U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

RESEARCH PAPER RP1669

Part of Journal of Research of the National Bureau of Standards, Volume 35, September 1945

LAPPED BAR SPLICES IN CONCRETE BEAMS

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ABSTRACT

An investigation was conducted to determine the general hehavior and strength of lapped bar splices that varied in length and method of lapping. The bond strength developed in the splice and the slip of bar were determined for two types and two sizes of reinforcement. The resulting data clearly illustrated the manner in which the stress was transferred from one lapped bar to the other; the relative merits of the two types of bars, as well as the effectiveness of the two methods of lapping, are also shown.

CONTENTS

I. INTRODUCTION

1. OBJECT AND SCOPE OF INVESTIGATION

There is little information available in the technical literature concerning the behavior of lapped reinforcing-bar splices. As far as is known to the authors, such data that have been published pertain to relatively long laps involving plain round bars.[1] It therefore seemed desirable to conduct a study of this type of splice, including such variables as length, method of lapping, and type of deformed bar.

Specifically, the purpose of the tests described in this paper was first, to determine the distribution of stress along the lapped bars and the accompanying bar slip; second, to compare the effectiveness of

[1] W. A. Slater, F. E. Richart, and G. G. Scofield, Tests of bond resistance between concrete and steel Tech. Pap. BS (1920) T173; or W. A. Slater, Structural laboratory investigations in reinforced concrete mad by Concrete Ship Section, Emergency Fleet Corporation, Proc. Am. Concrete Inst. **xv** (1919).

the lapped bars spaced 1½-bar diameters apart with that of the lapped bars in contact with each other; and, third, to compare the behavior of two types of reinforcing bars, one having a relatively greater lug height than the other. Both bars were considered to be among the best available as far as bonding properties were concerned.

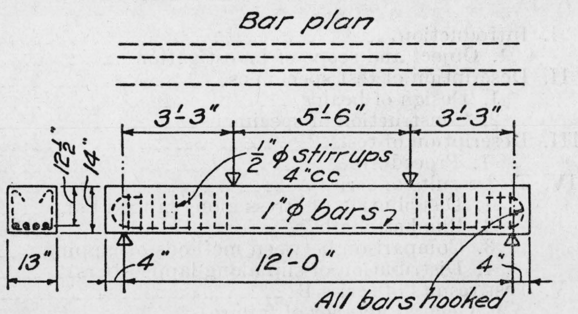
The test program was divided into two parts, as indicated in table 1. One part covered the tests of large beams containing bars 1 in. in diameter, and the other, tests of small beams reinforced with bars ½ in. in diameter. For each size of bar, two sets of tests were made, designated series A and series B. All tests were made on each of the two types of bars.

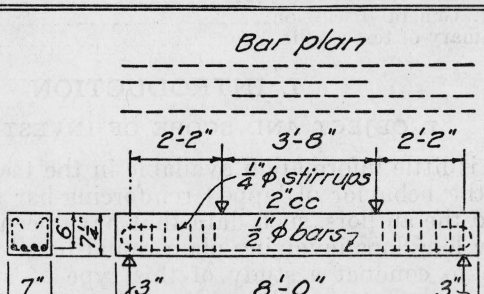
The tests of series A were primarily concerned with the manner in which the tensile stress or bond stress varied along the lapped bars and the magnitude of the slip at various points. The data also served to compare the behavior of the two types of bars and the relative

TABLE 1.—*Schedule of tests.*

	Series	Specimen	Nominal length of lap, in.
1" φ bars	A	A-50	50
		A-40	40
		A-30	30
		A-20	20
		A-40X	40
		A-30X	30
		A-20X	20
	B	B-40	40
		B-30	30
		B-20	20
		B-30X	30
		B-20X	20
½" φ bars	A	A-50	25
		A-40	20
		A-30	15
		A-20	10
		A-40X	20
		A-30X	15
		A-20X	10
	B	B-40	20
		B-30	15
		B-20	10
		B-10	5
		B-30X	15
		B-20X	10
		B-10X	5

DESIGN DETAILS OF BEAMS





Note:—
In specimens designated with the letter "X" following specimen number, lapped bars were in contact with each other. In all other beams, bars were spaced 1½ dia. clear.

effectiveness of the two methods of lap splicing. The length of splice in this series varied from 20- to 50-bar diameters and only a single test was made for each length of lap, type, and size of bar.

Series B was planned to provide values of average maximum bond stress for several lengths of lap. However, there were few well-defined bond failures and, notwithstanding the use of high-yield-strength reinforcement, many specimens failed by yielding of the bars beyond the splice. These tests, however, had some value in indicating the effectiveness of the shorter laps. In this series, the length of the splices varied from 10- to 40-bar diameters, and in all but a few instances duplicate tests were made.

II. DESCRIPTION OF TEST SPECIMENS

1. DESIGN OF BEAMS

Details of the test specimens are shown in the diagrams of table 1. As indicated in the bar plan, each beam contained a single lap splice and two continuous bars. The beams were designed to permit a clear spacing of 1½-bar diameters between all the bars at a section through the splice, and their effective depth was such that theoretically, for a stress of 20,000 psi in the continuous bars, the concrete was stressed to 1,500 psi in compression, assuming a modular ratio of $n=8$. This design resulted in a section, outside the region of the lap splice, containing 1.4 percent of tensile reinforcement.

The span of the large beams (containing the 1-in. bars) was 12 ft and that of the small beams (with the ½-in. bars) was 8 ft. Load was applied to the beams at two points, so spaced as to provide a region of constant moment sufficient in extent to accommodate the longest lap splice of 50-bar diameters. The actual lengths of lap were slightly greater than the given nominal values in order to accommodate an even multiple of a 5-in. spacing of gage holes. The exact values were ¼-in. and ½ in. greater than the nominal lengths for the ½-in. and 1-in. bars, respectively.

The reinforcement consisted of two types of bars, illustrated in figure 1, and designated by number. Bar No. 1 had average lug heights of 0.020 in. and 0.027 in., whereas Bar No. 2 had average lug heights of 0.031 in. and 0.063 in. for the ½-in. and 1-in. bars, respectively. The approximate bearing areas of the lugs per lineal inch are given in table 2. For the specimens of series A, the reinforcing bars were of intermediate grade or better, whereas the bars used in beams of series B were exclusively of high-strength steel, having a yield point of from 53,000 to 62,000 psi. Their dimensions and mechanical properties are listed in tables 2 and 3, respectively.

The concrete was designed for a compressive strength of 4,500 psi at 28 days and consisted of moderate-heat-of-hardening portland cement and washed Potomac River sand and gravel, the latter having a maximum size of ¾ in. The proportions of cement, sand, and gravel in the mix were, respectively, 1:2.5:3.3 by dry weight; and the net water content, 7½ gal of water per sack of cement, corresponding to a water-cement ratio of 0.67 by weight. The resulting concrete had an average slump of 3½ in. and developed an average compressive strength of 4,700 psi tested dry at 28 days.

TABLE 2.—*Dimensions of reinforcement*

Bar number	Bar size	Diameter [1]	Area [1]	Average lug height	Lugs per yard	Approximate bearing area of lugs per lineal inch
	in.	*in.*	*in.²*	*in.*		*in.²/in.*
2	½	0.49	0.190	0.031	128	0.16
	1	1.00	.787	.063	80	.42
1	½	0.51	.198	020	100	.08
	1	1.00	.785	.027	50	.11

[1] As determined by weight-length method.

TABLE 3.—*Mechanical properties of reinforcement*

[Each value is the average of three tests]

Test series	Bar numbers	Bar size	Yield point	Tensile strength	Elongation in 8 in.
		in.	*psi*	*psi*	*%*
A	2	½	50,000	79,800	20.4
	1	½	61,800	90,000	22.0
	2	1	45,000	71,600	26.2
	1	1	51,600	97,200	18.8
B	2	½	61,800	97,400	16.6
	1	½	55,000	92,600	18.0
	2	1	60,400	94,200	18.8
	1	1	53,000	92,300	23.1

2. CONSTRUCTION OF SPECIMENS

Four beams were generally cast at one time, two small beams and two large beams, both pairs containing splices of equal length in terms of the bar diameter. One of each pair contained the No. 1 bar and the other the No. 2 bar. The reinforcement was rigidly supported on wire chairs as well as on tapered wooden inserts. Removal of the latter from the cast beam provided openings to the bars for strain measurements. Spacing of the inserts is shown in figure 2 for beams of series A. The beams of series B contained gage holes, similarly spaced, but confined to the region outside the limits of the splice.

The free ends of the lapped bars were saw cut in order to avoid the distorted ends generally accompanying shear cuts. Where no space was provided between the lapped bars, they were firmly wired together at the center and near the ends of the lap with soft iron wire. The concrete was vibrated into place in the beams and the control cylinders. Twenty-four hours after casting, the side forms of the beams and cylinders were removed. The test specimens were then wrapped with several layers of wet burlap and cured in this condition for a period of 7 days, after which they were permitted to dry in the laboratory for 21 days before testing.

III. DESCRIPTION OF TESTS

1. PROCEDURE

In order to facilitate the measurement of strain, the beams were tested in an inverted position on standard beam supports resting on the platen of a 600,000-lb hydraulic testing machine equipped with

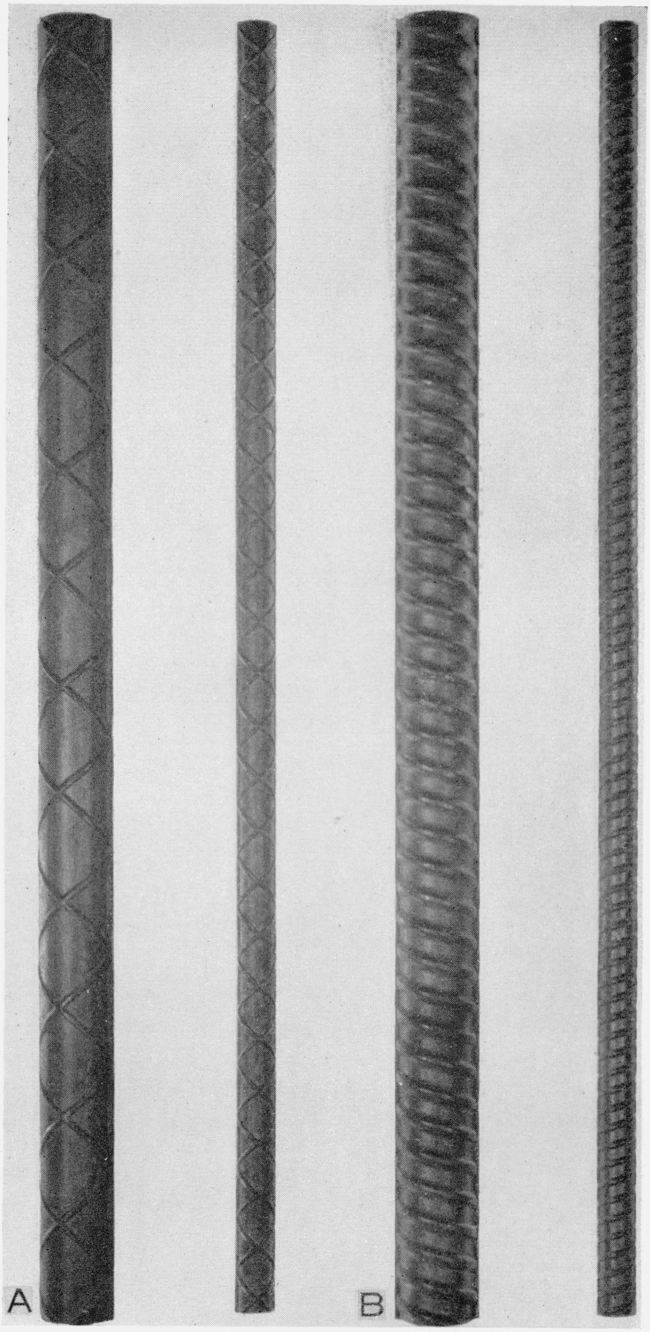


FIGURE 1.—*Reinforcing bars.*

A, Bar No. 1; *B*, bar No. 2.

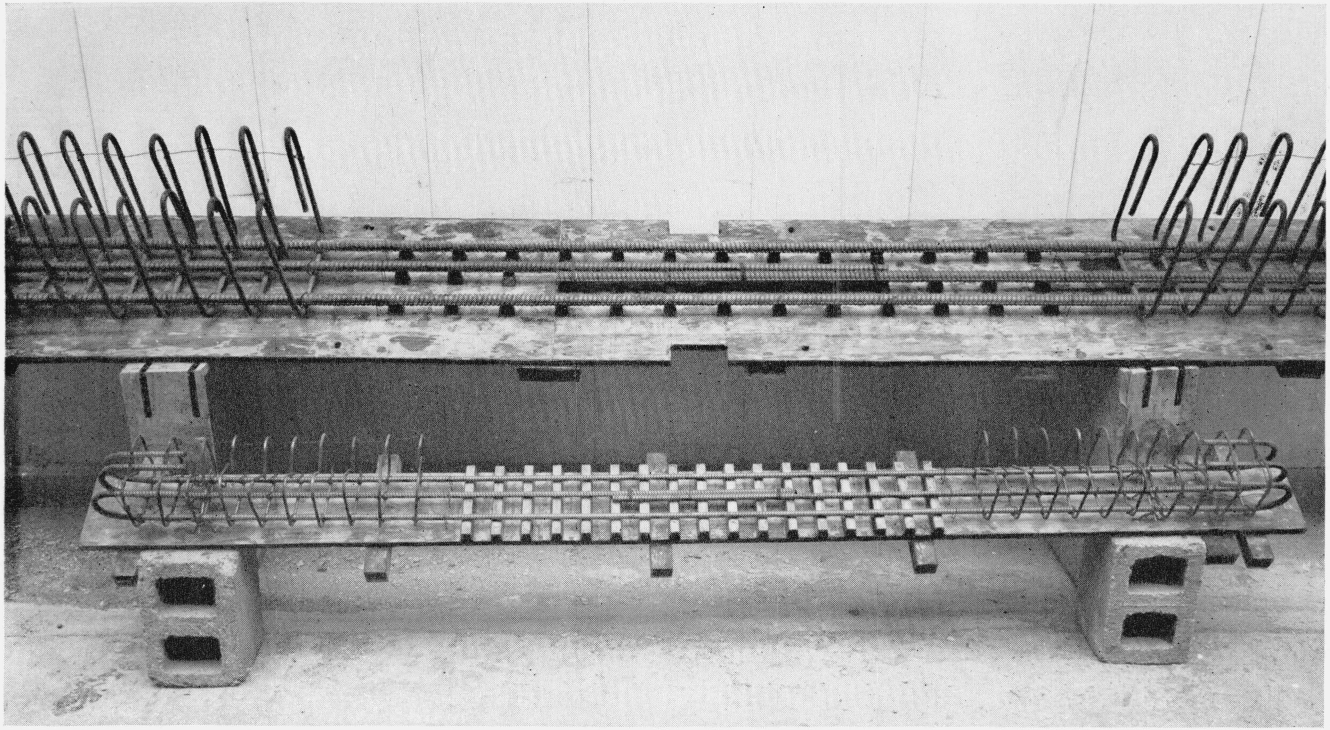


FIGURE 2.—*Reinforcement for 30-bar diameter splice.*

Lapped bars in contact. Specimen type A-30x.

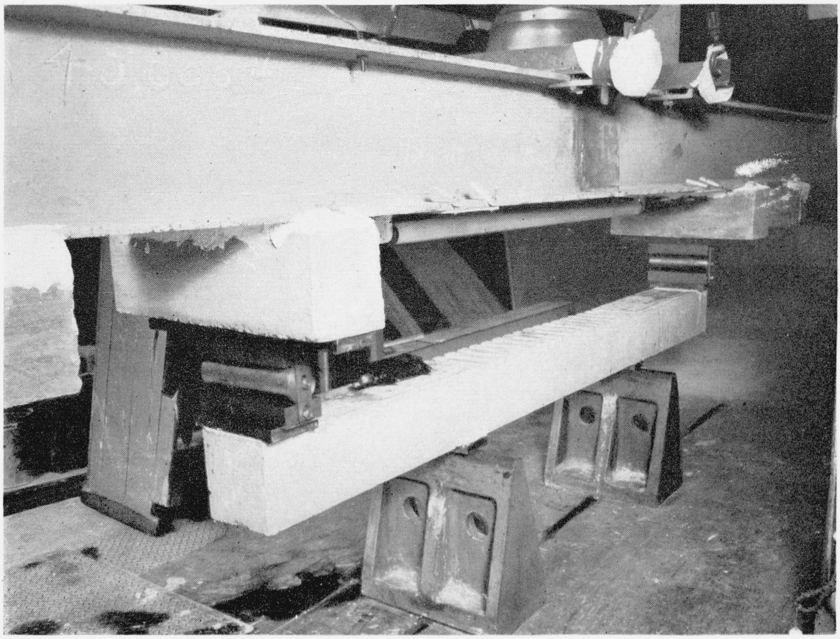


FIGURE 3.—*Eight-foot beam of series A under load.*

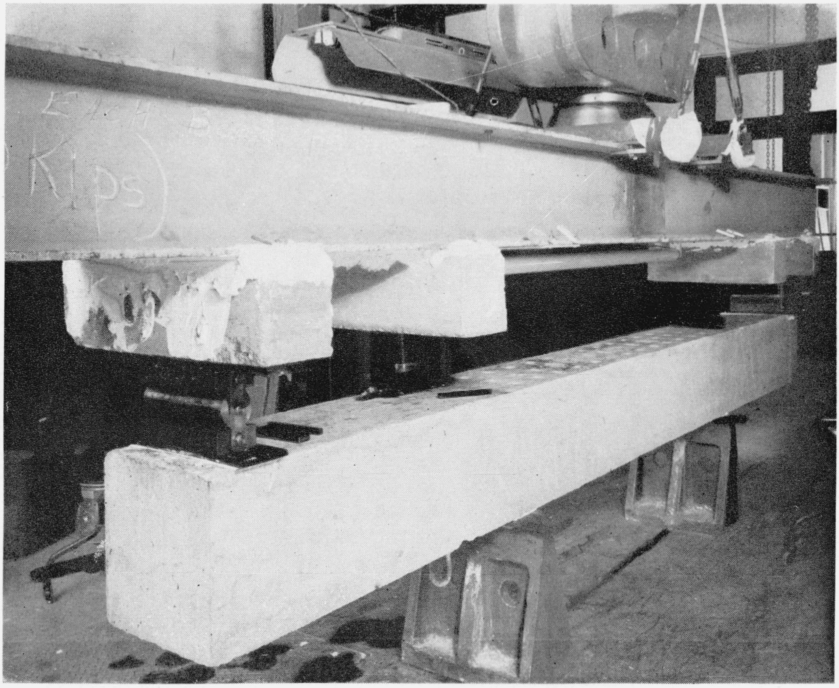


FIGURE 4.—*Twelve-foot beam of series A under load.*

a 30,000-lb gage. The load was applied near the ends of the specimens through a pair of wide-flange I-beams resting on rollers and bearing plates, which can be observed in figures 3 and 4. The weight of the loading beams and auxiliary equipment was approximately 2,400 lb and was considered as part of the total applied load.

Strain-gage readings were obtained with a 5-in. Whittemore gage for 8 to 10 increments of load. In the tests of series A, strain measurements were made at 2½-in. and 5-in. intervals on the ½- and 1-in. bars, respectively, the intervals extending from the free ends of the lapped bar to the load points and at a number of selected points on the continuous bars. Slip of the lapped bars was determined with the strain gage by observing the relative movement between gage holes on the lapped bars and those on the continuous bars one gage length removed. The readings were corrected for strain in the bars as well as for the angle of the line of measurement. Measurements of strain in the tests of series B were confined to gage lines outside the region of the splice, thus avoiding the uncertain effect of openings in the concrete on the bond stresses along the lapped bars. The average bond stress could be determined from the observed tensile stress in the bars at the ends of the lap.

During the latter stages of the test, the beams were carefully scrutinized for possible longitudinal cracks, which, in some beams, formed in the concrete along the lapped bars when the maximum load was reached.

IV. TEST RESULTS OF SERIES A

1. DISTRIBUTION OF STRESS ALONG LAPPED BARS

The strains at corresponding gage lines on each of the two bars of the lap were averaged and converted to stress on the assumption that E_s was 30,000,000 psi, and load-stress diagrams plotted for all of the gage points along the bar. Typical diagrams are shown in figure 5. The curves are arranged in the order that the gage lines appear on the lapped bar, starting at the free end. After initial cracking of the concrete, the stress in the bar at various points was closely proportional to the load until either the bond stress within the gage line approached a maximum or the yield point of the steel was reached. The curves for the portion of the bar near the free end clearly show the maximum tensile stress, which is also a measure of the maximum bond stress that the bar was capable of developing within the first few inches of embedment.

The variation of tensile stress along the lapped bars of the various specimens is shown in figures 6 to 13. The plotted values were taken from the load-stress curves described above for loads near the maximum and for loads that produced a stress of about 18,000 to 20,000 psi in the bars outside the region of the splice. The pair of curves shown on each axis, one for each bar of the splice, are identical except that they are turned end for end. Both the No. 1 and No. 2 bars are represented in each figure.

The slope at any point on the curves is obviously a measure of the bond stress developed between the bar and the concrete at that point. The greatest bond stress was developed at the free end of the bar, and this stress decreased fairly uniformly in the 20- and 30-diameter laps

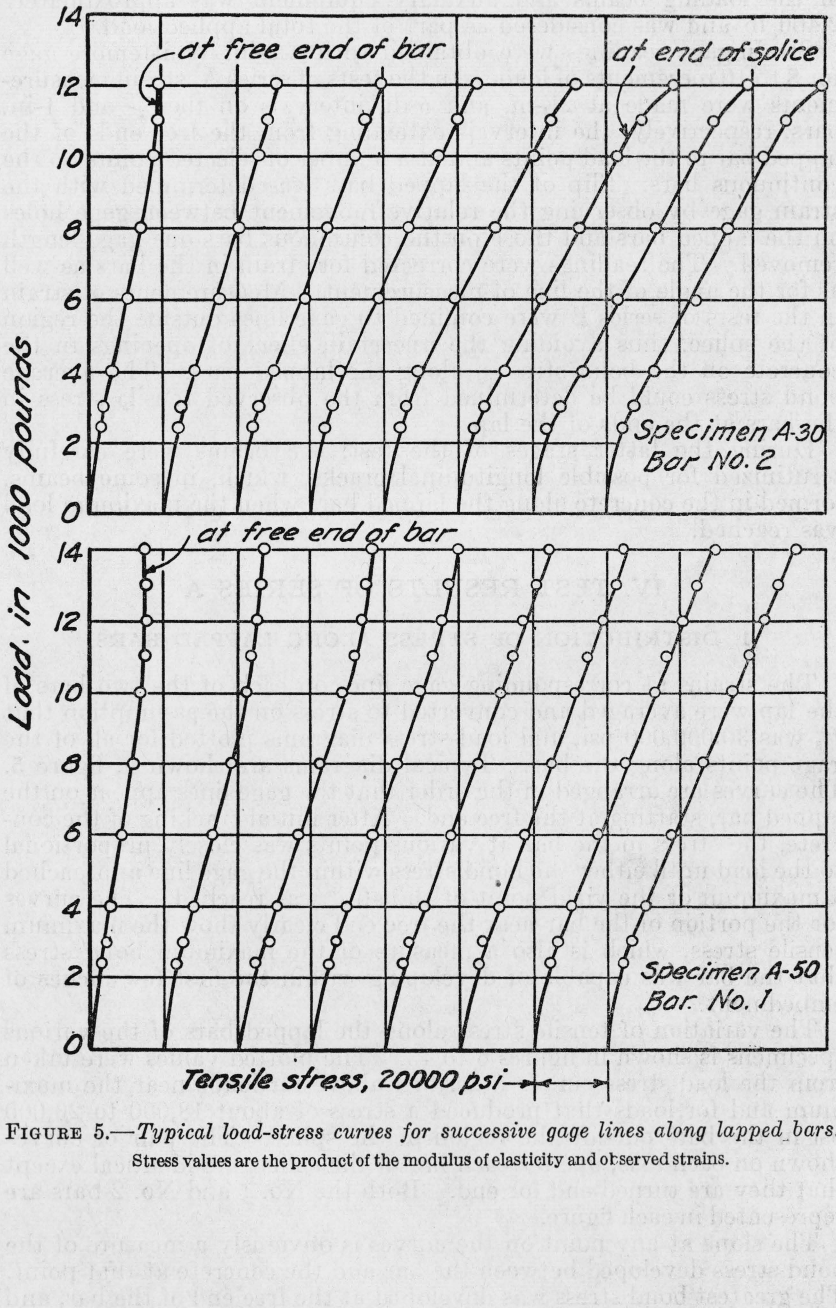


FIGURE 5.—*Typical load-stress curves for successive gage lines along lapped bars.*

Stress values are the product of the modulus of elasticity and observed strains.

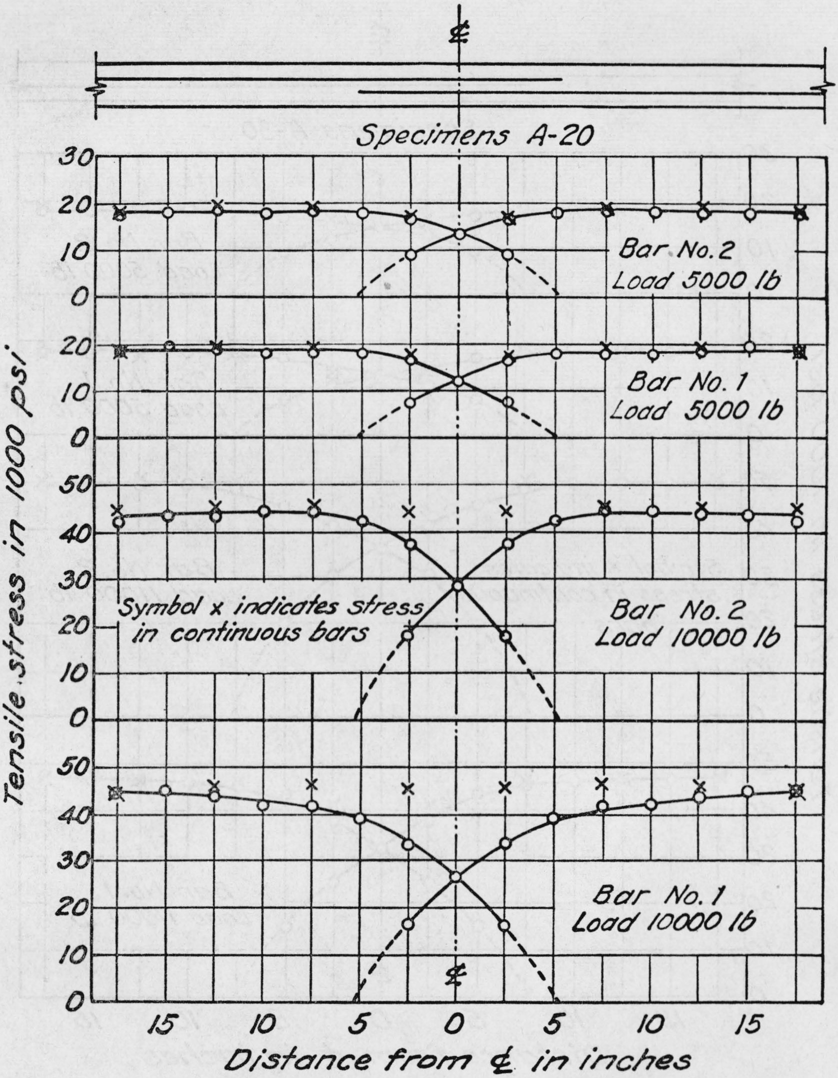


FIGURE 6.—*Distribution of stress along lapped bars.*

Length of splice 20-bar diameters. ½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

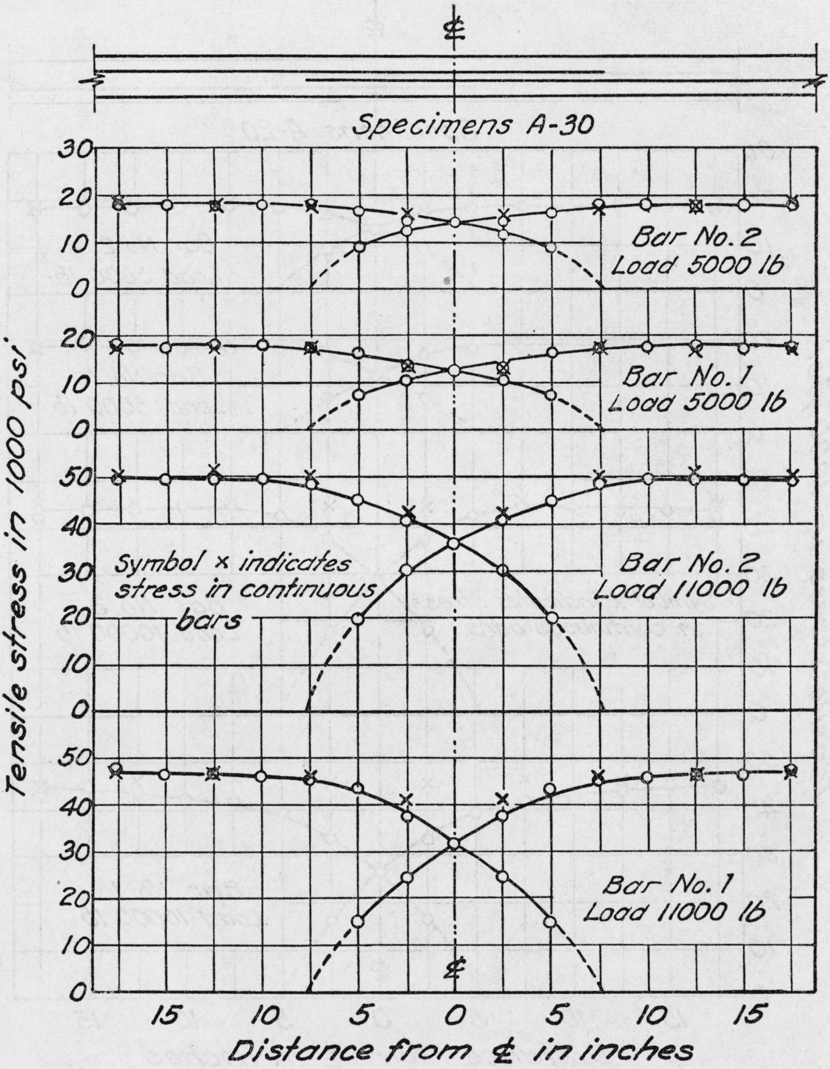


FIGURE 7.—*Distribution of stress along lapped bars.*

Length of splice 30-bar diameters. ½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

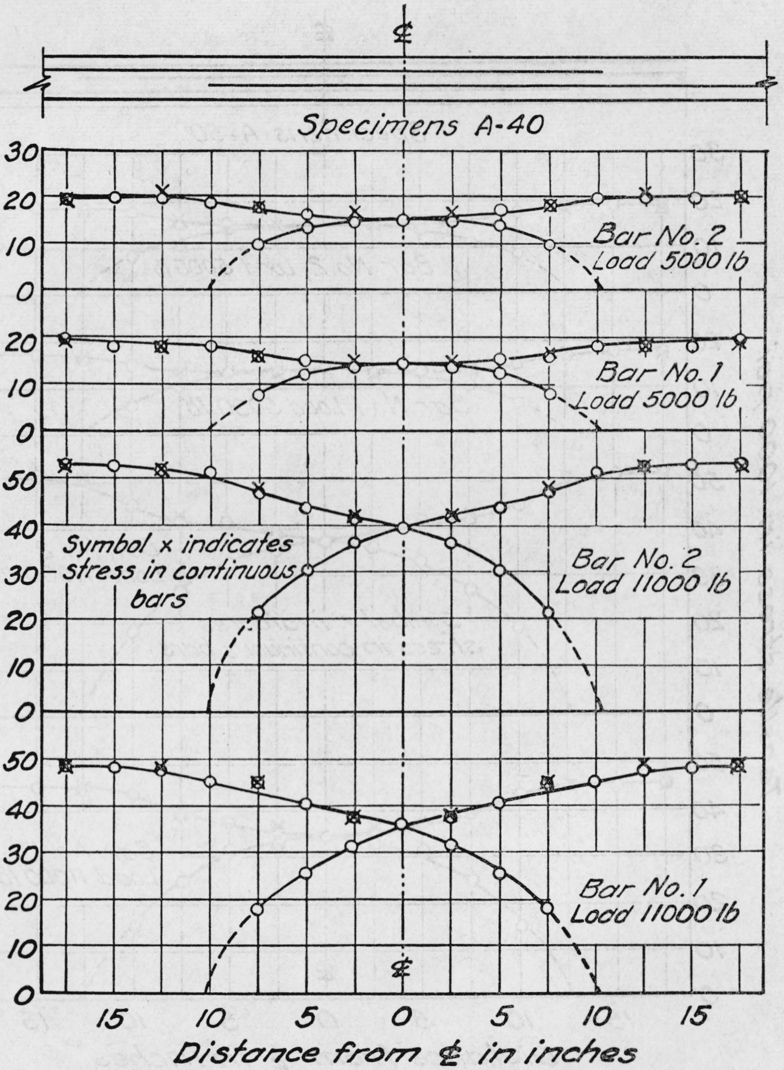


FIGURE 8.—*Distribution of stress along lapped bars.*

Length of splice 40-bar diameters. ½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

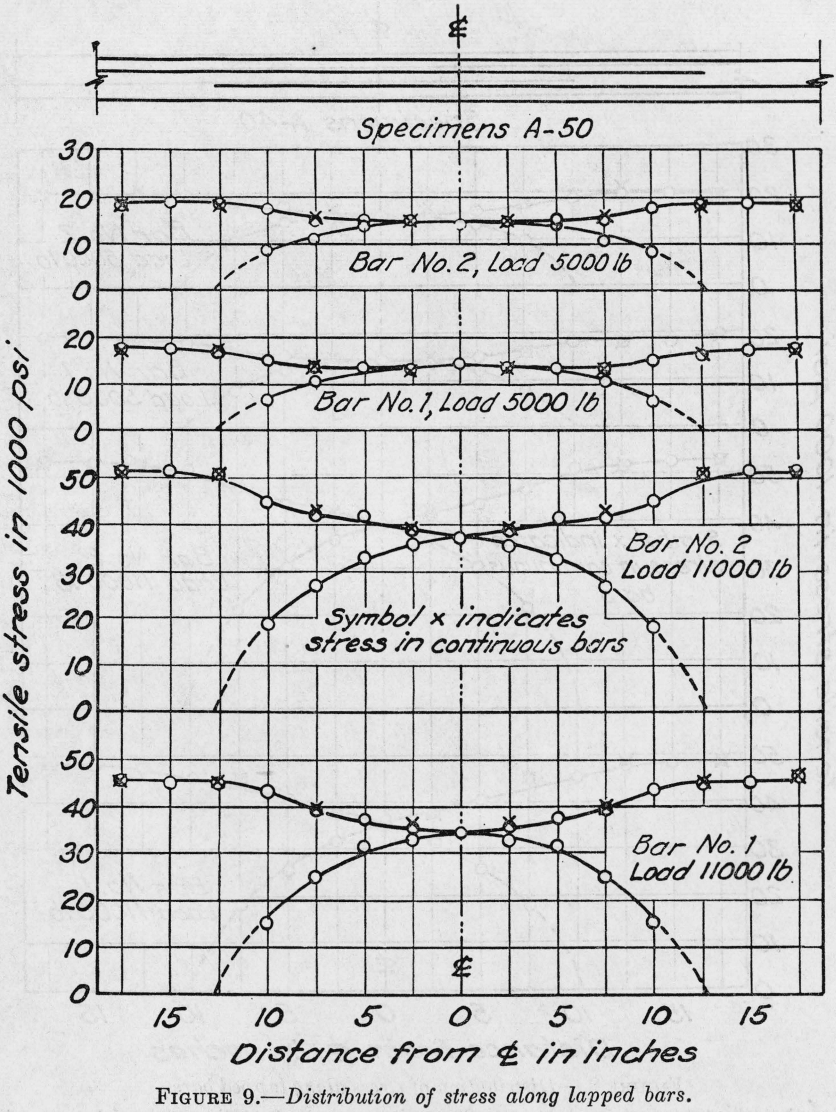


FIGURE 9.—*Distribution of stress along lapped bars.*

Length of splice 50-bar diameters. ½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

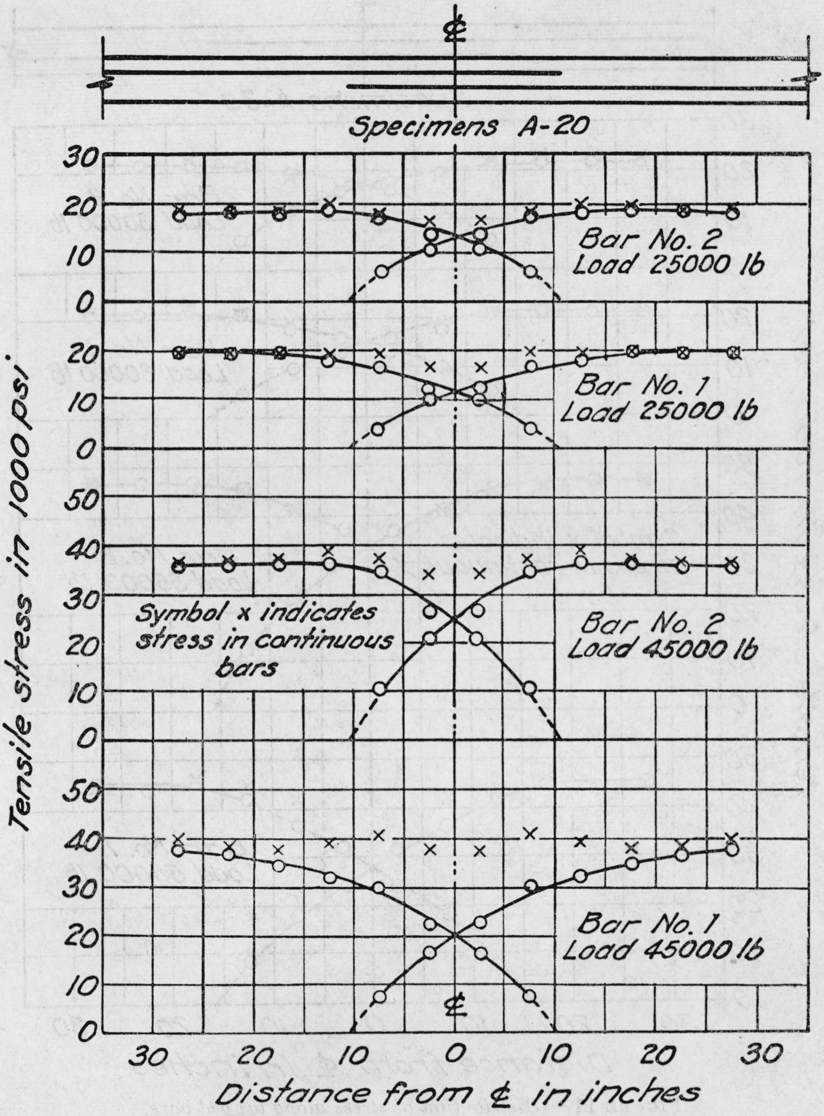


FIGURE 10.—*Distribution of stress along lapped bars.*

Length of splice 20-bar diameters. 1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

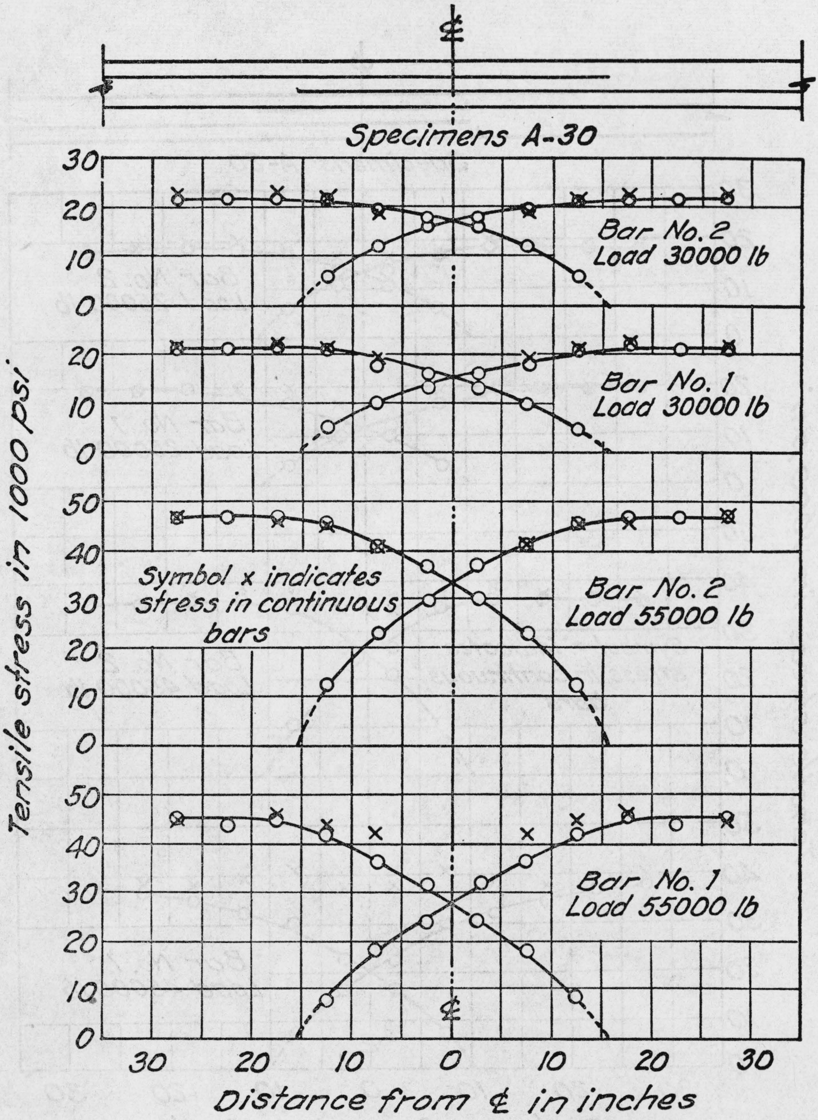


FIGURE 11.—*Distribution of stress along lapped bars.*

Length of splice 30-bar diameters. 1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

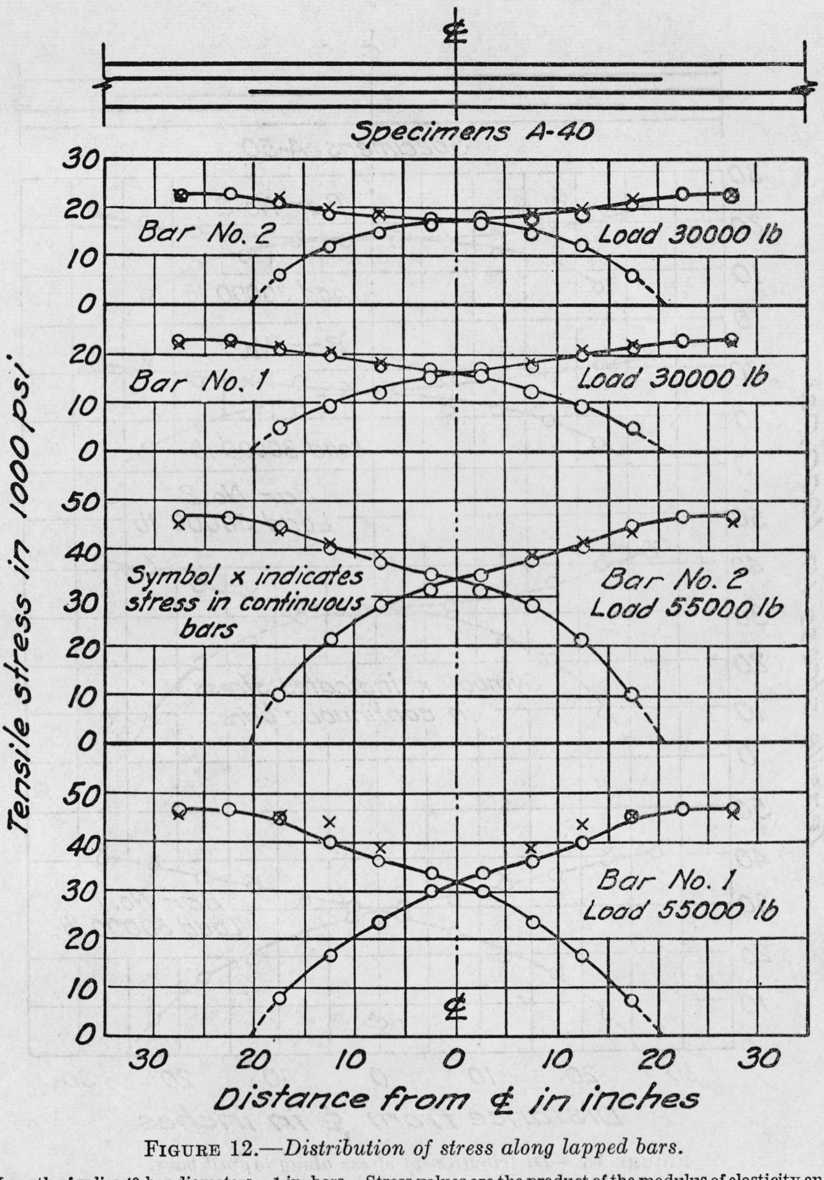


FIGURE 12.—*Distribution of stress along lapped bars.*

Length of splice 40-bar diameters. 1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

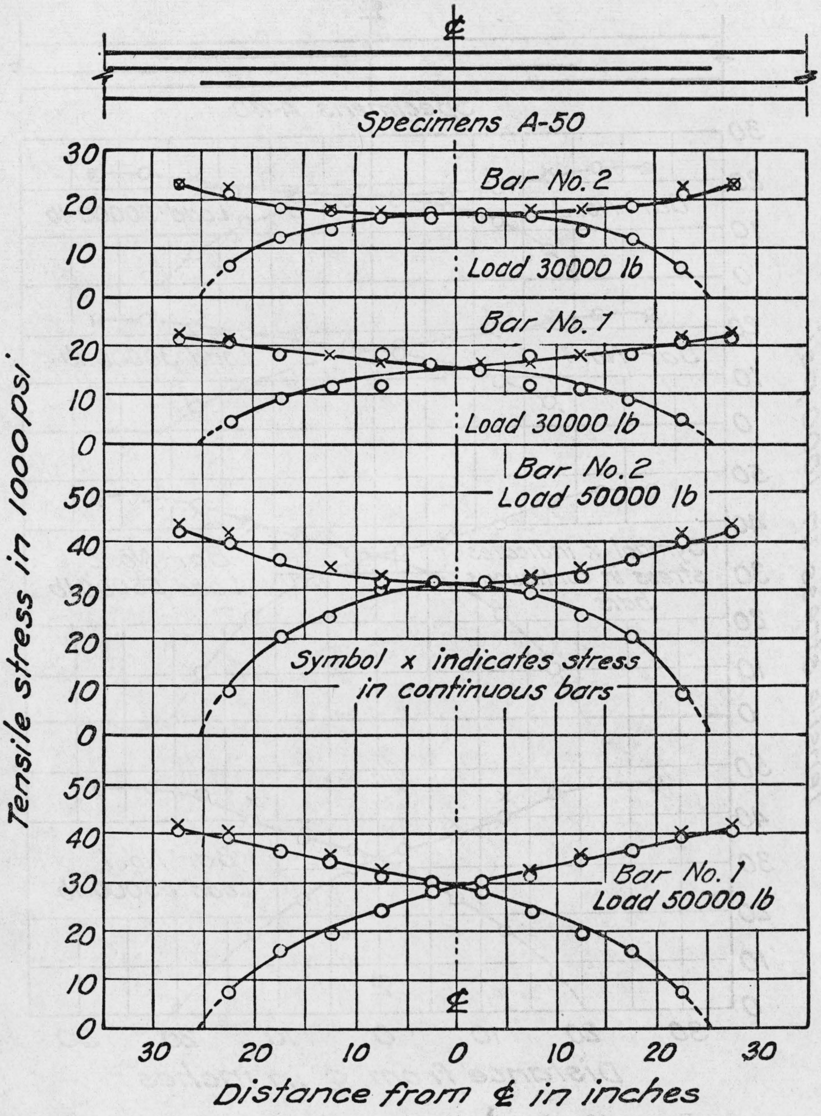


FIGURE 13.—*Distribution of stress along lapped bars.*

Length of splice 50-bar diameters. 1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

over the entire splice. In the longer splices, however, the bond stress, after a similar decrease reached a low value within the middle third, then increased toward the end of the lap. In some instances, where the stresses at the loaded end were less than 30,000 psi, the bars within the middle third of the splice did not develop any bond stress. This was particularly evident in the 40-diameter splices and the 50-diameter splices of the No. 2 bars. From the standpoint of efficiency, such a splice is longer than necessary.

The stress in the continuous bars at various points in the region of the splices is also indicated on the diagrams by a small cross. Except for splices 20-bar diameters in length, the effect of the lapped bars was to greatly decrease the stress in the continuous bars within the limits of the lap, in many instances very closely approaching the stress in the portion of the lapped bar from the center of the lap to its loaded end. In beams containing the 20-diameter splices, the stress in the continuous bars was, in general, fairly constant over the entire lap, the effective steel area of the lapped bars apparently being equivalent to a single bar at any section.

A detailed comparison between the stress distribution curves for each length of lap is shown in figure 14. The curves represent the stress distribution for a load of 10,000 lb on the beams containing the ½-in. bars and 45,000 lb for the beams containing the 1-in. bars. These loads stressed the reinforcement beyond the splice to 45,000 and 37,000 psi, respectively. The slopes of the curves in the vicinity of the origin, which represents the free end of the bar, are almost identical for each set of curves, consequently the bond stress developed within the first few inches of bar embedment was practically alike, regardless of the length of splice for a given load and type of bar.

It is to be expected that some relationship exists between the bond stress at the free end of the lapped bar and the tensile stress in the bar at the other limit of the splice. Figure 15 indicates, within certain limits, a linear relationship which, for each type of bar, apparently is independent of the length of splice for laps of 30-bar diameters or more. Thus, the data for the 30-, 40-, and 50-diameter laps appear to group themselves about individual straight lines, one for the No. 1 bar and one for the No. 2 bar, between tensile stresses of 5,000 and 40,000 psi. The 20-diameter lap-splices also show a similar relationship, but the slopes of the lines are, in some instances, greater than those of the longer splices. Where they differ, the data for the 20-diameter lap are indicated by a broken line.

The distribution of tensile stresses along the lapped bars for a given load and for various lengths of lap is compared in greater detail for both types of bar in figures 16 and 17. In every instance, the No. 2 bars picked up stresses more rapidly at their free ends than the No. 1 bar, although the rate of increase of stress beyond an embedment of five-bar diameters was not significantly different. In a well-designed splice, the normal stress, that is, the stress the bar would normally carry if it were continuous, should be reached at the end of the splice. In figures 18 and 19, the observed stresses in the lapped bars at the end of the splice are plotted with respect to the load applied to the beams for each length of lap. Also shown by solid lines is the load-stress relationship that would obtain if the bars were continuous. This normal stress was assumed to be the same as the average stress

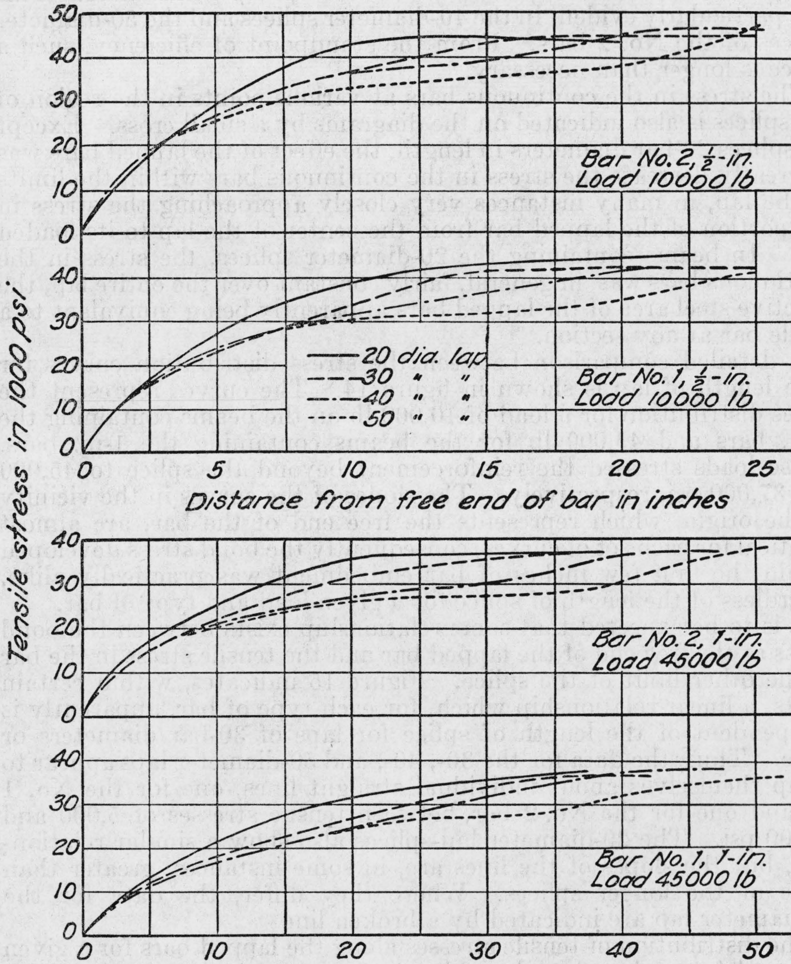


FIGURE 14.—*Distribution of stress along lapped bars for various lengths of splice.*

Stress values are the product of the modulus of elasticity and observed strains.

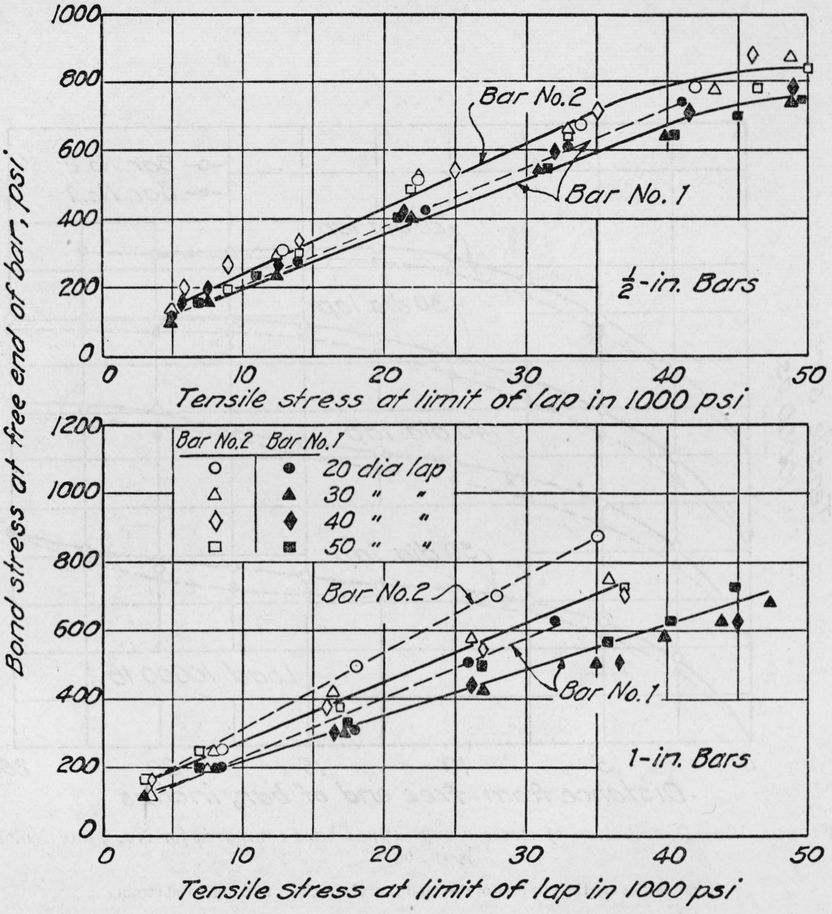


FIGURE 15.—*Relation between bond stress at free end of bar and tensile stress at limit of lap.*

Stress values are the product of the modulus of elasticity and observed strains.

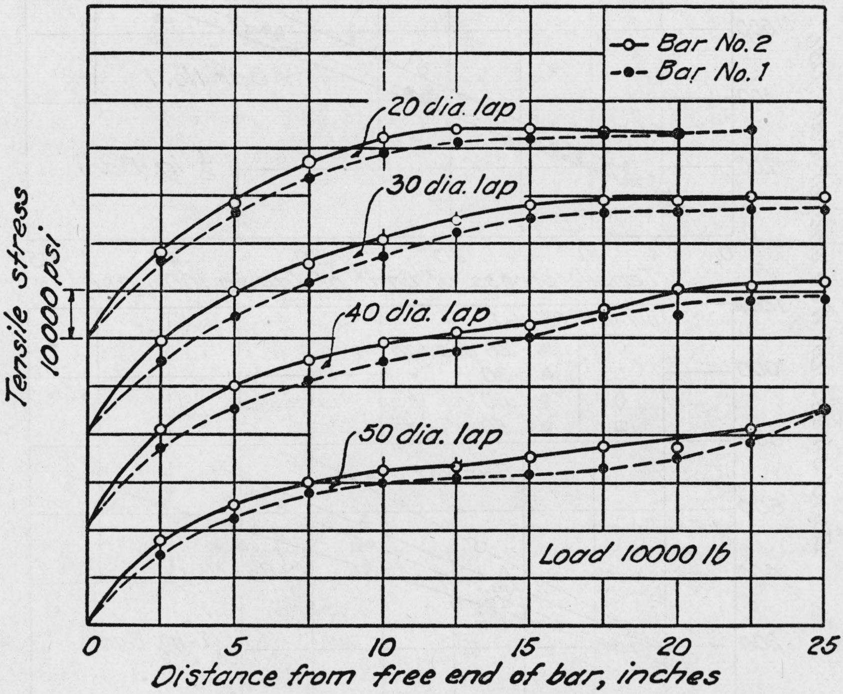


FIGURE 16.—*Distribution of stress along lapped bars compared for No. 2 and No. 1 ½-in. bars.*

Stress values are the product of the modulus of elasticity and observed strains.

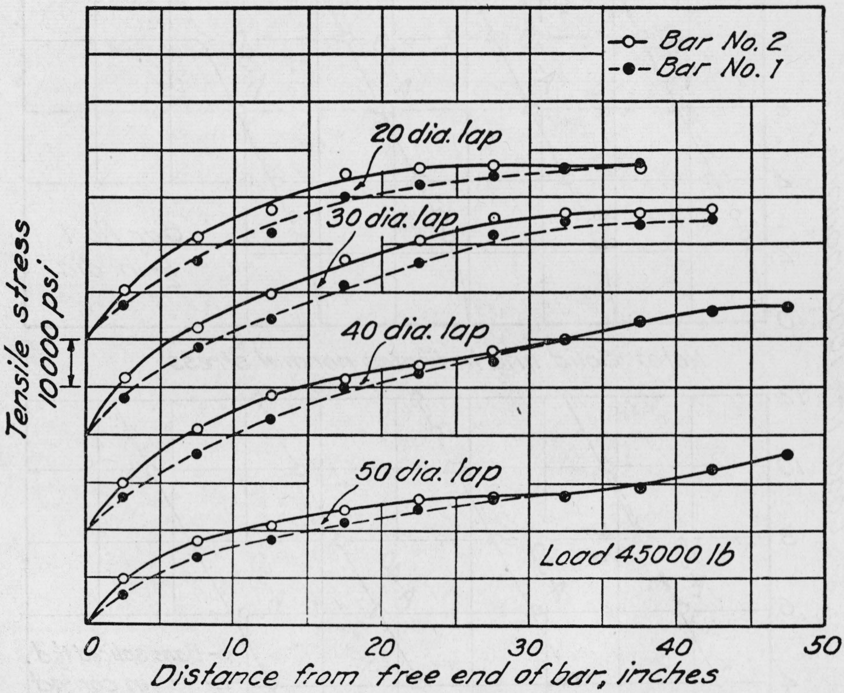


FIGURE 17.—*Distribution of stress along lapped bars compared for No. 2 and No. 1 1-in. bars.*

Stress values are the product of the modulus of elasticity and observed strains.

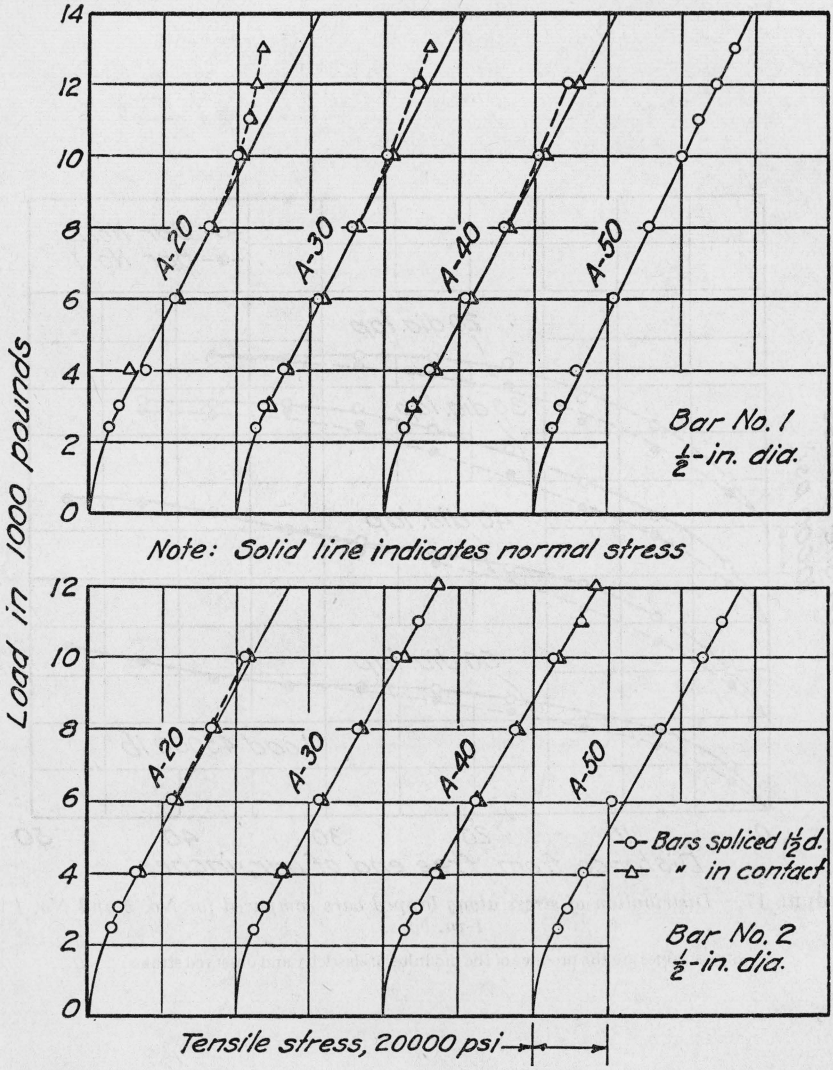


FIGURE 18.—*Load-stress relation for lapped bars at limits of the splice.*

Beams of series A. ½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

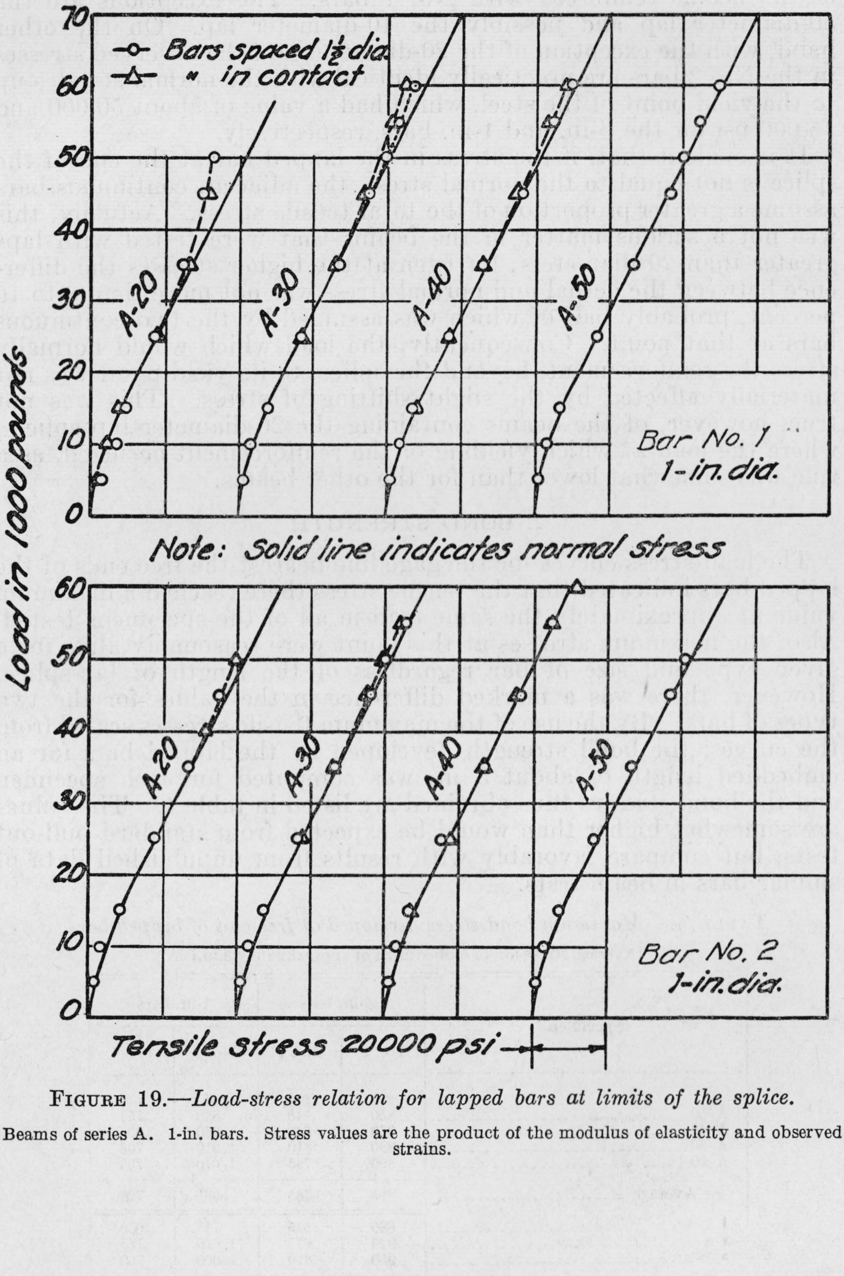


FIGURE 19.—*Load-stress relation for lapped bars at limits of the splice.*

Beams of series A. 1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

observed in both the continuous and lapped bars well outside the limits of the splice. The deviation of the observed stress from the normal stress beyond a value of about 35,000 psi is evident for most of the beams reinforced with No. 1 bars. The exceptions are the 50-diameter lap and possibly the 40-diameter lap. On the other hand, with the exception of the 20-diameter lap, the observed stresses in the No. 2 bars are practically identical with the normal stresses up to the yield point of the steel, which had a value of about 50,000 and 45,000 psi for the ½-in. and 1-in. bars, respectively.

It is evident that, if the stress in the lapped bar at the end of the splice is not equal to the normal stress, the adjacent continuous bars assume a greater proportion of the total tensile stress. Actually, this was not a serious matter in the beams that were tested with laps greater than 20 diameters; for even at the higher stresses the difference between the actual and normal stress was not more than 8 to 10 percent, probably half of which was assumed by the two continuous bars at that point. Consequently, the load which would normally stress the reinforcement, beyond the splice, to its yield point was not materially affected by the slight shifting of stress. This was not true, however, of the beams containing the 20-diameter lap splices, where the load at which yielding of the reinforcement occurred, as a rule was somewhat lower than for the other beams.

2. BOND STRENGTH

The load-stress curves for the gage line nearest the free ends of the lapped bars indicated that the tensile stress there reached a maximum value at approximately the same load in all of the specimens tested. Also, the maximum stresses at this point were reasonably alike for a given type and size of bar regardless of the length of lap-splice. However, there was a marked difference in the values for the two types of bars. By the use of the maximum tensile stresses scaled from the curves, the bond strength developed by the lapped bars for an embedded length of about 3 in. was computed for each specimen and the bond stresses thus obtained are listed in table 4. The values are somewhat higher than would be expected from standard pull-out tests, but compare favorably with results from unpublished data of similar bars in beam tests.

TABLE 4.—*Maximum bond stress developed at free end of lapped bars*

[Average stress for an embedment of approximately 3 in.]

Specimen	½-in. bars		1-in. bars	
	No. 2	No. 1	No. 2	No. 1
	psi	*psi*	*psi*	*psi*
A-50	850	745	880	755
A-40	970	840	960	655
A-30	880	810	1,010	705
A-20	890	745	1,010	755
Average	895	785	965	720
[a] A-40x	880	675	755	630
[a] A-30x	920	675	1,010	755
[a] A-20x	950	810	1,000	760
Average	917	720	922	715

[a] Lapped bars in contact with each other.

3. COMPARISON BETWEEN METHODS OF LAPPING

The results of the two methods of lapping, one in which the lapped bars are spaced 1½ diameters clear and the other where they are in contact, are compared in figures 20 and 21. Here the stress distribution curves are shown for a given load and for each length of splice. There is practically no difference in the stress between the curves representing each type of lap at any point for the 1-in. bars and little difference for the ½-in. bars. These differences are probably no greater than would be obtained in duplicate tests. A further comparison is shown in figures 18 and 19, in which the load-stress curves for the lapped bars at the limits of the lap are shown for both types of splice.

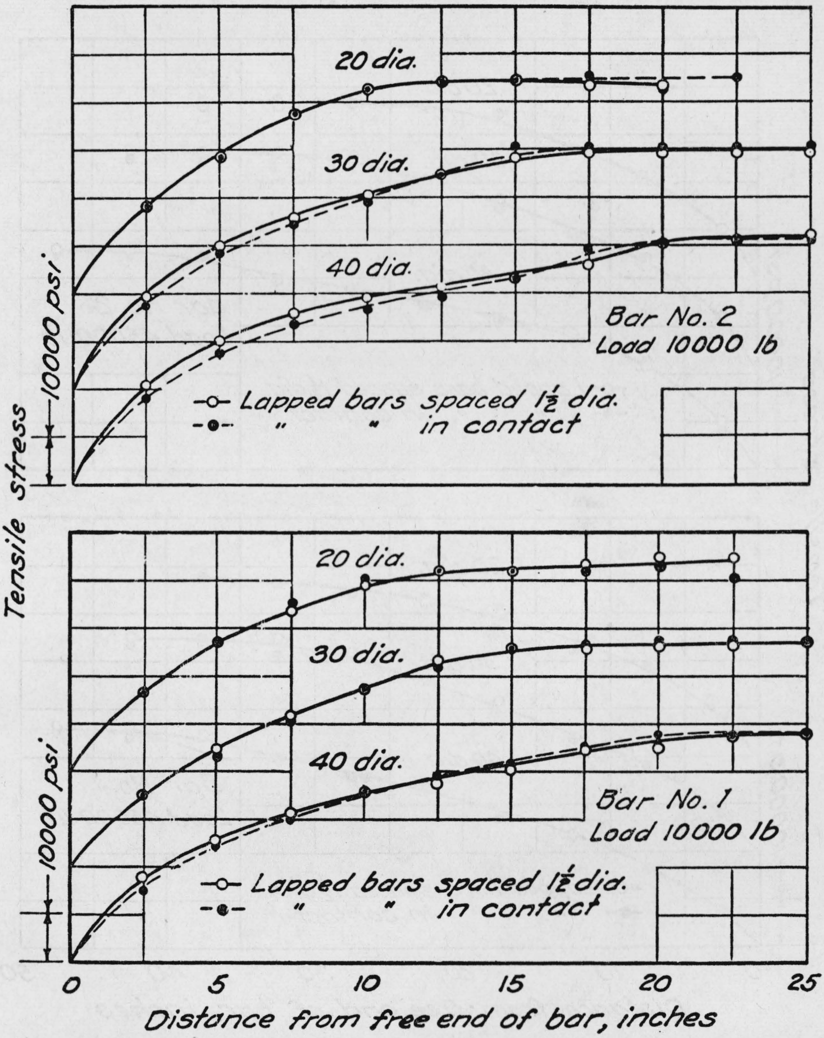


FIGURE 20.—*Distribution of stress along the lapped bars of two types of lap-splices.*
½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

Here, again, the differences are small and in most instances negligible. It is also evident from table 4 that it made little difference in the bond strength in these tests whether the lapped bars were spaced 1½ diameters apart or were in contact.

4. DISTRIBUTION OF SLIP ALONG LAPPED BARS

There were large differences in slip between certain specimens, and these differences were not always consistent. It is highly probable that wide variations in slip data, obtained in the manner described herein, would also be observed in duplicate tests. It should be noted that the slip at each point along the lapped bar was reckoned from a point directly opposite it on the adjacent continuous bar, and

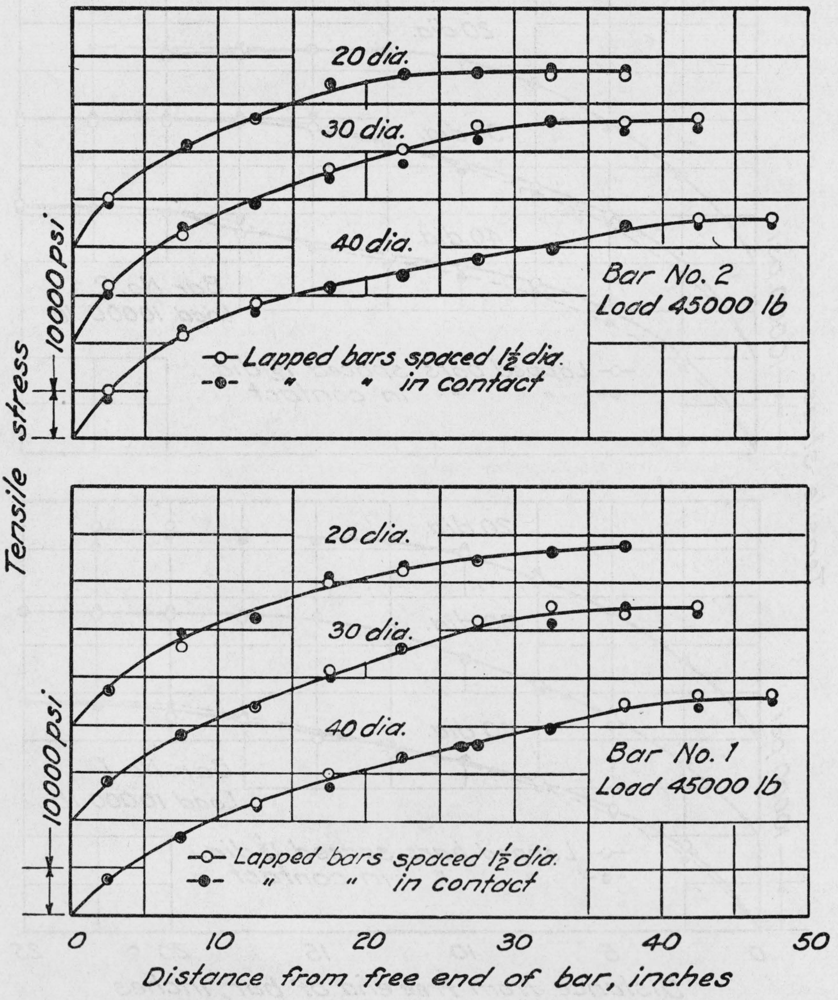


Figure 21.—*Distribution of stress along lapped bars of two types of lap-splices.*

1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

consequently does not necessarily indicate the relative movement of the bar with respect to the concrete.

Slip starts, quite naturally, at the free end of the bar, where the bond stress is always the greatest, and progresses along the bar as the tensile stresses increase at the loaded end. In this respect, the behavior of the bar differs from that in the usual pull-out or beam tests for bond. The distribution of the slip along the lapped bars for various lengths of splice is shown in figures 22 and 23. The data are plotted for two loads, one of which produced a tensile stress of approximately 18,000 psi and the other about 40,000 psi at the loaded ends of the lapped bars. Most of the evidence seems to indicate that the distribution and magnitude of the slip is independent of the length of the splice. There appears to be a serious departure from this principle with the No. 1 bars at higher loads. The discrepancy is not readily accounted for except insofar as a part of the variation might be accidental. Within the range of working stresses, however, the length of lap seems to have little or no effect upon the magnitude of the slip for that bar.

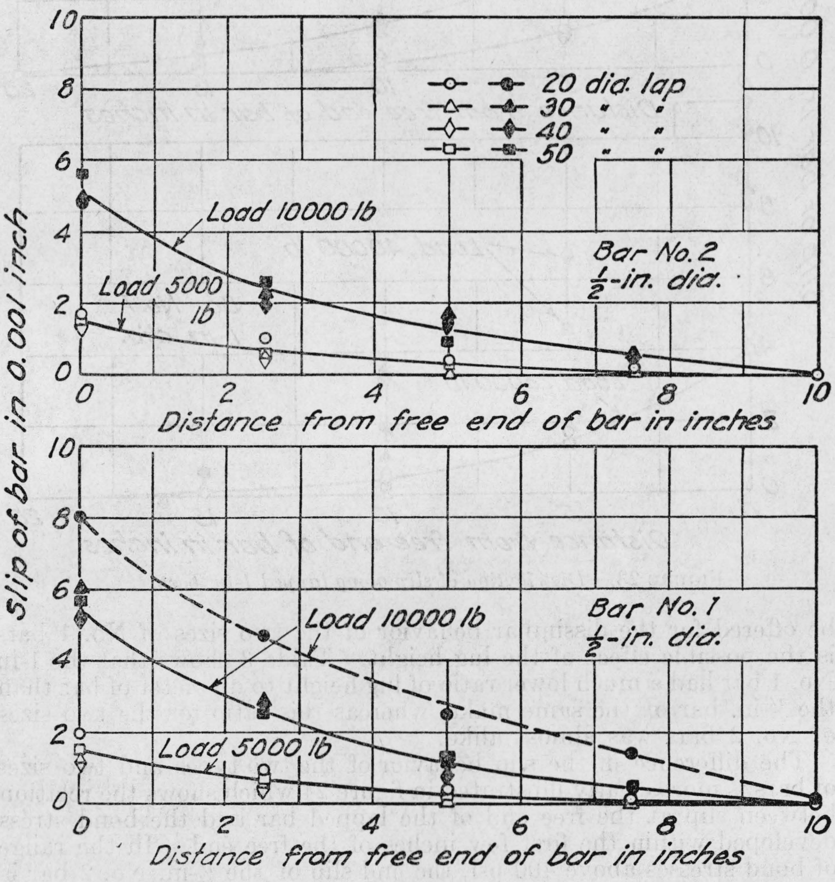


FIGURE 22.—*Distribution of slip along lapped ½-in. bars.*

With one exception, there was little difference in slip between the No. 1 and No. 2 ½-in. bars for a given tensile stress at the loaded ends of the lapped bars. The exception was the 20-diameter lapped No. 1 bar, which showed a considerably greater slip than any of the other lapped bars of this size. The 1-in. No. 1 bars, however, exhibited a decidedly greater slip for a given load or end stress than the 1-in. No. 2 bars or either of the ½-in. bars. The only explanation that can

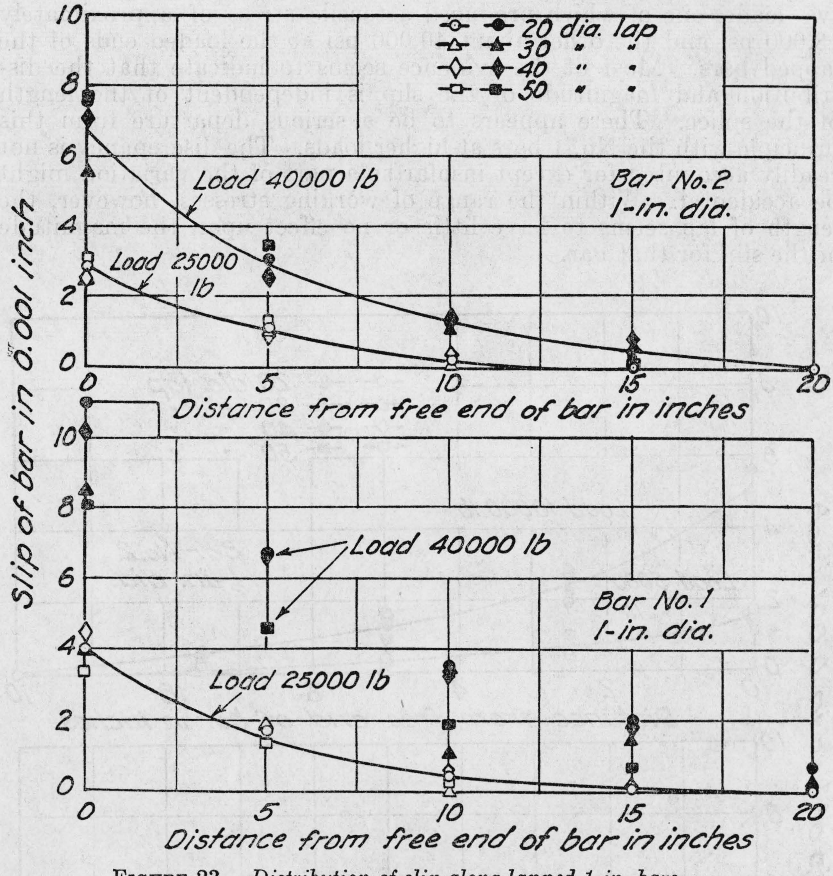


Figure 23.—*Distribution of slip along lapped 1-in. bars.*

be offered for the dissimilar behavior of the two sizes of No. 1 bars is the possible effect of the lug height. Table 3 shows that the 1-in No. 1 bar had a much lower ratio of lug height to diameter of bar than the ½-in. bar of the same make, whereas this ratio for the two sizes of No. 2 bars was almost alike.

The difference in the slip behavior of the two types and two sizes of bars is more clearly illustrated in figure 24 which shows the relation between slip at the free end of the lapped bar and the bond stress developed within the first few inches of the free end. In the range of bond stresses above 400 psi, the end slip of the ½-in. No. 2 bar is somewhat less than the 1-in. bar of the same make and as previously noted the slip of the ½-in. No. 1 bar is very much less than the 1-in. No. 1 bar for all bond stresses.

It is to be noted that slip is not directly proportional to the bond stress developed by the bar, but apparently is some exponential function of this stress, the expression for the relationship depending upon the type of bar.

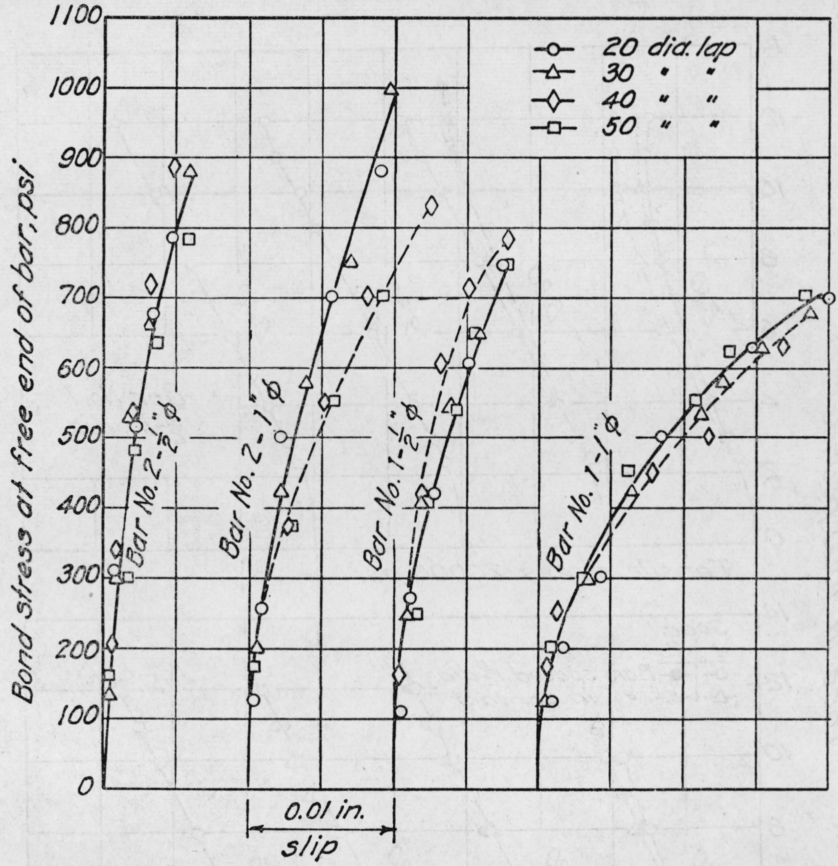


FIGURE 24.—*Relation between slip at free end of bar and bond stress near free end.*

V. TEST RESULTS OF SERIES B

1. GENERAL MANNER OF FAILURE

As stated in section II, 2, the tests of series B were planned to determine the average maximum bond stress developed by the lapped bars for various lengths of lap. Although the specimens contained high-yield-strength reinforcement, many of the beams failed in tension. All the 30- and 40-diameter lap splices developed the yield strength of the bar beyond the ends of the lap, and all the 10-diameter splices failed in bond. On the other hand, about half of the 20-bar-diameter splices failed in tension and the remainder failed in bond. Many of the bond failures were not well-defined because, in some instances, there was a gradual shifting of stress from the lapped bar to the continuous bars as the bond strength was reached. Some of the bond failures, however, were very evident from an examination of the load-stress curves of the lapped bars outside the limits of the splice. The strain in the bar at that point reached a maximum, as shown in figures 25 and 26, and either remained at that value or decreased with an increase in load. The breakdown of bond was also

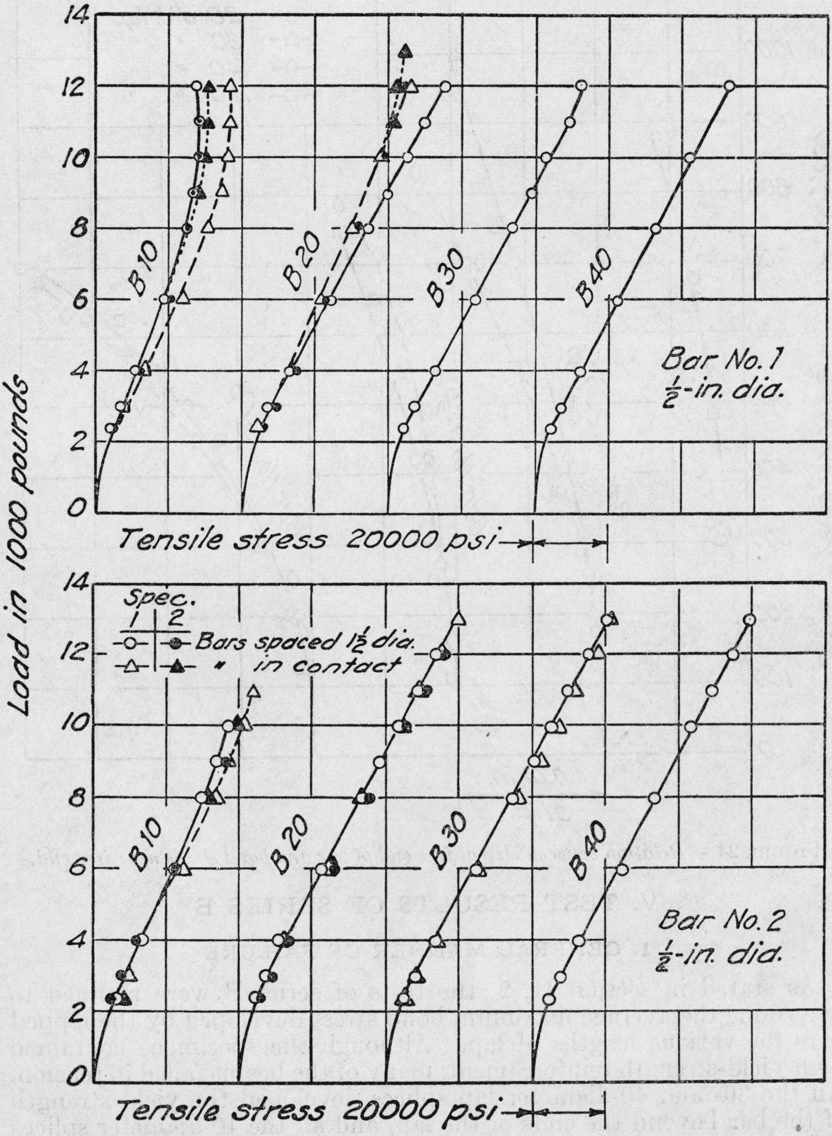


FIGURE 25.—*Load-stress relation for lapped bars outside limits of splice.*

Beams of series B. ½-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

reflected, to some extent, by a change in the slope of the load-strain curves for the continuous bars at this section of the beam.

2. AVERAGE BOND STRENGTH

Table 5 lists the maximum average bond stress developed by the various lapped bars. The values are based on the maximum tensile stress reached at a point just beyond the limits of the splice and on the total length of bar embedment, which was considered to be the distance from the free end of the bar to the midpoint of the first gage line.

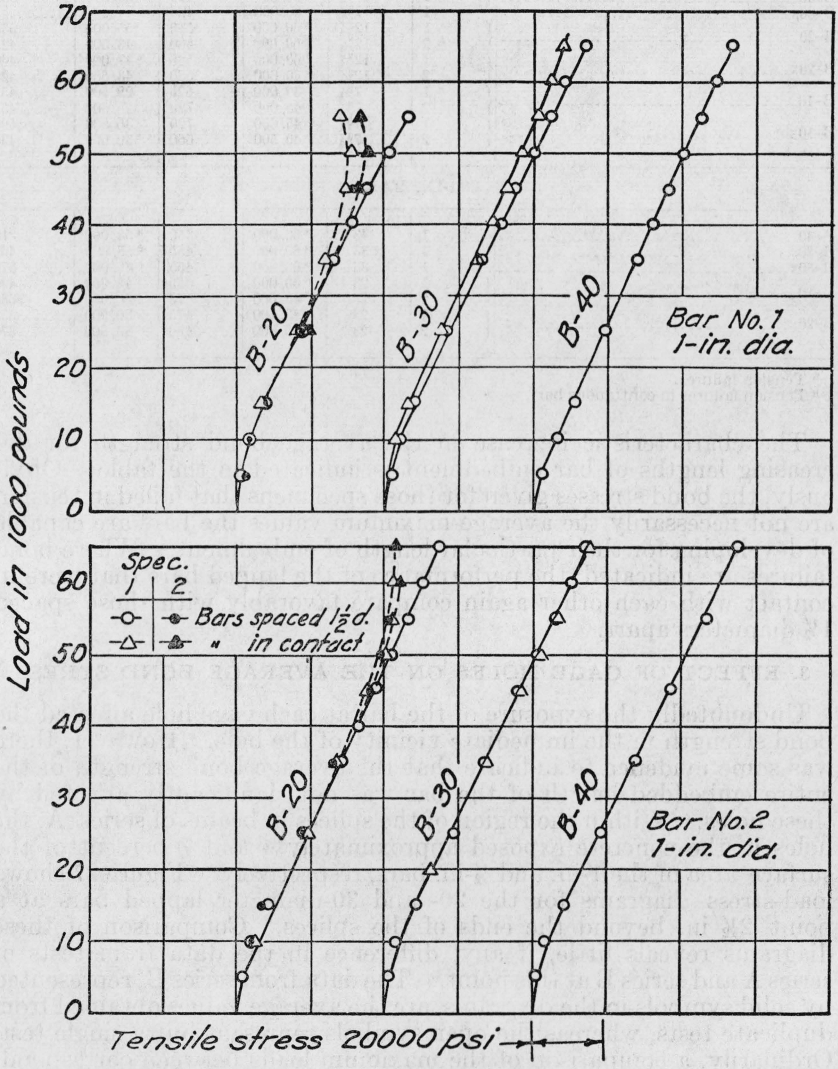


FIGURE 26.—*Load-stress relation for lapped bars outside limits of splice.*

Beams of series B. 1-in. bars. Stress values are the product of the modulus of elasticity and observed strains.

TABLE 5.—*Average bond stresses developed by lapped bars just before failure*

[Tests of series B]

Specimen	Specimen number	Length of embedment	Bar No. 2 Tensile stress	Bar No. 2 Bond stress	Bar No. 1 Tensile stress	Bar No. 1 Bond stress
½-IN. BARS						
		in.	*psi*	*psi*	*psi*	*psi*
B-40	1	22¾	[a] 60,000	325	[a] 52,000	300
B-30	1	17¾	[a] 60,000	420	[a] 55,000	385
B-30x	1	17¾	[a] 60,000	420	----------	----------
B-20	1	12¾	[a] 60,000	580	[a] 55,000	535
	2	12¾	[a] 60,000	580	43,500	425
B-20x	1	12¾	[a] 60,000	580	47,000	460
	2	12¾	[a] 60,000	580	43,500	425
B-10	1	7¾	39,000	625	28,500	455
	2	7¾	45,000	720	28,500	455
B-10x	1	7¾	45,000	720	36,800	590
	2	7¾	40,500	650	30,600	490
1-IN. BARS						
B-40	1	43	[a] 60,000	350	[a] 53,000	310
B-30	1	33	[a] 60,000	455	[a] 53,000	405
B-30x	1	33	[a] 60,000	455	[b] 49,000	370
B-20	1	23	[a] 60,000	655	45,000	490
	2	23	43,500	475	30,000	330
B-20x	1	23	43,500	475	30,000	330
	2	23	45,000	490	33,800	370

[a] Tension failures.
[b] Tension failures in continuous bar.

The characteristic increase in the average bond strength for decreasing lengths of bar embedment is indicated in the table. Obviously, the bond stresses given for those specimens that failed in tension are not necessarily the average maximum values the bars are capable of developing for their particular length of embedment. Where bond failures are indicated, the performance of the lapped bars that were in contact with each other again compare favorably with those spaced 1½ diameters apart.

3. EFFECT OF GAGE HOLES ON THE AVERAGE BOND STRESS

Undoubtedly the exposure of the bar at each gage hole affected the bond strength in the immediate vicinity of the hole. However, there was some evidence to indicate that the average bond strength of the entire embedded length of the bar was not significantly affected by these holes. Within the region of the splices in beams of series A, the holes in the concrete exposed approximately 4 and 7 percent of the surface area of the 1-in. and ½-in. bars, respectively. Figure 27 shows load-stress diagrams for the 20- and 30-diameter lapped bars at a point 2½ in. beyond the ends of the splices. Comparison of these diagrams reveals little, if any, difference in the data from tests of series A and series B at this point. The data from series B, represented by solid symbols in the diagrams, are the average values obtained from duplicate tests, whereas the open symbols represent but a single test. Ordinarily, a comparison of the maximum loads between corresponding beams, at least for the shorter splices, would indicate the effect of exposing the reinforcement in this manner. However, ultimate failure of most of the beams in series A was due to yielding of the reinforcement.

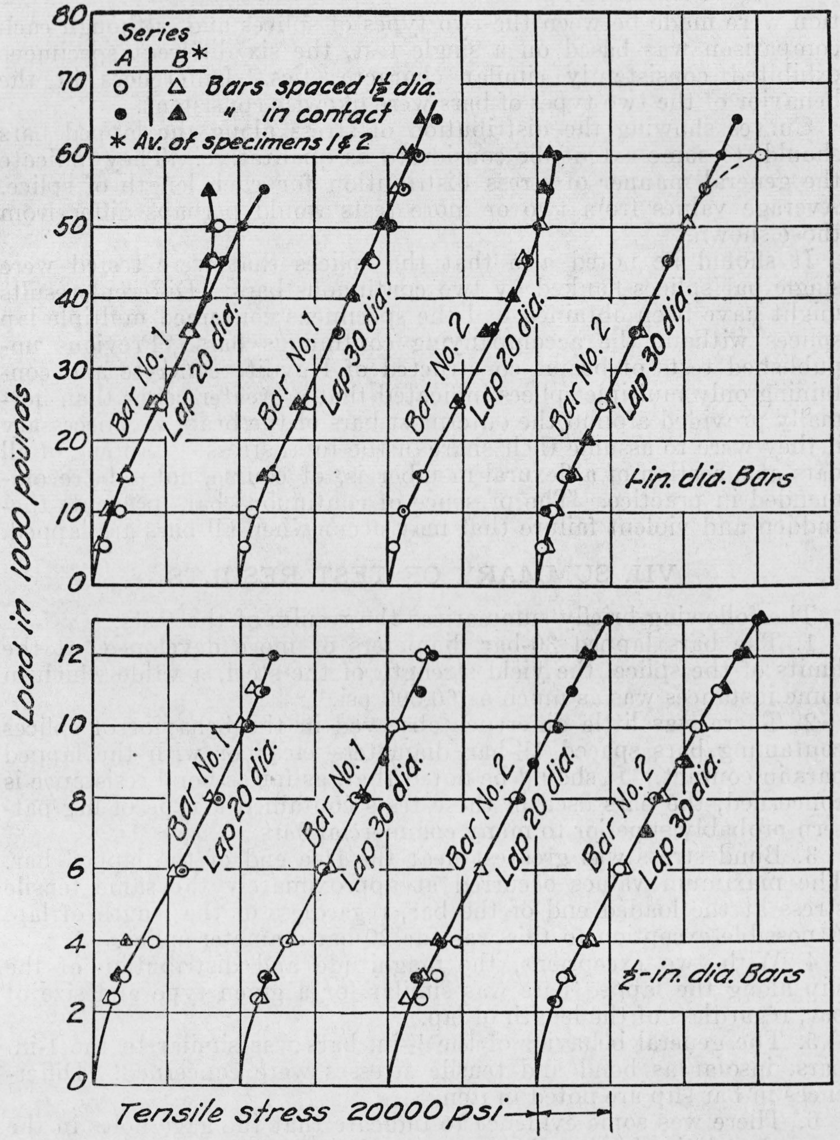


FIGURE 27.—*Comparison between load-stress diagrams of series A and series B.*

Stress outside limits of splice. Stress values are the product of the modulus of elasticity and observed strains.

VI. DISCUSSION OF RESULTS

1. GENERAL DISCUSSION

It is recognized that much of the data presented are based on single tests, from which sound conclusions may not always be drawn. It is significant, however, that, except where observations of bar slip were concerned, the data were consistent from specimen to specimen. For example, comparisons of bond stress and its manner of distribution were made between the two types of splices and, although each comparison was based on a single test, the six different specimens exhibited consistently similar characteristics. Differences in the behavior of the two types of bars were likewise consistent.

Curves showing the distribution of stress along the lapped bars should, to some extent, be considered as qualitative. They indicate the general manner of stress distribution for each length of splice. Average values from two or more tests would perhaps differ from those shown.

It should be noted also that the splices that were tested were single bar splices flanked by two continuous bars. Different results might have been obtained had the specimens contained multiple lap splices without the accompanying continuous bars. Previous unpublished tests of beams constructed of Haydite concrete and containing only multiple splices indicated that a greater cover than normally provided around the outermost bars of the beam was necessary if they were to assume their share of the total stress. Lapping of all bars at a section of a flexural member is, of course, not to be recommended in practice. The presence of continuous bars prevents the sudden and violent failure that may occur when all bars are lapped.

VII. SUMMARY OF TEST RESULTS

The following briefly summarizes the results of the tests:

1. The bars lapped 30-bar diameters or more developed, at the limits of the splice, the yield strength of the steel, a value which in some instances was as much as 60,000 psi.
2. There was little difference observed in the behavior of splices containing bars spaced 1½-bar diameters clear or with the lapped bars in contact. It should be noted that, as far as bond resistance is concerned, the bars used in these tests contained a type of lug pattern probably superior to many commercial bars.
3. Bond stress was greatest near the free end of the lapped bar. The maximum values occurred at approximately the same tensile stress at the loaded end of the bar, regardless of the length of lap. A possible exception to this was the 20-bar-diameter splice.
4. With two exceptions, the magnitude and distribution of the slip along the lapped bars was similar for a given type and size of bar, regardless of the length of lap.
5. The general behavior of the ½-in. bars was similar to the 1-in. bars, insofar as bond and tensile stresses were concerned. Differences in bar slip are noted in item 8.
6. There was some evidence to indicate that the gage holes in the concrete of the beams did not seriously affect the strength of the splice.
7. The No. 2 bar which had a considerably greater bearing area of the lug per inch length of bar, not only picked up stress at its free end in the splice more rapidly but developed greater maximum bond strenghts than the No. 1 bar.
8. The 1-in.-diameter No. 1 bar exhibited a considerably greater slip for a given bond stress than any of the other bars. The differences between the two types of bar of the ½-in. size were minor. Both showed slightly less end slip than the 1-in. No. 2 bar for a given bond stress at the free end of the bar.

Washington, March 21, 1945.