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Anchorage Strength of Closely Spaced Hooked Bars

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The effect of close spacing on the anchorage strength of standard hooks is investigated. Sixty-seven simulated beam-column joint specimens were tested, each containing three, four, or six No. 5, 8, or 11 (No. 16, 25, or 36) hooked bars arranged in one or two layers with center-to-center spacing ranging from two to six bar diameters. Anchorage strengths are compared with those of specimens containing two hooked bars with spacings of six to 12 bar diameters. The results demonstrate that the provisions in ACI 318-14 tend to overestimate the anchorage strength of hooked bars as concrete compressive strength and bar size increase and as spacing between bars decreases. Decreasing center-to-center spacing below six bar diameters results in lower anchorage strengths than for hooked bars with wider spacing. The anchorage strength of hooked bars can be represented by considering the minimum of the horizontal and vertical spacing between bars.

Keywords: anchorage; beam-column joints; high-strength concrete; high-strength steel; hooks; reinforced concrete; reinforcement; spacing; staggered hooks.

INTRODUCTION

Hooks are used to anchor steel reinforcing bars where member dimensions do not permit using straight bars. The design provisions for hooked bars in the ACI Building Code (ACI 318-14) are based on the results of 38 tests of simulated beam-column joints by Marques and Jirsa (1975) and Pinc et al. (1977). Twenty-four additional tests by Hamad et al. (1993) were used to account for the effect of epoxy coatings. The test specimens in these studies contained two hooked bars. This contrasts with practice, where members often contain more than two bars—bars that may be separated by a clear spacing as little as one bar diameter.

The tests described in this paper are part of a larger study that includes work reported by Searle et al. (2014), Sperry et al. (2015a,b, 2017a,b, 2018), Yasso et al. (2017), and Ajaam et al. (2017). Sperry et al. (2015b, 2017a,b, 2018) evaluated tests of 245 simulated beam-column joint specimens with two hooked bars fabricated using normalweight concrete with compressive strengths ranging from 2570 to 16,500 psi (17.7 to 114 MPa). Bar stresses at failure ranged from 30,800 to 143,900 psi (212 to 992 MPa). Sperry et al. (2015b, 2017a,b) observed that for specimens containing two widely spaced hooked bars, anchorage strengths calculated based on the provisions of ACI 318-14 overestimate anchorage strengths for larger hooked bars and overestimate the effects of concrete compressive strength and confining reinforcement. Sperry et al. observed that the effect of concrete compressive strength on the anchorage strength of hooked bars is proportional to the compressive strength raised to the 0.29 power, rather than the square root of compressive strength currently used in Code provisions. Sperry et al. (2015b, 2018) also found that for 180-degree hooked bars, confining reinforcement in the form of closed hoops increases anchorage strength regardless of orientation (parallel or perpendicular to the embedment length), while for 90-degree hooked bars, confining reinforcement oriented parallel to the embedment length increases anchorage strength more than confining reinforcement oriented perpendicular to the embedment length.

Ajaam et al. (2017) measured strain along the straight portion of the hooked bars and on hoops serving as the confining reinforcement within the joint region. The results showed that hoops oriented parallel to the embedment length of hooked bars and located within eight to 10 bar diameters of the straight portion of the hooked bar within the joint region exhibited increases in strain at earlier loading stages than those located further away from the hooked bars and yielded prior to hooked bar anchorage failure, confirming the previous findings by Sperry et al. (2015b, 2017b).

This paper compares test results of widely and closely spaced hooked bars with the provisions in ACI 318-14. It addresses the effects of close spacing (in both vertical and horizontal planes) between hooked bars on anchorage strength based on test results for simulated beam-column joint specimens containing three, four, and six closely spaced hooked bars arranged in one or two layers. The anchorage strengths of the closely spaced hooked bars from the current study are compared with anchorage strengths based on the best-fit equation by Ajaam et al. (2017) describing the anchorage strength of hooked bars in simulated beam-column joints containing two widely spaced hooked bars.

RESEARCH SIGNIFICANCE

The design provisions in ACI 318-14 for the development of hooked bars are based on a limited number of tests using specimens containing only two hooked bars. The effects of close spacing or placing hooked bars in more than one layer are not reflected in those provisions. This study evaluates the effect of horizontal and vertical bar spacing on the anchorage strength of hooked bars in beam-column joints. The study aims to expand the range of data and better understand the anchorage behavior of members containing closely spaced hooked bars and how the anchorage strength in these members is related to the anchorage strength in members with widely spaced hooked bars with and without confining reinforcement.

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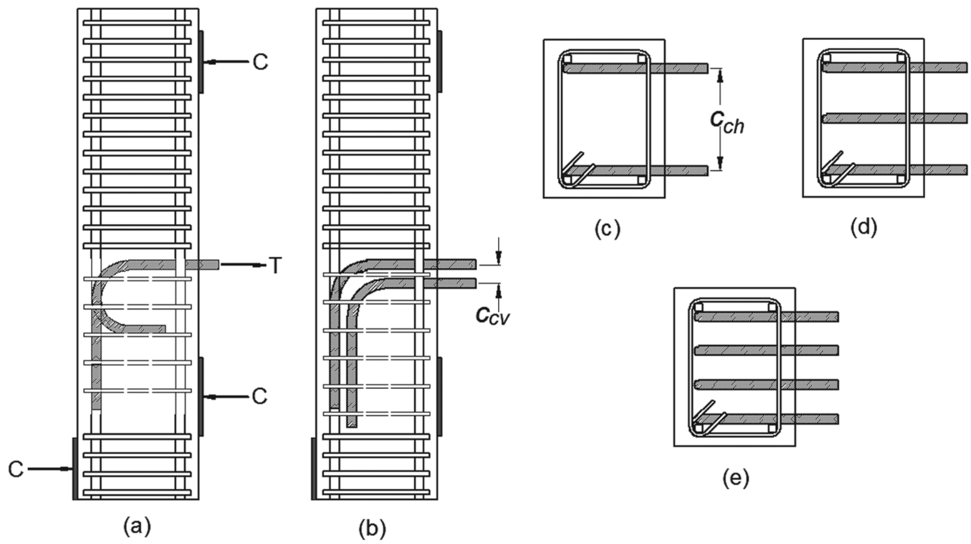

Fig. 1—Schematic of test specimens: (a) side view of specimen with hooks in one layer; (b) side view of specimen with staggered hooks; (c) plan view of specimen with two hooks; (d) plan view of specimen with three hooks; and (e) plan view of specimen with four hooks.

EXPERIMENTAL PROGRAM

This paper includes the test results of 67 simulated beam-column joint specimens that contain three or four No. 5 (No. 16), three No. 8 (No. 25), or three No. 11 (No. 36) closely spaced (defined as a center-to-center spacing between bars of six bar diameters, $6d_b$, or less) hooked bars arranged in one layer, and four or six No. 5 (No. 16) or four No. 11 (No. 36) closely spaced hooked bars arranged in two layers (referred to as staggered hooks). In addition, 202 specimens containing two hooked bars, most with spacings between 6 and $12d_b$ (Marques and Jirsa 1975; Pinc et al. 1977; Hamad et al. 1993; Ramirez and Russell 2008; Lee and Park 2010; Sperry et al. 2015a, 2017a; Ajaam et al. 2017) are included for comparison. Specimens with closely spaced hooked bars in one layer had a center-to-center spacing of $3d_b$, $4d_b$, $5d_b$, $5.5d_b$, or $6d_b$. Specimens with closely spaced hooked bars arranged in two layers had a horizontal center-to-center spacing of $6d_b$ or $12d_b$ and a vertical center-to-center spacing of $2d_b$ or $2.6d_b$. Out of the 67 specimens, 23 contained no confining reinforcement and 44 contained either two No. 3 (No. 10) hoops or No. 3 (No. 10) hoops spaced no greater than $3d_b$ (five, six, seven, or eight No. 3 hoops, depending on specimen geometry), the latter qualifying for the use of the 0.8 development length modification factor permitted in Section 25.4.3.2 of ACI 318-14. All confining reinforcement was oriented parallel to the embedment length of the hooked bar.

Concrete compressive strengths ranged from 4490 to 12,190 psi (31 to 84 MPa), and hooked bar embedment lengths ranged from 5.2 to 23.5 in. (132 to 597 mm). Hooked bar stresses at failure ranged from 30,400 to 117,100 psi (210 to 808 MPa). The nominal side cover was 2-1/2 in. (65 mm). The effects of hooked bar size, center-to-center spacing, staggering hooked bars, amount of confining reinforcement within the joint region, concrete compressive strength, and embedment length are investigated.

Test specimens

The test specimens, shown in Fig. 1, were designed to simulate exterior beam-column joints. Column widths ranged from 10-5/8 to 21-1/2 in. (270 to 546 mm). The nominal tail cover was 2 in. (50 mm) for all specimens. Longitudinal and transverse reinforcement outside the joint region was selected to ensure adequate flexural and shear strength based on the assumption that all hooked bars would reach peak load simultaneously. The height of the column, 54 in. (1370 mm) for No. 5 and No. 8 (No. 16 and No. 25) hooked bars and 96 in. (2440 mm) for No. 11 (No. 36) hooked bars, was selected so that the support reactions would not interfere with the forces within the joint (Peckover and Darwin 2013).

In this study, embedment length ℓ_{eh} refers to the distance measured from the column face to the back of the tail of the hook, in contrast to the development length ℓ_{dh}, which refers to the minimum embedment length required in Section 25.4.3 of ACI 318-14 to ensure that a bar can develop its yield strength. Embedment lengths ℓ_{eh} were chosen to ensure anchorage failure prior to bar yielding. The embedment lengths were calculated by extrapolating trends from results from earlier tests.

The longitudinal column steel layout, notation, specimen geometry, and test results for the beam-column joint specimens used in this analysis are presented in Appendix A.*

Material properties

Normalweight concrete with nominal compressive strengths of 5000, 8000, and 12,000 psi (34, 55, and 83 MPa) was used for the specimens. Actual compressive strengths ranged from 4490 to 12,190 psi (31 to 84 MPa). The concrete contained Type I/II portland cement, river sand, and crushed limestone coarse aggregate with a maximum size of 3/4 in. (19 mm). Pea gravel was used in the 12,000 psi (83 MPa)

*The Appendix is available at **www.concrete.org/publications** in PDF format, appended to the online version of the published paper. It is also available in hard copy from ACI headquarters for a fee equal to the cost of reproduction plus handling at the time of the request.

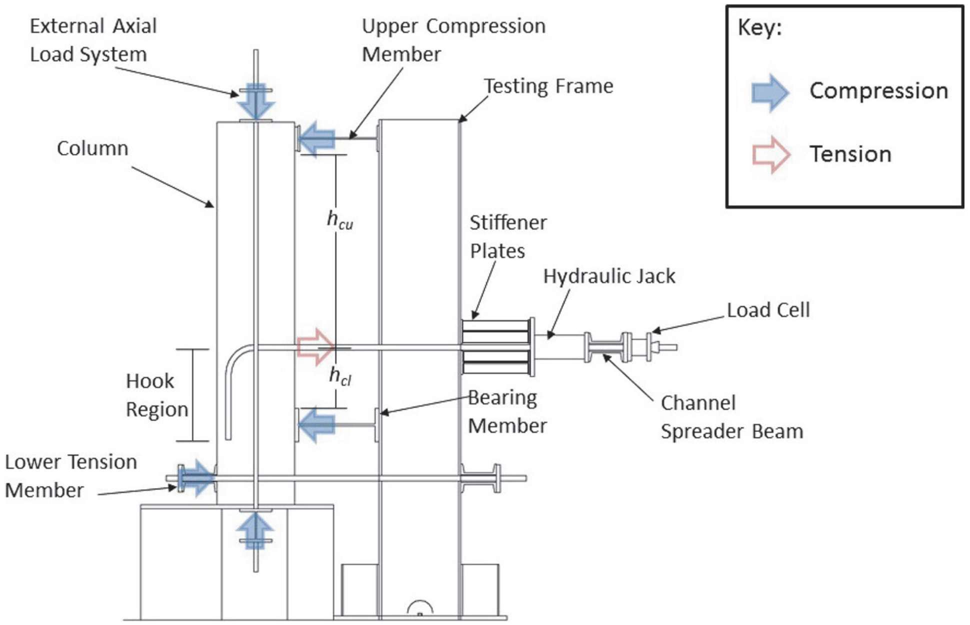

Fig. 2—Test frame.

Table 1—Hooked bar properties

Bar size	ASTM designation	Yield strength, ksi*	Tensile strength, ksi*	Nominal diameter, in.	Average rib spacing, in.	Average rib height		Gap width		Relative rib area‡
						A†, in.	B‡, in.	Side 1, in.	Side 2, in.	
5	A1035	119.5	162.5	0.625	0.391	0.038	0.034	0.200	0.175	0.073
8	A615	94.0	128.3	1	0.666	0.059	0.056	0.146	0.155	0.073
8	A1035§	120.0‖	168.0‖	1	0.666	0.059	0.056	0.146	0.155	0.073
8	A1035#	122.0‖	168.0‖	1	0.686	0.068	0.065	0.186	0.181	0.084
8	A1035**	129.0	167.3	1	0.666	0.056	0.059	0.146	0.155	0.073
11	A615	88.2	122.1	1.41	0.894	0.080	0.074	0.204	0.196	0.069
11	A1035	131.0	165.7	1.41	0.830	0.098	0.088	0.248	0.220	0.085

*Tests performed as part of this study. †Per ASTM A615, A706. ‡Per ACI 408R-03. ‖From mill report. §Heat 1. #Heat 2. **Heat 3.

Notes: 1 in. = 25.4 mm; 1 ksi = 6.89 MPa.

concrete to improve workability. Polycarboxylate-based high-range water-reducing admixtures were used to control slump. Mixture proportions are listed in Appendix B.

Hooked bars were fabricated from ASTM A1035 Grade 120 (830 MPa) and ASTM A615 Grade 80 (550 MPa) steel. ASTM A615 Grade 60 (420 MPa) reinforcing bars were used as confining steel in all specimens and as longitudinal reinforcement in most specimens. For some specimens where the flexural demand on the column was high, ASTM A1035 Grade 120 (830 MPa) bars were used to keep the column longitudinal reinforcement ratio to a reasonable value. Specimens with Grade 80 (550 MPa) hooked bars or Grade 120 (830 MPa) column longitudinal bars are indicated in Appendix A. Yield strength, tensile strength, nominal diameter, deformation dimensions and spacing, and relative rib area for the deformed steel bars used as hooked bars are presented in Table 1. Representative stress-strain curves are included in Appendix B.

Loading system and test procedure

Figure 2 shows the test frame used in this study. The test frame is a modified version of the frame used by Marques and Jirsa (1975) and applies tensile forces to the hooked bars and a compression reaction from the bearing member simulating the action of a reinforced concrete beam on the joint. The upper compression member prevents the column from overturning and is placed so as to not interfere with the hook region. The flange widths for the upper compression member and the bearing member were 6-5/8 in. (168 mm) and 8-3/8 in. (213 mm), respectively. The locations of the reaction forces for the different size hooked bars, measured from the center of the hooked bar, are shown in Table 2.

Table 2—Location of reaction forces

Size of hooked bar	No. 5 (No. 16)	No. 8 (No. 25)	No. 11 (No. 36)
Specimen height, in.	54	54	96
Distance from center of hook to top of bearing member flange, h_{cl}, in.*	5-1/4	10	19-1/2
Distance from center of hook to bottom of upper compression member flange, h_{cu}, in.*	18-1/2	18-1/2	48-1/2

*Refer to Fig. 2.

Note: 1 in. = 25.4 mm.

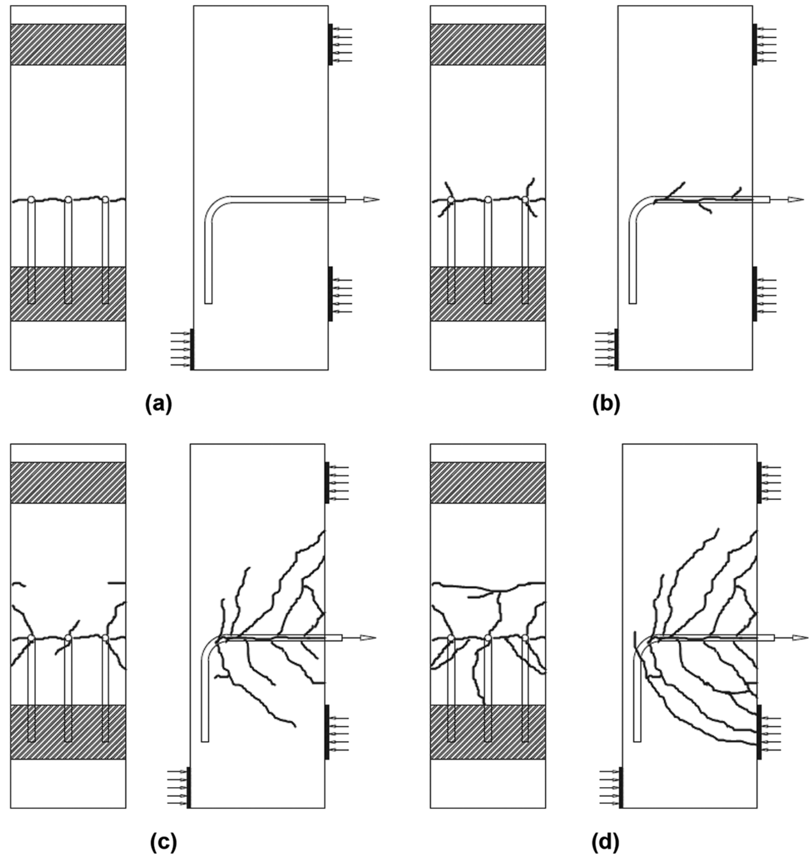

Fig. 3—Front and side views depicting crack progression.

A constant axial force of 30,000 lb (133,447 N) was applied to specimens with No. 5 and No. 8 (No. 16 and No. 25) hooked bars (producing axial stresses of 95 to 360 psi [0.66 to 2.48 MPa]) and a constant axial stress of 280 psi (1.93 MPa) was applied to specimens with No. 11 (No. 36) hooked bars. Marques and Jirsa (1975) found that differences in axial stress up to 3000 psi (21 MPa) did not affect the anchorage strength of the hooked bars; thus, the effect of different values of axial stress was not examined in this study. The test frame was designed to accommodate two to six hooked bars in one or two layers. A detailed description of the test apparatus is provided by Ajaam et al. (2017).

Hydraulic jacks were used to apply a tensile force through a spreader beam (Fig. 2) to the hooked bars, simulating tensile forces in beam negative reinforcement. The tensile load was applied monotonically in steps of 5000 or 10,000 lb (22,240 to 44,480 N), depending on the specimen size. Loading was paused after each step to allow cracks to be marked. In all cases, the anchorage strength of the hooked bars was taken as the average force per hooked bar corresponding to the maximum total force during the test. The maximum force for each hooked bar was also recorded and included in Appendix A.3, although this did not, in general, coincide with the maximum total force on the system.

TEST RESULTS AND DISCUSSION

Crack progression

Cracking progressed in a similar manner during loading for most of the specimens (Ajaam et al. 2017). The first crack appeared on the front face of the column, initiating from the external hooked bars and propagating horizontally toward both the interior and the side face of the column (Fig. 3(a)). In specimens with closely spaced hooked bars, the first crack was more prone to propagate toward the internal hooked bars than to propagate toward the side face of the column. As the load increased, horizontal cracks continued to grow on the side face of the column along the straight portion of the hooked bars up to approximately the location of the bend (Fig. 3(b)). At this point, vertical and diagonal cracks appeared on the front face of the column originating from the external hooked bars and on the side face of the column originating from the horizontal crack. As the load further increased, the vertical and diagonal cracks on the side face of the column continued to grow toward the front face of the column above and below the hook location (Fig. 3(c)). Near failure, the inclined cracks on the side face of the column extended around the column corner to the front face and widened (Fig. 3(d)). Failure was marked by concrete breakout on the front face of the column or by the concrete cover over the side of the hook splitting along the side face of the column.

Failure modes

Two primary modes of failure were observed during the tests of the beam-column joints. Concrete breakout (CB) occurs when a concrete block pulls out with the hooked bars on the front face of the column. Side splitting (SS) occurs when the side of the column splits off due to the wedging action of the hook. A secondary mode of failure, tail kickout (TK), was observed in a few specimens in conjunction with the other failure modes. Tail kickout occurs when the tail of a

90-degree hook pushes the concrete cover off the back of the column, often exposing the tail of the hook. The primary mode of failure was established by comparing the relative amounts of damage between the front and side faces of the column. Of the 67 specimens in this study, all of which contained at least three hooked bars, 44 exhibited concrete breakout only, 16 exhibited a combination of concrete breakout and side splitting with concrete breakout being dominant, and seven exhibited side splitting only, representing a greater percentage of breakout failures than observed by Sperry et al. (2015a,b, 2017a) for specimens containing two hooked bars. The principal mode of failure was governed by bar size and member geometry (Tables A.4 through A.6 in Appendix A), with the 27 specimens containing No. 5 (No. 16) and 26 of the 27 specimens containing No. 8 (No. 25) hooked bars exhibiting concrete breakout as the only or principal failure mode. Of the 13 specimens containing No. 11 (No. 36) hooked bars, all six staggered hook specimens exhibited side splitting as the only failure mode and two of the other seven exhibited side splitting as the only or principal failure mode. The tendency of the No. 11 (No. 36) staggered hooked bars to cause side splitting is likely due to the high wedging action provided by two large bars on each side of the beam-column joint.

Test results compared to ACI 318-14

Test results for specimens with two widely spaced hooked bars, specimens with three or four closely spaced hooked bars in one layer, and specimens with four or six closely spaced hooked bars in two layers with different levels of confining reinforcement are compared with the stress calculated based on the development length provisions in ACI 318-14, (Eq. (1)). The purpose of this comparison is to determine the degree to which the current Code provisions represent the anchorage strength of hooked bars

$$\ell_{dh} = \left(\frac{f_y \psi_e \psi_c \psi_r}{50\lambda\sqrt{f_c'}} \right) d_b \quad (1)$$

where f_y is the yield strength of hooked bars (psi); f_c' is the specified concrete compressive strength (psi); d_b is the hooked bar diameter (in.); ψ_e = 1.2 for epoxy-coated or zinc and epoxy dual-coated bar and 1.0 for uncoated or zinc-coated (galvanized) bar; ψ_c = 0.7 for No. 11 (No. 36) and smaller bars with concrete side cover not less than 2.5 in. (65 mm) and tail cover not less than 2 in. (50 mm) (this limit on tail cover is required for hooked bars with a 90-degree bend angle), otherwise, ψ_c = 1.0; ψ_r = 0.8 for No. 11 (No. 36) and smaller bars with 90- or 180-degree bend angle enclosed along the straight portion of the bar with ties or stirrups perpendicular to the straight portion of the bar at $3d_b$ spacing or smaller; ψ_r = 0.8 for No. 11 (No. 36) and smaller bars with 90-degree bend angle enclosed along the tail extension with ties or stirrups perpendicular to the tail extension at $3d_b$ spacing or smaller; otherwise, ψ_r = 1.0; λ = 0.75 for lightweight concrete and 1.0 for normalweight concrete. Because all specimens involved in this analysis contained uncoated hooked bars cast with normalweight concrete, ψ_e and λ = 1.0.

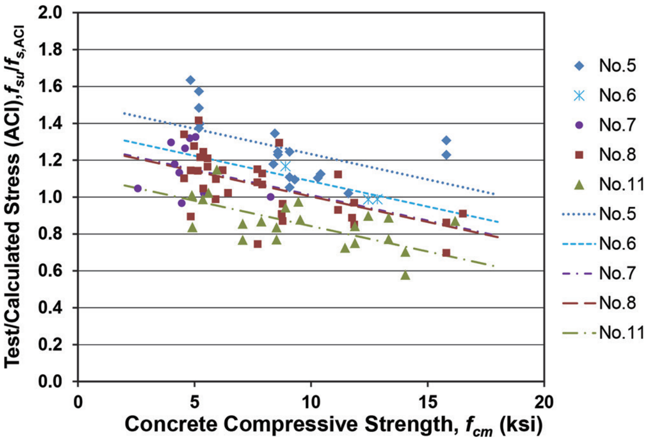

Fig. 4—Ratio of test-to-calculated stress $f_{su}/f_{s,ACI}$ versus concrete compressive strength f_{cm} for specimens with two widely spaced hooked bars without confining reinforcement. (Note: 1 ksi = 6.89 MPa.)

For the purpose of comparison, Eq. (1) can be solved for the bar stress, using $f_{s,\mathrm{ACI}}$ in place of f_y. The development length ℓ_{dh} is replaced by the embedment length ℓ_{eh}, and the specified concrete compressive strength f_c' is replaced by the measured concrete compressive strength f_{cm}

$$f_{s,\mathrm{ACI}} = \frac{50\ell_{eh}\sqrt{f_{cm}}}{\psi_c \psi_r d_b} \quad (2)$$

When calculating bar stress $f_{s,\mathrm{ACI}}$, measured values of embedment length ℓ_{eh} and concrete compressive strength f_{cm} are used. The concrete compressive strength f_{cm} is measured on the day of the test. Specimens included in this analysis had a nominal concrete side cover of 2.5 in. (65 mm) or, in the case of some of the specimens containing two hooked bars, 3.5 in. (90 mm), and a nominal concrete tail cover of 2 in. (50 mm); thus, ψ_c equaled 0.7 for all cases. The provisions in ACI 318-14 limit the square root of concrete compressive strength to 100 psi (8.3 MPa); this limit is not applied in the current comparisons to determine the accuracy with which the $\sqrt{f_c'}$ represents the contribution of concrete compressive strength to the anchorage strength of hooked bars.

Throughout this paper, a regression analysis technique based on dummy variables, a least-squares analysis method that allows differences in populations to be considered when formulating relationships between principle variables (Draper and Smith 1981), is used to identify trend lines in the data.

Figure 4 compares the ratios of bar stress at anchorage failure to the value calculated using Eq. (2), $f_{su}/f_{s,\mathrm{ACI}}$, versus concrete compressive strength f_{cm} for specimens with two widely spaced hooked bars without confining reinforcement. Figure 5 shows a similar comparison for specimens with more than two hooked bars with a center-to-center spacing of $6d_b$ or less. The bar stress f_{su} is calculated based on the average bar force T (the peak total load carried by the specimen divided by the number of hooked bars). The figures include test results for 88 specimens with two hooked bars and 24 specimens with three or four hooked bars in one layer

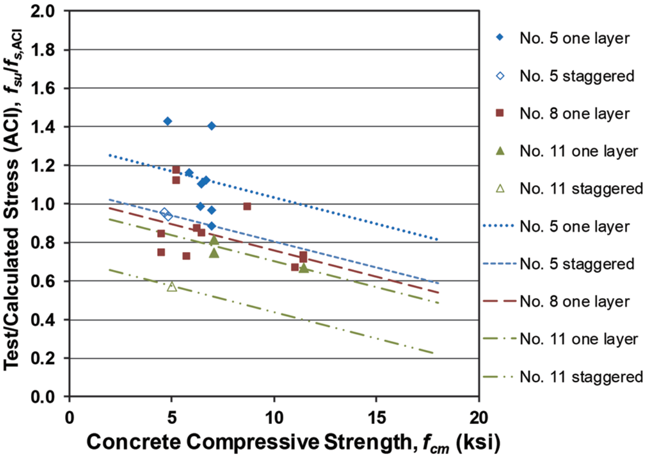

Fig. 5—Ratio of test-to-calculated stress $f_{su}/f_{s,ACI}$ *versus concrete compressive strength* f_{cm} *for specimens with three, four, or six closely spaced hooked bars without confining reinforcement. (Note: 1 ksi = 6.89 MPa.)*

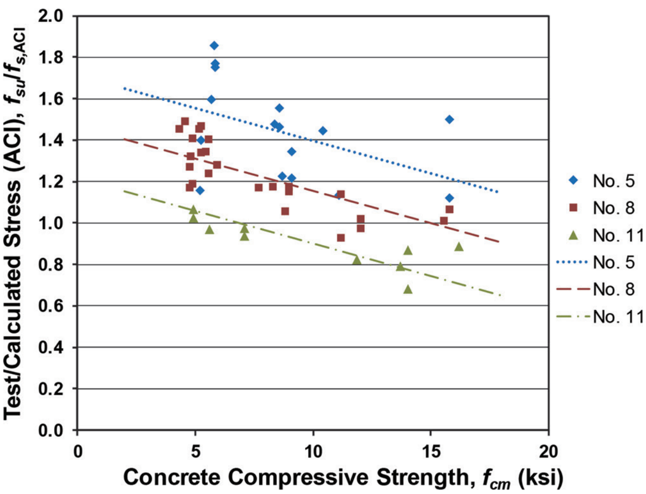

Fig. 6—Ratio of test-to-calculated stress $f_{su}/f_{s,ACI}$ *versus concrete compressive strength* f_{cm} *for specimens with two widely spaced hooked bars with two No. 3 (No. 10) hoops as confining reinforcement. (Note: 1 ksi = 6.89 MPa.)*

or four or six hooked bars in two layers. The trend lines from the dummy variable analysis, with the data separated based on the bar size, have a negative slope and decrease in value with increasing bar size. For widely spaced hooked bars (Fig. 4), the trend line for No. 8 (No. 25) hooked bars falls below 1.0 at a concrete compressive strength of 9800 psi (68 MPa); for No. 11 (No. 36) hooked bars, this occurs at 4600 psi (32 MPa). This analysis shows that the bar stress predicted by Eq. (2) becomes progressively less conservative as the concrete compressive strength and bar size increase, matching the observations by Sperry et al. (2017a).

The trend lines for the closely spaced hooked bars (Fig. 5) fall below 1.0 at lower concrete compressive strengths and are much lower in all cases than those for the specimens with widely spaced hooked bars (Fig. 4), likely because the provisions in ACI 318-14 do not recognize the effect of close spacing of hooked bars. For bars of the same size, the trend

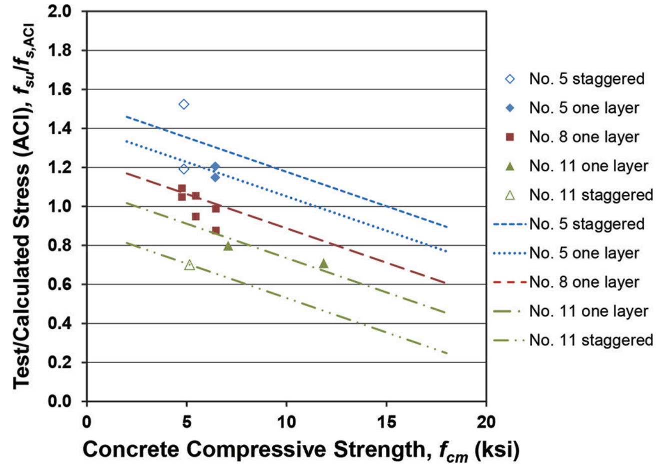

Fig. 7—Ratio of test-to-calculated stress $f_{su}/f_{s,ACI}$ *versus concrete compressive strength* f_{cm} *for specimens containing three, four, or six closely spaced hooked bars with two No. 3 (No. 10) hoops as confining reinforcement. (Note: 1 ksi = 6.89 MPa.)*

lines for the staggered hooked bars fall below those for the closely spaced hooked bars in a single layer.

Figures 6 and 7 compare the ratio $f_{su}/f_{s,\mathrm{ACI}}$ versus concrete compressive strength f_{cm} for specimens with two widely spaced hooked bars and with more than two closely spaced hooked bars, respectively, for specimens with two No. 3 (No. 10) hoops as confining reinforcement within the joint region. Two No. 3 (No. 10) hoops within the joint region do not satisfy the Code requirements allowing the use of the 0.8 modification factor ψ_r. The figures include test results for 51 specimens with two hooked bars and 13 specimens with three, four, or six hooked bars arranged in one or two layers. As in the previous comparisons, the trend lines have negative slopes. Specimens with two No. 3 (No. 10) hoops as confining reinforcement have bar stress ratios $f_{su}/f_{s,\mathrm{ACI}}$ that are greater than specimens without confining reinforcement; this is expected because the hoops add to anchorage strength, but the provisions in ACI 318-14 do not account for the contribution of this low amount of confining reinforcement. Regardless, the trend lines still show that the current Code provisions can produce unsafe designs (values below 1.0), especially for closely spaced hooked bars.

Figures 8 and 9 compare the ratio $f_{su}/f_{s,\mathrm{ACI}}$ versus the concrete compressive strength f_{cm} for specimens containing two widely spaced hooked bars and with more than two closely spaced hooked bars, respectively, with No. 3 (No. 10) hoops spaced at not greater than $3d_b$ as confining reinforcement within the joint region. The figures include data from 63 specimens with two hooked bars and 29 specimens with three, four, or six hooked bars arranged in one layer or in two layers. All values of $f_{s,\mathrm{ACI}}$ include ψ_r of 0.8. Figure 8 includes specimens containing hooked bars with 180-degree bend angle and parallel hoops (not permitted by ACI 318-14) based on the findings by Sperry et al. (2015a,b, 2018) that hooked bars with 90- and 180-degree bend angles achieve similar increases in strength with the addition of confining reinforcement.

As in the other comparisons, the trend lines in Fig. 8 and 9 have negative slopes and decrease in value with increasing

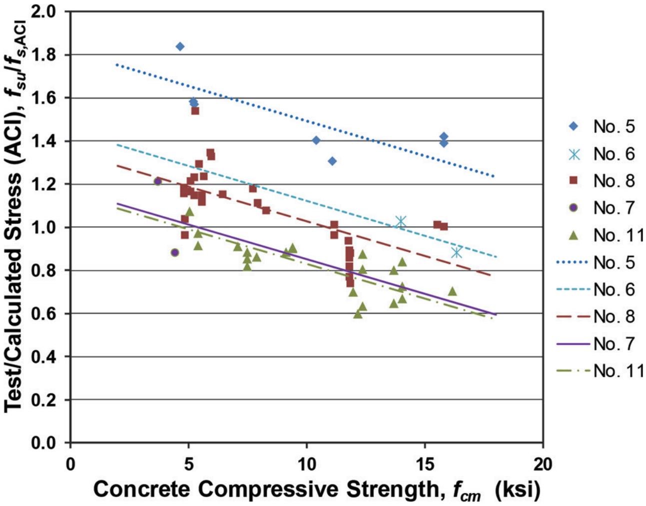

Fig. 8—*Ratio of test-to-calculated stress* $f_{su}/f_{s,ACI}$ *versus concrete compressive strength* f_{cm} *for specimens with two widely spaced hooked bars with No. 3 (No. 10) hoops spaced at* $3d_b$ *as confining reinforcement. (Note: 1 ksi = 6.89 MPa.)*

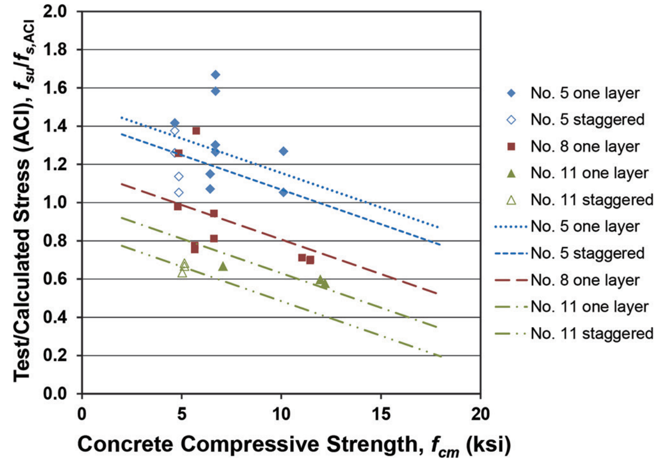

Fig. 9—*Ratio of test-to-calculated stress* $f_{su}/f_{s,ACI}$ *versus concrete compressive strength* f_{cm} *for specimens with three, four, or six closely spaced hooked bars with No. 3 (No. 10) hoops spaced at* $3d_b$ *as confining reinforcement. (Note: 1 ksi = 6.89 MPa.)*

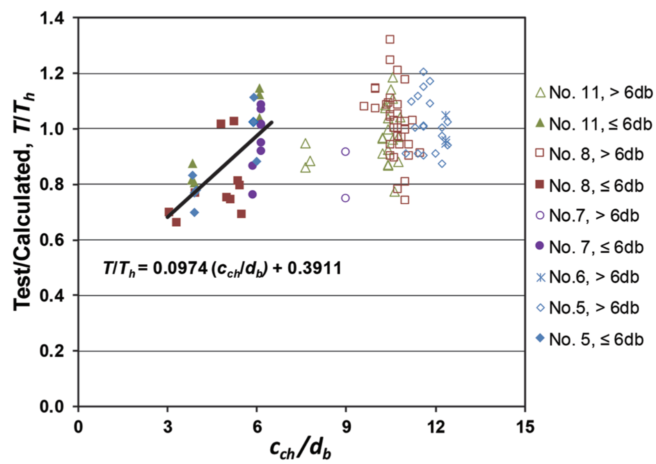

Fig. 10—*Ratio of test-to-calculated anchorage force* T/T_h *versus center-to-center spacing normalized to bar diameter* c_{ch}/d_b *for specimens with widely and closely spaced hooked bars without confining reinforcement, with* T_h *based on Eq. (3).*

bar size. Even though more confining reinforcement was provided within the joint region than for the specimens with two No. 3 (No. 10) hoops, the trend lines in Fig. 8 and 9 fall below 1.0 at concrete compressive strengths lower than those for the specimens with two No. 3 (No. 10) hoops as confining reinforcement, shown in Fig. 6 and 7. This indicates that the incorporation of the modification factor of 0.8 in Eq. (1) is unconservative, particularly for large or closely spaced hooked bars.

Effect of spacing between hooked bars

The effect of spacing between hooked bars was investigated by comparing the anchorage strength T of specimens containing No. 5, 8, and 11 (No. 16, 25, and 36) hooked bars with center-to-center spacing not greater than $6d_b$ with the anchorage strength of specimens containing widely spaced hooked bars. To do this, the values of T for the specimens were compared with the anchorage strength calculated using an empirically based descriptive equation for two widely spaced hooked bars developed by Ajaam et al. (2017). The equation is based on the results of 237 beam-column joint tests from studies by Marques and Jirsa (1975), Hamad et al. (1993), Ramirez and Russell (2008), Lee and Park (2010), Sperry et al. (2015a), and Ajaam et al. (2017). The equation, shown as Eq. (3), has a mean test-to-calculated strength ratio of 1.0, and a coefficient of variation and standard deviation of 0.112. The test-to-calculated strength ratios range between 0.67 and 1.27

$$T_h = 294 f_{cm}^{0.295} \ell_{eh}^{1.084} d_b^{0.470} + 55{,}050\left(\frac{A_{th}}{n}\right)^{1.017} d_b^{0.73} \quad (3)$$

where T_h is the anchorage strength of widely spaced hooked bars (lb); f_{cm} is the measured concrete compressive strength (psi); ℓ_{eh} is the embedment length of the hooked bar measured from the face of the column to the end of the hook (in.); d_b is the hooked bar diameter (in.); A_{th} is area of confining reinforcement (in.^{2}) within $8d_b$ from the top of the hooked bar for No. 8 (No. 25) bars and smaller or within $10d_b$ for No. 9 (No. 28) bars or larger; and n is the number of hooked bars in the joint.

Figure 10 shows the ratio of average bar force at failure T to the calculated bar force T_h for specimens without confining reinforcement based on Eq. (3) versus the center-to-center spacing between hooked bars normalized to bar diameter, c_{ch}/d_b. The figure includes the specimens with two widely spaced hooked bars used to develop Eq. (3) and the specimens containing three or four closely spaced hooked bars tested as part of this study. The figure shows that there is a reduction in anchorage strength in specimens with closely spaced hooked bars with a center-to-center spacing of less than $6d_b$.

Based on the best-fit line shown in Fig. 10 for the specimens containing closely spaced hooked bars without confining reinforcement, the ratio of the anchorage strength

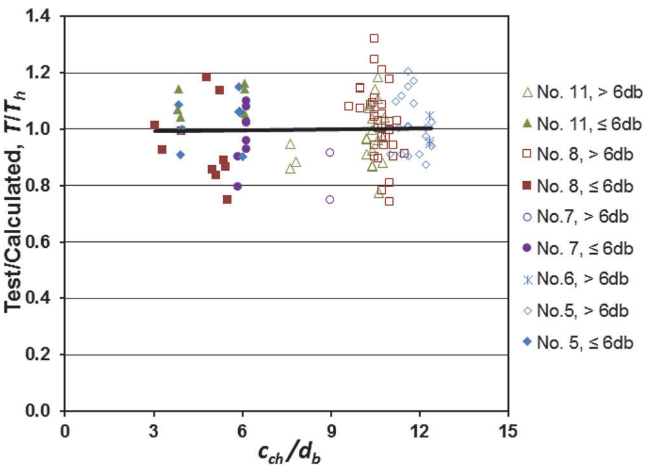

Fig. 11—Ratio of test-to-calculated anchorage force T/T$_h$ *versus center-to-center spacing normalized to bar diameter* c$_{ch}$/d$_b$ *for specimens with widely and closely spaced hooked bars without confining reinforcement, with* T$_h$ *based on Eq. (4) and (5).*

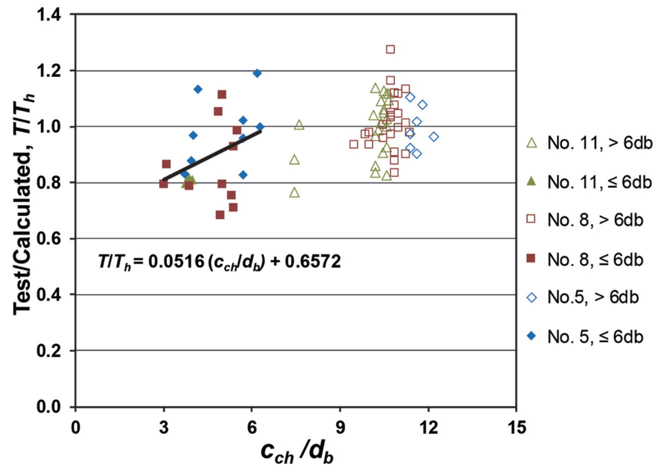

Fig. 12—Ratio of test-to-calculated anchorage force T/T$_h$ *versus center-to-center spacing normalized to bar diameter* c$_{ch}$/d$_b$ *for specimens with widely and closely spaced hooked bars with No. 3 (No. 10) hoops spaced at* 3d$_b$ *as confining reinforcement, with* T$_h$ *based on Eq. (3).*

of closely spaced hooked bars to the anchorage strength of widely spaced hooked bars is

$$\left(0.0974\frac{c_{ch}}{d_b}+0.3911\right)\leq 1.0 \tag{4}$$

where c_{ch} is the center-to-center spacing between hooked bars, and d_b is the hooked bar diameter. The ratio is taken as 1.0 when the center-to-center spacing c_{ch} is greater than or equal to $6d_b$. The test results show that, for the most part, hooked bars spaced at $6d_b$ or more are far enough apart so that they do not interact and can therefore be treated as widely spaced (Fig. 10). Multiplying the first term of Eq. (3) by the ratio in Eq. (4) gives the anchorage strength of closely spaced hooked bars without confining reinforcement

$$T_h = 294 f_{cm}^{0.295}\ell_{eh}^{1.084}d_b^{0.470}\left(0.0974\frac{c_{ch}}{d_b}+0.391\right) \tag{5}$$

Figure 11 shows the test-to-calculated strength ratio T/T_h based on Eq. (4) and (5) for the specimens containing closely- and widely spaced hooked bars without confining reinforcement versus the center-to-center spacing normalized to bar diameter c_{ch}/d_b. The best-fit line represents all specimens in the figure. Equation (5) was used to calculate the predicted failure load for specimens with center-to-center spacing less than or equal to $6d_b$. The average test-to-calculated strength ratio is 1.0 with a maximum of 1.32, a minimum of 0.74, and a standard deviation of 0.115. The nearly horizontal trend line in Fig. 11 shows that Eq. (4) and (5) accurately account for the effect of closely spaced hooked bars without confining reinforcement.

Figure 12 shows the test-to-calculated anchorage strength ratio T/T_h versus center-to-center spacing between hooked bars normalized to bar diameter c_{ch}/d_b for specimens with No. 3 (No. 10) hoops spaced at $3d_b$ as confining reinforcement in the joint region. As stated previously, only hoops located within $8d_b$ for No. 5 and No. 8 (No. 16 and No. 25) bars or $10d_b$ for No. 11 (No. 36) bars from the top of the hooked bar are treated as contributing to anchorage strength. Comparing Fig. 12 with Fig. 10, it can be seen that, as in the case of hooked bars without confining reinforcement, there is a reduction in strength for closely spaced hooked bars with a center-to-center spacing less than $6d_b$ confined by No. 3 (No. 10) hoops spaced at $3d_b$. The reduction due to close spacing between the hooked bars, however, is not as great as for specimens without confining reinforcement. Based on the best-fit line for the specimens with closely spaced hooked bars with confining reinforcement shown in Fig. 12, the ratio of the anchorage strength for closely spaced hooked bars to the anchorage strength of widely spaced hooked bars is represented by

$$\left(0.0516\frac{c_{ch}}{d_b}+0.6572\right)\leq 1.0 \tag{6}$$

As is the case for specimens without confining reinforcement, the ratio is taken as 1.0 when the center-to-center spacing is greater than or equal to $6d_b$.

To account for the effect of closely spaced hooked bars for specimens with No. 3 (No. 10) hoops spaced at $3d_b$ as confining reinforcement, the hooked bar anchorage strength calculated using Eq. (3) is multiplied by the ratio in Eq. (6) to get

$$T_h = \left(294 f_{cm}^{0.295}\ell_{eh}^{1.084}d_b^{0.470}+55{,}050\left(\frac{A_{th}}{n}\right)^{1.017}d_b^{0.73}\right)\left(0.0516\frac{c_{ch}}{d_b}+0.6572\right) \tag{7}$$

Figure 13 shows the test-to-calculated strength ratio based on Eq. (6) and (7) for the specimens containing widely and closely spaced hooked bars with No. 3 (No. 10) hoops spaced at $3d_b$ as confining reinforcement in the joint region versus center-to-center spacing normalized to bar diameter c_{ch}/d_b. The best-fit line represents all specimens. The mean value of

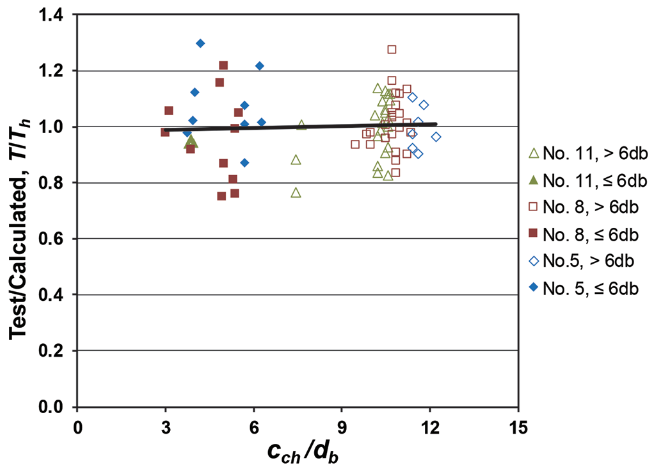

Fig. 13—Ratio of test-to-calculated anchorage force T/T_h *versus center-to-center spacing normalized to bar diameter* c_{ch}/d_b *for specimens with widely and closely spaced hooked bars with No. 3 (No. 10) hoops spaced at* $3d_b$ *as confining reinforcement, with* T_h *based on Eq. (6) and (7).*

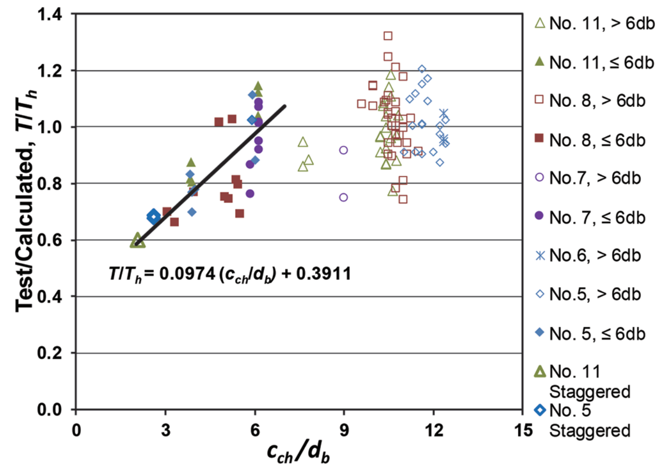

Fig. 14—Ratio of test-to-calculated bar force at failure T/T_h *for specimens without confining reinforcement including staggered-hook specimens versus center-to-center spacing normalized to bar diameter* c_{ch}/d_b*, with* T_h *based on Eq. (3).*

T/T_h is 1.0, with a maximum of 1.29, a minimum of 0.75, and a standard deviation of 0.113. The nearly horizontal trend line in Fig. 13 shows that Eq. (6) and (7) accurately account for the effect of spacing between hooked bars with No. 3 (No. 10) hoops spaced at $3d_b$ as confining reinforcement.

For closely spaced hooked bars that are confined by an intermediate amount of confining reinforcement within the joint region, a linear interpolation between Eq. (4) and (6) may be used (Yasso et al. 2017; Ajaam et al. 2017).

Effect of staggering hooked bars

The effect of staggering hooked bars on anchorage strength was investigated using test results for the specimens containing closely spaced No. 5 and No. 11 (No. 16 and No. 36) hooked bars arranged in two layers. The hooked bars had a 90-degree bend angle with a nominal side cover of 2.5 in. (65 mm) and a nominal tail cover of 2 in. (50 mm).

Figures 14 and 15 show the test-to-calculated ratios of average bar force at failure T/T_h, respectively, for specimens without confining reinforcement and with No. 3 (No. 10) hoops spaced at $3d_b$ as confining reinforcement plotted versus the center-to-center spacing between hooked bars, expressed in multiples of bar diameter c_{ch}/d_b. These figures include the staggered-hook specimens. The calculated average bar forces T_h are based on the descriptive equation for widely spaced hooked bars (Eq. (3)). The center-to-center spacing is based on the minimum of the horizontal or vertical spacing between hooked bars. The trend lines are calculated using the closely spaced hooked bars data points shown in Fig. 10 and 12 and do not include the staggered-hook specimens. As shown in Fig. 14 and 15, the results for staggered-hook specimens fall along the trend lines for closely-spaced hooked bars, indicating that the anchorage strength of staggered hooked bars can be represented by the relationship obtained for closely-spaced hooked bars in a single layer. When compared with Eq. (5) and (7), as appropriate, the staggered-hook specimens with No. 5 and No. 11 (No. 16 and No. 36) hooked bars have average ratios of test-to-calculated bar force T/T_h of 1.10 and 0.97, respectively.

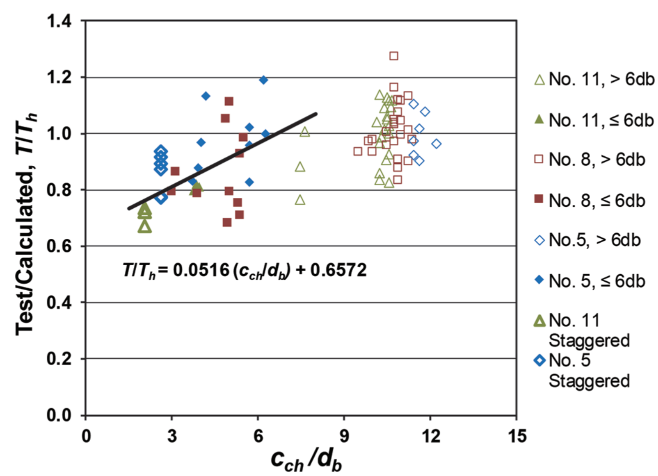

Fig. 15—Ratio of test-to-calculated bar force at failure T/T_h *for specimens with No. 3 (No. 10) hoops spaced at* $3d_b$ *as confining reinforcement including staggered-hook specimens versus center-to-center spacing normalized to bar diameter* c_{ch}/d_b*, with* T_h *based on Eq. (3).*

SUMMARY AND CONCLUSIONS

In this study, 67 simulated beam-column joint specimens were tested, as a continuation of previous work at the University of Kansas, to investigate the anchorage strength of closely-spaced and staggered hooked bars. The specimens contained three or four No. 5 (No. 16), three No. 8 (No. 25), or three No. 11 (No. 36) hooked bars arranged in one layer, or four or six No. 5 (No. 16) or four No. 11 (No. 36) hooked bars arranged in two layers. The center-to-center spacing between the bars ranged from $2d_b$ to $6d_b$. The results for these specimens were compared with the provisions in ACI 318-14 and with the results of specimens containing two hooked bars with a center-to-center spacing between hooked bars ranging from $6d_b$ to $12d_b$. The specimens were cast using normalweight concrete. The concrete compressive strength ranged from 4490 to 12,190 psi (31 to 84 MPa), and embedment length ranged from 5.2 to 23.5 in. (132 to 597 mm). The stresses in the hooked bars at anchorage failure ranged from 30,400 to 117,100 psi (210 to 808 MPa). The descriptive equation developed by Ajaam et al. (2017) to calculate the anchorage strength of two widely spaced hooked bars was modified to account for the effect of spacing between hooked bars for specimens with and without confining reinforcement.

The following conclusions are based on the results and analysis described in this paper:

1. The provisions in ACI 318-14 for the development length for hooked bars become progressively unconservative as concrete compressive strength and bar size increase, and do not account for the lower anchorage strength of closely spaced hooked bars.

2. The incorporation of the modification factor based on confining reinforcement in the current Code provisions for development length overestimates the anchorage strength of hooked bars, particularly for large or closely spaced hooked bars.

3. Concrete breakout is the dominant failure mode for specimens containing closely spaced hooked bars.

4. Hooked bars with a center-to-center spacing below six bar diameters exhibit lower anchorage strengths than hooked bars with wider spacing. The anchorage strength of closely spaced hooked bars decreases as bar spacing decreases, but close spacing has less effect if the hooked bars are confined by closed hoops.

5. The anchorage strength of staggered hooked bars can be represented by considering the minimum of the horizontal and vertical clear spacing between hooked bars.

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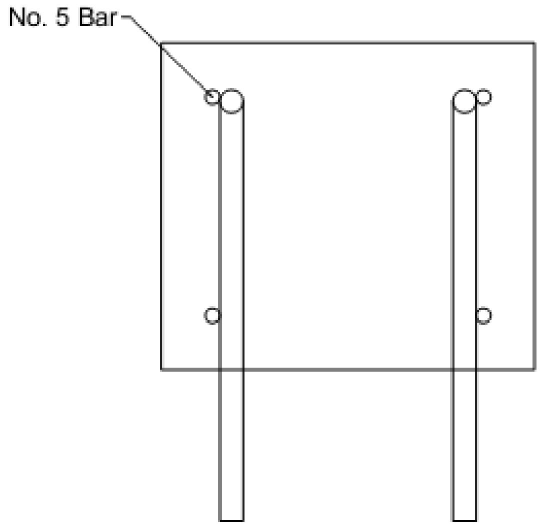
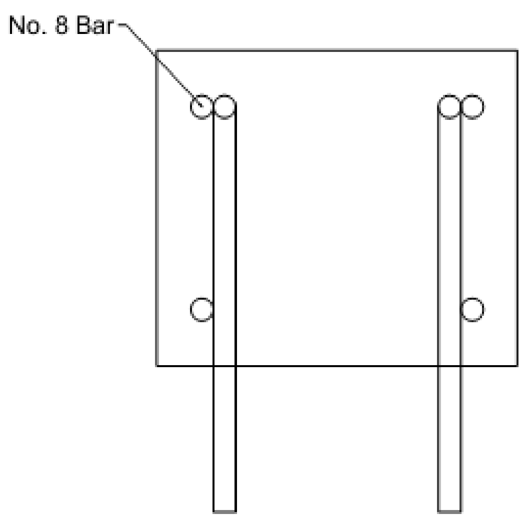
Appendix A: Comprehensive Test Results

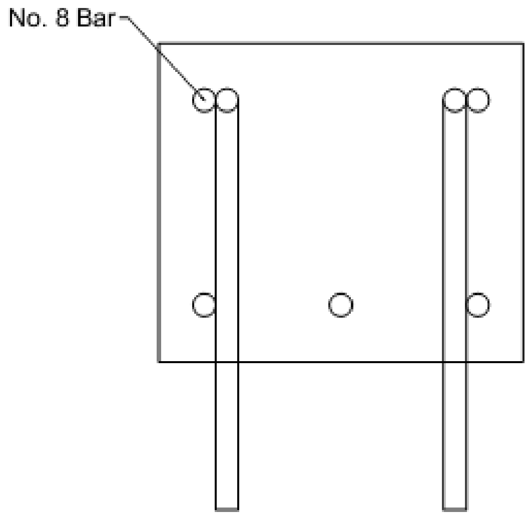
A.1 Longitudinal Column Steel Layout



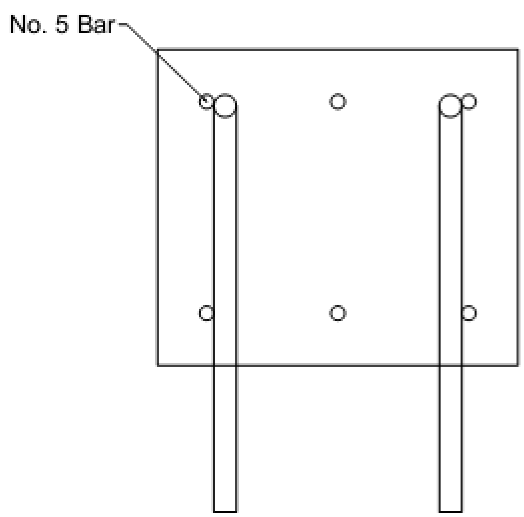
Layout A1–Longitudinal column reinforcement-4 No. 5 (No. 16) bars. Transverse reinforcement not shown.



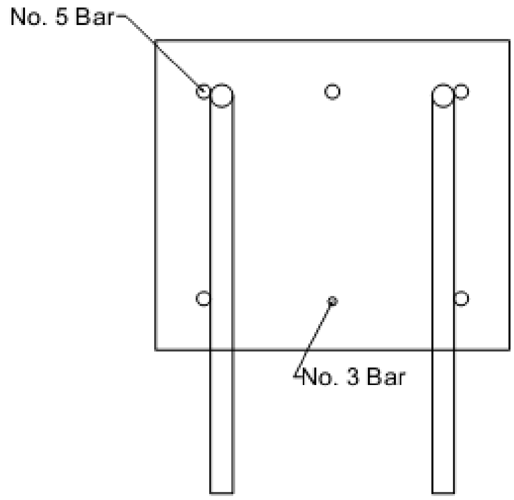
Layout A2–Longitudinal column reinforcement-4 No. 8 (No. 25) bars. Transverse reinforcement not shown.



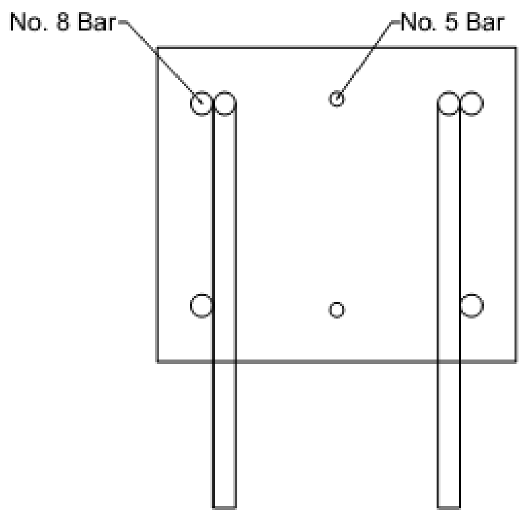
Layout A3–Longitudinal column reinforcement-5 No. 8 (No. 25) bars. Transverse reinforcement not shown.



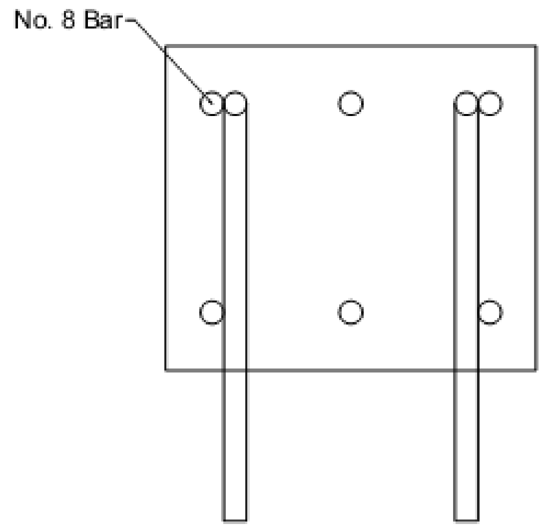
Layout A4–Longitudinal column reinforcement-6 No. 5 (No. 16) bars. Transverse reinforcement not shown.



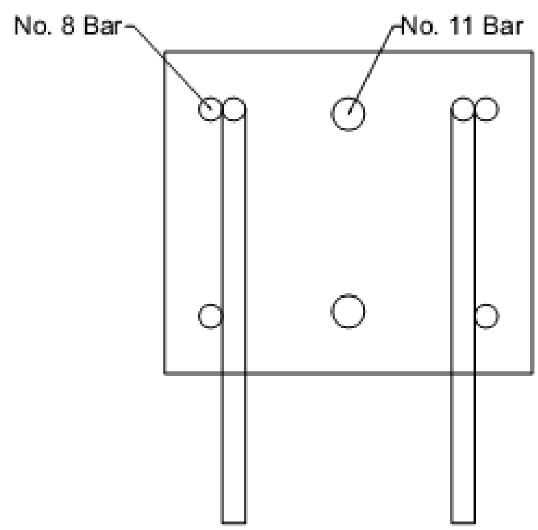
Layout A5–Longitudinal column reinforcement-5 No. 5 (No. 16) bars + 1 No. 3 (No. 10) bar. Transverse reinforcement not shown.



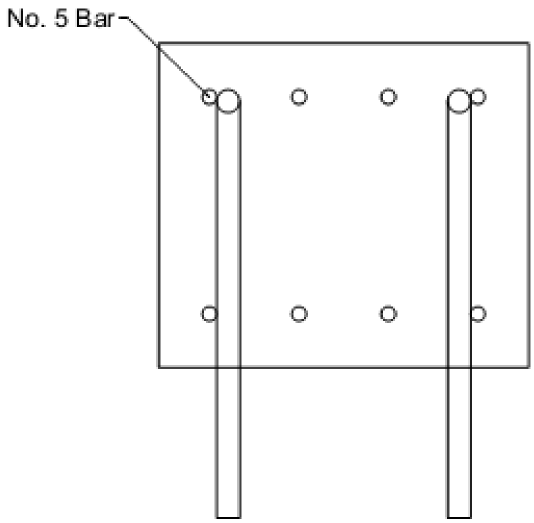
Layout A6–Longitudinal column reinforcement-4 No. 8 (No. 25) bars + 2 No. 5 (No. 16) bars. Transverse reinforcement not shown.



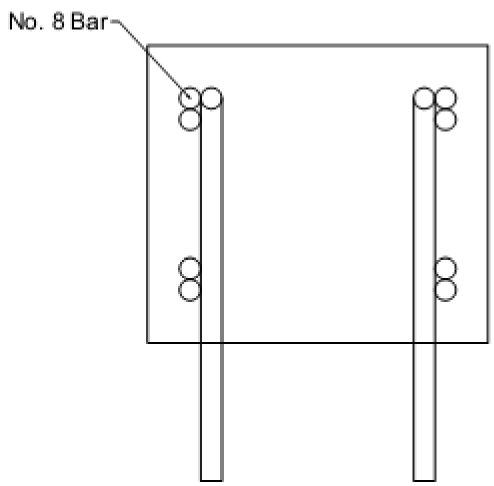
Layout A7–Longitudinal column reinforcement-6 No. 8 (No. 25) bars. Transverse reinforcement not shown.



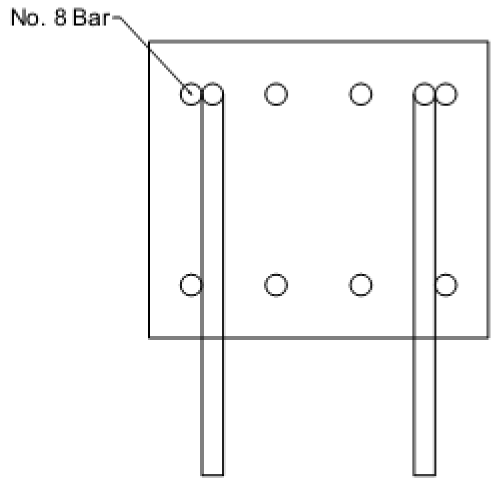
Layout A8–Longitudinal column reinforcement-4 No. 8 (No. 25) bars + 2 No. 11 (No. 36) bars. Transverse reinforcement not shown.



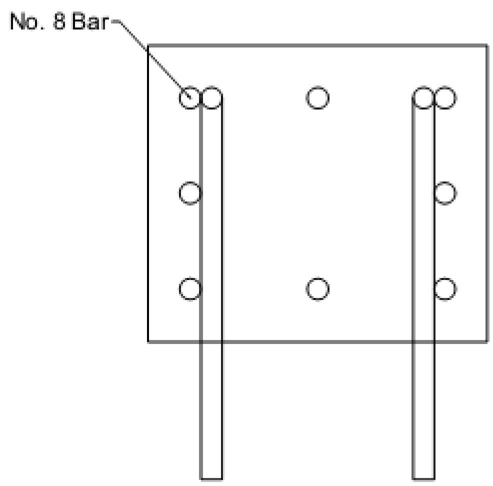
Layout A9–Longitudinal column reinforcement-8 No. 5 (No. 16) bars. Transverse reinforcement not shown.



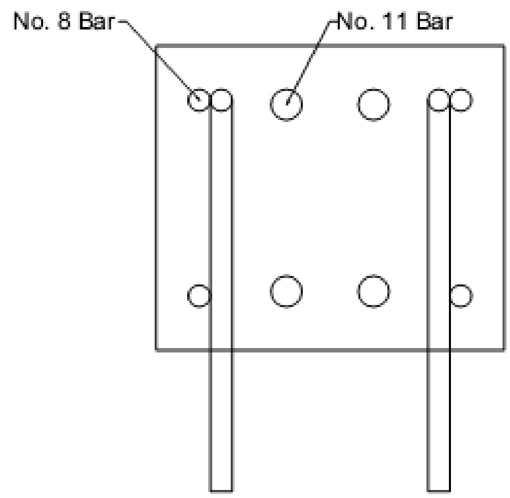
Layout A10–Longitudinal column reinforcement-8 No. 8 (No. 25) bars (four bundles of two bars each). Transverse reinforcement not shown.



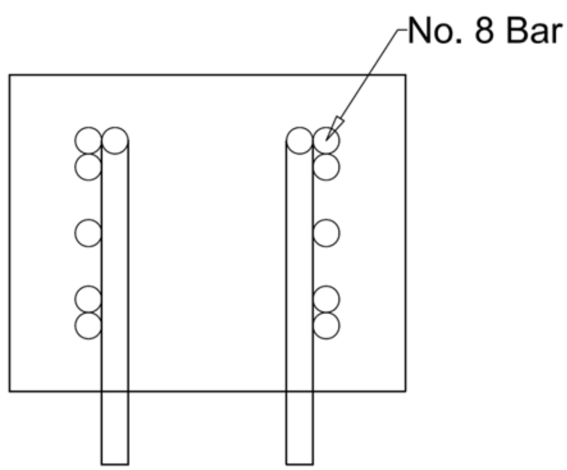
Layout A11–Longitudinal column reinforcement-8 No. 8 (No. 25) bars (distributed across two column faces). Transverse reinforcement not shown.



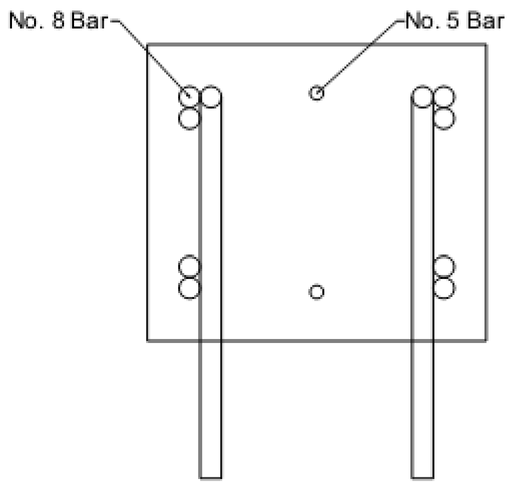
Layout A12–Longitudinal column reinforcement-8 No. 8 (No. 25) bars (distributed across four column faces). Transverse reinforcement not shown.



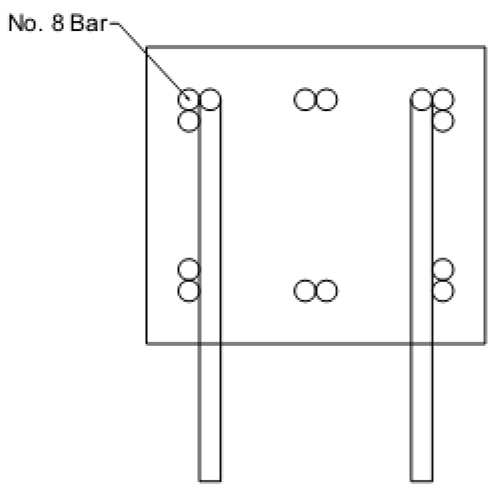
Layout A13–Longitudinal column reinforcement-4 No. 8 (No. 25) bars + 4 No. 11 (No. 36) bars. Transverse reinforcement not shown.



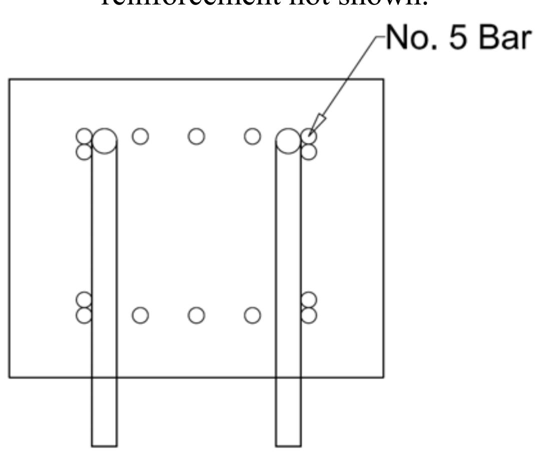
Layout A14–Longitudinal column reinforcement-10 No. 8 (No. 25) bars (four bundles of two bars and two single bars). Transverse reinforcement not shown.



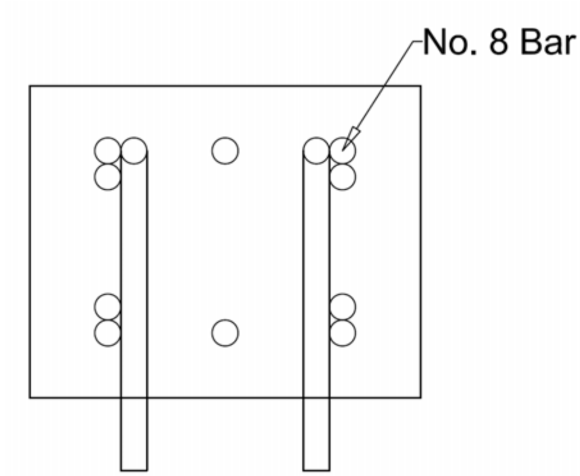
Layout A15–Longitudinal column reinforcement-8 No. 8 (No. 25) bars + 2 No. 5 (No. 16) bars. Transverse reinforcement not shown.



Layout A16–Longitudinal column reinforcement-12 No. 8 (No. 25) bars. Transverse reinforcement not shown.



Layout A17–Longitudinal column reinforcement-14 No. 5 (No. 16) bars (four bundles of two bars and six single bars). Transverse reinforcement not shown.



Layout A18–Longitudinal column reinforcement-10 No. 8 (No. 25) bars (four bundles of two bars and two single bars). Transverse reinforcement not shown.

A.2 Notation

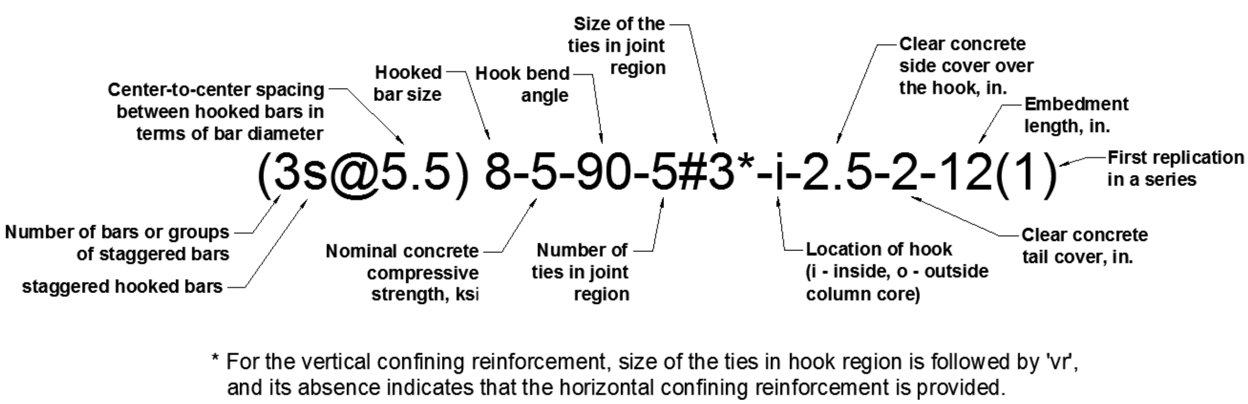


Fig. A.1–Specimen designation

A_{cti} Total area of cross-ties inside the hook region

A_h Area of hooked bar

A_s Area of longitudinal steel in the column

A_{th} Total cross-sectional area of all confining reinforcement parallel to ℓ_{dh} for hooked bars being developed and located within $8d_b$ of the top (bottom) of the bars in the direction of the hook for No. 3 (No. 10) through No. 8 (No. 25) hooked bars or within $10d_b$ of the top (bottom) of the bars in the direction of the hook for No. 9 (No. 28) through No. 11 (No. 36) hooked bars; or total cross-sectional area of all confining reinforcement perpendicular to ℓ_{dh}

$A_{tr,l}$ Area of single leg of confining reinforcement inside hook region

b Column width

c_{ch} Minimum center-to-center spacing between hooked bars

c_{cv} Vertical center-to-center spacing between hooked bars

c_h Clear spacing between hooked bars, inside-to-inside spacing

c_{so} Clear cover measured from the side of the hook to the side of the column

$c_{so,\text{avg}}$ Average clear cover of the hooked bars

c_{th} Clear cover measured from the tail of the hook to the back of the column

d_b Nominal diameter of the hooked bar

d_{cto} Nominal bar diameter of cross-ties outside the hook region

d_s Nominal bar diameter of confining reinforcing steel outside the hook region

d_{tr} Nominal bar diameter of confining reinforcement inside the hook region

f_c' Specified concrete compressive strength

f_{cm} Measured average concrete compressive strength

$f_{s,\text{ACI}}$ Stress in hook as calculated by Section 25.4.3 of ACI 318-14

f_{su} Average peak stress on hooked bars at failure

$f_{su,\max}$ Maximum stress on individual hooked bar

f_{ys} Nominal yield strength of longitudinal reinforcing steel in the column

f_{yt} Nominal yield strength of confining reinforcement

h Column depth

h_c Width of bearing member

h_{cl} Height measured from the center of the hook to the top of the bearing member

ℓ_{dh} Development length of hooked bar

ℓ_{eh} Embedment length measured from the back of the hook to the front of the column

$\ell_{eh,\text{avg}}$ Average embedment length of hooked bars

n Number of hooked bars confined by N legs

N_{cti} Total number of cross-ties used as supplemental reinforcement inside the hook region

N_{cto} Number of cross-ties used per layer as supplemental reinforcement outside the hook region and spaced at s_s

N_h Number of hooked bars loaded simultaneously

N_{tr} Number of stirrups/ties crossing the hook

R_r Relative rib area

s_{cti} Center-to-center spacing of cross-ties in the hook region

s_{tr} Center-to-center spacing of confining reinforcement in the hook region

s_s Center-to-center spacing of stirrups/ties outside the hook region

T Average load on hooked bars at failure

T_h Hooked bar anchorage strength

T_{ind} Load on individual hooked bar at failure

T_{max} Maximum load on individual hooked bar

T_{total} Sum of loads on hooked bars at failure

λ Factor for lightweight concrete as defined in ACI 318-14 Section 25.4.3.2

ψ_e Epoxy factor as defined in ACI 318-14 Section 25.4.3.2

ψ_c factor for cover as defined in ACI 318-14 Section 25.4.3.2

ψ_r factor for confinement in the hook region

A.3 Test Results

Table A.1 Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
1	5-5-90-0-i-2.5-2-8	A B	90°	-	A1035	8.1 8.0	8.1	4830	9	0.625
2	5-5-90-0-i-2.5-2-10	A B	90°	-	A1035	9.4 9.4	9.4	5230	6	0.625
3	5-5-90-0-i-2.5-2-7	A B	90°	-	A1035	6.9 7.0	6.9	5190	7	0.625
4	5-8-90-0-i-2.5-2-6	A B	90°	-	A615	6.8 6.8	6.8	8450	14	0.625
5	5-8-90-0-i-2.5-2-6(1)	A B	90°	-	A1035	6.1 6.5	6.3	9080	11	0.625
6	5-8-90-0-i-2.5-2-8	A B	90°	-	A1035	8.0 7.5	7.8	8580	15	0.625
7	5-12-90-0-i-2.5-2-10	A B	90°	-	A1035	10.0 11.0	10.5	10290	14	0.625
8	5-12-90-0-i-2.5-2-5	A B	90°	-	A1035	5.1 4.8	4.9	11600	84	0.625
9	5-15-90-0-i-2.5-2-5.5	A B	90°	-	A1035	6.1 5.8	5.9	15800	62	0.625
10	5-15-90-0-i-2.5-2-7.5	A B	90°	-	A1035	7.3 7.3	7.3	15800	62	0.625
11	5-5-90-0-i-3.5-2-10	A B	90°	-	A1035	10.5 10.4	10.4	5190	7	0.625
12	5-5-90-0-i-3.5-2-7	A B	90°	-	A1035	7.5 7.6	7.6	5190	7	0.625
13	5-8-90-0-i-3.5-2-6	A B	90°	-	A615	6.3 6.4	6.3	8580	15	0.625
14	5-8-90-0-i-3.5-2-6(1)	A B	90°	-	A1035	6.5 6.6	6.6	9300	13	0.625
15	5-8-90-0-i-3.5-2-8	A B	90°	-	A1035	8.6 8.5	8.6	8380	13	0.625
16	5-12-90-0-i-3.5-2-5	A B	90°	-	A1035	5.5 5.4	5.4	10410	15	0.625
17	5-8-180-0-i-2.5-2-7	A B	180°	-	A1035	7.4 7.1	7.3	9080	11	0.625
18	5-8-180-0-i-3.5-2-7	A B	180°	-	A1035	7.4 7.3	7.3	9080	11	0.625
19	5-5-90-2#3-i-2.5-2-8	A B	90°	Para	A1035	8.0 7.5	7.8	5860	8	0.625
20	5-5-90-2#3-i-2.5-2-6	A B	90°	Para	A615	6.0 5.8	5.9	5800	9	0.625
21	5-8-90-2#3-i-2.5-2-6	A B	90°	Para	A1035	6.0 6.0	6.0	8580	15	0.625
22	5-8-90-2#3-i-2.5-2-8	A B	90°	Para	A1035	8.3 8.5	8.4	8380	13	0.625
23	5-12-90-2#3-i-2.5-2-5	A B	90°	Para	A1035	5.8 5.8	5.8	11090	83	0.625
24	5-15-90-2#3-i-2.5-2-6	A B	90°	Para	A1035	6.3 6.5	6.4	15800	61	0.625
25	5-15-90-2#3-i-2.5-2-4	A B	90°	Para	A1035	3.5 4.0	3.8	15800	61	0.625

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load Kips	Long. Reinf. Layout°
1	A B	0.073	13.1	10.3	5.25	8.375	2.5 2.6	2.5	2.1 2.3	6.8	7.4	2	30	A2
2	A B	0.073	13.1	12.3	5.25	8.375	2.8 2.6	2.7	2.9 2.9	6.4	7.1	2	30	A4
3	A B	0.073	13.0	9.6	5.25	8.375	2.5 2.5	2.5	2.8 2.6	6.8	7.4	2	30	A1
4	A B	0.073	13.0	8.0	5.25	8.375	2.8 2.6	2.7	1.3 1.3	6.4	7.0	2	80	A1
5	A B	0.073	13.3	8.8	5.25	8.375	2.5 2.5	2.5	2.6 2.3	7.0	7.6	2	30	A1
6	A B	0.073	13.1	10.0	5.25	8.375	2.5 2.8	2.6	2.0 2.5	6.6	7.3	2	80	A1
7	A B	0.073	12.8	12.5	5.25	8.375	2.4 2.5	2.4	2.5 1.5	6.6	7.3	2	30	A4
8	A B	0.073	13.0	7.3	5.25	8.375	2.6 2.6	2.6	2.1 2.5	6.5	7.1	2	30	A1
9	A B	0.073	12.6	7.7	5.25	8.375	2.4 2.4	2.4	1.6 1.9	6.6	7.3	2	30	A1
10	A B	0.073	12.9	9.8	5.25	8.375	2.5 2.5	2.5	2.6 2.6	6.6	7.3	2	30	A2
11	A B	0.073	14.8	12.3	5.25	8.375	3.5 3.5	3.5	1.8 1.9	6.5	7.1	2	30	A4
12	A B	0.073	15.1	8.8	5.25	8.375	3.4 3.5	3.4	1.3 1.1	7.0	7.6	2	30	A1
13	A B	0.073	15.0	8.0	5.38	8.375	3.6 3.5	3.6	1.8 1.6	6.6	7.3	2	80	A1
14	A B	0.073	15.6	8.6	5.25	8.375	3.8 3.8	3.8	2.1 1.9	6.9	7.5	2	30	A1
15	A B	0.060	15.5	10.0	5.25	8.375	3.6 3.5	3.6	1.4 1.5	7.1	7.8	2	80	A1
16	A B	0.073	15.5	7.2	5.25	8.375	3.6 3.6	3.6	1.7 1.8	7.0	7.6	2	30	A1
17	A B	0.073	12.6	9.5	5.25	8.375	2.5 2.6	2.6	2.1 2.4	6.3	6.9	2	30	A1
18	A B	0.073	15.4	9.3	5.25	8.375	3.6 3.4	3.5	1.9 2.0	7.1	7.8	2	30	A1
19	A B	0.073	12.9	10.0	5.38	8.375	2.5 2.5	2.5	2.0 2.5	6.6	7.3	2	80	A1
20	A B	0.060	13.1	8.5	5.25	8.375	2.6 2.6	2.6	2.5 2.8	6.6	7.3	2	80	A1
21	A B	0.073	13.0	8.0	5.25	8.375	2.8 2.9	2.8	2.0 2.0	6.1	6.8	2	80	A1
22	A B	0.073	12.9	10.0	5.25	8.375	2.6 2.5	2.6	1.8 1.5	6.5	7.1	2	80	A5
23	A B	0.073	13.0	8.8	5.25	8.375	2.5 2.8	2.6	3.0 3.0	6.5	7.1	2	30	A1
24	A B	0.073	12.6	8.2	5.25	8.375	2.4 2.4	2.4	1.9 1.7	6.6	7.3	2	30	A2
25	A B	0.073	13.0	6.1	5.25	8.375	2.5 2.5	2.5	2.6 2.1	6.8	7.4	2	30	A9

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
1	A	32068	31463	64895	32448	27694	103445	104670	64057	-	CB/SS
	B	33433	33433				107847			-	CB/SS
2	A	37404	34303	67166	33583	33379	120656	108333	77484	-	CB/SS
	B	32864	32864				106012			-	CB/SS
3	A	26607	26607	52529	26265	24025	85831	84724	57119	-	CB/SS
	B	26095	25922				84176			0.192	CB/SS
4	A	27578	27102	59140	29570	26929	88961	95387	70913	-	CB/SS
	B	32135	32038				103663			-	SS/CB
5	A	21741	21741	44849	22425	25578	70131	72338	68744	0.296	CB
	B	24995	23109				80630			.330(.030)	CB
6	A	31878	31469	63347	31673	31422	102831	102172	82042	-	SS/CB
	B	35934	31878				115915			-	SS/CB
7	A	40823	40823	83314	41657	46084	131688	134377	121728	0.191	SS
	B	42491	42491				137066			-	CB/SS/TK
8	A	19389	19389	38441	19220	21064	62546	62001	60775	-	CB/SS
	B	23171	19051				74745			-	CB
9	A	36163	32648	65021	32511	28183	116656	104873	85295	-	CB
	B	32373	32373				104430			-	CB
10	A	42470	42464	84441	42221	34999	137001	136196	104150	-	CB
	B	41977	41977				135410			-	*
11	A	43228	43228	83855	41927	37416	139446	135250	85935	-	SS/CB
	B	41140	40626				132710			-	SS/CB
12	A	27197	27197	53033	26516	26381	87732	85537	62265	-	SS
	B	25884	25836				83498			-	CB/SS
13	A	25129	25129	50950	25475	25154	81060	82178	66825	-	CB/SS
	B	29054	25822				93723			-	CB/SS
14	A	24440	24440	49083	24541	26867	78838	79166	72327	0.152	CB/SS
	B	27541	24643				88842			.178(.150)	CB/SS
15	A	39109	31179	65490	32745	34767	126159	105629	89581	-	CB/SS
	B	34311	34311				110679			-	SS
16	A	22045	22040	44241	22121	22652	71114	71357	63404	-	CB
	B	23158	22201				74702			-	CB
17	A	26722	26722	54217	27108	29722	86199	87446	78954	0.194	CB/SS
	B	35215	27495				113596			.146(.016)	SS/CB
18	A	34057	30094	61508	30754	30000	109860	99206	79634	0.251	SS/CB
	B	31441	31414				101422			.237(.021)	CB/SS
19	A	37932	37807	74307	37154	32213	122360	119850	67802	-	SS/CB
	B	38949	36500				125642			-	SS/CB
20	A	31846	29697	58888	29444	24865	102730	94980	51134	-	CB/SS
	B	29191	29191				94164			-	CB/SS
21	A	33454	30402	61277	30638	27940	107916	98833	63517	-	CB/SS
	B	30874	30874				99595			-	CB/SS
22	A	39822	39791	80336	40168	38077	128457	129574	87619	-	CB/SS
	B	40545	40545				130789			-	CB/SS
23	A	25201	25120	48696	24348	28654	81295	78542	69203	-	CB/SS
	B	29393	23576				94816			-	CB
24	A	42381	42381	85276	42638	34576	136714	137542	91580	-	CB
	B	42895	42895				138371			-	CB
25	A	18652	18652	37334	18667	21256	60167	60217	53871	-	CB
	B	21256	18683				68569			-	CB

[a] Calculated based on Eq. (3)

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
1	A B	60	-	-	-	-	-	-	-	0.500	3.00	-	-	3.16	60
2	A B	60	-	-	-	-	0.33	3	3.0	0.375	3.00	-	-	1.89	60
3	A B	60	-	-	-	-	0.80	4	2.5	0.500	3.50	-	-	1.27	60
4	A B	60	-	-	-	-	0.80	4	4.0	0.500	4.00	-	-	1.27	60
5	A B	60	-	-	-	-	0.66	6	3.0	0.500	3.00	-	-	1.27	60
6	A B	60	-	-	-	-	0.80	4	4.0	0.500	4.00	-	-	1.27	60
7	A B	60	-	-	-	-	0.11	1	7.0	0.375	5.00	-	-	1.89	60
8	A B	60	-	-	-	-	0.66	6	2.5	0.500	3.00	-	-	1.27	60
9	A B	60	-	-	-	-	-	-	-	0.375	2.50	-	-	1.27	60
10	A B	60	-	-	-	-	-	-	-	0.375	3.50	-	-	3.16	60
11	A B	60	-	-	-	-	0.33	3	3.0	0.375	3.00	-	-	1.89	60
12	A B	60	-	-	-	-	0.80	4	2.5	0.375	3.50	-	-	1.27	60
13	A B	60	-	-	-	-	0.80	4	4.0	0.500	4.00	-	-	1.27	60
14	A B	60	-	-	-	-	0.66	6	3.0	0.500	3.00	-	-	1.27	60
15	A B	60	-	-	-	-	0.80	4	4.0	0.500	4.00	-	-	1.27	60
16	A B	60	-	-	-	-	0.66	6	2.5	0.500	3.00	-	-	1.27	60
17	A B	60	-	-	-	-	0.22	2	4.0	0.500	3.00	-	-	1.27	60
18	A B	60	-	-	-	-	0.22	2	4.0	0.500	3.00	-	-	1.27	60
19	A B	60	0.375	0.11	2	4.00	-	-	-	0.375	4.00	-	-	1.27	60
20	A B	60	0.375	0.11	2	4.00	-	-	-	0.375	4.00	-	-	1.27	60
21	A B	60	0.375	0.11	2	4.00	-	-	-	0.500	4.00	-	-	1.27	60
22	A B	60	0.375	0.11	2	4.00	-	-	-	0.500	4.00	-	-	1.67	60
23	A B	60	0.375	0.11	2	3.30	0.33	3	3.3	0.500	3.00	-	-	1.27	60
24	A B	60	0.375	0.11	2	3.00	-	-	-	0.375	2.75	-	-	3.16	60
25	A B	60	0.375	0.11	2	3.00	-	-	-	0.375	1.75	-	-	2.51	60

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
26	5-5-90-2#3-i-3.5-2-6	A B	90°	Para	A1035	6.0 5.8	5.9	5230	6	0.625
27	5-5-90-2#3-i-3.5-2-8	A B	90°	Para	A1035	7.9 7.5	7.7	5190	7	0.625
28	5-8-90-2#3-i-3.5-2-6	A B	90°	Para	A1035	6.5 6.0	6.3	8580	15	0.625
29	5-8-90-2#3-i-3.5-2-8	A B	90°	Para	A1035	7.1 7.0	7.1	8710	16	0.625
30	5-12-90-2#3-i-3.5-2-5	A B	90°	Para	A1035	5.6 5.3	5.4	10410	15	0.625
31	5-5-180-2#3-i-2.5-2-8	A B	180°	Para	A1035	8.0 8.0	8.0	5670	7	0.625
32	5-5-180-2#3-i-2.5-2-6	A B	180°	Para	A615	5.8 5.5	5.6	5860	8	0.625
33	5-8-180-2#3-i-2.5-2-7	A B	180°	Para	A1035	7.0 7.3	7.1	9080	11	0.625
34	5-8-180-2#3-i-3.5-2-7	A B	180°	Para	A1035	6.8 6.9	6.8	9080	11	0.625
35	5-5-90-5#3-i-2.5-2-8	A B	90°	Para	A1035	7.8 7.8	7.8	4660	7	0.625
36	5-5-90-5#3-i-2.5-2-7	A B	90°	Para	A1035	5.6 7.0	6.3	5230	6	0.625
37	5-12-90-5#3-i-2.5-2-5	A B	90°	Para	A1035	5.1 5.8	5.4	10410	15	0.625
38	5-15-90-5#3-i-2.5-2-4	A B	90°	Para	A1035	3.8 4.1	4.0	15800	62	0.625
39	5-15-90-5#3-i-2.5-2-5	A B	90°	Para	A1035	5.0 5.1	5.1	15800	62	0.625
40	5-5-90-5#3-i-3.5-2-7	A B	90°	Para	A1035	7.5 6.8	7.1	5190	7	0.625
41	5-12-90-5#3-i-3.5-2-5	A B	90°	Para	A1035	5.3 4.8	5.0	11090	83	0.625

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
26	A B	0.073	14.5	8.3	5.25	8.375	3.4 3.4	3.4	2.3 2.5	6.5	7.1	2	30	A1
27	A B	0.073	14.9	10.3	5.25	8.375	3.4 3.5	3.4	2.3 2.8	6.8	7.4	2	30	A1
28	A B	0.073	14.9	8.0	5.25	8.375	3.5 3.8	3.6	1.5 2.0	6.4	7.0	2	80	A1
29	A B	0.060	14.9	10.0	5.25	8.375	3.5 3.5	3.5	2.9 3.0	6.6	7.3	2	80	A5
30	A B	0.073	15.1	7.4	5.25	8.375	3.8 3.5	3.6	1.8 2.2	6.6	7.3	2	30	A1
31	A B	0.073	13.1	10.0	5.25	8.375	2.5 2.5	2.5	2.0 2.0	6.9	7.5	2	80	A1
32	A B	0.060	13.1	7.8	5.25	8.375	2.6 2.6	2.6	2.0 2.3	6.6	7.3	2	80	A1
33	A B	0.073	12.6	9.3	5.25	8.375	2.5 2.5	2.5	2.3 2.1	6.4	7.0	2	30	A1
34	A B	0.073	15.1	9.2	5.25	8.375	3.4 3.5	3.4	2.4 2.3	7.0	7.6	2	30	A1
35	A B	0.073	13.1	10.1	5.25	8.375	2.5 2.9	2.7	2.4 2.3	6.5	7.1	2	30	A2
36	A B	0.073	13.3	9.3	5.25	8.375	2.8 2.8	2.8	3.6 2.3	6.5	7.1	2	30	A1
37	A B	0.073	13.0	7.3	5.25	8.375	2.6 2.6	2.6	2.1 1.5	6.5	7.1	2	30	A1
38	A B	0.073	12.8	6.0	5.25	8.375	2.4 2.5	2.4	2.2 1.9	6.6	7.3	2	30	A9
39	A B	0.073	12.8	7.1	5.25	8.375	2.4 2.3	2.4	2.1 1.9	6.8	7.4	2	30	A2
40	A B	0.073	15.1	9.5	5.25	8.375	3.4 3.5	3.4	2.0 2.8	7.0	7.6	2	30	A1
41	A B	0.073	14.4	7.0	5.25	8.375	3.3 3.3	3.3	2.5 1.5	6.6	7.3	2	30	A1

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
26	A	21341	21146	42186	21093	24241	68842	68042	48557	0.183	SS/CB
	B	21262	21040				68586			-	SS/CB
27	A	43675	43675	89329	44665	31107	140887	144079	63551	-	CB
	B	45654	45654				147271			-	CB
28	A	29930	29930	60069	30035	29018	96549	96886	66163	-	CB
	B	30139	30139				97223			-	CB/SS
29	A	38022	28716	57312	28656	32671	122652	92439	75329	-	CB
	B	28596	28596				92246			-	CB
30	A	27860	27860	56728	28364	26786	89871	91497	63404	-	CB
	B	28869	28869				93124			0.349	CB
31	A	34036	33674	68157	34078	32916	109795	109930	68845	-	CB/SS
	B	34483	34483				111236			-	CB/SS
32	A	26852	26782	53456	26728	23970	86620	86220	49211	-	CB/SS
	B	26912	26674				86814			-	CB
33	A	34580	29762	58459	29230	33301	111548	94289	77592	-	CB/SS
	B	28697	28697				92572			.369(.081)	CB/SS
34	A	29310	29285	61862	30931	31916	94550	99777	74189	-	CB/SS
	B	32577	32577				105086			.329(.028)	CB
35	A	42760	42711	86059	43030	38887	137936	138805	75578	-	CB/SS
	B	44727	43348				144280			-	CB/SS
36	A	32080	32080	63393	31696	34379	103484	102246	65216	-	CB
	B	31340	31313				101095			-	CB/SS
37	A	33923	33923	68839	34420	35294	109428	111031	79255	0.292	CB/SS
	B	34916	34916				112634			0.295	SS/CB
38	A	31312	31312	62637	31318	30850	101006	101027	71266	0.603	CB
	B	31325	31325				101048			0.378	CB
39	A	38574	38574	78312	39156	36351	124434	126309	90907	-	CB
	B	46165	39737				148921			-	BY
40	A	44301	36844	72050	36025	37373	142906	116210	73328	-	CB
	B	35206	35206				113568			-	CB
41	A	31472	31396	60882	30441	33714	101522	98196	75221	-	CB
	B	31302	29485				100973			-	CB

[a] Calculated based on Eq. (3)

Table A.1 Cont. Comprehensive test results and data for specimens containing two No. 5 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
26	A B	60	0.375	0.11	2	3.50	0.11	1	3.5	0.375	3.50	-	-	1.27	60
27	A B	60	0.375	0.11	2	3.50	-	-	-	0.375	4.00	-	-	1.27	60
28	A B	60	0.375	0.11	2	4.00	-	-	-	0.500	4.00	-	-	1.27	60
29	A B	60	0.375	0.11	2	4.00	-	-	-	0.500	4.00	-	-	1.67	60
30	A B	60	0.375	0.11	2	3.33	0.33	3	3.3	0.500	3.00	-	-	1.27	60
31	A B	60	0.375	0.11	2	2.50	-	-	-	0.375	4.00	-	-	1.27	60
32	A B	60	0.375	0.11	2	2.50	-	-	-	0.375	4.00	-	-	1.27	60
33	A B	60	0.375	0.11	2	2.00	-	-	-	0.375	3.00	-	-	1.27	60
34	A B	60	0.375	0.11	2	2.00	-	-	-	0.375	3.00	-	-	1.27	60
35	A B	60	0.375	0.11	5	1.88	-	-	-	0.500	3.00	-	-	3.16	60
36	A B	60	0.375	0.11	5	1.75	-	-	-	0.500	3.50	-	-	1.27	60
37	A B	60	0.375	0.11	5	1.67	-	-	-	0.500	3.00	-	-	1.27	60
38	A B	60	0.375	0.11	5	1.75	-	-	-	0.375	1.75	-	-	2.51	60
39	A B	60	0.375	0.11	5	1.75	-	-	-	0.375	2.25	-	-	3.16	60
40	A B	60	0.375	0.11	5	1.75	-	-	-	0.500	3.50	-	-	1.27	60
41	A B	60	0.375	0.11	5	1.70	-	-	-	0.500	3.00	-	-	1.27	60

Table A.2 Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
42	8-5-90-0-i-2.5-2-16	A B	90°	-	A1035[b]	16.0 16.8	16.4	4980	7	1
43	8-5-90-0-i-2.5-2-9.5	A B	90°	-	A615	9.0 10.3	9.6	5140	8	1
44	8-5-90-0-i-2.5-2-12.5	A B	90°	-	A615	13.3 13.3	13.3	5240	9	1
45	8-5-90-0-i-2.5-2-18	A B	90°	-	A1035[b]	19.5 17.9	18.7	5380	11	1
46	8-5-90-0-i-2.5-2-13	A B	90°	-	A1035[b]	13.3 13.5	13.4	5560	11	1
47	8-5-90-0-i-2.5-2-15(1)	A B	90°	-	A1035[b]	14.5 15.3	14.9	5910	14	1
48	8-5-90-0-i-2.5-2-15	A B	90°	-	A1035[b]	15.3 14.4	14.8	6210	8	1
49	8-5-90-0-i-2.5sc-2tc-10	A B	90°	-	A615	10.0 10.0	10.0	5920	12	1
50	8-8-90-0-i-2.5-2-8	A B	90°	-	A1035[b]	8.9 8.0	8.4	7910	15	1
51	8-8-90-0-i-2.5-2-10	A B	90°	-	A1035[b]	9.8 9.5	9.6	7700	14	1
52	8-8-90-0-i-2.5-2-8(1)	A B	90°	-	A1035[b]	8.0 8.0	8.0	8780	13	1
53	8-8-90-0-i-2.5sc-2tc-9	A B	90°	-	A615	9.5 9.5	9.5	7710	25	1
54	8-12-90-0-i-2.5-2-9	A B	90°	-	A1035[b]	9.0 9.0	9.0	11160	77	1
55	8-12-90-0-i-2.5-2-12.5	A B	90°	-	A1035[c]	12.9 12.8	12.8	11850	39	1
56	8-12-90-0-i-2.5-2-12	A B	90°	-	A1035[c]	12.1 12.1	12.1	11760	34	1
57	8-15-90-0-i-2.5-2-8.5	A B	90°	-	A1035[c]	8.8 8.9	8.8	15800	61	1
58	8-15-90-0-i-2.5-2-13	A B	90°	-	A1035[c]	12.8 12.8	12.8	15800	61	1
59	8-5-90-0-i-3.5-2-18	A B	90°	-	A1035[b]	19.0 18.0	18.5	5380	11	1
60	8-5-90-0-i-3.5-2-13	A B	90°	-	A1035[b]	13.4 13.4	13.4	5560	11	1
61	8-5-90-0-i-3.5-2-15(2)	A B	90°	-	A1035[c]	15.6 14.9	15.3	5180	8	1
62	8-5-90-0-i-3.5-2-15(1)	A B	90°	-	A1035[c]	15.4 15.1	15.3	6440	9	1
63	8-8-90-0-i-3.5-2-8(1)	A B	90°	-	A1035[b]	7.8 7.8	7.8	7910	15	1
64	8-8-90-0-i-3.5-2-10	A B	90°	-	A1035[b]	8.8 10.8	9.8	7700	14	1
65	8-8-90-0-i-3.5-2-8(2)	A B	90°	-	A1035[b]	8.5 8.0	8.3	8780	13	1
66	8-12-90-0-i-3.5-2-9	A B	90°	-	A1035[b]	9.0 9.0	9.0	11160	77	1

[a] Heat 1, [b] Heat 2, [c] Heat 3, as described in Table 1

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
42	A B	0.078	17.0	17.9	10.5	8.375	2.8 2.8	2.8	1.8 1.4	9.5	10.5	2	80	A2
43	A B	0.078	16.8	12.0	10.5	8.375	2.8 2.5	2.6	3.0 1.8	9.5	10.5	2	80	A2
44	A B	0.078	17.3	14.5	10.5	8.375	2.8 2.8	2.8	1.3 1.3	9.8	10.8	2	80	A2
45	A B	0.078	17.5	20.3	10.5	8.375	2.5 2.5	2.5	0.8 2.4	10.5	11.5	2	30	A6
46	A B	0.078	16.8	15.3	10.5	8.375	2.5 2.5	2.5	2.0 1.8	9.8	10.8	2	30	A2
47	A B	0.073	16.7	17.3	10.5	8.375	2.5 2.6	2.5	2.8 2.0	9.6	10.6	2	30	A2
48	A B	0.073	16.6	17.3	10.5	8.375	2.5 2.6	2.6	2.0 2.9	9.5	10.5	2	30	A2
49	A B	0.073	17.6	12.3	10.5	8.375	2.5 2.9	2.7	2.3 2.3	10.3	11.3	2	57	A17
50	A B	0.078	16.3	10.0	10.5	8.375	2.8 2.9	2.8	1.1 2.0	8.6	9.6	2	30	A2
51	A B	0.078	16.6	12.0	10.5	8.375	2.8 2.9	2.8	2.3 2.5	9.0	10.0	2	30	A2
52	A B	0.078	17.0	10.8	10.5	8.375	2.8 2.8	2.8	2.8 2.8	9.5	10.5	2	30	A2
53	A B	0.073	17.3	11.0	10.5	8.375	2.5 2.8	2.6	1.5 1.5	10.0	11.0	2	30	A2
54	A B	0.078	17.0	11.4	10.5	8.375	2.8 2.6	2.7	2.4 2.4	9.6	10.6	2	30	A2
55	A B	0.073	17.4	14.6	10.5	8.375	2.6 2.6	2.6	1.7 1.8	10.1	11.1	2	30	A2
56	A B	0.073	16.8	14.0	10.5	8.375	2.5 2.4	2.5	1.9 1.9	9.8	10.8	2	30	A2
57	A B	0.073	17.0	10.8	10.5	8.375	2.5 2.5	2.5	2.0 1.9	10.0	11.0	2	30	A6
58	A B	0.073	16.8	14.8	10.5	8.375	2.4 2.5	2.4	2.1 2.0	9.9	10.9	2	30	A7
59	A B	0.078	18.5	20.4	10.5	8.375	3.8 3.4	3.6	1.4 2.4	9.4	10.4	2	30	A6
60	A B	0.078	18.4	15.3	10.5	8.375	3.6 3.4	3.5	1.9 1.9	9.4	10.4	2	30	A2
61	A B	0.073	18.5	17.3	10.5	8.375	3.5 3.5	3.5	1.6 2.4	9.5	10.5	2	30	A2
62	A B	0.073	18.8	17.1	10.5	8.375	3.3 3.4	3.3	1.8 2.0	10.1	11.1	2	30	A2
63	A B	0.078	18.3	10.0	10.5	8.375	3.5 3.8	3.6	2.3 2.3	9.0	10.0	2	30	A2
64	A B	0.078	18.5	12.0	10.5	8.375	3.8 3.8	3.8	3.3 1.3	9.0	10.0	2	30	A2
65	A B	0.078	19.4	10.6	10.5	8.375	3.6 3.8	3.7	2.1 2.6	10.0	11.0	2	30	A2
66	A B	0.078	19.0	11.3	10.5	8.375	3.5 3.8	3.6	2.4 2.1	9.8	10.8	2	30	A2

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} Lb	T lb	T_h[a] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
42	A	83310	83310	166479	83239	75129	105455	105366	82541	-	CB/SS
	B	86063	83169				108940			-	CB/TK
43	A	44627	44627	88971	44485	42617	56489	56311	49289	-	CB
	B	65800	44344				83291			-	SS
44	A	65254	65254	131639	65819	60617	82600	83316	68510	-	SS/B
	B	69872	66385				88446			-	SS
45	A	100169	82023	161763	80881	88700	126796	102381	97907	-	CB/SS/TK
	B	79805	79740				101018			0.153	CB/SS/TK
46	A	73143	65881	131078	65539	62317	92586	82960	71237	-	SS
	B	65197	65197				82527			-	CB/SS
47	A	64532	64532	127534	63767	71202	81686	80718	81681	-	CB/SS
	B	87275	63002				110475			-	SS
48	A	76256	76162	150955	75478	71921	96527	95541	83377	-	SS/CB
	B	80724	74793				102182			-	SS/CB
49	A	47731	47731	95363	47681	46311	60420	60356	54958	-	SS/SS
	B	47658	47631				60327			-	SS
50	A	54674	45317	90486	45243	41955	69208	57269	53601	-	CB/TK
	B	45169	45169				57176			-	CB/SS
51	A	50000	49985	102911	51455	48013	63291	65134	60328	0.195	CB
	B	52926	52926				66995			0.185	CB
52	A	38047	35988	73642	36821	40839	48161	46609	53544	0.387	CB/SS
	B	37660	37654				47671			0.229	CB/SS
53	A	35543	35543	70199	35100	47355	44991	44430	59583	0.104	CB
	B	34656	34656				43868			0	CB
54	A	50809	50677	99845	49923	49806	64315	63193	67912	0.219	CB/SS
	B	54796	49168				69362				SS/CB
55	A	66009	65995	133873	66937	74357	83555	84730	99624	0.295	CB/SS
	B	77378	67878				97947			0.266	CB/SS
56	A	70689	65980	131758	65879	69883	89479	83391	93920	-	SS/CB
	B	65778	65778				83263			0.0119	CB/SS
57	A	43063	43063	87150	43575	53940	54510	55158	79122	-	CB
	B	44087	44087				55807			-	CB
58	A	77232	77232	156239	78120	80729	97762	98885	114756	-	CB/SS
	B	79007	79007				100009			-	CB
59	A	96026	96026	190743	95372	87736	121552	120724	96925	0.181	CB/SS/TK
	B	105140	94717				133089			-	CB/SS
60	A	69449	67892	136199	68099	62317	87910	86202	71237	-	CB/SS
	B	68307	68307				86464			-	SS/CB
61	A	106184	89959	175417	87709	70361	134410	111024	78398	-	SS
	B	85459	85459				108176			-	SS/CB
62	A	71216	70412	141302	70651	75028	90146	89432	87415		SS/CB
	B	79405	70890				100512				SS
63	A	43697	43697	87690	43845	38261	55313	55500	49234	0.144	SS/CB
	B	43993	43993				55687			0.156	SS/CB
64	A	55230	55088	111134	55567	48690	69911	70338	61111	0.195	CB/SS
	B	71880	56046				90987			0.242	SS/CB
65	A	41170	41170	84069	42034	42225	52114	53208	55217	0.133	CB
	B	42930	42899				54341			0.201	CB
66	A	61380	61380	120477	60238	49806	77696	76251	67912		CB
	B	68385	59097				86563			0.434	CB/SS

[a] Calculated based on Eq. (3)

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
42	A B	60	-	-	-	-	2.00	10	3.0	0.50	3.00	-	-	3.16	60
43	A B	60	-	-	-	-	2.00	10	3.0	0.50	3.00	-	-	3.16	60
44	A B	60	-	-	-	-	2.00	10	3.0	0.50	3.00	-	-	3.16	60
45	A B	60	-	-	-	-	1.10	10	3.0	0.38	3.50	0.375	1	3.78	60
46	A B	60	-	-	-	-	1.00	5	3.0	0.50	3.00	0.375	1	3.16	60
47	A B	60	-	-	-	-	1.10	10	3.0	0.38	3.50	0.375	2	3.16	60
48	A B	60	-	-	-	-	1.10	10	3.0	0.38	3.50	0.375	2	3.16	60
49	A B	60	-	-	-	-	-	-	-	0.50	4.00	-	-	4.34	120
50	A B	60	-	-	-	-	1.60	8	4.0	0.50	1.75	-	-	3.16	60
51	A B	60	-	-	-	-	1.60	8	4.0	0.63	3.50	-	-	3.16	60
52	A B	60	-	-	-	-	1.60	8	4.0	0.50	1.50	-	-	3.16	60
53	A B	60	-	-	-	-	-	-	-	0.38	4.00	-	-	3.16	60
54	A B	60	-	-	-	-	0.88	8	4.0	0.50	4.00	0.375	2	3.16	60
55	A B	60	-	-	-	-	-	-	-	0.50	2.25	-	-	3.16	60
56	A B	60	-	-	-	-	-	-	-	0.38	4.00	-	-	3.16	60
57	A B	60	-	-	-	-	-	-	-	0.38	4.00	-	-	3.78	60
58	A B	60	-	-	-	-	-	-	-	0.38	5.00	-	-	4.74	60
59	A B	60	-	-	-	-	1.10	10	3.0	0.38	3.50	0.375	1	3.78	60
60	A B	60	-	-	-	-	1.00	5	3.0	0.50	3.00	0.375	1	3.16	60
61	A B	60	-	-	-	-	1.10	10	3.0	0.38	3.50	0.375	2	3.16	60
62	A B	60	-	-	-	-	1.10	10	3.0	0.38	3.50	0.375	2	3.16	60
63	A B	60	-	-	-	-	1.60	8	4.0	0.50	1.75	-	-	3.16	60
64	A B	60	-	-	-	-	1.60	8	4.0	0.63	3.50	-	-	3.16	60
65	A B	60	-	-	-	-	1.60	8	4.0	0.50	1.50	-	-	3.16	60
66	A B	60	-	-	-	-	0.88	8	4.0	0.50	4.00	0.375	2	3.16	60

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
67	8-8-90-0-i-4-2-8	A B	90°	-	A1035[b]	7.6 8.0	7.8	8740	12	1
68	8-5-180-0-i-2.5-2-11	A B	180°	-	A615	11.0 11.0	11.0	4550	7	1
69	8-5-180-0-i-2.5-2-14	A B	180°	-	A1035[b]	14.0 14.0	14.0	4840	8	1
70	8-8-180-0-i-2.5-2-11.5	A B	180°	-	A1035[b]	9.3 9.3	9.3	8630	11	1
71	8-12-180-0-i-2.5-2-12.5	A B	180°	-	A1035[c]	12.8 12.5	12.6	11850	39	1
72	8-5-180-0-i-3.5-2-11	A B	180°	-	A615	11.6 11.6	11.6	4550	7	1
73	8-5-180-0-i-3.5-2-14	A B	180°	-	A1035[b]	14.4 13.9	14.1	4840	8	1
74	8-15-180-0-i-2.5-2-13.5	A B	180°	-	A1035[c]	13.8 13.5	13.6	16510	88	1
75	8-5-90-2#3-i-2.5-2-16	A B	90°	Para	A1035[b]	15.0 15.8	15.4	4810	6	1
76	8-5-90-2#3-i-2.5-2-9.5	A B	90°	Para	A615	9.0 9.3	9.1	5140	8	1
77	8-5-90-2#3-i-2.5-2-12.5	A B	90°	Para	A615	12.0 12.0	12.0	5240	9	1
78	8-5-90-2#3-i-2.5-2-8.5	A B	90°	Para	A1035[c]	8.9 9.6	9.3	5240	6	1
79	8-5-90-2#3-i-2.5-2-14	A B	90°	Para	A1035[c]	13.5 14.0	13.8	5450	7	1
80	8-5-90-2#3-i-2.5-2-10	A B	90°	Para	A615	10.0 10.3	10.1	5920	13	1
81	(2@3) 8-5-90-2#3-i-2.5-2-10	A B	90°	Para	A615	10.0 10.5	10.3	4760	11	1
82	(2@5) 8-5-90-2#3-i-2.5-2-10	A B	90°	Para	A615	9.6 10.0	9.8	4760	11	1
83	8-8-90-2#3-i-2.5-2-8	A B	90°	Para	A1035[b]	8.0 8.5	8.3	7700	14	1
84	8-8-90-2#3-i-2.5-2-10	A B	90°	Para	A1035[b]	9.9 9.5	9.7	8990	17	1
85	8-12-90-2#3-i-2.5-2-9	A B	90°	Para	A1035[b]	9.0 9.0	9.0	11160	77	1
86	8-12-90-2#3-i-2.5-2-11	A B	90°	Para	A1035[c]	10.5 11.3	10.9	12010	42	1
87	8-15-90-2#3-i-2.5-2-11	A B	90°	Para	A1035[c]	11.3 10.8	11.0	15800	61	1
88	8-5-90-2#3-i-3.5-2-17	A B	90°	Para	A1035[b]	17.5 17.0	17.3	5570	12	1

[a] Heat 1, [b] Heat 2, [c] Heat 3, as described in Table 1

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
67	A B	0.078	19.9	10.5	10.5	8.375	4.5 3.9	4.2	2.9 2.5	9.5	10.5	2	30	A2
68	A B	0.078	17.5	13.0	10.5	8.375	3.0 2.8	2.9	2.0 2.0	9.8	10.8	2	80	A2
69	A B	0.078	17.1	16.0	10.5	8.375	2.8 2.6	2.7	2.0 2.0	9.8	10.8	2	80	A2
70	A B	0.078	17.5	13.8	10.5	8.375	3.0 3.0	3.0	4.5 4.5	9.5	10.5	2	30	A2
71	A B	0.073	17.1	14.9	10.5	8.375	3.0 2.5	2.8	2.1 2.4	9.6	10.6	2	30	A2
72	A B	0.078	19.5	13.0	10.5	8.375	3.8 3.8	3.8	1.4 1.4	10.0	11.0	2	80	A2
73	A B	0.078	19.4	16.0	10.5	8.375	3.9 3.8	3.8	1.6 2.1	9.8	10.8	2	80	A2
74	A B	0.073	17.0	15.8	10.5	8.375	2.5 2.5	2.5	2.0 2.3	10.0	11.0	2	30	A7
75	A B	0.078	17.1	17.9	10.5	8.375	2.8 2.9	2.8	2.9 2.1	9.5	10.5	2	80	A2
76	A B	0.078	17.0	11.6	10.5	8.375	2.5 2.5	2.5	2.6 2.3	10.0	11.0	2	80	A2
77	A B	0.078	17.0	14.6	10.5	8.375	2.8 2.8	2.8	2.6 2.6	9.5	10.5	2	80	A2
78	A B	0.073	17.1	10.7	10.5	8.375	3.0 3.0	3.0	1.8 1.1	9.1	10.1	2	30	A2
79	A B	0.073	17.0	16.1	10.5	8.375	2.8 3.0	2.9	2.6 2.1	9.3	10.3	2	30	A2
80	A B	0.073	17.4	12.0	19.5	8.375	2.5 2.6	2.6	2.0 1.8	10.3	11.3	2	57	A17
81	A B	0.073	9.3	12.0	10.5	8.375	2.5 2.5	2.5	2.0 1.5	2.3	3.3	2	30	A2
82	A B	0.073	10.9	12.0	10.5	8.375	2.5 2.5	2.5	2.4 2.0	3.9	4.9	2	30	A2
83	A B	0.078	16.9	10.0	10.5	8.375	3.0 2.9	2.9	2.0 1.5	9.0	10.0	2	30	A2
84	A B	0.078	16.0	12.0	10.5	8.375	2.8 2.8	2.8	2.1 2.5	8.5	9.5	2	30	A2
85	A B	0.078	17.0	11.3	10.5	8.375	2.9 2.6	2.8	2.3 2.3	9.5	10.5	2	30	A2
86	A B	0.073	17.0	12.9	10.5	8.375	2.8 2.8	2.8	2.4 1.6	9.5	10.5	2	30	A2
87	A B	0.073	17.0	13.1	10.5	8.375	2.5 2.5	2.5	1.9 2.4	10.0	11.0	2	30	A11
88	A B	0.078	18.9	19.3	10.5	8.375	3.3 3.5	3.4	1.8 2.3	10.1	11.1	2	30	A2

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
67	A	37554	37554	74863	37431	39749	47537	47381	52170	-	CB/SS
	B	48708	37309				61656			-	CB
68	A	45587	45587	92286	46143	47517	57705	58409	52999	0.275	SS/CB
	B	50511	46699				63938			-	SS
69	A	49439	49439	98305	49152	62857	62581	62218	69570	0.088	SS
	B	69415	48866				87867			0.096	SS
70	A	62777	62777	142967	71484	47561	79465	90485	61379	-	CB/SS
	B	80190	80190				101506			-	CB/SS
71	A	74782	74782	150417	75208	73178	94661	95201	98166	0.193	CB/SS
	B	92250	75635				116772			0.242	CB
72	A	58575	58145	118584	59292	50452	74145	75053	56011	0.372	CB/SS
	B	60519	60439				76606			0.239	SS
73	A	63745	63689	127009	63504	63466	80690	80385	70191	-	SS
	B	78050	63320				98797			-	CB/SS
74	A	90688	90688	179833	89916	87654	114795	113818	125050	-	-
	B	89145	89145				112841			-	CB/SS
75	A	80014	79629	159258	79629	75277	101284	100796	76166	-	SS/CB
	B	92780	79629				117443			-	CB
76	A	54916	53621	107242	53621	46047	69513	67874	46729	-	CB
	B	53621	53621				67874			-	CB
77	A	74108	67801	144135	72067	60267	93808	91225	62047	-	CB
	B	76334	76334				96625			-	CB/SS
78	A	52863	52862	101122	50561	46878	66915	64001	47828		CB/SS
	B	48439	48260				61315				SS
79	A	76959	76388	153927	76964	69663	97416	97422	72506		SS/CB
	B	77540	77540				98151				CB/SS
80	A	55820	55820	112405	56203	52765	70659	71143	55645		CB/SS
	B	56628	56585				71681			-	CB/SS
81	A	58584	58435	93619	46810	50430	74157	59253	50513		CB
	B	47051	35184				59558			-	CB
82	A	48430	48412	97029	48515	48369	61303	61411	48357	0.23	CB
	B	48617	48617				61541			0.108	CB
83	A	46211	46211	95751	47876	46448	58495	60602	51710	-	CB/SS
	B	55377	49540				70098			-	CB/SS
84	A	60670	60670	122047	61024	56438	76797	77245	65609	0.186	CB
	B	67001	61378				84812			0.152	CB
85	A	61813	61813	122026	61013	55632	78244	77232	67912	0.345	CB/SS
	B	60251	60213				76267			0.361	SS/CB
86	A	68128	68101	137365	68683	68317	86237	86940	85128	0.181	CB
	B	79794	69264				101004			0.165	CB
87	A	99011	83072	166640	83320	74429	125330	105468	98763	-	CB
	B	83603	83567				105827			0.123	CB
88	A	102613	91402	179829	89914	87988	129889	113816	91958	-	SS
	B	88572	88426				112117			-	SS/CB

[a] Calculated based on Eq. (3)

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
67	A B	60	-	-	-	-	1.60	8	4.0	0.50	1.75	-	-	3.16	60
68	A B	60	-	-	-	-	0.44	4	3.5	0.50	3.50	-	-	3.16	60
69	A B	60	-	-	-	-	0.44	4	3.5	0.50	3.50	-	-	3.16	60
70	A B	60	-	-	-	-	0.44	4	3.0	0.50	3.00	-	-	3.16	60
71	A B	60	-	-	-	-	-	-	-	0.50	2.25	-	-	3.16	60
72	A B	60	-	-	-	-	0.44	4	3.5	0.50	3.50	-	-	3.16	60
73	A B	60	-	-	-	-	0.44	4	3.5	0.50	3.50	-	-	3.16	60
74	A B	60	-	-	-	-	-	-	-	0.50	4.00	-	-	4.74	60
75	A B	60	0.375	0.11	2	3.00	2.00	10	3.0	0.50	3.00	-	-	3.16	60
76	A B	60	0.375	0.11	2	3.00	2.00	10	3.0	0.50	3.00	-	-	3.16	60
77	A B	60	0.375	0.11	2	3.00	2.00	10	3.0	0.50	3.00	-	-	3.16	60
78	A B	60	0.375	0.11	2	7.50	2.00	10	2.5	0.50	3.25	0.5	1	3.16	60
79	A B	60	0.375	0.11	2	6.00	0.88	8	3.0	0.50	3.50	0.5	1	3.16	60
80	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	4.00	-	-	4.34	120
81	A B	60	0.375	0.11	2	3.00	-	-	-	0.38	4.00	-	-	3.16	120
82	A B	60	0.375	0.11	2	3.00	-	-	-	0.38	5.00	-	-	3.16	120
83	A B	60	0.375	0.11	2	7.13	1.20	6	4.0	0.50	1.50	-	-	3.16	60
84	A B	60	0.375	0.11	2	7.13	1.20	6	4.0	0.63	3.50	-	-	3.16	60
85	A B	60	0.375	0.11	2	8.00	0.88	8	4.0	0.50	4.00	0.375	2	3.16	60
86	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	2.00	-	-	3.16	60
87	A B	60	0.375	0.11	2	5.50	-	-	-	0.38	4.00	-	-	6.32	60
88	A B	60	0.375	0.11	2	8.00	0.80	4	4.0	0.50	4.00	0.375	1	3.16	60

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
89	8-5-90-2#3-i-3.5-2-13	A B	90°	Para	A1035[b]	13.8 13.5	13.6	5560	11	1
90	8-8-90-2#3-i-3.5-2-8	A B	90°	Para	A1035[b]	8.0 8.1	8.1	8290	16	1
91	8-8-90-2#3-i-3.5-2-10	A B	90°	Para	A1035[b]	8.8 8.8	8.8	8990	17	1
92	8-12-90-2#3-i-3.5-2-9	A B	90°	Para	A1035[b]	9.0 9.0	9.0	11160	77	1
93	8-5-180-2#3-i-2.5-2-11	A B	180°	Para	A615	10.8 10.5	10.6	4550	7	1
94	8-5-180-2#3-i-2.5-2-14	A B	180°	Para	A1035[b]	13.5 14.0	13.8	4870	9	1
95	8-8-180-2#3-i-2.5-2-11.5	A B	180°	Para	A1035[b]	10.5 10.3	10.4	8810	14	1
96	8-12-180-2#3-i-2.5-2-11	A B	180°	Para	A1035[c]	11.1 10.4	10.8	12010	42	1
97	8-5-180-2#3-i-3.5-2-11	A B	180°	Para	A1035[b]	10.1 10.6	10.4	4300	6	1
98	8-5-180-2#3-i-3.5-2-14	A B	180°	Para	A1035[b]	13.5 13.6	13.6	4870	9	1
99	8-15-180-2#3-i-2.5-2-11	A B	180°	Para	A1035[b]	11.1 11.1	11.1	15550	87	1
100	8-5-90-5#3-i-2.5-2-10b	A B	90°	Para	A1035[a]	10.3 10.5	10.4	5440	8	1
101	8-5-90-5#3-i-2.5-2-10c	A B	90°	Para	A1035[a]	10.5 10.5	10.5	5650	9	1
102	8-5-90-5#3-i-2.5-2-15	A B	90°	Para	A1035[b]	15.3 15.8	15.5	4850	7	1
103	8-5-90-5#3-i-2.5-2-13	A B	90°	Para	A1035[b]	13.8 13.5	13.6	5560	11	1
104	8-5-90-5#3-i-2.5-2-12(1)	A B	90°	Para	A1035[c]	11.5 11.1	11.3	5090	7	1
105	8-5-90-5#3-i-2.5-2-12	A B	90°	Para	A1035[c]	11.3 12.3	11.8	5960	7	1
106	8-5-90-5#3-i-2.5-2-12(2)	A B	90°	Para	A1035[c]	12.4 12.0	12.2	5240	6	1
107	8-5-90-5#3-i-2.5-2-8	A B	90°	Para	A1035[c]	7.8 7.4	7.6	5240	6	1
108	8-5-90-5#3-i-2.5-2-10a	B	90°	Para	A1035[a]	10.5	10.5	5270	7	1
109	8-5-90-5#3-i-2.5-2-10	A B	90°	Para	A1035	10.0 9.3	9.6	5920	13	1
110	(2@3) 8-5-90-5#3-i-2.5-2-10	A B	90°	Para	A615	10.0 10.5	10.3	4805	12	1
111	(2@5) 8-5-90-5#3-i-2.5-2-10	A B	90°	Para	A615	9.9 9.5	9.7	4805	12	1
112	8-8-90-5#3-i-2.5-2-8	A B	90°	Para	A1035[b]	7.3 7.3	7.3	8290	16	1
113	8-8-90-5#3-i-2.5-2-9	A B	90°	Para	A615	8.6 9.0	8.8	7710	25	1

[a] Heat 1, [b] Heat 2, [c] Heat 3, as described in Table 1

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
89	A B	0.078	19.0	15.3	10.5	8.375	3.1 3.6	3.4	1.5 1.8	10.3	11.3	2	30	A2
90	A B	0.078	17.9	10.0	10.5	8.375	3.6 3.8	3.7	2.0 1.9	8.5	9.5	2	30	A2
91	A B	0.078	17.9	12.0	10.5	8.375	3.6 3.8	3.7	3.3 3.3	8.5	9.5	2	30	A2
92	A B	0.078	19.3	11.3	10.5	8.375	3.6 4.0	3.8	2.3 2.4	9.6	10.6	2	30	A2
93	A B	0.078	16.8	13.0	10.5	8.375	2.8 2.5	2.6	2.3 2.5	9.5	10.5	2	80	A2
94	A B	0.078	17.3	16.0	10.5	8.375	2.8 2.8	2.8	2.5 2.0	9.8	10.8	2	80	A2
95	A B	0.078	17.5	12.8	10.5	8.375	2.8 2.8	2.8	2.3 2.5	10.0	11.0	2	30	A2
96	A B	0.073	16.8	13.2	10.5	8.375	2.5 2.6	2.6	2.1 2.8	9.6	10.6	2	30	A2
97	A B	0.078	18.6	13.0	10.5	8.375	3.4 3.5	3.4	2.9 2.4	9.8	10.8	2	80	A2
98	A B	0.078	19.1	16.0	10.5	8.375	3.6 3.8	3.7	2.5 2.4	9.8	10.8	2	80	A2
99	A B	0.073	17.3	13.1	10.5	8.375	2.8 2.8	2.8	2.1 2.0	9.8	10.8	2	30	A7
100	A B	0.084	17.3	12.3	10.5	8.375	2.8 2.6	2.7	2.0 1.8	9.9	10.9	2	80	A2
101	A B	0.084	17.0	12.5	10.5	8.375	2.5 2.5	2.5	2.0 2.0	10.0	11.0	2	80	A2
102	A B	0.078	17.1	17.2	10.5	8.375	2.8 2.5	2.6	1.9 1.4	9.9	10.9	2	30	A2
103	A B	0.078	17.1	15.3	10.5	8.375	2.5 2.4	2.4	1.5 1.8	10.3	11.3	2	30	A2
104	A B	0.073	16.8	14.1	10.5	8.375	2.5 2.5	2.5	2.6 3.0	9.8	10.8	2	30	A2
105	A B	0.073	16.6	14.3	10.5	8.375	2.5 2.4	2.4	3.0 2.0	9.8	10.8	2	30	A2
106	A B	0.073	16.1	14.1	10.5	8.375	2.5 2.6	2.6	1.8 2.1	9.0	10.0	2	30	A2
107	A B	0.073	16.6	10.3	10.5	8.375	2.8 2.9	2.8	2.6 2.9	9.0	10.0	2	30	A2
108	B	0.084	16.8	12.3	10.5	8.375	2.5	2.5	1.8	9.8	10.8	2	80	A2
109	A B	0.073	17.5	12.2	19.5	8.375	2.5 2.8	2.6	2.2 2.9	10.3	11.3	2	57	A17
110	A B	0.073	9.2	12.0	10.5	8.375	2.4 2.8	2.6	2.0 1.5	2.0	3.0	2	30	A2
111	A B	0.073	10.9	12.0	10.5	8.375	2.3 2.4	2.3	2.1 2.5	4.3	5.3	2	30	A2
112	A B	0.078	16.1	10.0	10.5	8.375	2.9 2.8	2.8	2.8 2.8	8.5	9.5	2	30	A2
113	A B	0.073	17.8	11.0	10.5	8.375	2.8 3.3	3.0	2.4 2.0	9.8	10.8	2	30	A2

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
89	A B	81199 86858	81199 79522	160720	80360	69408	102783 109946	101722	72568	- -	SS/CB SS/CB
90	A B	48324 49258	48324 49222	97545	48773	46320	61169 62352	61738	52435	0.31 .340(.147)	CB CB
91	A B	53960 53810	53960 53810	107770	53885	51149	68304 68113	68209	59260	- -	SS CB
92	A B	50266 49289	50266 49289	99555	49777	55632	63628 62391	63009	67912	0.15	CB/SS CB/SS
93	A B	64232 61892	58650 61819	120469	60235	51589	81306 78345	76246	51193	0.26 0.087	SS/CB SS/CB
94	A B	87080 76851	75744 76814	152558	76279	67579	110228 97279	96556	68539	0.774 0.199	CB CB/SS
95	A B	70102 59494	56934 59408	116343	58171	60020	88737 75309	73635	69558	0.261 .25(.027)	CB/SS CB/SS
96	A B	73700 66200	63140 66170	129310	64655	67539	93291 83797	81842	84150	- -	CB CB
97	A B	57158 54943	56965 54772	111737	55869	49685	72352 69548	70720	48595	0.167 0.212	SS/CB SS/CB
98	A B	68293 90408	68293 58642	126934	63467	66666	86446 114441	80338	67605	- -	CB/SS CB/SS
99	A B	79626 78291	79553 78291	157845	78922	74738	100792 99103	99902	98813	- -	CB/SS CB
100	A B	78824 66728	75418 64012	139430	69715	64827	99777 84466	88247	68323	0.129 -	CB/SS CB
101	A B	68947 69633	68071 69604	137674	68837	65977	87275 88143	87136	70469	- -	CB/SS CB/SS
102	A B	77125 72603	74150 72603	146753	73377	88206	97627 91903	92882	96574	0.196 -	CB/SS CB/SS
103	A B	93116 81340	83412 81340	164752	82376	81399	117868 102962	104273	90710	- -	SS/CB CB/SS
104	A B	66726 75878	66726 66001	132727	66363	68448	84463 96048	84004	72061	- -	SS/CB SS/CB
105	A B	84900 72000	* 72000	72000	72000	73089	107468 91139	91139	80992		SS SS
106	A B	72359 77425	72321 70619	142939	71470	73181	91593 98006	90468	78770		CB/SS CB/SS
107	A B	48024 47008	47948 47008	94956	47478	50814	60790 59503	60099	48878	 0.321	CB CB
108	B	82800	82800	82800	82800	64998	104800	104800	68100	0.164	CB/SS
109	A B	70403 70390	70322 70390	140712	70356	62248	89118 89102	89058	66122		CB/SS CB/SS
110	A B	61451 58224	57620 58224	115845	57922	62545	77787 73702	73319	63438	0.05 0.37	CB/SS CB/SS
111	A B	59715 52232	59715 52205	111921	55960	59889	75589 66116	70836	59957	0.12 0.29	CB CB
112	A B	56006 51206	49326 51206	100532	50266	53905	70893 64818	63628	58938	0.3 .375 (.092)	CB CB
113	A B	64834 64027	64834 63961	128795	64397	61468	82068 81047	81516	69089	 0	CB CB

[a] Calculated based on Eq. (3)

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
89	A B	60	0.375	0.11	2	8.00	0.44	4	4.0	0.50	3.00	-	-	3.16	60
90	A B	60	0.375	0.11	2	7.13	1.20	6	4.0	0.50	1.50	-	-	3.16	60
91	A B	60	0.375	0.11	2	7.13	1.20	6	4.0	0.63	3.50	-	-	3.16	60
92	A B	60	0.375	0.11	2	8.00	0.88	8	4.0	0.50	4.00	0.375	2	3.16	60
93	A B	60	0.375	0.11	2	3.50	-	-	-	0.50	3.50	-	-	3.16	60
94	A B	60	0.375	0.11	2	3.50	-	-	-	0.50	3.50	-	-	3.16	60
95	A B	60	0.375	0.11	2	3.00	-	-	-	0.50	3.00	-	-	3.16	60
96	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	2.00	-	-	3.16	60
97	A B	60	0.375	0.11	2	3.50	-	-	-	0.50	3.50	-	-	3.16	60
98	A B	60	0.375	0.11	2	3.50	-	-	-	0.50	3.50	-	-	3.16	60
99	A B	60	0.375	0.11	2	5.00	-	-	-	0.50	4.00	-	-	4.74	60
100	A B	60	0.375	0.11	5	3.00	1.10	10	3.0	0.63	5.00	-	-	3.16	60
101	A B	60	0.375	0.11	5	3.00	1.10	10	3.0	0.63	5.00	-	-	3.16	60
102	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.375	2	3.16	60
103	A B	60	0.375	0.11	5	3.00	1.00	5	3.0	0.50	3.00	0.375	1	3.16	60
104	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.5	2	3.16	60
105	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.5	2	3.16	60
106	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.375	1	3.16	60
107	A B	60	0.375	0.11	5	3.00	1.55	5	3.0	0.50	3.00	0.5	1	3.16	60
108	B	60	0.375	0.11	5	3.0	1.10	10	3.0	0.63	3.50	-	-	3.16	60
109	A B	60	0.375	0.11	5	3.00	-	-	-	0.50	4.00	-	-	4.34	120
110	A B	60	0.375	0.11	5	3.00	-	-	-	0.38	4.00	-	-	3.16	120
111	A B	60	0.375	0.11	5	3.00	-	-	-	0.38	4.00	-	-	3.16	120
112	A B	60	0.375	0.11	5	3.00	1.20	6	3.0	0.50	1.50	-	-	3.16	60
113	A B	60	0.375	0.11	5	3.00	-	-	-	0.38	4.00	-	-	3.16	120

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
114	8-12-90-5#3-i-2.5-2-9	A B	90°	Para	A1035[b]	9.0 9.0	9.0	11160	77	1
115	8-12-90-5#3-i-2.5-2-10	A B	90°	Para	A1035[c]	9.0 9.9	9.4	11800	38	1
116	8-12-90-5#3-i-2.5-2-12	A B	90°	Para	A1035[c]	12.2 12.3	12.2	11760	34	1
117	8-12-90-5#3vr-i-2.5-2-10	A B	90°	Perp	A1035[c]	10.3 10.2	10.2	11800	38	1
118	8-12-90-4#3vr-i-2.5-2-10	A B	90°	Perp	A1035[c]	10.6 10.3	10.4	11850	39	1
119	8-15-90-5#3-i-2.5-2-10	A B	90°	Para	A1035[c]	10.6 9.7	10.1	15800	60	1
120	8-5-90-5#3-i-3.5-2-15	A B	90°	Para	A1035[b]	15.8 15.8	15.8	4850	7	1
121	8-5-90-5#3-i-3.5-2-13	A B	90°	Para	A1035[b]	13.3 13.0	13.1	5570	12	1
122	8-5-90-5#3-i-3.5-2-12(1)	A B	90°	Para	A1035[c]	12.8 12.3	12.5	5090	7	1
123	8-5-90-5#3-i-3.5-2-12	A B	90°	Para	A1035[c]	12.5 11.8	12.1	6440	9	1
124	8-8-90-5#3-i-3.5-2-8	A B	90°	Para	A1035[b]	8.0 8.0	8.0	7910	15	1
125	8-12-90-5#3-i-3.5-2-9	A B	90°	Para	A1035[b]	9.0 9.0	9.0	11160	77	1
126	8-12-180-5#3-i-2.5-2-10	A B	180°	Para	A1035[c]	9.9 9.6	9.8	11800	38	1
127	8-12-180-5#3vr-i-2.5-2-10	A B	180°	Perp	A1035[c]	11.1 10.5	10.8	11800	38	1
128	8-12-180-4#3vr-i-2.5-2-10	A B	180°	Perp	A1035[c]	10.5 10.0	10.3	11850	39	1
129	8-15-180-5#3-i-2.5-2-9.5	A B	180°	Para	A1035[c]	9.6 9.8	9.7	15550	87	1

[a] Heat 1, [b] Heat 2, [c] Heat 3, as described in Table 1

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
114	A B	0.078	16.6	11.5	10.5	8.375	2.5 2.6	2.6	2.5 2.5	9.5	10.5	2	30	A2
115	A B	0.073	16.8	12.2	10.5	8.375	2.6 2.3	2.4	3.2 2.3	9.9	10.9	2	30	A2
116	A B	0.073	16.9	14.2	10.5	8.375	2.4 2.5	2.4	2.0 1.9	10.0	11.0	2	30	A2
117	A B	0.073	16.6	11.9	10.5	8.375	2.5 2.4	2.4	1.7 1.7	9.8	10.8	2	30	A2
118	A B	0.073	16.0	12.4	10.5	8.375	2.5 2.5	2.5	1.8 2.1	9.0	10.0	2	30	A2
119	A B	0.073	16.7	12.1	10.5	8.375	2.4 2.4	2.4	1.6 2.4	9.9	10.9	2	30	A11
120	A B	0.078	19.3	17.0	10.5	8.375	3.6 3.5	3.5	1.3 1.3	10.3	11.3	2	30	A2
121	A B	0.078	19.3	15.4	10.5	8.375	3.4 3.5	3.4	2.1 2.4	10.4	11.4	2	30	A2
122	A B	0.073	18.7	14.3	10.5	8.375	3.5 3.4	3.5	1.6 2.1	9.8	10.8	2	30	A2
123	A B	0.073	18.6	14.2	10.5	8.375	3.4 3.5	3.4	1.7 2.4	9.8	10.8	2	30	A2
124	A B	0.078	18.0	10.0	10.5	8.375	3.5 3.6	3.6	2.0 2.0	8.9	9.9	2	30	A2
125	A B	0.078	18.1	11.5	10.5	8.375	3.3 3.4	3.3	2.5 2.5	9.5	10.5	2	30	A2
126	A B	0.073	16.9	12.2	10.5	8.375	2.3 2.8	2.5	2.3 2.6	9.9	10.9	2	30	A2
127	A B	0.073	16.8	12.4	10.5	8.375	2.5 2.5	2.5	1.3 1.9	9.8	10.8	2	30	A2
128	A B	0.073	17.0	12.3	10.5	8.375	2.8 2.5	2.6	1.8 2.3	9.8	10.8	2	30	A2
129	A B	0.073	17.3	11.7	10.5	8.375	2.5 2.8	2.6	2.1 1.9	10.0	11.0	2	30	A10

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
114	A B	66512 63119	66512 62994	129507	64753	67624	84193 79897	81966	84890	0.224 0.252	CB/SS CB/SS
115	A B	66000 64599	64479 64582	129061	64530	71125	83544 81771	81684	91533	0.44 0.547	CB/SS SS/CB
116	A B	90544 86469	88954 86469	175422	87711	88286	114613 109454	111027	118308	- -	CB/SS SS/CB
117	A B	59428 64145	59428 61011	120439	60219	64101	75225 81196	76227	99111	0.236 0.246	CB CB
118	A B	80288 59267	59214 59267	118481	59241	64308	101630 75021	74988	81157	0.123 0.101	CB/SS CB
119	A B	111610 90223	89783 90223	180007	90003	80522	141278 114207	113928	113633	- 0.407	CB/SS CB/SS
120	A B	81187 87144	81187 79494	160681	80341	89282	102768 110309	101697	97934	.214(.026) -	SS/CB SS/CB
121	A B	89620 75971	78290 75847	154137	77069	78905	113443 96166	97555	87460	- -	SS SS/CB
122	A B	78862 75869	78813 74050	152863	76431	74237	99825 96037	96749	79625	- -	SS/CB SS
123	A B	79156 79258	79156 79145	158301	79150	76326	100198 100327	100190	86877	 0.162	CB CB/SS
124	A B	55391 56240	55391 56228	111619	55810	57419	70116 71190	70645	63527	- -	CB CB
125	A B	68822 82227	68822 66841	135663	67831	67624	87116 104084	85863	84890	 0.415	CB/SS CB/SS
126	A B	63041 81419	63041 65173	128214	64107	73041	79798 103062	81148	94564	- 0.339	CB/SS CB
127	A B	67538 68023	67538 68023	135560	67780	67772	85491 86105	85798	104869	- 0.321	CB CB
128	A B	69654 68753	69654 68723	138377	69188	63150	88170 87030	87580	79699	- -	CB CB
129	A B	85951 85951	85951 85951	171901	85951	77101	108798 108798	108798	107512	- -	SS CB/SS

[a] Calculated based on Eq. (3)

Table A.2 Cont. Comprehensive test results and data for specimens containing two No. 8 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
114	A B	60	0.375	0.11	5	3.00	0.88	8	4.0	0.50	4.00	0.375	2	3.16	60
115	A B	60	0.375	0.11	5	3.00	-	-	-	0.50	1.75	-	-	3.16	60
116	A B	60	0.375	0.11	5	3.00	-	-	-	0.38	4.00	-	-	3.16	120
117	A B	60	0.375	0.11	5	1.75	-	-	-	0.50	1.75	-	-	3.16	60
118	A B	60	0.375	0.11	4	2.25	-	-	-	0.50	1.75	-	-	3.16	60
119	A B	60	0.375	0.11	5	3.00	-	-	-	0.38	3.00	-	-	6.32	60
120	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.375	2	3.16	60
121	A B	60	0.375	0.11	5	3.00	1.00	5	3.0	0.50	3.00	0.375	1	3.16	60
122	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.5	2	3.16	60
123	A B	60	0.375	0.11	5	3.00	0.55	5	3.0	0.38	3.50	0.5	2	3.16	60
124	A B	60	0.375	0.11	5	3.00	1.20	6	3.0	0.50	1.50	-	-	3.16	60
125	A B	60	0.375	0.11	5	3.00	0.88	8	4.0	0.50	4.00	0.375	2	3.16	60
126	A B	60	0.375	0.11	5	3.00	-	-	-	0.50	1.75	-	-	3.16	60
127	A B	60	0.375	0.11	5	1.75	-	-	-	0.50	1.75	-	-	3.16	60
128	A B	60	0.375	0.11	4	2.25	-	-	-	0.50	1.75	-	-	3.16	60
129	A B	60	0.375	0.11	5	3.00	-	-	-	0.50	4.00	-	-	6.32	60

Table A.3 Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
130	11-5-90-0-i-2.5-2-14	A B	90°	-	A615	13.5 15.3	14.4	4910	13	1.41
131	11-5-90-0-i-2.5-2-26	A B	90°	-	A1035	26.0 26.0	26.0	5360	6	1.41
132	11-5-90-0-i-2.5-2-16	A B	90°	-	A1035	16.3 15.8	16.0	4890	8	1.41
133	(2@7.5) 11-8-90-0-i-2.5-2-15[a]	A B	90°	-	A1035	14.8 14.8	14.8	7070	30	1.41
134	(2@7.5) 11-8-90-0-i-2.5-2-18[a]	A B	90°	-	A1035	17.3 17.0	17.1	7070	30	1.41
135	11-8-90-0-i-2.5-2-17	A B	90°	-	A1035	17.3 18.0	17.6	9460	9	1.41
136	11-8-90-0-i-2.5-2-21	A B	90°	-	A1035	20.0 21.1	20.6	7870	6	1.41
137	11-8-90-0-i-2.5-2-17	A B	90°	-	A1035	16.3 18.1	17.2	8520	7	1.41
138	(2@7.5) 11-12-90-0-i-2.5-2-17[a]	A B	90°	-	A615	17.3 17.5	17.4	11476	50	1.41
139	11-12-90-0-i-2.5-2-17	A B	90°	-	A1035	16.1 16.9	16.5	11880	35	1.41
140	11-12-90-0-i-2.5-2-17.5	A B	90°	-	A1035	17.6 17.8	17.7	13330	31	1.41
141	11-12-90-0-i-2.5-2-25	A B	90°	-	A1035	24.9 24.4	24.6	13330	34	1.41
142	11-15-90-0-i-2.5-2-24	A B	90°	-	A1035	24.0 24.8	24.4	16180	62	1.41
143	11-15-90-0-i-2.5-2-10	A B	90°	-	A615	9.5 9.5	9.5	14050	76	1.41
144	11-15-90-0-i-2.5-2-15	A B	90°	-	A1035	14.0 14.0	14.0	14050	77	1.41
145	11-5-90-0-i-3.5-2-17	A B	90°	-	A1035	18.1 17.6	17.9	5600	24	1.41
146	11-5-90-0-i-3.5-2-14	A B	90°	-	A615	14.8 15.3	15.0	4910	13	1.41
147	11-5-90-0-i-3.5-2-26	A B	90°	-	A1035	26.3 25.8	26.0	5960	8	1.41
148	11-8-180-0-i-2.5-2-21	A B	180°	-	A1035	21.3 20.9	21.1	7870	6	1.41
149	11-8-180-0-i-2.5-2-17	A B	180°	-	A1035	17.8 18.0	17.9	8520	7	1.41
150	11-12-180-0-i-2.5-2-17	A B	180°	-	A1035	16.6 16.6	16.6	11880	35	1.41
151	11-5-90-2#3-i-2.5-2-17	A B	90°	Para	A1035	17.4 17.8	17.6	5600	24	1.41
152	11-5-90-2#3-i-2.5-2-14	A B	90°	Para	A615	13.5 13.8	13.6	4910	13	1.41

[a] specimen had smaller column width

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
130	A B	0.069	21.6	16.0	19.5	8.375	2.8 2.8	2.8	2.5 0.8	13.3	14.7	2	97	A7
131	A B	0.085	21.5	28.1	19.5	8.375	2.5 2.9	2.7	2.1 2.1	13.3	14.7	2	169	A12
132	A B	0.085	22.1	18.7	19.5	8.375	2.7 2.8	2.7	2.8 2.6	13.8	15.3	2	116	A18
133	A B	0.085	17.2	17.4	19.5	8.375	2.5 2.5	2.5	2.8 2.6	9.3	10.8	2	84	A14
134	A B	0.085	17.6	20.1	19.5	8.375	2.8 2.7	2.7	2.8 3.1	9.3	10.8	2	99	A14
135	A B	0.085	21.2	19.3	19.5	8.375	2.5 2.5	2.5	2.0 1.3	13.4	14.8	2	114	A16
136	A B	0.085	21.1	23.4	19.5	8.375	2.5 2.8	2.6	3.4 2.3	13.0	14.4	2	138	A13
137	A B	0.085	21.3	19.3	19.5	8.375	2.5 2.5	2.5	3.0 1.1	13.5	14.9	2	115	A8
138	A B	0.085	17.8	19.4	19.5	8.375	2.6 2.8	2.7	2.0 2.0	9.6	11.0	2	96	A14
139	A B	0.085	21.2	19.3	19.5	8.375	2.5 2.6	2.6	3.1 2.4	13.3	14.7	2	114	A13
140	A B	0.085	22.8	19.8	19.5	8.375	3.8 2.5	3.1	2.1 2.0	13.8	15.2	2	126	A7
141	A B	0.085	20.9	27.3	19.5	8.375	2.5 2.5	2.5	2.4 2.9	13.1	14.5	2	160	A12
142	A B	0.085	21.3	26.0	19.5	8.375	2.5 2.5	2.5	2.0 1.3	13.5	14.9	2	155	A11
143	A B	0.085	21.9	12.0	19.5	8.375	2.8 2.7	2.7	2.5 2.5	13.6	15.0	2	74	A15
144	A B	0.085	21.4	17.0	19.5	8.375	2.8 2.8	2.8	3.0 3.0	13.0	14.4	2	102	A15
145	A B	0.085	23.8	20.0	19.5	8.375	4.0 3.9	3.9	1.8 2.5	13.1	14.5	2	133	A7
146	A B	0.069	23.7	16.3	19.5	8.375	3.8 3.9	3.8	1.5 1.0	13.3	14.7	2	108	A7
147	A B	0.085	23.8	28.4	19.5	8.375	3.8 3.8	3.8	2.1 2.6	13.5	14.9	2	189	A12
148	A B	0.085	21.1	23.1	19.5	8.375	2.9 2.4	2.7	1.8 2.2	13.0	14.4	2	137	A13
149	A B	0.085	21.4	19.1	19.5	8.375	2.4 2.5	2.4	1.4 1.1	13.8	15.2	2	115	A8
150	A B	0.085	21.6	19.2	19.5	8.375	3.0 2.5	2.8	2.5 2.5	13.3	14.7	2	116	A13
151	A B	0.085	21.3	19.6	19.5	8.375	2.5 2.6	2.6	2.3 1.8	13.4	14.8	2	117	A7
152	A B	0.069	21.7	16.0	19.5	8.375	2.8 2.9	2.8	2.5 2.3	13.3	14.7	2	97	A7

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
130	A B	67248.9 81430.3	67249 65931	133180	66590	76344	43108 52199	42686	51027	0.139 -	CB/SS SS
131	A B	165682 146801	150653 146801	297454	148727	148978	106206 94103	95338	96429	- -	CB/SS CB/SS/TK
132	A B	85060 98253	80730 98062	178792	89396	85644	54526 62983	57305	56680	 -	SS SS
133	A B	76673 74284	76635 73991	150627	75313	87421	49150 47618	48278	62828	 -	CB/SS CB/SS
134	A B	99745 95484	99278 95479	194757	97379	102785	63939 61208	62422	72945	 -	CB/SS CB/SS
135	A B	131998 141233	131969 132141	264111	132055	115557	84614 90534	84651	86842	- -	CB/TK CB/TK
136	A B	127061 147904	127061 123191	250252	125126	129367	81449 94810	80209	92409	- -	CB/TK CB
137	A B	105626 115172	105537 104020	209557	104779	109031	67709 73828	67166	80368	- -	SS CB
138	A B	105142 109014	105142 108295	213436	106718	120453	67398 69881	68409	94292	 -	SS SS
139	A B	148361 120380	148361 120380	268741	134371	115057	95103 77167	86135	91106	- -	SS SS/CB
140	A B	125648 123622	125648 123597	249245	124622	128351	80544 79245	79886	103451	- 0.25	SS/TK SS
141	A B	205050 198110	201395 198091	399486	199743	183761	131443 126994	128040	144027	- -	SS SS
142	A B	212601 231323	212601 213928	426530	213265	192429	136283 148284	136708	157068	- -	SS/TK SS/TK
143	A B	52097 50882	52097 50866	102962	51481	66433	33395 32617	33001	57045	- -	CB CB
144	A B	93327 91008	93327 91008	184335	92168	101163	59825 58339	59082	84066	- -	SS SS
145	A B	105772 117570	105772 110472	216244	108122	100521	67803 75366	69309	67763	0.187 -	SS/TK SS
146	A B	82600.5 68981.7	70046 68982	139027	69514	79950	52949 44219	44560	53246	- -	CB/SS CB/SS/TK
147	A B	198346 181661	183026 181481	364508	182254	153715	127145 116449	116829	101683	- -	SS/CB CB/SS
148	A B	137773 126839	129406 126839	256246	128123	132782	88316 81307	82130	94656	- -	CB CB/SS
149	A B	101710 121269	101710 99197	200907	100453	113768	65199 77737	64393	83583	- -	CB CB
150	A B	106726 108195	106726 108195	214921	107461	116002	68414 69356	68885	91796	0.156 -	SS/CB SS
151	A B	108406 103234	98172 103218	201390	100695	106103	69491 66176	64548	66578	- -	SS/CB SS/CB
152	A B	77717.7 77213.7	77718 77127	154845	77422	79521	49819 49496	49630	48365	0.206 -	CB/SS SS

[a] Calculated based on Eq. (3)

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
130	A B	60	-	-	-	-	2.4	12	4.0	0.50	4.0	0.375	2	4.74	60
131	A B	60	-	-	-	-	1.86	6	4.0	0.50	4.0	0.375	1	6.32	60
132	A B	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
133	A B	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
134	A B	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
135	A B	60	-	-	-	-	-	-	-	0.50	6.0	-	-	9.48	60
136	A B	60	-	-	-	-	-	-	-	0.50	6.0	-	-	9.40	60
137	A B	60	-	-	-	-	-	-	-	0.50	8.0	-	-	6.28	60
138	A B	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
139	A B	60	-	-	-	-	-	-	-	0.50	6.0	-	-	9.40	60
140	A B	60	-	-	-	-	2.4	12	4.0	0.50	4.0	-	-	4.74	60
141	A B	60	-	-	-	-	3.6	18	4.0	0.50	4.0	0.5	1	6.32	60
142	A B	60	-	-	-	-	-	-	-	0.50	3.5	-	-	6.32	60
143	A B	60	-	-	-	-	-	-	-	0.50	4.5	-	-	6.94	120
144	A B	60	-	-	-	-	-	-	-	0.50	4.5	-	-	6.94	120
145	A B	60	-	-	-	-	2.4	12	4.0	0.50	4.0	0.375	2	4.74	60
146	A B	60	-	-	-	-	2.4	12	4.0	0.50	4.0	0.375	2	4.74	60
147	A B	60	-	-	-	-	1.86	6	4.0	0.50	4.0	0.375	1	6.32	60
148	A B	60	-	-	-	-	-	-	-	0.50	6.0	-	-	9.40	60
149	A B	60	-	-	-	-	-	-	-	0.50	8.0	-	-	6.28	60
150	A B	60	-	-	-	-	-	-	-	0.50	6.0	-	-	9.40	60
151	A B	60	0.375	0.11	2	8.00	2	10	4.0	0.50	4.0	0.375	2	4.74	60
152	A B	60	0.375	0.11	2	8.00	2.4	12	4.0	0.50	4.0	0.375	2	4.74	60

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
153	(2@7.5) 11-8-90-2#3-i-2.5-2-17[a]	A B	90°	Para	A1035	16.3 16.5	16.4	7070	31	1.41
154	(2@7.5) 11-12-90-2#3-i-2.5-2-16[a]	A B	90°	Para	A615	15.4 15.3	15.3	11850	51	1.41
155	11-12-90-2#3-i-2.5-2-17.5	A B	90°	Para	A1035	18.0 17.5	17.8	13710	30	1.41
156	11-15-90-2#3-i-2.5-2-23	A B	90°	Para	A1035	23.5 23.5	23.5	16180	62	1.41
157	11-15-90-2#3-i-2.5-2-10	A B	90°	Para	A615	10.0 10.0	10.0	14045	76	1.41
158	11-15-90-2#3-i-2.5-2-15	A B	90°	Para	A1035	14.0 14.3	14.1	14045	80	1.41
159	11-5-90-2#3-i-3.5-2-17	A B	90°	Para	A1035	17.5 17.8	17.6	7070	28	1.41
160	11-5-90-2#3-i-3.5-2-14	A B	90°	Para	A615	14.5 13.4	13.9	4910	12	1.41
161	11-5-90-6#3-i-2.5-2-20	A B	90°	Para	A1035	19.5 19.0	19.3	5420	7	1.41
162	11-5-90-6#3-i-2.5-2-16	A B	90°	Para	A1035	15.5 15.3	15.4	5030	9	1.41
163	(2@7.5) 11-8-90-6#3-i-2.5-2-15[a]	A B	90°	Para	A1035	13.8 14.3	14.0	7070	31	1.41
164	11-8-90-6#3-i-2.5-2-16	A B	90°	Para	A1035	15.5 16.4	15.9	9120	7	1.41
165	11-8-90-6#3-i-2.5-2-22	A B	90°	Para	A1035	21.3 21.5	21.4	9420	8	1.41
166	11-8-90-6#3-i-2.5-2-22	A B	90°	Para	A1035	21.9 22.0	21.9	9420	8	1.41
167	11-8-90-6#3-i-2.5-2-15	A B	90°	Para	A1035	15.8 15.3	15.5	7500	5	1.41
168	11-8-90-6#3-i-2.5-2-19	A B	90°	Para	A1035	19.1 19.4	19.2	7500	5	1.41
169	(2@7.5) 11-12-90-6#3-i-2.5-2-14[a]	A B	90°	Para	A1035	13.5 13.6	13.6	11960	52	1.41
170	11-12-90-6#3-i-2.5-2-17	A B	90°	Para	A1035	17.1 16.5	16.8	12370	37	1.41
171	11-12-90-6#3-i-2.5-2-16	A B	90°	Para	A1035	14.8 16.0	15.4	13710	31	1.41
172	11-12-90-6#3-i-2.5-2-22	A B	90°	Para	A1035	21.9 21.5	21.7	13710	31	1.41
173	11-15-90-6#3-i-2.5-2-22	A B	90°	Para	A1035	22.3 22.4	22.3	16180	62	1.41
174	11-15-90-6#3-i-2.5-2-10a	A B	90°	Para	A615	9.5 10.0	9.8	14045	76	1.41
175	11-15-90-6#3-i-2.5-2-10b	A B	90°	Para	A615	9.5 9.8	9.6	14050	77	1.41
176	11-15-90-6#3-i-2.5-2-15	A B	90°	Para	A1035	14.5 15.0	14.8	14045	80	1.41

[a] specimen had smaller column width

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	R_r	B in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
153	A B	0.085	17.5	19.1	19.5	8.375	2.5 2.8	2.7	3.0 2.5	9.3	10.8	2	94	A14
154	A B	0.085	17.9	18.1	19.5	8.375	2.9 3.0	3.0	2.6 2.9	9.1	10.5	2	90	A14
155	A B	0.085	21.1	19.5	19.5	8.375	2.5 2.5	2.5	1.5 2.0	13.3	14.7	2	115	A7
156	A B	0.085	21.3	25.0	19.5	8.375	2.8 2.8	2.8	1.5 1.5	13.0	14.4	2	149	A11
157	A B	0.085	22.0	12.0	19.5	8.375	2.8 3.0	2.9	2.0 2.0	13.4	14.8	2	74	A15
158	A B	0.085	21.5	17.0	19.5	8.375	2.6 2.6	2.6	3.0 2.8	13.6	15.0	2	102	A15
159	A B	0.085	23.4	19.7	19.5	8.375	3.6 3.6	3.6	2.1 2.0	13.4	14.8	2	129	A7
160	A B	0.069	23.7	16.1	19.5	8.375	3.8 3.9	3.8	1.6 2.8	13.3	14.7	2	107	A7
161	A B	0.085	20.9	22.3	19.5	8.375	2.6 2.6	2.6	2.8 3.3	12.9	14.3	2	130	A7
162	A B	0.085	21.9	18.4	19.5	8.375	2.7 2.8	2.7	3.0 3.0	13.6	15.0	2	113	A18
163	A B	0.085	18.3	17.5	19.5	8.375	3.2 3.0	3.1	3.8 3.3	9.3	10.8	2	90	A14
164	A B	0.085	21.2	18.3	19.5	8.375	2.5 2.5	2.5	2.8 1.9	13.4	14.8	2	108	A16
165	A B	0.085	21.4	24.1	19.5	8.375	2.5 2.6	2.6	2.8 2.6	13.5	14.9	2	145	A11
166	A B	0.085	21.7	24.2	19.5	8.375	2.6 2.9	2.8	2.3 2.2	13.4	14.8	2	147	A16
167	A B	0.085	21.6	17.3	19.5	8.375	2.8 2.5	2.6	1.5 2.0	13.5	14.9	2	104	A13
168	A B	0.085	21.4	21.0	19.5	8.375	2.5 2.6	2.6	2.0 1.7	13.5	14.9	2	126	A13
169	A B	0.085	17.4	16.4	19.5	8.375	2.7 2.8	2.7	2.6 3.0	9.1	10.5	2	80	A14
170	A B	0.085	21.4	19.1	19.5	8.375	2.6 3.0	2.8	1.9 2.6	13.0	14.4	2	114	A13
171	A B	0.085	20.8	18.0	19.5	8.375	2.5 2.5	2.5	3.3 2.0	13.0	14.4	2	105	A7
172	A B	0.085	22.1	24.3	19.5	8.375	2.9 3.1	3.0	2.4 2.8	13.3	14.7	2	150	A12
173	A B	0.085	21.8	24.0	19.5	8.375	3.0 2.5	2.8	1.8 1.6	13.5	14.9	2	147	A10
174	A B	0.085	21.5	12.0	19.5	8.375	2.6 2.8	2.7	2.5 2.0	13.4	14.8	2	72	A15
175	A B	0.085	21.4	12.0	19.5	8.375	2.8 2.8	2.8	2.5 2.3	13.0	14.4	2	72	A10
176	A B	0.085	21.5	17.0	19.5	8.375	2.6 2.6	2.6	2.5 2.0	13.6	15.0	2	102	A15

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
153	A	105741	104665	212061	106031	105400	67783	67968	69750	-	CB/SS
	B	107791	107397				69097			-	CB/SS
154	A	107954	107954	217436	108718	113531	69201	69691	84456	-	SS/CB
	B	109513	109482				70201			-	SS/CB
155	A	133178	132555	260779	130389	137403	85371	83583	105286	-	SS
	B	129868	128223				83249			-	SS
156	A	232100	212550	419150	209575	192436	148782	134343	151429	-	SS
	B	206900	206600				132628			-	SS/CB
157	A	64250	64250	127881	63940	77713	41186	40987	60036	-	CB
	B	63631	63631				40789				CB
158	A	115577	115577	230377	115189	109619	74088	73839	84801	-	CB/SS
	B	114801	114801				73590			-	CB/SS
159	A	107807	107807	219287	109644	113531	69107	70284	75074	-	SS/CB/TK
	B	111480	111480				71462			-	SS
160	A	92718.8	82732	164549	82275	81314	59435	52740	49474	-	CB/SS
	B	81848.2	81817				52467			-	SS/CB/TK
161	A	153119	137617	272543	136272	130785	98153	87354	89741	0.274	CB/SS
	B	134977	134927				86524			-	CB/SS
162	A	120540	120540	231247	115623	105604	77269	74118	69050	-	SS
	B	110898	110707				71089			-	SS
163	A	107629	107442	212380	106190	105507	68993	68070	74542	-	CB/SS
	B	104987	104938				67300			-	CB/SS
164	A	147508	136385	265971	132986	125392	94556	85247	96379	-	CB/SS
	B	129692	129586				83136			-	CB/SS
165	A	204260	186246	369138	184569	165165	130936	118314	131369	-	*
	B	183175	182892				117420			-	SS
166	A	197739	190740	382084	191042	169230	126756	122463	134827	-	*
	B	191344	191344				122656			-	SS/CB
167	A	142278	108602	216623	108312	116769	91204	69431	85001	-	SS
	B	108021	108021				69245			-	SS/CB
168	A	182735	144766	290860	145430	141425	117138	93224	105395	-	CB/SS
	B	146093	146093				93650			-	CB/SS
169	A	100805	100724	204076	102038	116119	64618	65409	93940	-	SS/CB
	B	103464	103353				66323			-	SS/CB
170	A	179693	161019	323295	161648	141727	115188	103620	118408	0.334	CB/SS
	B	162285	162277				104029			-	SP/SS
171	A	115139	115089	230394	115197	134072	73807	73844	113998	-	SS/CB
	B	127542	115306				81758			0.952	SS/CB
172	A	206283	203983	402379	201189	184342	132233	128967	160802	-	SS/CB
	B	199234	198395				127714			-	CB
173	A	204557	200084	395618	197809	197732	131126	126801	179722	-	CB/SS
	B	195710	195534				125455			-	SS/CB
174	A	83558	83558	165362	82681	91221	53563	53001	73169	-	CB
	B	81804	81804				52438			-	CB
175	A	76605	76605	151158	75579	90279	49106	48448	72244		CB
	B	74596	74553				47818			-	CB
176	A	145670	145664	290534	145267	129939	93378	93120	110692	-	CB
	B	144870	144870				92866			-	CB

[a] Calculated based on Eq. (3)

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
153	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	2.5	-	-	7.90	60
154	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	2.5	-	-	7.90	60
155	A B	60	0.375	0.11	2	12.00	2.4	12	4.0	0.50	4.0	-	-	4.74	60
156	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	3.0	-	-	6.32	60
157	A B	60	0.38	0.11	2	8.00	-	-	-	0.50	4.5	-	-	6.94	120
158	A B	60	0.375	0.11	2	8.00	-	-	-	0.50	4.5	-	-	6.94	120
159	A B	60	0.375	0.11	2	8.00	2	10	4.0	0.50	4.0	0.375	2	4.74	60
160	A B	60	0.375	0.11	2	8.00	2.4	12	4.0	0.50	4.0	0.375	2	4.74	60
161	A B	60	0.375	0.11	6	4.00	1.2	6	4.0	0.50	4.0	0.375	2	4.74	60
162	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	2.5	-	-	7.90	60
163	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	2.5	-	-	7.90	60
164	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.48	60
165	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	2.5	-	-	6.32	60
166	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.48	60
167	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.40	60
168	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.40	60
169	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	2.5	-	-	7.90	60
170	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.40	60
171	A B	60	0.375	0.11	6	4.00	2.4	12	4.0	0.50	4.0	0.375	1	4.74	60
172	A B	60	0.375	0.11	6	4.00	3.06	12	4.0	0.50	4.0	0.375	2	6.32	60
173	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	3.0	-	-	6.32	60
174	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	4.5	-	-	6.94	120
175	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	4.5	-	-	6.32	120
176	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	4.5	-	-	6.94	120

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
177	11-5-90-6#3-i-3.5-2-20	A B	90°	Para	A1035	20.5 20.3	20.4	5420	7	1.41
178	11-8-180-6#3-i-2.5-2-15	A B	180°	Para	A1035	15.1 15.5	15.3	7500	5	1.41
179	11-8-180-6#3-i-2.5-2-19	A B	180°	Para	A1035	19.6 19.9	19.8	7870	6	1.41
180	(2@7.5) 11-12-180-6#3-i-2.5-2-14[a]	A B	180°	Para	A1035	14.4 14.4	14.4	12190	56	1.41
181	11-12-180-6#3-i-2.5-2-17	A B	180°	Para	A1035	16.9 16.5	16.7	12370	37	1.41
182	11-12-180-6#3-i-2.5-2-17	A B	180°	Para	A1035	16.8 16.8	16.8	12370	37	1.41

[a] specimen had smaller column width

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	R_r	B in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout[o]
177	A B	0.085	23.6	22.3	19.5	8.375	3.8 3.9	3.8	1.8 2.0	13.1	14.5	2	147	A7
178	A B	0.085	21.8	17.1	19.5	8.375	2.9 3.1	3.0	2.0 1.6	13.0	14.4	2	104	A13
179	A B	0.085	21.8	21.2	19.5	8.375	2.9 2.9	2.9	1.5 1.3	13.3	14.7	2	129	A13
180	A B	0.085	17.6	16.6	19.5	8.375	2.5 3.2	2.9	2.0 2.4	9.1	10.5	2	82	A14
181	A B	0.085	21.7	19.8	19.5	8.375	2.6 2.8	2.7	2.9 3.3	13.5	14.9	2	120	A7
182	A B	0.085	21.4	19.4	19.5	8.375	2.5 2.8	2.6	2.7 2.6	13.4	14.8	2	117	A13

[o] Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	$f_{su,\text{max}}$ psi	f_{su} psi	$f_{s,\text{ACI}}$ psi	Slip at Failure in.	Failure Type
177	A B	150216 135259	136607 135036	271643	135821	137640	96293 86704	87065	94986	- -	SS/CB SS
178	A B	112423 110981	112423 110933	223356	111678	115538	72066 71142	71588	83973	- -	SS SS
179	A B	170000 149000	149000 149000	298000	149000	146730	108974 95513	95513	110947	- -	CB/SS CB/SS
180	A B	90862 97049	90862 97049	187911	93955	122768	58245 62211	60228	100536	- -	SS/CB SS/CB
181	A B	123150 117638	115105 117638	232743	116371	140769	78942 75409	74597	117527	- 0.379	CB CB/SS
182	A B	148872 173034	148872 148484	297356	148678	141488	95431 110919	95306	118188	- -	CB/SS SS/CB

[a] Calculated based on Eq. (3)

Table A.3 Cont. Comprehensive test results and data for specimens containing two No. 11 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
177	A B	60	0.375	0.11	6	4.00	1.2	6	4.0	0.50	4.0	0.375	2	4.74	60
178	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.40	60
179	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.40	60
180	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	2.5	-	-	7.90	60
181	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	3.0	-	-	4.74	60
182	A B	60	0.375	0.11	6	4.00	-	-	-	0.50	6.0	-	-	9.40	60

Table A.4 Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
183	(3) 5-5-90-0-i-2.5-2-8	A B C	90°	-	A1035	8.0 8.0 7.8	7.9	4830	9	0.625
184	(4@4) 5-5-90-0-i-2.5-2-6	A B C D	90°	-	A1035	5.4 5.3 4.8 5.3	5.2	6430	11	0.625
185	(4@4) 5-5-90-0-i-2.5-2-10	A B C D	90°	-	A1035	9.0 8.0 9.3 9.9	9.0	6470	12	0.625
186	(4@4) 5-8-90-0-i-2.5-2-6	A B C D	90°	-	A1035	6.3 5.8 5.8 6.0	5.9	6950	18	0.625
187	(4@6) 5-8-90-0-i-2.5-2-6	A B C D	90°	-	A1035	6.0 6.0 5.8 6.0	5.9	6693	21	0.625
188	(3@4) 5-8-90-0-i-2.5-2-6	A B C	90°	-	A1035	6.0 5.6 6.0	5.9	6950	18	0.625
189	(3@6) 5-8-90-0-i-2.5-2-6	A B C	90°	-	A1035	6.4 5.9 5.8	6.0	6950	18	0.625
190	(3@10) 5-5-90-2#3-i-2.5-2-7	A B C	90°	Para	A1035	6.9 7.0 7.0	7.0	5950	12	0.625
191	(4@4) 5-5-90-2#3-i-2.5-2-6	A B C D	90°	Para	A1035	6.3 6.1 6.3 6.4	6.3	6430	11	0.625
192	(4@4) 5-5-90-2#3-i-2.5-2-8	A B C D	90°	Para	A1035	8.4 7.8 8.0 7.8	8.0	6430	11	0.625
193	(3@6) 5-8-90-5#3-i-2.5-2-6.25	A B C	90°	Para	A1035	5.0 6.3 5.3	5.5	10110	196	0.625
194	(3@4) 5-8-90-5#3-i-2.5-2-6	A B C	90°	Para	A1035	6.0 6.3 6.0	6.1	6703	22	0.625
195	(3@6) 5-8-90-5#3-i-2.5-2-6	A B C	90°	Para	A1035	6.0 6.0 6.0	6.0	6703	22	0.625
196	(3) 5-5-90-5#3-i-2.5-2-8	A B C	90°	Para	A1035	7.8 7.8 7.8	7.8	4660	7	0.625

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	R_r	B in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load Kips	Long. Reinf. Layout°
183	A B C	0.073	13.065	10.1	5.3	8.375	2.5 6.3 2.6	2.5	2.1 2.1 2.4	3.1 3.0 -	3.8 3.6 -	3	30	A2
184	A B C D	0.073	13.2	8.2	5.3	8.375	2.4 4.9 5.1 2.8	2.6	2.8 2.9 3.4 2.9	1.9 1.9 1.8 -	2.5 2.6 2.4 -	4	30	A1
185	A B C D	0.073	13.2	12.3	5.3	8.375	2.6 5.0 5.0 2.8	2.7	3.3 4.3 3.0 2.4	1.8 1.9 1.6 -	2.4 2.6 2.3 -	4	30	A1
186	A B C D	0.073	12.9	8.0	5.3	8.375	2.5 5.0 5.0 2.5	2.5	1.8 2.3 2.3 2.0	1.9 1.6 1.9 -	2.5 2.3 2.6 -	4	30	A2
187	A B C D	0.073	17.3	8.0	5.3	8.375	2.7 6.5 6.5 2.7	2.7	2.0 2.0 2.3 2.0	3.1 3.1 3.1 -	3.8 3.8 3.8 -	4	30	A2
188	A B C	0.073	10.75	8.0	5.3	8.375	2.6 5.6 2.7	2.6	2.0 2.4 2.0	1.8 1.9 -	2.4 2.5 -	3	30	A2
189	A B C	0.073	13.25	8.0	5.3	8.375	2.6 6.2 2.7	2.6	1.6 2.1 2.3	3.0 3.1 -	3.6 3.8 -	3	30	A2
190	A B C	0.073	18.515	9.1	5.3	8.375	2.5 8.8 2.7	2.6	2.3 2.1 2.1	5.8 5.8 -	6.4 6.4 -	3	30	A2
191	A B C D	0.073	12.9	8.1	5.3	8.375	2.5 5.0 4.8 2.5	2.5	1.9 2.0 1.9 1.8	1.9 1.9 1.6 -	2.5 2.5 2.3 -	4	30	A1
192	A B C D	0.073	13.0	10.1	5.3	8.375	2.5 5.0 4.9 2.5	2.5	1.8 2.4 2.1 2.4	1.9 1.9 1.8 -	2.5 2.5 2.4 -	4	30	A1
193	A B C	0.073	12.75	8.8	5.3	8.375	2.5 5.4 2.5	2.5	3.8 2.6 3.6	2.9 3.0 -	3.5 3.6 -	3	30	A1
194	A B C	0.073	10.85	8.0	5.3	8.375	2.5 5.0 2.5	2.5	2.0 1.8 2.0	2.1 1.9 -	2.7 2.5 -	3	30	A2
195	A B C	0.073	13.375	8.0	5.3	8.375	2.5 5.0 2.5	2.5	2.0 2.0 2.0	3.4 3.1 -	4.0 3.8 -	3	30	A2
196	A B C	0.073	12.815	10.2	5.3	8.375	2.5 6.0 2.6	2.5	2.5 2.5 2.3	2.9 3.0 -	3.5 3.6 -	3	30	A2

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	T_h[b] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
183	A	24392	23610	83608	27869	27142	26229	78685	89901	62879	-	CB
	B	33639	32864					108513			-	CB
	C	28681	27134					92521			-	CB
184	A	12150	12150	58167	14542	18612	14478	39194	46909	47396	-	CB
	B	16822	16822					54265			-	CB
	C	15517	15510					50055			-	CB
	D	13684	13684					44142			-	CB
185	A	27937	27938	113608	28402	34130	26107	90119	91619	83022	-	CB
	B	28572	28455					92168			0.358	CB
	C	44806	31762					144535			-	CB
	D	27649	25453					89190			-	CB
186	A	17307	17307	61916	15479	22119	17060	55829	49932	56570	-	CB/SS
	B	17615	17430					56823			-	CB
	C	14066	13684					45374			-	CB
	D	14082	13495					45426			-	CB/SS
187	A	20647	17356	77211	19303	21875	21349	66603	62267	55514	-	CB
	B	22459	22123					72448			-	CB
	C	22914	22649					73916			-	CB
	D	15140	15082					48839			-	CB
188	A	18497	18326	50416	16805	21867	16868	59668	54211	55975	-	CB
	B	17550	17370					56613			-	CB
	C	14720	14720					47484			-	CB
189	A	25526	25526	74657	24886	22372	21619	82342	80277	57166	-	CB
	B	34858	25964					112445			-	CB
	C	23167	23167					74732			-	CB
190	A	29818	29751	93888	31296	27838	27838	96185	100954	61356	-	CB/SS
	B	46276	34654					149278			-	CB
	C	30092	29482					97070			-	CB/SS
191	A	22446	21831	85621	21405	24896	19682	72406	69049	57277	-	CB
	B	22211	18818					71648			0.23	CB
	C	24049	23273					77577			-	CB
	D	21725	21699					70081			0.484	CB
192	A	23977	23111	104069	26017	31785	25311	77345	83926	73028	-	CB
	B	31206	28774					100665			0.365	CB
	C	35987	28714					116087			-	CB
	D	23712	23469					76490			0.398	CB
193	A	27125	27035	77489	25830	31106	29606	87498	83321	79002	-	CB
	B	32375	24934					104436			-	CB
	C	27035	25519					87210			-	CB
194	A	35751	35751	104667	34889	30837	26927	115326	112545	71151	-	CB
	B	34693	34518					111913			-	CB
	C	34397	34397					110958			-	CB
195	A	37827	37754	109345	36448	30503	29816	122023	117576	70176	-	CB
	B	34172	34152					110232			-	CB
	C	37469	37439					120868			-	CB
196	A	34695	34636	99781	33260	34613	32944	111918	107291	75578	-	CB/SS
	B	34774	34483					112174			-	CB
	C	39269	30662					126675			-	CB

[a] Calculated based on Eq. (3)

[b] Calculated based on Eq. (5) for specimens without confining reinforcement and Eq. (7) for specimens with confining reinforcement, with linear interpolation between the two equations for specimens with confining reinforcement between no confinement and No. 3 (No. 10) spaced at $3d_b$.

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
183	A B C	60	-	-	-	-	-	-	-	0.500	3.0	-	-	3.16	60
184	A B C D	60	-	-	-	-	1.10	10	2.0	0.375	2.5	0.375	1	1.27	60
185	A B C D	60	-	-	-	-	1.10	10	2.0	0.375	3.0	0.500	1	1.27	60
186	A B C D	60	-	-	-	-	-	-	-	0.375	3.0	-	-	3.16	60
187	A B C D	60	-	-	-	-	-	-	-	0.375	3.0	-	-	3.16	60
188	A B C	60	-	-	-	-	-	-	-	0.375	3.0	-	-	3.16	60
189	A B C	60	-	-	-	-	-	-	-	0.375	3.0	-	-	3.16	60
190	A B C	60	0.38	0.11	2	3	-	-	-	0.375	3.0	-	-	3.16	60
191	A B C D	60	0.375	0.11	2	4.0	0.66	6	4.0	0.375	3.0	0.375	2	1.27	60
192	A B C D	60	0.375	0.11	2	5.0	1.20	6	2.5	0.375	3.0	0.500	2	1.27	60
193	A B C	60	0.375	0.11	5	1.7	-	-	-	0.50	3.0	0.375	1	1.27	60
194	A B C	60	0.375	0.11	5	1.7	-	-	-	0.38	3.0	-	-	3.16	120
195	A B C	60	0.375	0.11	5	1.7	-	-	-	0.38	3.0	-	-	3.16	120
196	A B C	60	0.375	0.11	5	1.88	-	-	-	0.50	3.0	-	-	3.16	60

Table A.4 Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
197	(4@4) 5-5-90-5#3-i-2.5-2-7	A B C D	90°	Para	A1035	6.6 7.9 7.5 6.5	7.1	6430	11	0.625
198	(4@4) 5-5-90-5#3-i-2.5-2-6	A B C D	90°	Para	A1035	6.0 6.5 6.6 6.3	6.3	6430	11	0.625
199	(4@6) 5-8-90-5#3-i-2.5-2-6	A B C D	90°	Para	A1035	6.0 6.0 6.0 6.0	6.0	6693	21	0.625
200	(4@4) 5-8-90-5#3-i-2.5-2-6	A B C D	90°	Para	A1035	5.8 5.5 6.3 6.5	6.0	6703	22	0.625
201	(3@6) 5-8-90-5#3-i-3.5-2-6.25	A B C	90°	Para	A1035	6.3 6.3 6.3	6.3	10110	196	0.625
202	(2s) 5-5-90-0-i-2.5-2-8	A B C D	90°	-	A1035	8.0 8.0 6.5 6.4	7.2	4660	7	0.625
203	(3s) 5-5-90-0-i-2.5-2-8	A B C D E F	90°	-	A1035	8.0 7.8 8.0 6.6 6.5 6.8	7.3	4830	9	0.625
204	(2s) 5-5-90-2#3-i-2.5-2-8	A B C D	90°	Para	A1035	7.5 7.3 5.8 5.8	6.6	4860	8	0.625
205	(3s) 5-5-90-2#3-i-2.5-2-8	A B C D E F	90°	Para	A1035	7.6 7.9 7.8 6.0 5.9 6.3	6.9	4830	8	0.625
206	(2s) 5-5-90-5#3-i-2.5-2-8	A B C D	90°	Para	A1035	7.8 7.5 6.3 6.0	6.9	4660	7	0.625

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	c_{cv} in.	N_h	Axial Load kips	Long. Reinf. Layout°
197	A B C D	0.073	12.5	9.1	5.3	8.375	2.5 4.6 4.6 2.4	2.4	2.5 1.3 1.6 2.6	1.5 2.0 1.6 -	2.1 2.6 2.3 -	-	4	30	A1
198	A B C D	0.073	13.1	8.5	5.3	8.375	2.5 5.1 5.0 2.6	2.6	2.5 2.0 1.9 2.3	2.0 1.8 1.8 -	2.6 2.4 2.4 -	-	4	30	A1
199	A B C D	0.073	17.8	8.0	5.3	8.375	2.7 6.5 6.5 2.7	2.7	2.0 2.0 2.0 2.0	3.4 3.4 3.1 -	4.0 4.0 3.8 -	-	4	30	A2
200	A B C D	0.073	13.1	8.0	5.3	8.375	2.5 5.0 5.0 2.5	2.5	2.3 2.5 1.8 1.5	1.9 1.9 1.9 -	2.5 2.5 2.5 -	-	4	30	A2
201	A B C	0.073	15	8.3	5.3	8.375	3.5 6.6 3.8	3.6	2.1 2.1 2.1	2.6 3.3 -	3.3 3.9	-	3	30	A1
202	A B C D	0.073	13.0	10.5	5.3	8.375	2.4 2.6 2.4 2.6	2.5	2.4 2.5 3.9 4.1	6.8 - 6.8 -	7.4 - 7.4 -	1.6 - 1.6 -	4	30	A2
203	A B C D E F	0.073	13.1	10.2	5.3	8.375	2.6 6.2 2.9 2.7 6.1 2.9	2.8	2.3 2.5 2.2 3.6 3.8 3.4	2.9 - 2.9 - 2.9 -	3.5 - 3.5 - 3.5 -	1.6 - 1.6 - 1.6 -	6	30	A2
204	A B C D	0.073	13.0	9.9	5.3	8.375	2.5 2.7 2.5 2.7	2.6	2.5 2.6 4.3 4.1	6.5 - 6.5 -	7.1 - 7.1 -	1.6 - 1.6 -	4	30	A2
205	A B C D E F	0.073	13.4	10.4	5.3	8.375	2.5 6.4 2.5 2.5 6.4 2.5	2.5	2.8 2.5 2.6 4.4 4.5 4.1	3.3 - 2.9 - 3.3 -	3.9 - 3.5 - 3.9 -	1.6 - 1.6 - 1.6 -	6	30	A2
206	A B C D	0.073	13.1	10.1	5.3	8.375	2.5 2.6 2.5 2.6	2.5	2.4 2.6 3.9 4.1	6.8 - 6.8 -	7.4 - 7.4 -	1.6 - 1.6 -	4	30	A2

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	T_h[b] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ psi	Slip at Failure in.	Failure Type
197	A	27259	26864	108458	27114	32589	27710	87932	87466	65295	-	CB
	B	37030	32039					119452			-	CB
	C	29522	29523					95232			-	CB
	D	22950	20032					74032			-	CB
198	A	24862	24863	103591	25898	29471	25363	80200	83541	58136	-	CB
	B	27208	27018					87768			-	CB
	C	26773	26774					86365			0.333	CB
	D	26616	24937					85858			-	CB
199	A	30306	30282	113284	28321	28370	27829	97761	91358	56099	-	CB
	B	30095	30085					97081			-	CB
	C	27572	27573					88942			-	CB
	D	25343	25344					81752			-	CB
200	A	27967	27968	109970	27493	28379	24518	90216	88686	56141	-	CB
	B	27348	27348					88219			-	CB
	C	28550	28551					92097			-	CB
	D	26208	26103					84542			-	CB
201	A	36112	36112	105803	35268	34487	32824	116491	113766	89775	-	CB
	B	33789	33344					108996			-	CB
	C	40826	36347					131696			0.454	CB
202	A	16451	16402	66910	16727	24303	15666	53068	53959	56328	-	CB
	B	17860	17626					57614			-	CB
	C	16108	15896					51962			-	CB
	D	17180	16986					55418			-	CB
203	A	19256	18970	100822	16804	24752	15957	62115	54205	57756	-	CB/SS
	B	17777	17190					57344			-	CB
	C	16665	16415					53759			-	CB/SS
	D	17653	17256					56945			-	CB/SS
	E	16840	16221					54324			-	CB
	F	16076	14769					51859			-	CB/SS
204	A	24315	24192	98921	24730	24228	18907	78436	79775	52285	-	CB
	B	26070	25851					84097			-	CB
	C	24318	24318					78445			-	CB
	D	24942	24560					80457			-	CB
205	A	17748	17684	121700	20283	24729	18142	57252	65430	54791	-	CB/SS
	B	18646	18646					60149			-	CB
	C	20129	19132					64933			-	CB/SS
	D	20126	20090					64921			-	CB/SS
	E	22971	19481					74100			-	CB
	F	26728	26667					86220			-	CB/SS
206	A	26624	26565	104722	26180	29292	23195	85883	84453	67045	-	CB/SS
	B	25700	24572					82902			-	CB/SS
	C	35101	26610					113230			-	CB/SS
	D	30396	26975					98052			-	CB/SS

[a] Calculated based on Eq. (3)

[b] Calculated based on Eq. (5) for specimens without confining reinforcement and Eq. (7) for specimens with confining reinforcement, with linear interpolation between the two equations for specimens with confining reinforcement between no confinement and No. 3 (No. 10) spaced at $3d_b$.

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
197	A B C D	60	0.375	0.11	5	1.8	0.55	5	1.8	0.375	2.8	0.500	2	1.27	60
198	A B C D	60	0.375	0.11	5	2.0	0.55	5	2.0	0.375	3.0	0.375	2	1.27	60
199	A B C D	60	0.375	0.11	5	1.7	-	-	-	0.375	3.0	-	-	3.16	120
200	A B C D	60	0.375	0.11	5	1.7	-	-	-	0.375	3.0	-	-	3.16	120
201	A B C	60	0.375	0.11	5	1.7	-	-	-	0.50	3.0	0.375	1	1.27	60
202	A B C D	60	-	-	-	-	-	-	-	0.500	4.0	-	-	3.16	60
203	A B C D E F	60	-	-	-	-	-	-	-	0.500	4.0	-	-	3.16	60
204	A B C D	60	0.38	0.11	2	3.0	-	-	-	0.500	4.0	-	-	3.16	60
205	A B C D E F	60	0.38	0.11	2	3.0	-	-	-	0.500	4.0	-	-	3.16	60
206	A B C D	60	0.38	0.11	5	1.9	-	-	-	0.500	4.0	-	-	3.16	60

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
207	(3s) 5-5-90-5#3-i-2.5-2-8	A B C D E F	90°	Para	A1035	7.3 7.3 7.3 5.6 5.6 5.6	6.4	4860	8	0.625
208	(2s) 5-5-90-6#3-i-2.5-2-8	A B C D	90°	Para	A1035	8.0 8.0 6.3 6.1	7.1	4660	7	0.625
209	(3s) 5-5-90-6#3-i-2.5-2-8	A B C D E F	90°	Para	A1035	7.5 7.6 7.6 6.0 6.0 6.0	6.8	4860	8	0.625

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	c_{cv} in.	N_h	Axial Load kips	Long. Reinf. Layout°
207	A B C D E F	0.073	13.4	10.2	5.3	8.375	2.5 6.4 2.5 2.5 6.4 2.5	2.5	2.9 2.9 3.0 4.5 4.5 4.6	3.3 - 3.1 - 3.3 -	3.9 - 3.8 - 3.9 -	1.6 - 1.6 - 1.6 -	6	30	A2
208	A B C D	0.073	12.9	10.2	5.3	8.375	2.3 2.6 2.3 2.6	2.4	2.3 2.1 4.0 4.0	6.8 - 6.8 -	7.4 - 7.4 -	1.6 - 1.6 -	4	30	A2
209	A B C D E F	0.073	13.3	10.1	5.3	8.375	2.5 6.3 2.7 2.5 6.3 2.7	2.6	2.6 2.5 2.5 4.1 4.1 4.1	3.1 - 3.0 - 3.1 -	3.8 - 3.6 - 3.8 -	1.6 - 1.6 - 1.6 -	6	30	A2

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	T_h[b] lb	$f_{su,\max}$ psi	f_{su} psi	$f_{s,\text{ACI}}$ psi	Slip at Failure in.	Failure Type
207	A	19579	19569	135587	22598	25871	20477	63157	72896	64137	-	CB/SS
	B	19723	19702					63621			-	CB/
	C	21562	21518					69555			-	CB/SS
	D	26618	26016					85866			-	CB/SS
	E	25828	25085					83316			-	CB
	F	23711	23697					76488			-	CB/SS
208	A	30896	30675	118113	29528	30093	25503	99666	95253	69191	-	CB/SS
	B	28622	28481					92329			-	CB/SS
	C	33425	30220					107822			-	CB/SS
	D	34127	28737					110087			-	CB/SS
209	A	22860	21119	132487	22081	27168	22617	73743	71230	67655	-	CB/SS
	B	17958	17707					57928			-	CB
	C	22305	19794					71950			-	CB/SS
	D	27432	25862					88492			-	CB/SS
	E	27393	25053					88365			-	CB
	F	23024	22953					74270			-	CB/SS

[a] Calculated based on Eq. (3)
[b] Calculated based on Eq. (5) for specimens without confining reinforcement and Eq. (7) for specimens with confining reinforcement, with linear interpolation between the two equations for specimens with confining reinforcement between no confinement and No. 3 (No. 10) spaced at $3d_b$.

Table A.4 Cont. Comprehensive test results and data for specimens containing Multiple No. 5 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
207	A B C D E F	60	0.38	0.11	5	1.9	-	-	-	0.500	4.0	-	-	3.16	60
208	A B C D	60	0.38	0.11	6	1.9	-	-	-	0.500	4.0	-	-	3.16	60
209	A B C D E F	60	0.38	0.11	6	1.9	-	-	-	0.500	4.0	-	-	3.16	60

Table A.5 Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
210	(3@5.5) 8-5-90-0-i-2.5-2-16	A B C	90°	-	A1035[b]	16.5 15.8 16.0	16.1	6255	13	1
211	(3@5.5) 8-5-90-0-i-2.5-2-10	A B C	90°	-	A1035[b]	9.0 9.4 9.8	9.4	6461	14	1
212	(3@5.5) 8-5-90-0-i-2.5-2-8	A B C	90°	-	A615	7.5 8.0 8.0	7.8	5730	18	1
213	(3@3) 8-5-90-0-i-2.5-2-10	A B C	90°	-	A615	10.0 10.3 10.0	10.1	4490	10	1
214	(3@5) 8-5-90-0-i-2.5-2-10	A B C	90°	-	A615	10.3 10.1 10.0	10.1	4490	10	1
215	(3@5.5) 8-8-90-0-i-2.5-2-8	A B C	90°	-	A1035[b]	7.8 8.8 7.3	7.9	8700	24	1
216	(3@3) 8-12-90-0-i-2.5-2-12	A B C	90°	-	A1035[c]	12.1 12.1 12.2	12.1	11040	31	1
217	(3@4) 8-12-90-0-i-2.5-2-12	A B C	90°	-	A1035[c]	12.9 12.5 12.5	12.6	11440	32	1
218	(3@5) 8-12-90-0-i-2.5-2-12	A B C	90°	-	A1035[c]	12.3 12.0 12.3	12.2	11460	33	1
219	(3@5) 8-5-180-0-i-2.5-2-10	A B C	180°	-	A615	10.0 10.0 10.0	10.0	5260	15	1
220	(3@5.5) 8-5-90-2#3-i-2.5-2-14	A B C	90°	Para	A1035[b]	14.6 13.9 14.8	14.4	6460	14	1
221	(3@5.5) 8-5-90-2#3-i-2.5-2-8.5	A B C	90°	Para	A1035[b]	9.8 8.8 8.9	9.1	6460	14	1
222	(3@5.5) 8-5-90-2#3-i-2.5-2-14(1)	A B C	90°	Para	A1035[c]	14.7 15.2 14.8	14.9	5450	7	1
223	(3@5.5) 8-5-90-2#3-i-2.5-2-8.5(1)	A B C	90°	Para	A1035[c]	7.3 8.9 8.4	8.2	5450	7	1
224	(3@5) 8-5-90-2#3-i-2.5-2-10	A B C	90°	Para	A615	10.5 10.6 10.4	10.5	4760	11	1
225	(3@5) 8-5-180-2#3-i-2.5-2-10	A B C	180°	Para	A615	9.6 9.8 9.8	9.7	5400	16	1

[a] Heat 1, [b] Heat 2, [c] Heat 3, as described in Table 1

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Hook	R_r	b in.	H in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
210	A B C	0.078	17.25	18.1	10.5	8.375	2.6 8.0 2.8	2.7	1.6 2.4 2.1	4.4 4.5 -	5.4 5.5 -	3	30	A2
211	A B C	0.078	16.88	12.2	10.5	8.375	2.6 7.9 2.5	2.6	3.2 2.8 2.4	4.4 4.4 -	5.4 5.4 -	3	30	A2
212	A B C	0.073	17	10.0	10.5	8.375	2.5 8.0 2.5	2.5	2.5 2.0 2.0	4.5 4.5 -	5.5 5.5 -	3	30	A10
213	A B C	0.073	12.75	12.0	10.5	8.375	2.6 5.5 2.5	2.6	2.0 1.8 2.0	2.4 2.3 -	3.4 3.3 -	3	30	A2
214	A B C	0.073	16	12.0	10.5	8.375	2.3 7.3 2.5	2.4	1.8 1.9 2.0	4.0 4.3 -	5.0 5.3 -	3	30	A2
215	A B C	0.078	16.38	10.1	10.5	8.375	3.0 8.2 2.8	2.9	2.4 1.4 2.9	4.3 3.4 -	5.3 4.4 -	3	30	A2
216	A B C	0.073	12.06	14.0	10.5	8.375	2.5 5.4 2.4	2.5	1.8 1.9 1.8	2.1 2.0 -	3.1 3.0 -	3	30	A2
217	A B C	0.073	13.88	14.1	10.5	8.375	2.5 6.4 2.5	2.5	1.3 1.6 1.6	2.9 3.0 -	3.9 4.0 -	3	30	A2
218	A B C	0.073	15.88	14.0	10.5	8.375	2.4 7.4 2.5	2.4	1.8 2.0 1.8	4.0 4.0 -	5.0 5.0 -	3	30	A2
219	A B C	0.073	16.5	12.0	10.5	8.375	2.5 7.8 2.5	2.5	2.0 2.0 2.0	4.3 4.3 -	5.3 5.3 -	3	30	A10
220	A B C	0.078	17.13	16.1	10.5	8.375	2.8 8.0 2.5	2.6	1.5 2.2 1.3	4.4 4.5 -	5.4 5.5 -	3	30	A2
221	A B C	0.078	16.5	10.7	10.5	8.375	2.5 7.8 2.5	2.5	0.9 1.9 1.8	4.3 4.3 -	5.3 5.3 -	3	30	A4
222	A B C	0.073	16.81	16.4	10.5	8.375	2.8 7.9 2.6	2.7	1.7 1.2 1.6	4.2 4.3 -	5.2 5.3 -	3	30	A2
223	A B C	0.073	16.75	10.8	10.5	8.375	2.3 7.9 2.6	2.5	3.5 1.8 2.3	4.5 4.3 -	5.5 5.3 -	3	30	A2
224	A B C	0.073	16.63	12.0	10.5	8.375	2.5 8.0 2.8	2.6	1.5 1.4 1.6	4.5 3.9 -	5.5 4.9 -	3	30	A2
225	A B C	0.073	16.05	12.0	10.5	8.375	2.5 7.8 2.3	2.4	2.4 2.3 2.3	4.2 4.2 -	5.2 5.2 -	3	30	A10

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Hook	$T_{\max}$ lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	T_h[b] lb	$f_{su,\max}$ psi	f_{su} psi	$f_{s,\text{ACI}}$ Psi	Slip at Failure in.	Failure Type
	A	65266	65265					82615			-	CB
210	B	103741	76608	188393	62798	78804	72600	131318	79491	90858	0.191	CB
	C	46521	46520					58887			-	CB
	A	26783	26683					33903			-	CB
211	B	57434	55164	108161	36054	44309	40551	72701	45637	53826	-	CB
	C	26314	26314					33309			-	CB
	A	30459	30459					38556				CB
212	B	23292	23292	73234	24411	35196	32639	29484	30900	42354		CB
	C	19482	19482					24661			0.15	CB
	A	30671	30671					38824			0.09	CB
213	B	43708	33363	85439	28480	43069	30769	55327	36050	48261	0.12	CB
	C	21404	21405					27094			-	CB
	A	30145	30145					38158			0.015	CB
214	B	38965	34709	96899	32300	43162	38450	49323	40886	48357	-	CB
	C	3259	32045					4126			-	CB
	A	41000	37670					51899			-	CB
215	B	41000	37670	113010	37670	40269	34646	51899	47684	52744	-	CB
	C	41000	37670					51899			-	CB
	A	56490	56461					71506			0.194	SS
216	B	46273	38034	144116	48039	68592	47316	58573	60808	90999	-	CB
	C	55048	49621					69681			-	CB
	A	56769	56681					71859			0.255	CB/SS
217	B	76126	57568	167466	55822	72422	56133	96362	70661	96453	-	CB
	C	57723	53216					73067			-	CB/SS
	A	53307	53307					67477			-	CB
218	B	66123	42900	157056	52352	69611	61162	83700	66268	93033	-	CB
	C	60849	60849					77024			-	CB
	A	41465	40204					52487				CB
219	B	60400	59739	137789	45930	44724	40385	76456	58139	51804		CB
	C	37920	37846					48000			0.123	CB
	A	66835	66811					84601			-	CB
220	B	65764	42778	171782	57261	74514	69084	83246	72482	82766	-	CB
	C	62311	62193					78875			-	CB
	A	25157	24718					31844			0.215	CB
221	B	68732	58920	122656	40885	46883	42744	87003	51754	52387	0.285	CB
	C	39164	39019					49575			-	CB
	A	58682	58531					74281			-	CB/TK
222	B	97141	67310	196009	65336	73377	66709	122963	82704	78438	-	CB/TK
	C	70217	70168					88882			-	CB/TK
	A	36593	35595					46320			-	CB
223	B	43607	30047	97104	32368	40340	37294	55199	40972	43284	-	CB
	C	35210	31462					44570			-	CB
	A	43315	43030					54829			0.26	CB
224	B	54636	48236	134004	44668	49641	45002	69159	56542	51745	0.26	CB
	C	42769	42739					54138			-	CB
	A	59312	59313					75078				CB
225	B	4934	49344	154502	51501	47504	42918	6246	65191	50958		CB
	C	45845	45845					58032			0.14	CB

[a] Calculated based on Eq. (3)

[b] Calculated based on Eq. (5) for specimens without confining reinforcement and Eq. (7) for specimens with confining reinforcement, with linear interpolation between the two equations for specimens with confining reinforcement between no confinement and No. 3 (No. 10) spaced at $3d_b$.

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
210	A B C	60	-	-	-	-	2.0	10	3	0.50	3.0	0.375	1	3.16	60
211	A B C	60	-	-	-	-	2.0	10	3	0.50	3.0	0.500	1	3.16	60
212	A B C	60	-	-	-	-	-	-	-	0.50	4.0	-	-	6.32	120
213	A B C	60	-	-	-	-	-	-	-	0.38	3.0	-	-	3.16	120
214	A B C	60	-	-	-	-	-	-	-	0.38	4.0	-	-	3.16	120
215	A B C	60	-	-	0	-	2.2	20	3	0.50	1.8	-	-	3.16	60
216	A B C	60	0.375	0.11	0	-	-	-	-	0.38	3.0	-	-	3.16	120
217	A B C	60	0.375	0.11	0	-	-	-	-	0.38	3.0	-	-	3.16	120
218	A B C	60	0.375	0.11	0	-	-	-	-	0.38	3.0	-	-	3.16	120
219	A B C	60	-	0.11	-	-	-	-	-	0.50	3.0	-	-	6.32	120
220	A B C	60	0.375	0.11	2	7.5	2.0	10	2.5	0.38	3.0	0.500	2	3.16	60
221	A B C	60	0.375	0.11	2	7.5	2.0	10	2.5	0.38	2.5	0.500	2	1.89	60
222	A B C	60	0.375	0.11	2	6	1.6	8	3	0.38	2.5	0.375	2	3.16	60
223	A B C	60	0.375	0.11	2	6	2.0	10	3	0.50	2.5	0.375	1	3.16	60
224	A B C	60	0.375	0.11	2	3	-	-	-	0.38	3.0	-	-	3.16	120
225	A B C	60	0.375	0.11	2	3	-	-	-	0.50	3.0	-	-	6.32	120

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
226	(3@5.5) 8-5-90-5#3-i-2.5-2-8	A B C	90°	Para	A1035[b]	8.0 8.1 7.8	8.0	6620	15	1
227	(3@5.5) 8-5-90-5#3-i-2.5-2-12	A B C	90°	Para	A1035[b]	12.4 12.1 12.1	12.2	6620	15	1
228	(3@5.5) 8-5-90-5#3-i-2.5-2-8(1)	A B C	90°	Para	A1035[c]	7.3 8.4 7.3	7.6	5660	8	1
229	(3@5.5) 8-5-90-5#3-i-2.5-2-12(1)	A B C	90°	Para	A1035[c]	11.4 12.5 12.0	12.0	5660	8	1
230	(3@5.5) 8-5-90-5#3-i-2.5-2-8(2)	A B C	90°	Para	A615	8.0 8.0 8.5	8.2	5730	18	1
231	(3@3) 8-5-90-5#3-i-2.5-2-10	A B C	90°	Para	A615	10.0 9.8 9.9	9.9	4810	12	1
232	(3@5) 8-5-90-5#3-i-2.5-2-10	A B C	90°	Para	A615	10.0 10.0 9.8	9.9	4850	13	1
233	(3@3) 8-12-90-5#3-i-2.5-2-12	A B C	90°	Para	A1035[c]	11.9 11.9 11.6	11.8	11040	31	1
234	(3@4) 8-12-90-5#3-i-2.5-2-12	A B C	90°	Para	A1035[c]	12.5 12.0 12.5	12.3	11440	32	1
235	(3@5) 8-12-90-5#3-i-2.5-2-12	A B C	90°	Para	A1035[c]	11.9 12.4 12.3	12.2	11460	33	1
236	(3@5) 8-5-180-5#3-i-2.5-2-10	A B C	180°	Para	A615	9.9 9.8 9.5	9.7	5540	17	1

[a] Heat 1, [b] Heat 2, [c] Heat 3, as described in Table 1

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	N_h	Axial Load kips	Long. Reinf. Layout°
226	A B C	0.078	16.63	10.2	10.5	8.375	2.5 7.6 2.5	2.5	2.2 2.1 2.4	4.1 4.5 -	5.1 5.5 -	3	30	A10
227	A B C	0.078	16.75	14.2	10.5	8.375	2.5 7.8 2.5	2.5	1.8 2.1 2.1	4.3 4.5 -	5.3 5.5	3	30	A1
228	A B C	0.073	16.63	10.1	10.5	8.375	2.9 7.6 2.9	2.9	2.9 1.8 2.9	3.8 4.1 -	4.8 5.1 -	3	30	A2
229	A B C	0.073	16.88	14.2	10.5	8.375	2.5 7.8 2.6	2.6	2.8 1.7 2.2	4.3 4.5 -	5.3 5.5 -	3	30	A2
230	A B C	0.073	17	10.0	10.5	8.375	2.8 8.0 2.3	2.5	2.0 2.0 1.5	4.5 4.5 -	5.5 5.5 -	3	30	A10
231	A B C	0.073	12.25	12.0	10.5	8.375	2.8 5.9 2.3	2.5	2.0 2.3 2.1	2.1 2.1 -	3.1 3.1 -	3	30	A7
232	A B C	0.073	16.25	12.0	10.5	8.375	2.5 7.5 2.8	2.6	2.0 2.0 2.3	4.0 4.0 -	5.0 5.0 -	3	30	A3
233	A B C	0.073	12	14.1	10.5	8.375	2.5 5.5 2.5	2.5	2.3 2.3 2.5	2.0 2.0 -	3.0 3.0 -	3	30	A2
234	A B C	0.073	13.75	14.3	10.5	8.375	2.5 6.3 2.5	2.5	1.8 2.3 1.8	2.8 3.0 -	3.8 4.0 -	3	30	A2
235	A B C	0.073	16	14.1	10.5	8.375	2.5 7.5 2.5	2.5	2.2 1.7 1.8	4.0 4.0 -	5.0 5.0 -	3	30	A2
236	A B C	0.073	15.75	12.0	10.5	8.375	2.3 7.0 2.8	2.5	2.1 2.3 2.5	3.8 4.0 -	4.8 5.0 -	3	30	A10

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] Lb	T_h[b] lb	$f_{su,max}$ psi	f_{su} psi	$f_{s,ACI}$ Psi	Slip at Failure in.	Failure Type
	A	30586	30530					38716			0.388	CB
226	B	46989	46919	111379	37126	49157	45804	59480	46995	57814	0.477	CB
	C	34069	33930					43125			-	CB
	A	60325	60281					76361			0.198	CB
227	B	110823	80058	198283	66094	71221	66595	140282	83664	88689	-	CB
	C	59279	57944					75037			-	CB
	A	29839	29789					37771			-	CB
228	B	30241	29643	94108	31369	45852	41836	38280	39708	51219	0.297	CB
	C	34714	34676					43942			0.381	CB
	A	55543	44226					70308			-	CB
229	B	74581	74581	143554	47851	67278	62908	94406	60571	80327	0.435	CB
	C	44410	24747					56215			0.927	CB
	A	57652	57652					72977				CB
230	B	43308	43309	143982	47994	48617	45771	54820	60752	55196		CB
	C	43030	43021					54468			0.54	CB
	A	48766	48766					61729			-	CB
231	B	44849	44503	141829	47276	54763	44844	56771	59843	61149	0.13	CB
	C	48560	48560					61468			0	CB
	A	58896	58896					74552			-	CB
232	B	63376	55612	183916	61305	55066	50422	80223	77602	61662	-	CB
	C	69408	69408					87858			-	CB
	A	70368	68183					89073			0.302	CB
233	B	84954	56310	186619	62206	78344	63650	107537	78742	110622	0.256	CB
	C	62126	62127					78641			0.251	CB
	A	70706	69965					89501			0.262	CB
234	B	100028	68745	194819	64940	82403	70671	126618	82202	117781	-	CB
	C	63666	56110					80590			0.205	CB
	A	59447	59447					75249			-	CB
235	B	85455	65587	194282	64761	81663	74780	108171	81976	116689	-	CB
	C	69248	69248					87656			0.18	CB
	A	55363	55236					70080				CB
236	B	60892	60892	176006	58669	55773	50709	77078	74264	64518		CB
	C	59877	59877					75794			0.382	CB

[a] Calculated based on Eq. (3)

[b] Calculated based on Eq. (5) for specimens without confining reinforcement and Eq. (7) for specimens with confining reinforcement, with linear interpolation between the two equations for specimens with confining reinforcement between no confinement and No. 3 (No. 10) spaced at $3d_b$.

Table A.5 Cont. Comprehensive test results and data for specimens containing Multiple No. 8 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
226	A B C	60	0.375	0.11	5	3.3	2.0	10	3.25	0.38	2.5	0.500	2	1.89	60
227	A B C	60	0.375	0.11	5	3.2	2.0	10	3.2	0.38	2.5	0.500	2	1.27	60
228	A B C	60	0.375	0.11	5	3	2.0	10	3	0.50	2.5	0.375	1	3.16	60
229	A B C	60	0.375	0.11	5	3	1.0	5	2.75	0.50	3.5	0.500	1	3.16	60
230	A B C	60	0.375	0.11	5	3	-	-	-	0.50	4.0	-	-	6.32	120
231	A B C	60	0.375	0.11	5	3	-	-	-	0.50	4.0	-	-	4.74	120
232	A B C	60	0.375	0.11	5	3	-	-	-	0.38	3.0	-	-	3.95	120
233	A B C	60	0.375	0.11	5	3	-	-	-	0.38	3.0	-	-	3.16	120
234	A B C	60	0.375	0.11	5	3	-	-	-	0.38	3.0	-	-	3.16	120
235	A B C	60	0.375	0.11	5	3	-	-	-	0.38	3.0	-	-	3.16	120
236	A B C	60	0.375		5	3	-	-	-	0.50	3.0	-	-	6.32	120

Table A.6 Comprehensive test results and data for specimens containing Multiple No. 11 hooked bars

	Specimen	Hook	Bend Angle	Trans. Reinf. Orient.	Hook Bar Type	ℓ_{eh} in.	$\ell_{eh,avg}$ in.	f'_c psi	Age days	d_b in.
237	(3@3.75) 11-8-90-0-i-2.5-2-20	A B C	90°	-	A1035	19.6 20.0 20.0	19.9	7070	30	1.41
238	(3@3.75) 11-8-90-0-i-2.5-2-24	A B C	90°	-	A1035	23.5 23.5 23.5	23.5	7070	30	1.41
239	(3@3.75) 11-12-90-0-i-2.5-2-22	A B C	90°	-	A615	21.9 21.3 21.9	21.7	11460	50	1.41
240	(3@3.75) 11-8-90-2#3-i-2.5-2-23	A B C	90°	Para	A1035	22.0 22.0 21.9	22.0	7070	31	1.41
241	(3@3.75) 11-12-90-2#3-i-2.5-2-21	A B C	90°	Para	A615	21.0 21.0 20.9	21.0	11850	51	1.41
242	(3@3.75) 11-8-90-6#3-i-2.5-2-21	A B C	90°	Para	A1035	19.9 20.1 20.2	20.0	7070	51	1.41
243	(3@3.75) 11-12-90-6#3-i-2.5-2-19	A B C	90°	Para	A1035	18.4 18.1 18.4	18.3	11960	52	1.41
244	(3@3.75) 11-12-180-6#3-i-2.5-2-19	A B C	180°	Para	A1035	18.9 18.8 18.9	18.8	12190	56	1.41
245	(2s) 11-5-90-0-i-2.5-2-16	A B C D	90°	-	A1035	16.0 16.3 13.3 13.5	14.8	5030	9	1.41
246	(2s) 11-5-90-2#3-i-2.5-2-16	A B C D	90°	Para	A1035	15.9 16.0 13.3 13.3	14.6	5140	10	1.41
247	(2s) 11-5-90-6#3-i-2.5-2-16	A B C D	90°	Para	A1035	15.5 15.5 12.3 12.8	14.0	5030	9	1.41
248	(2s) 11-5-90-7#3-i-2.5-2-16	A B C D	90°	Para	A1035	15.5 15.5 13.0 13.0	14.3	5140	10	1.41
249	(2s) 11-5-90-8#3-i-2.5-2-16	A B C D	90°	Para	A1035	15.9 15.9 13.3 13.3	14.6	5140	10	1.41

Table A.6 Cont. Comprehensive test results and data for specimens containing Multiple No. 11 hooked bars

	Hook	R_r	b in.	h in.	h_{cl} in.	h_c in.	c_{so} in.	$c_{so,avg}$ in.	c_{th} in.	c_h in.	c_{ch} in.	c_{cv} in.	N_h	Axial Load kips	Long. Reinf. Layout°
237	A B C	0.085	17.51	22.1	19.5	8.375	2.7 7.9 2.7	2.7	2.4 2.0 2.3	3.8 4.1 -	5.3 5.5 -	-	3	108	A14
238	A B C	0.085	17.88	26.3	19.5	8.375	2.7 8.1 2.9	2.8	2.8 2.8 2.9	4.0 4.1 -	5.4 5.5 -	-	3	132	A14
239	A B C	0.085	18.12	24.1	19.5	8.375	2.8 8.3 2.9	2.9	2.1 2.8 2.4	4.1 4.1 -	5.5 5.5 -	-	3	122	A14
240	A B C	0.085	17.49	25.4	19.5	8.375	2.5 7.8 2.8	2.7	3.3 3.3 3.8	3.8 4.1 -	5.3 5.5 -	-	3	124	A14
241	A B C	0.085	17.87	23.0	19.5	8.375	2.7 8.2 2.8	2.7	1.8 2.1 2.3	4.1 4.1 -	5.5 5.5 --	-	3	115	A14
242	A B C	0.085	18.06	23.3	19.5	8.375	2.8 8.4 2.7	2.7	3.4 3.2 3.2	4.2 4.2 -	5.6 5.6 -	-	3	118	A14
243	A B C	0.085	17.87	21.1	19.5	8.375	2.8 8.2 2.8	2.8	2.8 3.0 2.6	4.0 4.1 -	5.4 5.5 -	-	3	106	A14
244	A B C	0.085	17.5	21.1	19.5	8.375	2.9 8.2 2.5	2.7	2.1 2.3 2.5	3.8 4.0 -	5.3 5.4 -	-	3	104	A14
245	A B C D	0.085	21.74	18.1	19.5	8.375	2.5 2.8 2.5 2.8	2.7	2.0 2.0 4.8 4.8	13.6 - 13.6 -	15.0 - 15.0 -	2.8 - 2.8 -	4	110	A18
246	A B C D	0.085	21.74	18.4	19.5	8.375	2.5 2.5 2.5 2.5	2.5	2.6 2.3 5.5 5.0	13.8 - 13.8 -	15.3 - 15.3 -	2.8 - 2.8 -	4	112	A18
247	A B C D	0.085	21.96	18.4	19.5	8.375	2.8 2.8 2.8 2.8	2.8	2.9 2.9 6.1 5.6	13.6 - 13.6 -	15.0 - 15.0 -	2.8 - 2.8 -	4	113	A18
248	A B C D	0.085	21.75	18.4	19.5	8.375	2.8 2.7 2.8 2.7	2.7	2.9 2.9 5.4 5.4	13.5 - 13.5 -	14.9 - 14.9 -	2.8 - 2.8 -	4	112	A18
249	A B C D	0.085	21.74	18.6	19.5	8.375	2.5 2.5 2.5 2.5	2.5	2.3 3.1 4.9 5.8	13.8 - 13.8 -	15.3 - 15.3 -	2.8 - 2.8 -	4	113	A18

° Longitudinal column configurations shown in Appendix A, Layouts A1 – A18

Table A.6 Cont. Comprehensive test results and data for specimens containing Multiple No. 11 hooked bars

	Hook	T_{max} lb	T_{ind} lb	T_{total} lb	T lb	T_h[a] lb	T_h[b] lb	$f_{su,max}$ psi	f_{su} Psi	$f_{s,ACI}$ psi	Failure Type
	A	99788	99284					63967			CB/SS
237	B	112356	91009	295464	98488	120813	92155	72023	63133	84665	CB
	C	107432	105171					68867			CB/SS
	A	118707	118707					76094			CB/SS
238	B	140381	132010	380928	126976	144871	111142	89988	81395	100099	CB
	C	130244	130212					83490			CB/SS
	A	127199	126150					81538			SS/CB
239	B	131246	125954	369539	123180	152996	118016	84132	78961	117518	CB
	C	118472	117434					75944			SS/CB
	A	119045	117909					76311			CB/SS
240	B	139657	120432	349768	116589	139560	110736	89524	74737	93539	CB
	C	111428	111428					71428			CB/SS
	A	129640	129578					83103			SS
241	B	131158	127727	383435	127812	153987	123304	84076	81930	115585	CB
	C	126160	126130					80872			SS
	A	118266	118209					75811			CB/SS
242	B	174241	112198	333863	111288	137046	118168	111693	71338	106701	CB
	C	104398	103456					66922			CB/SS
	A	115766	115766					74209			CB/SS
243	B	120830	120824	354900	118300	144116	123429	77455	75833	126707	CB
	C	118310	118310					75840			CB/SS
	A	119106	119075					76350			CB/SS
244	B	173226	120760	357136	119045	148999	126941	111042	76311	131695	CB
	C	123231	117301					78994			CB/SS
	A	55287	55287					35440			SS
245	B	59579	59571	191800	47950	79067	46846	38192	30737	52994	SS
	C	37935	37353					24317			SS
	D	39589	39589					25377			SS
	A	57407	57407					36800			SS
246	B	62971	62971	231994	57998	82366	58442	40366	37178	53008	SS
	C	53264	53239					34143			SS
	D	58430	58377					37455			SS
	A	61785	61701					39606			SS
247	B	67354	67354	248710	62177	86027	65735	43176	39857	62875	SS
	C	61978	61978					39730			SS
	D	57746	57676					37017			SS
	A	73174	73124					46906			SS
248	B	77729	77621	269727	67432	87963	70152	49826	43225	64693	SS
	C	60463	60239					38759			SS
	D	58805	58743					37695			SS
	A	81845	77857					52464			SS
249	B	74134	74134	282018	70505	93648	74497	47522	45195	66123	SS
	C	67907	65363					43530			SS
	D	64726	64664					41491			SS

[a] Calculated based on Eq. (3)

[b] Calculated based on Eq. (5) for specimens without confining reinforcement and Eq. (7) for specimens with confining reinforcement, with linear interpolation between the two equations for specimens with confining reinforcement between no confinement and No. 3 (No. 10) spaced at $3d_b$.

Table A.6 Cont. Comprehensive test results and data for specimens containing Multiple No. 11 hooked bars

	Hook	f_{yt} ksi	d_{tr} in.	$A_{tr,l}$ in.^{2}	N_{tr}	s_{tr} in.	A_{cti} in.^{2}	N_{cti}	s_{cti} in.	d_s in.	s_s in.	d_{cto} in.	N_{cto}	A_s in.^{2}	f_{ys} ksi
237	A B C	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
238	A B C	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
239	A B C	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
240	A B C	60	0.38	0.11	2	8	-	-	-	0.50	2.5	-	-	7.90	60
241	A B C	60	0.38	0.11	2	8	-	-	-	0.50	2.5	-	-	7.90	60
242	A B C	60	0.38	0.11	6	4	-	-	-	0.50	2.5	-	-	7.90	60
243	A B C	60	0.38	0.11	6	4	-	-	-	0.50	2.5	-	-	7.90	60
244	A B C	60	0.38	0.11	6	4	-	-	-	0.50	2.5	-	-	7.90	60
245	A B C D	60	-	-	-	-	-	-	-	0.50	2.5	-	-	7.90	60
246	A B C D	60	0.38	0.11	2	8	-	-	-	0.50	2.5	-	-	7.90	60
247	A B C D	60	0.38	0.11	6	4	-	-	-	0.50	2.5	-	-	7.90	60
248	A B C D	60	0.38	0.11	7	4	-	-	-	0.50	2.5	-	-	7.90	60
249	A B C D	60	0.38	0.11	8	3.3	-	-	-	0.50	2.5	-	-	7.90	60

Table A.7 Test results for other researches referenced in this paper

		Specimen	Bend Angle	l_{eh}	f_{cm}	f_y	d_b	b	h_{cl}
				in.	psi	psi	in.	in.	in.
Marques and Jirsa (1975)	250	J7-180-12-1H	180°	10	4350	64000	0.88	12	11.5
	251	J7-180-15-1 H	180°	13	4000	64000	0.88	12	11.5
	252	J7-90-12-1H	90°	10	4150	64000	0.88	12	11.5
	253	J7-90-15-1-H	90°	13	4600	64000	0.88	12	11.5
	254	J7-90-15-1- L	90°	13	4800	64000	0.88	12	11.5
	255	J7-90-15-1M	90°	13	5050	64000	0.88	12	11.5
	256	J 7- 90 -15 -3a - H	90°	13	3750	64000	0.88	12	11.5
Hamad et al. (1993)	257	7-90-U	90°	10	2570	60000	0.88	12	11
	258	7-90-U'	90°	10	5400	60000	0.88	12	11
Ramirez & Russell (2008)	259	I-1	90°	6.5	8910	81900	0.75	15	12
	260	I-3	90°	6.5	12460	81900	0.75	15	12
	261	I-5	90°	6.5	12850	81900	0.75	15	12
	262	I-2	90°	12.5	8910	63100	1.41	15	12
	263	I-2'	90°	15.5	9540	63100	1.41	15	12
	264	I-4	90°	12.5	12460	63100	1.41	15	12
	265	III-13	90°	6.5	13980	81900	0.75	15	12
	266	III-15	90°	6.5	16350	81900	0.75	15	12
Lee & Park (2010)	267	H1	90°	18.7	4450	87000	0.88	14.6	*
	268	H2	90°	11.9	8270	87000	0.88	14.6	*
	269	H3	90°	15	4450	87000	0.88	14.6	*

*Information not provided

Table A.7 Cont. Test results for other researches referenced in this paper

		h_c	c_{so}	c_{th}	c_h	c_{ch}	N_h	A_h	d_{tr}	$A_{tr,l}$	N_{tr}	s_{tr}	T	T_h[a]
		in.	in.	in.	in.	in.		in.^{2}	in.	in.^{2}		in.	lb	lb
Marques and Jirsa (1975)	250	6	2.88	2	4.5	5.4	2	0.6	-	-	-	-	36600	39778
	251	6	2.88	2	4.5	5.4	2	0.6	-	-	-	-	52200	51573
	252	6	2.88	2	4.5	5.4	2	0.6	-	-	-	-	37200	39229
	253	6	2.88	2	4.5	5.4	2	0.6	-	-	-	-	54600	53744
	254	6	2.88	2	4.5	5.4	2	0.6	-	-	-	-	58200	54423
	255	6	2.88	2	4.5	5.4	2	0.6	-	-	-	-	60000	55244
	256	6	2.88	2	4.5	5.4	2	0.6	0.375	0.11	8	2.5	58800	72216
Hamad et al. (1993)	257	6	3	2	4.25	5.1	2	0.6	-	-	-	-	25998	34058
	258	6	3	2	4.25	5.1	2	0.6	-	-	-	-	36732	42398
Ramirez & Russel (2008)	259	6	2.5	2.5	8.5	9.3	2	0.44	-	-	-	-	30000	28654
	260	6	2.5	2.5	8.5	9.3	2	0.44	-	-	-	-	30000	31635
	261	6	2.5	2.5	8.5	9.3	2	0.44	-	-	-	-	30500	31924
	262	6	2.5	2.5	7.18	8.6	2	1.56	-	-	-	-	88000	78316
	263	6	2.5	2.5	7.18	8.6	2	1.56	-	-	-	-	105000	100904
	264	6	2.5	2.5	7.18	8.6	2	1.56	-	-	-	-	99100	86464
	265	6	2.5	2.5	8.5	9.3	2	0.44	0.375	0.11	4	7.5	41300	47134
	266	6	2.5	2.5	8.5	9.3	2	0.44	0.375	0.11	4	7.5	38500	48680
Lee & Park (2010)	267	*	3	2	7	7.9	2	0.6	-	-	-	-	59208	79135
	268	*	3	2	7	7.9	2	0.6	-	-	-	-	52797	57788
	269	*	3	2	7	7.9	2	0.6	0.375	0.11	4	2.63	53761	78275

[a] Calculated based on Eq. (3)
*Information not provided

Appendix B: Material Properties

B.1 Concrete Mixture Proportions

Table B.1 Concrete mixture proportions

Material	Quantity (SSD)		
Design Compressive Strength, psi	**5,000**	**8,000**	**12,000**
Type I/II Cement, lb/yd^3	600	700	750
Water, lb/yd^3	263	225	217
Kansas River Sand[1], lb/yd^3	1,396	1,375	1,050
Pea Gravel[2], lb/yd^3	-	-	316
Crushed Limestone[3], lb/yd^3	1,734	1,683	1,796
Estimated Air Content, %	1	1	1
High-Range Water-Reducer, oz (US)	30	171	78
w/c ratio	0.44	0.32	0.29

Bulk specific gravity (saturated surface dry) =[1]2.63, [2]2.59, and [3]2.60
Note: 1 psi = 6.89 kPa, 1 oz = 29.57 ml, and 1 lb/yd^3 = 0.593 kg/m^3

B.2 Stress-Strain Curves

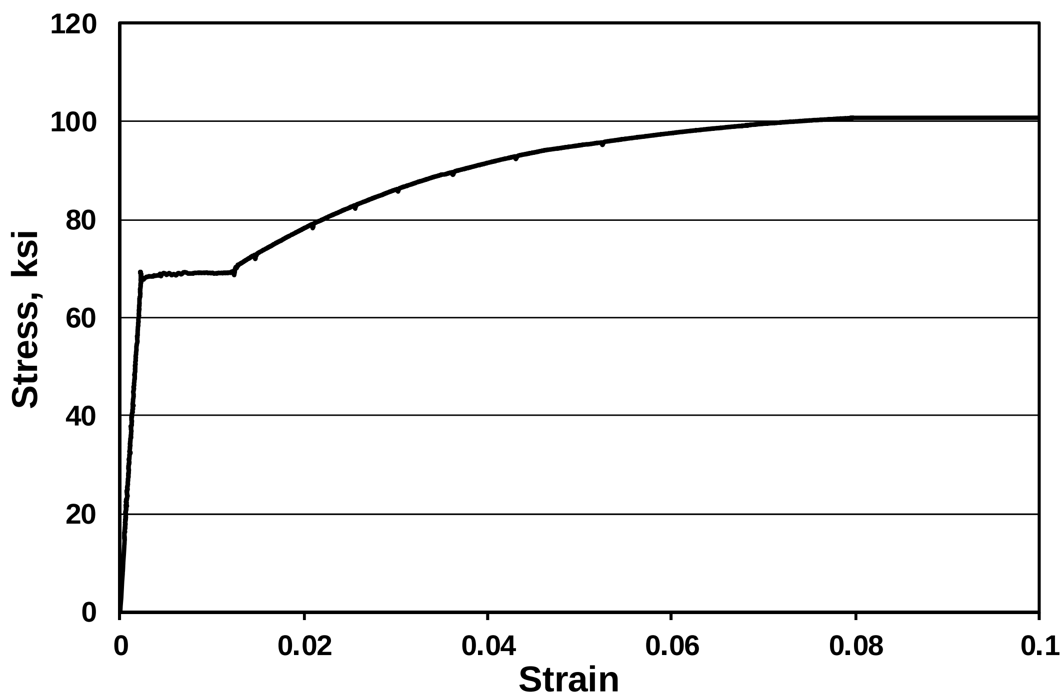


Fig. B.1–Stress-strain curve for No. 3 (No. 10) bars (A615 steel)

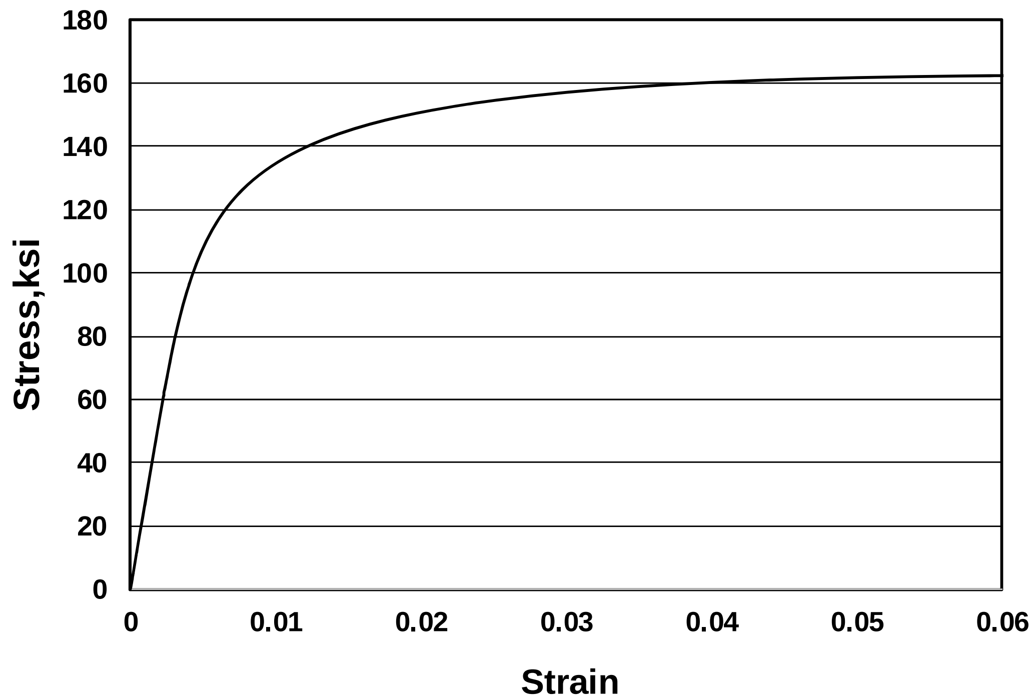


Fig. B.2–Stress-strain curve for No. 5 (No. 16) bars (A1035 steel)

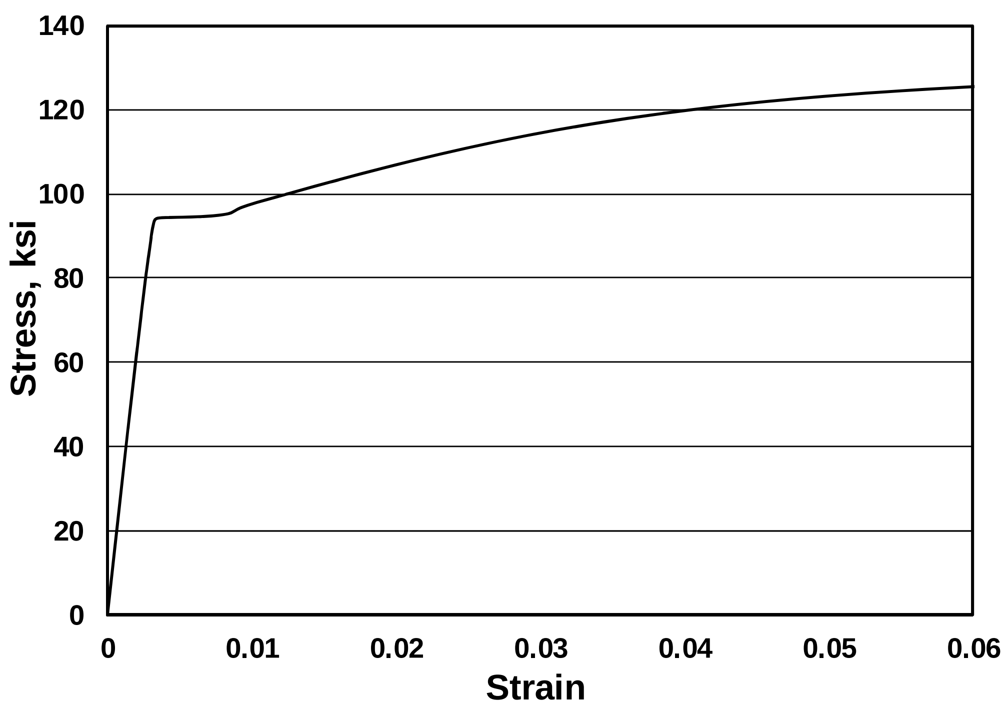


Fig. B.3–Stress-strain curve for No. 8 (No. 25) bars (A615 steel)

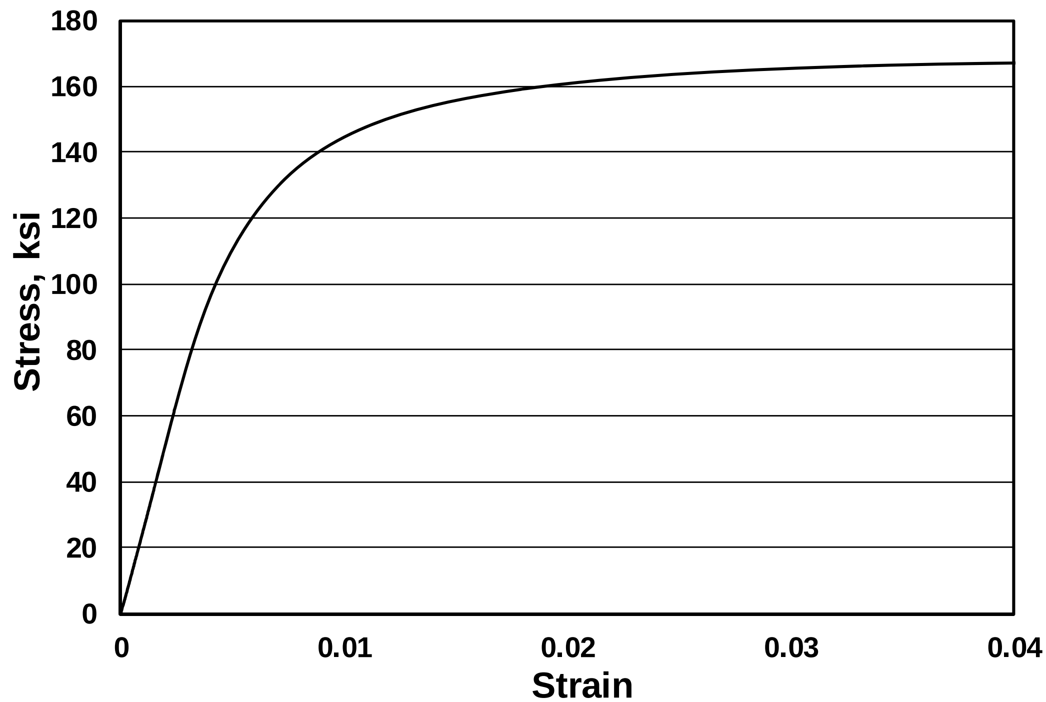


Fig. B.4–Stress-strain curve for No. 8 (No. 25) bars (A1035 steel)

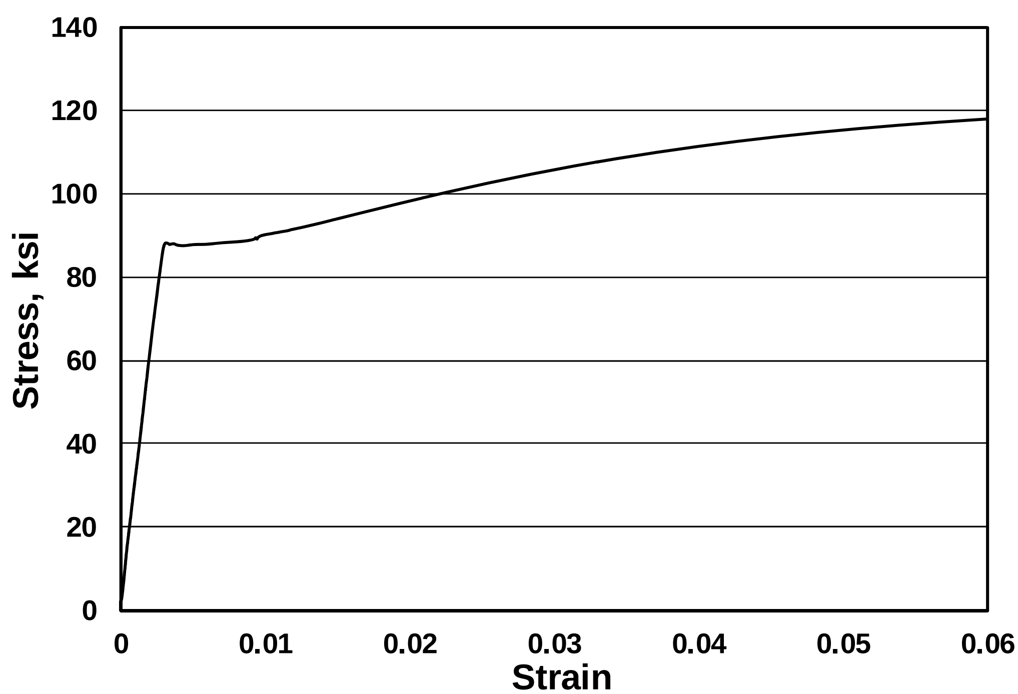


Fig. B.5–Stress-strain curve for No. 11 (No. 36) bars (A615 steel)

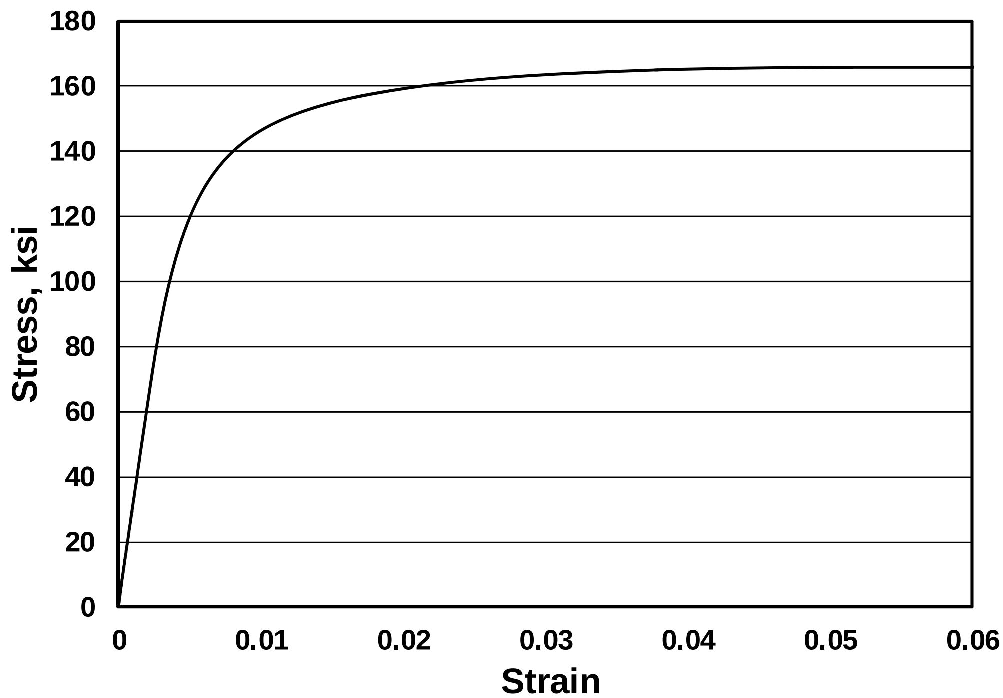


Fig. B.6–Stress-strain curve for No. 11 (No. 36) bars (A1035 steel)