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Anchorage Strength Of Epoxy-Coated Hooked Bars



by Bilal S. Hamad, James O. Jirsa, and Natalie I. D'Abreu de Paulo

The objective of the study was to determine anchorage characteristics of epoxy-coated hooked bars. The 1989 ACI Code (ACI 318-89) does not address this subject and there is no information in the literature.

Twenty-five specimens simulating beam-column joints in a structure were tested to assess the effect of several variables on relative bond characteristics of uncoated and epoxy-coated hooked bars. Variables included bar size [#7 and #11 (22 and 36 mm)], concrete strength [3, 4, and 8 ksi (21, 28 and 55 MPa)], amount of side concrete cover normal to the plane of the hook [$2\frac{7}{8}$ in. (73 mm) in most specimens; $1\frac{7}{8}$ in. (48 mm) in two tests], hook geometry (90- and 180-deg hooks), and amount of transverse reinforcement (column ties) in the beam-column joint.

Test results indicated that epoxy-coated hooked bars consistently developed lower anchorage capacities and greater slips than companion uncoated bars. A design modification was recommended for development length of epoxy-coated hooked bars.

Keywords: anchorage, development, detailing, bond, reinforcement, hooked bars, epoxy-coating

Fusion-bonded epoxy coating provides an effective, easy to use, and economical method of protection against deterioration of reinforced concrete structures caused by corrosion of steel reinforcement. The purpose of epoxy coating is to prevent corrosion inducing chloride ions from reaching the steel surface. Epoxy-coated bars are used in nearly all types of structures where concrete is exposed to a corrosive environment. Applications include bridge decks, reinforced concrete pavements, parking garages, chemical plants, power plants, refineries and subways.

All previous research studies on epoxy-coated bars were either pullout tests, beam end specimens, or beam splice tests in which bond characteristics of straight coated bars were investigated. To date there has been no work on the anchorage performance of epoxy-coated hooked bars. In the 1989 ACI Building Code (ACI 318-89),[1] the basic development length ℓ_{db} of a straight deformed bar was modified to account for epoxy coating but the effect of epoxy coating on basic development length ℓ_{hb} of a hooked bar was not addressed.

In 1972, Jirsa and Marques[2] reported a series of tests to determine capacity of uncoated hooked bars. Nineteen specimens simulating exterior beam-column joints in a frame structure were tested to evaluate the capacity of uncoated anchored beam reinforcement subjected to varying degrees of confinement at the joint. The types of confinement included vertical column reinforcement, lateral reinforcement through the joint, side concrete cover, and column axial load. Tests were conducted using two #7 (22-mm) or two #11 (36-mm) bars anchored in 50 in. (127 cm) long columns. Standard 90- or 180-deg hooks conforming to ACI 318 specifications were used. In each test column axial load was applied and maintained constant throughout the loading sequence. To simulate beam moment acting on the column, tension was applied to the anchored bars and a reaction assembly transferred compression load to the specimen. In general, failure in most tests was sudden and resulted in the entire side cover of the column spalling away to the level of the hooked anchorage.

Based on slip and strain measurements and observations of failure, Marques and Jirsa[2] made the following conclusions:

1. Level of column axial load did not influence significantly the behavior of hooked bar anchorages.
2. Embedment length between the beginning of a standard hook and the critical section at the face of the column was the prime factor in determining the anchorage capacity.
3. Placement of column bars inside or outside the anchored beam bars did not influence stress or slip characteristics of anchored bars.
4. Ties through the joint reduced slip and increased capacity but only if tie spacing was small relative to the bend diameter of the anchored bar.
5. Concrete cover did not appear to influence stress-slip characteristics provided that cover was sufficient to prevent a local failure in the vicinity of the bent portion of the hooked anchorage.
6. There was little difference between the capacity of 90- and 180-degree hooks; however, slip at a given stress was greater for 180-deg hooks.

RESEARCH SIGNIFICANCE

To date there have been no reported data on the effect of epoxy coating on hooked bar anchorage capacity. The research reported herein provides information which will in-

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dicate the adjustments to be made when designing coated hooked bars. The results can be used for improving structural design codes.

OBJECTIVE

The objective of this study was to evaluate the behavior and anchorage capacity of epoxy-coated hooked bars relative to uncoated bars. Effects of bar size, concrete strength, concrete cover, lateral reinforcement through the joint, and hook geometry on the relative performance of uncoated and epoxy-coated hooked bars were evaluated. Since current ACI Building Code (ACI 318-89)[1] hooked bar specifications were originally based on test results of Marques and Jirsa,[2] design of the specimens was similar to allow comparison of test results.

EXPERIMENTAL PROGRAM

Design of specimens

The test specimens are identified in Table 1. A four-term notation system was used to identify variables of each specimen. The first term is bar size: #7 or #11 (22 or 36 mm). The second term is hook geometry: 90 or 180 deg. The third term indicates whether the bar is uncoated (U) or epoxy-coated (C). The fourth term of the notation, if present, is used for three indications: T4 or T6 indicates presence of #3 (10-mm) ties in the hook region; SC indicates small concrete cover; and HS indicates high strength concrete.

The specimen simulated full-scale beam-column joints. To determine the influence of epoxy coating on hooked bar anchorages, coating application was the only variable in each pair of tests. In each specimen, two #7 or #11 (22 or 36-mm) beam bars were anchored in a 48 in. (122 cm) long column. Standard 90- or 180-deg hooks conforming to ACI 318-89[1] standard hook details were used. Geometrical and reinforcement details of a #11 (36-mm) hooked bar specimen with #3 (10-mm) ties at 6 in. (15 cm) in the joint region, are shown

Table 1—Hooked bar test specimens

Series no.	Specimen notation	f_c', ksi	Bar size, mm	Angle of bend, deg	Ties in joint region
One	7-90-U*	5.4	#7	90	—
	7-90-C*	5.4	#7	90	—
	11-90-U*	5.4	#11	90	—
	11-90-C*	5.4	#11	90	—
Two	7-90-U-T4	3.7	#7	90	#3 @ 4 in.
	&-90-C-T4	3.7	#7	90	#3 @ 4 in.
	11-90-U-T6	3.7	#11	90	#3 @ 6 in.
	11-90-C-T6	3.7	#11	90	#3 @ 6 in.
Three	7-180-U-T4	3.9	#7	180	#3 @ 4 in.
	7-180-C-T4	3.9	#7	180	#3 @ 4 in.
	11-180-U-T6	3.9	#11	180	#3 @ 6 in.
	11-180-C-T6	3.9	#11	180	#3 @ 6 in.
Four	7-90-U	2.57	#7	90	—
	7-90-C	2.57	#7	90	—
	11-90-U	2.57	#11	90	—
	11-90-C	2.57	#11	90	—
Five	7-90-U-SC†	4.23	#7	90	—
	7-90-C-SC†	4.23	#7	90	—
	11-90-U-T4	4.23	#11	90	#3 @ 4 in.
	11-90-C-T4	4.23	#11	90	#3 @ 4 in.
Six	11-90-U-HS	7.2	#11	90	—
	11-90-C-HS	7.2	#11	90	—
	11-180-U-HS	7.2	#11	180	—
	11-180-C-HS	7.2	#11	180	—

†The nominal side cover concrete over the hooked bars was 10⅞ in. (5 cm) witth the column bars placed inside the beam bars. In all other test specimens, the nominal side cover was 2⅞ (7 cm) with the beam bars placed inside the column bars.

#3 = 10 mm; # 7 = 22 mm' #11 = 36 mm; 1 ksi = 6.895 MPa; 1 in. = 25.4 mm.

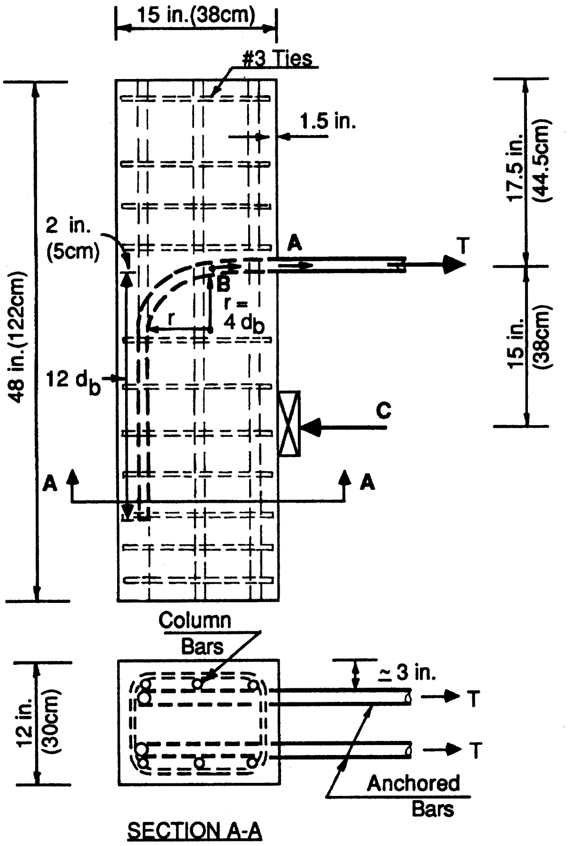

Fig. 1—Specimens with #11 (36 mm) hooked bars, #3 (10 mm ties at 6 in. (15 cm) in joint region

in Fig. 1. The 48-in. (122-cm) column height was chosen to permit embedment of the hooked bars and to allow some additional column length above and below an assumed beam depth of 20 in. (51 cm). The width of the beam was 12 in. (30 cm) and was equal to the width of the column. The column dimension in the plane of the hook was 12 in. (30-cm) for #7 (22-mm) bars and 15 in. (38 cm) for #11 (36-mm) bars. This dimension was chosen so that development length provided for the #7 or the #11 (22 or 36-mm) hooked bars would be shorter than required by Section 12.5.1 of the ACI Code (ACI 318-89)[1] and that bond failure occurred before the steel yielded. In all specimens, concrete cover over the ties was 1½ in. (38 mm). Cover in the plane of the hooks over the tail extension of the anchored beam bars was 2 in. (50 mm).

The 12-in. x 12-in. (30 x 30-cm) column was reinforced with four #8 (25-mm) longitudinal bars and #3 (10-mm) ties at 6 in. (15 cm) outside the joint. The 12 x 15-in. (30 x 38-cm) column was reinforced with six #8 (25-mm) longitudinal bars. In series One, the column contained #3 (10-mm) ties at 6 in. (15 cm) outside the joint and there were signs of anchorage failure of the column bars. Therefore, in the next five series, the spacing of the #3 (10-mm) column ties below the joint was reduced to about 3 in.(7.5 cm). Small anchor plates were welded to some of the column bars at the base of the specimen. In all epoxy-coated hooked bar specimens except 7-90-C* and 11-90-C*, column longitudinal bars were also coated.

The anchored bars extended past the face of the column to accommodate the centerhole hydraulic rams. The length of #7 and #11 (22 and 36-mm) reinforcing bars, measured to the outside end of the hook, was 50 in. (127 cm).

Materials

Reinforcing bars of each size were from the same heat of steel and had a parallel (bamboo) deformation pattern. Beam bars [#7 and #11 (22 and 36-mm)] and column bars [#3 and #8 (10 and 25-mm] were all Grade 60 (410 MPa) and met ASTM A615-87a.[3] The average coating thickness, measured with a dry film thickness gage (Category—Type 1, magnetic pulloff) for all epoxy-coated hooked bars was around 8 mils (0.2 mm).

Three non-air-entrained concrete mix designs were ordered from a ready-mix company, and were proportioned to yield a compression strength of 3, 4, and 8 ksi (21, 28, and 55 MPa). However, proportions of the mixes delivered varied from the design according to the moisture content of the aggregates. For 3 and 4 ksi (21, 28 MPa) batches, water was added before casting to obtain a slump of 5.0 to 6.0 in. (13 to 15 cm). For the 8 ksi (55 MPa) batch, 55 oz/yd^3 (2100 cm^3/m^3) of superplasticizer admixture were added to achieve a slump of 7.0 in. (18 cm).

Slip instrumentation

Slip of the anchored reinforcing bar relative to the concrete was measured using a procedure developed by Minor[4] and used by Marques and Jirsa.[2] A wire was attached to the anchored bar at selected locations. For one of the two anchored bars, slip was measured at two points representing the loaded-end position and the beginning of the standard hook of the anchored bar (Points A and B in Fig. 1). For the second bar, slip was measured only at the loaded-end position. A plastic tube was placed over the entire length of the wire to prevent bonding and to allow free movement of the piano wire. Slip wires extended from the anchored bars to the back surface of the specimen behind the hook where the movement of the wires was measured.

Test setup

The method of loading simulated the reaction conditions at a joint in a frame structure. A schematic elevation and top views of the test frame are shown in Fig. 2. A bending moment was applied at the face of the test specimen by a couple consisting of a tensile force in the test bars (applied by means of two center-hole hydraulic rams) and a compressive force concentrated at a distance of 14 in. (36 cm) below the centerline of the bars. The compression force was applied by a 2-in. (5-cm) thick plate welded to the reaction column simulating a 6-in. (15-cm) deep compression zone of the assumed beam.

The reaction column consisted of two structural channels connected and stiffened by 1-in. thick plates. The steel column was welded to a base plate and bolted to the test floor. To balance the moment imposed by the simulated beam, a horizontal reaction was provided through 1-in. threaded tie rods near the bottom of the reaction column. In the first series, there was a tendency for the test specimen to rotate and bend towards the reaction column. Therefore, in the next five series, a plate was placed between the top of the specimen and the reaction column to prevent excessive rotation of the specimen. Tensile load was generally applied in 1.0- or 2.0-kip (4.5 or 9 kN) increments for #7 (22-mm) bar specimens and in 2.0- or 4.0-kip (9 or 18 kN) increments for #11 (36-mm) bar specimens until bond failure or bar yield occurred.

Additional details of the test program can be found in Reference 5.

MODE OF FAILURE

In nearly all tests, the cracking sequence followed similar patterns. On the side of the specimen, cracks first appeared in the vicinity of the assumed compression zone and extended downward and upward at about 45-deg angles (see Fig. 3). Cracks also appeared almost at the same time in the side cover near the bent portion of the hooked bar. Just before failure, cracks widened and the number increased. Cracks were also seen on the front face of the column spreading horizontally and vertically from the two anchored bars. With the exception of the #7 (22-mm) bar specimens of the second series which yielded, failure was sudden and the load dropped immediately to a fraction of the maximum level.

After testing, spalled side cover was removed from a few specimens to examine cracking and crushing of the concrete in the vicinity of the hook. The following observations were made:

1. Less effort was needed to remove the cover over epoxy-coated hooked bars than uncoated bars because of the lack of adhesion between concrete and epoxy coating.
2. A large portion of side cover was easily removed in specimens with a small cover (7-90-U-SC and 7-90-C-SC), and in normal strength concrete specimens with no ties in the joint region.
3. Soundness of concrete in the hook regions of specimens with ties in the joint region or with high strength concrete, was evident when trying to remove side cover.
4. Concrete deposits remained on the sides of the deformations of uncoated bars. However, epoxy-coated bars were clean and had no concrete residue left on the bar.
5. Close examination of hook regions showed crushing of the concrete at the inner radius of the bend.
6. In all test specimens with 90-degree hooks, horizontal cracks appeared on the back face of the specimen near the tail of the hook at high levels of loading. With large slips and with the tendency of the bar to straighten under tension, the tail end of the hook tended to kick out (or pry against the concrete), thus splitting the concrete cover behind the hook. However, these cracks were very small, implying that a cover of 2 in. over the tail extension as used in all test specimens should be sufficient for design purposes.

TEST RESULTS

The results of the 24 hooked bar specimens, [maximum loads, corresponding loaded-end slips, and bond ratios (coated to uncoated)] are listed in Table 2. Also listed are the maximum loads normalized to 4 ksi (28 MPa) $\sqrt{4/f_c'}$. In general, the results show that epoxy-coated hooked bars developed lower anchorage capacities and larger slips at the same load levels than uncoated hooked bars. Bond ratios varied from 0.76 to 0.94 with an average of 0.84 and a standard deviation of 0.06.

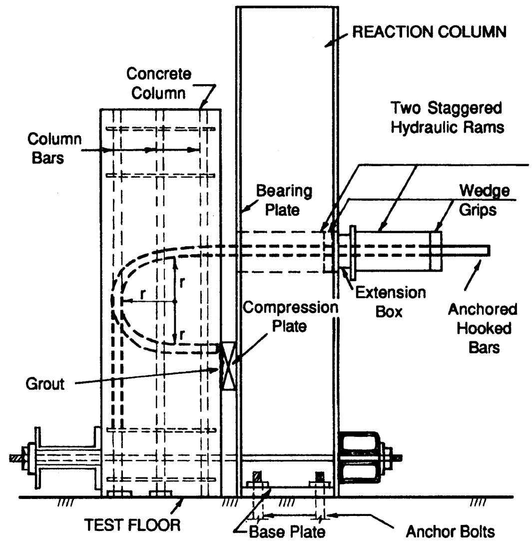

Fig. 2—Schematic of test setup, elevation view

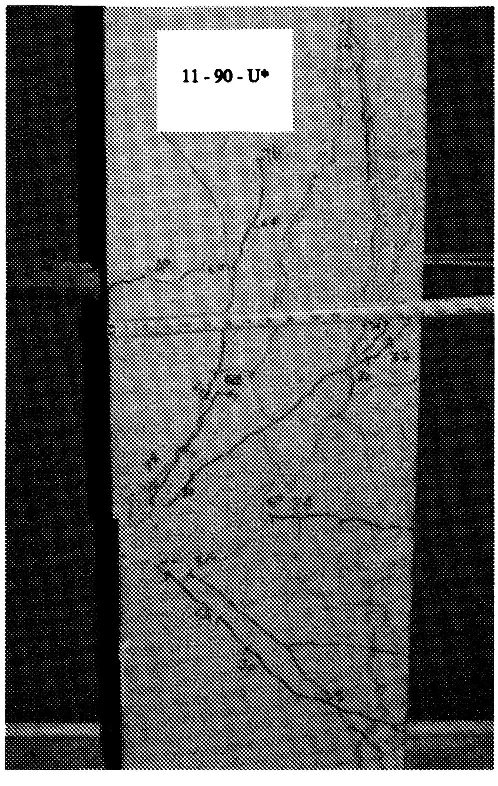

*Fig. 3—Crack pattern of Specimen 11-90-U**

Effect of bar size.

Test results listed in Table 2 show that for the range of the variables investigated, bond ratios (coated to uncoated) varied from 0.77 to 0.87 for the #7 (22-mm) hooked bars and from 0.76 to 0.94 for the #11 (36-mm) hooked bars. Bar size had no effect on the anchorage performance of epoxy-coated hooked bars relative to uncoated hooked bars.

Effect of concrete strength

As shown in Fig. 4, anchorage strength of a #7 (22-mm) or #11 (36-mm) hooked bar, uncoated or epoxy-coated, increased as the concrete strength increased. However, the reduction in anchorage strength of epoxy-coated hooked bars relative to uncoated bars was not greatly affected.

Effect of concrete cover

As shown in Fig. 5, anchorage strength of a #7 (22-mm) hooked bar, uncoated or epoxy-coated, decreased about 8 percent as cover decreased from 3 in. (7.5 cm) to 1¾ in. (2.5 cm). Reduced concrete cover caused a reduction in lateral confinement of the joint region and its restraint against splitting. Variation in concrete cover did not affect the reduction in anchorage strength of epoxy-coated bars relative to uncoated bars. Bond ratios (coated to uncoated) for both covers were the same, 0.77.

Effect of joint ties

In general, ties in the region of the hooked bar increased ultimate load at failure of uncoated and epoxy-coated #7 (22-mm) and #11 (36-mm) hooked bars. As shown in Fig. 6, anchorage strength of #11 (36-mm) hooked bars increased as the spacing of the #3 (10-mm) ties in the joint region decreased with all other conditions (concrete strength, concrete cover, and hook geometry) identical. With loads normalized to a concrete strength of 4000 psi, anchorage capacity of #11 (36-mm) uncoated 90-degree hooked bars, relative to the case with no joint ties, increased approximately 25 percent with #3 (10-mm) ties at 6 in. (15 mm) or about four times the diameter of the anchored bar and 36 percent with #3

Table 2—Test results of hooked bar tests

Specimen notation	f_c', ksi	P_{max}, kips	f_{su}, ksi	Lead slip, in.	P_{max}, kips Normalized at f_c' = 4 ksi	Bond ratio u (coated) / u (uncoated)
7-90-U*	5.4	36.7	61.2	—	31.6	—
7-90-C*	5.4	28.3	47.2	—	24.3	0.77
11-90-U*	5.4	75.0	48.0	—	64.6	—
11-90-C*	5.4	66.3	42.5	—	57.1	0.88
7-90-UT4	3.7	39.2	Y†	0.075	—	—
7-90-C-T4	3.7	36.0	Y†	0.090	—	—
11-90-U-T6	3.7	71.8	46.0	0.120	74.7	—
11-90-C-T6	3.7	68.4	43.9	0.132	70.1	0.94
7-180-U-T4	3.9	34.6	57.7	0.060	35.0	—
7-180-C-T4	3.9	30.2	50.3	0.082	30.6	0.87
11-180-C-T6	3.9	**	—	—	—	—
11-180-C-T6	3.9	66.3	42.5	0.120	67.2	—
7-90-U	2.57	26.0	43.33	0.024	32.4	—
7-90-C	2.57	21.0	35.0	0.050	26.2	0.81
11-90-U	2.57	48.0	30.8	0.030	59.9	—
11-90-C	2.57	40.6	26.0	0.038	50.7	0.85
11-90-U-SC‡	4.23	30.0	49.9	0.029	29.2	—
11-90-C-SC‡	4.23	23.11	38.5	0.033	22.5	0.77
11-90-U-T4	4.23	83.2	53.3	0.110	81.0	—
11-90-C-T4	4.23	66.3	42.5	0.074	64.5	0.80
11-90-U-HS	7.2	73.8	47.3	0.040	—	—
11-90-C-HS	7.2	55.7	35.7	0.046	—	0.76
11-180-U-HS	7.2	58.9	37.7	0.027	—	—
11-90-C-HS	7.2	54.1	34.7	0.075	—	0.92

*Slip measurements of the four specimens of the first series were not reliable.

†Y = yielded bar.

‡Measured side concrete cover over the hooked bar was 1.75 in. (4.5 cm). In all other test specimens, the measured side cover was approximately 3 in. (7.5 cm).

**Specimen could not be tested to failurre.

1 ksi = 6.895 MPa; 1 kip = 4.448 kN; 0.1 in. = 25.4 mm.

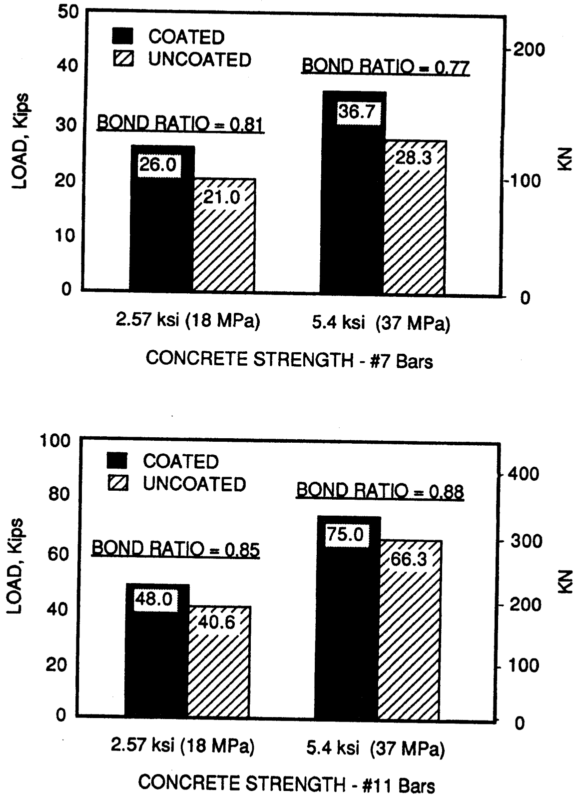

Fig. 4—Effect of concrete strength on anchorage capacities of uncoated and epoxy-coated 90-deg hooked bars

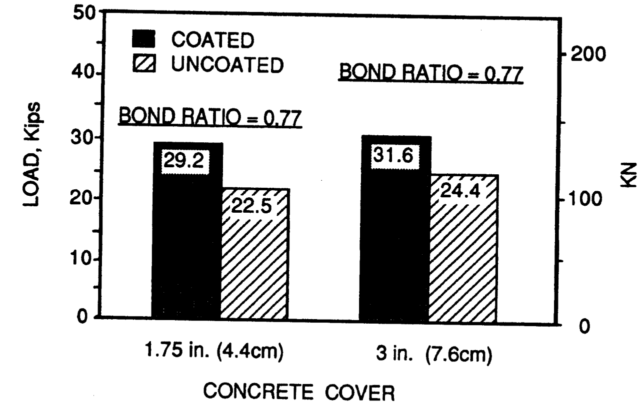

Fig. 5—Effect of concrete cover on anchorage capacity of #7 (22 mm) uncoated and epoxy coated 90-deg hooked bars. Loads aare normalized to f_c' *= 4 ksi (28 MPa)*

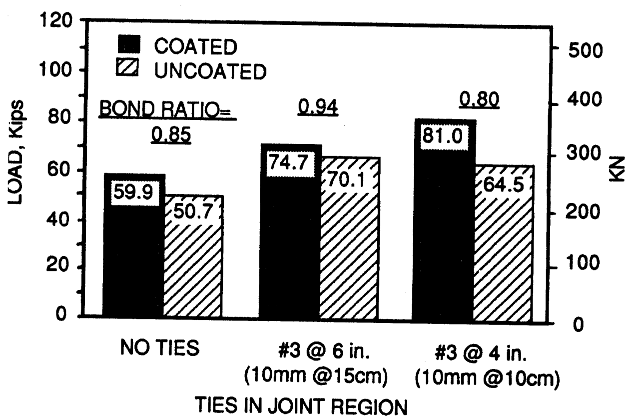

Fig. 6—Effect of joint ties on anchorage capacity of #11 (29 mm) uncoated and epoxy coated 90-deg hooked bars. Loads aare normalized to f_c' *= 4 ksi (28 MPa)*

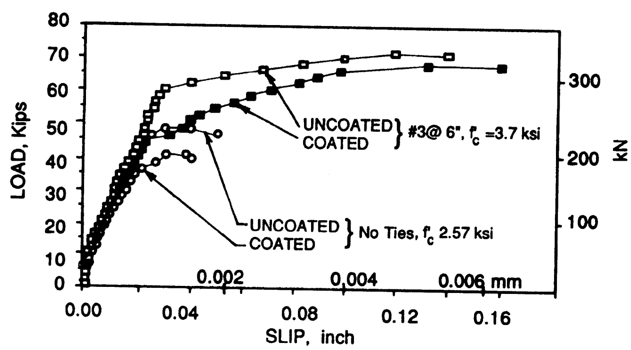

Fig. 7—Effect of lateral reinforcement through joint on load-slip behavior of #11 (36 mm) uncoated and epoxy-coated 90-deg hooked bars

(10-mm) ties at 4 in. at about three times the bar diameter in the joint region. For #11 (36-mm) epoxy-coated hooked bars, increases in anchorage capacity were 38 and 27 percent.

Section 12.5.3.3 of ACI 318-89[1] modifies the basic development length of a hooked bar, #11 (36-mm) or smaller, by a factor of 0.8 if the hook is enclosed with ties at a spacing not greater than $3d_b$. This reflects an assumed increase in anchorage strength of 25 percent (1/0.8 = 1.25). The test results of #11 (36-mm) hooked bars indicate a similar increase in strength with a tie spacing of about $3d_b$ in the joint region. Taking into consideration the small number of tests included in this study and the wide scatter of bond results, the ACI recommendation seems appropriate.

Test results listed in Table 2 show that bond ratios (coated to uncoated) varied from 0.76 to 0.92 when no ties were present in the joint region and from 0.8 to 0.94 when ties were present.

Moreover, the presence of ties in the joint region improved load-slip behavior of uncoated and epoxy-coated hooked bars. As shown in Fig. 7, the presence of joint ties improved both the strength and deformation capacities at failure of #11 (36-mm) hooked bars. Slips at failure of uncoated and coated bars were more than twice the slips when no ties were present in the joint region.

Effect of hook geometry

Bond ratios (coated to uncoated), listed in Table 2, do not indicate a major influence of hook geometry on relative capacities of uncoated and epoxy-coated hooked bars. For 180-degree hooked bars, bond ratios were 0.87 and 0.92 for two different cases. Bond ratios for the 90-degree hooked bars varied from 0.76 to 0.94.

COMPARISON WITH MARQUES AND JIRSA TEST RESULTS

In Table 3, results of some of the uncoated hooked bar tests are compared with results of similar tests done by Marques and Jirsa.[2] The only difference between the two sets of tests is the column axial load applied in the Marques and Jirsa tests. Marques and Jirsa concluded that the influence of column axial load on load-slip behavior was negligible. Loads at failure for different tests are normalized for = 4 ksi. The differences between the results of comparative tests are within 15 percent. Taking into consideration the scatter of bond data and the presence of applied axial loads in one set of tests, differences are minimal.

DESIGN RECOMMENDATIONS

Based on the test results, a 20 percent increase in the basic development length is recommended for coated hooked bars as indicated in Figure 8, which shows the variation in bond strength for coated vs. uncoated bars tested in this study. An addition to Sec. 12.5 of ACI 318-89[1] is suggested:

12.5.3.6—Epoxy-coated reinforcement 1.2

CONCLUSIONS

Based on the mode of failure of the twenty-four hooked bar specimens, the anchorage capacities, and the load-slip characteristics, the following conclusions are drawn:

1. Number 11 (36-mm) hooked bars (coated or uncoated) were consistently less stiff (more slip at a given stress level) than #7 (22-mm) hooked bars.

2. Anchorage capacities and load-slip stiffness of #7 (22-mm) and #11 (36-mm) hooked bars increased with concrete strength. The use of $\sqrt{f_c'}$ was appropriate for reflecting the influence of concrete strength.

3. Ties in the beam-column joint region improved both the anchorage capacity and the load-slip behavior of both coated and uncoated bars. Bars failed at higher loads and with larger slip or deformation capacity before failure.

4. Ninety-degree hooked bars developed slightly larger anchorage capacities than 120-degree hooked bars. Also, 90-degree hooked bars were stiffer than 180-degree hooked bars at a high load levels prior to failure. Coating did not influence these comparisons.

5. Epoxy-coated hooked bars consistently developed lower anchorage capacities and load-slip stiffnesses than companion uncoated hooked bars.

6. Relative anchorage strength and load-slip behavior of uncoated and epoxy-coated hooked bars were independent of bar size, concrete strength, side concrete cover, or hook geometry.

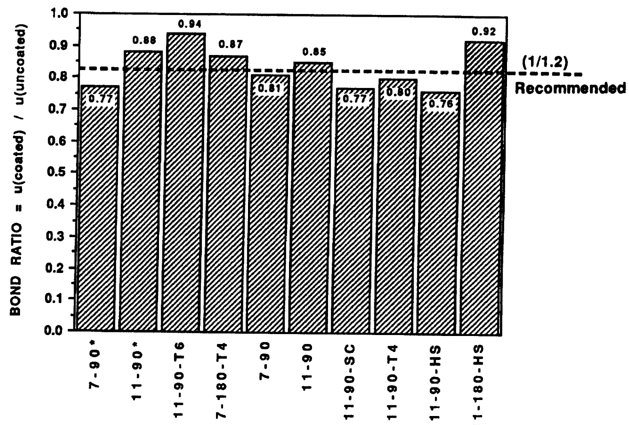

Fig. 8—Variation of bond ratios (coated to uncoated) for hooked bar specimens

Table 3—Comparison of test results of Marques and Jirsa[2]

Specimen notation	Bar size	Angle of bend, deg	Ties in joint region	Column size	Column axial load, kips	P_{max}, kips normalized at f_c' =4 ksi
7-90-U*	#7	90	—	12 x 12	0	31.6
J7-90-12-1-H†	#7	90	—	12 x 12	420	36.5
7-180-U-T4	#7	180	#3 @ 4 in.	12 x 12	0	35.0
J7-180-12-1-H†	#7	180	—	12 x 12	425	35.1
11-90-U*	#11	90	—	12 x 15	0	64.6
J11-90-15-1-L†	#11	90	—	12 x 15	154	74.7
711-90-15-1-H†	#11	90	—	12 x 15	540	67.7
11-90-U-T6	#11	90	#3 @ 6 in.	12 x 15	0	74.7
J11-90-15-3-L†	#11	90	#3 @ 5 in.	12 x 15	150	87.8
11-90-U-T4	#11	90	#3 @ 4 in.	12 x 15	0	81.0
J11-90-15-3a-L†	#11	90	#3 @ 2.5 in.	12 x 15	175	96.3

† Marques and Jirsa tests.

Note: Nominal side concrete cover over hooked bars in all tests included in this comparison was 2⅞ in (7 cm).

#3 = 10 mm; # 7 = 22 mm' #11 = 36 mm; 1 ksi = 6.895 MPa; 1 in. = 25.4 mm.

7. Ties in the joint region did not improve markedly the relative anchorage strength of companion uncoated and epoxy-coated hooked bars. The average bond ratio for specimens with ties in the joint region was 0.87 with a standard deviation of 0.07. For all hooked bar specimens tested, the average bond ratio was 0.84 with a standard deviation of 0.06.

8. Based on the test results, a 20 percent increase in the basic development length of an uncoated hooked bar is recommended for epoxy-coated hooked bars.

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NOTATION

d_b = diameter of reinforcing bar
f_c' = compressive strength of concrete
f_{su} = ultimate stress in reinforcing bar
ℓ_{hb} = basic development length of standard hook in tension
P_{max} = maximum applied load

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