $K_{tr} = 0$ obtained from Fig. 22. Considering only members with $K_{tr} \leq 3$ (Fig. 26), the average value of C/U_n rises to 0.87 at $K_{tr} = 3$.

Based on these figures, the splice length of a coated bar without transverse reinforcement should be 1/0.74 = 1.35 times longer than an uncoated bar without transverse reinforcement, while the splice length of a similar coated bar with transverse reinforcement and $K_{tr} = 3$ could be as low as 1/0.87 = 1.15 times longer than an uncoated bar without transverse reinforcement. The latter number is significant for bridge design since the 1989 AASHTO Bridge Specifications do not take advantage of the higher bond strength obtained with transverse reinforcement.

A note of caution is necessary. As shown in Table 8, if the results of Hamad and Jirsa are excluded from the analysis for $K_{tr} \leq 3$, C/U_n at $K_{tr} = 3$ is only 0.82, which translates to a development length modification factor of 1.22. Thus, without running additional tests, it would be prudent to use a development length modification factor that is closer to 1.22 than to 1.15.

Effect of Splice Length and Class

The results of two test groups in this study indicate that C/U may (1) decrease with splice length and (2) increase when Class A splices are used in place of Class B ACI/Class C AASHTO splices.

Group B6 used splice lengths of 22¾ in. instead of 16 in., as used for the rest of the beams. The splices in Group B6 produced C/U ratios ranging from 0.63 to 0.69, compared to values of 0.75 to 0.86 for other beam specimens with C-pattern No. 8 bars. Since splice strengths tend to exhibit a great deal of scatter, it is not clear whether these results represent a trend.

The effect of splicing less than 50 percent of the reinforcement at one section is illustrated by the four slabs in Group S7, in which only one of three bars was spliced. In this case, the values of C/U for the specimens without and with stirrups are 0.83 and 0.85, respectively, compared to average values of 0.79 and 0.75 for No. 6 bar specimens containing C-pattern bars with more than 50 percent of the bars spliced within the test region (groups S1, S2, S4 and S8). The higher values of C/U obtained in Group S7 suggest that the detrimental effects of epoxy coating on bond strength may be reduced if fewer than 50 percent of the bars are spliced in one region.

It should be emphasized that the comparisons made in this section represent only a small number of tests. Considering the high variability of bond strength, additional tests will be necessary before these trends can be verified.

In the next section, the test results are compared to values obtained from predictive equations.

Comparison with Predictive Equations

Predictive Equations–The test results from the current study, along with the results of splice tests by Hamad and Jirsa (1990), Treece and Jirsa (1987, 1989), and Choi et al. (1990a, 1991), are compared with the design equations in the AASHTO Bridge Specifications (1989), which coincide with those of the 1983 ACI Building Code, the provisions of ACI 318-89, and the predictive equations of Orangun, Jirsa, and Breen (1977). For the purposes of comparison, epoxy-coated bar factors (AASHTO 1989, ACI 1989) are not used in these calculations.

The expression for the basic development length is the same in the AASHTO Bridge Specifications (1989) and ACI 318-89. The basic development length, l_d in inches, is given by

$$l_d = \frac{0.04\, A_b\, f_y}{\sqrt{f'_c}} \tag{2}$$

in which

A_b = area of an individual bar, sq. in.;

f_y = yield strength of reinforcement, psi;

$\sqrt{f'_c}$ = square root of concrete compressive strength, psi.

Substituting the splice length, l_s, for l_d, and the bar stress, f_s, for the yield strength, f_y, and solving for f_s provides an expression for the predicted bar stress at failure.

$$f_s = \frac{l_s \sqrt{f'_c}}{0.04\ A_b} = \frac{25\ l_s \sqrt{f'_c}}{A_b} \tag{3}$$

The AASHTO (1989) design provisions provide that the basic development length in Eq. 2 may be decreased by 20 percent for reinforcement that is spaced laterally at least 6 in. on center and has at least 3 in. of cover measured in the direction of the spacing. ACI 318-89 uses the same factor, but with the 6 in. and 3 in. criteria replaced with 5 and $2^1/_2$ bar diameter clear spacing requirements. A 20 percent reduction in l_d (or l_s) means that the stress, f_s, in Eq. 3 should be modified by a factor of 1/0.8 = 1.25. This factor applies to all of the slabs tested in this study (groups S1-S7).

Under the AASHTO (1989) provisions, an additional factor of 1/1.7 is applied to f_s for most tests evaluated to account for the use of AASHTO Class C splices (more than 50 percent of the reinforcement spliced within the lap length). The 1/1.7 factor is not used to modify the values of f_s from group S7, since those slabs contained Class A splices.

Under the provisions of ACI 318-89, f_s is modified by 1/1.3 to account for the use of ACI Class B splices. Like the AASHTO Class C splice provision, this provision applies to all specimens evaluated, except those in group S7. Under the provisions of section 12.2.3 of ACI 318-89, an additional modification factor, 1/2.0, is applied to f_s for two beams in group B3 because of low cover (less than two bar diameters). Factors of 1/2.0 or 1/1.4 for low cover (see section 12.2.3 of ACI 318-89) are also applied for a number of other tests (Treece and Jirsa 1987, 1989, Choi et al. 1990a, 1991, Hamad and Jirsa 1990) that are analyzed in this report.

Both the AASHTO (1989) and ACI (1989) provisions include factors for top reinforcement (horizontal reinforcement so placed that more than 12 in. of fresh concrete is cast in the member below the reinforcement). These factors, 1.4 and 1.3, respectively, are included in the current analysis. The top-reinforcement or "top-bar" factor must be applied to the tests by Treece and Jirsa (1987, 1989) and Hamad and Jirsa (1990).

The expression used by Orangun, Jirsa, and Breen (1977) to predict splice strength is given in Eq. 4 in terms of steel stress at failure.

$$f_s = \left[1.2 + \frac{3\,C}{d_b} + \frac{50\,d_b}{l_s} + \frac{A_{tr}\,f_{yt}}{500\,s\,d_b}\right] \frac{4\,l_s \sqrt{f'_c}}{d_b} \qquad (4)$$

in which

C = smaller of bottom (top) cover or one-half of clear spacing between splices.

The Orangun et al. predictions include no provision for top reinforcement.

Comparisons–The results of the comparisons of the predictive equations with the tests from the current study, plus the tests by Treece and Jirsa (1987, 1989), Choi et al. (1990a, 1991), and Hamad and Jirsa (1990), are listed in Tables 9-11 and summarized in Table 12. As stated earlier, the comparisons do not include the AASHTO or ACI epoxy-coated bar factors.

The comparisons indicate that, on the average, the experimental splice strengths exceed those predicted by the design expressions (AASHTO 1989, ACI 1989) for both coated and uncoated bars. The opposite is true for the predictions provided by the Orangun et al. (1977) equation, except for the members with uncoated bars and no transverse reinforcement, which produce a test/prediction ratio of about 1.0. The relative values produced by the three procedures are not totally unexpected; the design equations are deliberately conservative, while the Orangun et al. equation is a best fit of data. Overall, the ratios of test strength to predicted strength obtained from the Orangun, Jirsa, Breen equation are more consistent and exhibit significantly less scatter than do similar ratios obtained from the AASHTO and ACI provisions. A detailed comparison follows.

Tables 12a, b, and c contain summaries of the comparisons with test results for the AASHTO (1989), ACI (1989), and Orangun, Jirsa, Breen (1977) predictions. The results are grouped by bar surface (coated and uncoated), the use of transverse reinforcement (no stirrups or stirrups within the splice length), and test series (B1-B7, S1-S8, Hamad and Jirsa, Treece and Jirsa, Choi et al.). In addition to comparisons based on individual test series, the comparisons for the three groups that include transverse reinforcement, B1-B7 and S1-S8 from the current study and the beams tested by Hamad and Jirsa (1990), are combined. Overall comparisons for all test specimens are also included. For each category, comparisons are made based on the mean value of the ratio of the test strength to the predicted strength and the coefficient of variation (COV). The number of specimens in each category is indicated. Tables 12a, b, and c also include a summary of the values of C/U based on the mean test/prediction ratios for each category. The overall comparison involves 113 splice specimens, 65 of which are from the current study.

The ACI (1989) provisions, on the average, provide less conservative estimates of splice strength than do the AASHTO (1989) provisions. However, comparisons with the AASHTO provisions exhibit less scatter, as demonstrated by generally lower coefficients of variation. For example, for all uncoated-bar specimens, the ACI provisions produce a mean test/prediction ratio of 1.87 and a COV of 0.439, compared to a mean test/prediction ratio of 2.04 and a COV of 0.303 for AASHTO.

The highest test/prediction ratios for the two sets of design provisions are obtained from the tests by Hamad and Jirsa (1990) and Treece and Jirsa (1987, 1989). All of the specimens tested by Hamad and most of those tested by Treece contained top reinforcement. Thus, application of the 1/1.4 (AASHTO 1989) and the 1/1.3 (ACI 1989) factors to calculate f_s has a significant impact on reducing the predicted splice strength. These specimens also had low covers and/or bar spacings which require the use of additional factors, under the provisions of section 12.2.3 of ACI 318-89, that further reduce the predicted strength.

The lowest test/prediction ratios based on the AASHTO and ACI provisions, 1.514 and 1.197 for uncoated bars, respectively, are obtained for the specimens in groups S1-S8. This may be due to the fact that, although these specimens did not contain "top reinforcement," they did contain top-cast (upper surface) reinforcement. As demonstrated by Brettmann, Darwin, and Donahey (1986), significantly reduced bond strength can occur for upper surface bars, even if less than 12 in. of fresh concrete is placed below the bars.

Selected comparisons provide an understanding of the relationship between the test results and the predicted strengths.

AASHTO–For the combined (B1-B7, S1-S8, Hamad and Jirsa) results, the mean test/prediction ratios for the AASHTO (1989) provisions for members with coated reinforcement are 1.30 for members without stirrups and 1.53 for members with stirrups. Adding the results of Treece and Jirsa (1987, 1989) and Choi et al. (1990a, 1991), the ratio is 1.50 for all coated-bar splices without stirrups (Treece and Jirsa and Choi et al. did not test beams with stirrups). These values compare to mean test/prediction ratios for the combined results (B1-B7, S1-S8, Hamad and Jirsa) for splices with uncoated bars, 1.78 for members without no stirrups and 2.0 for members with stirrups. The average for all specimens with uncoated bars and no stirrups is 2.03.

ACI–The test/prediction ratios for the ACI 318-89 provisions for bars with coated reinforcement are 1.15 and 1.40 for the combined (B1-B7, S1-S8, Hamad and Jirsa) results for members without and with stirrups, respectively. For uncoated bars, the ratios are 1.51 and 1.81 for members without and with stirrups, respectively. For all specimens without stirrups, the ratios for coated and uncoated bars are 1.42 and 1.91, respectively.

Orangun, Jirsa, Breen–Of the three procedures, the Orangun, Jirsa, Breen (1977) equation consistently provides the most accurate predictions for the uncoated bar specimens without stirrups, exhibiting strength ratios close to 1.0. However, Eq. 4 significantly over predicts the strength provided by transverse reinforcement for the specimens analyzed in this study. For the combined (B1-B7, S1-S8, Hamad and Jirsa) results, the mean test/prediction ratios for coated bar specimens are 0.73 and 0.68, for members without and with stirrups, respectively. For members with uncoated bars, the corresponding ratios are 0.99 and 0.90, respectively. Adding the results from Treece and Jirsa (1987, 1989) and Choi et al. (1990a, 1991), the ratios for members without stirrups are 0.75 and 1.02 for coated and uncoated bar specimens, respectively.

C/U Ratios–The test/prediction ratios in Tables 12a, b, and c for coated and uncoated bars are combined to obtain C/U ratios that are also presented in those tables.

The C/U ratios presented in Table 12c, based on comparison with the Orangun, Jirsa, Breen equation, are theoretically the most useful, since for uncoated bars, Eq. 4 gives a far better prediction of splice strength than do the design equations. However for application to design, it makes more sense to consider the C/U ratios calculated from the test/prediction ratios obtained with the design equations, assuming that the safety and accuracy of the design equations for uncoated bar splices are considered satisfactory. From a practical point of view, a choice is not necessary, since the values of C/U obtained from the mean test/prediction ratios in Tables 12a, b, and c are nearly identical for each category of comparison.

For comparison with the AASHTO (1989) provisions, the results of the current study, combined with those of Hamad and Jirsa (1990), provide C/U values of 0.73 and 0.75 for members without and with stirrups, respectively. For comparison with the ACI (1989) provisions, the respective values are 0.76 and 0.78, while, in comparison to the Orangun, Jirsa, Breen (1977) equation, the respective values are 0.74 and 0.76. Adding the results of Treece and Jirsa (1987, 1989) and Choi et al. (1990a, 1991) to the other studies provides C/U values of 0.74, 0.75, and 0.74, respectively, for the AASHTO, ACI, and Orangun et al. comparisons for members without stirrups. These values differ significantly from the value of 0.66 that led Treece and Jirsa (1987,

1989) to recommend the 1.5 epoxy-coated bar development length modification factor now is use in the 1989 AASHTO Bridge Specifications and ACI 318-89. The higher values of C/U obtained in the current analysis represent over five times the number of test results used to develop the original recommendations.

DESIGN RECOMMENDATIONS

The test results and analyses presented in this report demonstrate that (1) transverse reinforcement increases the splice strength of coated as well as uncoated bars and that (2) the current provisions for epoxy-coated reinforcement are overconservative for most applications. When combined with the earlier work at the University of Kansas (Choi et al. 1990a, 1991, Darwin et al. 1990a), a picture develops which shows that the values of the current epoxy-coated bar development length modification factors do not accurately reflect the bond strength of members containing epoxy-coated bars. The earlier work shows that increased cover reduces the deleterious effects of epoxy coating. However, the positive effects of increased cover do not justify the large changes in the epoxy-coated bar factors used in the 1989 AASHTO Bridge Specifications and the 1989 ACI Building Code. A factor of 1.5 is too high for bars with as little as two bar diameters of cover, and factors of 1.15 and 1.2 are too low for bars with a minimum of three bar diameters of cover.

The analysis presented in the previous section illustrates that a C/U ratio of 0.74 conservatively represents the effect of epoxy coating on splice strength. Thus, it may be reasoned that the inverse of 0.74, 1.35, could serve as a conservative epoxy-coated bar development length modification factor, whether the anchored bar is confined with transverse reinforcement or not. The questions might be asked: Why not use the minimum value of C/U obtained in tests rather than an average value? Isn't the minimum value needed for safety? The answer is that the bond strengths provided by epoxy-coated bars exhibit no greater scatter than those provided by uncoated bars. Thus, if the engineering community can accept the scatter that is inherent in the bond strength of uncoated bars, comparisons should be made based on average strengths rather than minimum ratios of coated to uncoated bar-bond strengths.

The provisions of ACI 318-89 and the Orangun, Jirsa, Breen (1977) equation account for improvements in bond strength provided by transverse reinforcement. Thus, when using either the ACI 318-89 provisions or the Orangun et al. equation, a single development length modification factor is satisfactory in all cases. The AASHTO Bridge Specifications, however, do not take advantage of improvements in bond strength provided by transverse reinforcement. Therefore, it would be possible to allow the use of a reduced development length modification factor in conjunction with the AASHTO Bridge Specifications as they are currently framed without resulting in designs that are any less safe than are provided by uncoated bars without transverse reinforcement. Based on the analysis of Fig. 26, it appears that a modification factor of 1.20 would be reasonable for members with transverse reinforcement providing a K_{tr} value of at least 3.0. As mentioned earlier, the analysis of Fig. 26 showed that a development length modification factor of 1.15 could be justified at $K_{tr} = 3.0$, but that a more conservative value appears to be justified without some additional test results. Presumably, development length modification factors between 1.35 and 1.2 could be used for values of K_{tr} between 0 and 3.0. However, it is highly doubtful that a variable factor would be practical, based on the extra design effort required. If adopted, the 1.20 development length modification factor would be most effectively applied to the inner layer of reinforcing bars in slabs and walls.

For the purposes of calculating the value of K_{tr}, the definitions presented with Eq. 1 and illustrated in Fig. 19 for A_{tr} should be used. To determine when the transverse reinforcement intercepts a crack plane, as indicated in Fig. 19a, or an individual set of cracks, as indicated in Fig. 19b, the definition shown in Fig. 19b should be used for bars with a lateral center-to-center spacing of 6 in. or greater. The definition should in Fig. 19a applies for closer spacings.

The application of the proposed provisions is demonstrated in Tables 13a, b and c. In Tables 13a and b, the AASHTO (1989) and ACI (1989) provisions are modified to include the recommended epoxy-coated bar modification factors. A 1.35 factor is applied in all cases for ACI 318-89 and to all comparisons, except groups S1-S8, for the AASHTO provisions; a factor of 1.20 is used for S1-S8. As can be seen, the test/prediction ratios for specimens containing coated bars increase to values which are very close to those produced by the uncoated bars. For example, for the modified AASHTO (1989) provisions, the test/theory ratio for splices with coated bars without stirrups increases to 2.02, compared to a value of 2.03 for splices with uncoated bars without stirrups. For splices with stirrups, the ratio increases to 2.01 for coated bars compared to 2.05 for uncoated bars. Similar improvements are made for ACI 318-89.

The application of the 1.35 factor with the Orangun, Jirsa, Breen equation (Table 13c), produces values of test/prediction ratios which are also very similar for coated and uncoated bars.

CONCLUSIONS

Based on tests of 65 beam and slab splice specimens and the analysis of those specimens plus an additional 48 specimens from earlier studies, it may be concluded that:

1. Epoxy coatings significantly reduce the splice strength of deformed reinforcing bars in concrete. However, the extent of the reduction is less than used to select the development length modification factors in the 1989 AASHTO Bridge Specifications and 1989 ACI Building Code.
2. The percentage decrease in splice strength caused by epoxy coatings is independent of the degree of transverse reinforcement.
3. Transverse reinforcement improves the strength of splices containing both coated and uncoated bars. The percentage increase in strength is approximately the same for both coated and uncoated bars for equal amounts of transverse reinforcement.
4. The added strength provided by transverse reinforcement allows the use of a reduced epoxy-coated bar development length modification factor, if adequate transverse reinforcement is provided and the provisions do not otherwise take into account the beneficial effect of

transverse reinforcement on development and splice length.

5. A single epoxy-coated bar development length modification factor, 1.35, is applicable for use in the ACI Building Code. A factor of 1.35 is also applicable for use in the AASHTO Bridge Specifications for bars with transverse reinforcement providing values of $K_{tr} < 3.0$. A factor of 1.20 is applicable for use with the AASHTO Bridge Specifications for bars with transverse reinforcement providing values of $K_{tr} \geq 3.0$.

FUTURE WORK

Two observations made during the current study, combined with the limited range of bar sizes used in the tests, strongly suggest three areas of needed research.

1. The current study suggests that an increased splice length may result in a reduced value of C/U. However, very little information exists on the effect of epoxy coatings as a function of development or splice length. A series of test specimens designed specifically to evaluate the effect of development and splice length on the relative strengths of coated and uncoated bars appears to be highly desirable.
2. Tests of splices have normally produced C/U ratios that are below those observed for beam-end specimens. This lower strength may result from the combined effect of multiple bars slipping in the splice specimens, as well as statistical effects based on "weakest link" behavior. The observation that the values of C/U may be considerably higher for Class A splices than for Class B/Class C splices suggests that additional study would be worthwhile to better understand this behavior as a function of the number of bars that are spliced or developed. Reductions in development length modification factors are possible.
3. The study by Choi, Hadje-Ghaffari, Darwin, and McCabe (1990a, 1991), which included 630 beam-end specimens, demonstrated that the effect of epoxy coating is a function of deformation pattern and bar size. The 113 splice tests that have been carried out to date have not specifically

addressed the effect of either deformation pattern or bar size. The statistical nature of bond and splice strength requires that a large number of specimens be evaluated to observe significant trends. While tests on the scale of those used in the earlier University of Kansas study (Choi et al. 1990a, 1990b, 1991) will not be necessary, additional effort is justified to improve the understanding of the effects of both deformation pattern and bar size on splice strength.

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Table 1 Average Test Bar Data

Bar Size	Def. Pattern	Yield Str. (ksi)	Def. Spacing (in.)	Def Height @ (in.)	Def. Gap (in.)	Def. Angle (deg.)	Bearing Area per Inch * (in.)	Related Rib Area +	Bearing Area Ratio ** (in.-1)
3	S	68.9	0.245	0.017	0.088	90	0.058	0.049	0.526
3	C	54.1	0.249	0.019	0.087	60	0.058	0.049	0.533
3	N	77.3	0.244	0.019	0.100	70	0.069	0.059	0.630
5	C	72.3	0.413	0.041	0.116	60	0.151	0.077	0.486
6	S	69.5	0.484	0.042	0.125	90	0.165	0.070	0.375
6	C	72.4	0.479	0.049	0.168	60	0.179	0.076	0.406
8	S	71.1	0.667	0.055	0.145	90	0.219	0.070	0.277
8	C	69.0	0.654	0.062	0.163	60	0.222	0.071	0.281
8	N	63.8	0.604	0.060	0.100	70	0.245	0.078	0.311

@ Per ASTM A 615

* Bearing area of the deformations divided by the spacing of the deformations. Bearing area based on closely spaced measurements of ribs.

+ The ratio of the bearing area of the deformations to the shearing area between the deformations (bearing area divided by the nominal perimeter of the bar).

$ The ratio of the bearing area of the deformations to the area of the bar (bearing area divided by the nominal area of the bar).

Table 2 Concrete Mixture Proportions (Cubic Yard Batch Weights)

Group	Nominal Strength (psi)	W/C Ratio	Cement (lb)	Water (lb)	Aggregate Fine+ (lb)	Aggregate Coarse* (lb)
B1-B3	6000	0.37	765	281	1264	1642
B4	6000	0.36	767	279	1267	1646
B5-B6	5500	0.45	615	278	1421	1620
B7,S1-S7	5500	0.46	600	275	1481	1575
S8	5500	0.40	611	242	1512	1607

+ Kansas River Sand - Lawrence Sand Co., Lawrence, KS, bulk specific gravity = 2.62, absorption = 0.5%, finenes modulus = 3.0.

* Crushed limestone - Hamm's Quarry, Perry, KS, bulk specific gravity = 2.52, absorption = 3.5%, maximum size = 3/4 in., unit weigth = 97.2 lb/cubic ft.

Note: Air volume ranged from 1.5% to 2.0%

Table 3 Concrete Properties

Group	Slump (in.)	Concrete Temperature (F)	Age at Test (days)	Average Compressive Strength (psi)
B1	3 3/4	62	8	5990
B2	4 1/2	70	7	6200
B3	1 3/4	71	4	6020
B4	3	83	6	6450
B5	3 3/4	84	11	5490
B6	3 1/4	87	9	5850
B7	5 1/4	88	10	5240
S1	4	88	12	5040
S2	4	77	10	5370
S3	4 1/4	72	9	5030
S4	3	66	5	5290
S5	3 3/4	67	8	5100
S6	5	59	6	5410
S7	6	47	5	5400
S8	3 1/4	47	5	5440

Table 4 Crack Data For Beams in Groups B1 and B2

Group No.	Specimen Label *	Average Coating Thickness (mils)	No. of Cracks	Widest Crack (mils)	Bar Stress for Crack Comparison (ksi)
B1	8N3-16-0-U	0.0	7	5	27.7
	8N3-16-2-U	0.0	10	5	27.7
	8N3-16-1-C	7.5	6	7	27.7
	8N3-16-2-C	9.6	12	5	27.7
B2	8C3-16-0-U	0.0	6	7	25.0
	8C3-16-2-U	0.0	8	5	25.0
	8C3-16-0-C	11.2	8	7	25.0
	8C3-16-2-C	8.7	5	5	25.0

* Specimen Label : #DS-L-N-B

\# = bar size
D = deformation pattern : C,N
S = stirrup bar size
L = splice length
N = number of stirrups
B = U - uncoated bars
C - coated bars

Table 5 Current Study : B1—B7 Splice Tests

Group No.	Specimen Label *	No. of Splices	Avg. Coat. Thck. (mils)	Avg. Cover (in.)	Ult. Moment (k-in.)	Ult. Stress (ksi)	Norm. Stress (ksi)	Relative ** Strengths $\frac{C}{U}$	$\frac{U}{Un}$	$\frac{C}{Cn}$	$\frac{C}{Un}$
B1	8N3-16-0-U	3	0.0	2.00	1433	50.4	48.3	--	1.00	--	--
	8N3-16-2-U	3	0.0	2.00	1604	56.5	54.1	--	1.12	--	--
	8N3-16-1-C	3	7.5	2.00	1086	38.2	36.6	--	--	--	0.76
	8N3-16-2-C	3	9.6	2.00	1214	42.7	40.9	0.76	--	--	0.85
B2	8C3-16-0-U	3	0.0	1.84	1376	46.5	43.8	--	1.00	--	--
	8C3-16-2-U	3	0.0	1.83	1305	44.2	41.6	--	0.95	--	--
	8C3-16-0-C	3	11.2	1.75	1146	38.5	36.3	0.83	--	1.00	0.83
	8C3-16-2-C	3	8.7	1.78	1124	38.0	35.8	0.86	--	0.99	0.82
B3	8S3-16-0-U	3	0.0	2.04	1361	47.0	45.0	--	1.00	--	--
	8S3-16-2-U	3	0.0	2.08	1348	46.6	44.5	--	0.99	--	--
	8S3-16-0-C	3	9.9	2.06	911	30.9	29.5	0.66	--	1.00	0.66
	8S3-16-2-C	3	9.8	2.07	921	32.0	30.6	0.69	--	1.04	0.68
	8S3-16-0-C	3	10.3	1.04	759	26.5	25.4	--	--	1.00	--
	8S3-16-2-C	3	9.8	1.05	871	30.3	29.0	--	--	1.14	--
B4	8S3-16-0-U	3	0.0	2.10	1228	42.7	39.5	--	1.00	--	--
	8S3-16-2-U	3	0.0	2.04	1384	47.4	43.8	--	1.11	--	--
	8S3-16-3-U	3	0.0	2.10	1456	50.4	46.6	--	1.18	--	--
	8S3-16-0-C	3	10.7	2.11	884	30.8	28.4	0.72	--	1.00	0.72
	8S3-16-2-C	3	9.8	2.00	932	32.1	29.6	0.68	--	1.04	0.75
	8S3-16-3-C	3	8.9	2.03	887	30.8	28.4	0.61	--	1.00	0.72
B5	8C3-16-0-U	3	0.0	2.05	1158	39.7	39.8	--	1.00	--	--
	8C3-16-2-U	3	0.0	2.06	1367	46.6	46.6	--	1.17	--	--
	8C3-16-3-U	3	0.0	2.06	1244	43.2	43.3	--	1.09	--	--
	8C3-16-0-C	3	8.6	2.01	931	31.8	31.9	0.80	--	1.00	0.80
	8C3-16-3-C	3	8.0	2.06	1024	34.7	34.7	0.80	--	1.09	0.87
B6	8C3-22 3/4-0-U	3	0.0	2.15	1489	51.6	50.0	--	1.00	--	--
	8C3-22 3/4-3-U	3	0.0	2.17	1620	56.2	54.5	--	1.09	--	--
	8C3-22 3/4-4-U	3	0.0	2.16	1595	55.6	53.9	--	1.08	--	--
	8C3-22 3/4-0-C	3	9.0	2.00	952	33.4	32.3	0.65	--	1.00	0.65
	8C3-22 3/4-3-C	3	8.6	2.13	1027	35.6	34.6	0.63	--	1.07	0.69
	8C3-22 3/4-4-C	3	9.9	2.18	1112	38.5	37.4	0.69	--	1.16	0.75
B7	8C3-16-0-U	2	0.0	2.12	885	45.2	46.3	--	1.00	--	--
	8C3-16-3-U	2	0.0	2.03	1019	51.5	52.7	--	1.14	--	--
	8C3-16-0-C	2	11.4	2.12	759	38.7	39.7	0.86	--	1.00	0.86
	8C3-16-3-C	2	9.9	2.08	759	38.7	39.7	0.75	--	1.00	0.86
							Mean =	0.72	1.05	1.03	0.75

* Specimen Label : #DS-L-N-B
# = bar size
D = deformation pattern : S,C,N
S = stirrup bar size
L = splice length
N = number of stirrups
B = U - uncoated bars
C - coated bars

Note:
1.) all bars bottom-cast
2.) Norm.Stress = Ult.Stress(5500/f'c)^1/2
3.) 1 mil = 0.001 in.
4.) Nominal cover listed for B1 because cover was not measured for group B1.

** Relative Strengths
$\frac{C}{U}$, $\frac{U}{Un}$, $\frac{C}{Cn}$, $\frac{C}{Un}$
U = uncoated bars
C = coated bars
n = no stirrups within splice length

Cs = min (side cover, 1/2 clear spacing)
= 1.5 in. for B1-B6
= 2.0 in. for B7

Table 6 Current Study : S1–S8 Splice Tests

Group No.	Specimen Label *	No. of Splices	Avg. Coat. Thck. (mils)	Avg. Cover (in.)	Ult. Moment (k-in.)	Ult. Stress (ksi)	Norm. Stress (ksi)	Relative ** Strengths $\frac{C}{U}$	$\frac{U}{Un}$	$\frac{C}{Cn}$	$\frac{C}{Un}$
S1	6C3-10-0-U	3	0.0	2.36	295	44.1	46.0	--	1.00	--	--
	6C3-10-0-C	3	8.0	2.39	227	34.0	35.5	0.77	--	1.00	0.77
S2	6C3-10-0-U	3	0.0	2.19	317	47.4	48.0	--	1.00	--	--
	6C3-10-2-U	3	0.0	2.16	342	51.0	51.7	--	1.08	--	--
	6C3-10-0-C	3	6.1	2.19	245	36.7	37.1	0.77	--	1.00	0.77
	6C3-10-2-C	3	6.4	2.09	227	34.0	34.4	0.67	--	0.93	0.72
S3	6S3-10-0-U	3	0.0	2.18	309	46.3	48.4	--	1.00	--	--
	6S3-10-2-U	3	0.0	2.21	348	52.1	54.5	--	1.13	--	--
	6S3-10-0-C	3	6.4	2.04	237	35.5	37.1	0.77	--	1.00	0.77
	6S3-10-2-C	3	6.1	2.08	237	35.5	37.2	0.68	--	1.00	0.77
S4	6C5-10-0-U	3	0.0	2.07	314	46.9	47.9	--	1.00	--	--
	6C5-10-2-U	3	0.0	1.96	349	52.1	53.2	--	1.11	--	--
	6C5-10-0-C	3	8.9	2.10	214	32.0	32.6	0.68	--	1.00	0.68
	6C5-10-2-C	3	8.3	1.98	262	39.1	39.9	0.75	--	1.22	0.83
S5	8C5-16-0-U	3	0.0	2.09	486	43.1	44.8	--	1.00	--	--
	8C5-16-2-U	3	0.0	2.09	434	38.6	40.1	--	0.89	--	--
	8C5-16-0-C	3	10.3	2.09	338	30.0	31.1	0.70	--	1.00	0.70
	8C5-16-2-C	3	10.1	2.05	318	28.3	29.3	0.73	--	0.94	0.66
S6	8C5-16-0-U	3	0.0	2.08	406	36.0	36.3	--	1.00	--	--
	8C5-16-4-U	3	0.0	2.15	461	40.9	41.2	--	1.14	--	--
	8C5-16-0-C	3	9.5	2.08	261	23.1	23.3	0.64	--	1.00	0.64
	8C5-16-4-C	3	9.8	2.04	307	27.2	27.4	0.67	--	1.18	0.76
S7	6C5-10-0-U	1	0.0	2.10	458	68.4	69.0	--	1.00	--	--
	6C5-10-2-U	1	0.0	2.10	451	67.4	68.0	--	0.98	--	--
	6C5-10-0-C	1	8.2	2.14	381	56.9	57.4	0.83	--	1.00	0.83
	6C5-10-2-C	1	7.2	2.06	384	57.3	57.8	0.85	--	1.01	0.84
S8	6C5-10-0-U	2	0.0	2.03	250	37.3	37.5	--	1.00	--	--
	6C5-10-2-U	2	0.0	2.11	356	53.2	53.5	--	1.43	--	--
	6C5-10-0-C	2	10.9	2.06	233	34.8	35.0	0.93	--	1.00	0.93
	6C5-10-2-C	2	8.2	2.05	294	44.0	44.2	0.83	--	1.26	1.18
							Mean =	0.75	1.05	1.04	0.79

* Specimen Label : #DS-L-N-B

# = bar size
D = deformation pattern : S,C
S = stirrup bar size
L = splice length
N = number of stirrups
B = U - uncoated bars
C - coated bars

Note: 1.) all bars top-cast
2.) Norm.Stress = Ult.Stress(5500/f'c)^1/2
3.) 1 mil = 0.001 in.

Cs = min (side cover, 1/2 clear spacing)
= 3.25 in. for S1-S4,S7,S8
= 3 in. for S5, S6

** Relative Strengths

$\frac{C}{U}$, $\frac{U}{Un}$, $\frac{C}{Cn}$, $\frac{C}{Un}$

U = uncoated bars
C = coated bars
n = no stirrups within splice length

Table 7 Other Studies

Treece & Jirsa (1987, 1989)

Group No.	Specimen Label *	No. of Splices	Avg. Coat. Thck. (mils)	Cover (in.)	Ult. Stress (ksi)	Norm. Stress (ksi)	Relative ** Strength $\frac{C}{U}$
1	6D0-12-0-C	3	10.6	2	33.0	37.5	0.62
	6D0-12-0-C	3	4.8	2	46.2	52.6	0.87
	6D0-12-0-U	3	0.0	2	53.1	60.4	--
2	6D0-24-0-C	3	9.0	7/8	44.8	53.5	0.71
	6D0-24-0-C	3	4.5	3/4	47.9	57.2	0.76
	6D0-24-0-U	3	0.0	1	63.3	75.6	--
3	11D0-36-0-C	3	9.1	2	28.3	29.6	0.65
	11D0-36-0-C	3	5.9	2	30.4	31.8	0.70
	11D0-36-0-U	3	0.0	2	43.3	45.3	--
4	11D0-36-0-C	3	11.0	2	24.9	28.2	0.54
	11D0-36-0-U	3	0.0	2	45.9	52.0	--
5	6D0-16-0-C	3	14.0	3/4	35.0	29.0	0.55
	6D0-16-0-U	3	0.0	7/8	63.3	52.4	--
6	11D0-18-0-C	3	7.4	2 1/4	25.3	20.6	0.63
	11D0-18-0-U	3	0.0	2 1/8	40.3	32.9	--
7	6D0-16-0-C	3	10.3	5/8	41.1	27.2	0.65
	6D0-16-0-U	3	0.0	3/4	63.3	41.8	--
8	11D0-18-0-C	3	9.7	2	33.8	24.5	0.72
	11D0-18-0-U	3	0.0	2	46.9	33.9	--
9	11D0-18-0-C	3	8.7	2	27.5	20.8	0.64
	11D0-18-0-U	3	0.0	2	43.0	32.6	--
						Mean =	0.67

Note: All groups were top-cast except for group 4 and 9 which were bottom-cast.

Cs = min (side cover, 1/2 clear spacing) = 2 in. for all members.

Choi et al. (1990a, 1991)

Group No.	Specimen Label *	No. of Splices	Avg. Coat. Thck. (mils)	Nomin. Cover (in.)	Ult. Moment (k-in.)	Ult. Stress (ksi)	Norm. Stress (ksi)	Relative ** Strength $\frac{C}{U}$
1	5N0-12-0-U	2	0.0	1	521	62.5	63.3	--
	5N0-12-0-U	3	0.0	1	813	65.3	66.2	--
	5N0-12-0-C	3	9.5	1	609	49.0	49.0	0.75
2	6S0-12-0-U	2	0.0	1	543	45.8	43.8	--
	6S0-12-0-C	2	8.3	1	511	43.1	41.2	0.94
	6C0-12-0-U	2	0.0	1	610	51.4	49.2	--
	6C0-12-0-C	2	8.8	1	466	39.3	37.6	0.76

Table 7 Other Studies (continued)

3	8S0-16-0-U	2	0.0	1.5	854	43.1	41.3	--
	8S0-16-0-C	2	9.4	1.5	768	38.7	37.2	0.90
	8N0-16-0-U	2	0.0	1.5	858	43.3	41.5	--
	8N0-16-0-C	2	9.5	1.5	737	37.2	35.7	0.86
4	11S0-24-0-U	2	0.0	2	1459	40.2	39.0	--
	11S0-24-0-C	2	9.3	2	1053	29.0	28.1	0.72
	11C0-24-0-U	2	0.0	2	1372	37.8	36.7	--
	11C0-24-0-C	2	10.3	2	1128	31.1	30.1	0.82
Note: all bars were bottom-cast							Mean =	0.82

Cs = min (side cover, 1/2 clear spacing) = 2 in. for all members

Hamad & Jirsa (1990)

Group No.	Specimen Label *	No. of Splices	Nomin. Coat. Thck. (mils)	Nomin. Cover (in.)	Ult. Stress (ksi)	Norm. Stress (ksi)	Relative ** Strengths C/U	U/Un	C/Cn	C/Un
1	11P3-30-0-U	2	0.0	2	34.8	42.5	--	1.00	--	--
	11P3-30-0-C	2	8.0	2	25.6	31.2	0.74	--	1.00	0.74
	11P3-30-3-U	2	0.0	2	37.7	46.0	--	1.08	--	--
	11P3-30-3-C	2	8.0	2	30.5	37.2	0.81	--	1.19	0.88
	11P3-30-6-U	2	0.0	2	41.6	48.7	--	1.15	--	--
	11P3-30-6-C	2	8.0	2	34.8	40.8	0.84	--	1.31	0.96
2	11P3-30-6-U	3	0.0	2	33.0	38.7	--	--	--	--
	11P3-30-6-C	3	8.0	2	28.2	33.0	0.85	--	--	--
3	6P3-18-0-U	3	0.0	2	62.2	75.5	--	1.00	--	--
	6P3-18-0-C	3	8.0	2	41.7	50.6	0.67	--	1.00	0.67
	6P3-18-3-U	3	0.0	2	68.8	83.4	--	1.10	--	--
	6P3-18-3-C	3	8.0	2	51.1	61.9	0.74	--	1.22	0.82
Note: all bars top-cast						Mean =	0.78	1.07	1.14	0.81

* Specimen Label : #DS-L-N-B
\# = bar size
D = deformation pattern :
S,C,N, P (parallel),
D (diamond)
S = stirrup bar size
L = splice length
N = number of stirrups
B = U - uncoated bars
C - coated bars

Note:
1.) Norm.Stress = Ult.Stress(5500/f'c)^1/2
2.) 1 mil = 0.001 in.

** Relative Strengths
$\frac{C}{U}$, $\frac{U}{Un}$, $\frac{C}{Cn}$, $\frac{C}{Un}$
U = uncoated bars
C = coated bars
n = no stirrups within splice length

Cs = min (side cover, 1/2 clear spacing)
= 2 in. for Group No. 1
= 1.41 in. for Group No. 2
= 0.625 in. for Group No. 3

Table 8 Data for Best Fit Analyses of Relative Bond Strengths versus K_{tr}

All K_{tr}

Ratio	No. of Specimens	Slope	Stand. Dev.	Coef. of Corr.	Mean at 0.0	Mean at 3.0	Mean at 5.0	Mean at 10.0
For Current Study:								
C/U	26	-0.002	0.077	0.902	0.743	0.737	0.733	0.723
U/Un	29	0.020	---	0.556	1.000	1.059	1.098	1.196
C/Cn	26	0.016	---	0.735	1.000	1.048	1.079	1.158
C/Un	28	0.013	0.099	0.959	0.750	0.788	0.813	0.875
For Current Study and Hamad & Jirsa:								
C/U	31	-0.001	0.072	0.888	0.742	0.739	0.737	0.732
U/Un	34	0.020	---	0.536	1.000	1.061	1.102	1.204
C/Cn	31	0.018	---	0.512	1.000	1.054	1.091	1.181
C/Un	33	0.014	0.095	0.930	0.752	0.794	0.821	0.890

$K_{tr} < 3.0$

Ratio	No. of Specimens	Slope	Stand. Dev.	Coef. of Corr.	Mean at 0.0	Mean at 3.0
For Current Study:						
C/U	14	-0.022	0.083	0.939	0.760	0.694
U/Un	17	0.067	---	0.735	1.000	1.201
C/Cn	14	0.029	---	0.370	1.000	1.087
C/Un	16	0.021	0.074	0.946	0.757	0.819
For Current Study and Hamad & Jirsa:						
C/U	19	0.001	0.074	0.894	0.743	0.746
U/Un	22	0.065	---	0.775	1.000	1.196
C/Cn	19	0.065	---	0.586	1.000	1.196
C/Un	21	0.044	0.069	0.914	0.741	0.873

U = uncoated bars
C = coated bars
n = no stirrups within splice length

Table 9 Test/Prediction Ratios for B1–B7 Splice Tests

Group No.	Specimen Label *	Average Coating Thickness (mils)	Norm. Stress (ksi)	AASHTO Stress (ksi)	ACI Stress (ksi)	OJB Stress (ksi)	Test/Prediction		
							AASHTO	ACI	OJB
B1	8N3-16-0-U	0.0	48.33	22.09	28.88	41.89	2.19	1.67	1.15
	8N3-16-2-U	0.0	54.10	22.09	28.88	48.61	2.45	1.87	1.11
	8N3-16-1-C	7.5	36.63	22.09	28.88	45.25	1.66	1.27	0.81
	8N3-16-2-C	9.6	40.95	22.09	28.88	48.61	1.85	1.42	0.84
B2	8C3-16-0-U	0.0	43.75	22.09	28.88	41.89	1.98	1.52	1.05
	8C3-16-2-U	0.0	41.65	22.09	28.88	46.59	1.89	1.44	0.89
	8C3-16-0-C	11.2	36.28	22.09	28.88	41.89	1.64	1.26	0.87
	8C3-16-2-C	8.7	35.79	22.09	28.88	46.59	1.62	1.24	0.77
B3	8S3-16-0-U	0.0	44.95	22.09	28.88	41.89	2.04	1.56	1.07
	8S3-16-2-U	0.0	44.51	22.09	28.88	47.88	2.02	1.54	0.93
	8S3-16-0-C	9.9	29.49	22.09	28.88	41.89	1.34	1.02	0.70
	8S3-16-2-C	9.8	30.57	22.09	28.88	47.88	1.38	1.06	0.64
	8S3-16-0-C	10.3	25.37	22.09	14.44	35.48	1.15	1.76	0.72
	8S3-16-2-C	9.8	28.95	22.09	14.44	40.90	1.31	2.01	0.71
B4	8S3-16-0-U	0.0	39.47	22.09	28.88	41.89	1.79	1.37	0.94
	8S3-16-2-U	0.0	43.81	22.09	28.88	47.88	1.98	1.52	0.92
	8S3-16-3-U	0.0	46.58	22.09	28.88	50.88	2.11	1.61	0.92
	8S3-16-0-C	10.7	28.44	22.09	28.88	41.89	1.29	0.99	0.68
	8S3-16-2-C	9.8	29.61	22.09	28.88	47.88	1.34	1.03	0.62
	8S3-16-3-C	8.9	28.45	22.09	28.88	50.88	1.29	0.99	0.56
B5	8C3-16-0-U	0.0	39.78	22.09	28.88	41.89	1.80	1.38	0.95
	8C3-16-2-U	0.0	46.61	22.09	28.88	46.59	2.11	1.61	1.00
	8C3-16-3-U	0.0	43.26	22.09	28.88	48.95	1.96	1.50	0.88
	8C3-16-0-C	8.6	31.87	22.09	28.88	41.89	1.44	1.10	0.76
	8C3-16-3-C	8.0	34.69	22.09	28.88	48.95	1.57	1.20	0.71
B6	8C3-22 3/4-0-U	0.0	50.02	31.41	41.07	53.30	1.59	1.22	0.94
	8C3-22 3/4-3-U	0.0	54.46	31.41	41.07	60.36	1.73	1.33	0.90
	8C3-22 3/4-4-U	0.0	53.93	31.41	41.07	62.72	1.72	1.31	0.86
	8C3-22 3/4-0-C	9.0	32.34	31.41	41.07	53.30	1.03	0.79	0.61
	8C3-22 3/4-3-C	8.6	34.56	31.41	41.07	60.36	1.10	0.84	0.57
	8C3-22 3/4-4-C	9.9	37.35	31.41	41.07	62.72	1.19	0.91	0.60
B7	8C3-16-0-U	0.0	46.32	22.09	28.88	49.01	2.10	1.60	0.95
	8C3-16-3-U	0.0	52.73	22.09	28.88	60.04	2.39	1.83	0.88
	8C3-16-0-C	11.4	39.68	22.09	28.88	49.01	1.80	1.37	0.81
	8C3-16-3-C	9.9	39.65	22.09	28.88	60.68	1.80	1.37	0.65

* Specimen Label : #DS-L-N-B

# = bar size
D = deformation pattern : S,C,N
S = stirrup bar size
L = splice length

N = number of stirrups
B = U - uncoated bars
C - coated bars

Table 10 Test/Prediction Ratios for S1–S8 Splice Tests

Group No.	Specimen Label *	Average Coating Thickness (mils)	Norm. Stress (ksi)	AASHTO Stress (ksi)	ACI Stress (ksi)	OJB Stress (ksi)	Test/Prediction		
							AASHTO	ACI	OJB
S1	6C3-10-0-U	0.0	46.03	30.98	40.52	56.92	1.49	1.14	0.81
	6C3-10-0-C	8.0	35.45	30.98	40.52	57.39	1.14	0.87	0.62
S2	6C3-10-0-U	0.0	47.95	30.98	40.52	54.23	1.55	1.18	0.88
	6C3-10-2-U	0.0	51.65	30.98	40.52	65.62	1.67	1.27	0.79
	6C3-10-0-C	6.1	37.10	30.98	40.52	54.23	1.20	0.92	0.68
	6C3-10-2-C	6.4	34.37	30.98	40.52	64.51	1.11	0.85	0.53
S3	6S3-10-0-U	0.0	48.40	30.98	40.52	54.07	1.56	1.19	0.90
	6S3-10-2-U	0.0	54.53	30.98	40.52	66.41	1.76	1.35	0.82
	6S3-10-0-C	6.4	37.12	30.98	40.52	51.85	1.20	0.92	0.72
	6S3-10-2-C	6.1	37.17	30.98	40.52	64.36	1.20	0.92	0.58
S4	6C5-10-0-U	0.0	47.87	30.98	40.52	52.33	1.55	1.18	0.91
	6C5-10-2-U	0.0	53.18	30.98	40.52	62.46	1.72	1.31	0.85
	6C5-10-0-C	8.9	32.64	30.98	40.52	52.80	1.05	0.81	0.62
	6C5-10-2-C	8.3	39.89	30.98	40.52	62.77	1.29	0.98	0.64
S5	8C5-16-0-U	0.0	44.78	27.61	36.11	50.29	1.62	1.24	0.89
	8C5-16-2-U	0.0	40.05	27.61	36.11	64.53	1.45	1.11	0.62
	8C5-16-0-C	10.3	31.13	27.61	36.11	50.29	1.13	0.86	0.62
	8C5-16-2-C	10.1	29.34	27.61	36.11	63.96	1.06	0.81	0.46
S6	8C5-16-0-U	0.0	36.25	27.61	36.11	50.15	1.31	1.00	0.72
	8C5-16-4-U	0.0	41.20	27.61	36.11	65.39	1.49	1.14	0.63
	8C5-16-0-C	9.5	23.32	27.61	36.11	50.15	0.84	0.65	0.47
	8C5-16-4-C	9.8	27.42	27.61	36.11	63.82	0.99	0.76	0.43
S7	6C5-10-0-U	0.0	69.02	52.67	52.67	52.80	1.31	1.31	1.31
	6C5-10-2-U	0.0	67.97	52.67	52.67	64.67	1.29	1.29	1.05
	6C5-10-0-C	8.2	57.38	52.67	52.67	53.44	1.09	1.09	1.07
	6C5-10-2-C	7.2	57.80	52.67	52.67	64.04	1.10	1.10	0.90
S8	6C5-10-0-U	0.0	37.48	30.98	40.52	51.69	1.21	0.92	0.73
	6C5-10-2-U	0.0	53.48	30.98	40.52	64.83	1.73	1.32	0.82
	6C5-10-0-C	10.9	34.99	30.98	40.52	52.17	1.13	0.86	0.67
	6C5-10-2-C	8.2	44.18	30.98	40.52	63.88	1.43	1.09	0.69

* Specimen Label : #DS-L-N-B

# = bar size
D = deformation pattern : S,C
S = stirrup bar size
L = splice length
N = number of stirrups
N = number of stirrups
B = U - uncoated bars
C - coated bars

Table 11 Test/Prediction Ratios for Other Studies

Treece & Jirsa (1987, 1989)

Group No.	Specimen Label *	Average Coating Thickness (mils)	Norm. Stress (ksi)	AASHTO Stress (ksi)	ACI Stress (ksi)	OJB Stress (ksi)	Test/Prediction		
							AASHTO	ACI	OJB
1	6D0-12-0-C	10.6	37.54	21.25	37.40	58.50	1.77	1.00	0.64
	6D0-12-0-C	4.8	52.56	21.25	37.40	58.50	2.47	1.41	0.90
	6D0-12-0-U	0.0	60.41	21.25	37.40	58.50	2.84	1.62	1.03
2	6D0-24-0-C	9.0	53.48	42.49	29.92	59.45	1.26	1.79	0.90
	6D0-24-0-C	4.5	57.18	42.49	29.92	54.70	1.35	1.91	1.05
	6D0-24-0-U	0.0	75.56	42.49	29.92	64.19	1.78	2.53	1.18
3	11D0-36-0-C	9.1	29.59	17.98	18.08	56.15	1.65	1.64	0.53
	11D0-36-0-C	5.9	31.79	17.98	18.08	56.15	1.77	1.76	0.57
	11D0-36-0-U	0.0	45.28	17.98	18.08	56.15	2.52	2.50	0.81
4	11D0-36-0-C	11.0	28.19	17.98	18.08	56.15	1.57	1.56	0.50
	11D0-36-0-U	0.0	51.97	17.98	18.08	56.15	2.89	2.87	0.93
5	6D0-16-0-C	14.0	28.95	28.33	19.95	41.41	1.02	1.45	0.70
	6D0-16-0-U	0.0	52.35	28.33	19.95	44.58	1.85	2.62	1.17
6	11D0-18-0-C	7.4	20.62	8.99	9.04	35.49	2.29	2.28	0.58
	11D0-18-0-U	0.0	32.85	8.99	9.04	35.49	3.65	3.63	0.93
7	6D0-16-0-C	10.3	27.15	28.33	19.95	38.25	0.96	1.36	0.71
	6D0-16-0-U	0.0	41.82	28.33	19.95	41.41	1.48	2.10	1.01
8	11D0-18-0-C	9.7	24.45	8.99	9.04	35.49	2.72	2.70	0.69
	11D0-18-0-U	0.0	33.93	8.99	9.04	35.49	3.77	3.75	0.96
9	11D0-18-0-C	8.7	20.82	8.99	9.04	35.49	2.32	2.30	0.59
	11D0-18-0-U	0.0	32.55	8.99	9.04	35.49	3.62	3.60	0.92

Choi et al. (1990a, 1991)

Group No.	Specimen Label *	Nominal Coating Thickness (mils)	Norm. Stress (ksi)	AASHTO Stress (ksi)	ACI Stress (ksi)	OJB Stress (ksi)	Test/Prediction		
							AASHTO	ACI	OJB
1	5N0-12-0-U	0.0	63.3	42.22	49.29	49.01	1.50	1.28	1.29
	5N0-12-0-U	0.0	66.2	42.22	49.29	49.01	1.57	1.34	1.35
	5N0-12-0-C	9.5	49.6	42.22	49.29	49.01	1.17	1.01	1.01
2	6S0-12-0-U	0.0	43.8	29.74	34.73	39.51	1.47	1.26	1.11
	6S0-12-0-C	8.3	41.2	29.74	34.73	39.51	1.39	1.19	1.04
	6C0-12-0-U	0.0	49.2	29.74	34.73	39.51	1.65	1.42	1.25
	6C0-12-0-C	8.8	37.6	29.74	34.73	39.51	1.26	1.08	0.95

Table 11 Test/Prediction Ratios for Other Studies (continued)

3	8S0-16-0-U	0.0	41.3	22.09	20.63	41.89	1.87	2.00	0.99
	8S0-16-0-C	9.4	37.2	22.09	20.63	41.89	1.68	1.80	0.89
	8N0-16-0-U	0.0	41.5	22.09	20.63	41.89	1.88	2.01	0.99
	8N0-16-0-C	9.5	35.7	22.09	20.63	41.89	1.62	1.73	0.85
4	11S0-24-0-U	0.0	39.0	16.78	15.67	42.38	2.32	2.49	0.92
	11S0-24-0-C	9.3	28.1	16.78	15.67	42.38	1.67	1.79	0.66
	11C0-24-0-U	0.0	36.7	16.78	15.67	42.38	2.19	2.34	0.87
	11C0-24-0-C	10.3	30.1	16.78	15.67	42.38	1.79	1.92	0.71

Hamad & Jirsa (1990)

Group No.	Specimen Label *	Nominal Coating Thickness (mils)	Norm. Stress (ksi)	AASHTO Stress (ksi)	ACI Stress (ksi)	OJB Stress (ksi)	Test/Prediction		
							AASHTO	ACI	OJB
1	11P3-30-0-U	0.0	42.48	14.98	15.07	49.26	2.84	2.82	0.86
	11P3-30-0-C	8.0	31.22	14.98	15.07	49.26	2.08	2.07	0.63
	11P3-30-3-U	0.0	46.01	14.98	15.07	55.70	3.07	3.05	0.83
	11P3-30-3-C	8.0	37.16	14.98	15.07	55.70	2.48	2.47	0.67
	11P3-30-6-U	0.0	48.72	14.98	15.07	62.14	3.25	3.23	0.78
	11P3-30-6-C	8.0	40.75	14.98	15.07	62.14	2.72	2.70	0.66
2	11P3-30-6-U	0.0	38.67	14.98	10.55	40.46	2.58	3.67	0.96
	11P3-30-6-C	8.0	33.03	14.98	10.55	40.46	2.20	3.13	0.82
3	6P3-18-0-U	0.0	75.48	31.87	22.44	41.17	2.37	3.36	1.83
	6P3-18-0-C	8.0	50.61	31.87	22.44	41.17	1.59	2.26	1.23
	6P3-18-3-U	0.0	83.38	31.87	22.44	56.34	2.62	3.72	1.48
	6P3-18-3-C	8.0	61.92	31.87	22.44	56.34	1.94	2.76	1.10

* Specimen Label : #DS-L-N-B

# = bar size
D = deformation pattern : S,C,N, P (parallel), D (diamaond)
S = stirrup bar size
N = number of stirrups
B = U - uncoated bars
C - coated bars

Table 12a Test/Prediction Ratios — AASHTO

	Current Study		Hamad & Jirsa	B1-B7 S1-S8 Hamad & Jirsa	Treece & Jirsa	Choi et al.	All Specimens
	B1-B7	S1-S8					
Cn							
Mean	1.383	1.098	1.835	1.302	1.763	1.511	1.496
COV	0.194	0.105	0.189	0.243	0.328	0.157	0.301
No.	7	8	2	17	12	7	36
Cs							
Mean	1.465	1.169	2.335	1.529	-----	-----	1.529
COV	0.170	0.129	0.145	0.308	----	----	0.308
No.	11	7	4	22	--	--	22
C-all							
Mean	1.433	1.131	2.168	1.430	1.763	1.511	1.508
COV	0.176	0.118	0.184	0.295	0.328	0.157	0.301
No.	18	15	6	39	12	7	58
Un							
Mean	1.926	1.450	2.605	1.782	2.711	1.806	2.034
COV	0.108	0.104	0.128	0.239	0.320	0.176	0.335
No.	7	8	2	17	9	8	34
Us							
Mean	2.035	1.587	2.880	2.047	-----	-----	2.047
COV	0.119	0.113	0.115	0.252	----	----	0.252
No.	10	7	4	21	--	--	21
U-all							
Mean	1.990	1.514	2.788	1.928	2.711	1.806	2.039
COV	0.115	0.115	0.118	0.254	0.320	0.176	0.303
No.	17	15	6	38	9	8	55
$\frac{\text{Cn(mean)}}{\text{Un(mean)}}$	0.718	0.757	0.704	0.731	0.650	0.837	0.736
$\frac{\text{Cs(mean)}}{\text{Us(mean)}}$	0.720	0.737	0.811	0.747	-----	-----	0.747
$\frac{\text{C-all(mean)}}{\text{U-all(mean)}}$	0.720	0.747	0.778	0.742	0.650	0.837	0.740

COV = coeficient of variation
No. = number of specimens
C = coated bars

U = uncoated bars
n = no stirrups within splice length
s = stirrups within splice length

Table 12b Test/Prediction Ratios – ACI

	Current Study		Hamad & Jirsa	B1-B7 S1-S8 Hamad & Jirsa	Treece & Jirsa	Choi et al.	All Specimens
	B1-B7	S1-S8					
Cn							
Mean	1.183	0.873	2.165	1.153	1.763	1.503	1.424
COV	0.267	0.141	0.062	0.400	0.269	0.260	0.365
No.	7	8	2	17	12	7	36
Cs							
Mean	1.211	0.930	2.765	1.404	-----	-----	1.404
COV	0.266	0.143	0.099	0.510	----	----	0.510
No.	11	7	4	22	--	--	22
C-all							
Mean	1.200	0.899	2.565	1.295	1.763	1.503	1.417
COV	0.259	0.141	0.148	0.482	0.269	0.260	0.421
No.	18	15	6	39	12	7	58
Un							
Mean	1.473	1.145	3.090	1.509	2.802	1.768	1.912
COV	0.108	0.111	0.124	0.422	0.262	0.284	0.433
No.	7	8	2	17	9	8	34
Us							
Mean	1.556	1.256	3.418	1.811	-----	-----	1.811
COV	0.119	0.074	0.096	0.459	----	----	0.459
No.	10	7	4	21	--	--	21
U-all							
Mean	1.522	1.197	3.308	1.676	2.802	1.768	1.873
COV	0.115	0.102	0.106	0.451	0.262	0.284	0.439
No.	17	15	6	38	9	8	55
Cn(mean) / Un(mean)	0.803	0.762	0.701	0.764	0.629	0.850	0.745
Cs(mean) / Us(mean)	0.778	0.740	0.809	0.775	-----	-----	0.775
C-all(mean) / U-all(mean)	0.788	0.751	0.775	0.773	0.629	0.850	0.757

COV = coeficient of variation
No. = number of specimens
C = coated bars
U = uncoated bars
n = no stirrups within splice length
s = stirrups within splice length

Table 12c Test/Prediction Ratios – Orangun, Jirsa, & Breen

	Current Study		Hamad & Jirsa	B1-B7 S1-S8 Hamad & Jirsa	Treece & Jirsa	Choi et al.	All Specimens
	B1-B7	S1-S8					
Cn							
Mean	0.736	0.683	0.930	0.733	0.697	0.873	0.748
COV	0.117	0.257	0.456	0.250	0.244	0.166	0.240
No.	7	8	2	17	12	7	36
Cs							
Mean	0.680	0.604	0.813	0.680	-----	-----	0.680
COV	0.141	0.266	0.253	0.223	----	----	0.223
No.	11	7	4	22	--	--	22
C-all							
Mean	0.702	0.646	0.852	0.703	0.697	0.873	0.722
COV	0.134	0.260	0.299	0.236	0.244	0.166	0.237
No.	18	15	6	39	12	7	58
Un							
Mean	1.007	0.893	1.345	0.993	0.993	1.096	1.017
COV	0.083	0.206	0.510	0.261	0.121	0.166	0.208
No.	7	8	2	17	9	8	34
Us							
Mean	0.929	0.798	1.013	0.901	-----	-----	0.901
COV	0.080	0.147	0.317	0.195	----	----	0.195
No.	10	7	4	21	--	--	21
U-all							
Mean	0.961	0.848	1.123	0.942	0.993	1.096	0.973
COV	0.089	0.199	0.383	0.233	0.121	0.166	0.211
No.	17	15	6	38	9	8	55
$\frac{\text{Cn(mean)}}{\text{Un(mean)}}$	0.730	0.764	0.691	0.739	0.701	0.796	0.736
$\frac{\text{Cs(mean)}}{\text{Us(mean)}}$	0.732	0.757	0.802	0.755	-----	-----	0.755
$\frac{\text{C-all(mean)}}{\text{U-all(mean)}}$	0.730	0.761	0.758	0.746	0.701	0.796	0.742

COV = coeficient of variation
No. = number of specimens
C = coated bars

U = uncoated bars
n = no stirrups within splice length
s = stirrups within splice length

Table 13a Test/Prediction Ratios with Epoxy–Coated Bar Development Length Modification Factors* – AASHTO

	Current Study B1-B7	Current Study S1-S8	Hamad & Jirsa	B1-B7 S1-S8 Hamad & Jirsa	Treece & Jirsa	Choi et al.	All Specimens
Cn							
Mean	1.869	1.481	2.475	1.757	2.379	2.043	2.020
COV	0.195	0.104	0.191	0.242	0.328	0.156	0.301
No.	7	8	2	17	12	7	36
Cs							
Mean	1.978	1.401	3.155	2.008	-----	-----	2.008
COV	0.169	0.126	0.144	0.340	----	----	0.340
No.	11	7	4	22	--	--	22
C-all							
Mean	1.936	1.444	2.928	1.899	2.379	2.043	2.016
COV	0.176	0.114	0.185	0.311	0.328	0.156	0.313
No.	18	15	6	39	12	7	58
Cn(mean) / Un(mean)	0.970	1.021	0.950	0.986	0.878	1.131	0.993
Cs(mean) / Us(mean)	0.972	0.883	1.095	0.981	-----	-----	0.981
C-all(mean) / U-all(mean)	0.973	0.954	1.050	0.985	0.878	1.131	0.989

COV = coeficient of variation
No. = number of specimens
C = coated bars
U = uncoated bars
n = no stirrups within splice length
s = stirrups within splice length

* Modification Factor = 1.20 for Ktr > 3.0 , = 1.35 otherwise

Note: see Table.12a for uncoated bar data

Table 13b Test/Prediction Ratios with Epoxy–Coated Bar Development Length Modification Factors* – ACI

	Current Study		Hamad & Jirsa	B1-B7 S1-S8 Hamad & Jirsa	Treece & Jirsa	Choi et al.	All Specimens
	B1-B7	S1-S8					
Cn							
Mean	1.599	1.178	2.925	1.556	2.382	2.029	1.923
COV	0.267	0.142	0.060	0.401	0.269	0.261	0.366
No.	7	8	2	17	12	7	36
Cs							
Mean	1.635	1.257	3.735	1.897	-----	-----	1.897
COV	0.266	0.141	0.100	0.510	----	----	0.510
No.	11	7	4	22	--	--	22
C-all							
Mean	1.621	1.215	3.465	1.748	2.382	2.029	1.913
COV	0.259	0.141	0.148	0.482	0.262	0.261	0.421
No.	18	15	6	39	12	7	58
$\frac{\text{Cn(mean)}}{\text{Un(mean)}}$	1.086	1.029	0.947	1.031	0.850	1.148	1.006
$\frac{\text{Cs(mean)}}{\text{Us(mean)}}$	1.051	1.001	1.093	1.047	-----	-----	1.047
$\frac{\text{C-all(mean)}}{\text{U-all(mean)}}$	1.065	1.015	1.047	1.043	0.850	1.148	1.021

COV = coeficient of variation
No. = number of specimens
C = coated bars

U = uncoated bars
n = no stirrups within splice length
s = stirrups within splice length

* Modification Factor = 1.35

Note: see Table.12b for uncoated bar data

Table 13c Test/Prediction Ratios with Epoxy-Coated Bar Development Length Modification Factors* – Orangun, Jirsa, & Breen

	Current Study		Hamad & Jirsa	B1-B7 S1-S8 Hamad & Jirsa	Treece & Jirsa	Choi et al.	All Specimens
	B1-B7	S1-S8					
Cn							
Mean	0.994	0.922	1.260	0.990	0.941	1.179	1.010
COV	0.117	0.257	0.456	0.250	0.244	0.166	0.240
No.	7	8	2	17	12	7	36
Cs							
Mean	0.918	0.815	1.100	0.921	-----	-----	0.918
COV	0.141	0.266	0.253	0.223	----	----	0.223
No.	11	7	4	22	--	--	22
C-all							
Mean	0.948	0.872	1.150	0.949	0.941	1.179	0.975
COV	0.134	0.260	0.299	0.236	0.244	0.166	0.237
No.	18	15	6	39	12	7	58
Cn(mean) / Un(mean)	0.986	1.031	0.933	0.998	0.946	1.075	0.994
Cs(mean) / Us(mean)	0.988	1.022	1.083	1.019	-----	-----	1.019
C-all(mean) / U-all(mean)	0.986	1.027	1.023	1.007	0.946	1.075	1.002

COV = coeficient of variation
No. = number of specimens
C = coated bars

U = uncoated bars
n = no stirrups within splice length
s = stirrups within splice length

* Modification Factor = 1.35

Note: see Table.12c for uncoated bar data

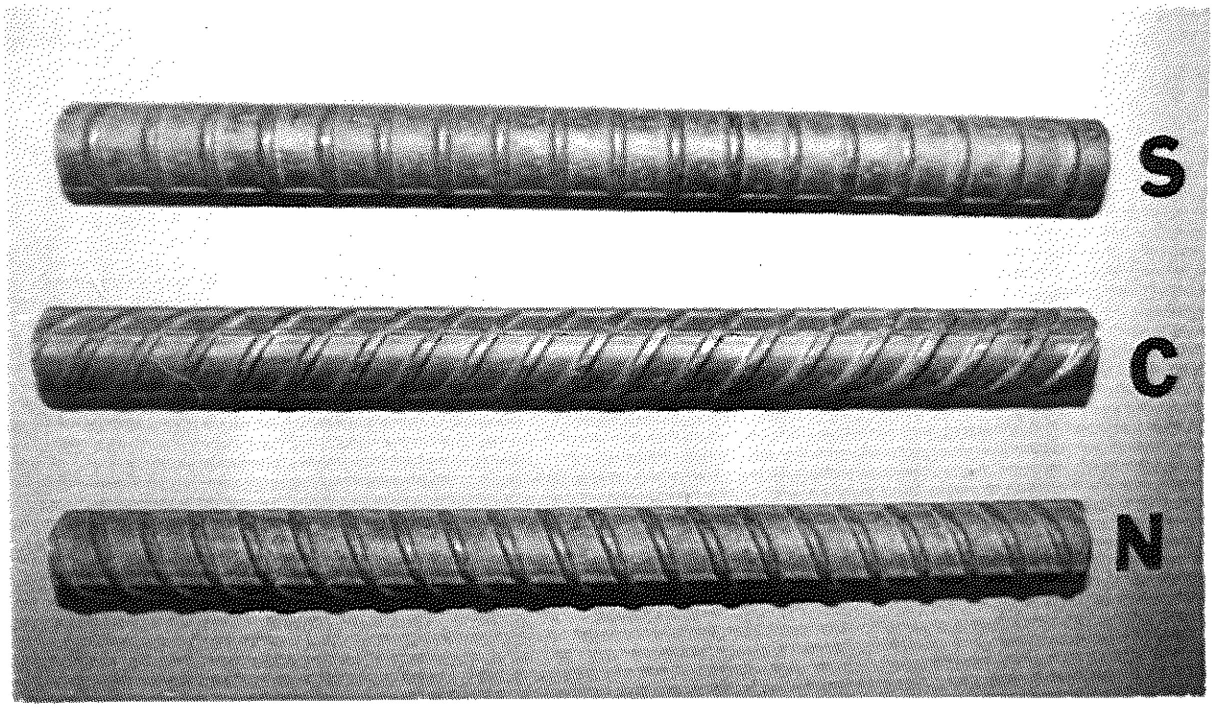


Fig. 1 Reinforcing Bar Deformation Patterns

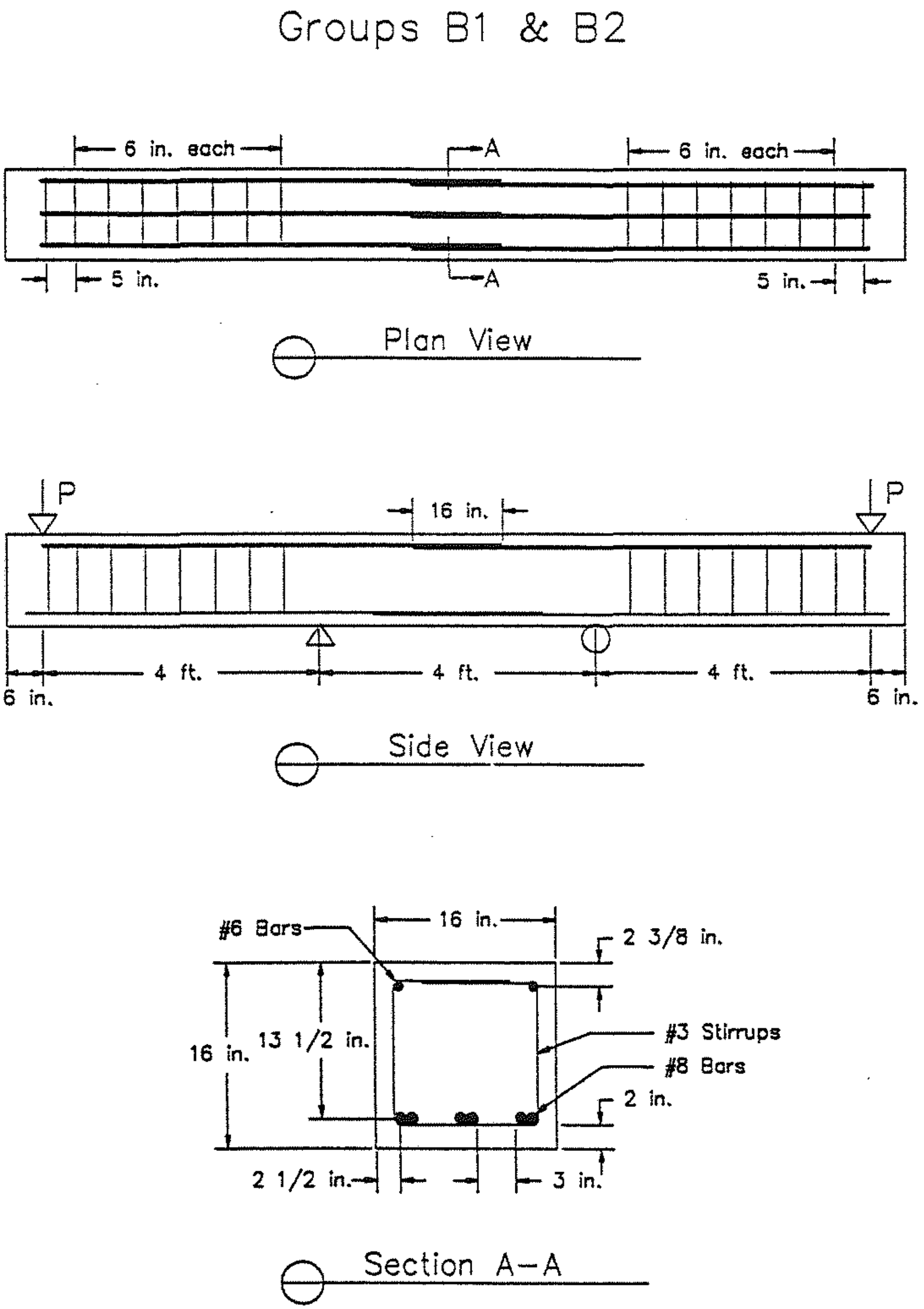


Fig. 2 Beam Splice Specimens

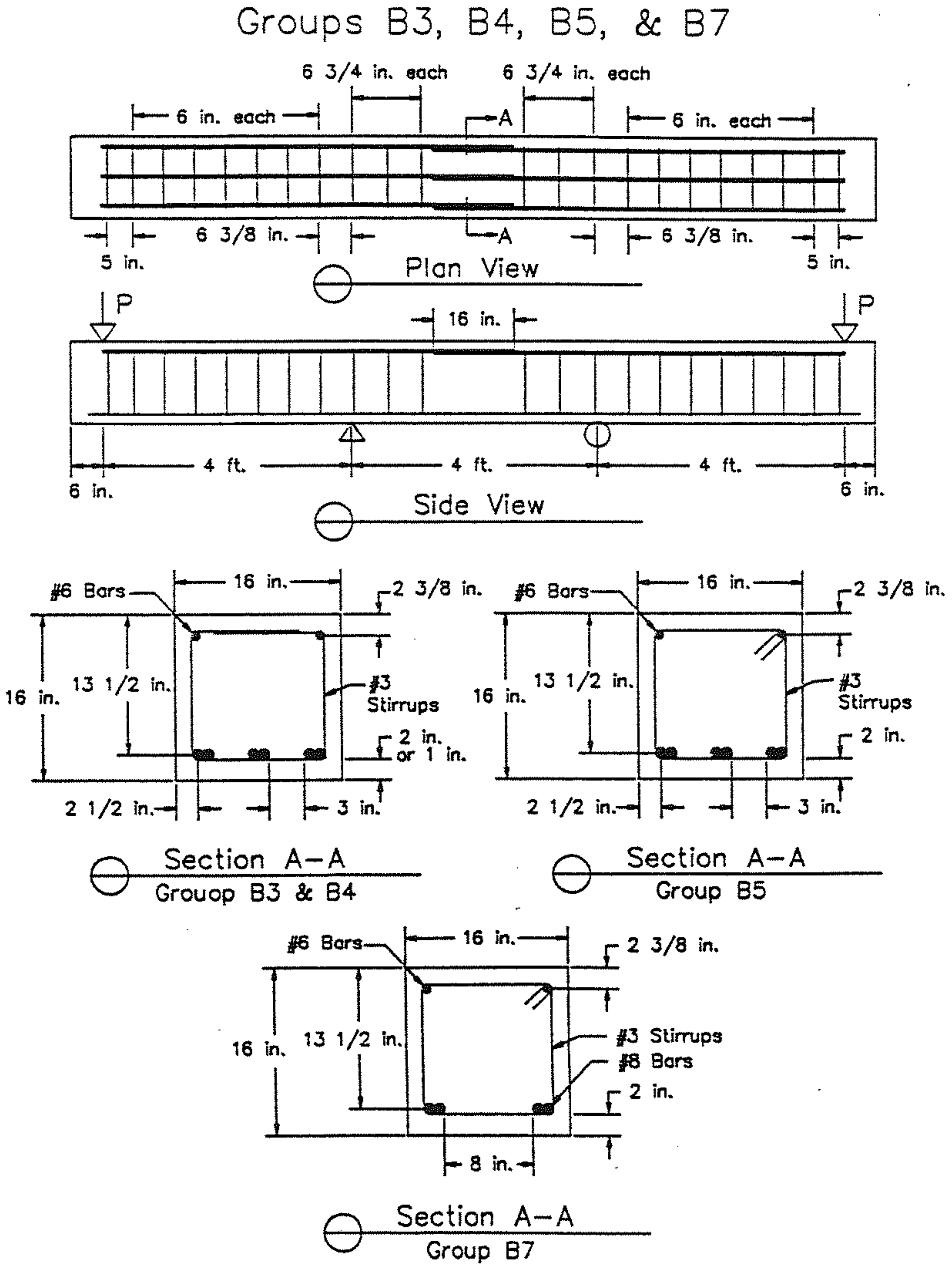
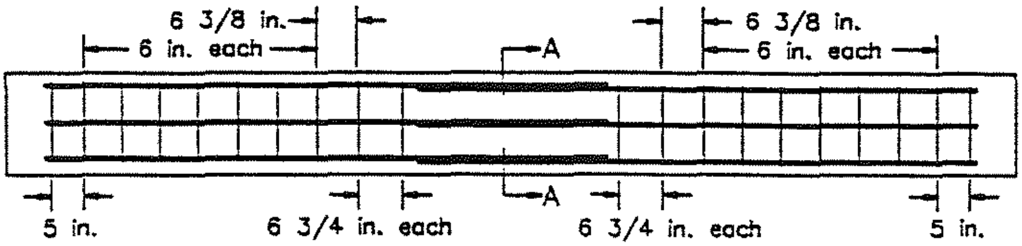
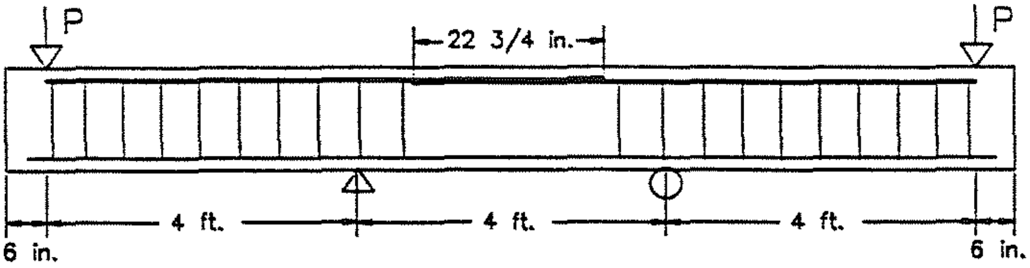


Fig. 2 Beam Splice Specimens (continued)

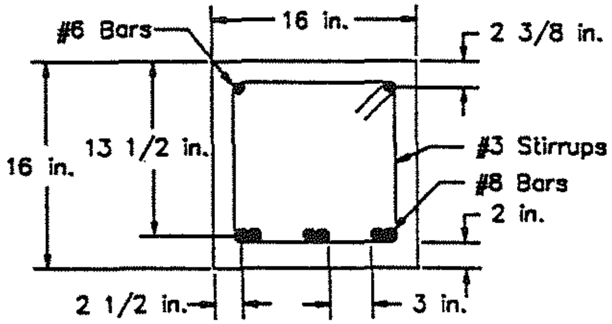
Group B6



Plan View



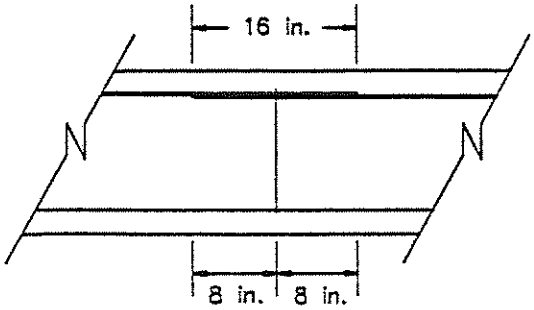
Side View



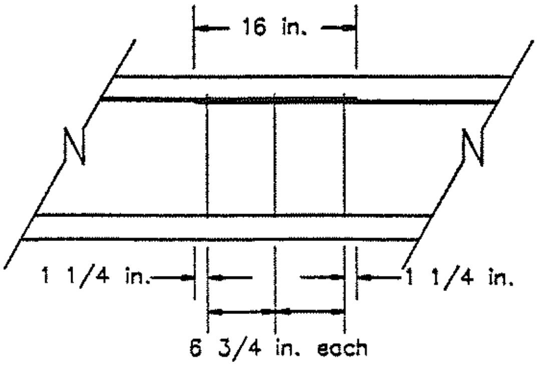
Section A–A

Fig. 2 Beam Splice Specimens (continued)

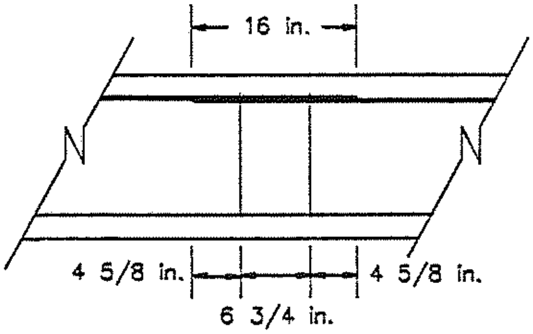
Spacing for 16 in. Splice Length:



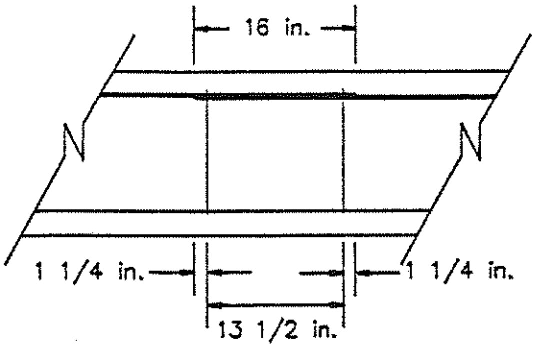
One Stirrup : Group B1



Three Stirrups : Groups B4, B5, & B7

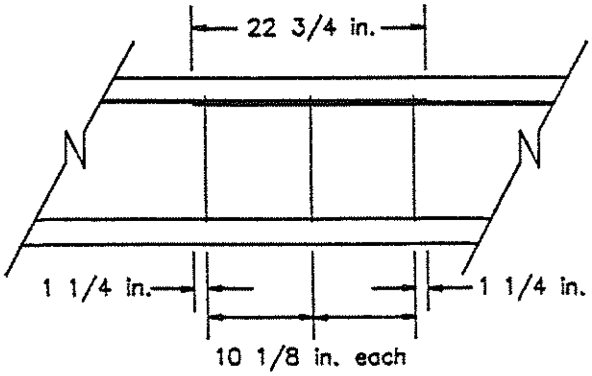


Two Stirrups : Groups B1, B2, & B3

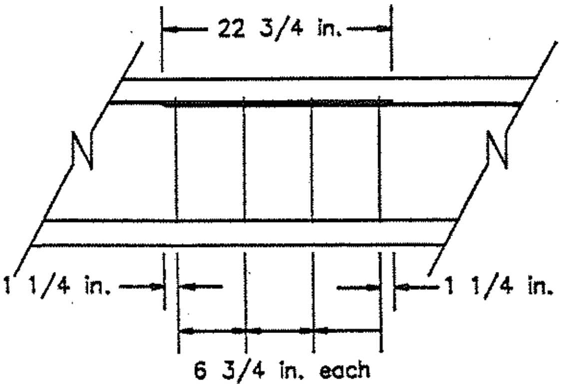


Two Stirrups : Groups B4, B5, & B7

Spacing for 22 3/4 in. Splice Length:



Three Stirrups : Group B6



Four Stirrups : Group B6

Fig. 2 Beam Splice Specimens (continued)

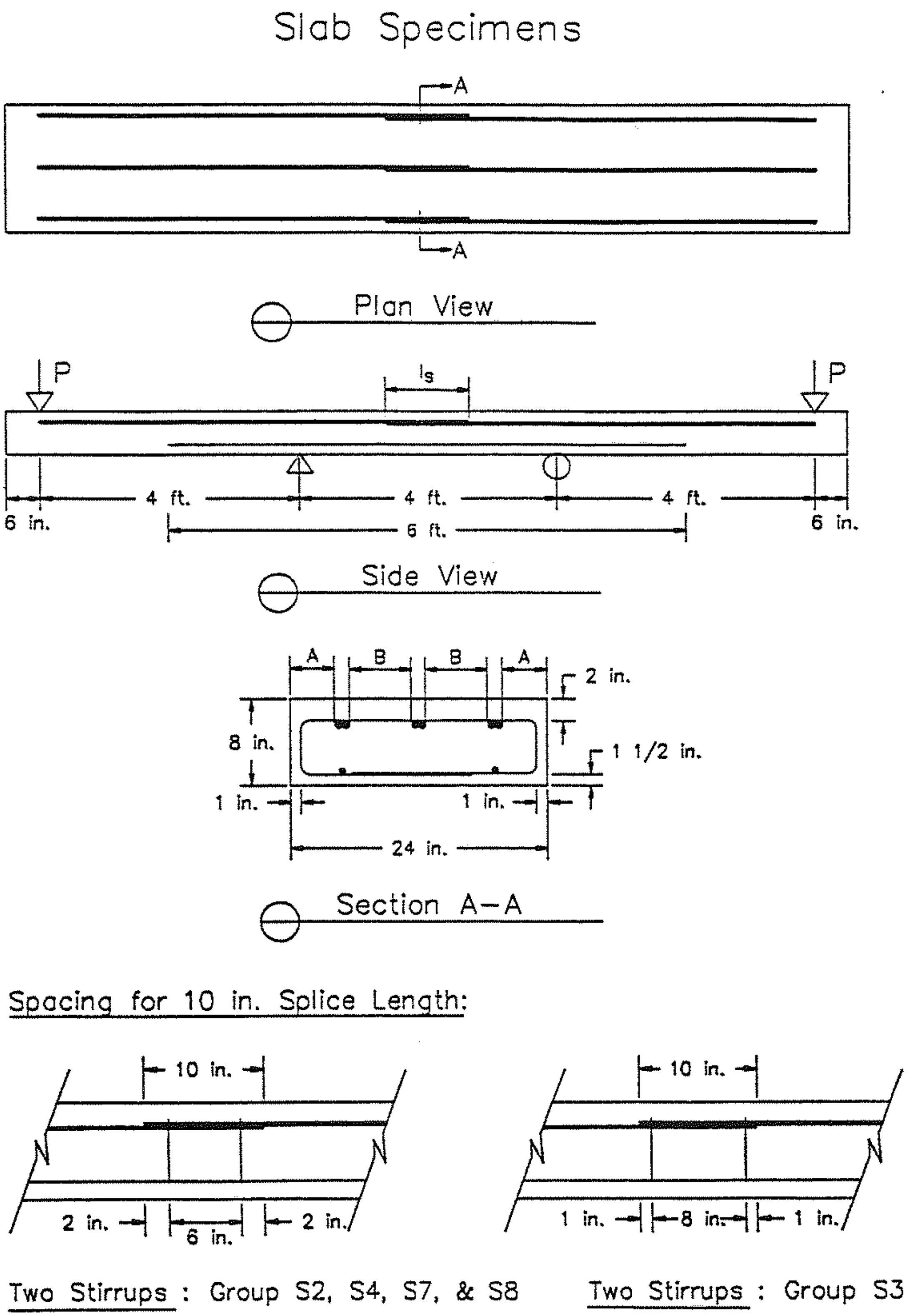
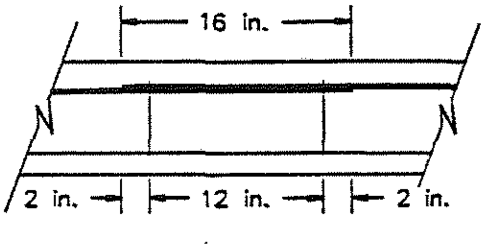
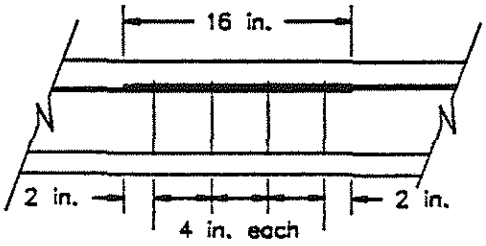


Fig. 3 Slab Splice Specimens

Spacing for 16 in. Splice Length:



Two Stirrups : Group S5



Four Stirrups : Group S6

Group Numbers	Bar Size	Stirrup Bar Size	No. of Splices	A (in.)	B (in.)
S1	#6	#3	3	3 1/4	6 1/2
S2	#6	#3	3	3 1/4	6 1/2
S3	#6	#3	3	3 1/4	6 1/2
S4	#6	#5	3	3 1/4	6 1/2
S5	#8	#5	3	3	6
S6	#8	#5	3	3	6
S7	#6	#5	1	3 1/4	6 1/2
S8	#6	#5	2	3 1/4	6 7/8

Note: Group S7 had one splice with two continuous bars on each side of the splice.
Group S8 had two splices with one continuous bar in the center.

Fig. 3 Slab Splice Specimens (continued)

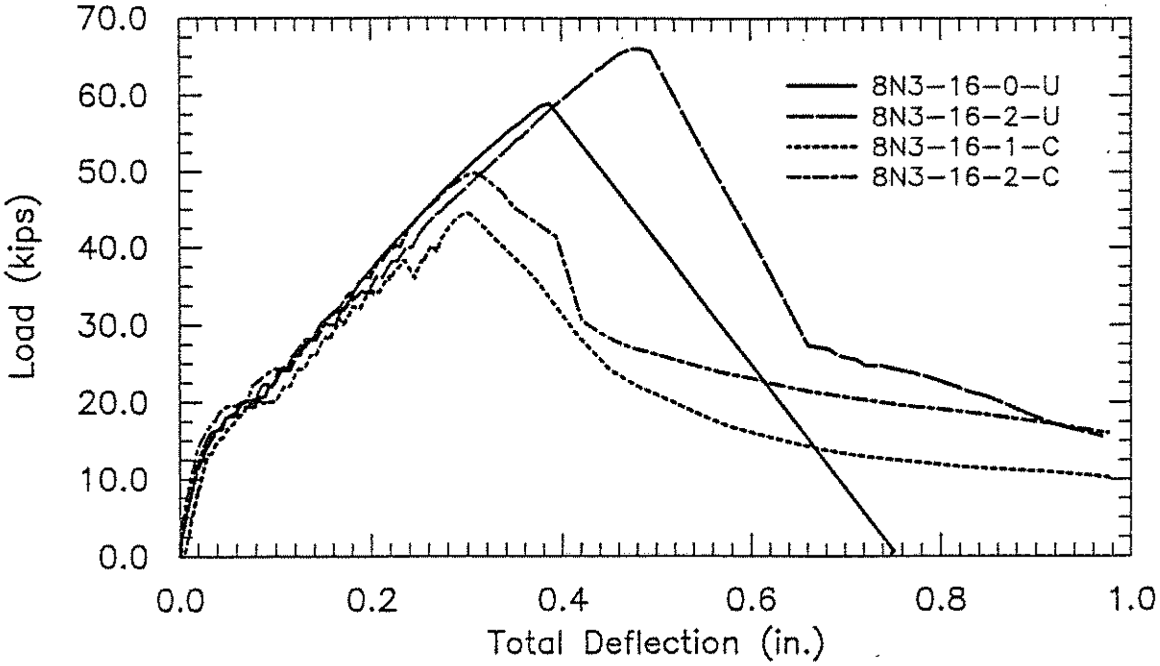


Fig. 4 Load-Deflection Curves for Group B1

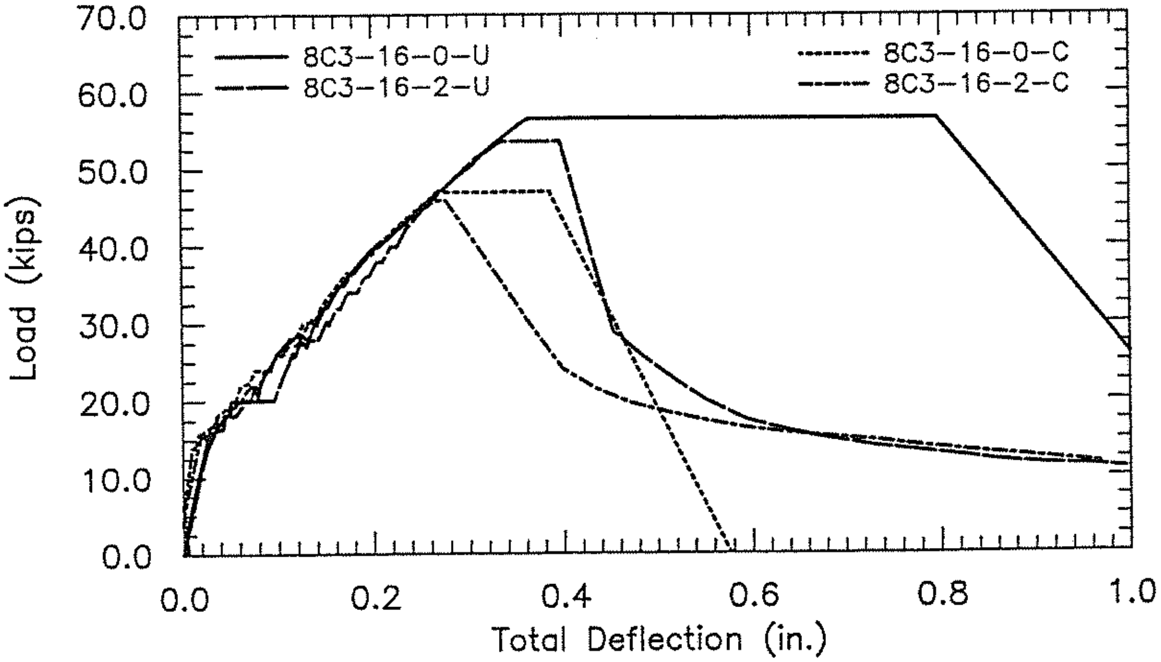


Fig. 5 Load-Deflection Curves for Group B2

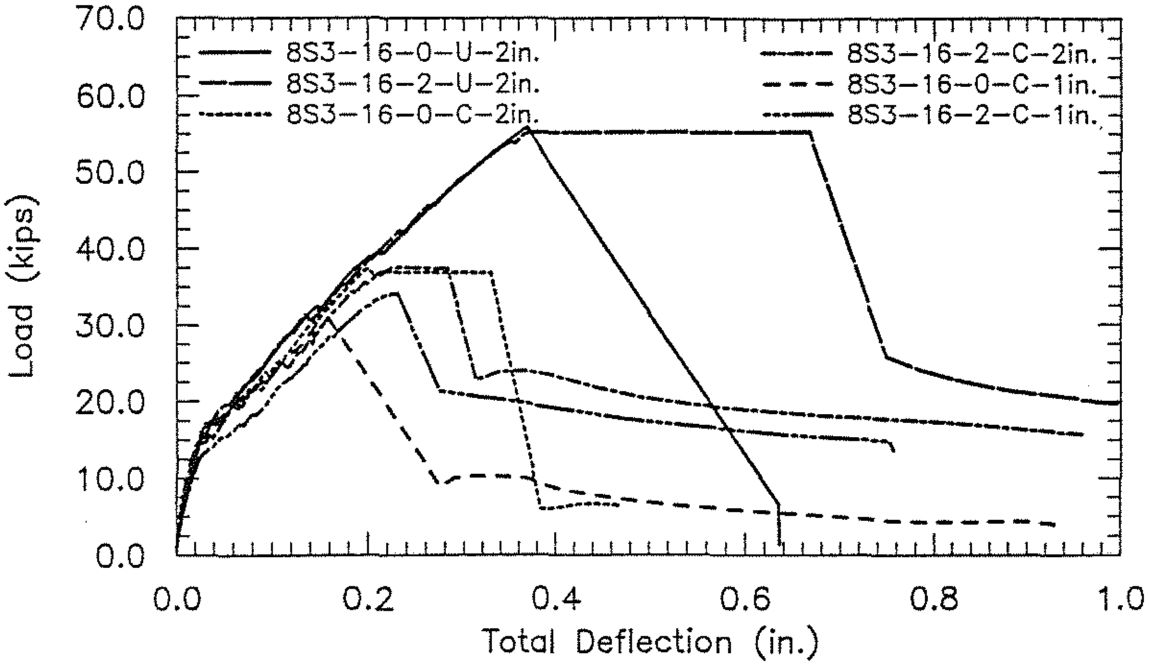


Fig. 6 Load−Deflection Curves for Group B3

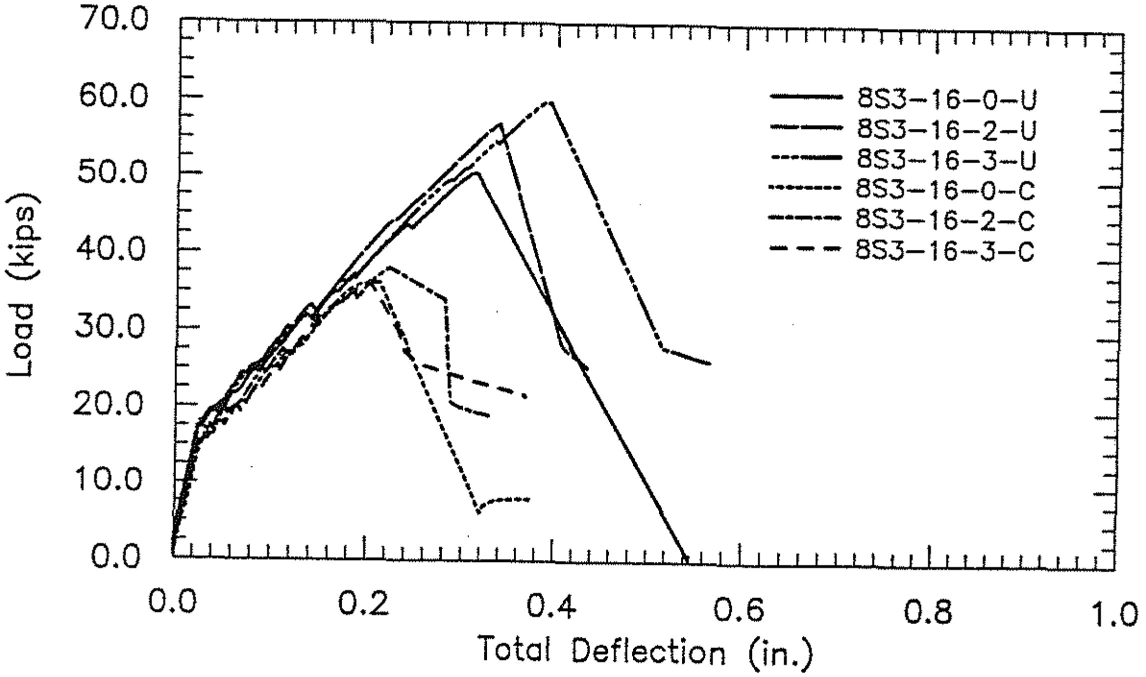


Fig. 7 Load−Deflection Curves for Group B4

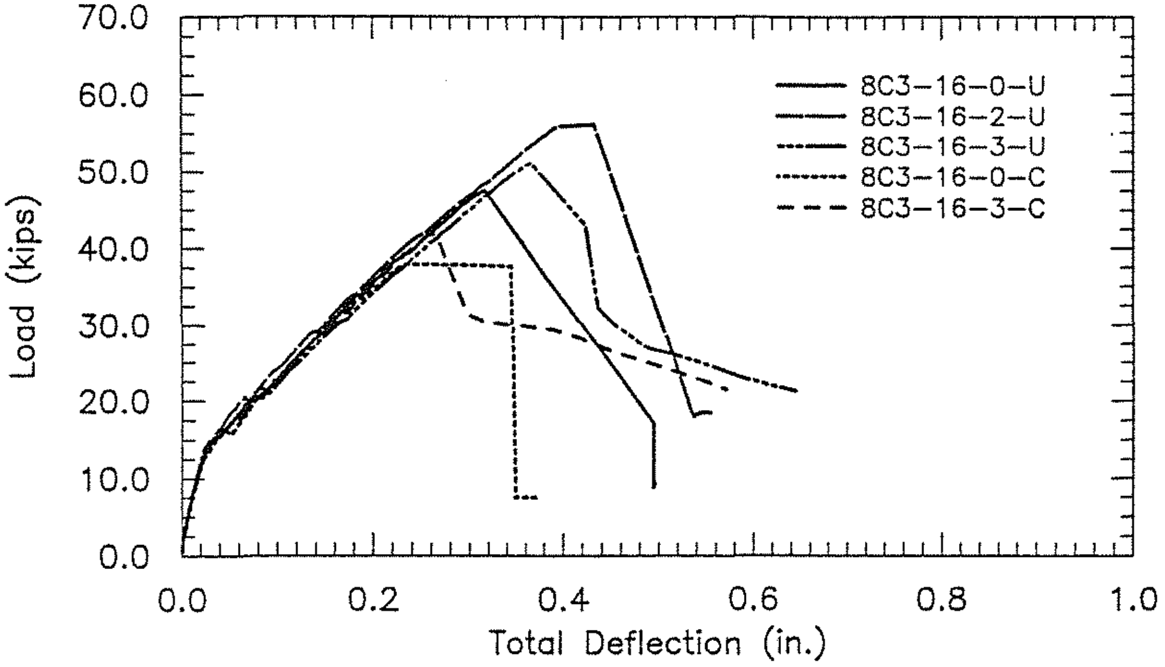


Fig. 8 Load-Deflection Curves for Group B5

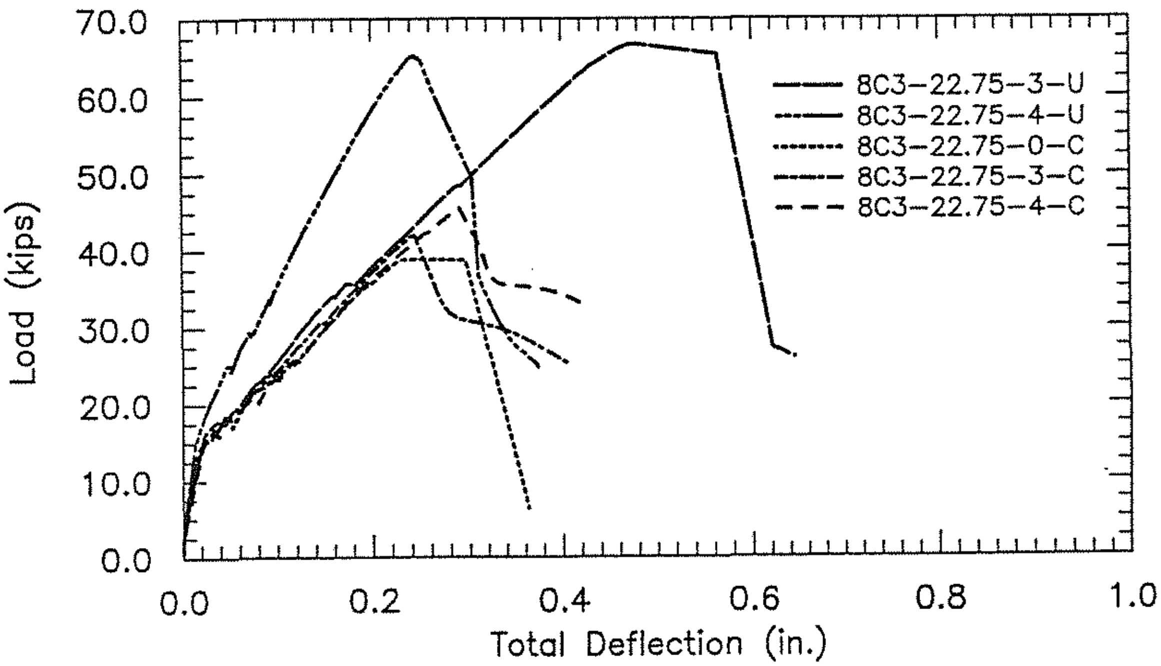


Fig. 9 Load-Deflection Curves for Group B6

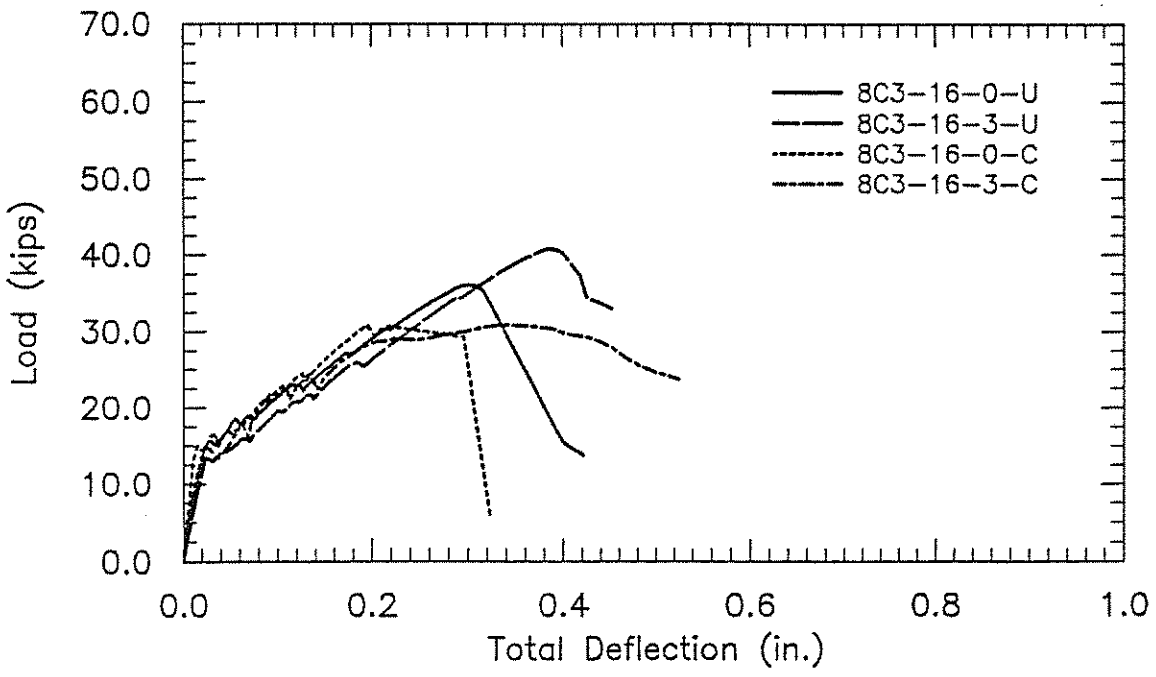


Fig. 10 Load-Deflection Curves for Group B7

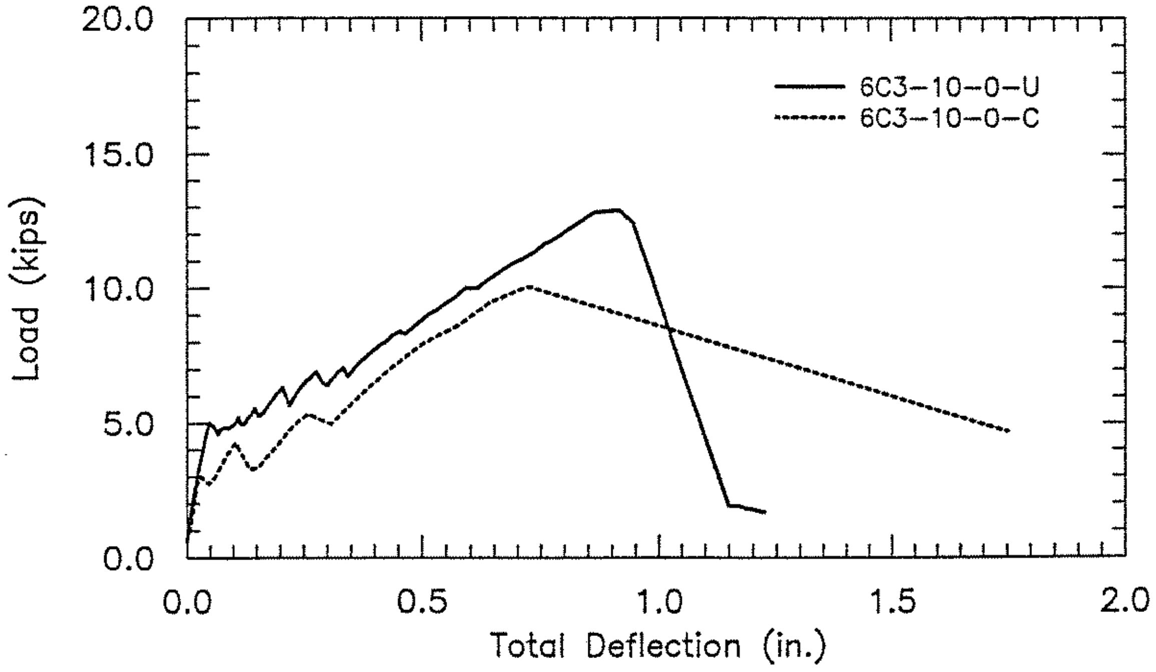


Fig. 11 Load-Deflection Curves for Group S1

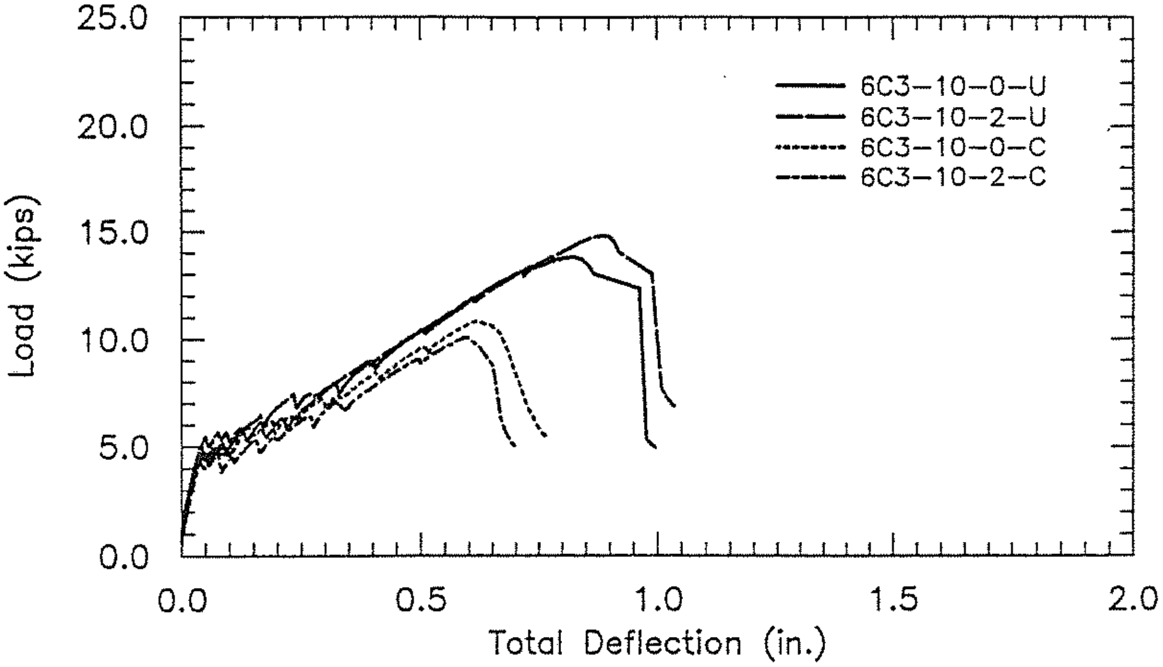


Fig. 12 Load-Deflection Curves for Group S2

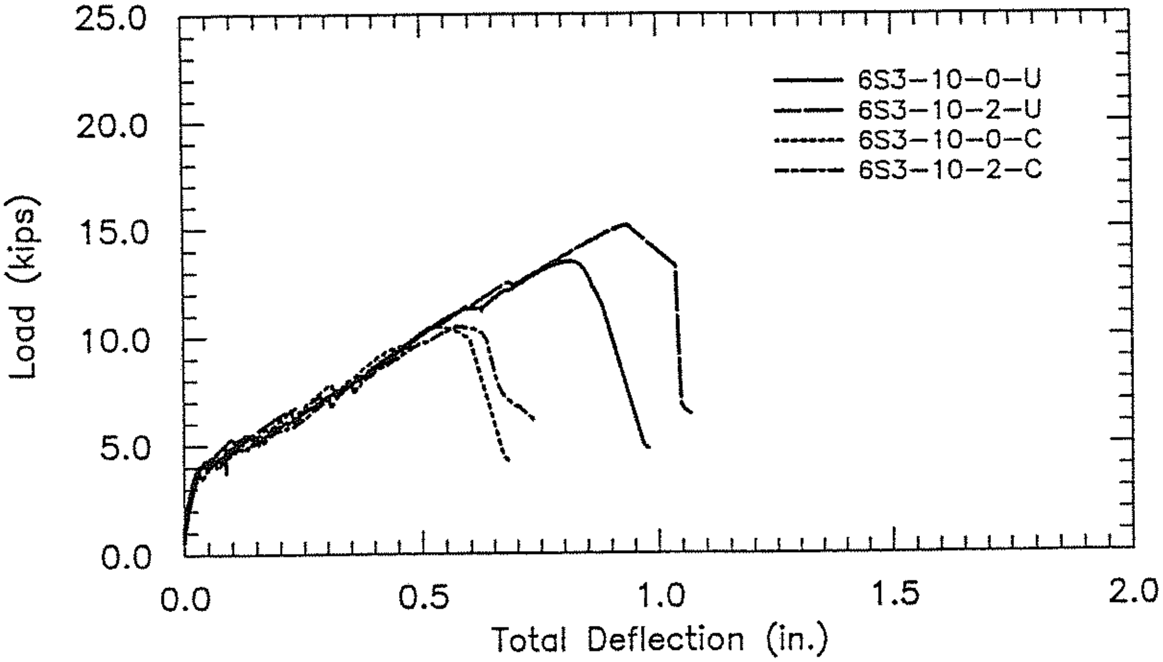


Fig. 13 Load-Deflection Curves for Group S3

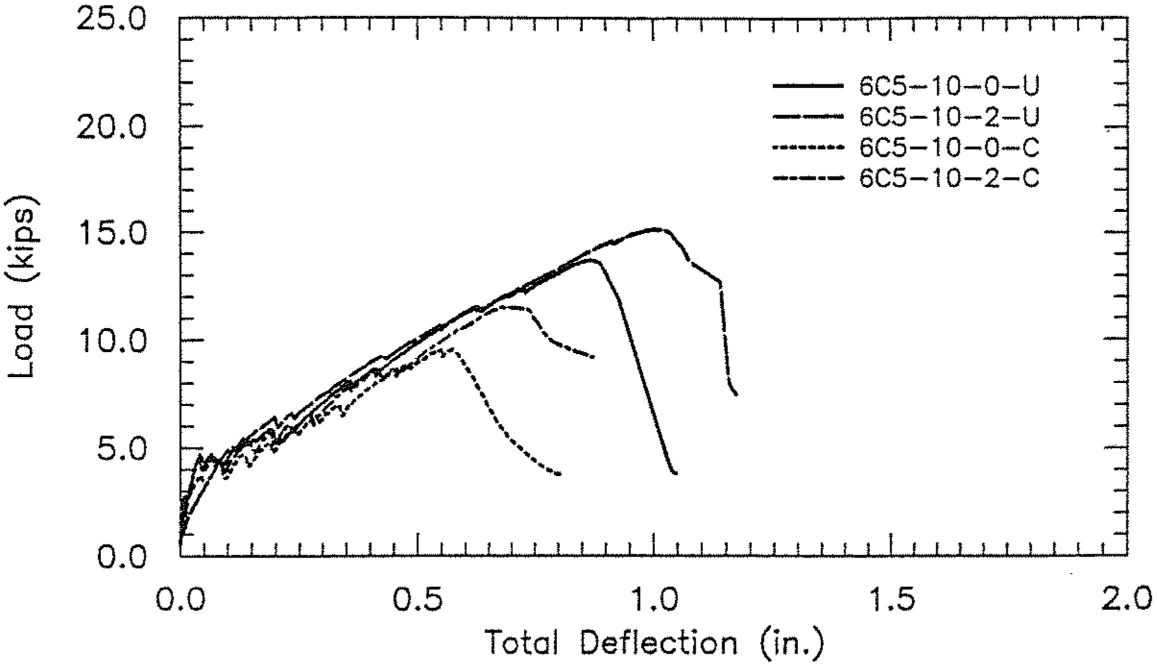


Fig. 14 Load–Deflection Curves for Group S4

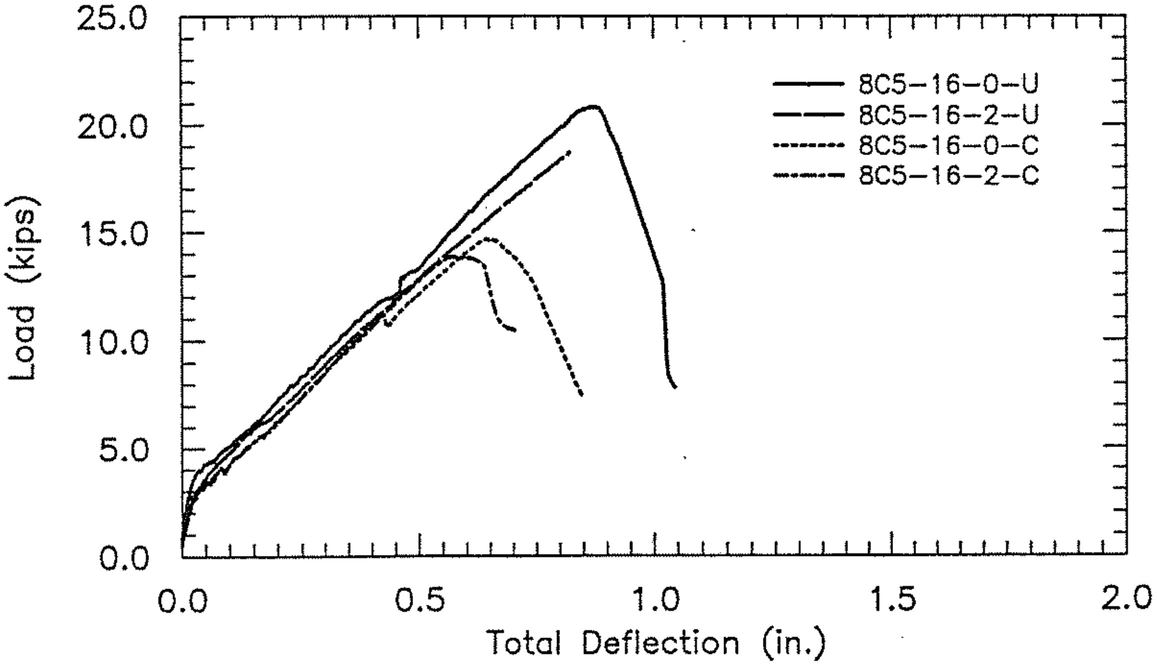


Fig. 15 Load–Deflection Curves for Group S5

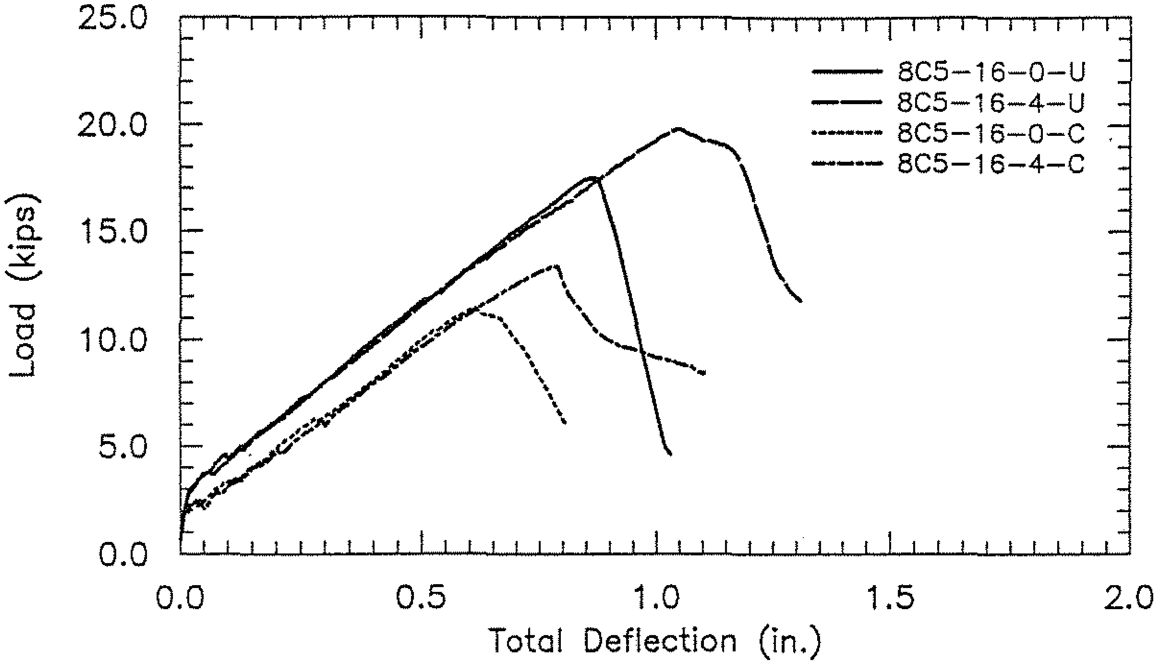


Fig. 16 Load-Deflection Curves for Group S6

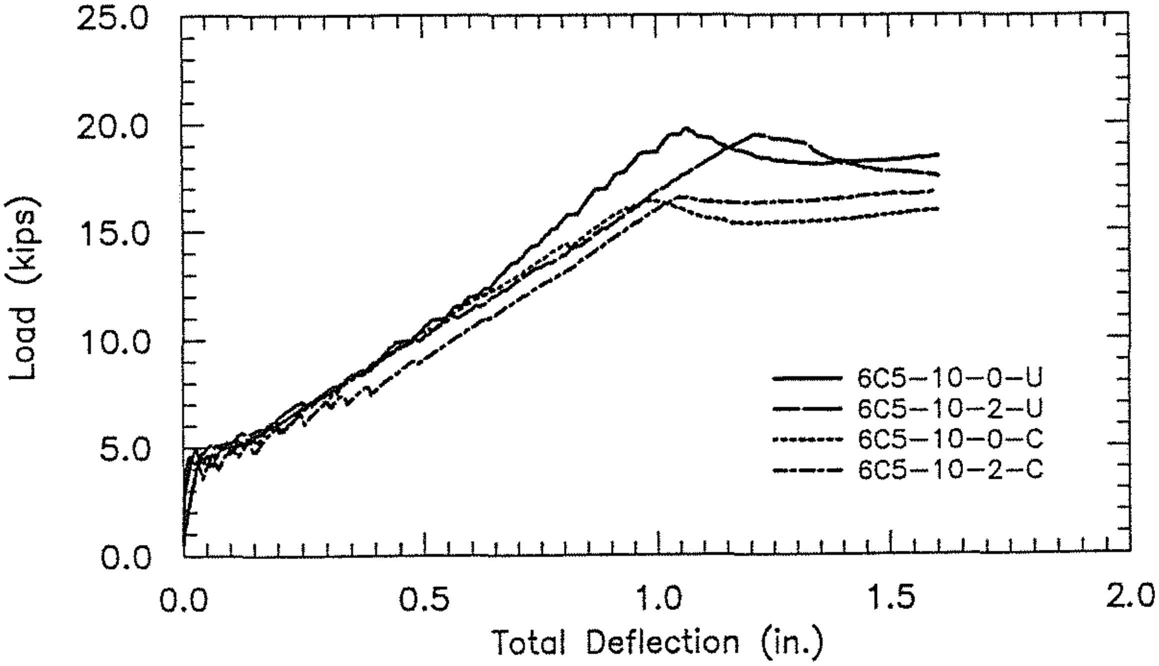


Fig. 17 Load-Deflection Curves for Group S7

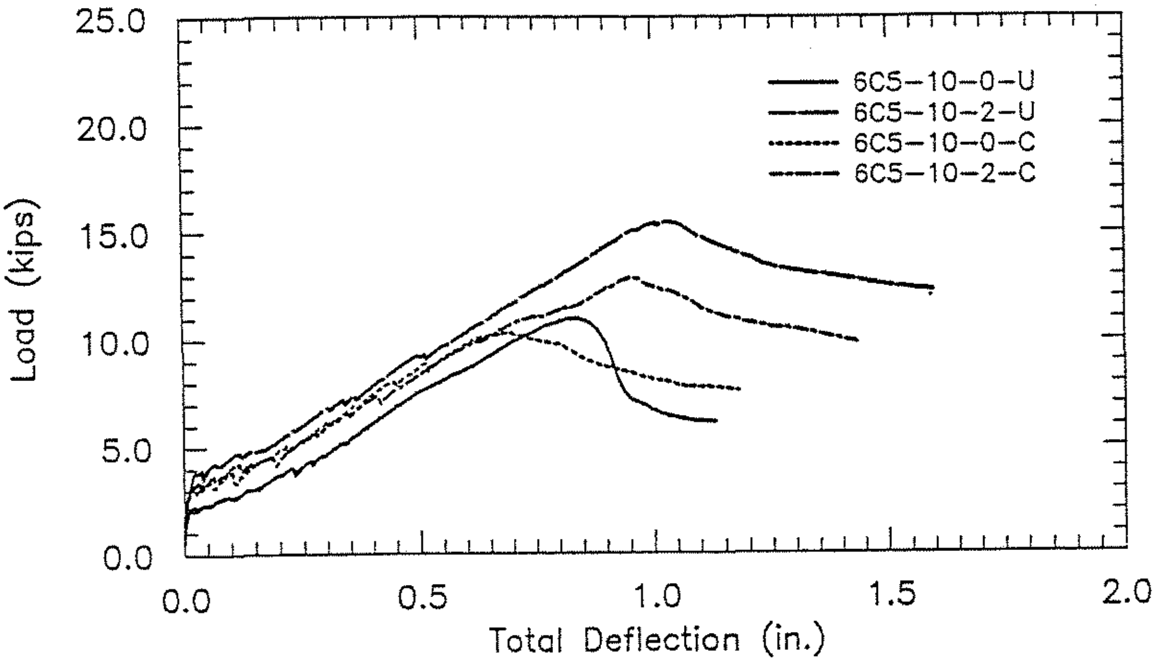
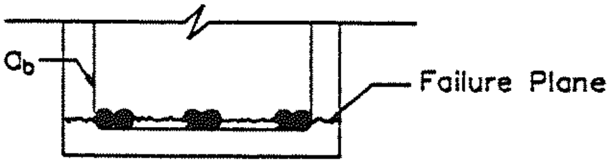
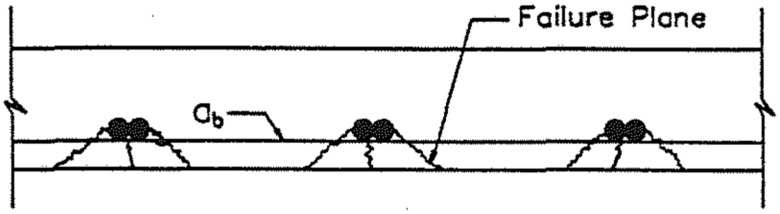


Fig. 18 Load-Deflection Curves for Group S8



$$A_{tr} = \frac{\Sigma a_b}{\text{No. of splices}} = \frac{2a_b}{3}$$

(a)



$$A_{tr} = \frac{\Sigma a_b}{\text{No. of splices}} = \frac{a_b}{1} = a_b$$

(b)

Fig. 19 Area of Transverse Reinforcement: Definitions
(a) For center-to-center spacing < 6 in.
(b) For center-to-center spacing ≥ 6 in.

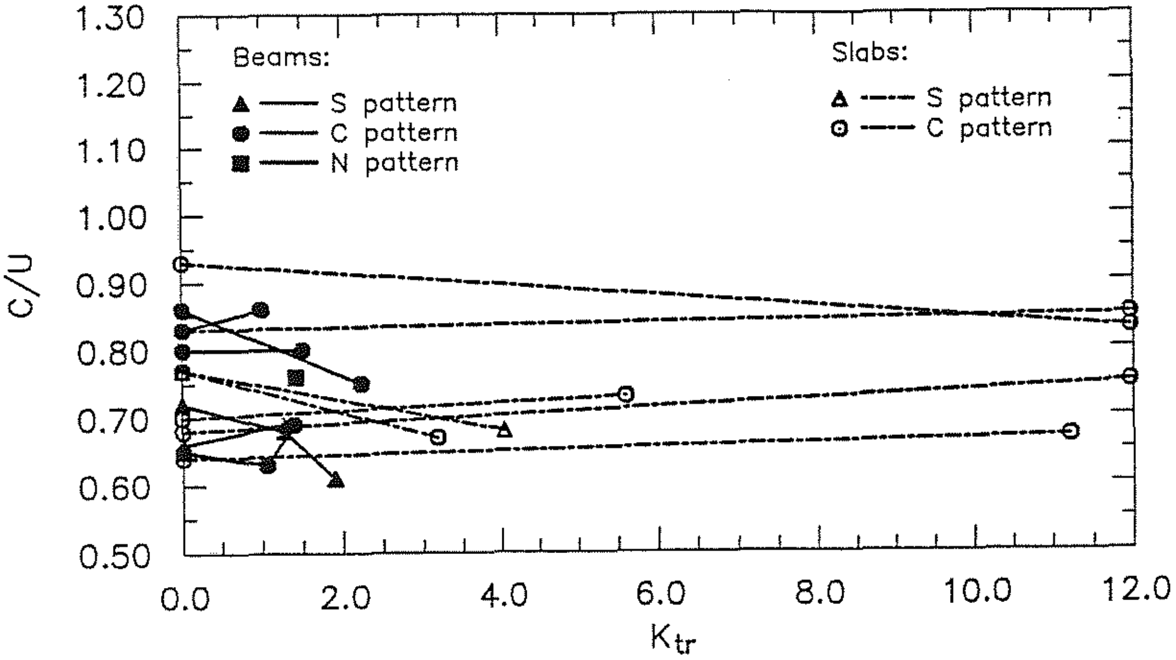


Fig. 20 Relative Bond Strength, C/U, versus K_{tr}

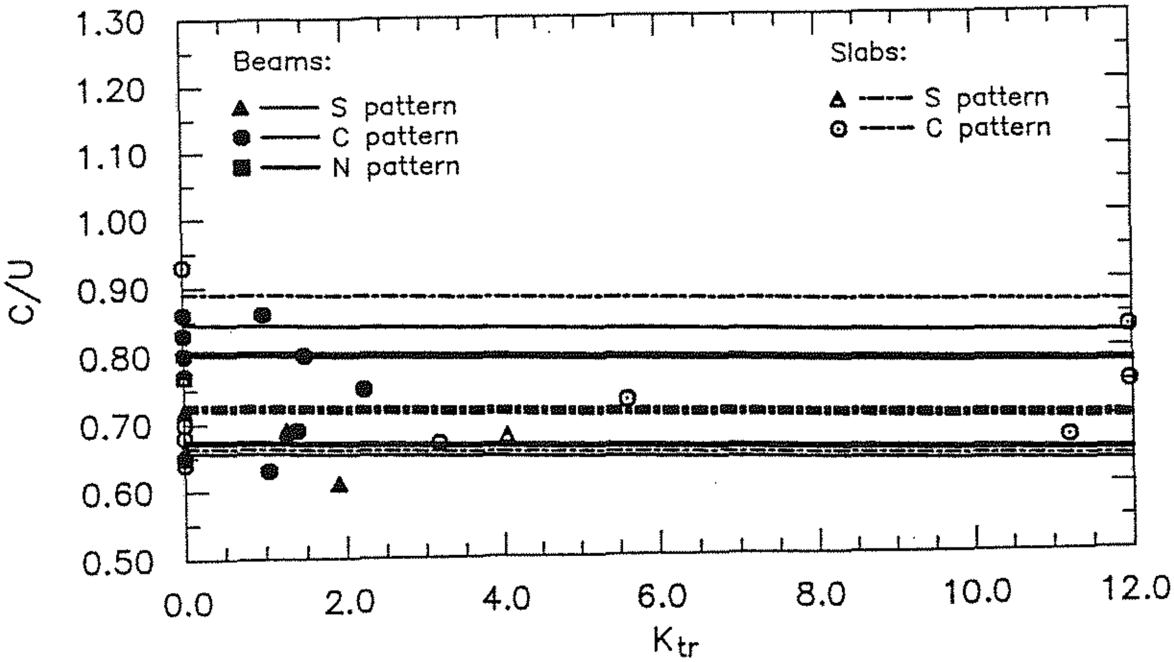


Fig. 21 Relative Bond Strength, C/U, versus K_{tr}

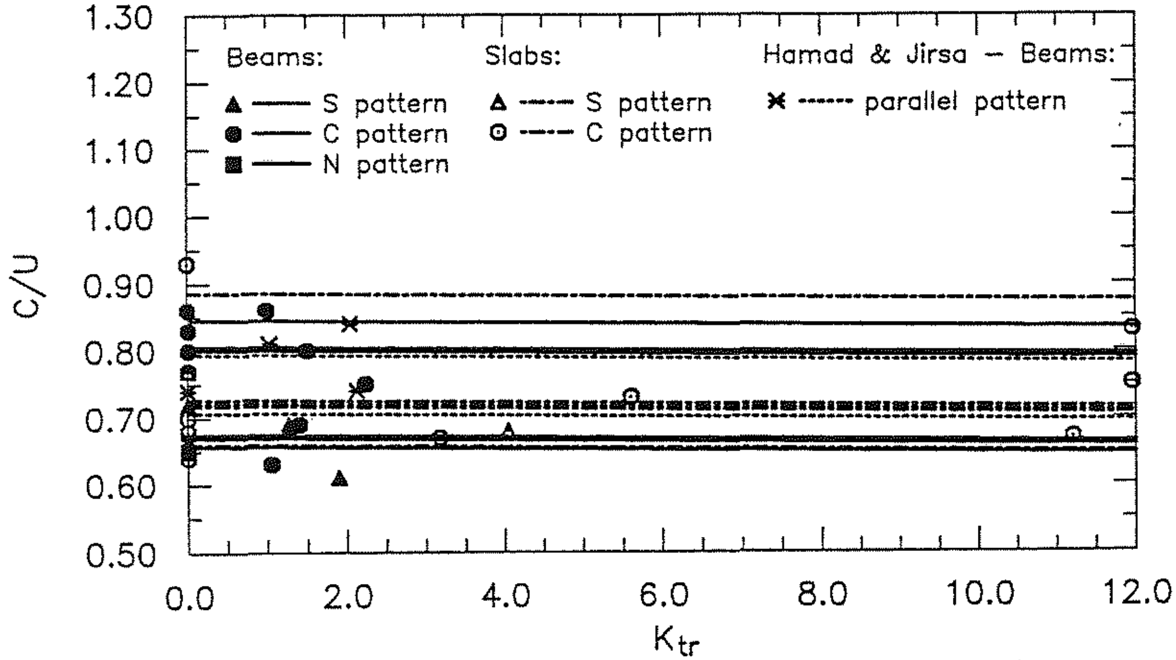


Fig. 22 Relative Bond Strength, C/U, versus K_{tr} for Current Tests Plus Hamad and Jirsa (1990)

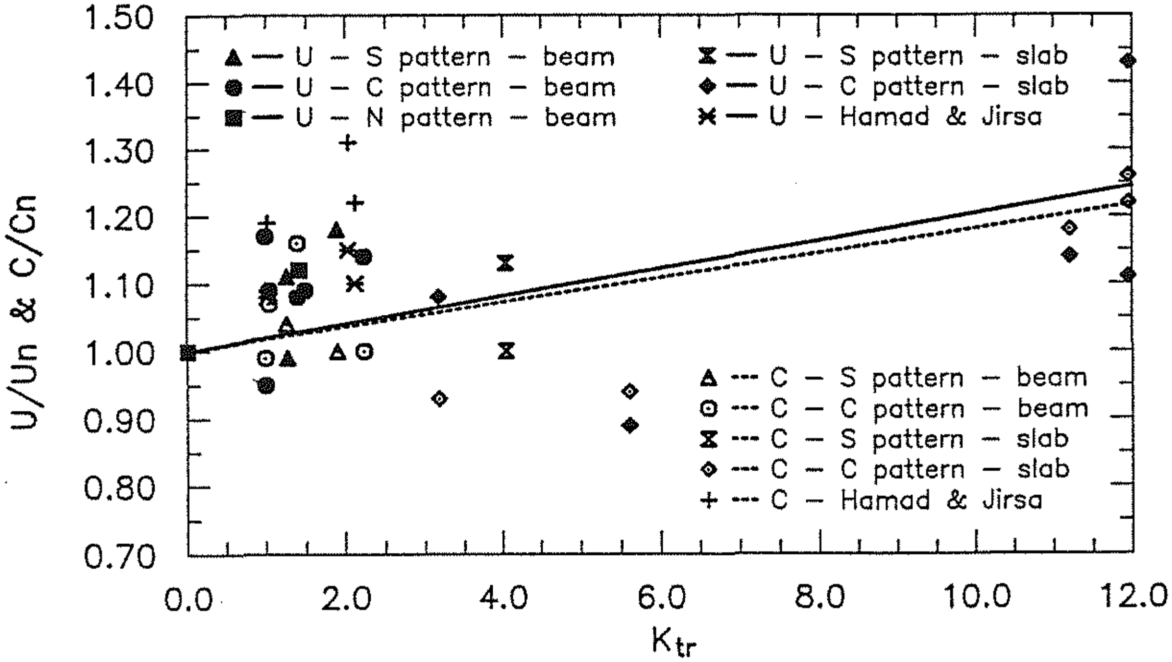


Fig. 23 Relative Bond Strengths, U/Un and C/Cn, versus K_{tr} for Current Tests Plus Hamad and Jirsa (1990)

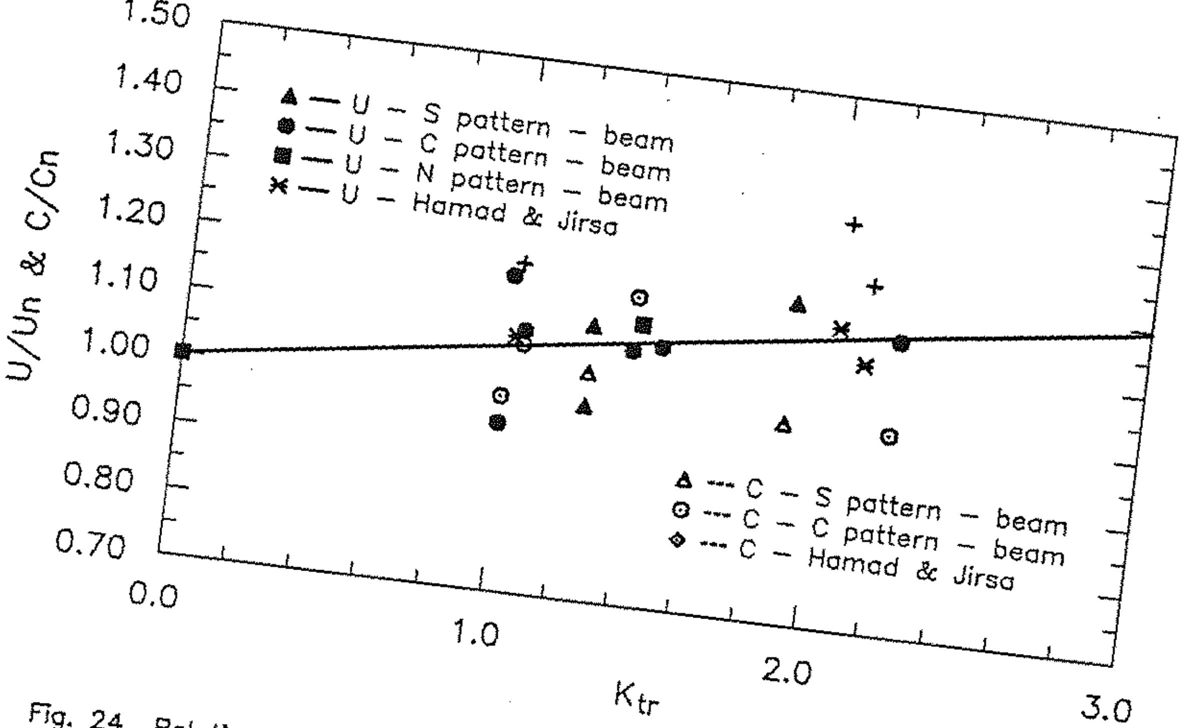


Fig. 24 Relative Bond Strengths, U/Un and C/Cn, versus K_{tr}, K_{tr} <3.0 for Current Tests Plus Hamad and Jirsa (1990)

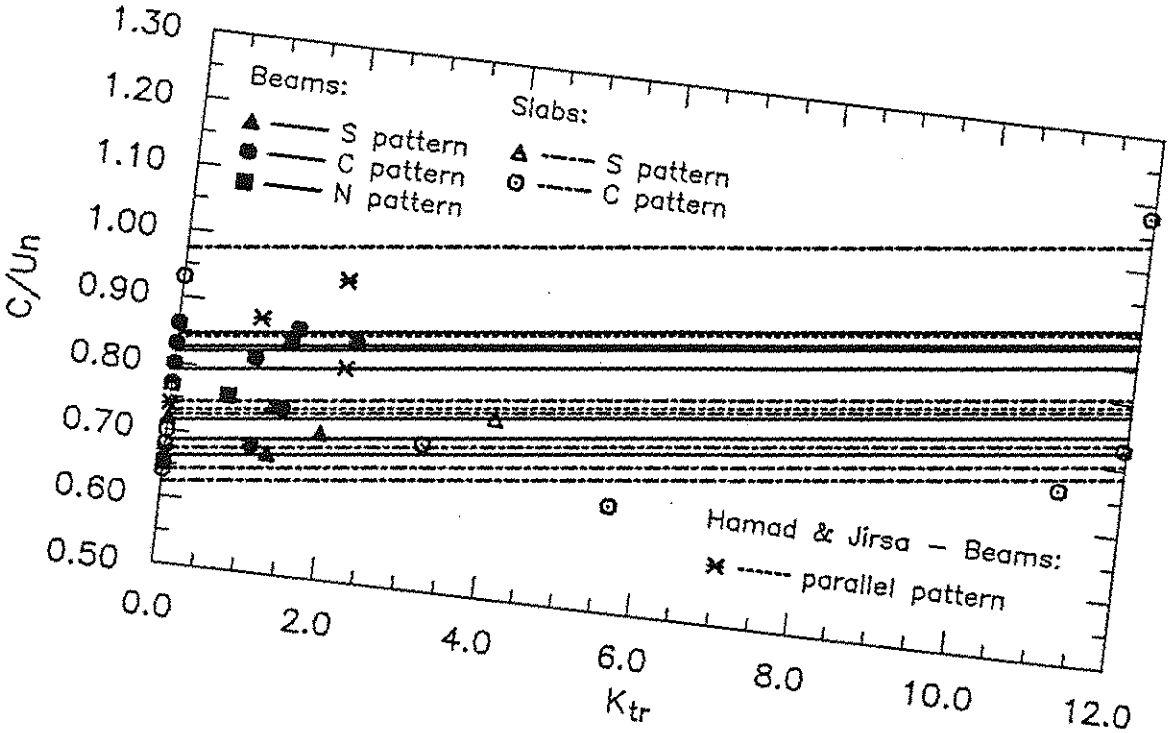


Fig. 25 Relative Bond Strength, C/Un, versus K_{tr} for Current Tests Plus Hamad and Jirsa (1990)

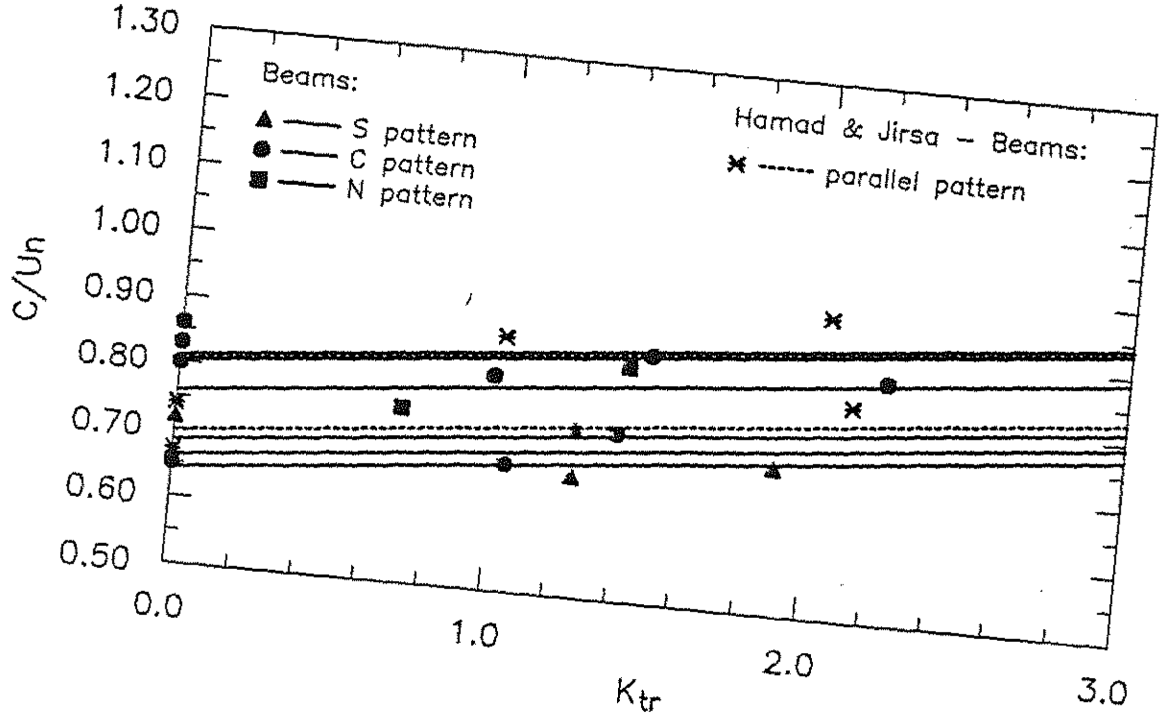


Fig. 26 Relative Bond Strength, C/Un, versus K_{tr}, $K_{tr} < 3.0$ for Current Tests Plus Hamad and Jirsa (1990)

APPENDIX A

BEAM-END TESTS FOR NO. 3 BARS

Seven beam-end specimens (4 with uncoated bars and 3 with coated bars) were fabricated and tested in accordance with the procedure used by Choi et al. (1990a, 1990b, 1991). The specimens contained bottom-cast S-pattern No. 3 bars, were 9 in. wide by 24 in. long, and had a $16^1/_8$ in. depth, which provided 15 in. of concrete above the bars and 2 bar diameters of cover below the bars.

The bars projected 22 in. out from the face of the test specimen. Two polyvinyl chloride (PVC) pipes were used as bond beakers to limit the bonded length of the test bars and to prevent a cone type failure on the front face. The inside diameter of the PVC pipe matched the diameter of the test bar. A bonded length of 2 in. was selected to insure that the bars did not yield before bond failure occurred. The length of bond breaking PVC pipe at the front of the bar (lead length) was $^1/_2$ in.

The test data are presented in Table A1. The C/U ratio for the tests is 0.79, which is lower than the value of C/U obtained for any group of No. 5 or No. 6 bars tested by Choi et al. (1990a, 1990b, 1991). This reverses the trend observed by Choi that C/U increases as bar diameter decreases. The greater reduction in strength for the No. 3 bars may have occurred because the bond strength of epoxy-coated bars becomes more sensitive to coating thickness as bar diameter decreases (Choi et al. 1990a, 1990b, 1991). Thus, the lower value of C/U is not unexpected.

Table A1 Beam-end Tests

Specimen Label *	Average Coating Thickness (mils)	Cover (in.)	Ultimate Bond Force (lb)
3S9-2-U	0.0	0.78	3000
3S9-2-U	0.0	0.84	3550
3S9-2-U	0.0	0.78	3830
3S9-2-U	0.0	0.75	3480
3S9-2-C	10.7	0.75	2480
3S9-2-C	10.3	0.75	3050
3S9-2-C	10.2	0.75	2650

Average for Uncoated Bars = 3470 lbs.
Average for Coated Bars = 2730 lbs.
C/U Ratio = 0.79

* Specimen Label : #DT-L-B
- # = bar size
- D = deformation pattern : S
- L = bonded length in inches
- B = U - uncoated bars
  C - coated bars

Note: 1.) concrete strength = 5960 psi.
2.) lead length = 1/2 in.

Table B1 Actual Dimensions for Groups B1–B7

Group No.	Specimen Label *	Cover (in.)	Eff. Depth (in.)	Depth of Beam (in.)	Width of Beam (in.)
B1	8N3-16-0-U	2.00	13.50	16.00	16.00
	8N3-16-2-U	2.00	13.50	16.00	16.00
	8N3-16-1-C	2.00	13.50	16.00	16.00
	8N3-16-2-C	2.00	13.50	16.00	16.00
B2	8C3-16-0-U	1.84	13.99	16.33	16.00
	8C3-16-2-U	1.83	13.95	16.28	16.00
	8C3-16-0-C	1.75	14.14	16.39	16.00
	8C3-16-2-C	1.78	14.03	16.31	16.00
B3	8S3-16-0-U	2.04	13.69	16.23	16.09
	8S3-16-2-U	2.08	13.66	16.24	16.06
	8S3-16-0-C	2.06	13.97	16.53	16.09
	8S3-16-2-C	2.07	13.61	16.18	16.09
	8S3-16-0-C	1.04	13.59	15.13	16.06
	8S3-16-2-C	1.05	13.61	15.16	16.12
B4	8S3-16-0-U	2.10	13.62	16.22	16.08
	8S3-16-2-U	2.04	13.82	16.36	16.09
	8S3-16-3-U	2.10	13.68	16.28	16.09
	8S3-16-0-C	2.11	13.61	16.22	16.05
	8S3-16-2-C	2.00	13.77	16.27	16.05
	8S3-16-3-C	2.03	13.65	16.18	16.03
B5	8C3-16-0-U	2.05	13.72	16.27	16.09
	8C3-16-2-U	2.06	13.86	16.42	16.10
	8C3-16-3-U	2.06	13.56	16.12	16.09
	8C3-16-0-C	2.01	13.77	16.28	16.09
	8C3-16-3-C	2.06	13.88	16.44	16.06
B6	8C3-22 3/4-0-U	2.15	13.54	16.19	16.06
	8C3-22 3/4-3-U	2.17	13.53	16.20	16.06
	8C3-22 3/4-4-U	2.16	13.51	16.17	16.03
	8C3-22 3/4-0-C	2.00	13.66	16.16	16.06
	8C3-22 3/4-3-C	2.13	13.62	16.25	16.06
	8C3-22 3/4-4-C	2.18	13.54	16.22	16.09
B7	8C3-16-0-U	2.12	13.58	16.20	16.03
	8C3-16-3-U	2.03	13.77	16.30	16.00
	8C3-16-0-C	2.12	13.60	16.22	16.00
	8C3-16-3-C	2.08	13.62	16.20	16.00

* Specimen Label : #DS-L-N-B

\# = bar size

D = deformation pattern : S,C,N

S = stirrup bar size

L = splice length

N = number of stirrups

B = U - uncoated bars

C - coated bars

Note: Actual dimensions were not taken for group B1 and actual width measurements were not taken for group B2.

Table B2 Actual Dimensions for Groups S1–S8

Group No.	Specimen Label *	Cover (in.)	Eff. Depth (in.)	Depth of Beam (in.)	Width of Beam (in.)
S1	6C3-10-0-U	2.36	5.50	8.23	24.00
	6C3-10-0-C	2.39	5.44	8.20	23.94
S2	6C3-10-0-U	2.19	5.63	8.19	24.00
	6C3-10-2-U	2.16	5.77	8.30	24.00
	6C3-10-0-C	2.19	5.60	8.17	23.91
	6C3-10-2-C	2.09	5.80	8.27	23.97
S3	6S3-10-0-U	2.18	5.73	8.28	24.03
	6S3-10-2-U	2.21	5.69	8.27	24.00
	6S3-10-0-C	2.04	5.84	8.25	24.00
	6S3-10-2-C	2.08	5.72	8.17	23.97
S4	6C5-10-0-U	2.07	5.67	8.11	24.00
	6C5-10-2-U	1.96	5.79	8.13	24.03
	6C5-10-0-C	2.10	5.82	8.30	24.00
	6C5-10-2-C	1.98	5.72	8.08	24.00
S5	8C5-16-0-U	2.09	5.59	8.19	24.09
	8C5-16-2-U	2.09	5.58	8.17	24.00
	8C5-16-0-C	2.09	5.61	8.20	24.00
	8C5-16-2-C	2.05	5.60	8.16	24.09
S6	8C5-16-0-U	2.08	5.51	8.09	24.00
	8C5-16-4-U	2.15	5.50	8.14	24.00
	8C5-16-0-C	2.08	5.45	8.03	24.00
	8C5-16-4-C	2.04	5.65	8.19	24.06
S7	6C5-10-0-U	2.10	5.98	8.45	24.00
	6C5-10-2-U	2.10	5.62	8.09	24.09
	6C5-10-0-C	2.14	5.74	8.25	24.03
	6C5-10-2-C	2.06	5.70	8.13	24.03
S8	6C5-10-0-U	2.03	5.70	8.10	24.03
	6C5-10-2-U	2.11	5.64	8.12	24.06
	6C5-10-0-C	2.06	5.65	8.09	24.00
	6C5-10-2-C	2.05	5.78	8.20	24.03

* Specimen Label : #DS-L-N-B

# = bar size
D = deformation pattern : S,C
S = stirrup bar size
L = splice length
N = number of stirrups
B = U - uncoated bars
C - coated bars