A Study of Splices in Tensile Reinforcing Bars

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•THE NEED for reliable, practical and economical methods of splicing tensile reinforcing bars has long been known. In the field of precast concrete, such a connection or splice would lead to continuity for precast members resulting in increased strength, rigidity, and economy. In many long-span, flexural and eccentrically loaded compression members, it is frequently necessary to splice tensile reinforcing bars.

In the past this problem has been taken care of by lapping or butt-welding individual bars. Both of these approaches can adequately transfer the axial stress, but each has inherent undesirable characteristics. Lap splices usually initiate diagonal tensile cracks or failure at the point of cutoff of the stressed bars unless extra stirrups or ties are supplied in this region. Butt-welding of the ends of reinforcing bars is generally considered too expensive to be practical. Because of these undesirable features, other means of tensile splicing would gain wide acceptance if proper design criteria could be developed through research.

In response to this design need, several mechanical connectors have appeared on the market. However, due to the absence of proper research and testing, only limited acceptance has been gained. This is evidenced by the fact that most codes do not recognize such splices. In Sec. 1.7.5(c) of the 1961 AASHO specifications, the following statement appears:

> Tensile reinforcement shall not be spliced at points of maximum stress. When the reinforcement is spliced, the spliced bars shall lap sufficiently to develop the full strength in bond.

A further statement appears in Sec. 2.5.6:

> Splicing of bars, except where shown on the plans, will not be permitted without the written approval of the engineer. Splices shall be staggered as far as possible. Unless otherwise shown on the plans, bars in the bottom of beams and girders, and in walls, columns and haunches shall be lapped 20 diameters and bars near the top of beams and girders having more than 12 inches of concrete under the bars shall be lapped 35 diameters, to make the splice.

The 1963 code of the American Concrete Institute does not recommend the splicing of tensile bars at points of maximum stress, but such a splice when used is required to develop the full computed stress in the bar based on not more than $^3/_4$ of the permissible bond value. In addition, a minimum lap is specified for each of several grades of steel bars. To meet the 1963 ACI code, a welded butt splice or other approved positive connection must develop in tension at least 125 percent of the specified yield strength of the bar.

If mechanical splices are to have general acceptance, data must be obtained on the relative merits of mechanical splices compared with lap or butt-welded splices. The collection of these data and the critical evaluation of some of these types of connections were the objectives of the research reported in this paper.

Present Status of Research

In 1959 Eriksson (5) studied the sleeve splice. His testing program of 200 samples included only static tests, but treated extensively the variables of sleeve configuration,

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curing time, and grout strength, type, and thickness. Both tension and compression tests were performed. These tests showed the splices to have excellent reliability under compression loading and to react in a satisfactory manner to tension loadings. Eriksson's tests indicated that the splice was quite insensitive to the variables of mortar thickness, grout type and strength, and curing durations above 7 days, but highly sensitive to the splice sleeve length in the range of 2 to 10 bar diameters. Eriksson also recommended the use of nonshrinking mortar grout.

Other references dealt with lapped splices and with bond stresses. Although lapped splices have long been an accepted construction practice, the literature in this area was rather limited. The problems of bar spacing, type of bar deformations and lap length were investigated by Chamberlin (2), Walker (9), and Chinn et al (3). Kluge and Tuma (7) conducted tests on lapped splices of bar sizes up to No. 8.

There is extensive literature on the subject of bond stresses and tension pull-out specimens. One of the earliest reports is by Abrams (1), who developed many ideas on the nature of bond resistance and conducted extensive tests on pull-out and beam specimens. He illustrated the progressive nature of bond stress development and described the effect of bar deformations on maximum bond stresses.

Following the paper by Abrams, a number of investigators conducted tests on the bond resistance of various types and sizes of reinforcing bars. Among the most significant reports are those by Watstein (10), Clark (4), Mylrea (8), and Ferguson et al (6).

Scope of This Investigation

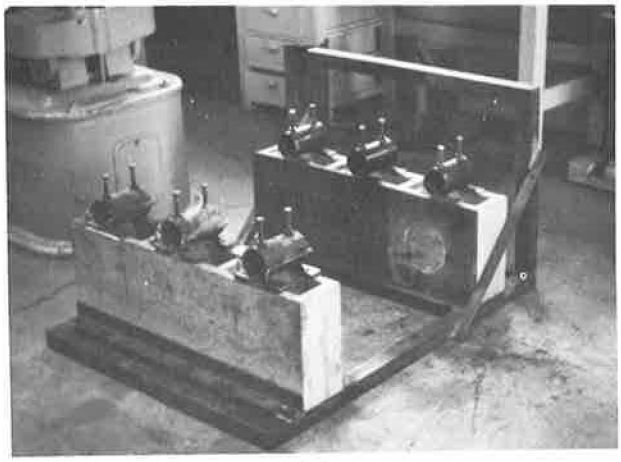
The results reported in this paper are divided into 2 main groups—40-ksi nominal yield strength deformed bars (ASTM A 15 and ASTM A 408) and 60-ksi (ASTM A 432) nominal yield strength deformed bars. All bars used were from the same mill and thus had the same deformation pattern. A series of control bars (continuous bars) and a series of each type connection were tested using Nos. 9, 10, 11 and 14S bars in each group. The control bars were from the same heat number as the spliced bars of the same size and yield strength. Thus any variation in performance between the control bar and each type of the connection could reasonably be attributed to the connection alone. Two control samples of each particular size and yield strength were tested. The results of these 2 tests were also compared with the mill test reports supplied by the fabricator.

Two samples of each bar size and steel grade of the butt-welded bars were tested. These results also were compared with the other splicing devices. After some study it was decided to limit the new type connections to 3 basic types and to designate them as exothermic No. 1, exothermic No. 2, and sleeve-with-metal-filler. Three identical samples of each bar size and steel grade were included.

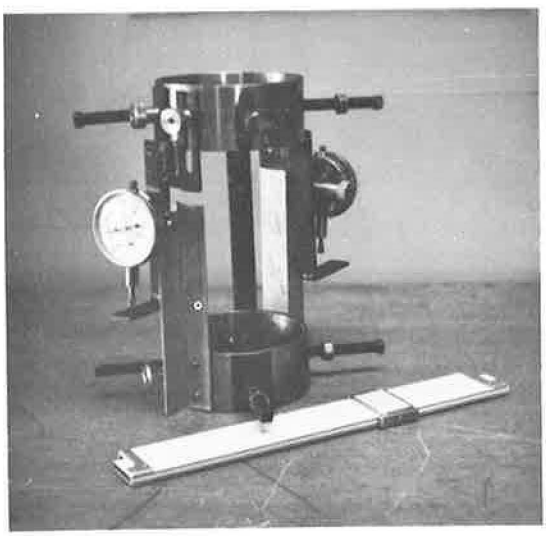
As a secondary study sleeves filled with epoxy and sleeves filled with expanded cement grout were also included in the investigation. Since it was felt that these connections would have to compare favorably with the sleeve-with-metal-filler connection to have significant practical value, each utilized the same sleeve which corresponded to the sleeve-with-metal-filler connection of the same bar size and steel grade. All bars in this secondary study were deformed No. 9 bars of 40-ksi nominal yield strength (ASTM A 15). Five sleeve samples filled with the expanded cement grout and at least 3 samples of each of 3 epoxy formulations were tested.

FABRICATION AND TESTING OF TENSILE SPLICES

The fabrication of the connections required a device to hold the 2 bars in rigid alignment during the splicing operation and a jig was constructed to fill this need (Fig. 1a). This jig could be used to make either vertical or horizontal connections, depending on its position. The sleeve-with-metal-filler connections were made with the axis of the reinforcing bar in a vertical position with the jig set on its end; all other connections were made with the axis of the reinforcing bar horizontal. In the case of the sleeve-with-metal-filler splices, either horizontal or vertical can be made. Although the investigation did not verify it, the supplier of this splice indicated that the splicing position does not affect the structural properties of the splice.



(a)



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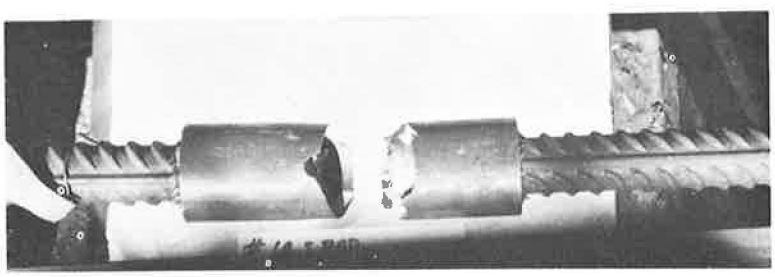
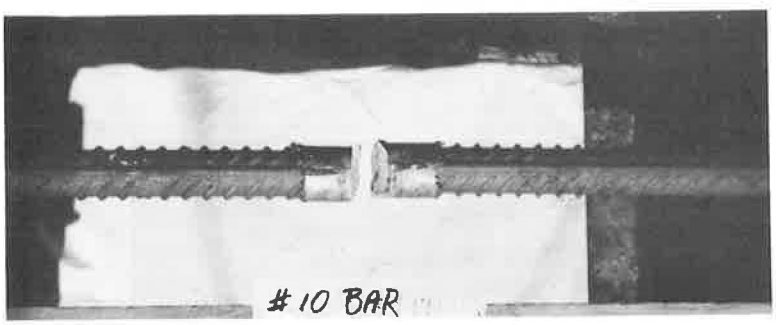


(c)

Figure 1. (a) Alignment jig. (b) Tensile extensometer. (c) Typical sleeve failure using sleeve-with-metal-filler type connection.

(d)



(e)

(f)

Figure 1. (d) Typical bar failure using sleeve-with-metal-filler type connection. (e) Typical exothermic No. 2 failure. (f) Typical exothermic splicing operation.

(g)

(h)

(i)

Figure 1. (g) Exothermic No. 1 connections being formed. (h) Surplus slag metal on exothermic No. 1 connection after its removal. (i) Typical cross section of exothermic No. 1 connection after failure.

TABLE I

TYPES AND NUMBER OF SAMPLES TESTED

NOMINAL YIELD STRENGTH (psi)	40,000				60,000				TOTAL SAMPLES TESTED
ASTM DESIGNATION	A-15	A-15	A-15	A-408	A-432	A-432	A-432	A-432	
BAR SIZE	#9	#10	#11	#14S	#9	#10	#11	#14S	
CONTROL BARS	2	2	2	2	2	2	2	2	16
BUTT WELDED	2	2	2	2	2	2	2	2	16
SLEEVE WITH METAL FILLER	3	3	3	3	3	3	3	3	24
EXOTHERMIC #1	3	3	3	3	3	3	3	3	24
EXOTHERMIC #2	3	3	3	3	3	3	3	3	24
EPOXY #1	5								5
EPOXY #2	5								5
EPOXY #3	3								3
EXPANDED GROUT	5								5
TOTAL NUMBER OF SAMPLES TESTED									122

The jig used for fabrication was relatively light and portable, which was convenient because the exothermic-type connections had to be made outdoors. These connections spewed bits of molten metal and produced a great deal of smoke from the mold during the reaction. In contrast, the sleeve-with-metal-filler connection generated a relatively small amount of heat and negligible smoke, and the fire hazard from the spewing bits of reactant material was minimal.

Two control bars were tested for each size and grade of steel used in this investigation (Table 1). The control bars consisted of 24-in. lengths cut from stock of the same heat used to make the other connections and were tested exactly the same way.

Connections

Butt Weld. —Two butt-welded connections were prepared and tested for each bar size and steel grade. In ordering the samples in this series of connections, each welded joint was specified to have sufficient strength so as to develop the full tensile strength of the bar, per American Welding Society specification D12.1, "Recommended Practices for Welding Reinforcing Steel, Metal Inserts, and Connections in Reinforced Concrete Construction." During the testing program, a value of 125 percent of the nominal yield strength of the bar was also considered, per 1963 ACI code Sec. 805(d).

Exothermic No. 1. —The exothermic No. 1 consisted essentially of a sand mold filled with reactant powder which, when ignited, reacted rather violently and changed to a molten state which flowed by gravity around and between the ends of the bars. A sealing paste was applied to the contact faces of the mold halves to prevent leakage. The bars were aligned with a $^3/_8$-in. gap between their ends by a spacer and the mold positioned so that the metal flow channel was directly over this gap. The ends of the mold around the reinforcing rod were luted with sealing sand and two metal discs were placed in the space provided at the bottom of the mold. The reactant powder was then poured into the mold and ignited. The reaction reached an extremely high temperature (4600 F) which melted the metal discs, thus allowing the molten metal to flow between and around the bars so as to weld them together. After a few minutes the remains of the mold, which is itself destroyed, can be removed, but a longer waiting period is recommended to permit the refractory portion of the mold to stress-relieve the weld area. Removal of flash and excess metal is not required but may be accomplished if space limitations demand it.

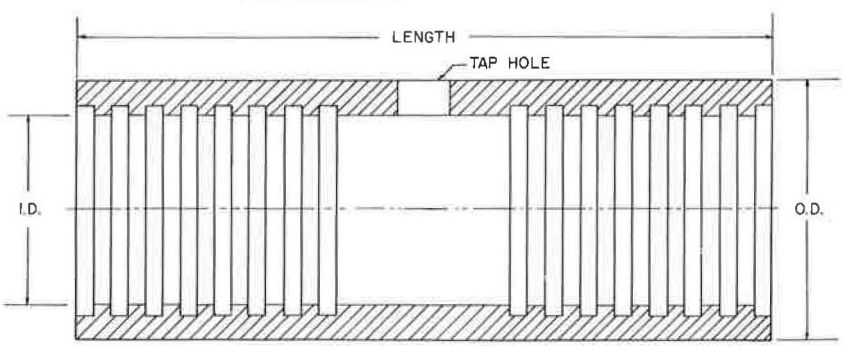
Exothermic No. 2. —The exothermic No. 2 connection very closely resembles the exothermic No. 1 connection. Both used luted sand molds with a reactant powder; both required a $^3/_8$-in. gap between bars, and both literally welded the bars together. There were some minor differences, however, in the physical procedure in making the two connections. The exothermic No. 2 used no sealing paste on the contact surfaces of

each half mold. A tight seal was obtained by clamping the half molds together with 2-in. C-clamps. Also, the molds fit rather loosely around the bars and small wooden wedges were placed at each end of the mold between the bar and the mold. This tended to stabilize the mold in the correct position and prevent rotation. After ignition of the reactant powder, the actual weld is formed in the same manner as the exothermic No. 1.

Sleeve-With-Metal-Filler. —This method of connecting reinforcing bars together consists of inserting the ends of both bars into a common sleeve and filling the sleeve with a metal filler material which mechanically locks the bars together. The ends of the bars must be clean, dry and free of rust, grease, dirt, etc. However, tightly adhering mill scale need not be removed. For vertical connections, as were used in this study, the bottom alignment fitting is positioned on the lower bar so that the gap between the bars will be at the center of the sleeve. Asbestos wicking or packing is placed around the bar at the top of the bottom alignment fitting (which supports the sleeve) and also at the top of the sleeve. The asbestos wicking at the top of the sleeve is positioned against the sleeve by the top alignment fitting. The pouring basin is then attached tightly around the small opening in the center of the sleeve. The crucible is then placed on top of the pouring basin. A small steel disc is placed in the bottom of the crucible over the tap hole and the filler cartridge of reactant powder is poured into the crucible. A small amount of starting powder is then placed on top of the reactant powder and ignited with a flint. Upon completion of the reaction in the basin the disc is melted, and the molten alloy metal flows into the sleeve through the small opening in the center of the sleeve. It cools, thus locking or keying the sleeve (through the internal grooves) to the reinforcing bars (through the bar deformations). It should be emphasized that this is a mechanical connection, not a weld. The sleeves used were proportioned in order to develop at least the ultimate tensile strength of each bar size and steel grade. Table 2 summarizes the geometric and physical properties of the splice sleeve.

TABLE 2

PROPERTIES OF SLEEVES USED



SLEEVE CROSS-SECTION

SPLICE SLEEVE						TENSILE STRENGTH OF SPLICE BASED ON AREA OF REBAR
BAR SIZE	NOMINAL YIELD STRENGTH OF REBAR (k.s.i.)	LENGTH (in)	O.D. (in)	I.D. (in)	AREA OF SLEEVE AT TAP HOLE (in^2)	$\frac{\text{AREA SLEEVE}}{\text{AREA REBAR}}$ x 80,000 p.s.i.
14S	60	7	2-3/4	2	2.564	91,200
	40	7	2-5/8	2	2.075	73,800
11	60	6	2-3/8	1-3/4	1.869	95,800
	40	6	2-1/4	1-3/4	1.446	74,200
10	60	5	2-1/4	1-5/8	1.746	110,000
	40	5	2-1/8	1-5/8	1.348	84,900
9	40 or 60	5	2	1-1/2	1.250	100,000

Sleeves With Epoxy No. 1, No. 2 and No. 3. —All epoxy connections used identical No. 9 bar sleeves as supplied by the manufacturer for the sleeve-with-metal-filler connections for bars meeting ASTM A 15 specifications. The epoxy served as the locking material in the sleeve and connected the bars together much as the sleeve-with-metal-filler connection. Although none of the epoxies were formulated for this particular purpose, it was desired to investigate their possible value in this area. Because of the limited amount of epoxy No. 3 available, only 3 samples of this type were made, but 5 samples each were made using epoxy No. 1 and No. 2.

Epoxy No. 1 and epoxy No. 3 were commercial formulations, while epoxy No. 2 was formulation 991-67 (General Purpose Adhesive) as outlined in American Railway Engineering Association Bulletin No. 573. When mixed, each epoxy had the consistency of a lightweight grease.

The epoxies presented some special handling problems as the pot life averaged only approximately 15 minutes and no special equipment was available to force it into the sleeves. In order to reduce the possibility of voids, each sleeve was filled with epoxy and then one bar was inserted, which forced out some excess epoxy. Then the second bar was inserted which forced out an additional excess quantity of epoxy. It was felt that a satisfactory procedure for filling the sleeves could be developed if the preliminary results of this limited test program should warrant it. The connections were tested one week from the date of fabrication after being cured at room temperature and humidity, and the stress-strain diagrams plotted when sufficient data resulted.

Sleeve With Expanded Cement Grout. —The sleeve-filled-with-grout connections also used the No. 9 bar sleeves supplied by the sleeve-with-metal-filler manufacturer. The bars were of ASTM A 15 material. The grout consisted of one part commercial expanding cement additive and one part of Type I portland cement. Enough water was added to render the mixture suitable for use in the sleeves. The method of fabrication was similar to the epoxy connections, i.e., one bar at a time was inserted into the grout-filled sleeve. Five samples were made. They were tested at 28 days after curing at room temperature in a moist chamber for 7 days followed by 21 days in air.

Testing Procedure

All tests conducted during this investigation were static tensile tests using a standard 8-in. gage length with the connection approximately centered within this length. All bar cross-sectional area calculations were based on the measured diameter of the bar at the base of the deformations. The special type of extensometer which was designed and constructed consisted of 2 rings, 8 in. apart (c/c of bolts), each fastened rigidly to the test specimen by 4 radial bolts (Fig. 1b). Two 0.0001-in. Ames dial gages were attached between the 2 rings and diametrically opposite each other, so that the average total strain recorded would be that of the centerline of the test specimen.

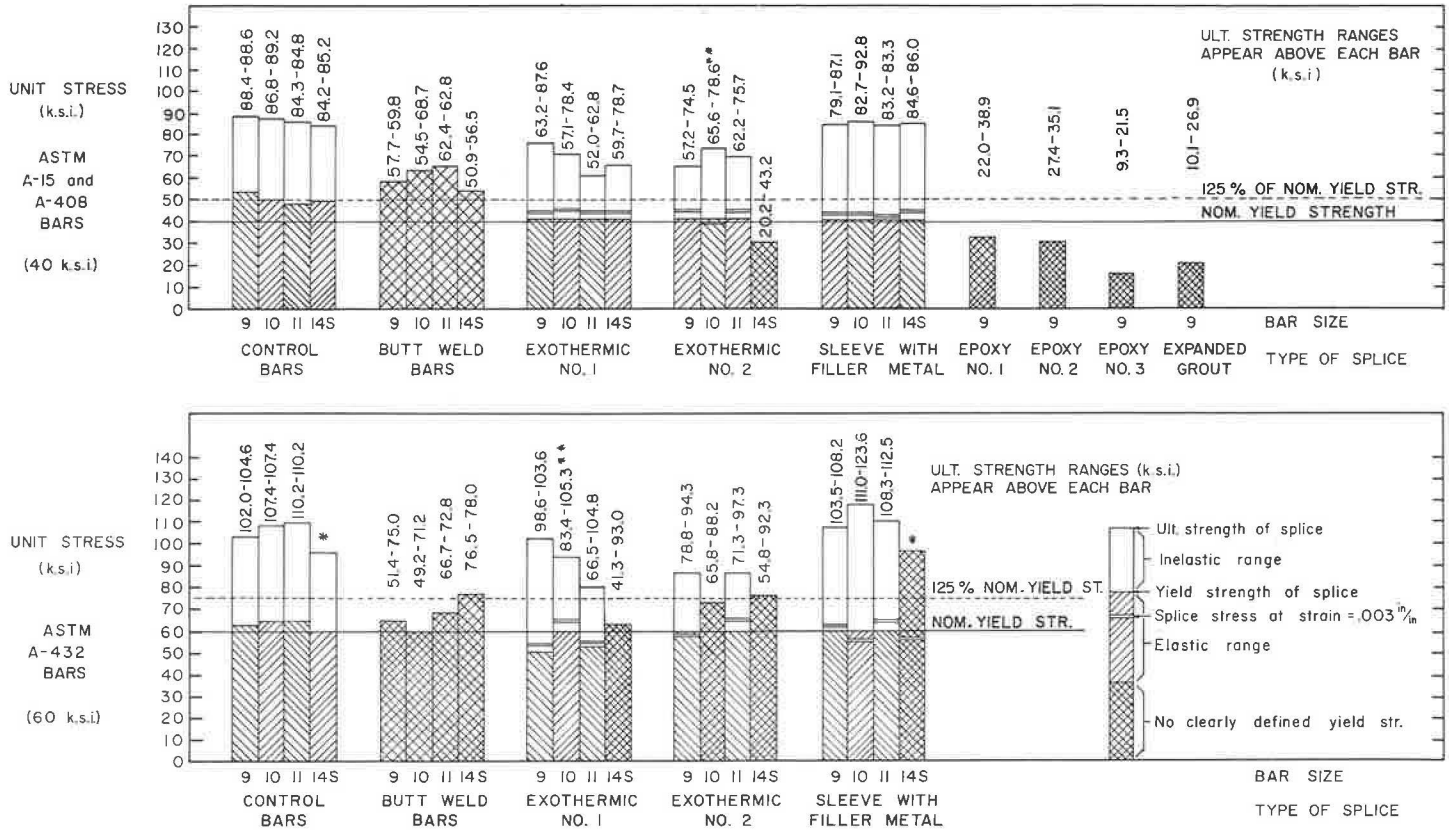
The loading rate was approximately 2000 lb per min for all tests. Because of their dependability against sudden failure, the sleeve-with-metal-filler connections were tested to the nominal yield strength before the gages were removed. After damaging several Ames dials due to premature failures of the exothermic-type connection, all subsequent test specimens were preloaded to approximately two-thirds of their nominal yield strength before the gages were set in place. When the connection had sufficient plastic strength to elongate the bar an appreciable amount after removal of the Ames dial gages large dividers and a 0.01-in. scale were used to obtain strain measurements until failure. All tests were conducted on a 200,000-lb Baldwin Universal testing machine which was calibrated before the investigation began.

Photographs of the test equipment and typical test samples are shown in Figure 1.

DISCUSSION OF TEST RESULTS

Control Bar

As expected, the control bars established the upper stress limits. A summary of all test results is shown in Figure 2. Also note the stress-strain curves for each sample shown in the Appendix, Figures A-1 through A-58. Each sample is compared with a bar without a splice (labeled control bar or theoretical bar).



* 1. Bars did not break as they exceeded the 200 kip limit of the testing machine.
2. Each control bar column and each butt weld column is the average of two test samples.
3. Each exothermic column and each sleeve with filler metal column is the average of three test samples.
4. Each epoxy column (nos. 1 and 2) is the average of five test samples using the same sleeve as used with the metal filled sleeve.
5. Each epoxy column (no. 3) is the average of three test samples using the same sleeve as used with the metal filled sleeve.
6. For No. 9 bars butt welded, insufficient data was available to determine yield strength or unit stress corresponding to .003 in/in of strain.
7. Epoxy no. 3 samples all failed during the preload test of approximately one-half the yield strength.
8. Expanded grout column is the average of five test samples using the same sleeve as used with the metal filled sleeve.
** 9. One sample separated when the mold was removed.

Figure 2. Summary of splice test results.

Butt-Welded Splice

The average values of the maximum stress indicate that the butt-welded connections exceeded the 125 percent of nominal yield strength criteria for 40-ksi nominal yield steel but failed to do so for the 60-ksi yield steel. With the 40-ksi yield steel, data in Figure 2 indicate that the welds were satisfactory but tend to mask some rather erratic test results since an average of 2 samples is shown. The individual stress-strain curves in the Appendix must be taken into account for an accurate analysis. All samples failed in the weld area which, in nearly all cases, showed porosity and a lack of full penetration.

Exothermic No. 1 Splice

All exothermic No. 1 connections proved satisfactory with the exception of the No. 14S bars of 60-ksi nominal yield strength. An average of these 3 samples gives an ultimate strength of just over the nominal yield strength.

All but 2 samples failed in the connection itself. An examination of the cross section after failure revealed a large variation in appearance ranging from uniformly solid to a honeycombing effect with relatively large voids. Oddly enough, no correlation could be established between the presence or absence of the voids and the ultimate strength. The 2 samples that did not fail in the connection itself were the No. 9 bar connections—the bar failed in both cases. One bar was of 40-ksi nominal yield strength, the other was of 60-ksi nominal yield strength.

It should also be noted that one of the 24 exothermic No. 1 connections failed to join the bar together. When the mold was removed, the bars simply fell apart. The reason for this was not determined. The tips of both bar ends were covered with reactant metal which seemed to indicate that they were approximately in the correct position with respect to the metal flow channel.

Exothermic No. 2 Splice

In general, the exothermic No. 2 connections were not as satisfactory as the exothermic No. 1 connections. In the 40-ksi grade group, the No. 14S bars failed prematurely. The reason for this is difficult to determine. The break, which always occurred in the general weld area, appeared solid and free of voids but had a very even, fine-grained appearance somewhat different from the control bar breaks. Some failures were located slightly outside of the original gap between bars, indicating that the tip of one bar had separated. However, the average ultimate stresses of the other bars in this group were all above the 125 percent yield strength level.

Like the exothermic No. 1, one of the 24 exothermic No. 2 connections was a total failure and fell apart when the mold was removed. However, the reason seemed to be a leak in the mold which allowed considerable molten metal to be lost.

Sleeve-With-Metal-Filler Splice

For ultimate strength and reliability, this connection equaled the control bars. There were no premature failures. Of the 24 samples tested, only 2 failures occurred in the sleeves and then at very high stresses. In all other samples, the bars themselves failed and did so at a stress comparable to that of the control bars. Like the No. 14S control bars of the 60 ksi group, the comparable connections did not break but reached the 200,000-lb limit of the testing machine (corresponding to a unit tensile stress of approximately 89 ksi).

Strain may prove detrimental, as the 0.003 in. per in. strain level was reached before the nominal yield strength in 2 of the 4 sizes of bars tested in the 60-ksi group while all of the bars of 40-ksi material passed the nominal yield strength before reaching this strain level.

Sleeves Filled With Epoxy No. 1, No. 2, No. 3 and Expanded Cement Grout

This was actually a splinter project of this study. As epoxies are fairly new and apparently quite versatile, it was decided to examine the feasibility of using typical

epoxies as filler material for sleeve-type tensile connections. For the same reason, a sleeve filled with commercial expanded cement grout was tested. All tests failed at such disappointingly low loads that this area was not explored further. Each sample failed in shear at the interface between the inside sleeve surface and the surface of the reinforcing bar.

PRELIMINARY CONCLUSIONS

Butt-Welded Splices

Because of the wide variation in the test results in this study as well as the cost involved, this type of splice was not completely satisfactory. This is especially true in the case of the ASTM A 432 bars. Under ideal welding conditions, ASTM A 15 and A 408 butt-welded splices may be acceptable.

Sleeve-With-Metal-Filler Splices

Based on the results of this study, the sleeve-with-metal-filler connection will, for all practical purposes, equal the ultimate strength of both 40-ksi and 60-ksi nominal yield strength bars. Their consistently high quality was remarkable, and, if the recommended procedure is followed, it appears that this splice can be used with complete confidence. However, the allowable strain may be a limiting factor when the higher strength ASTM A 432 bars are used since the metal filler allows much more strain than did the control bars. Thus, some of the advantage of high strength bars may be lost if local concrete cracking around the connection results. With ASTM A 15 and A 408 bars the nominal yield strength of the steel was reached before the connection strained 0.003 in. per in. and excessive strain may not be objectionable.

A very definite advantage of this type connection is that its quality can be ascertained with accuracy by visual inspection; i.e., if the filler metal is visible at each end of the sleeve after removal of the asbestos packing, it can reasonably be assumed that the sleeve contains the proper amount of filler. In addition, the connection is relatively quick and easy to make since only approximately 5 minutes are required before the equipment can be removed for the next setup. As the sleeve and filler metal are the only items consumed, no troublesome cleanup is necessary. The fire hazard is minimal due to the relatively mild reaction in the crucible and the use of a splash guard.

Exothermic Splices

Based on the samples tested, these connections do not appear to possess the high reliability of the sleeve-with-metal-filler connection, but the exothermic connections did give reasonable average values of maximum stress. However, the averaging of samples tends to hide a wide variation between individual samples. For example, exothermic No. 1 splice of 40-ksi nominal yield strength steel failed at stresses ranging from approximately 52,000 to 88,000 psi and for 60 ksi nominal yield strength steel, from 41,000 to 105,000 psi. The exothermic No. 2 splice of 40-ksi nominal yield strength steel failed at stresses ranging from approximately 20,000 to 79,000 psi and for 60 ksi nominal yield strength steel, from 55,000 to 97,000 psi.

Both of the exothermic splices strained relatively little up to the point of failure, which from the standpoint of deflection and cracking is a real advantage.

A definite disadvantage of this type connection appears to be its immunity from accurate visual inspection. Very little can be determined about its load-carrying capabilities by observing it visually. All samples of this type looked identical, but they failed over a wide range of stresses.

More time is required to make the exothermic connections than the sleeve-with-metal-filler type. Both exothermic-type connections are very similar and both require approximately 10 minutes per connection, but the clean-up time, i.e., removing the molds, could extend this somewhat. In addition, the fire hazard in the immediate vicinity of the reaction could be a problem around wooden formwork.

Epoxy No. 1, No. 2, No. 3 and Expanded Grout Splices

On the basis of this limited study, these connections appear to be totally inadequate and should not be used for tensile splicing of reinforcing bars unless the length of the splicing sleeve is significantly increased compared with the sleeve used in the metal-filled sleeve splice.

ACKNOWLEDGMENTS

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Research assistants serving on the project were Richard L. Gilbert, Ronald D. Wickens, and Robert P. Williams, all students of civil engineering at the University of Oklahoma.

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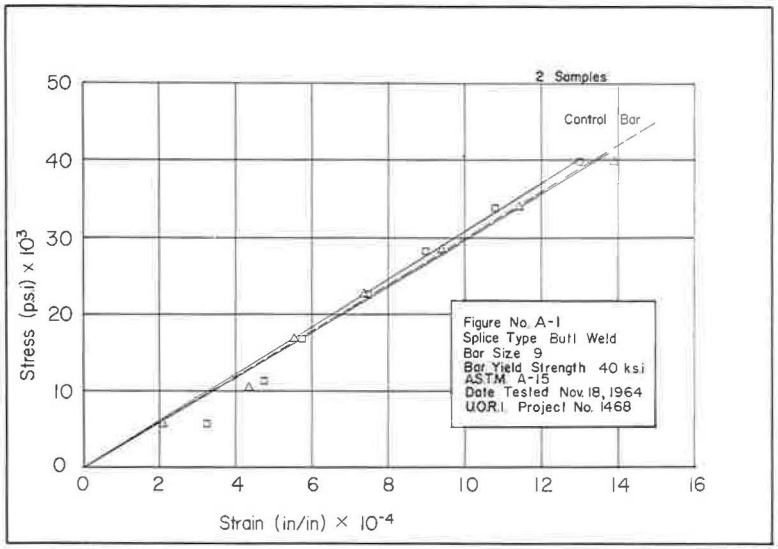
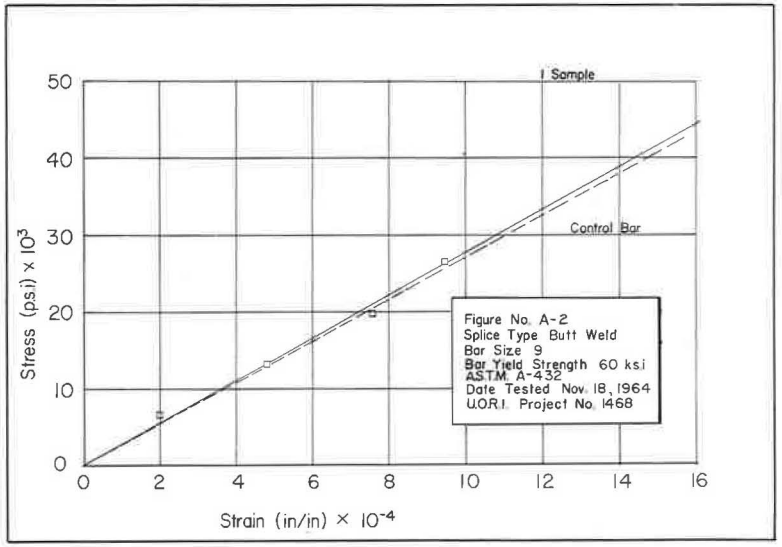
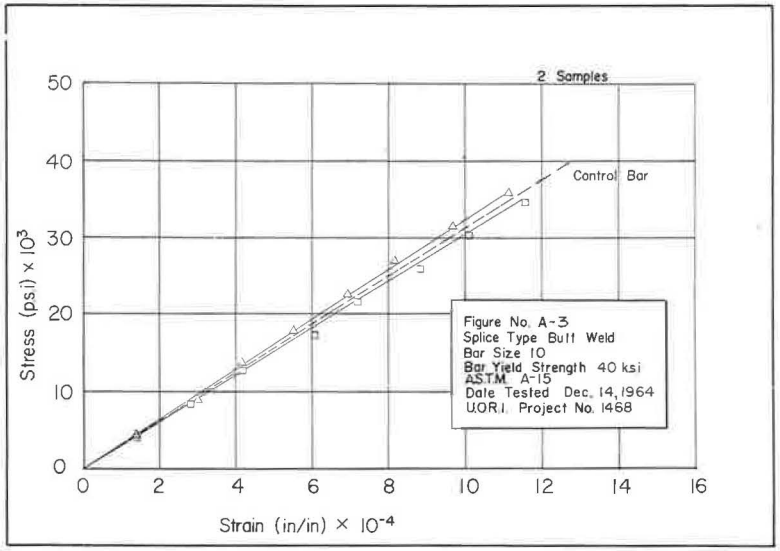
Appendix

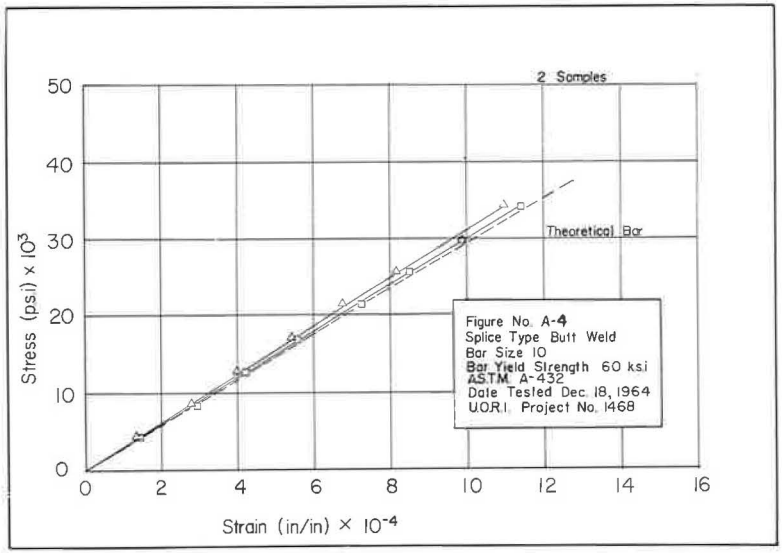
STRESS-STRAIN CURVES

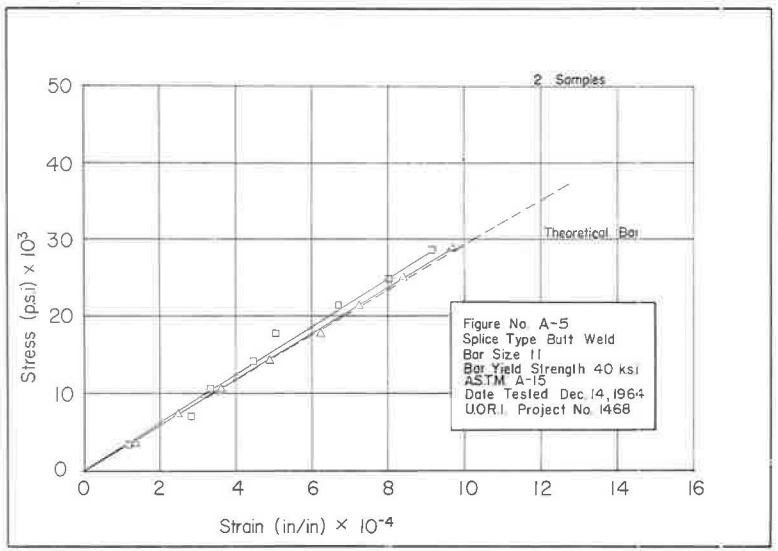
The individual stress-strain curves for each sample, shown in Figures A-1 through A-58, should be taken into account for an accurate analysis, since the average values used in the text might tend to mask erratic results.

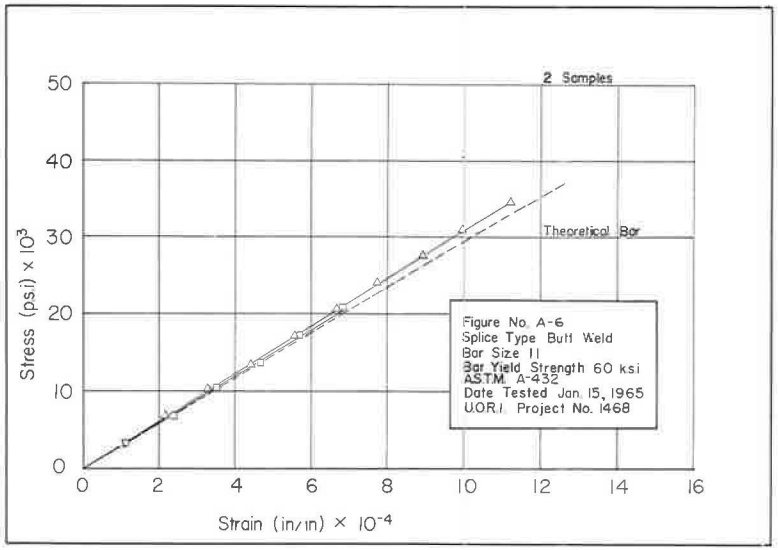

2 Samples
Control Bar
Figure No. A-1
Splice Type Butt Weld
Bar Size 9
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Nov. 18, 1964
U.O.R.I. Project No. 1468
Stress (psi) x 10^3
Strain (in/in) x 10^-4

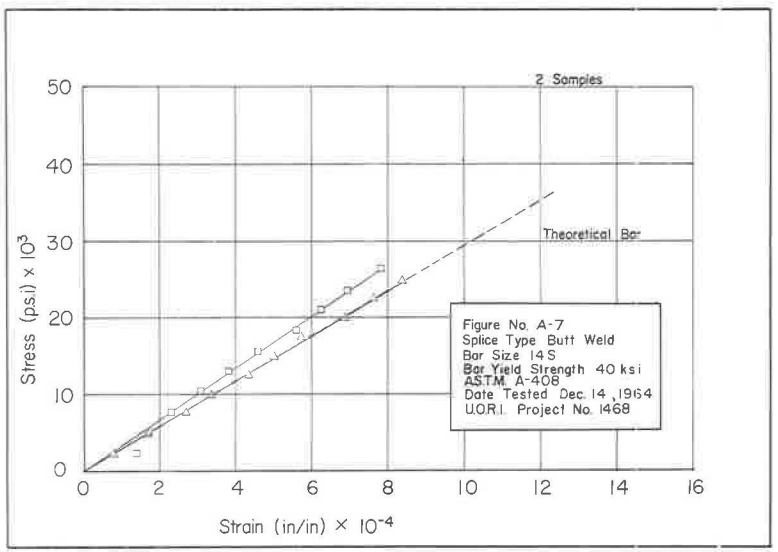

1 Sample
Control Bar
Figure No. A-2
Splice Type Butt Weld
Bar Size 9
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Nov. 18, 1964
U.O.R.I. Project No. 1468
Stress (psi) x 10^3
Strain (in/in) x 10^-4

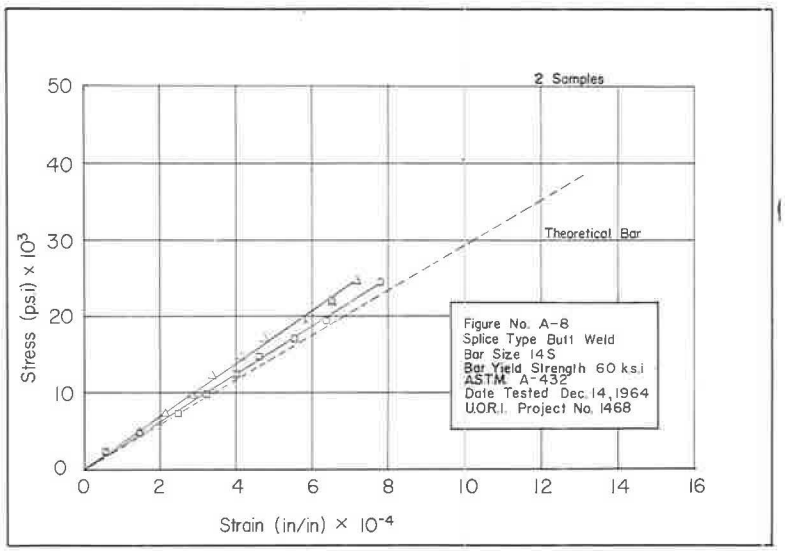

2 Samples
Control Bar
Figure No. A-3
Splice Type Butt Weld
Bar Size 10
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Dec. 14, 1964
U.O.R.I. Project No. 1468
Stress (psi) x 10^3
Strain (in/in) x 10^-4

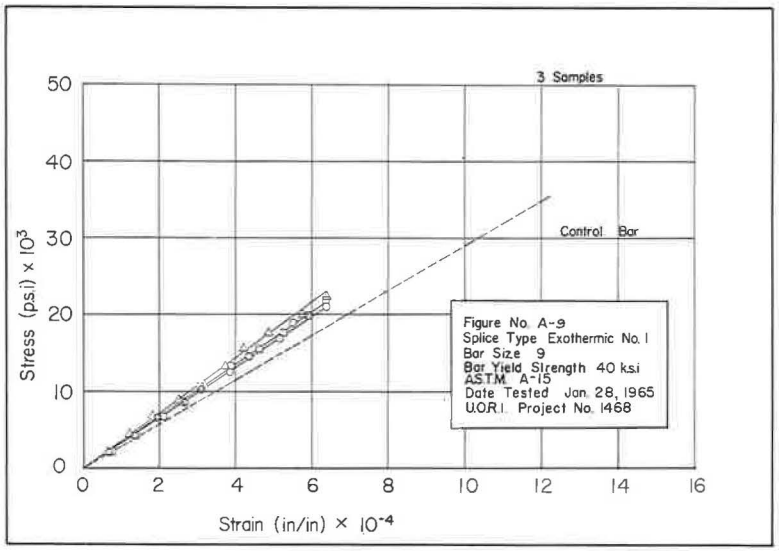

2 Samples
Theoretical Bar
Figure No. A-4
Splice Type Butt Weld
Bar Size 10
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Dec. 18, 1964
U.O.R.I. Project No. 1468
Stress (psi) x 10^3
Strain (in/in) x 10^-4

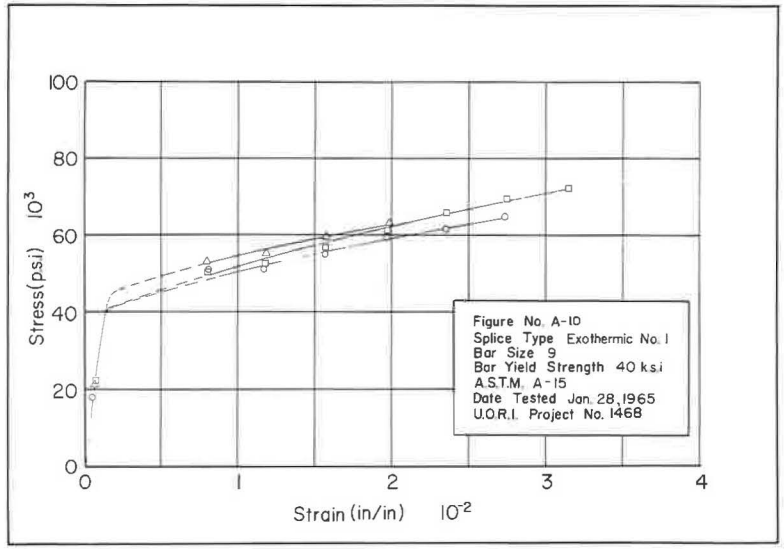

2 Samples
Theoretical Bar
Figure No. A-5
Splice Type Butt Weld
Bar Size 11
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Dec. 14, 1964
U.O.R.I. Project No. 1468
Stress (p.s.i) × 10³
Strain (in/in) × 10⁻⁴
0
10
20
30
40
50
0
2
4
6
8
10
12
14
16

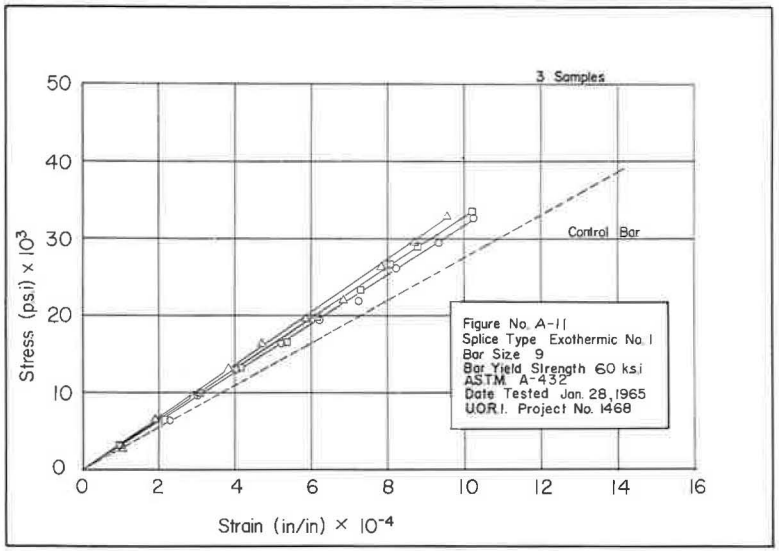

2 Samples
Theoretical Bar
Figure No. A-6
Splice Type Butt Weld
Bar Size 11
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 15, 1965
U.O.R.I. Project No. 1468
Stress (p.s.i) × 10³
Strain (in/in) × 10⁻⁴
0
10
20
30
40
50
0
2
4
6
8
10
12
14
16

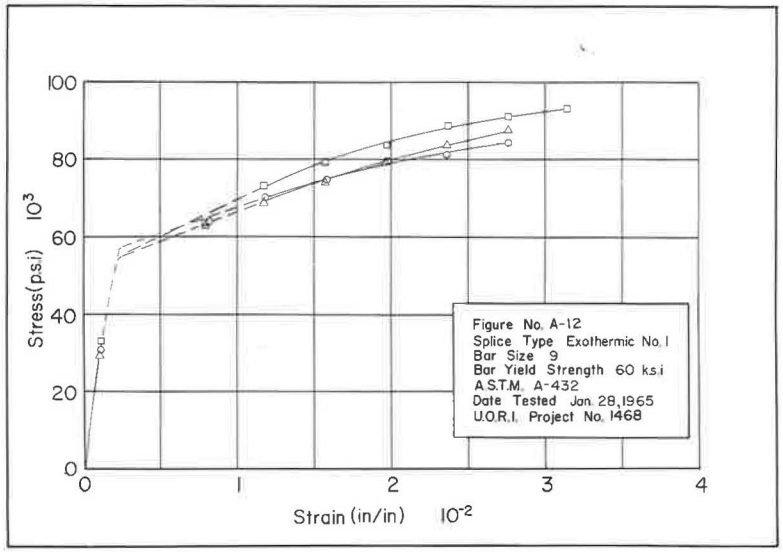

2 Samples
Theoretical Bar
Figure No. A-7
Splice Type Butt Weld
Bar Size 14S
Bar Yield Strength 40 ksi
A.S.T.M. A-408
Date Tested Dec. 14, 1964
U.O.R.I. Project No. 1468
Stress (p.s.i) × 10³
Strain (in/in) × 10⁻⁴
0
10
20
30
40
50
0
2
4
6
8
10
12
14
16

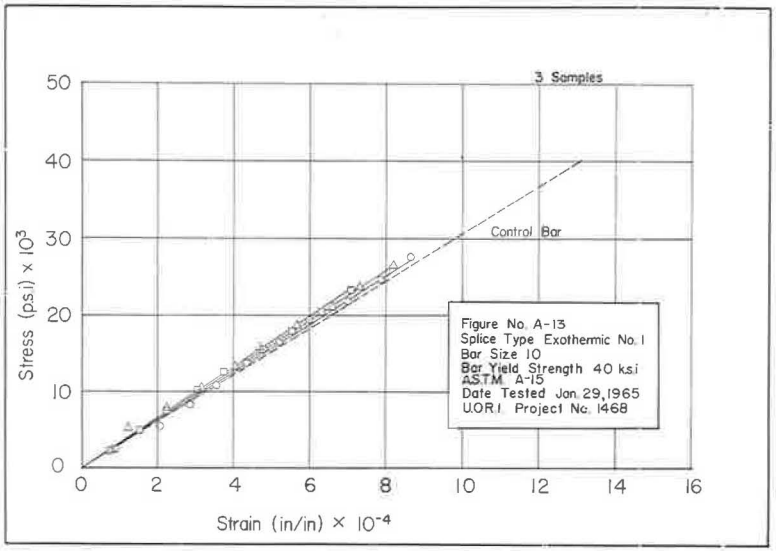

2 Samples
Theoretical Bar
Figure No. A-8
Splice Type Butt Weld
Bar Size 14S
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Dec. 14, 1964
U.O.R.I. Project No. 1468
Stress (p.s.i) × 10³
Strain (in/in) × 10⁻⁴
0
10
20
30
40
50
0
2
4
6
8
10
12
14
16

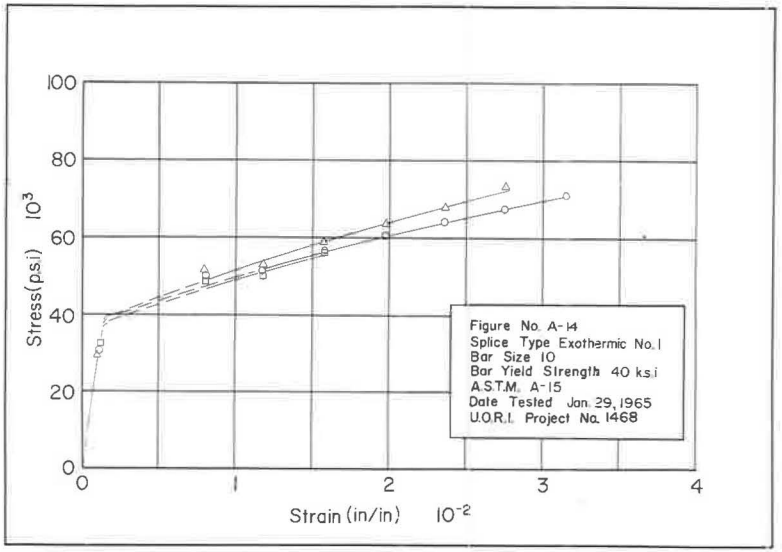

3 Samples
Control Bar
Stress (p.s.i) x 10^3
Strain (in/in) x 10^-4
Figure No. A-9
Splice Type Exothermic No. 1
Bar Size 9
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Jan. 28, 1965
U.O.R.I. Project No. 1468

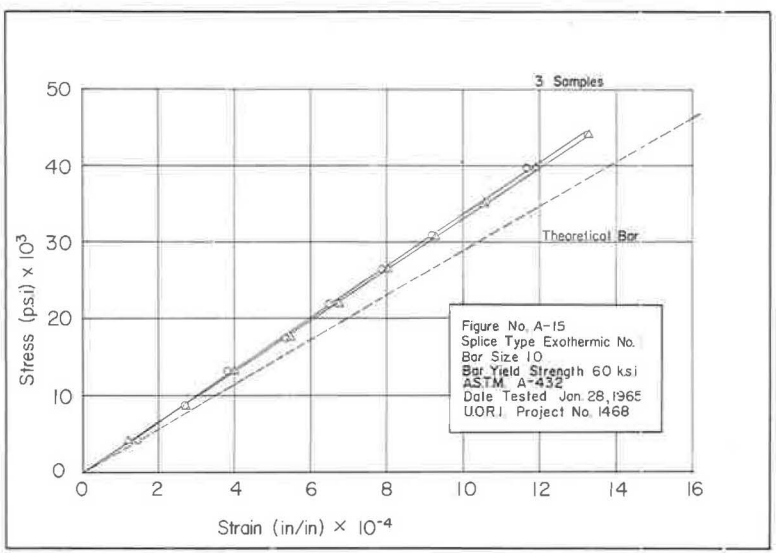

Stress(p.s.i) 10^3
Strain (in/in) 10^-2
Figure No. A-10
Splice Type Exothermic No. 1
Bar Size 9
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Jan. 28, 1965
U.O.R.I. Project No. 1468

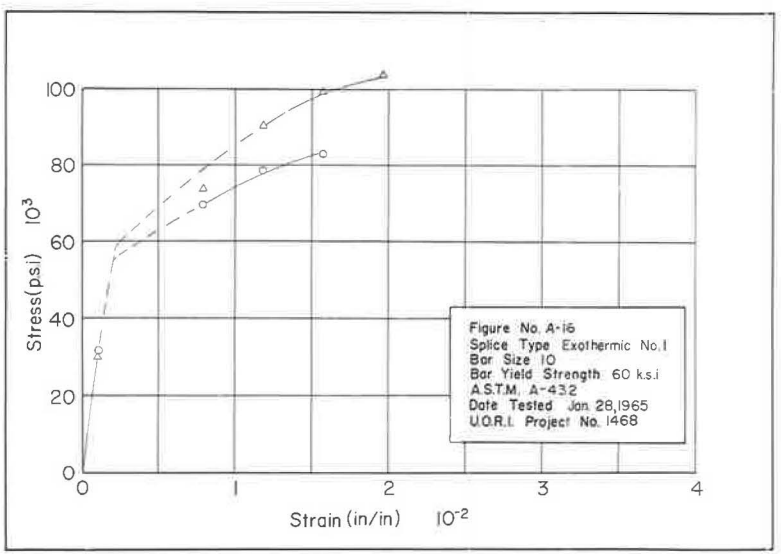

3 Samples
Control Bar
Stress (p.s.i) x 10^3
Strain (in/in) x 10^-4
Figure No. A-11
Splice Type Exothermic No. 1
Bar Size 9
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Jan. 28, 1965
U.O.R.I. Project No. 1468

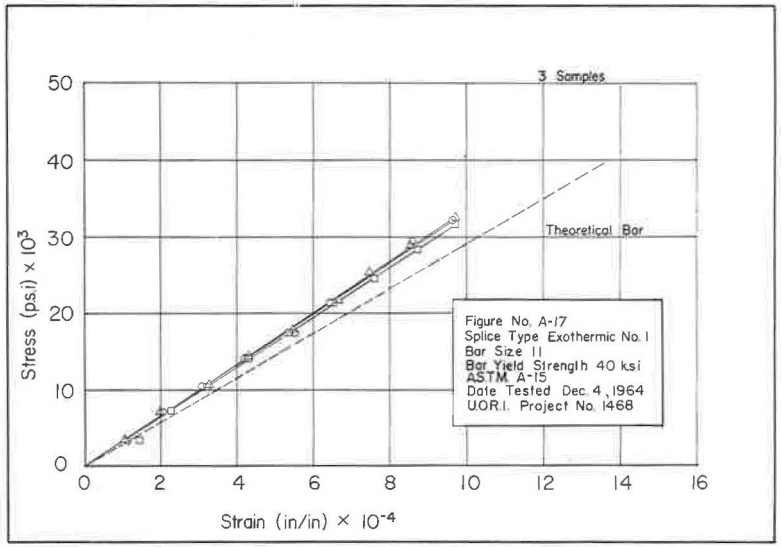

Stress(p.s.i) 10^3
Strain (in/in) 10^-2
Figure No. A-12
Splice Type Exothermic No. 1
Bar Size 9
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Jan. 28, 1965
U.O.R.I. Project No. 1468

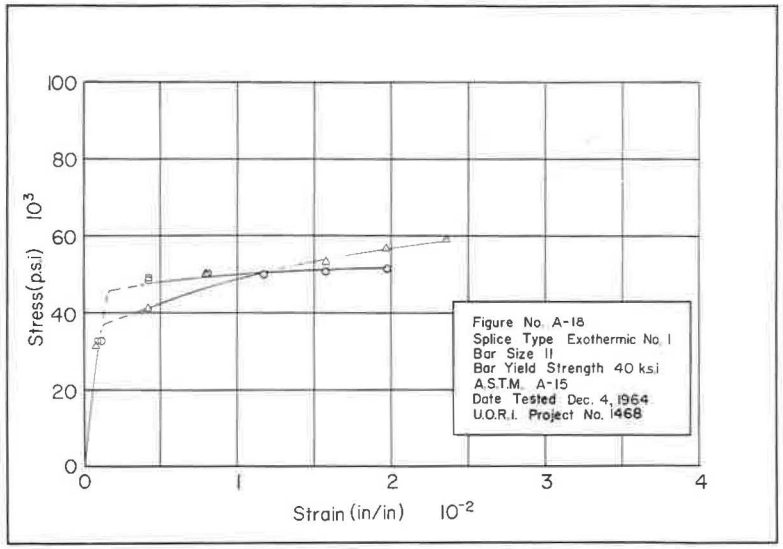

3 Samples
Control Bar
Stress (psi) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-13
Splice Type Exothermic No. 1
Bar Size 10
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Jan. 29, 1965
U.O.R.I. Project No. 1468

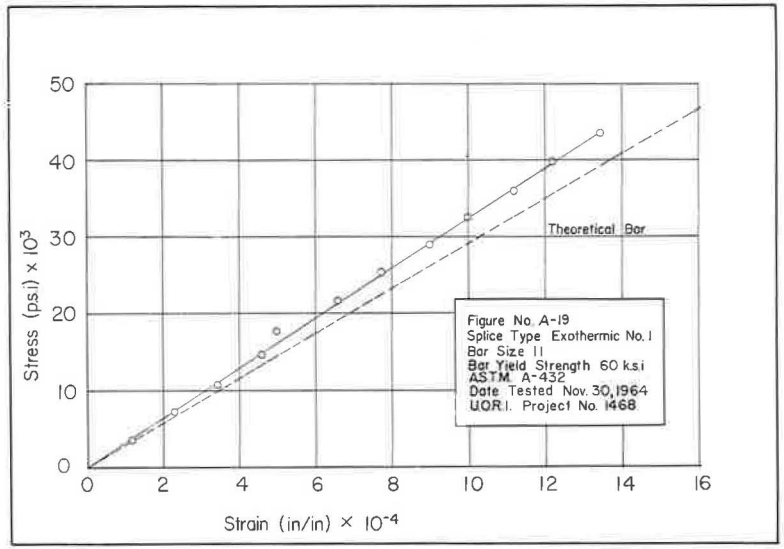

Stress(psi) 10³
Strain (in/in) 10⁻²
Figure No. A-14
Splice Type Exothermic No. 1
Bar Size 10
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Jan. 29, 1965
U.O.R.I. Project No. 1468

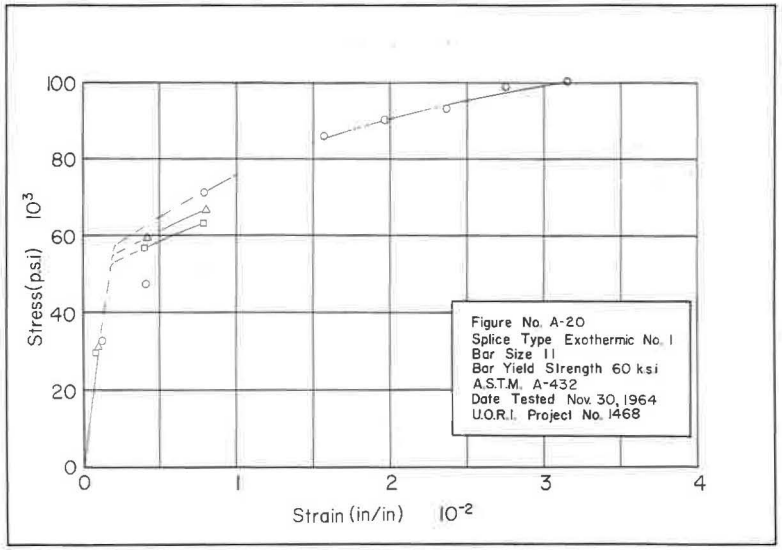

3 Samples
Theoretical Bar
Stress (psi) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-15
Splice Type Exothermic No.
Bar Size 10
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 28, 1965
U.O.R.I. Project No. 1468

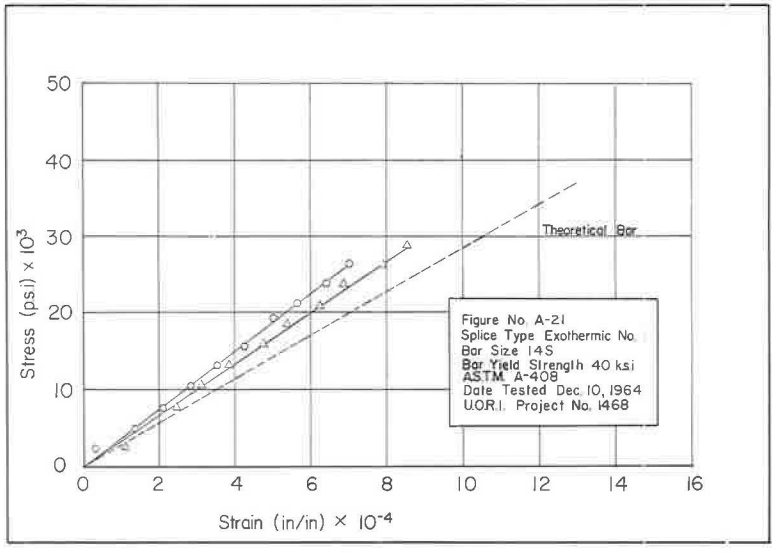

Stress(psi) 10³
Strain (in/in) 10⁻²
Figure No. A-16
Splice Type Exothermic No. 1
Bar Size 10
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 28, 1965
U.O.R.I. Project No. 1468

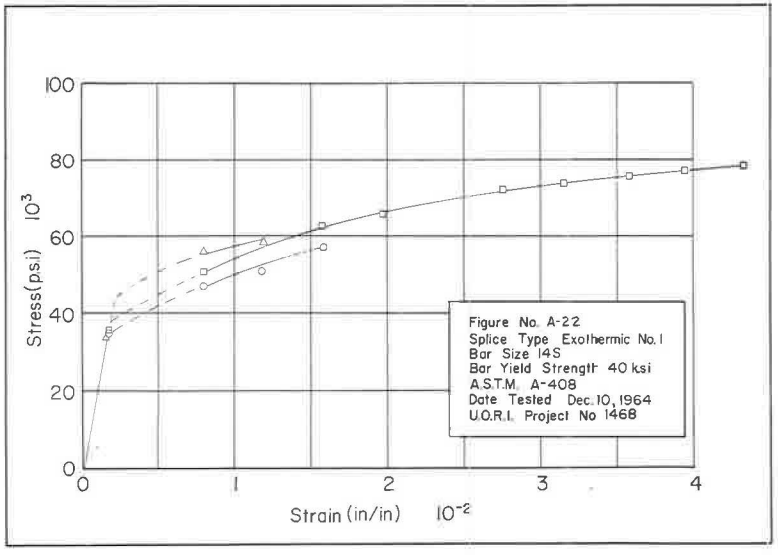

3 Samples
Theoretical Bar
Stress (psi) x 10^3
Strain (in/in) x 10^-4
Figure No. A-17
Splice Type Exothermic No. 1
Bar Size 11
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Dec. 4, 1964
U.O.R.I. Project No. 1468

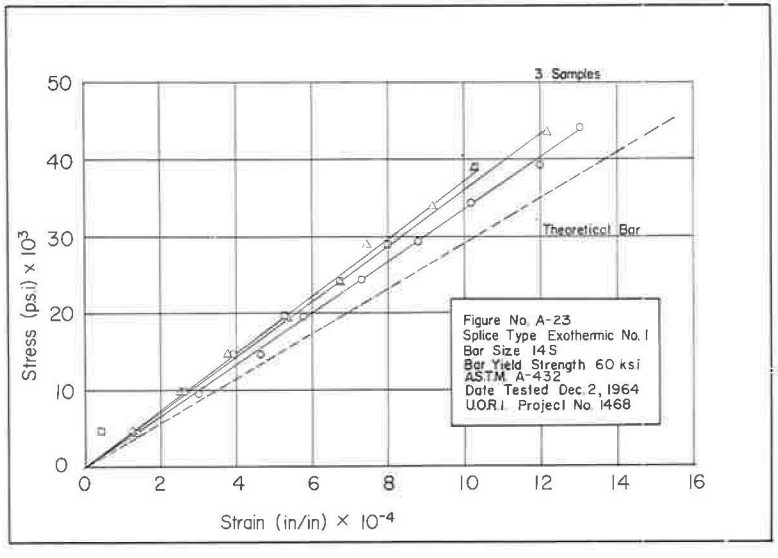

Stress(psi) 10^3
Strain (in/in) 10^-2
Figure No. A-18
Splice Type Exothermic No. 1
Bar Size 11
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Dec. 4, 1964
U.O.R.I. Project No. 1468

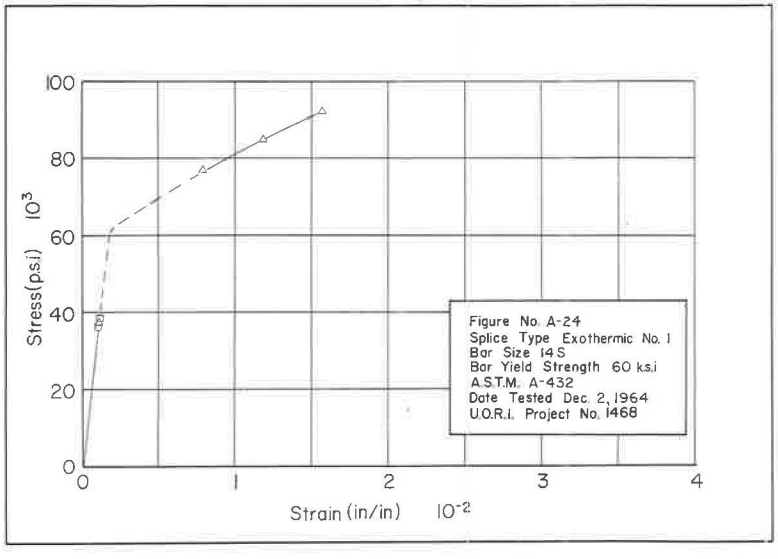

Theoretical Bar
Stress (psi) x 10^3
Strain (in/in) x 10^-4
Figure No. A-19
Splice Type Exothermic No. 1
Bar Size 11
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Nov. 30, 1964
U.O.R.I. Project No. 1468

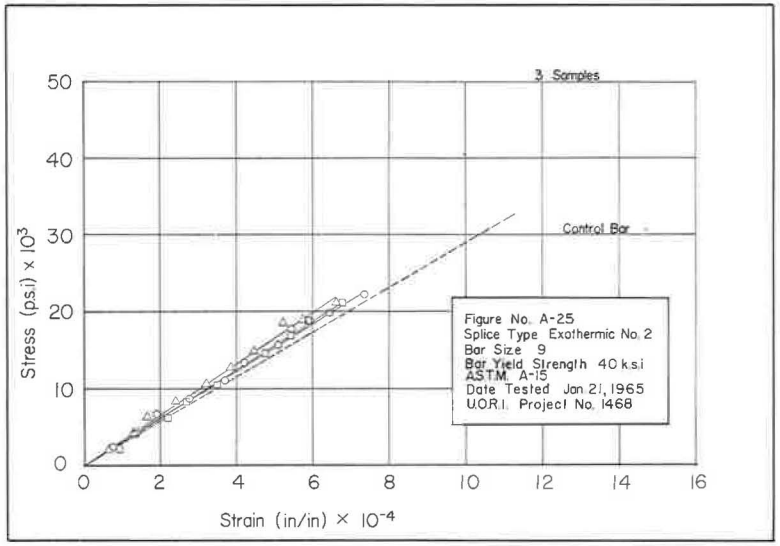

Stress(psi) 10^3
Strain (in/in) 10^-2
Figure No. A-20
Splice Type Exothermic No. 1
Bar Size 11
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Nov. 30, 1964
U.O.R.I. Project No. 1468

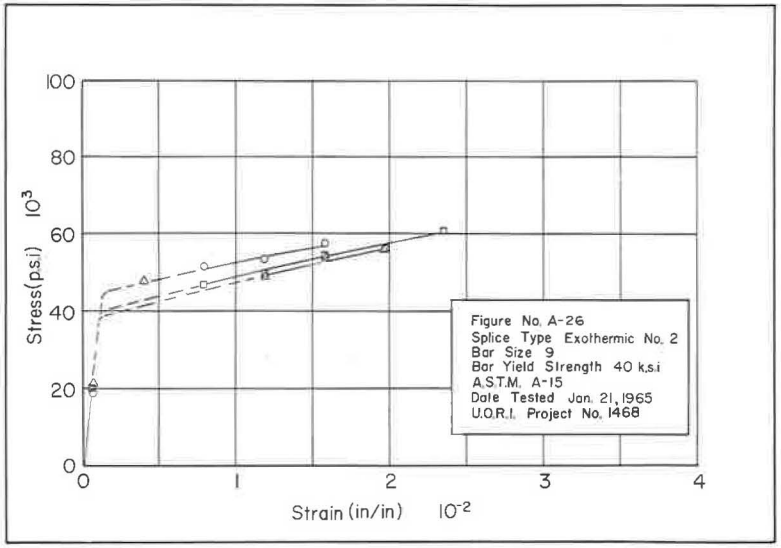

Stress (psi) × 10³
Strain (in/in) × 10⁻⁴
Theoretical Bar
Figure No. A-21
Splice Type Exothermic No.
Bar Size 14S
Bar Yield Strength 40 ksi
A.S.T.M. A-408
Date Tested Dec. 10, 1964
U.O.R.I. Project No. 1468

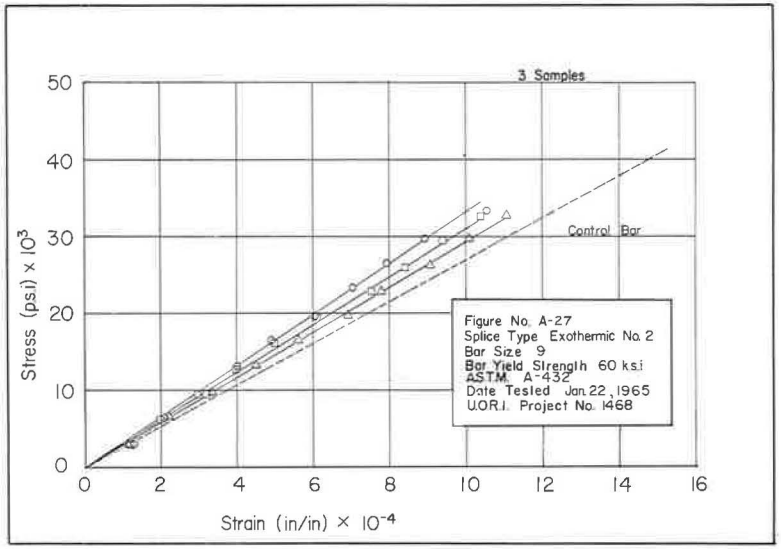

Stress(psi) 10³
Strain (in/in) 10⁻²
Figure No. A-22
Splice Type Exothermic No. 1
Bar Size 14S
Bar Yield Strength 40 ksi
A.S.T.M. A-408
Date Tested Dec. 10, 1964
U.O.R.I. Project No 1468

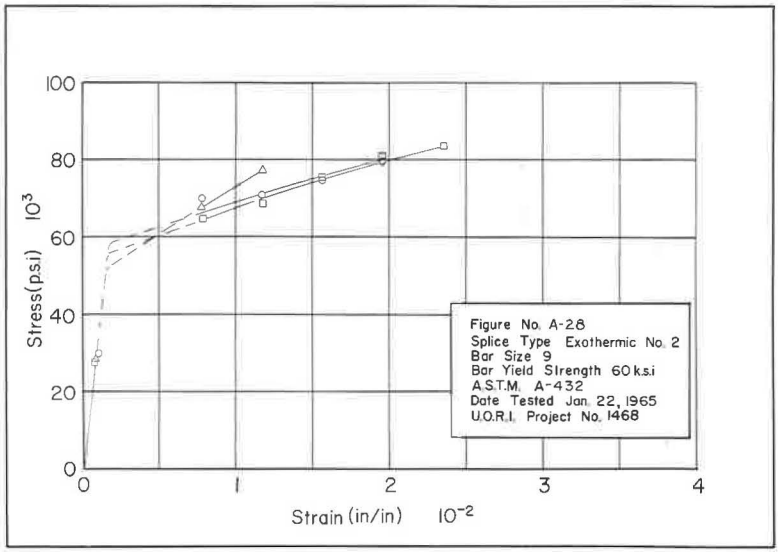

3 Samples
Theoretical Bar
Stress (psi) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-23
Splice Type Exothermic No. 1
Bar Size 14S
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Dec. 2, 1964
U.O.R.I. Project No. 1468

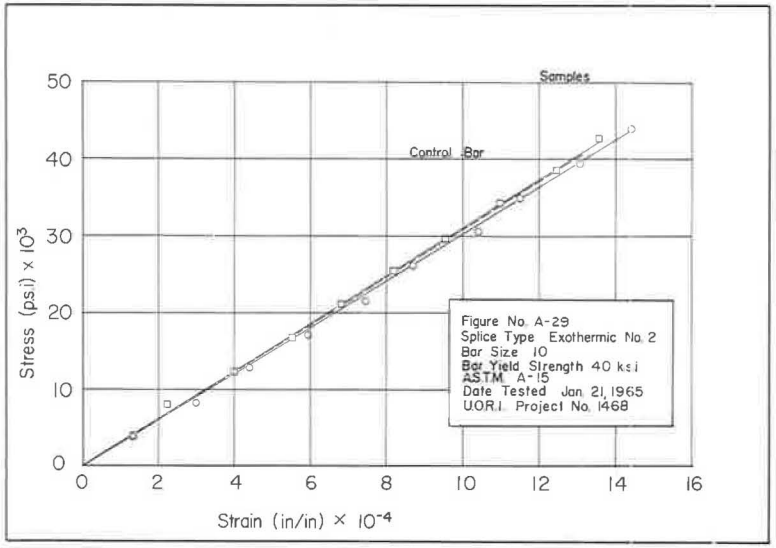

Stress(psi) 10³
Strain (in/in) 10⁻²
Figure No. A-24
Splice Type Exothermic No. 1
Bar Size 14S
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Dec. 2, 1964
U.O.R.I. Project No. 1468

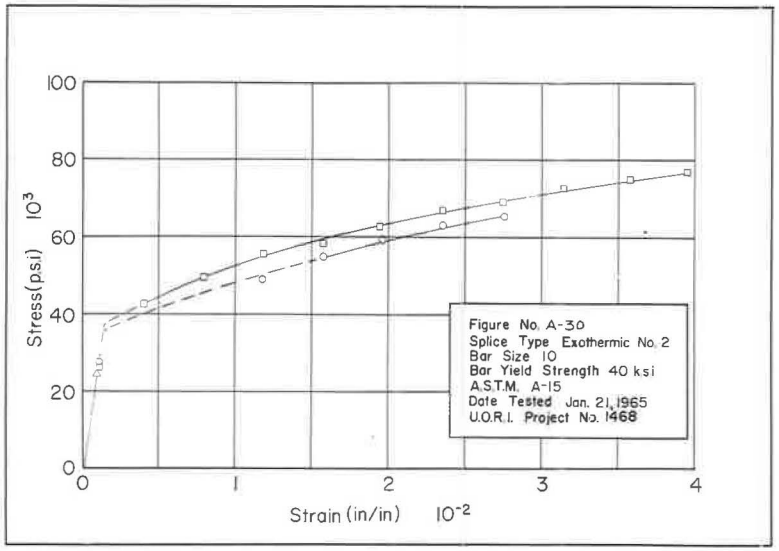

3 Samples
Control Bar
Stress (psi) x 10^3
Strain (in/in) x 10^-4
Figure No. A-25
Splice Type Exothermic No. 2
Bar Size 9
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Jan 21, 1965
U.O.R.I. Project No. 1468

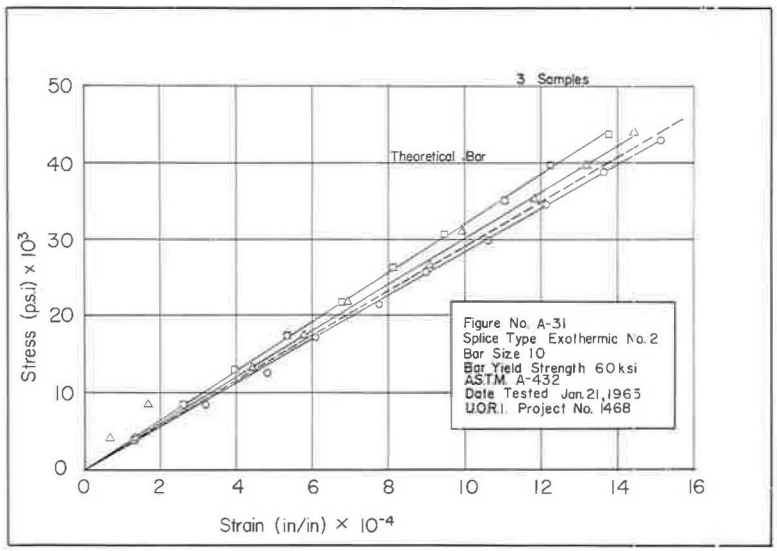

Stress(p.s.i) 10^3
Strain (in/in) 10^-2
Figure No. A-26
Splice Type Exothermic No. 2
Bar Size 9
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Jan. 21, 1965
U.O.R.I. Project No. 1468

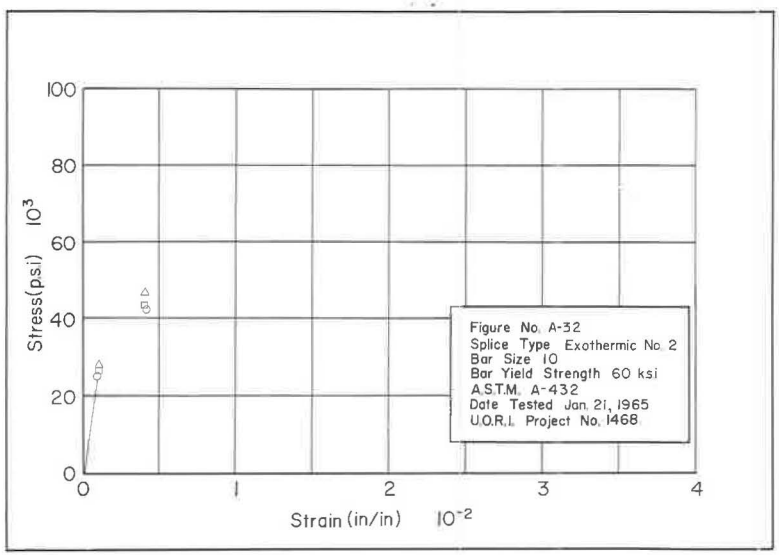

3 Samples
Control Bar
Stress (psi) x 10^3
Strain (in/in) x 10^-4
Figure No. A-27
Splice Type Exothermic No. 2
Bar Size 9
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Jan. 22, 1965
U.O.R.I. Project No. 1468

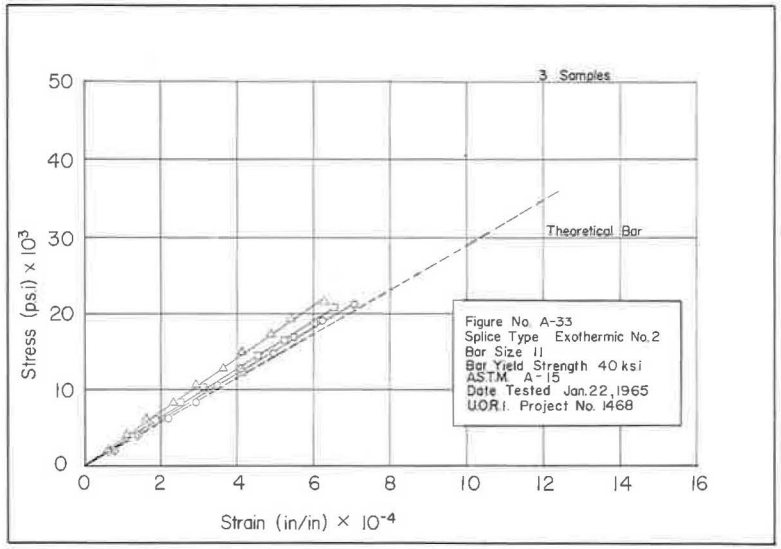

Stress(p.s.i) 10^3
Strain (in/in) 10^-2
Figure No. A-28
Splice Type Exothermic No. 2
Bar Size 9
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Jan. 22, 1965
U.O.R.I. Project No. 1468

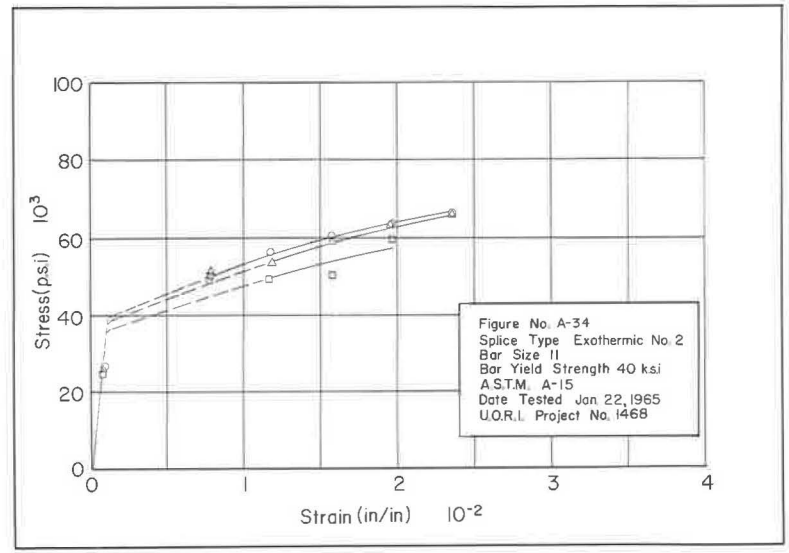

Samples
Control Bar
Stress (psi) x 10^3
Strain (in/in) × 10^-4
Figure No. A-29
Splice Type Exothermic No. 2
Bar Size 10
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Jan. 21, 1965
U.O.R.I. Project No. 1468

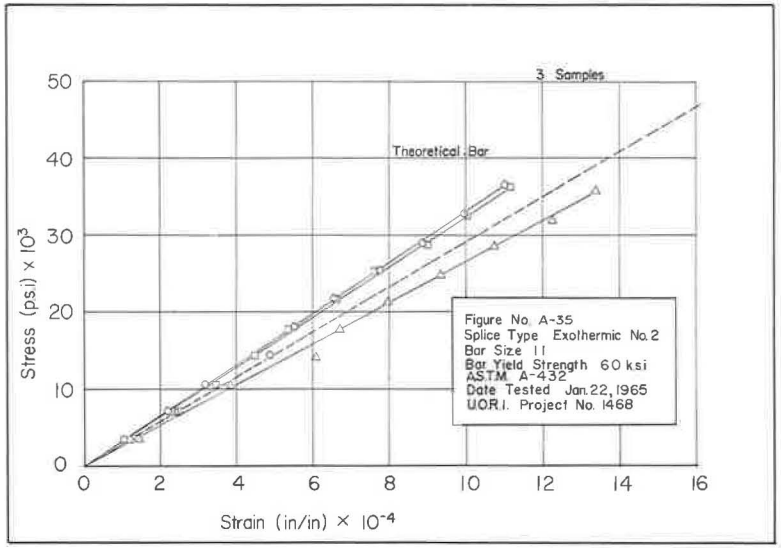

Stress(psi) 10^3
Strain (in/in) 10^-2
Figure No. A-30
Splice Type Exothermic No. 2
Bar Size 10
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Jan. 21, 1965
U.O.R.I. Project No. 1468

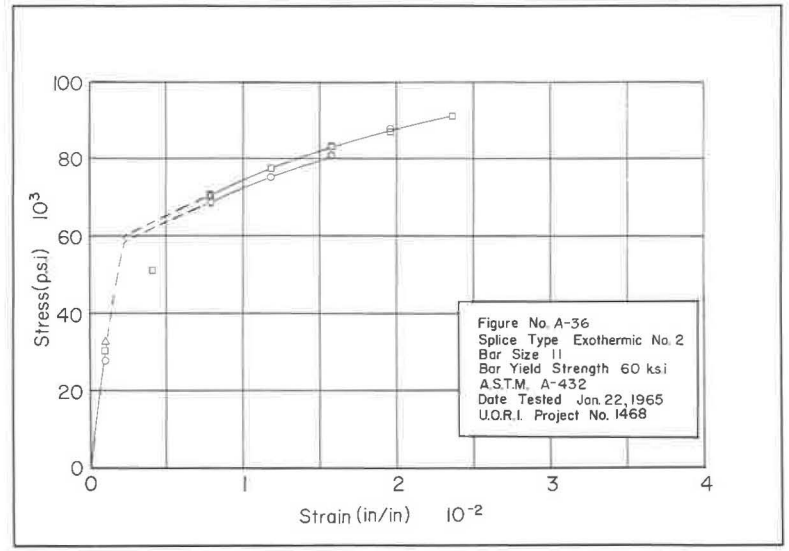

3 Samples
Theoretical Bar
Stress (psi) x 10^3
Strain (in/in) × 10^-4
Figure No. A-31
Splice Type Exothermic No. 2
Bar Size 10
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 21, 1965
U.O.R.I. Project No. 1468

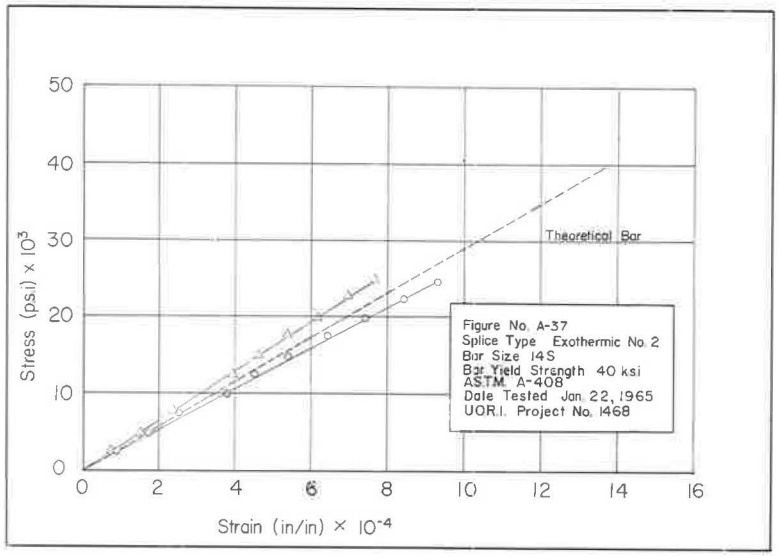

Stress(psi) 10^3
Strain (in/in) 10^-2
Figure No. A-32
Splice Type Exothermic No. 2
Bar Size 10
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 21, 1965
U.O.R.I. Project No. 1468


3 Samples
Theoretical Bar
Stress (psi) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-33
Splice Type Exothermic No. 2
Bar Size 11
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Jan. 22, 1965
U.O.R.I. Project No. 1468


Stress (psi) 10³
Strain (in/in) 10⁻²
Figure No. A-34
Splice Type Exothermic No. 2
Bar Size 11
Bar Yield Strength 40 ksi
A.S.T.M. A-15
Date Tested Jan. 22, 1965
U.O.R.I. Project No. 1468


3 Samples
Theoretical Bar
Stress (psi) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-35
Splice Type Exothermic No. 2
Bar Size 11
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 22, 1965
U.O.R.I. Project No. 1468


Stress (psi) 10³
Strain (in/in) 10⁻²
Figure No. A-36
Splice Type Exothermic No. 2
Bar Size 11
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Jan. 22, 1965
U.O.R.I. Project No. 1468



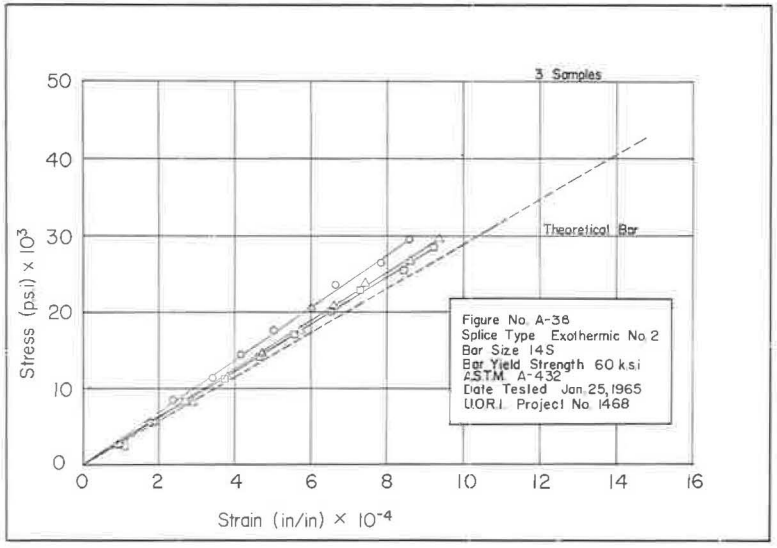
EXOTHERMIC NO. 2

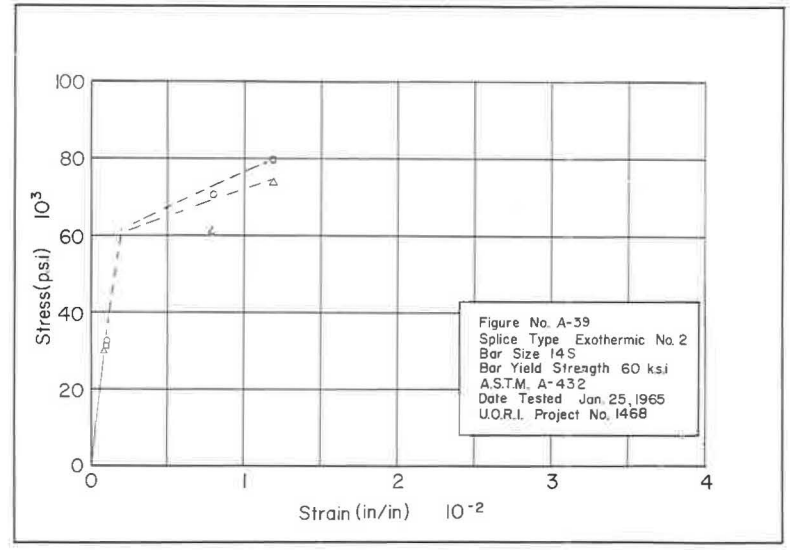
BAR SIZE - 14S

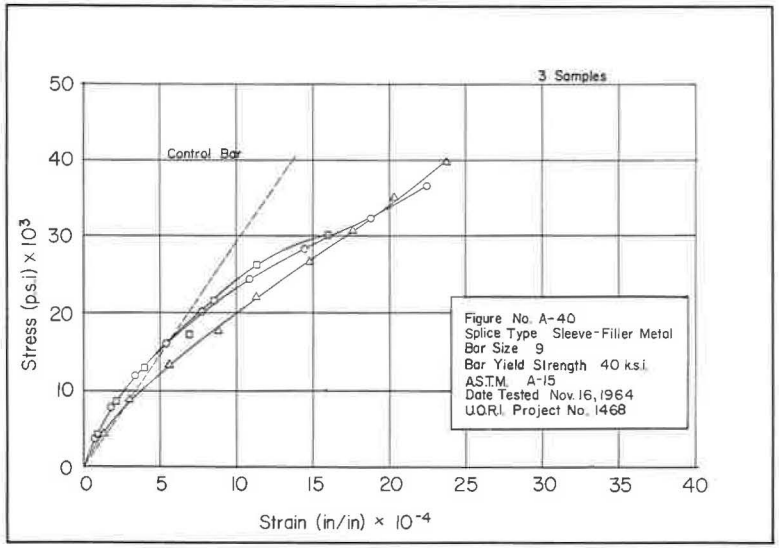
BAR YIELD STRENGTH - 40KSI

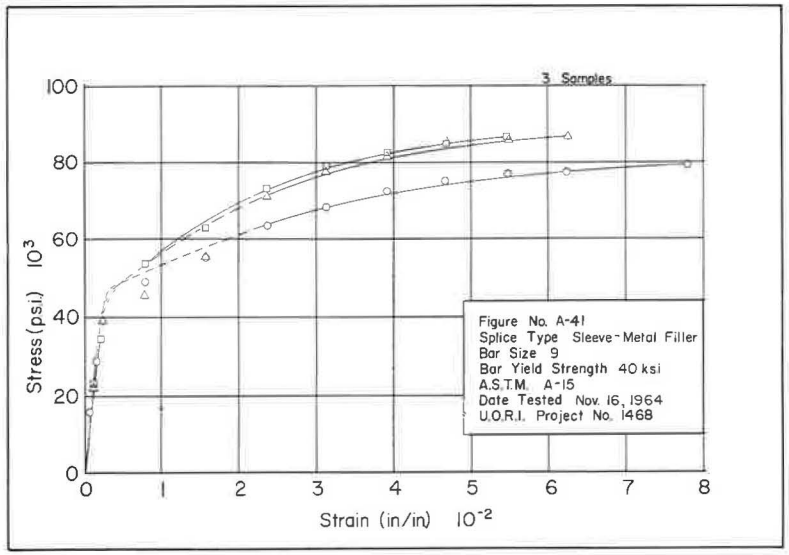
ASTM - A408

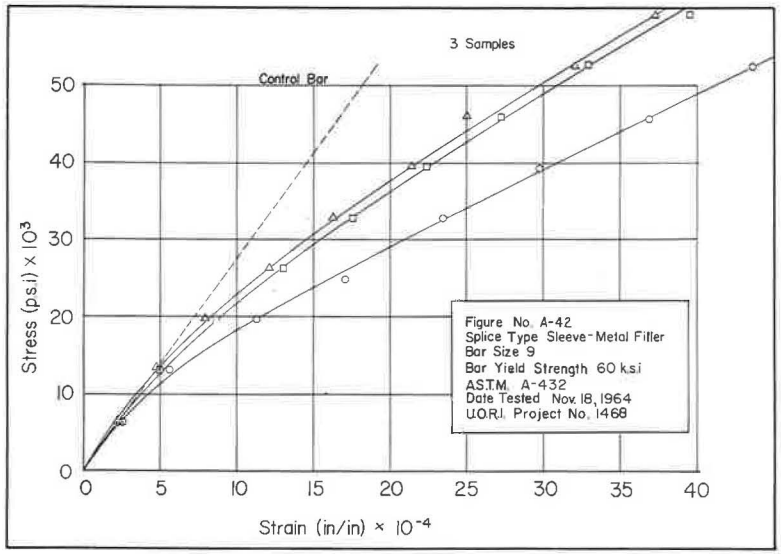
(FAILED BELOW NOMINAL YIELD STRENGTH)

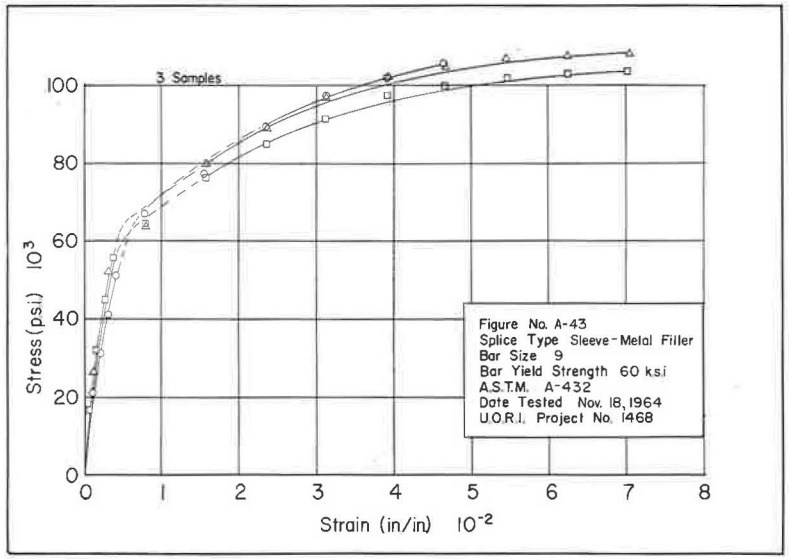


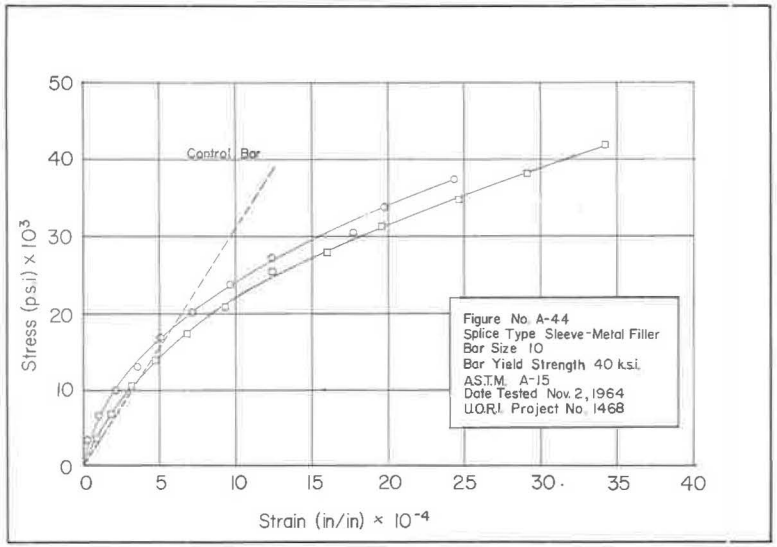


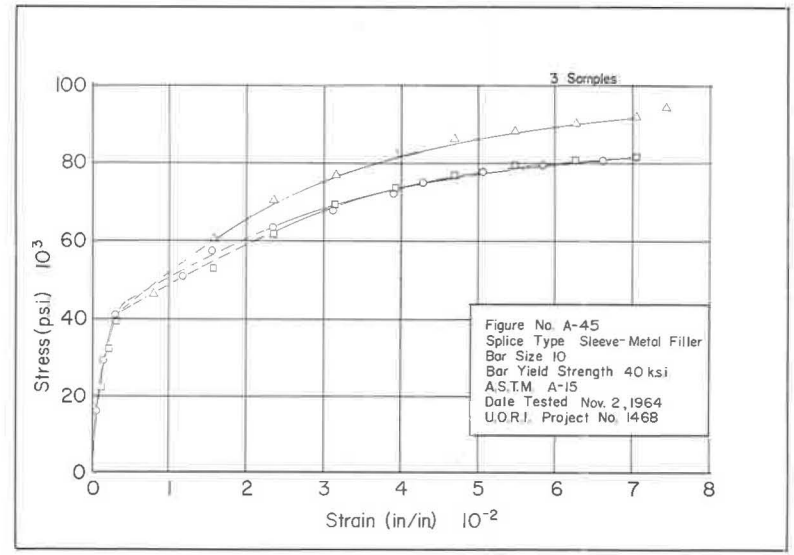

3 Samples
Control Bar
Stress (psi.) x 10^3
Strain (in/in) x 10^-4
Figure No. A-40
Splice Type Sleeve-Filler Metal
Bar Size 9
Bar Yield Strength 40 k.s.i.
A.S.T.M. A-15
Date Tested Nov. 16, 1964
U.O.R.I. Project No. 1468

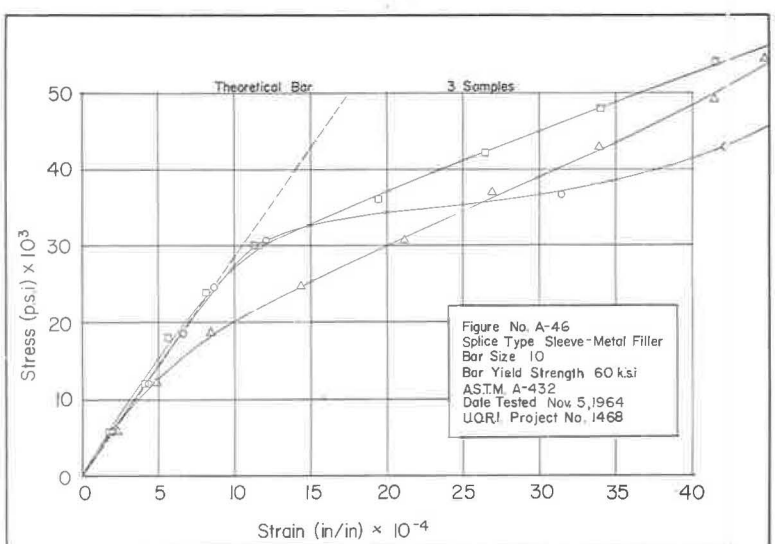

3 Samples
Stress (psi.) 10^3
Strain (in/in) 10^-2
Figure No. A-41
Splice Type Sleeve-Metal Filler
Bar Size 9
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Nov. 16, 1964
U.O.R.I. Project No. 1468

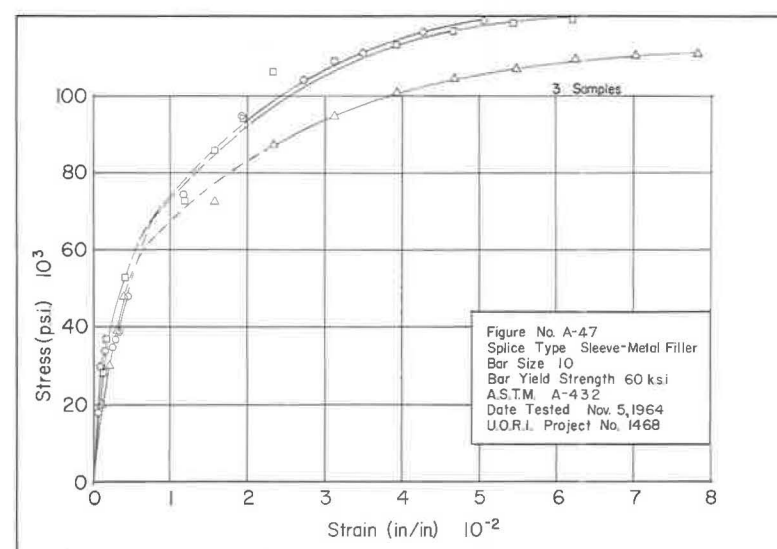

3 Samples
Control Bar
Stress (psi.) x 10^3
Strain (in/in) x 10^-4
Figure No. A-42
Splice Type Sleeve-Metal Filler
Bar Size 9
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Nov. 18, 1964
U.O.R.I. Project No. 1468

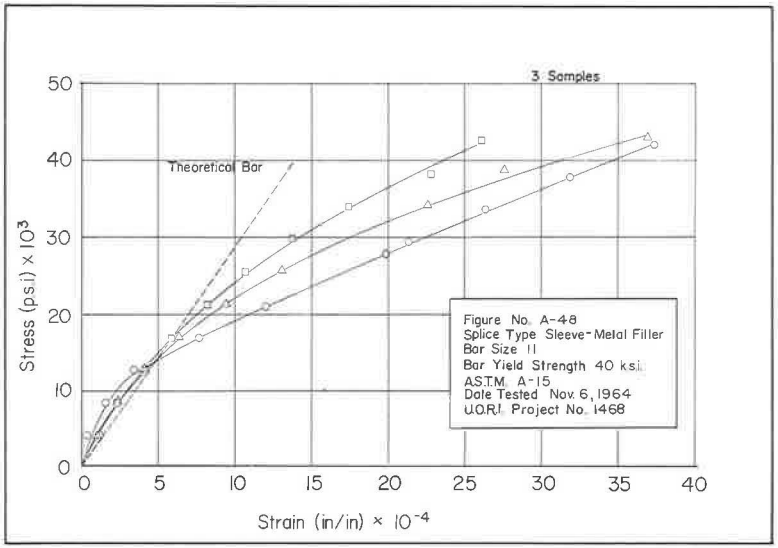

3 Samples
Stress (psi.) 10^3
Strain (in/in) 10^-2
Figure No. A-43
Splice Type Sleeve-Metal Filler
Bar Size 9
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Nov. 18, 1964
U.O.R.I. Project No. 1468

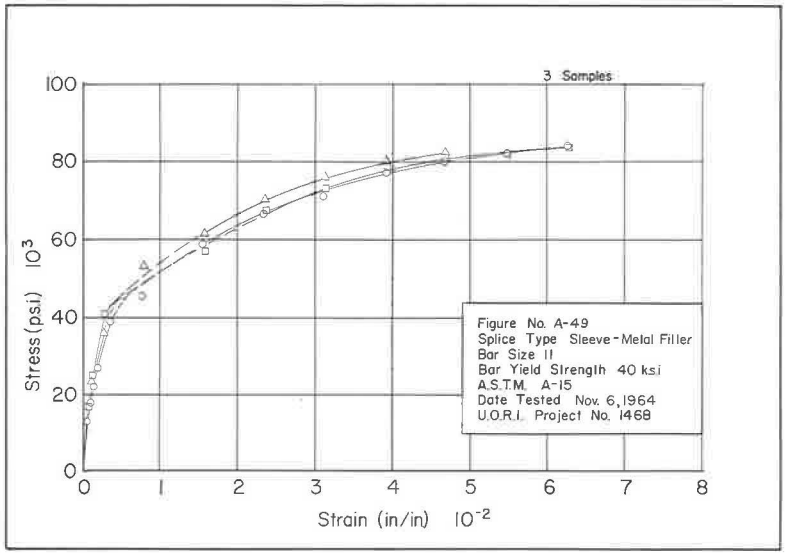

Control Bar
Stress (p.s.i) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-44
Splice Type Sleeve-Metal Filler
Bar Size 10
Bar Yield Strength 40 k.s.i.
A.S.T.M. A-15
Date Tested Nov. 2, 1964
U.O.R.I. Project No. 1468

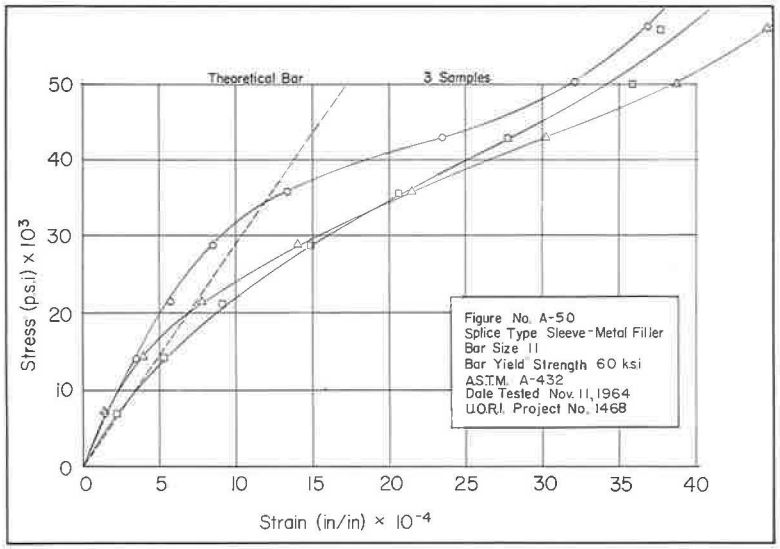

3 Samples
Stress (p.s.i) 10³
Strain (in/in) 10⁻²
Figure No. A-45
Splice Type Sleeve-Metal Filler
Bar Size 10
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Nov. 2, 1964
U.O.R.I. Project No. 1468

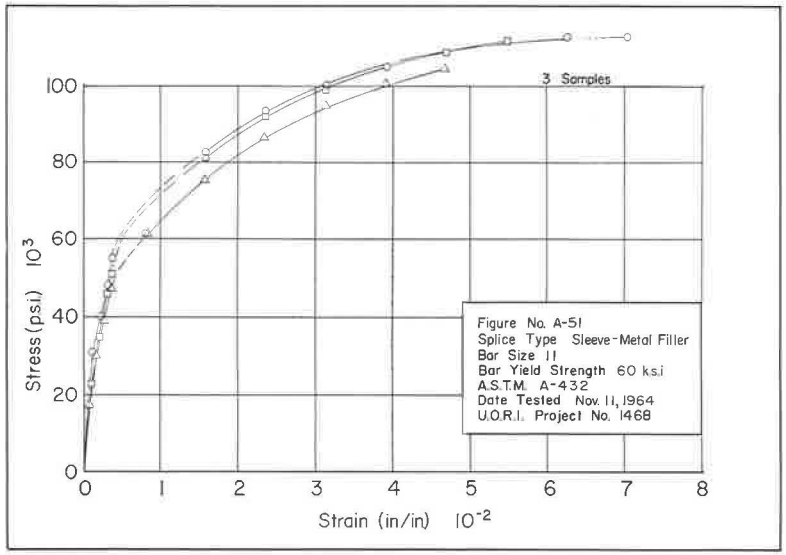

Theoretical Bar
3 Samples
Stress (p.s.i) × 10³
Strain (in/in) × 10⁻⁴
Figure No. A-46
Splice Type Sleeve-Metal Filler
Bar Size 10
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Nov. 5, 1964
U.O.R.I. Project No. 1468

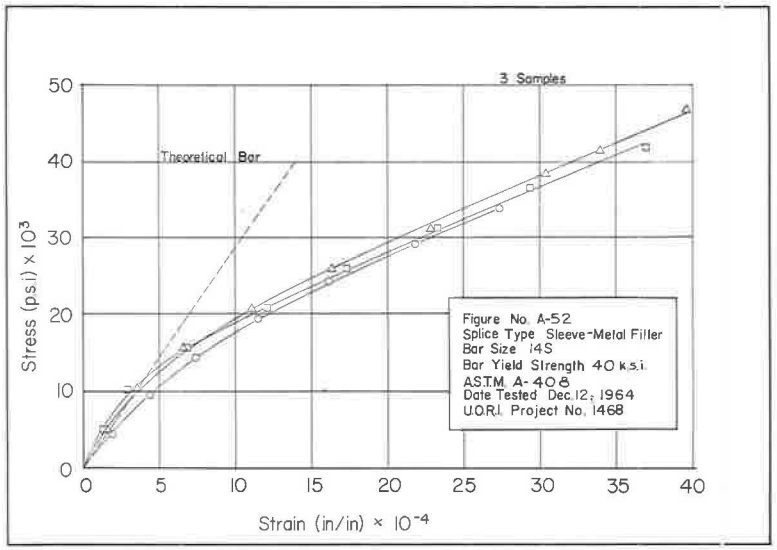

3 Samples
Stress (p.s.i) 10³
Strain (in/in) 10⁻²
Figure No. A-47
Splice Type Sleeve-Metal Filler
Bar Size 10
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Nov. 5, 1964
U.O.R.I. Project No. 1468

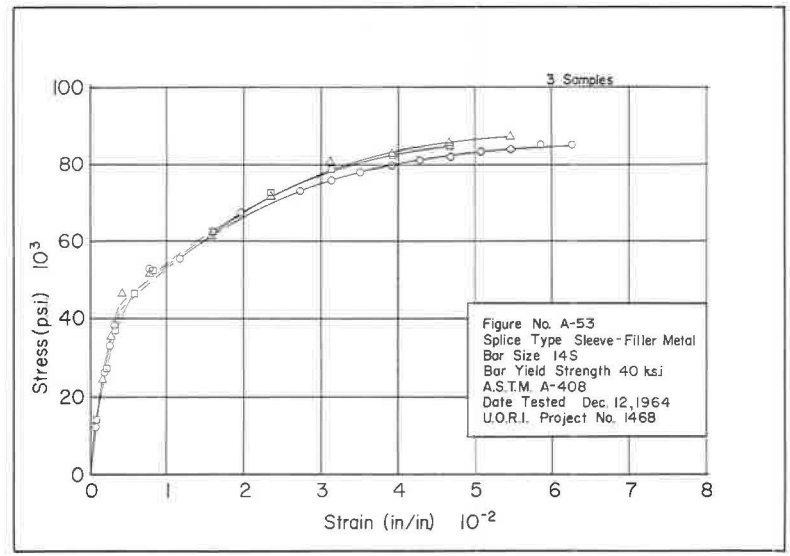

3 Samples
Theoretical Bar
Stress (p.s.i) x 10^3
Strain (in/in) x 10^-4
Figure No. A-48
Splice Type Sleeve-Metal Filler
Bar Size 11
Bar Yield Strength 40 k.s.i.
A.S.T.M. A-15
Date Tested Nov. 6, 1964
U.O.R.I. Project No. 1468

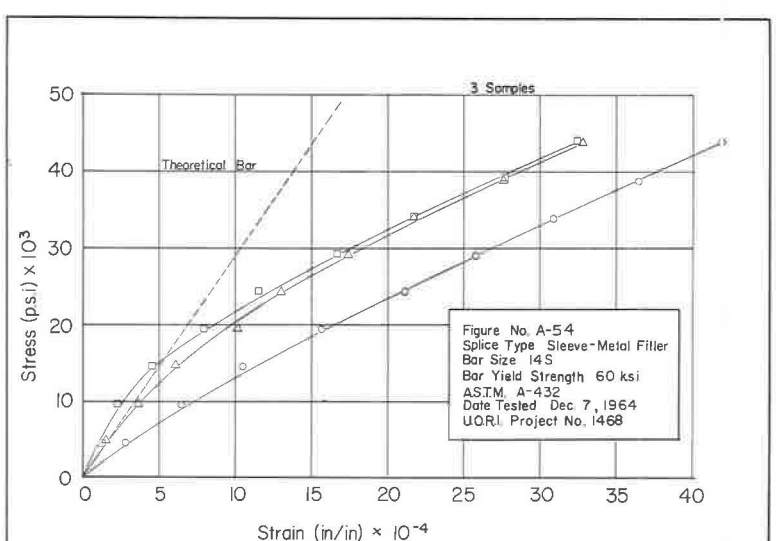

3 Samples
Stress (p.s.i) 10^3
Strain (in/in) 10^-2
Figure No. A-49
Splice Type Sleeve-Metal Filler
Bar Size 11
Bar Yield Strength 40 k.s.i
A.S.T.M. A-15
Date Tested Nov. 6, 1964
U.O.R.I. Project No. 1468

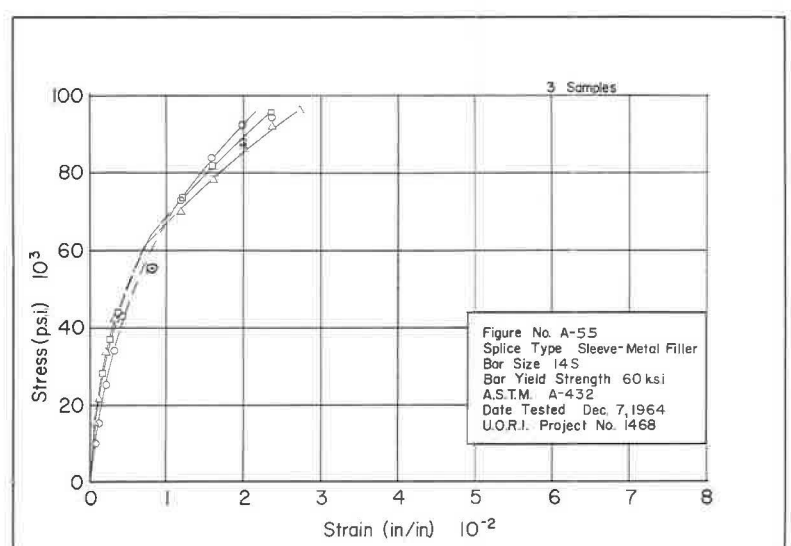

Theoretical Bar
3 Samples
Stress (p.s.i) x 10^3
Strain (in/in) x 10^-4
Figure No. A-50
Splice Type Sleeve-Metal Filler
Bar Size 11
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Nov. 11, 1964
U.O.R.I. Project No. 1468

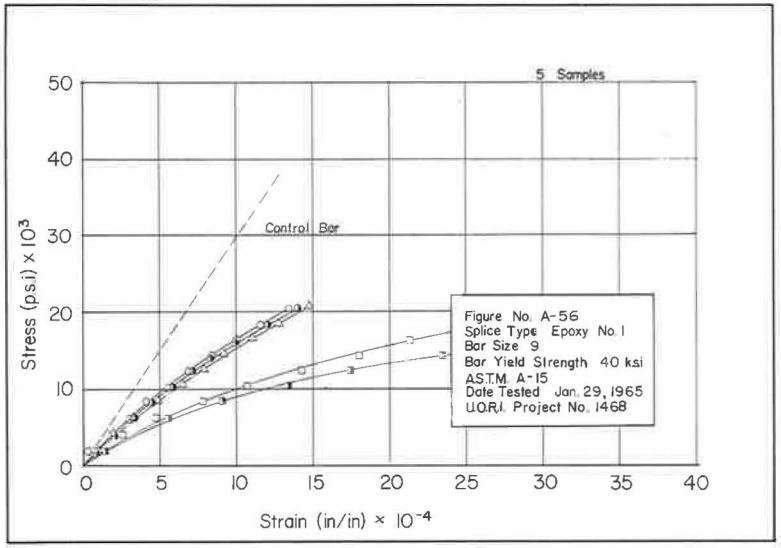

3 Samples
Stress (p.s.i) 10^3
Strain (in/in) 10^-2
Figure No. A-51
Splice Type Sleeve-Metal Filler
Bar Size 11
Bar Yield Strength 60 k.s.i
A.S.T.M. A-432
Date Tested Nov. 11, 1964
U.O.R.I. Project No. 1468

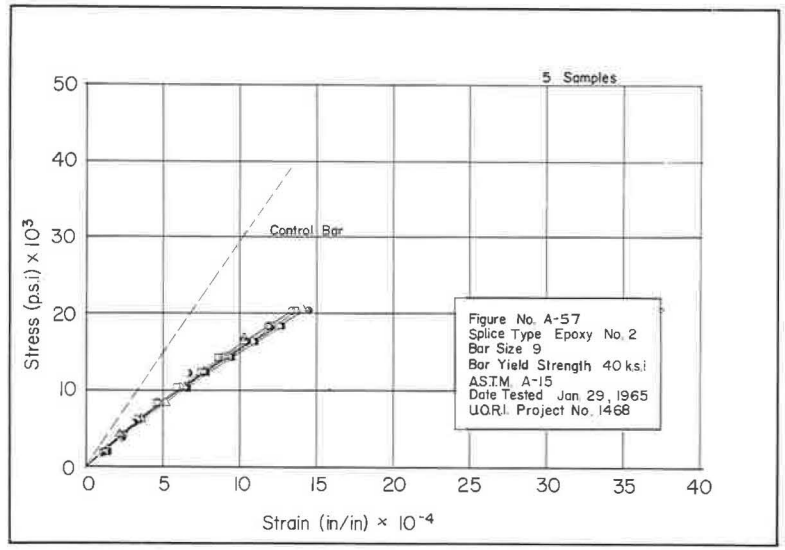

3 Samples
Theoretical Bar
Stress (psi) x 10^3
Strain (in/in) x 10^-4
Figure No. A-52
Splice Type Sleeve-Metal Filler
Bar Size 14S
Bar Yield Strength 40 k.s.i.
A.S.T.M. A-408
Date Tested Dec. 12, 1964
U.O.R.I. Project No. 1468


3 Samples
Stress (psi) 10^3
Strain (in/in) 10^-2
Figure No. A-53
Splice Type Sleeve-Filler Metal
Bar Size 14S
Bar Yield Strength 40 ksi
A.S.T.M. A-408
Date Tested Dec. 12, 1964
U.O.R.I. Project No. 1468


3 Samples
Theoretical Bar
Stress (psi) x 10^3
Strain (in/in) x 10^-4
Figure No. A-54
Splice Type Sleeve-Metal Filler
Bar Size 14S
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Dec. 7, 1964
U.O.R.I. Project No. 1468


3 Samples
Stress (psi) 10^3
Strain (in/in) 10^-2
Figure No. A-55
Splice Type Sleeve-Metal Filler
Bar Size 14S
Bar Yield Strength 60 ksi
A.S.T.M. A-432
Date Tested Dec. 7, 1964
U.O.R.I. Project No. 1468





EPOXY SPLICE NO. 3

BAR SIZE - 9

BAR YIELD STRENGTH - 40KSI

ASTM - A15

(NO DATA TAKEN - FAILED PREMATURELY)