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Bond of Concrete Reinforcing Bars

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The tests reported were made to compare the resistance to slip in concrete (bond) of deformed bars when tested in beams and companion pull-out specimens, to secure information on the effects of size of bar, the type of deformations on the bars, and the strength of concrete on the bond. The bars were cast in a horizontal position in all test specimens. The variables were depth of concrete under the bar, length of embedment of the bar in the concrete, strength of concrete, and diameter of bar. Slip of the bar was measured at the loaded and free ends. Three tests were made each with 2 in. of concrete under the bar, with 15 in. of concrete under the bar, and with 8-, 12-, and 16-in. embedments.

Bond strengths for the beams and the pull-out specimens were affected similarly by changes in the geometry of the bars and the bond test specimens. They were greater when the bars were near the bottom than when they were near the top of the specimens as cast. The highest bond strengths were obtained with bars having deformations conforming to suggested requirements for maximum spacing and minimum height and providing ratios of shearing to bearing areas less than 10, usually less than 6.

I. Introduction

The tests reported in this paper were made at the National Bureau of Standards under a Research Fellowship for the Committee on Reinforced Concrete Research of the American Iron and Steel Institute. This Committee consists of a representative from each of the principal producers of concrete reinforcing bars.

The primary purpose of the tests was to determine the bond value of concrete reinforcing bars when tested in beam specimens in accordance with the "Proposed test procedure to determine relative bond value of reinforcing bars" of Committee 208, Bond Stress, of the American Concrete Institute.[2] Additional objectives were to determine the correlation between the results of the beam and the pull-out tests made at the same time and under identical conditions, to secure information as to the influence of size of bar and strength of concrete on bond, and to test the experimental designs of deformations by member companies in their efforts to produce bars having bond resistance approaching the maximum consistent with economical commercial production.

II. Materials

1. Reinforcing Bars

The bars in this series of tests were nominally ½ in. round, ⅞ in. round, and 1⅛ in. square in size. The areas of the bars and details of the deformations are given in table 1. All ⅞-in. bars, except bar No. 16, and one ½-in. bar (No. 15) are illustrated in figure 1. Bar No. 16 was the same as bar No. 11 except for the height of deformations. The bars nominally 1⅛ in. in size, with two exceptions described below, were round in cross section with areas equal to 1⅛ in. square bars. Bars Nos. 2 and 18 were square in cross section and of a type similar to the ⅞ in. round bar No. 2.

With the exception of the plain bar (No. 9), all bars were deformed and were similar in type to those included in a series of tests previously reported,[3] but some had improved deformations. The plain bar and one unimproved deformed bar (No. 2) of a type heretofore in general use were

[1] Research Associate at the National Bureau of Standards, representing the American Iron & Steel Institute.

[2] Proposed test procedure to determine relative bond value of reinforcing bars, J. Am. Concrete Inst. **41**, 273 (Feb. 1945).

[3] A. P. Clark Comparative bond efficiency of deformed concrete reinforcing bars, J. Research NBS **37**, 399 (1946) RP1755.

included in these tests for the purpose of comparison.

TABLE 1. *Detail dimensions of bars*

Bars			Deformations				
Size	No.	Area	Spacing	Average height	Bearing area	Shearing area	Ratio of shearing to bearing area
in.		*in.²*	*in.*	*in.*	*in.²/in.*	*in.²/in.*	
½	2	0.200	1.234	0.018	0.013	0.835	64.2
½	5	.200	0.371	.038	.139	1.225	8.7
½	6	.198	.368	.027	.100	1.160	11.6
½	8	.200	.250	.031	.191	1.149	6.0
½	11	.196	.209	.028	.217	1.382	6.4
½	13	.202	.443	.030	.094	1.306	13.9
½	15	.200	.206	.041	.245	0.795	3.2
⅞	1	.603	.671	.056	.148	1.792	12.1
⅞	2	.599	1.412	.032	.040	1.621	40.1
⅞	3	.591	0.667	.060	.185	2.063	11.2
⅞	4	.599	.656	.050	.177	2.085	11.8
⅞	5	.599	.581	.057	.232	2.313	10.0
⅞	6	.606	.606	.058	.248	2.629	10.6
⅞	7	.610	.375	.033	.161	2.208	13.8
⅞	8	.610	.380	.050	.355	2.100	5.9
⅞	[a] 9	.597	-----	-----	-----	-----	----
⅞	10	.578	.398	.047	.276	1.981	7.2
⅞	11	.615	.368	.045	.305	1.930	6.3
⅞	12	.605	.296	.040	.327	1.867	5.7
⅞	13	.594	.762	.070	.242	2.460	10.2
⅞	14	.605	.434	.062	.359	1.956	5.5
⅞	17	.594	.633	.054	.207	2.234	10.8
1⅛	2	1.268	1.735	.034	.069	3.281	47.6
1⅛	5	1.245	0.921	.074	.282	3.500	12.4
1⅛	6	1.210	.944	.063	.263	3.139	11.9
1⅛	8	1.268	.544	.072	.522	3.373	6.5
1⅛	11	1.269	.525	.052	.385	3.298	8.6
1⅛	13	1.254	1.115	.078	.416	5.281	12.7
1⅛	15	1.278	0.517	.083	.479	2.906	6.1
1⅛	16	1.274	.475	.071	.589	2.888	4.9
1⅛	18	1.269	1.255	.036	.084	2.737	32.7

[a] Plain, no deformations.

2. Concrete

Concrete was machine mixed and rodded when placed in the molds. One brand of cement, from the same mill, which met the current ASTM Standard Specification for portland cement of type 1 was used throughout.

Coarse aggregate was Potomac River gravel ranging in size from No. 4 to 1 in. The fine aggregate was Potomac River sand described in the previous series (see footnote 2). There were three concretes of different mixes, which are hereafter referred to as 6,000-, 3,500-, and 2,000-lb concretes. The first concrete proportioned by weight in the ratio 1:1.4:2.0 with water-cement ratio of 5.15 gal per sack gave an average compressive strength for 6- by 12-in. cylinders at 28 days of 6,030 lb/in.² and an average slump of 5.5 in. The second concrete proportioned 1:2.91:4.04 with 8.7 gal of water per sack averaged 3,570 lb/in.² with a slump of 4.8 in. The third concrete proportioned 1:3.97:5.15 with 11.77 gal of water per sack averaged 1,840 lb/in.² with a slump of 4.5 in.

III. Description of Test Specimens

Beam specimens were 8 by 18 in. in cross section and 78 in. in over-all length. Two notches 6 in. long and 3 in. high near each end exposed the reinforcing bar. Half of the specimens were cast with the bar held 2 in. from the bottom of the mold and the other half with the bar held 2 in. from the top. The molds were of steel and fabricated in accordance with the details given in the report of the ACI Committee 208 (see footnote 2).

Pull-out specimens were 8 by 9 in. in cross section and 8, 12, and 16 in. in length. Two specimens were cast with the bars in a horizontal position, in a mold 18 in. in depth with one bar held near the bottom and one near the top comparable to the positions in the beams. At the end of 2 days, the block was removed from the mold and separated into two specimens. The molds were made of heavy steel sections and sealed to prevent leakage.

IV. Testing Procedure

The beams were tested in a 600,000-lb capacity hydraulic testing machine on supports 72 in. apart, the supports being a roller at one end and a spherical bearing unit at the other end. A beam in position for test with gages attached is shown in figure 2. The load was applied through a steel loading beam with a roller at one load point and a spherical bearing unit at the other load point. The load points were adjusted at 8, 12 and 16 in. from the supports. The distances of the load points from the supports thus corresponded to the three lengths of embedment of the bar. The load points in each case were directly over the outer edges of the 6-in. notches, which exposed the bar. In these notches two yokes were clamped into drilled contact points on 5-in. centers on each side of the bar. Dial gages attached to the yokes permitted measurement of the strain in the bar. The gage on the reaction side of the notch bore on a steel angle clip attached with a screw to the concrete at the edge of the notch; this gage measured the slip of the bar directly under the load (loaded end slip). Dial gages at each end of the beam, held in position by steel yokes, clamped to the concrete, measured the slip at the end (free end slip) of the bar. Deflection at the center of the beam was measured by a dial gage supported by an aluminum bar, whose ends were attached to the sides of the beam over the supports; this gage bore on an angle clip attached with a screw to the concrete. The specimens that were cast with the bar held 2 in. from the top were turned upside down in testing. The beams were removed from the mold 5 days after casting and kept moist until tested at the age of 28 to 30 days.

Pull-out specimens were tested in a 60,000-lb capacity universal hydraulic testing machine. The specimen, shown in figure 3, was seated on a rubber cushion on two segments of a 2-in. base plate attached to a spherical bearing block. Slip of the bar was measured with 0.0001-in. micrometer dial gages and estimated to 0.00005 in. At the loaded end two dial gages were held by a steel bar attached to the bottom face of the specimen by bolts secured into inserts cast in the specimen. The gages were in contact with a steel yoke fastened to the reinforcing bar 1 in. below the surface of the concrete. The support bar for the gages and the yoke were free to move in the recess in the base plate. The average of the two gage readings indicated the amount of movement of the point on the reinforcing bar at which the yoke was attached with reference to the lower face of the concrete. To give the slip at the face of the concrete (slip at loaded end), the gage readings were corrected for the elongation of the reinforcing bar in the 1-in. distance between the point of attachment of the yoke and the face of the concrete.

The slip at the free end was read directly from the gage mounted on a support, seated in plaster, on the top of the specimen with the point of the dial resting on the planed end of the bar.

With the ⅞-in. bars, 18 beam and 18 pull-out tests were made for each type of bar, three each with the bar in the bottom and top positions and with 8-, 12-, and 16-in. embedments. With ½-in. and 1⅛-in. bars, 12 tests each were made, three each in the bottom and top positions and with 8- and 12-in. embedments for the ½-in. and with 12- and 16-in. embedments for the 1⅛-in. bar.

V. Results and Discussions

Beams generally failed in bond, although with the longer embedments diagonal tension failure combined with bond failure occurred with some specimens. The pull-out specimens failed by splitting of the concrete in all cases except with the plain bar.

The relation of bond stress to slip of bar as shown by the curves and the comparative charts is based in all cases, unless otherwise shown, on the average results for all tests and all lengths of embedment of the bar and for 3,500-lb concrete.

The bond-slip relation of ⅞-in. bars in beams, as measured at the loaded and free ends and for bottom and top cast bars, is shown in figures 4, 5, 6, and 7. The deflection at the center of beams with bottom cast bars for increasing loads for each of the three embedments of the bar is shown in figures 8, 9, and 10. Typical crack patterns after failure of the beam are shown in figures 11 and 12. The bond-slip relation of ⅞-in. bars in pull-outs, for loaded and free ends and for bottom and top cast bars, is shown in figures 13, 14, 15, and 16.

Authorities considering the allowable unit stresses for bond to be permitted in design have used, by applying a suitable factor of safety, the average of bond stresses developed in tests at a slip of 0.01 in. at the loaded end and 0.005 in. at the free end. Figure 17 represents the bond stresses at loaded end slip of 0.01 in. and free end slip of 0.005 in. and the average of two as determined by beam and pull-out tests of ⅞-in. bottom and top cast bars.

The average performance of a bar through a range of slip values was used to obtain a comparison of bond developed in beam specimens with that in pull-out specimens cast at the same time. The bond stresses for slips of 0.0005, 0.001, 0.002, 0.003, 0.004, 0.005. 0.0075, and 0.01 in. at the loaded end were totaled for each and divided by the number of slip values to give an average value. Slips of 0.00005, 0.0001, 0.0005, and 0.001 in. were used in a similar manner for free end comparison. The results for loaded end and free end slips, on the basis outlined above for all ⅞-in. bars tested in both beam and pull-out specimens, shown in figure 18, indicated that the pull-out tests fairly represent the relative bonding efficiency of the bars. In table 2 the average values, as above, at the loaded end for each embedment of the bar as developed in pull-outs is listed and in table 3 the same information as developed in beams. Figure 19 gives a comparison of all bars in the series as tested in pull-outs for slips at the loaded end. Although the results for loaded and free end slips of top cast bars and free end slips of bottom cast bars were not as consistent as the results for loaded end slips of bottom cast bars, the load-slip relations were of similar form and show a consistent pattern for all tests in both types of specimens.

TABLE 2. *Average bond stress of pull-outs for slips of 0.0005, 0.001, 0.002, 0.003, 0.004, 0.005, 0.0075, and 0.01 in. at the loaded end*

Bar No.	Bond stress, lb/in.^{2}							
	7/8-in. Bottom cast				7/8-in. Top cast			
	Embedment				Embedment			
	8 in.	12 in.	16 in.	Avg.	8 in.	12 in.	16 in.	Avg.
1	435	274	222	310	257	147	151	185
2	350	291	223	288	161	104	102	122
3	426	301	224	317	224	154	172	183
4	456	351	235	347	308	175	172	218
5	498	330	236	355	258	254	153	222
6	407	357	220	328	305	223	159	228
7	445	337	258	347	208	227	201	212
8	543	390	291	408	437	289	210	312
9	325	176	168	223	138	84	97	106
10	525	360	290	392	313	176	196	228
11	531	392	258	394	399	282	233	305
13	428	354	232	338	219	269	129	206
14	480	358	272	370	438	361	264	354
17	436	295	221	318	378	195	159	244
	1/2-in. Bottom cast				1/2-in. Top cast			
2	319	231	---	275	211	106	---	158
5	426	282	---	354	344	169	---	256
6	458	286	---	372	201	206	---	204
8	496	304	---	400	320	314	---	317
11	409	312	---	360	418	274	---	346
13	391	247	---	319	150	120	---	135
15	475	342	---	408	466	309	---	387
	1 1/8-in. Bottom cast				1 1/8-in. Top cast			
2	---	268	192	230	---	194	144	169
5	---	336	264	300	---	226	192	209
6	---	177	237	207	---	177	190	184
8	---	362	290	326	---	304	278	291
13	---	299	261	275	---	242	133	188
15	---	388	279	334	---	348	264	306
16	---	365	262	313	---	277	247	262
18	---	321	198	260	---	193	170	181

TABLE 3. *Average bond stress in beams for slips of 0.0005, 0.001, 0.002, 0.003, 0.004, 0.005, 0.0075 and 0.01 in. at the loaded end*

Bar No.	Bond stress, lb/in.^{2}							
	7/8-in. Bottom cast				7/8-in. Top cast			
	Embedment				Embedment			
	8 in.	12 in.	16 in.	Avg.	8 in.	12 in.	16 in.	Avg.
1	424	336	242	334	226	182	160	189
2	272	244	205	240	114	97	98	103
3	431	359	250	347	215	192	143	183
4	435	344	282	354	203	217	183	201
5	460	350	287	366	177	220	212	203
6	431	345	258	345	208	193	166	189
7	454	361	259	358	171	152	158	160
8	561	412	292	422	379	207	208	265
9	228	188	194	203	---	---	---	---
11	571	416	325	437	259	251	233	248
	1/2-in. Bottom cast				1/2-in. Top cast			
2	191	217	---	204	73	79	---	76
6	403	277	---	340	202	196	---	199
	1 1/8-in. Bottom cast				1 1/8-in. Top cast			
2	---	213	195	204	---	161	151	156
6	---	361	287	324	---	201	191	196

The bond-slip relation of the 1/2-in. and 1 1/8-in. bars in pull-outs for loaded and free ends and bottom and top cast bars is shown in figures 20 to 27. The 1/2-in. bars were round, whereas the 1 1/8-in. bars were round in section with areas equal to that of a 1 1/8 in. square, except bar No. 2, which was a 1 1/8 in. square.

Results of tests of 1/2-, 7/8-, and 1 1/8-in. bars of type No. 6 are shown by the bond slip curves of figures 28, 29, 30, and 31 for loaded and free ends, bottom and top cast and beam and pull-out specimens.

Pull-out tests of 1/2- and 1 1/8-in. bars of type No. 6 in three concrete strengths are shown by the curves of figures 32, 33, 34, and 35.

The Committee on Reinforced Concrete Research of the American Iron and Steel Institute after a study of the results of the first series of bond tests (see footnote 3) sponsored the "Tentative specification for minimum requirements for the deformations of deformed steel bars for concrete reinforcement" ASTM Designation: A305–49. "Data from the present series of tests indicated two desirable revisions" of the above Tentative specifications; one changing the maximum average spacing of the deformations to seven-tenths of the nominal size of the bar, and the other changing the minimum height of deformations to $4\frac{1}{2}$ percent of the nominal size for $\frac{5}{8}$-in. bars and to 5 percent for bars $\frac{3}{4}$ in. and larger. "The Tentative Specification, including the revisions, has now been adopted as a standard ASTM designation A305–49."

The following bars met the requirements of ASTM A305–49: $\frac{7}{8}$-in. bars 5, 6, 8, 10, 11, and 14; $\frac{1}{2}$-in. bars 8, 11, 14, and 15; $1\frac{1}{8}$-in. bars 8, 14, 15, and 16.

VI. Summary

Bond tests were conducted on both beam and pull-out specimens in which the bars were cast in a horizontal position. The specimens provided three lengths of embedment and two different depths of concrete under the bars. Slip of the bar was measured at both the loaded and the free end.

The results of the tests with both types of specimens were as consistent as expected for bond tests. The least consistent data were those pertaining to the slips at the free ends of the bars and for the bars cast in the top position.

The correlation between the results of the beam and the pull-out tests was such as to indicate that pull-out tests can give reliable estimates of the bonding efficiency of deformed reinforcing bars. Although the data obtained from the two types of specimens did not always rate the bars in the same order, the differences in ratings were usually too small to be of practical significance; moreover, the relations between load and slip were of similar form and the general behavior of the bars was similar in the two types of tests. The plain bar gave the least bond; the old type of deformed bar gave a somewhat higher bond and the rest of the bars gave still higher values, with those meeting ASTM Specification A305–49 showing the highest bond.

The ratings of the bars were based upon the average performances for a range of slips at both the loaded and free ends, for either two or three lengths of embedment and with 2 or 15 in. of concrete beneath the bar as cast. The deformations of the bars that had the highest values of bond had bearing areas equal to or greater than the bearing area provided under ASTM A305–49 limitations of maximum spacing, minimum height and length of deformations, and the ratio of the shearing areas to bearing areas were less than 10. These results confirmed the previous observation that for good bond a maximum ratio of the shearing to bearing areas of 5 or 6 is desirable provided requirements of A305-49 are met.

The bond strengths obtained with bars conforming to the proposed specifications were much greater than those developed by bars in common use at the time Committee 318 on Standard Building Codes of the American Concrete Institute determined the allowable bond stresses of the building code requirements for reinforced concrete. The superior performance of the bars of improved types was most marked when the conditions were least favorable for obtaining a strong bond, that is, with the bars in top position in the beams as cast.

Albert E. Holbrook, Research Associate, was in charge of much of the laboratory procedure and the reduction of the very extensive data developed in these tests. Timothy Miles, Jr., laboratory assistant, carried out the laboratory work with ingenuity and care. Acknowledgement is made and appreciation expressed for the willing cooperation and very helpful advice and assistance of the Bureau staff.

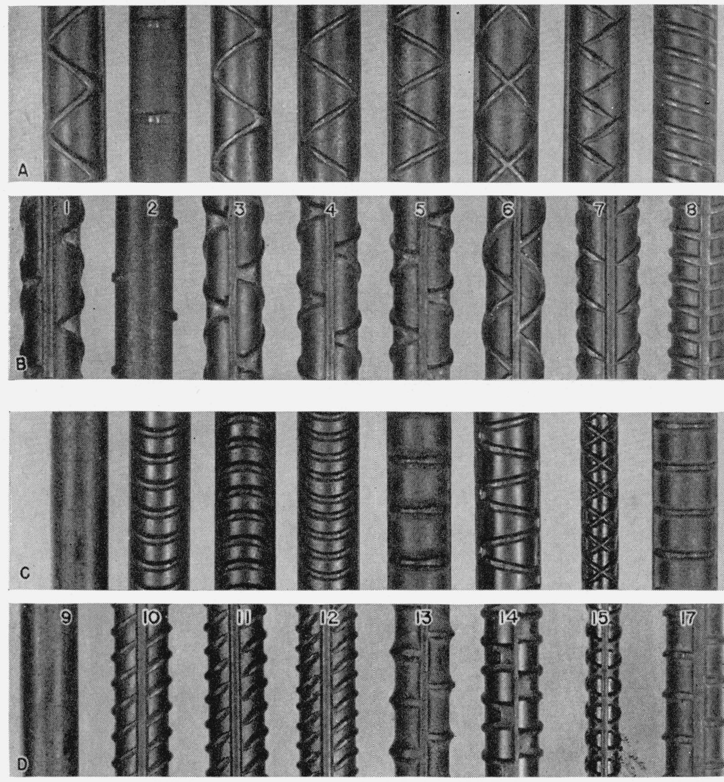

FIGURE 1. *Types of bars tested.*

A, Front view; B, side view of A; C, front view; D, side view of C.

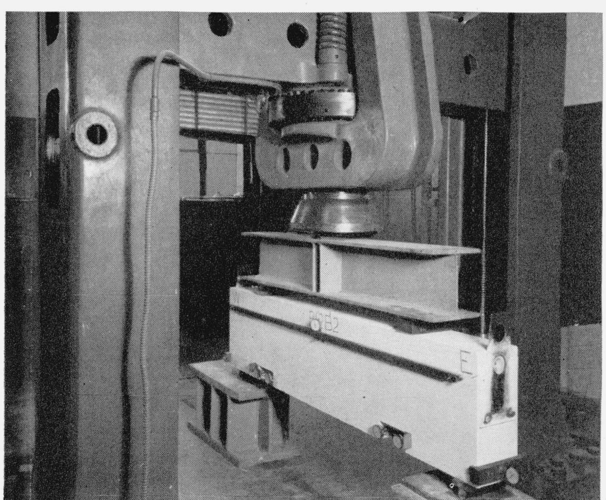

FIGURE 2. *Beam specimen in testing machine.*

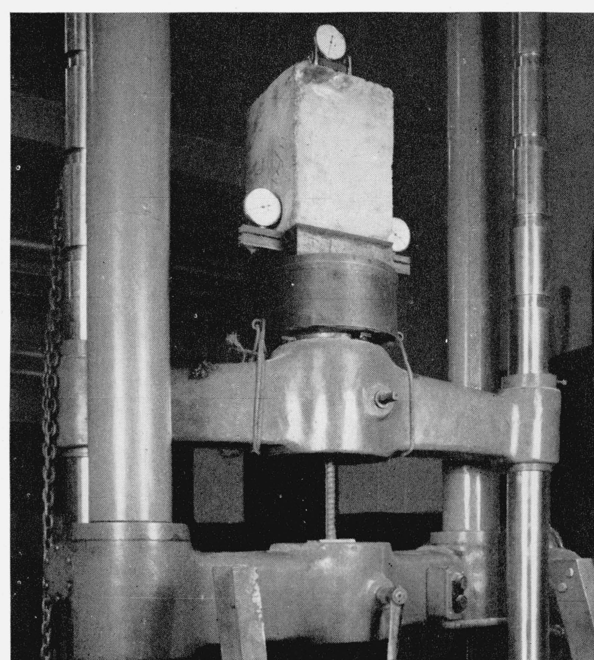

FIGURE 3. *Pull-out specimen in testing machine.*

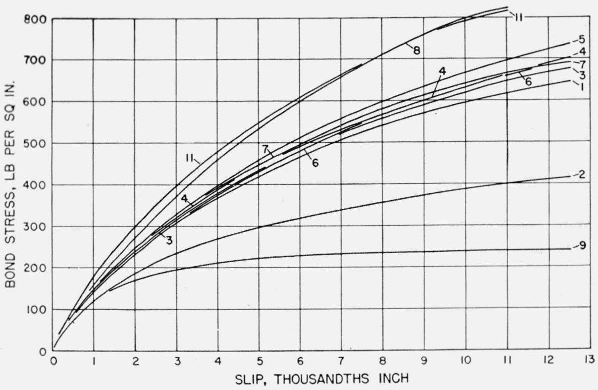

FIGURE 4. *Bond-slip curves for ⅞-in. bottom bars in beams.*

Slip measured at loaded end.

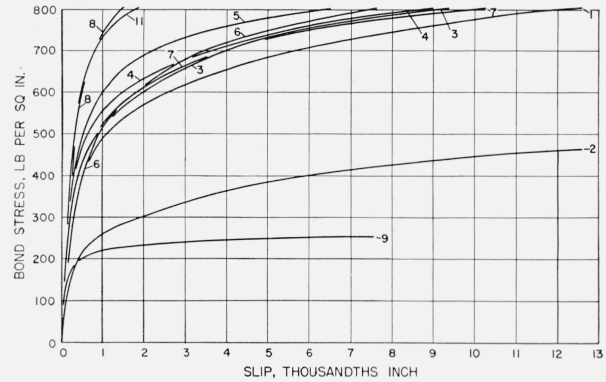

FIGURE 5. *Bond-slip curves for ⅞-in. bottom bars in beams.*

Slip measured at free end.

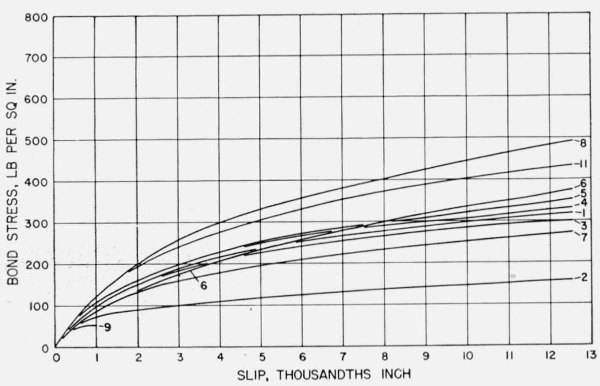

FIGURE 6. *Bond-slip curves for ⅞-in. top bars in beams.*

Slip measured at loaded end.

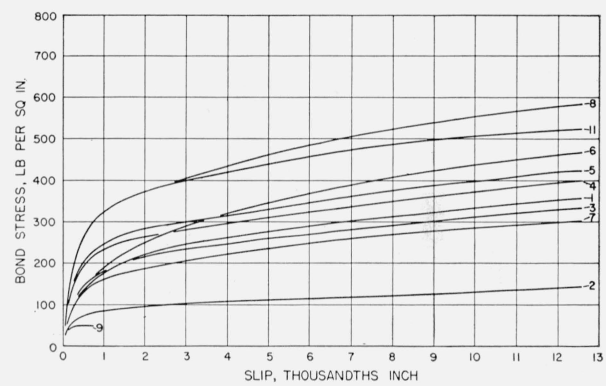

FIGURE 7. *Bond-slip curves for ⅞-in. top bars in beams.*

Slip measured at free end.

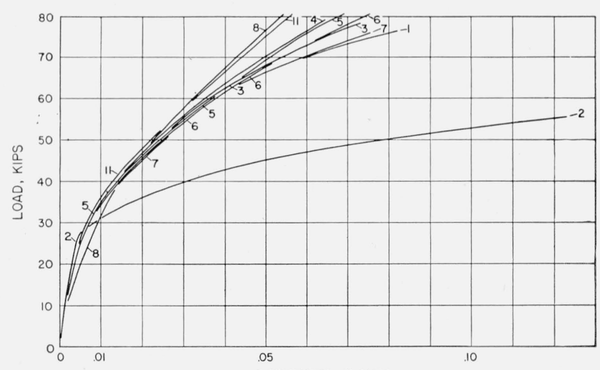

FIGURE 8. *Deflection curves for beams with ⅞-in. bottom bars.*

Embedded 8 in.

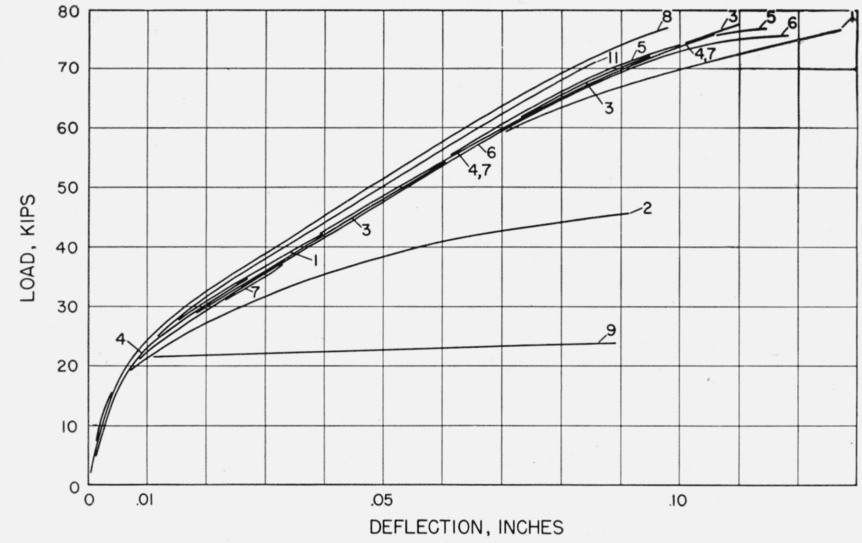

FIGURE 9. *Deflection curves for beams with 7/8-in. bottom bars.*

Embedded 12 in.

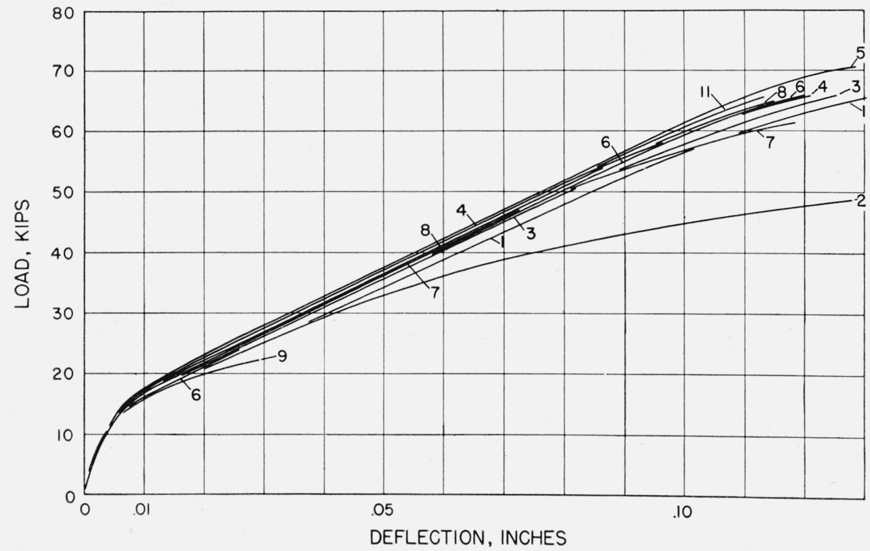

FIGURE 10. *Deflection curves for beams with 7/8-in. bottom bars.*

Embedded 16 in.

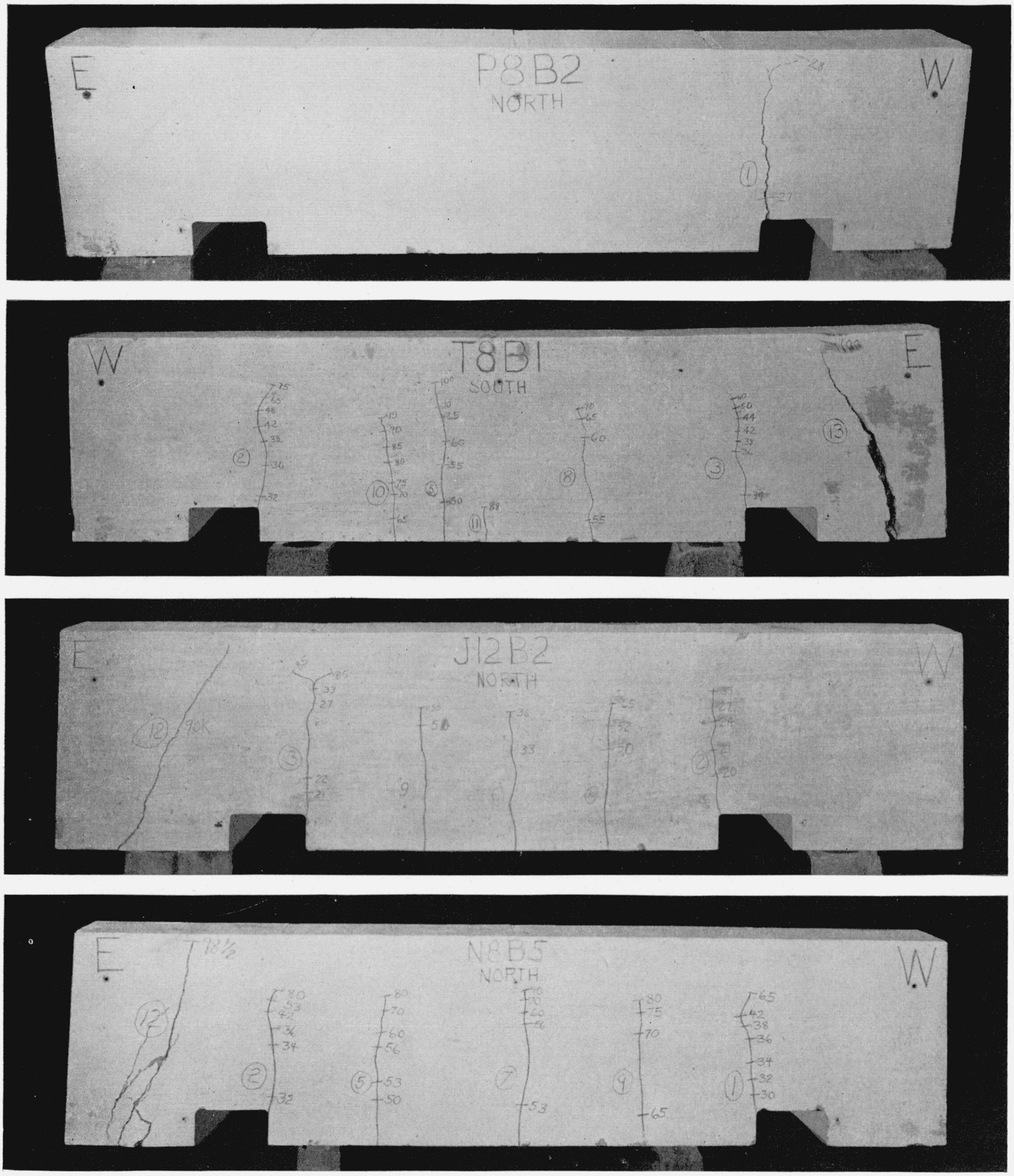

FIGURE 11. *Typical beam cracks at failure.*

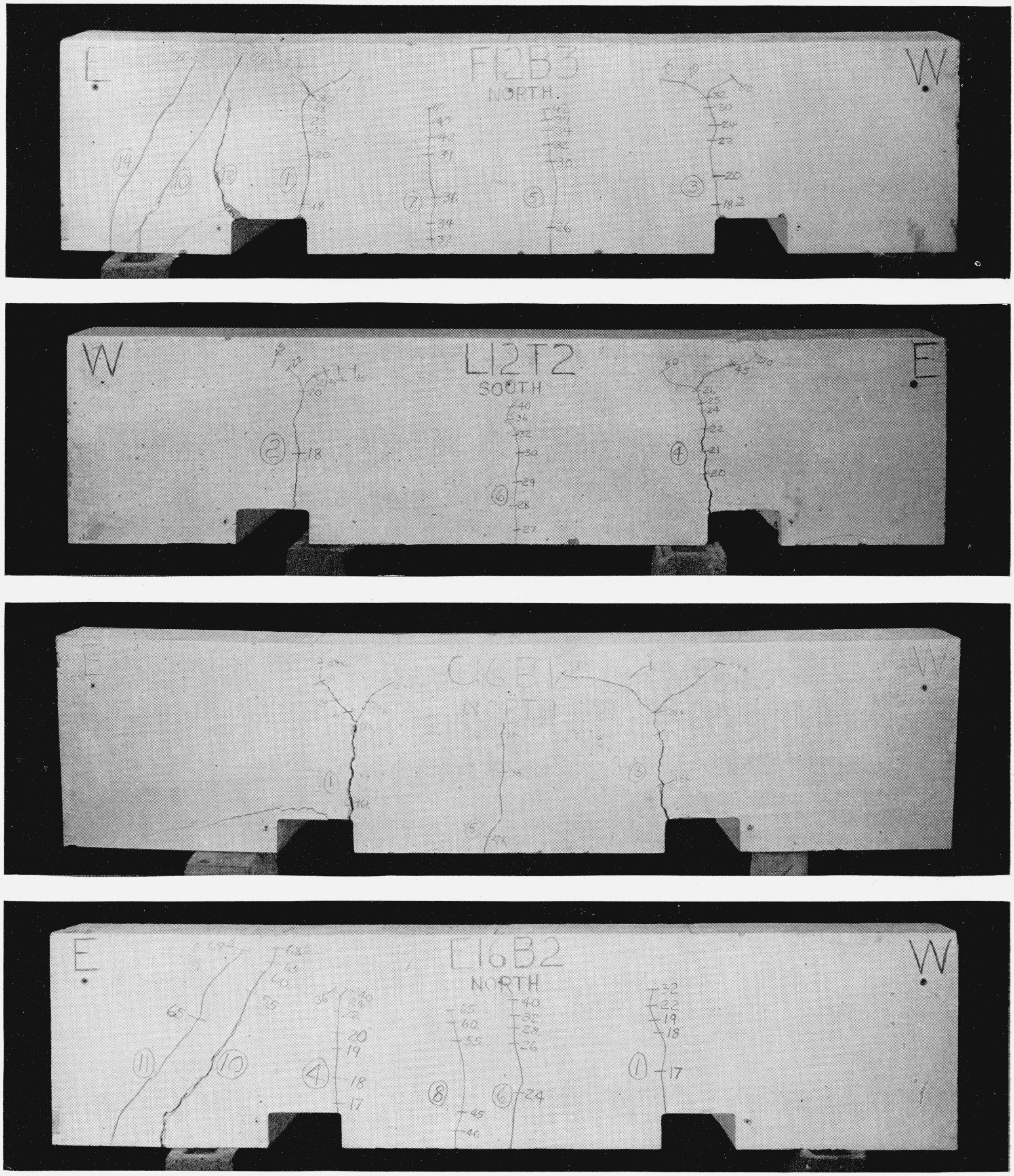

FIGURE 12. *Typical beam cracks at failure.*

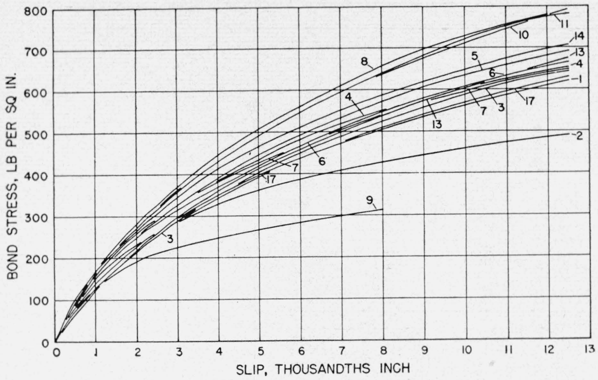

FIGURE 13. *Bond-slip curves for ⅞-in. bottom bars in pull-outs.*

Slip measured at loaded end.

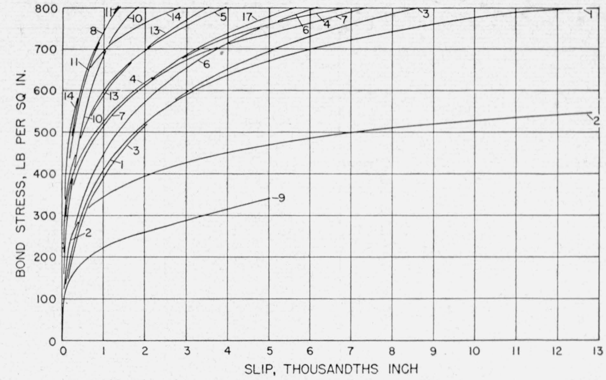

FIGURE 14. *Bond-slip curves for ⅞-in. bottom bars in pull-outs.*

Slip measured at free end.

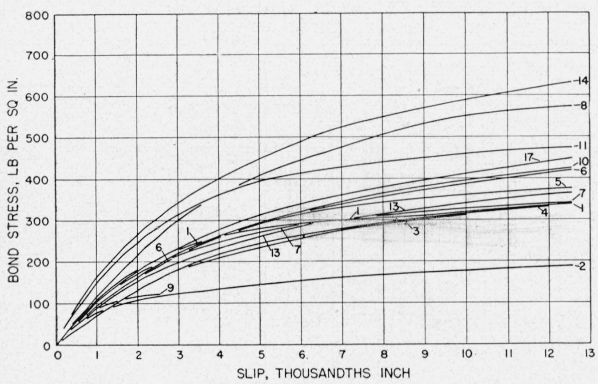

FIGURE 15. *Bond-slip curves for ⅞-in. top bars in pull-outs.*

Slip measured at loaded end.

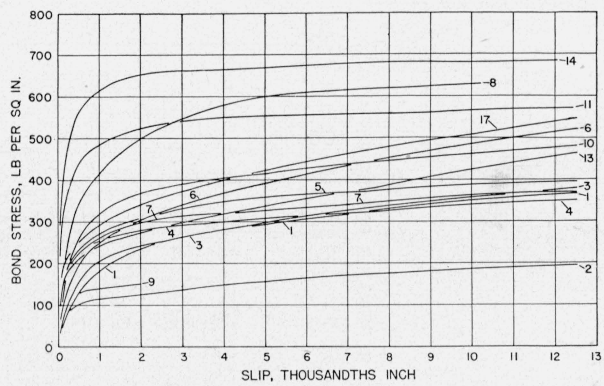

FIGURE 16. *Bond-slip curves for ⅞-in. top bars in pull-outs.*

Slip measured at free end.

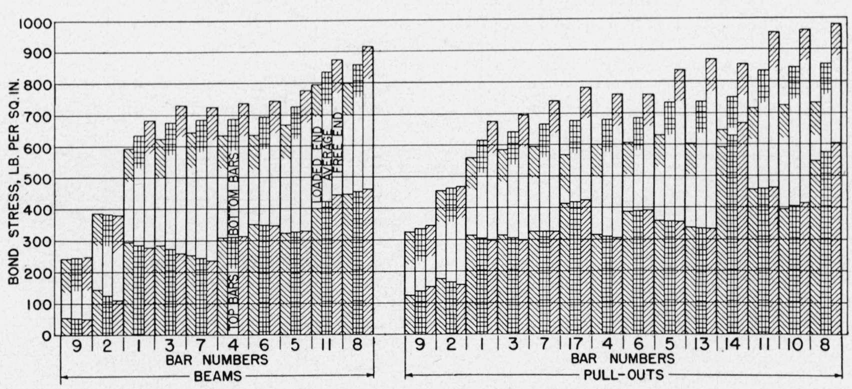

FIGURE 17. *Bond stress for each ⅞-in. bar.*

At loaded end slip of 0.01 in., free end slip of 0.005 in., and average of the two for bottom and top bars in beams and pull-outs.

859368—49——5

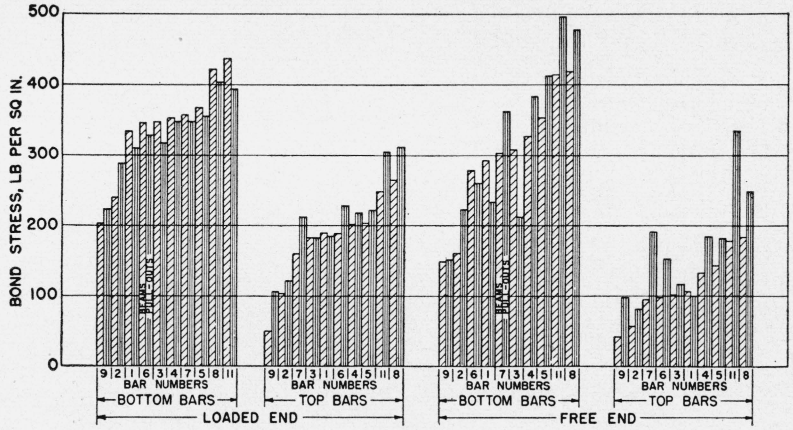

FIGURE 18. *Comparison of beam and pull-out tests of each ⅞-in. bar in bottom and top positions based on the average of bond stresses at slips of 0.0005, 0.001, 0.002, 0.003, 0.004, 0.005, 0.0075, and 0.01-in. measured at loaded end and the average at slips of 0.00005, 0.0001, 0.005, and 0.001-in. measured at free end.*

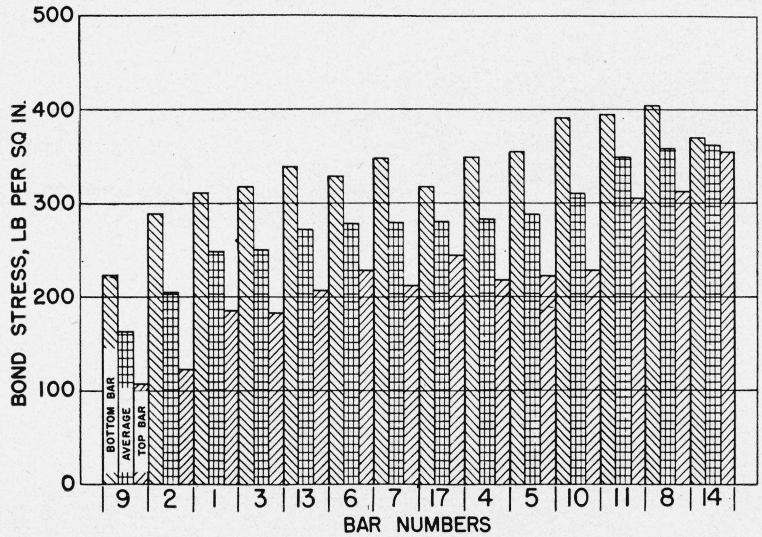

FIGURE 19. *Average of the bond stresses at slips of 0.0005, 0.001, 0.002, 0.003, 0.004, 0.005, 0.0075, and 0.01-in. measured at loaded end for each ⅞-in. bar in bottom and top positions in pull-outs.*

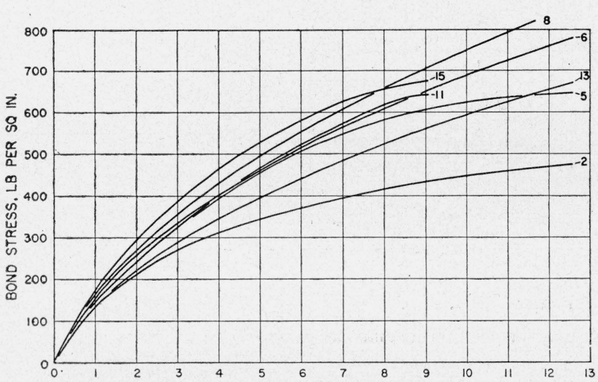

FIGURE 20. *Bond-slip curves for ½-in. bottom bars in pull-outs.*

Slip measured at loaded end.

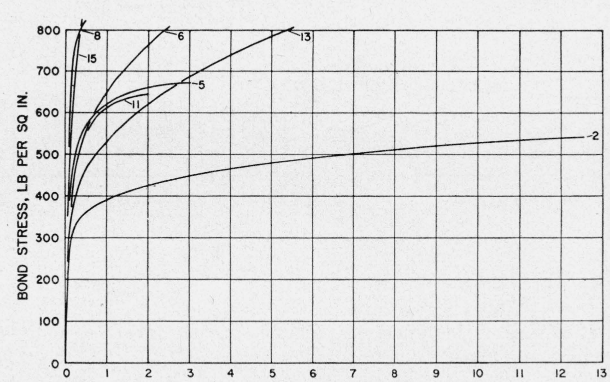

FIGURE 21. *Bond-slip curves for ½-in. bottom bars in pull-outs.*

Slip measured at free end.

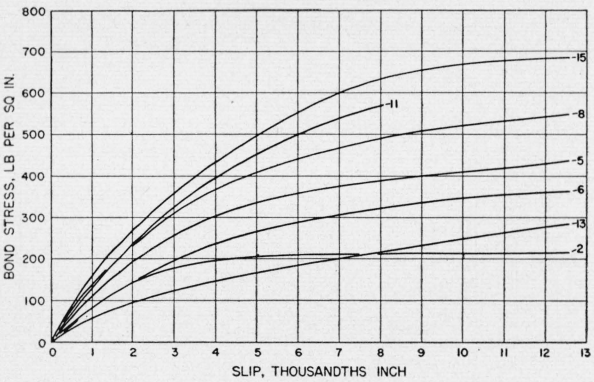

FIGURE 22. *Bond-slip curves for ½-in. top bars in pull-outs.*

Slip measured at loaded end.

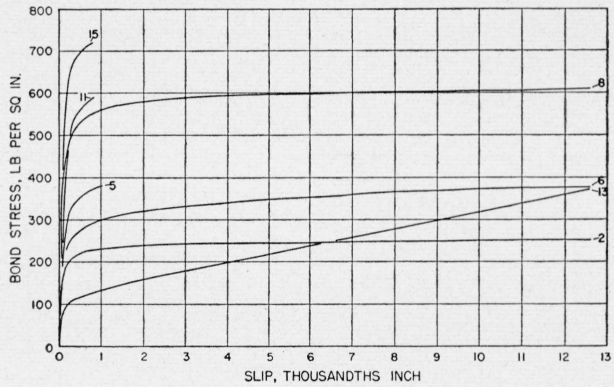

FIGURE 23. *Bond-slip curves for ½-in. top bars in pull-outs.*

Slip measured at free end.

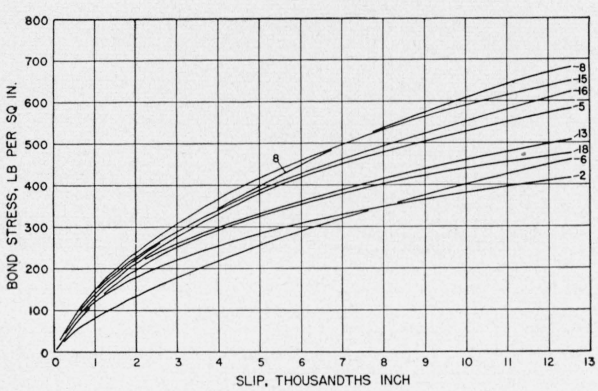

FIGURE 24. *Bond-slip curves for 1⅛-in. bottom bars in pull-outs.*

Slip measured at loaded end.

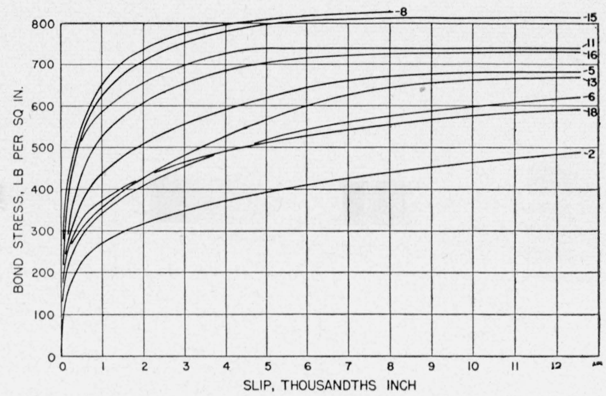

FIGURE 25. *Bond-slip curves for 1⅛-in. bottom bars in pull-outs.*

Slip measured at free end.

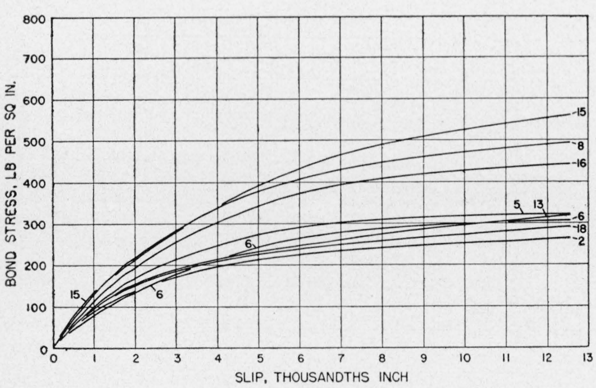

FIGURE 26. *Bond-slip curves for 1⅛-in. top bars in pull-outs.*

Slip measured at loaded end.

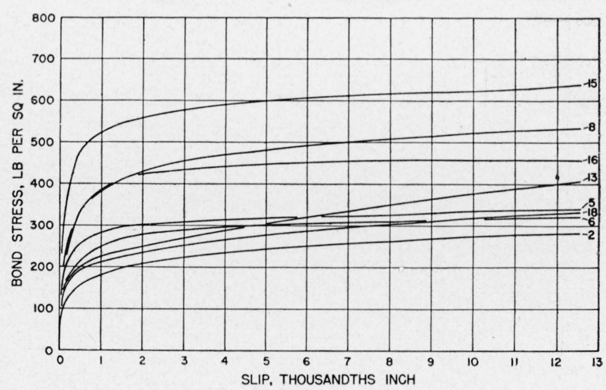

FIGURE 27. *Bond-slip curves for 1⅛-in. top bars in pull-outs.*

Slip measured at free end.

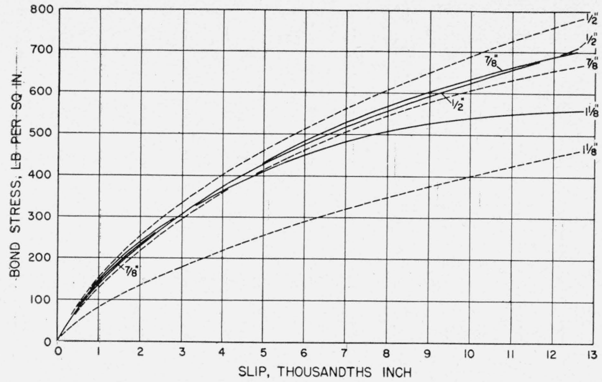

FIGURE 28. *Bond-slip curves for ½-, ⅞- and 1⅛-in. Bar No. 6 bottom cast in beams and pull-outs.*

Slip measured at loaded end. ------, Pull-outs; ——, beams.

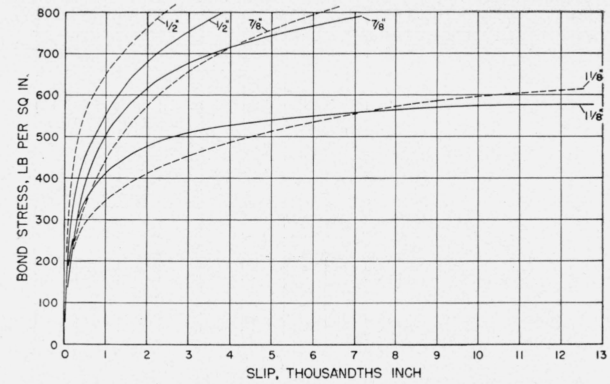

FIGURE 29. *Bond-slip curves for ½-, ⅞- and 1⅛-in. Bar No. 6 bottom cast in beams and pull-outs.*

Slip measured at free end. ------, Pull-outs; ——, beams.

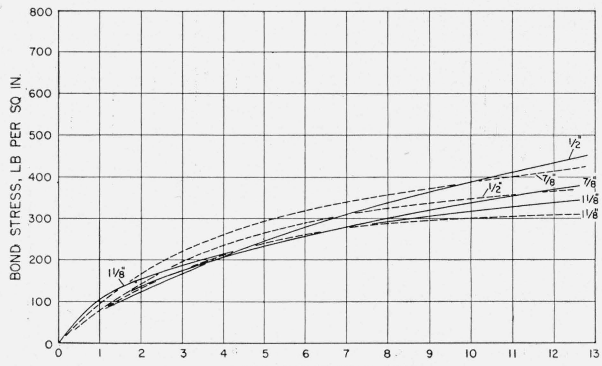

FIGURE 30. *Bond-slip curves for ½-, ⅞- and 1⅛-in. Bar No. 6 top cast in beams and pull-outs.*

Slip measured at loaded end------, Pull-outs; ——, beams.

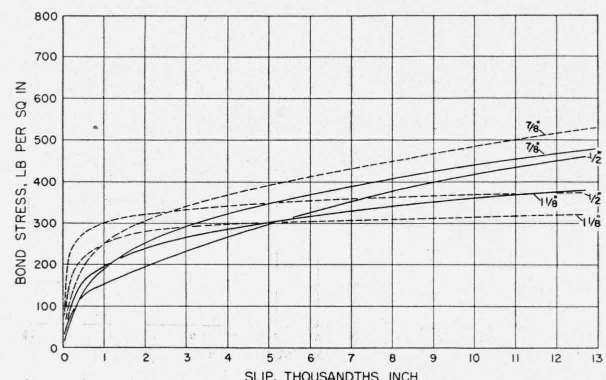

FIGURE 31. *Bond-slip curves for ½-, ⅞- and 1⅛-in. Bar No. 6 top cast in beams and pull-outs.*

Slip measured at free end. ------, Pull-outs; ——, beams.

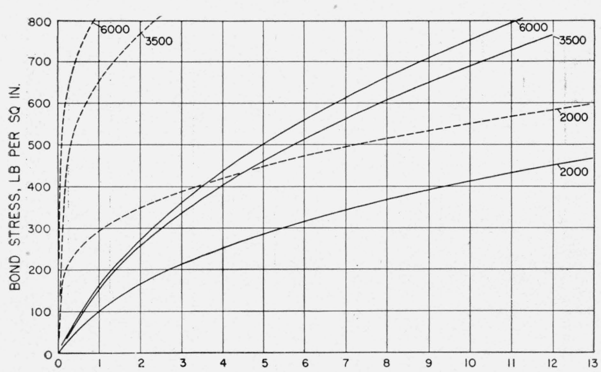

FIGURE 32. *Bond-slip curves for ½-in. Bar No. 6 in 2,000- 3,500- and 6,000-lb strength concretes, bottom cast, in pull-outs.*

Slip measured at loaded and free ends. ------, Free end; ——, loaded end.

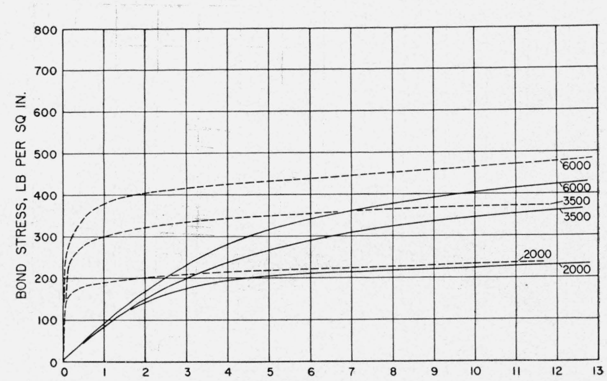

FIGURE 33. *Bond-slip curves for ½-in. Bar No. 6 in 2,000- 3,500- and 6,000-lb strength concretes, top cast, in pull-outs.*

Slip measured at loaded and free ends. ------, Free end; ——, loaded end.

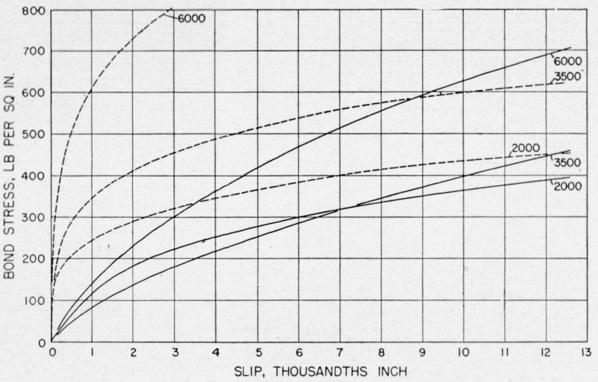

FIGURE 34. *Bond-slip curves for 1⅛-in. Bar No. 6 in 2,000- 3,500- and 6,000-lb strength concretes, bottom cast in pull-outs.*

Slip measured at loaded and free ends. ------, Free end; ——, loaded end.

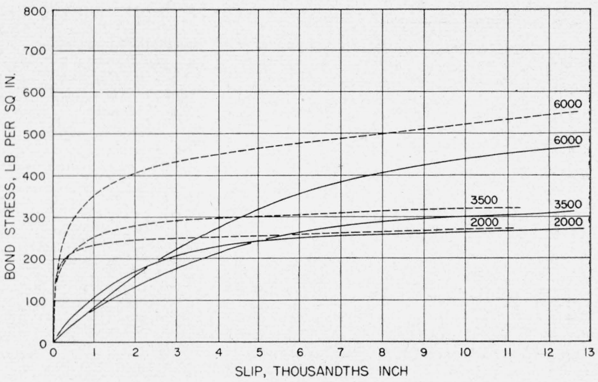

FIGURE 35. *Bond-slip curves for 1⅛-in. Bar No. 6 in 2,000-, 3,500- and 6,000-lb strength concretes, top cast, in pull-outs.*

Slip measured at loaded and free ends. ------, Free end; ——, loaded end.

WASHINGTON, August 16, 1949.