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Interrelationship of transverse anchorage and adhesive bond in welded wire reinforcement

Alan Arthur Becker

INTERRELATIONSHIP OF TRANSVERSE ANCHORAGE AND ADHESIVE BOND IN WELDED WIRE REINFORCEMENT

BY

ALAN A. BECKER

A

THESIS

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Approved by E. W. Carlton

Professor of Structural Engineering

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I also offer sincere thanks to Mr. T. J. Kauer and the Wire Reinforcement Institute for suggesting the problem and offering very helpful advice during the investigation, and generously furnishing the material necessary to carry out the required tests.

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INTRODUCTION

Concrete structures, either plain or reinforced, maintain a unique position in modern construction. With few exceptions, a concrete structure is the only type that is completely manufactured on the site of the work.

Historical Sketch

Masonry structures date as far back as 2700 B.C., with the construction of the world-famous Egyptian pyramids. The ancient Egyptians built their structures of large stone blocks some of which were as much as thirty feet long. The Chaldeans, in the year 2000 B.C. developed and furthered the use of kiln-burned bricks united with bitumen for their dwellings and temples. The Ancient Greeks developed three further types of masonry construction. The earliest was known as Cyclopean masonry, and consisted of huge stones of irregular shape, the spaces being filled with smaller stones. The second type was the "polygonal" in which the stones were carefully dressed and shaped to fit together firmly. The third type followed the pattern set by the early Egyptians, and consisted of nearly rectangular stones laid in horizontal courses. The

Greeks were the first to develop the carving of artistic forms from the stone, and the present civilization still admires the wonderful perfection of early Greek architecture.

The art of masonry construction was greatly advanced during the Roman period. The Romans developed and used the very first concrete. During this period the circular arch was developed and was the principal feature of masonry construction. Most Roman buildings consisted of heavy masonry walls supporting circular arched roofs. The Romans also developed lime mortar by adding sand, lime and a volcanic alumina silicate to water. Their walls were roughly cemented with this material and faced with brick or marble blocks.

Early concrete construction started with the development of Roman cement by James Parker, an Englishman, in 1796. This consisted of burned limestone containing a large proportion of clay. Early in the nineteenth century natural cement of the same type as that made by Parker was produced in the United States by Canvas White, a hydraulic engineer. This cement was manufactured and used quite extensively in hydraulic work. In 1824 Joseph Aspden, of Leeds, England, produced a mixture of slaked lime and clay at high temperature. In 1845 this cement was manufactured on a commercial scale, and has since been used throughout the world.

Portland Cement was manufactured in the United States by Mr. D. O. Saylar in 1875. From this beginning the great American Portland cement industry has developed. Numerous improvements in the manufacture and control of Portland cement have been made and contributed to the establishment of one of the largest industries of the United States.

The early use of concrete was mainly as a filler in heavy construction. Concrete walls were usually protected by a brick or stone facing. In 1861, Joseph Monier, a Parisian, constructed tubs and small water tanks of concrete in which a wire frame was embedded. This frame was, in reality, a wire mesh formed of wires or rods placed at right angles to each other. He patented his reinforcement, and in 1887 two German scientists published results of tests on the Monier system and a series of formulas for design. During the next ten years considerable development of this type of construction took place in many European countries. Reinforced concrete was applied to arches, floor slabs, beams, and walls.

The use of reinforced concrete spread to the United States during the latter part of the nineteenth century. It was applied to the construction of buildings and bridges during the 1890's and at that time a patent for the first deformed bar was taken out.

Since 1900 the use of reinforced concrete has rapidly increased, and been applied to almost every type and phase of construction. Recent developments in the field of improved techniques in mixing and placing, permitting higher unit stresses, rational design, and recognized standards of practice make it one of the major construction materials of the entire world.

The ability of any reinforced concrete structure to carry load depends upon the adhesion of the concrete to the steel reinforcing. The stresses developed in a reinforced concrete structual member must be transmitted to the steel through the bond between the steel and concrete. This adhesive force is known as the "bond" or "bond stress." What this stress actually amounts to is a resistance to shearing between the surfaces of the steel and concrete. Due to the presence of this "bond stress" the reinforced concrete member acts as a homogeneous beam, rather than two separate materials and this force tends to develop simultaneous and mutually helpful action.

Actually bond is of two kinds: adhesive bond and sliding resistance, which develops after the adhesion is broken. Professor Abrams of the Structural Materials Research Laboratory conducted a series of tests on plain round reinforcing rods and concluded that there was no slip until the bond stress reached an average value of 10% to 15% of the compressive strength of the concrete. The resistance up to this point was purely adhesive resistance. When the slip reached approximately .01 inch the maximum bond resistance occurred. When slip exceeded .01 inch the resistance was purely sliding friction.(1) Similar tests at the University of Illinois(2)

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(1) Bulletin 17. Structural Materials Research Laboratory, 1925.

(2) Bulletin 71. University of Illinois, 1913.

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showed that square bars give results about 75% of those obtained with plain round reinforcing bars. The same series of tests proved that deformed bars begin slipping at approximately the same bond stress as plain round rods, but the resistance to sliding due to the bearing of the projections on the concrete is considerably higher than for the plain bars. Deformed bars, however, allow considerable slip before sliding resistance comes into effect.

Many types of reinforcement are used in reinforced concrete design and construction. Usually round or square steel rods are used for floors, and slabs, built up members of structural steel shapes for columns and arches, and round spiral steel for lighter building columns. In European practice plain bars are commonly used, but in the United States deformed bars with small projections of various sizes, shapes, and design, often hooked at the ends, are given preference. Most of the steel used for the heretofore mentioned bars is hot-rolled and has an elastic limit in the vicinity of 35,000 psi.

Welded Wire Fabric, a new type of concrete reinforcement, was invented by the Clinton Wire Cloth Company, of Massachusetts near the turn of the century, and has been used as a reinforcing material for certain types of concrete construction for almost fifty years. It is used primarily for floor, roof, and highway slabs, concrete pipe, wall reinforcement, cement gun work, airport runways, and precast building products. The fabric is made in the form of a mesh, of cold drawn wire and has its elastic limit considerably raised by cold-drawing. This permits working stresses considerably above those allowed for hot-rolled steel.

"The values given for tension are limited to approximately 50% of the yield point of the reinforcement, but with an upper limit of 20,000 psi for important structural members and 25,000 psi for the special case of one way slabs reinforced with wire mesh and small size bars."(3)

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(3) Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete - Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete. 1940.

Welded Wire Fabric consists of longitudinal and transverse wires spaced at various intervals and electrically welded at all intersections. The wire is plain, but the rigidly connected cross wires provide mechanical anchorage, while the close spacing of the wires provide a greater bonding area than that of larger steel members of equal cross sectional area per foot of width.

Several investigations have been conducted on welded wire fabric. Professor Warren Raeder(4) tested several specimens of wire mesh as pull-out specimens and also tested wire mesh embedded in concrete beams. He concluded that the cold-drawn wire developed maximum bond stress at first slip, testing single wires by direct pull out. He also concluded that two welded cross wires were sufficient to develop the strength of a longitudinal wire in tension and that the weld on the cross wire broke after a slip of from .05 to .10 inches.

Mr. E. A. Weinel(5) tested several series of cold

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(4) Bond Tests on Welded Wire Mesh. 1933-1934
Professor Warren Raeder

(5) E. A. Weinel, The Mechanical Anchorage Value of the Transverse Wires in Welded Wire Fabric. Missouri School of Mines, 1948.

drawn wire by direct pull out from concrete cylinders and determined the actual mechanical anchorage value of the welds by greasing the longitudinal wires to release the adhesive bond.

Mr. Weinel also determined the anchorage value of the welds under multiple action, that is, with three welds acting at one time. This was accomplished by greasing three longitudinal wires and embedding a sheet of welded wire fabric in a two-section beam very similar to those used by the author. He found that the welds sheared at approximately two-thirds the load required to fail the longitudinal wire in tension. The total slip at failure was approximately .075 inches.

The investigation which follows is intended to furnish some basis for a structural and economic comparison of welded wire reinforcement fabric and ordinary reinforcing bars. The data collected by Mr. E. A. Weinel, together with that of the author, composes part of the research program of the Wire Reinforcement Institute.

Purpose and Object of Investigations

As was previously mentioned, Welded Wire Reinforcement Fabric has been applied only to certain "light types" of reinforced concrete construction. It has not as yet been applied as main tension reinforcement for most concrete structures, mainly due to the fact that a thorough investigation of the potentialities and possibilities of welded wire fabric has not as yet been conducted. It is expected that the data collected in this investigation coupled with data collected in similar investigations performed at the Missouri School of Mines and Metallurgy will furnish the basis for a structural and economic comparison between welded wire fabric and ordinary reinforcing bars.

The object of this investigation is to determine: (1) the mechanical anchorage and adhesive bond value of the welds in welded wire reinforcement fabric for various sizes of wire and for various spacings of the same wire; (2) the limiting size transverse and longitudinal wires of the welded wire fabric; (3) the effect of two-week and four-week rust on the bond stress of welded wire fabric. An attempt to draw a comparison of load and slip values between welded wire fabric and ordinary reinforcing bars is also part of the object of this investigation.

The work done by Mr. E. A. Weinel[6] served to

(6) Weinel, op. cit., p. 7

determine the effect on bond of varying the length of embeddment of the wires in concrete, and the anchorage value of the transverse wires in welded wire fabric. In his work, Mr. Weinel used a single length of plain wire for the determination of the effect on bond of varying length of embeddment. For the anchorage tests, Mr. Weinel used a single longitudinal and transverse wire with the surface of the longitudinal wire greased to release the adhesive bond, thus testing only the mechanical anchorage of the wire. He also conducted an anchorage test by releasing adhesive bond on three longitudinal wires embedded in a two-section beam, thus testing the anchorage value of three welds acting simultaneously. The results of the latter, however, were inconclusive, as only one set of tests were performed.

In this investigation, the author makes use of Mr. Weinel's method by testing anchorage value of the welds in much the same manner, the object being to test combined action of adhesive bond plus mechanical anchorage. Two section beams, very similar to those of Mr. Weinel's are used. The longitudinal wires, however, are not greased and in several cases two transverse wires are embedded in a beam, thus testing the action of six welds. The effect on the bond stress of two-week and four-week rust is a supplement to this part of the investigation.

By testing various combinations of longitudinal and transverse wires, the author endeavors to determine the limiting sizes and the combined adhesive bond plus mechanical anchorage values of the welds.

It is the hope of the author that this investigation will throw some light on the future value of Welded Wire Fabric.

Materials

The tests performed in this investigation were all conducted in the Materials Laboratory of the Civil Engineering Department of the Missouri School of Mines and Metallurgy.

Steel: The steel used throughout the investigation was Welded Wire Reinforcement fabric furnished by Colorado Fuel and Iron Company, American Steel and Wire Company, Pittsburg Steel Company, all members of the Wire Reinforcement Institute. The wire was all new, cold-drawn, structural steel wire fabric shipped to the laboratory in sheets and rolls. The wire had the following properties (average values):

Tensile Strength:	80,000 psi
Yield Stress:	75,000 psi
% Reduction of Area:	60%
% Elongation	3%
% Carbon	.12%
% Manganese	.42%
% Phosphorous	.012%
% Sulphur	.027%

The test specimens were cut from the sheets and rolls of the welded wire fabric. The wire was rust-free in all cases except that used in the experiments for the effect of rust on the bond stress. The following guages of wire were used: Longitudinal Wires: #2 and #00 guage transverse wires: #2, #3, #4, #6, and #8 guage for the beam tests and #00, #2, #6 and #10 for the rust experiment.

Concrete: The Wire Reinforcement Institute recommended that the concrete materials meet the Specifications for Class A concrete set up by the Missouri State Highway Department. They also recommended that the concrete be designed and mixed for an ultimate compressive strength of 3,000 psi. Fine and coarse aggregate was generously furnished by the Missouri State Highway Department. The coarse aggregate was standard 3/4 inch limestone, and the fine aggregate approved Pacific Sand. Several commercial brands of normal Portland Cement were used, namely: Atlas, Red Ring, Marguette and Air Entrained. The constituents were mixed in the proportion of 1:2.2:3.2 with $6\frac{1}{4}$ gallons of water per sack in a Lancaster laboratory concrete mixer. This mixture had an average slump of $3\frac{1}{2}$ inches and weighed approximately 150 pounds per cubic foot. One test cylinder six inches in diameter and twelve inches in height was cast for each batch of concrete mixed. The average compressive strength of the concrete at twenty-eight days was 3100 pounds per square inch.

Forms: Forms for the two section beams were constructed of 3/4 inch plywood. Two $\frac{1}{4}$ inch bolts were placed at each end to hold the sides and ends firmly together and during the pouring a clamp was placed over the center to hold the dividing partitions firmly to the sides. The forms were well oiled with motor oil before each pour.

Rusted Steel: The rusted steel specimens for the rust experiment were obtained by cutting the required lengths from straight wire furnished by Truscon Steel Company and exposing them to normal weather conditions. In the event of the absence of rain the wires were sprinkled with water, each day if necessary, and dried by the sun and air. Several specimens were taken indoors after two weeks and the remainder were left to obtain four-week rust.

Reinforcing Bars: Standard 3/8 inch round ribbed reinforcing bars, manufactured by Leclede Steel Company were used in the experiment for comparison of load vs. slip for reinforcing bars and welded wire fabric.

SPECIMENS AND TESTING APPARATUS

For the determination of: (1) the mechanical anchorage plus adhesive bond value of the welds and (2) the limiting size transverse and longitudinal wires of welded wire fabric, a sheet of wire consisting of three longitudinal wires and from four to six transverse wires, depending upon the spacing, was cut from a standard sheet of welded wire fabric as furnished by the manufacturer. Three such specimens were cut for each test and labeled as follows:

Mark	Long. Wire	Spacing	Trans. Wire	Spacing	Mfg.
M-1	#2 guage	4"	#6 guage	6"	Pittsburg Steel Prod.
M-2	#2 guage	2"	#2 guage	6"	Pitts. Steel
M-3	#2 guage	3"	#4 guage	6"	AS&W
M-4	#2 guage	2"	#8 guage	4"	CF&I
M-5	#2 guage	3"	#6 guage	12"	AS&W
M-6	#2 guage	4"	#8 guage	12"	CF&I
M-7	#2 guage	2"	#8 guage	8"	CF&I
M-8	#2 guage	3"	#4 guage	12"	AS&W

Additional specimens consisting of three longitudinal wires and from six to eight transverse wires, depending upon the spacing were cut and labeled as follows:

Mark	Long. Wire	Spacing	Trans. Wire	Spacing	Mfg.
DM-9	#2 guage	3"	#4 guage	12"	AS&W
DM-10	#2 guage	2"	#8 guage	4"	CF&I
DM-11	#2 guage	4"	#6 guage	6"	Pitts. Steel
DM-12	#2 guage	2"	#2 guage	6"	Pitts. Steel
DM-13	#2 guage	3"	#4 guage	6"	AS&W

Specimens were also cut consisting of two longitudinal wires and from four to six transverse wires, depending on spacing, as follows:

Mark	Long. Wire	Spacing	Trans. Wire	Spacing	Mfg.
OM-1	#00 guage	6"	#3 guage	6"	Truscon
OM-2	# 2 guage	6"	#4 guage	12"	Truscon

The final specimens for tests (1) and (2) consisted of two longitudinal wires and from six to seven transverse wires depending on spacing as follows:

Mark	Long. Wire	Spacing	Trans. Wire	Spacing	Mfg.
DOM-2	#00 guage	6"	#3 guage	6"	Truscon
DOM-3	# 2 guage	6"	#4 guage	12"	Truscon

Two section beams shown in detail on page 75 were poured for the testing of the steel specimens. The first, or anchorage section of the beam consisted of a concrete block thirteen inches wide, four inches deep, and twenty-four inches long. The second, or test section consisted of a concrete block thirteen inches wide, four inches deep and seventeen inches long. Beams of the M series were poured with the experimental specimens placed symmetrically two inches from the top and with one transverse wire embedded in the test section and two in the anchorage section. The length of embeddment of the longitudinal wires in the test section varied with the spacing of the transverse wires. For example, with transverse wires spaced at six inches, the embeddment of the longitudinal wires was five inches from the face of the cross section to the transverse wire, plus three inches beyond the transverse wire, or a total of eight inches. Similarly with the transverse wires spaced at twelve inches, the embeddment was eleven inches from the face to the transverse wire, plus three inches beyond, or a total of fourteen inches. In all beams of the M series except M7 beams, the longitudinal embeddment was equal to one inch less than the spacing between cross wires plus three inches. Due to the eight inch transverse wire spacing in the M7 beams, the embeddment of the longitudinal wire was only four inches.

Beams of the DM series were identical with M series beams except for the fact that one additional transverse wire was embedded in each section, making a total of two in the test section and three in the anchorage section.

Embeddment length of the longitudinal wires in the test section was also varied in the DM beams, due to the spacing of the transverse wires. With transverse wires spaced at four inches, the longitudinal embeddment was ten inches, with transverse wires spaced at six inches it was fourteen inches and with transverse spacing of twelve inches, longitudinal embeddment was sixteen inches.

Because of the limiting width of the beam, (thirteen inches) only two longitudinal wires could be used in the OM series beams. Beams were cast with one transverse wire in the test section and two in the anchorage section. Embeddment of the longitudinal wires was the same as for M series beams with the same transverse wire spacing.

The DOM series beams were identical with those of the OM series, except that one additional transverse wire was embedded in each section. The embeddment lengths of the longitudinal wires followed the pattern set in the casting of the DM series beams.

Three specimens were cast for each test to arrive at an average result and eliminate error so far as possible.

Testing Apparatus

The apparatus used for the testing of the two section beams was a Tinius-Olsen, 200,000 pound capacity testing machine, located in the Materials Laboratory of the

Department of Civil Engineering. The machine was fitted with two specially designed yokes as illustrated on the following page. The top yoke consisted of structural shapes, rods, plates, bolts, and nuts, as illustrated in Figure 1. This held the anchorage section in place while the lower yoke, identical with the upper, except that I beams were used in place of channels to allow the required spacing for the Ames Dials, was fitted to the test section of the beam. The Ames dials were bolted to the outer longitudinal wires of the fabric by means of wooden braces, their lower ends resting on the top surface of the test section. By tightening the two lower nuts, the test section was brought firmly against the upper face of the lower head of the testing machine, and the angles firmly against the lower face. The beam was then in place and ready for testing.

A special set of beams labeled C-1--C-6 were cast in an experiment to draw comparison of load and slip values between welded wire fabric and ordinary reinforcing bars. The C-3--C-6 beams were cast with a sheet of wire consisting of four longitudinal wires and eight transverse wires as follows:

Mark	Long. Wire	Spacing	Trans. Wire	Spacing	Mfg.
C-3-4	#2 guage	3"	#2 guage	6"	AS&W
C-5-6	#2 guage	3"	#2 guage	4"	AS&W

FIG. 1 TESTING APPARATUS

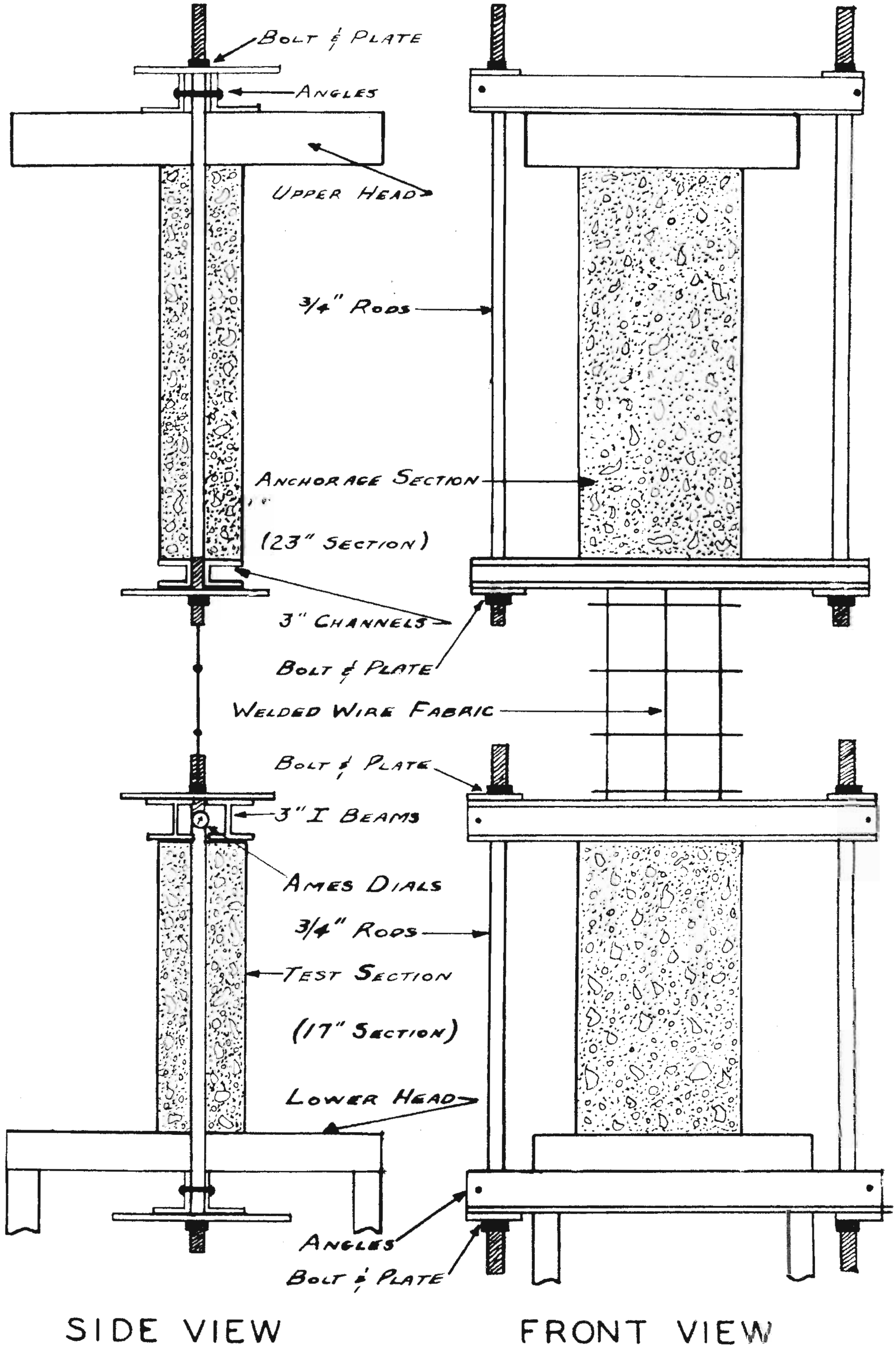

Figure 2

Front View of an M Series Beam
ready for testing

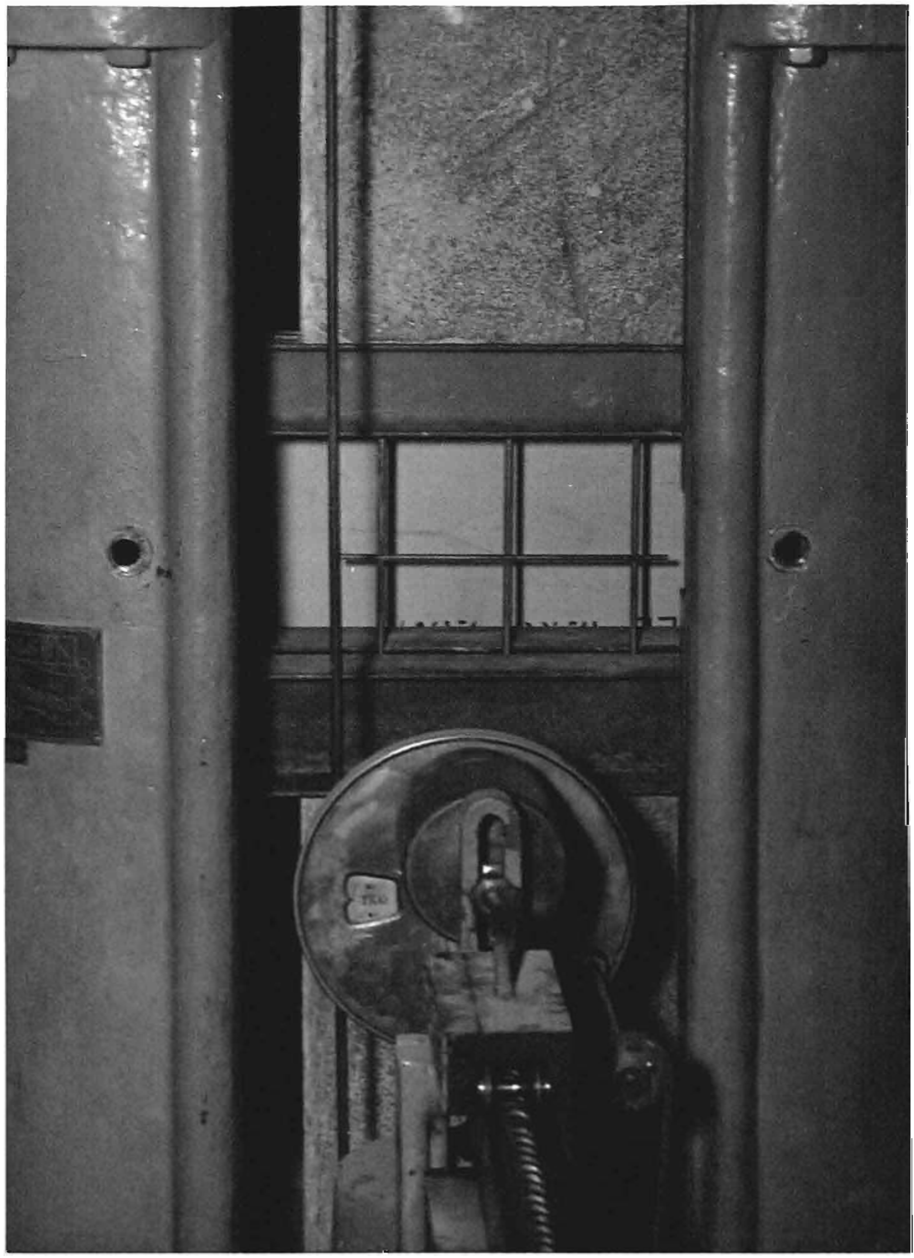

Figure 3

Close-up view of a typical M series beam suspended in the 200,000 pound capacity Tinius-Olsen testing machine.

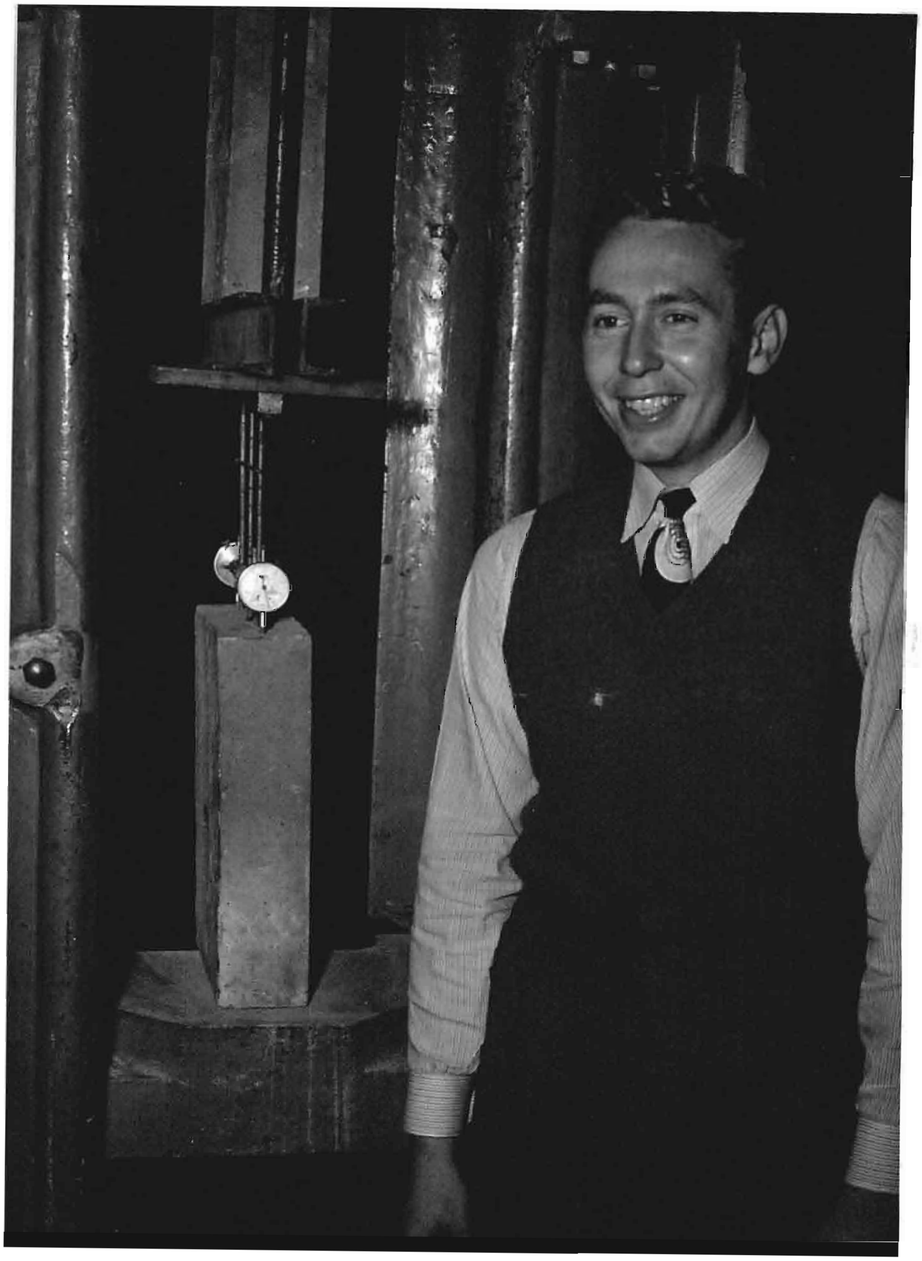

Figure 4

Close-up side view of a beam suspended in the testing machine, showing positions of the Ames Dials. Author is at the right.

Two transverse wires were embedded in the test section and three in the anchorage section of beams C-3-4, and three transverse wires in the test section and four in the anchorage section of beams C-5-6. The embeddment of the longitudinal wires in the test section was fourteen inches.

The beams labeled C-1-2 were cast with two standard 3/8" reinforcing bars placed symmetrically four inches about the center line of the beam. The bars were embedded fourteen inches in the test section and twenty-one inches in the anchorage section. Three-eights inch bars were selected for the experiment so that the same percentage of steel to concrete would exist in the C1-2 and C3-6 beams, the area of four #2 guage wires being 0.216 square inches, and two 3/8" bars 0.221 square inches. Testing was accomplished in the same manner as previously described.

Rust Experiment

For the determination of the effect of rust on the bond stress of welded wire fabric, four guages of wire were selected: #00, #2, #6, and #10. Eighteen specimens of straight, cold-drawn wire furnished by Truscon Steel Company were used for each guage. These specimens were cut to lengths of seventeen inches and then rusted by exposure to general normal weather conditions. In case of absence of rain, the wire was sprinkled with water, each day if necessary. At the end of two weeks, half of the specimens of each guage were taken in and the remainder were left to rust for a total of four weeks. It was observed that after two weeks of rusting, the wires exhibited a uniform scale, while the wires that were rusted four weeks became pitted in spots and rather flaky.

Concrete cylinders, six inches in diameter and twelve inches in length were cast, the concrete being proportioned in the same manner as the concrete for the beam tests. Three wires of each guage and with the same amount of rust were axially embedded in the cylinders to depths of six, eight, and twelve inches, thus affording three specimens for each separate test. A mean value of the resulting data from each of the three specimens furnished the final results used for each test. Seventy-two tests were performed in all--four guages of wire, embedded to three different depths, with two conditions of rust and three specimens compromising each test.

Testing was accomplished by means of an Emery-Southwark Testing Machine of 20,000 pounds capacity located in the Materials Laboratory of the Department of Civil Engineering.

TESTING PROCEDURE

(1) Concrete:

As was previously mentioned, the concrete was mixed in a Lancaster Laboratory Mixer for a period of two minutes prior to placing in the oil painted forms. The concrete was then carefully rodded to assure homogeneity. A slump test was performed for each batch, yielding an average slump value of three and one-half inches. A cylinder, previously described, was also cast for each batch, and tested by direct compression with the Tinius-Olsen 200,000 pound capacity testing machine. The average compressive strength at 28 days was 3100 psi.

The forms were removed from the beams and cylinders after 24 hours, and the specimens placed in a moist closet to cure for a period of twenty-eight days before testing. In some cases, due to lack of available space, the concrete was cured by storing the specimens in a tank of water. Test cylinders cured under water had the same compressive strength at 28 days as those cured in the moist closet.

(2) Beam Tests:

After placing the beam in the testing machine and fitting the two yokes (see page 20) the lower head was moved downward placing a load on the beam. The arrangement of the specimen placed the concrete in compression and the steel wires in tension. The Ames Dials mounted on each of the outer wires recorded slip plus elongation between the point on the wire at which they were mounted, and the upper edge of the test section. Unless the wire failed in tension between these two points, the elongation was comparatively small, and neglected in plotting curves of load versus slip. Dial readings were taken at successive 500 pound increments of load. As the load increased, the longitudinal wires began to pull out of the concrete block, thus destroying the adhesive bond of the wires and throwing all resistance but slipping resistance to the welds. As the loading continued, either the welds sheared or the longitudinal wires broke in tension. Loads at which this occurred were recorded, and also the peak load in case of a tension failure. The results of these tests are given in data sheets #1 through #20 (pages 35 - 71). "East Dial Slip" represents the average value of slip of the East Dial for three tests between successive 500 pound increments of load. For example, data sheet #1, the average slip of three tests from 0 pounds to 500 pounds was 0.003 inches; the average slip from 500 pounds to 1000 pounds was 0.004 inches, etc. "West Dial Slip" represents the same values for the West Dial. "Total Slip" represents the average of the East and West Dial Slip, added successively for each

500 pound increment of load. Thus on data sheet #1, the average slip which represents the total slip between the steel and concrete from 0 pounds to 500 pounds, was 0.0025 inches. By adding the average of the East and West Dial Slip between 500 and 1000pounds (.0025 inches) to this value, the total slip from 0 to 1000 pounds, or .005 inches is obtained. This process is continued to the failure load and thus reveals the total slip between 0 pounds and the failure load. In the case of data sheet #1, this value is 0.1390 inches.

In a few cases failure occurred by tension in the longitudinal wires between the mounting point of the dial and the face of the concrete. A discussion of this is included in the results.

Failure occurred in one of three ways for beams M1 through DOM 3: (1) by shearing of the welds; (2) by tension in the longitudinal wires; (3) by some defect in the construction of the Welded Wire Fabric. This is similarly discussed in the results.

Beams C-1-6 (comparison test of the welded wire fabric and ordinary reinforcing bar) were performed in the same manner and failed either by tension in the wires or bars, or in the case of the bars, by destroying all bond and pulling them directly out of the concrete.

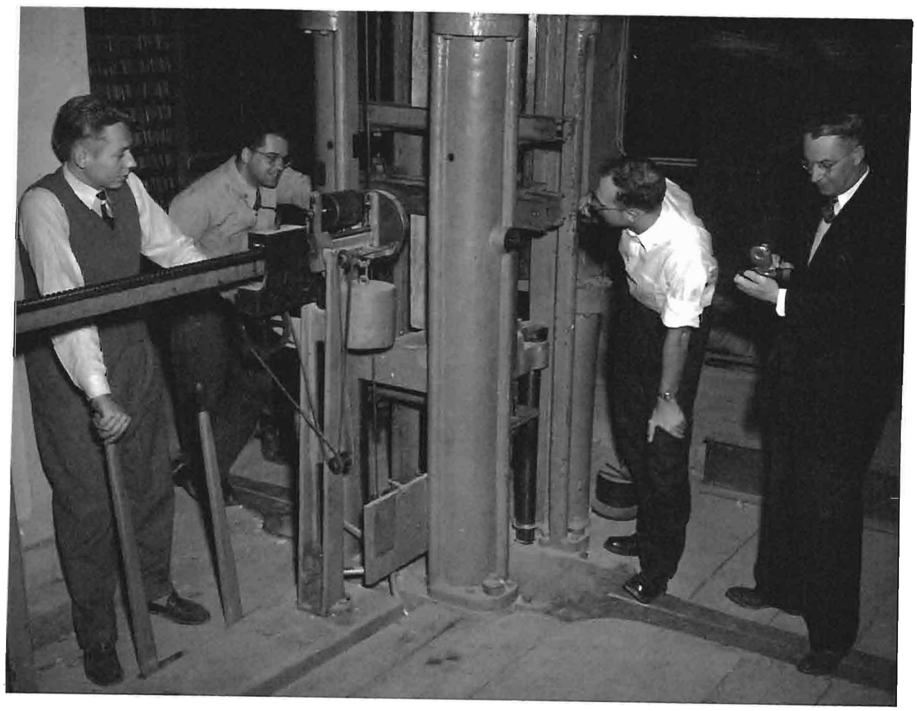

Figure 5

View showing a test of a typical M series beam. Mr. Heartz and Mr. Trace at the left and right respectively, are each reading an Ames Dial, Professor Carlton at the extreme right is taking data, and the author at the controls.

Data sheets #18, #19 and #20 show the results of this experiment and are tabulated in the same manner as sheets #1 through #17.

Cylinder Pull-Out Tests (Rust Experiment)

After curing for a period of 28 days, the specimens were removed from the moist closet and capped with a plaster of Paris mix to assure uniform distribution of pressure to the cylinder top as the load was applied.

The tests were made by inverting the cylinders and extending the wire downward through a one-inch circular opening in the upper, movable head of the Emery-Southwark 20,000 pound capacity testing machine. The plaster of Paris cap was bearing against the top surface of the head. The lower end of the wire was then clamped in position by jaws mounted in the lower stationary head of the machine. This arrangement placed the concrete in compression and the steel wire in tension during the test. Load was applied by raising the upper head of the machine. Application of the load continued until the bond between the steel and concrete failed, and the wire pulled out of the cylinder. In a few cases the wire broke in tension. The results of these tests are given in pages 76-78. The bar graphs (pages 80-83) were drawn up to afford a better comparison between the three

Figure 6

View showing a typical test of the effect of rust on the bond stress of wire reinforcement. Cylinder is being tested in the Emery-Southwark 20,000 pound capacity testing machine. Professor Carlton is at the right observing the test, Mr. Heartz taking data, and the author is at the controls.

types of specimens. Values for plain bars were obtained from the data collected by Mr. Weinel[7] in his investigation.

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(7) Weinel, op. cit., p. 7

<u>Accuracy of Experiments</u>

All results obtained are subject to the limitations of experimental and human error. Average values were taken in all cases to eliminate, as far as possible, errors which might be obtained in a single experiment. A discussion of possible errors and their compensation appears in the results.

MANUFACTURERS OF WELDED WIRE FABRIC USED IN THIS INVESTIGATION

American Steel and Wire Company

Truscon Steel Company

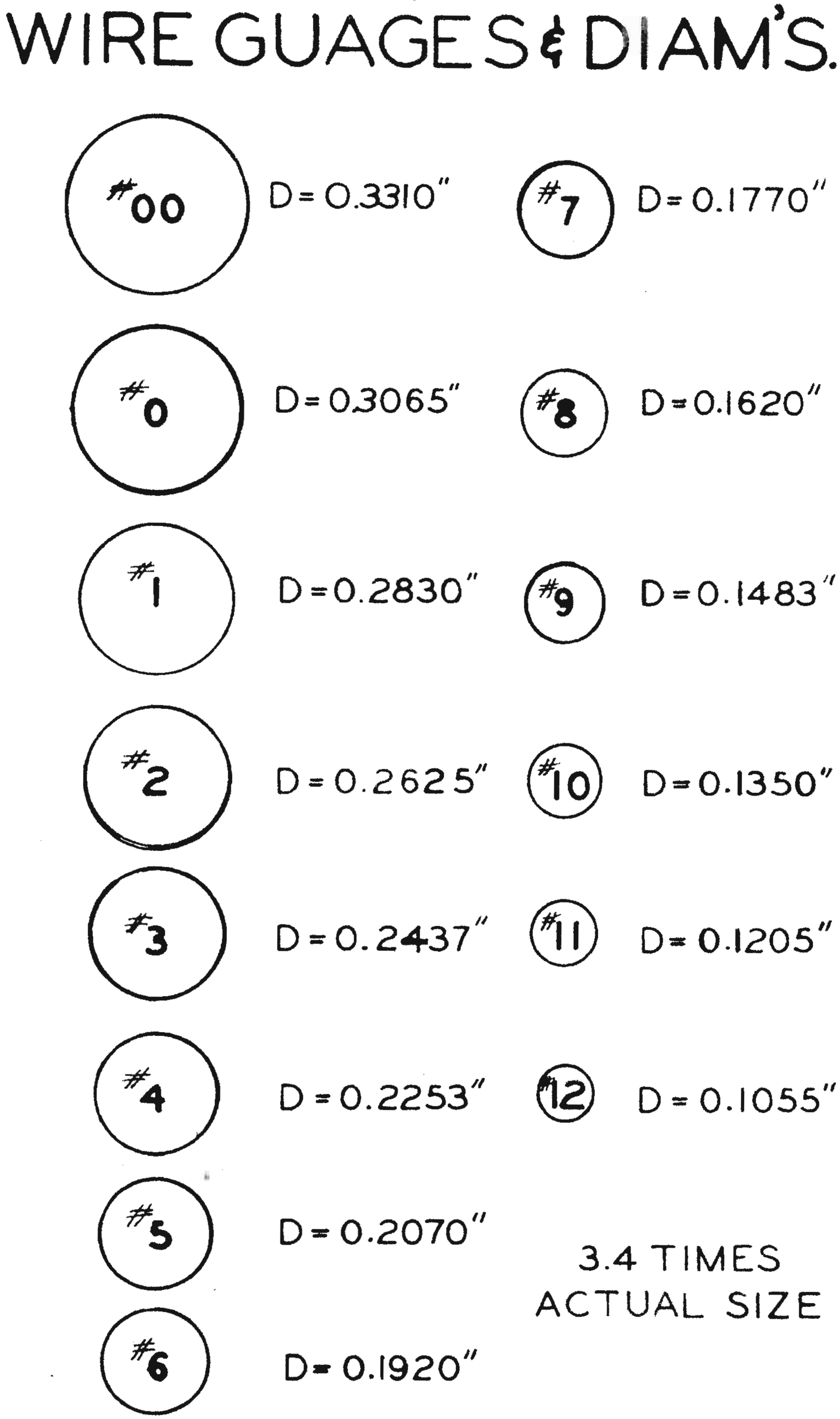
Keystone Steel and Wire Company

Colorado Fuel and Iron Corporation

Laclede Steel Company

Pittsburgh Steel Products Company

Figure 7


WIRE GUAGES & DIAM'S.
#00
D=0.3310"
#7
D=0.1770"
#0
D=0.3065"
#8
D=0.1620"
#1
D=0.2830"
#9
D=0.1483"
#2
D=0.2625"
#10
D=0.1350"
#3
D=0.2437"
#11
D=0.1205"
#4
D=0.2253"
#12
D=0.1055"
#5
D=0.2070"
3.4 TIMES
ACTUAL SIZE
#6
D=0.1920"

DATA SHEET 1

Investigation of Anchorage for Welded Wire Reinforcement Fabric

Load in pounds	E. Dial Slip inches	W. Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.003	.002	.0025	3080
1000	.004	.001	.0050	6160
1500	.003	.001	.0070	9240
2000	.002	.001	.0085	12300
2500	.001	.000	.0090	15400
3000	.002	.001	.0105	18500
3500	.001	.001	.0115	21600
4000	.002	.001	.0130	24700
4500	.002	.001	.0145	27800
5000	.002	.001	.0160	30900
5500	.002	.001	.0175	33900
6000	.002	.001	.0190	37000
6500	.002	.001	.0205	40200
7000	.002	.001	.0220	43200
7500	.002	.001	.0240	46200
8000	.002	.001	.0255	49300
8500	.002	.001	.0275	52400
9000	.003	.002	.0275	55500
9500	.004	.001	.0320	58600
10000	.003	.003	.0355	61700
10500	.003	.007	.0405	64800
11000	.004	.005	.0450	67900
11500	.006	.009	.0520	71000
12000	.004	.012	.0600	75000
12400	.039	.019	.0890	76600
10800	.005	.095	.1390	66700
10800	Failure by tension in long. wire (1) and by shearing of welds (1)			

Average failure load weld shear 12,000 lbs.

,Average failure load tension 10,800 lbs.

Average total slip weld shear .072"

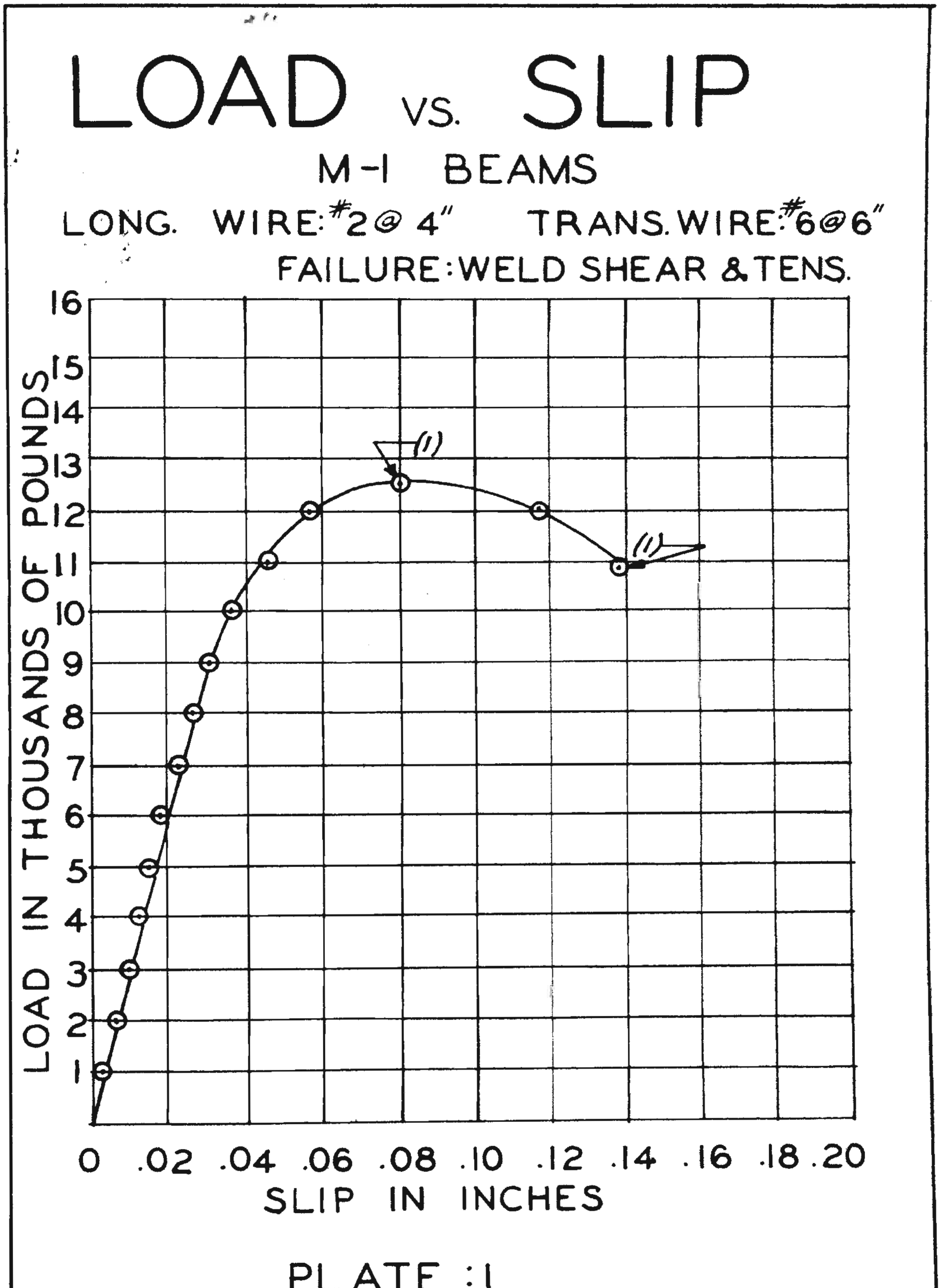
Average total slip tension .1390"

Average Peak load tension 12,400 lbs.

Average failure stress tension 66,700 psi

Average Peak Stress tension 76,700 psi

Beam Series M-1 Long. Wire #2 @ 4" Trans. Wire #6 @ 6"



LOAD VS. SLIP
M-1 BEAMS
LONG. WIRE: #2 @ 4"
TRANS. WIRE: #6 @ 6"
FAILURE: WELD SHEAR & TENS.
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
(1)
(1)
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES

PLATE : I

DATA SHEET 2

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total slip inches	Stress psi
0	.000	.000	.0000	0
500	.002	.001	.0015	3080
1000	.002	.002	.0035	6160
1500	.002	.001	.0050	9240
2000	.002	.002	.0070	12300
2500	.002	.002	.0090	15400
3000	.003	.002	.0115	18500
3500	.002	.002	.0135	21600
4000	.002	.004	.0165	24700
4500	.002	.002	.0185	27800
5000	.002	.002	.0205	30900
5500	.002	.002	.0225	33900
6000	.002	.002	.0245	37000
6500	.002	.002	.0265	40200
7000	.002	.002	.0285	43200
7500	.002	.003	.0310	46200
8000	.002	.002	.0330	49300
8500	.003	.002	.0355	52400
9000	.003	.002	.0380	55500
9500	.003	.002	.0405	58600
10000	.004	.004	.0445	61700
10500	.006	.006	.0505	64800
11000	.006	.006	.0565	67900
11500	.008	.011	.0660	71000
12000	.016	.012	.0900	74000
12300	.012	.030	.1260	75900
11350	.025	.038	.1570	70050
11340	Failure by tension in long. wire			

Average Failure Load 11,350 lbs.

Average Peak Load 12,300 lbs.

Average Failure stress 70,050 psi

Average Peak Stress 75,900 psi

Average Total Slip .1570 inches

Beam Series M-2 Longitudinal Wire #2 @ 2"

Transverse Wire #2 @ 6"

Average Stress represents stress in #2 long. wire

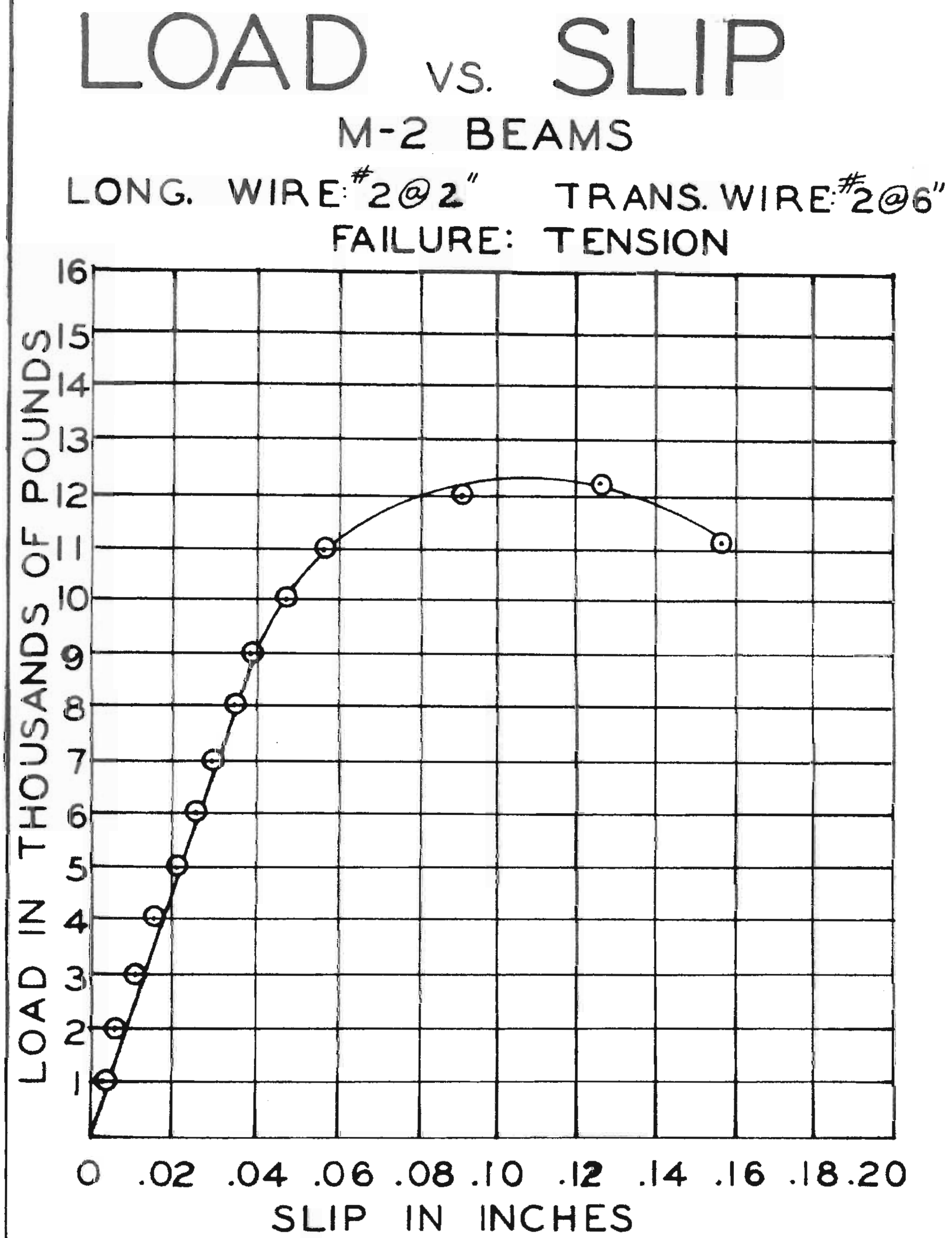

LOAD VS. SLIP
M-2 BEAMS
LONG. WIRE #2 @ 2"
TRANS. WIRE #2 @ 6"
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES

PLATE : 2

DATA SHEET 3

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.003	.003	.003	3080
1000	.002	.002	.005	6160
1500	.003	.002	.0075	9240
2000	.002	.001	.0090	12300
2500	.003	.001	.0110	15400
3000	.002	.001	.0125	18500
3500	.002	.001	.0140	21600
4000	.002	.002	.0160	24700
4500	.002	.001	.0175	27800
5000	.001	.002	.0190	30900
5500	.002	.002	.0210	33900
6000	.002	.002	.0230	37000
6500	.002	.002	.0250	40200
7000	.002	.002	.0270	43200
7500	.002	.002	.0290	46200
8000	.002	.003	.0315	49300
8500	.002	.004	.0345	52400
9000	.003	.004	.0380	55500
9500	.003	.004	.0415	58600
10000	.004	.004	.0455	61700
10500	.005	.005	.0505	64800
11000	.006	.007	.0570	67900
11500	.010	.013	.0685	71000
12000	.012	.043	.1175	74000
12380	.055	.000	.1645	76200
10333	.045	.057	.1645	63800
10300	Failure by tension in long. wire			

Average Failure load 10,333 lbs.

Average Peak Load 12,380 lbs.

Average Failure Stress 63,800 psi

Average Peak Stress 76,200 psi

Average Total Slip .1645 inches

Beam Series M-3 Longitudinal Wire #2 @ 3"

Transverse Wire #4 @ 6"

Average Stress represents stress in #2 long. wire

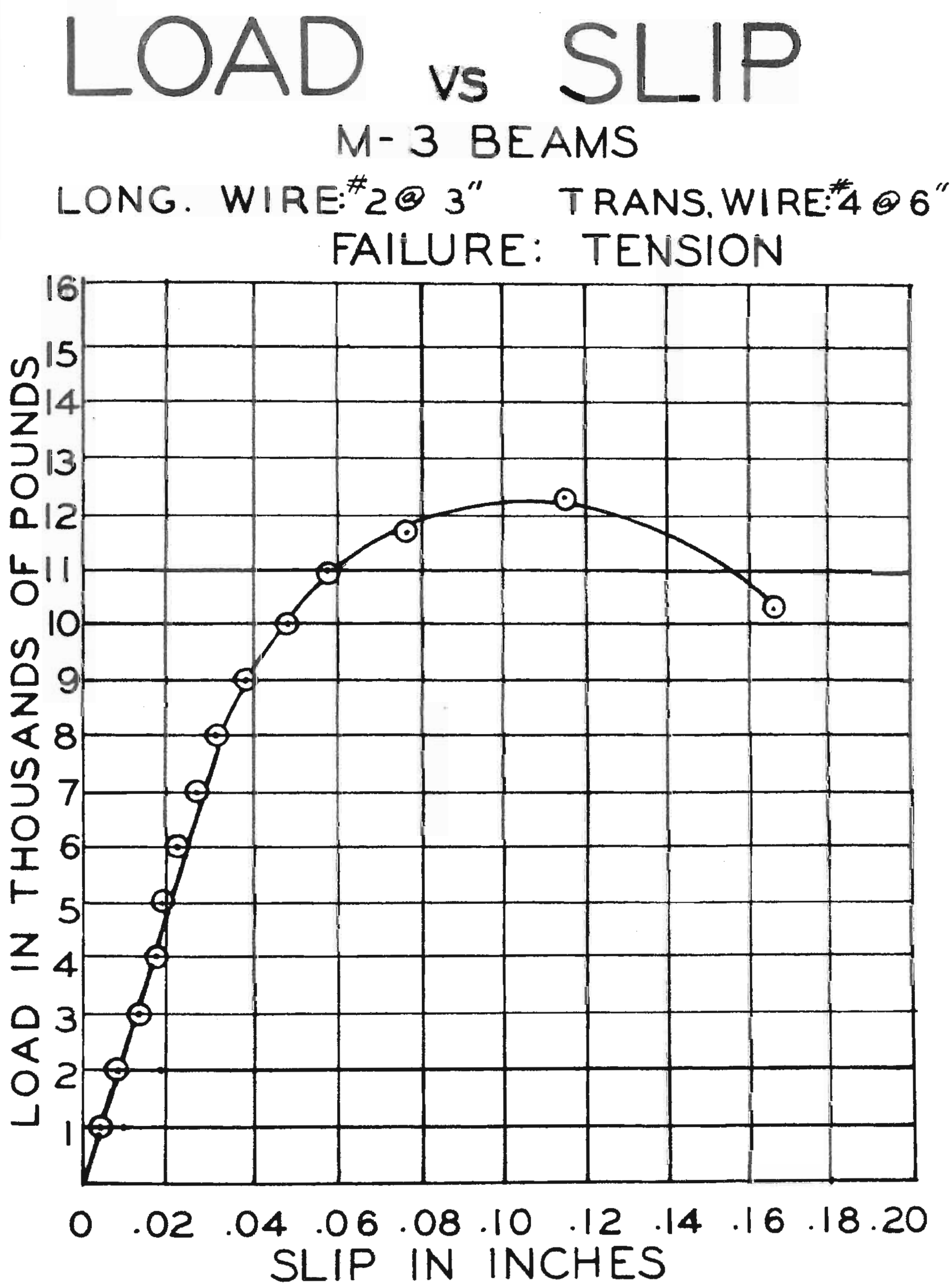

LOAD vs SLIP
M-3 BEAMS
LONG. WIRE #2 @ 3"
TRANS. WIRE #4 @ 6"
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES

PLATE : 3

DATA SHEET 4

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W. Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.007	.002	.0045	3080
1000	.008	.002	.0095	6160
1500	.004	.002	.0125	9240
2000	.005	.001	.0155	12300
2500	.004	.001	.0180	15400
3000	.004	.001	.0205	18500
3500	.004	.002	.0235	21600
4000	.005	.002	.0270	24700
4500	.005	.002	.0305	27800
5000	.004	.003	.0340	30900
5500	.006	.002	.0380	33900
5630	.010	.011	.0485	37000
5640	Failure by shearing of welds			

Average Failure Load 5,630 lbs.

Average Total Slip .0485

Average Stress 37,000 psi

Beam Series M-4 Longitudinal Wire #2 @ 2"

Transverse Wire #8 @ 4"

Average Stress represents stress in #2 long. wire

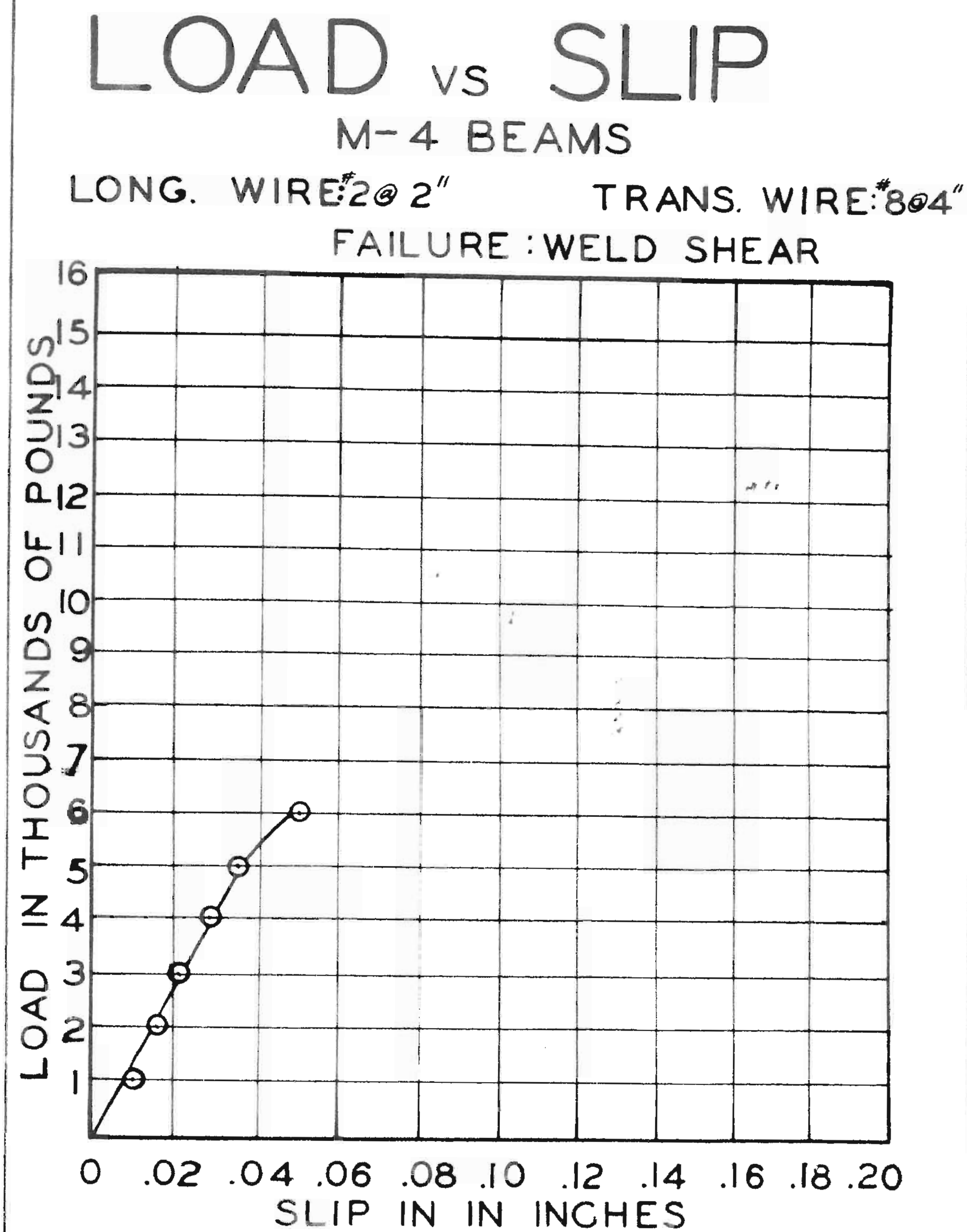

LOAD vs SLIP
M-4 BEAMS
LONG. WIRE #2 @ 2"
TRANS. WIRE: #8 @ 4"
FAILURE: WELD SHEAR
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN IN INCHES

PLATE: 4

DATA SHEET 5

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.003	.001	.0025	3080
1000	.003	.002	.0045	6160
1500	.002	.002	.0065	9240
2000	.003	.001	.0090	12300
2500	.003	.001	.0110	15400
3000	.002	.001	.0125	18500
3500	.004	.001	.0150	21600
4000	.003	.001	.0170	24700
4500	.003	.002	.0190	27800
5000	.005	.002	.0225	30900
5500	.004	.002	.0255	33900
6000	.005	.001	.0290	37000
6500	.005	.000	.0320	40200
7000	.004	.002	.0345	43200
7500	.007	.002	.0390	46200
8000	.007	.004	.0435	49300
8500	.009	.004	.0500	52400
9000	.009	.008	.0585	55500
9500	.012	.008	.0685	58600
10000	.012	.012	.0805	61700
10500	.011	.009	.0905	64800
11000	.020	.010	.1015	67900
9900	.060	.023	.1465	61200
9900	Failure by both tension and weld shear			

Average Failure load by Weld Shear 10,950 lbs.

Average Total Slip Weld Shear .0985 inches

Average Failure load tension 9,900 lbs.

Average Peak Load tension 11,000 lbs.

Average failure stress tension 61,200 psi

Average Peak stress tension 67,900 psi

Average Total Slip tension .1465 inches

Beam Series M-5 Long. Wire #2 @ 3" Trans. Wire #6 @ 12"

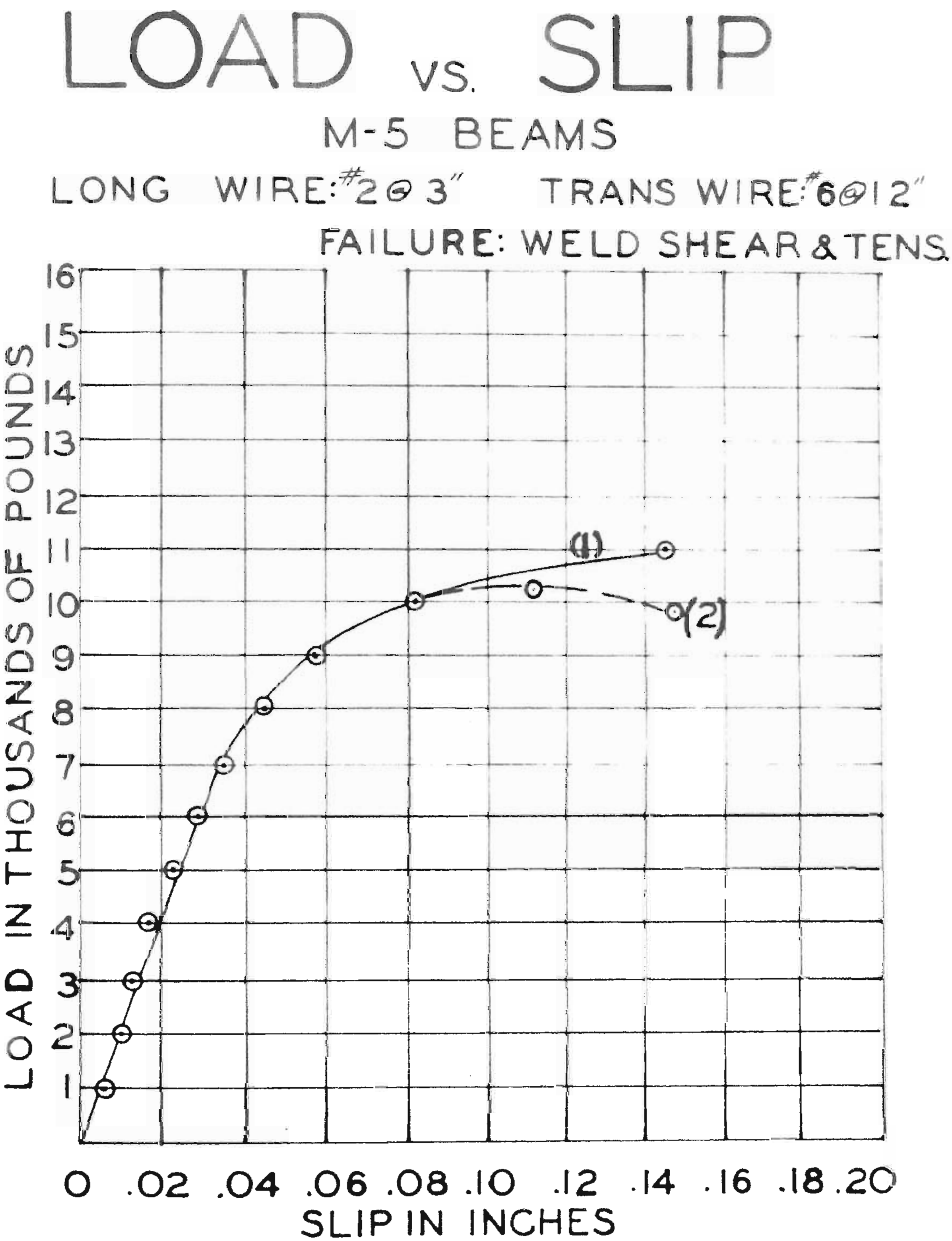

LOAD vs. SLIP
M-5 BEAMS
LONG WIRE: #2 @ 3"
TRANS WIRE: #6 @ 12"
FAILURE: WELD SHEAR & TENS.
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
(1)
(2)
0 .02 .04 .06 .08 .10 .12 .14 .16 .18 .20
SLIP IN INCHES

PLATE : 5

DATA SHEET 6

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.003	.002	.0025	3080
1000	.003	.001	.0045	6160
1500	.003	.001	.0065	9240
2000	.002	.001	.0080	12300
2500	.005	.003	.0120	15400
3000	.003	.001	.0140	18500
3500	.007	.003	.0190	21600
4000	.004	.002	.0220	24700
4500	.004	.002	.0250	27800
5000	.005	.004	.0295	30900
5500	.009	.004	.0360	33900
6000	.005	.004	.0405	37000
6500	.007	.005	.0465	40200
6570	.010	.011	.0565	40600
6580	Failure by shearing of welds			

Average Failure Load 6,580 lbs.

Average Total Slip .0565 inches

Average Stress 40,600 psi

Beam Series M-6 Longitudinal Wire #2 @ 4"

Transverse Wire #8 @ 12"

Average Stress represents stress in #2 long. wire

LOAD VS. SLIP

M-6 BEAMS

LONG. WIRE: #2@4"   TRANS. WIRE: #8@12"

FAILURE: WELD SHEAR

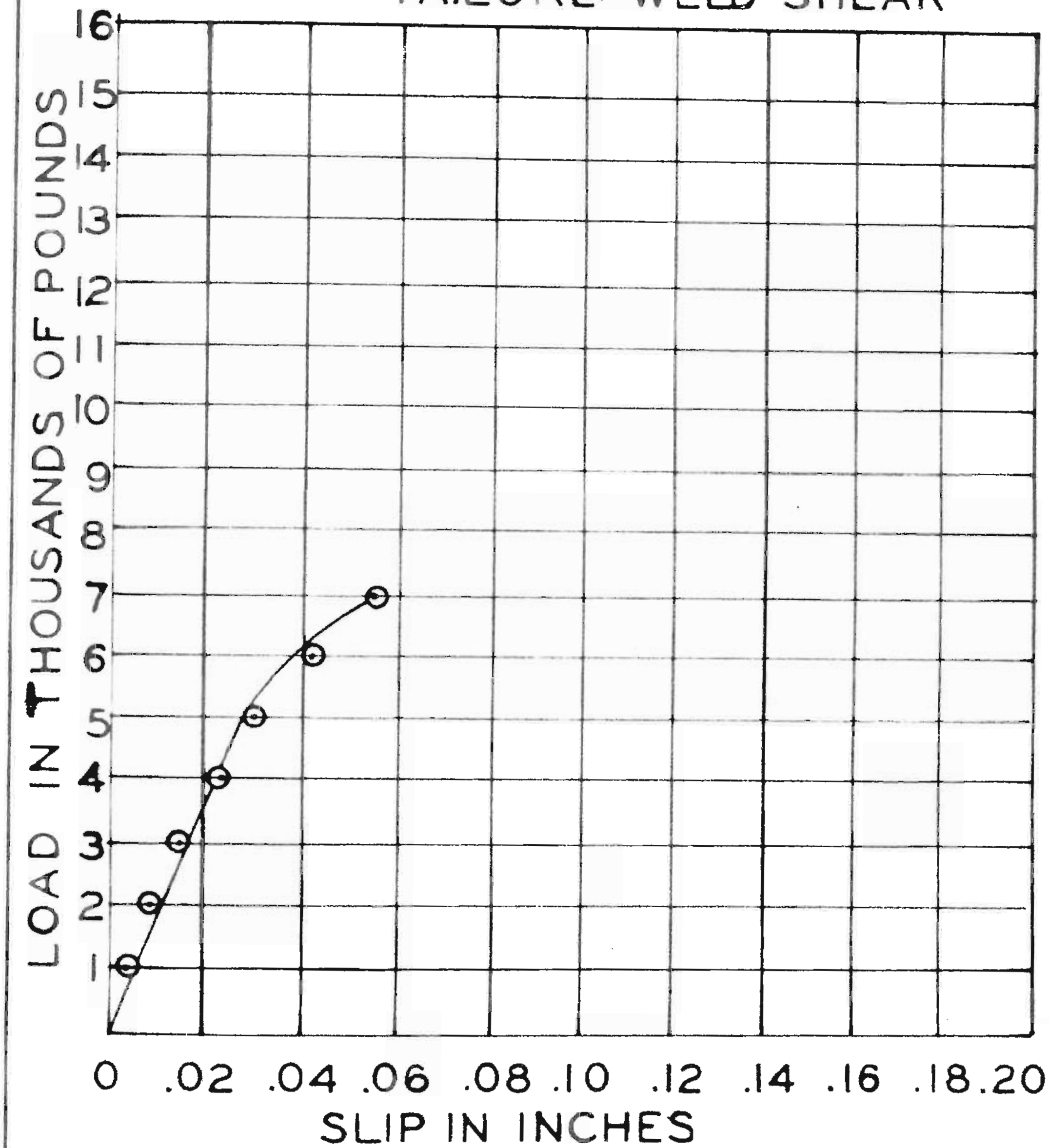


PLATE : 6

DATA SHEET 7

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip	W.Dial Slip	Total Slip	Stress
0	.000	.000	.0000	0
500	.004	.001	.0025	3080
1000	.003	.001	.0045	6160
1500	.003	.001	.0065	9240
2000	.002	.001	.0080	12300
2500	.002	.001	.0095	15400
3000	.005	.003	.0135	18500
3500	.006	.004	.0185	21600
4000	.006	.006	.0245	24700
4500	.010	.012	.0355	27800
4530	Failure by shearing of welds			28000

Average Failure load 4,530 lbs.

Average Total Slip .0355 inches

Average Stress 28,000 psi

Beam Series M-7 Longitudinal Wire #2 @ 2"

Transverse Wire #8 @ 8"

Average Stress represents stress in #2 long. wire

LOAD vs. SLIP

M-7 BEAMS

LONG. WIRE #2 @ 2"   TRANS. WIRE #8 @ 8"

FAILURE: WELD SHEAR

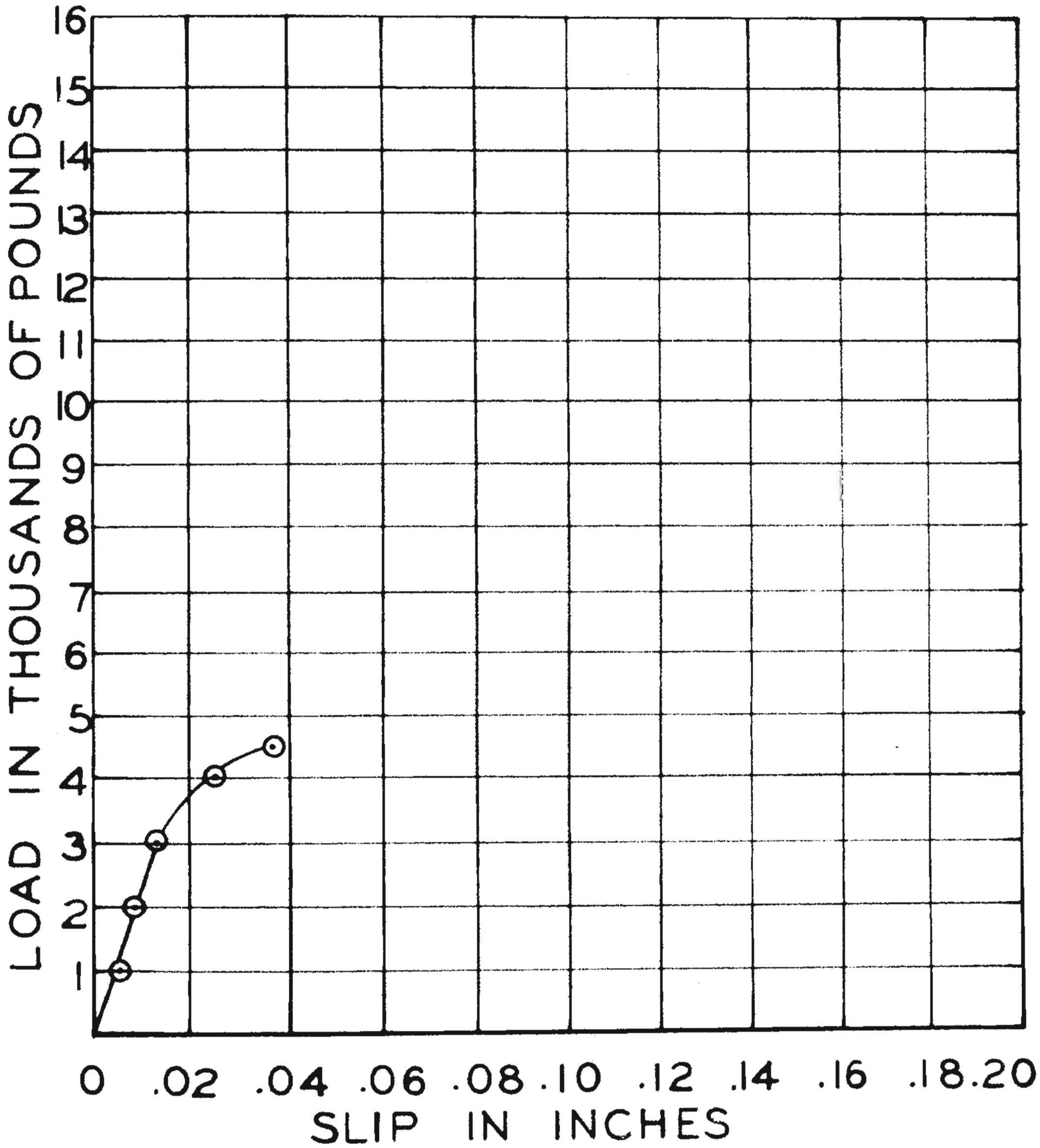


PLATE: 7

DATA SHEET 8

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.002	.001	.0015	3080
1000	.003	.001	.0035	6160
1500	.002	.000	.0050	9240
2000	.004	.001	.0065	12300
2500	.001	.002	.0075	15400
3000	.003	.002	.0100	18500
3500	.003	.001	.0120	21600
4000	.003	.001	.0140	24700
4500	.003	.001	.0160	27800
5000	.002	.001	.0175	30900
5500	.002	.001	.0190	33900
6000	.003	.003	.0210	37000
6500	.002	.001	.0230	40200
7000	.002	.002	.0250	43200
7500	.002	.002	.0270	46200
8000	.003	.003	.0295	49300
8500	.006	.003	.0340	52400
9000	.005	.003	.0380	55500
9500	.005	.004	.0425	58600
10000	.007	.005	.0485	61700
10500	.013	.009	.0595	64800
11000	.010	.011	.0640	67900
11330	.032	.023	.1035	71000
10000	.038	.029	.1425	61700

Failure by tension in long. wire

Average Failure Stress 61,700 lbs. sq. in.

Average Peak Stress 71,000 psi

Average Failure load 10,000 lbs.

Average Peak Stress 71,000 psi

Average Total Slip .1425 inches

Beam Series M-8 Longitudinal Wire #2 @ 3"

Transverse Wire #4 @ 12"

Average Stress represents stress in #2 long. wire

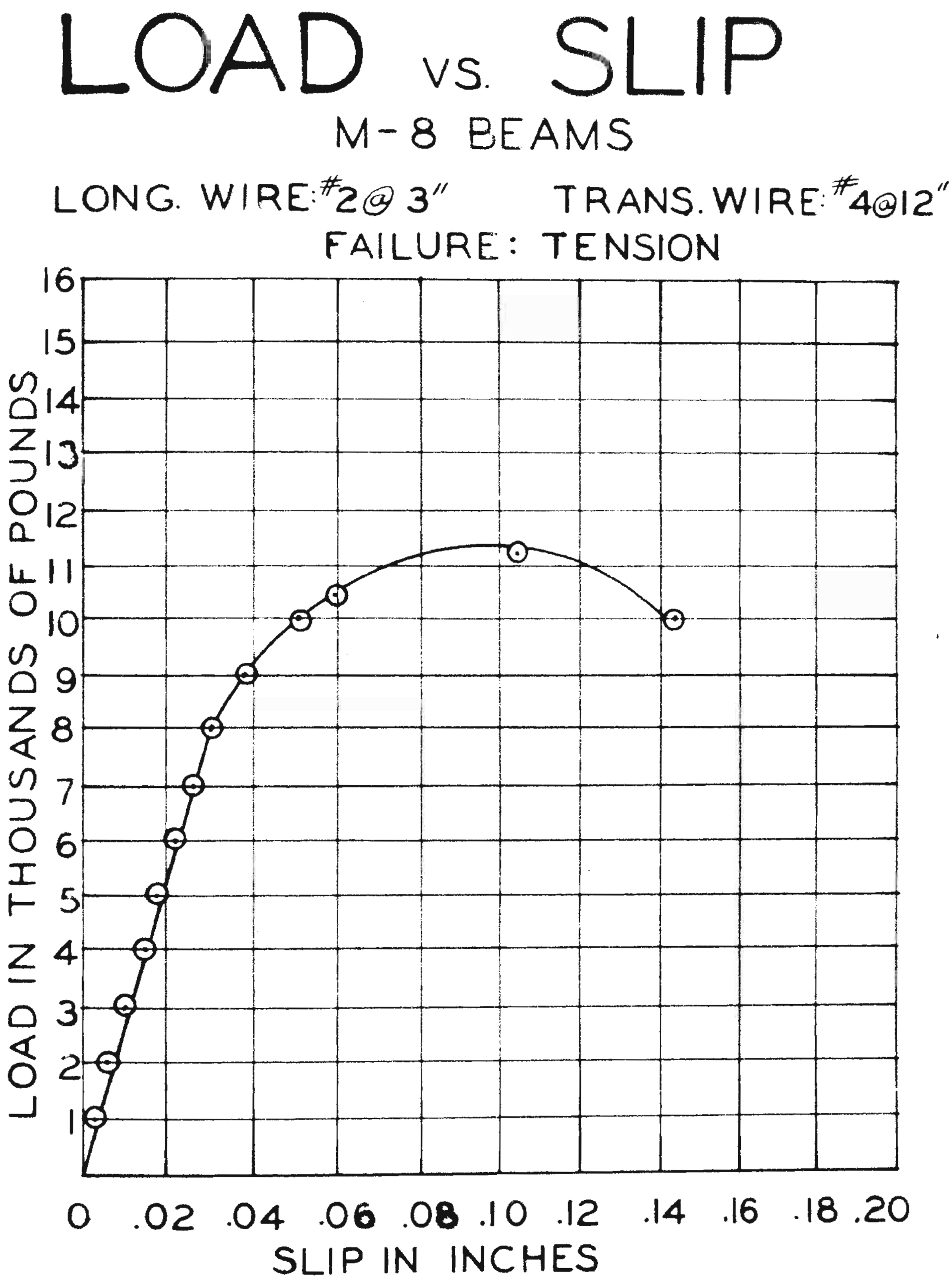

LOAD VS. SLIP
M-8 BEAMS
LONG. WIRE: #2 @ 3"
TRANS. WIRE: #4 @ 12"
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES

PLATE: 8

DATA SHEET 9

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.000	.000	.000	3080
1000	.001	.002	.0015	6160
1500	.005	.001	.0035	9240
2000	.002	.001	.0050	12300
2500	.002	.001	.0065	15400
3000	.002	.001	.0075	18500
3500	.002	.001	.0090	21600
4000	.001	.001	.0100	24700
4500	.002	.000	.0110	27800
5000	.001	.000	.0120	30900
5500	.001	.000	.0125	33900
6000	.001	.000	.0135	37000
6500	.003	.000	.0160	40200
7000	.005	.001	.0175	43200
7500	.002	.001	.0190	46200
8000	.002	.001	.0200	49300
8500	.002	.001	.0210	52400
9000	.002	.001	.0215	55500
9500	.001	.000	.0130	58600
10000	.001	.003	.0225	61700
10500	.000	.002	.0235	64800
11000	.006	.008	.0305	67900
11500	.002	.006	.0345	71000
12000	.004	.002	.0370	74000
12500	.014	.010	.0450	77100
12600	.010	.000	.0490	77700
11300	.020	.046	.0820	70000
11200	Failure by tension in long. wire			

Average Failure load 11,200 lbs.

Average Peak load 12,600 lbs.

Average Failure Stress 70,000 psi

Average Peak Stress 77,700 psi

Average Total Slip .0820 inches

Beam Series M-9 Longitudinal Wire #2 @ 3"

Transverse Wire #4 @ 12"

Average Stress represents stress in #2 long. wire

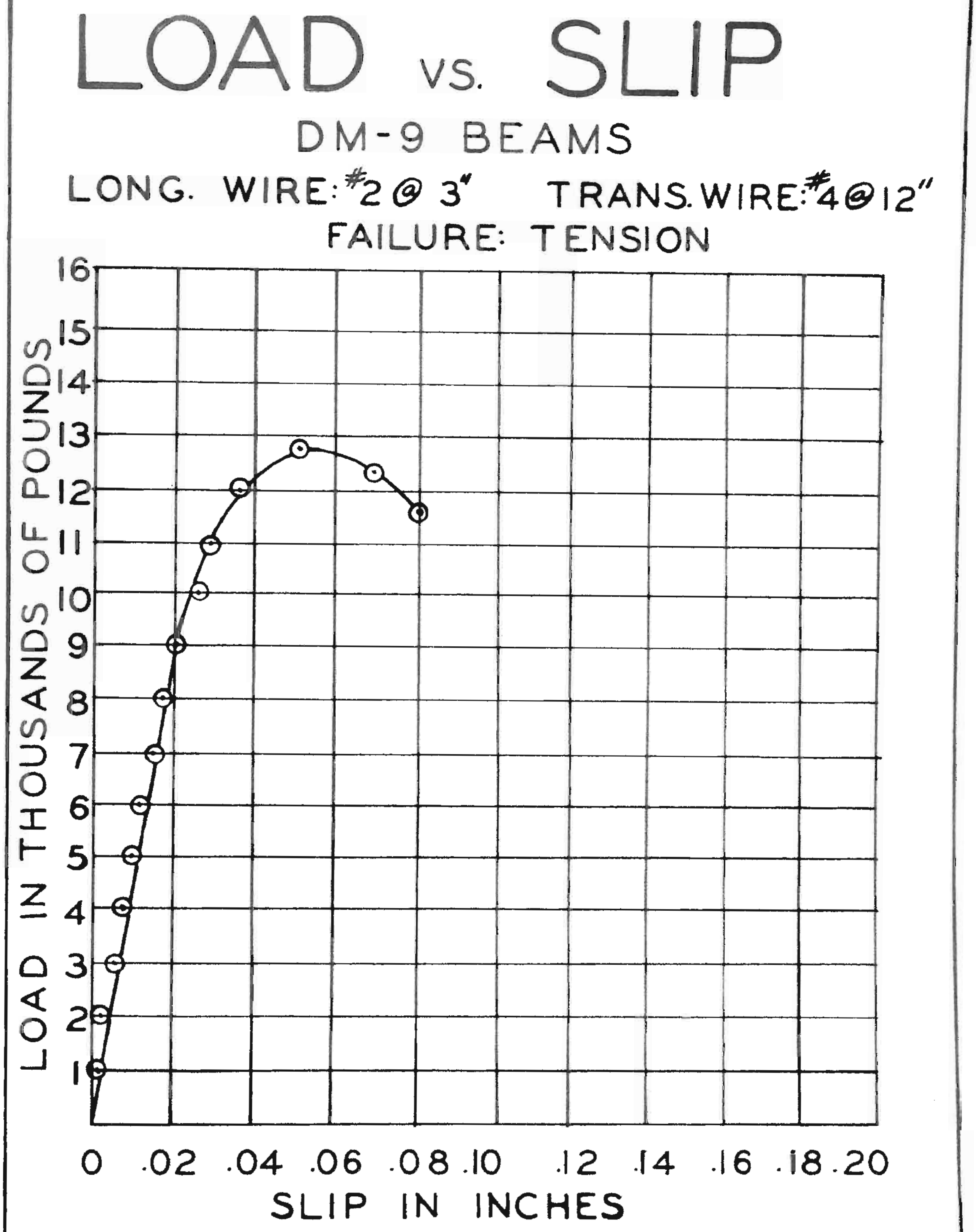

LOAD VS. SLIP
DM-9 BEAMS
LONG. WIRE: #2 @ 3"
TRANS. WIRE: #4 @ 12"
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 .02 .04 .06 .08 .10 .12 .14 .16 .18 .20
SLIP IN INCHES

PLATE : 9

DATA SHEET 10

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches		Total Slip inches	Stress psi
0	.000	.000		.000	0
500	.002	.000		.001	3080
1000	.002	.001		.002	6160
1500	.002	.001		.0035	9240
2000	.003	.001		.0045	12300
2500	.002	.001		.0070	15400
3000	.002	.001		.0085	18500
3500	.002	.001		.0100	21600
4000	.002	.000		.0110	24700
4500	.002	.001		.0120	27800
5000	.001	.000	Tens.	.0125	30900
5500	.001	.003		.0145	33900
6000	.001	.002	.0160	.0160	37000
6500	.001	.002	.0175	.0175	40200
7000	.001	.003	.0200	.0200	43200
7500	.001	.003	.0220	.0220	46200
8000	.001	.003	.0240	.0240	49300
8500	.002	.004	.0270	.0270	52400
9000	.001	.002	.0295	.0305	55500
9500	.001	.003	.0305	.0355	58600
10000	.001	.002	.0320	.0470	61700
10500	.001	.008	.0360	Break	64800
11000	.001	.004	.0380	Weld	67900
11500	.001	.005	.0410	Fail.	71000
12000	.001	.005	.0440		74000
12500	.002	.006	.0480		77100
13000	.006	.014	.0580		80200
13500	.009	.017	.0710		83300
11300	.017	.023	.0910		69900
11200	Failure by tension in long. wire				

(+) Average Failure load by weld shear (2) 10,000 lbs.

Average Failure load by tension (1) 11,300 lbs.

Average Failure Stress tension 69,900 psi

Average Peak load 13,500 lbs.

Average Peak Stress 83,300 psi

Average Total Slip (Tension) .0910 inches

Average Total Slip (Weld Shear) .047 inches

Beam Series DM-10 Long. Wire #2 @ 2" Trans. Wire #8 @ 4"

LOAD VS. SLIP

DM-10 BEAMS

LONG. WIRE #2 @ 2"   TRANS. WIRE #8 @ 4"

FAILURE: W.S. & TENSION

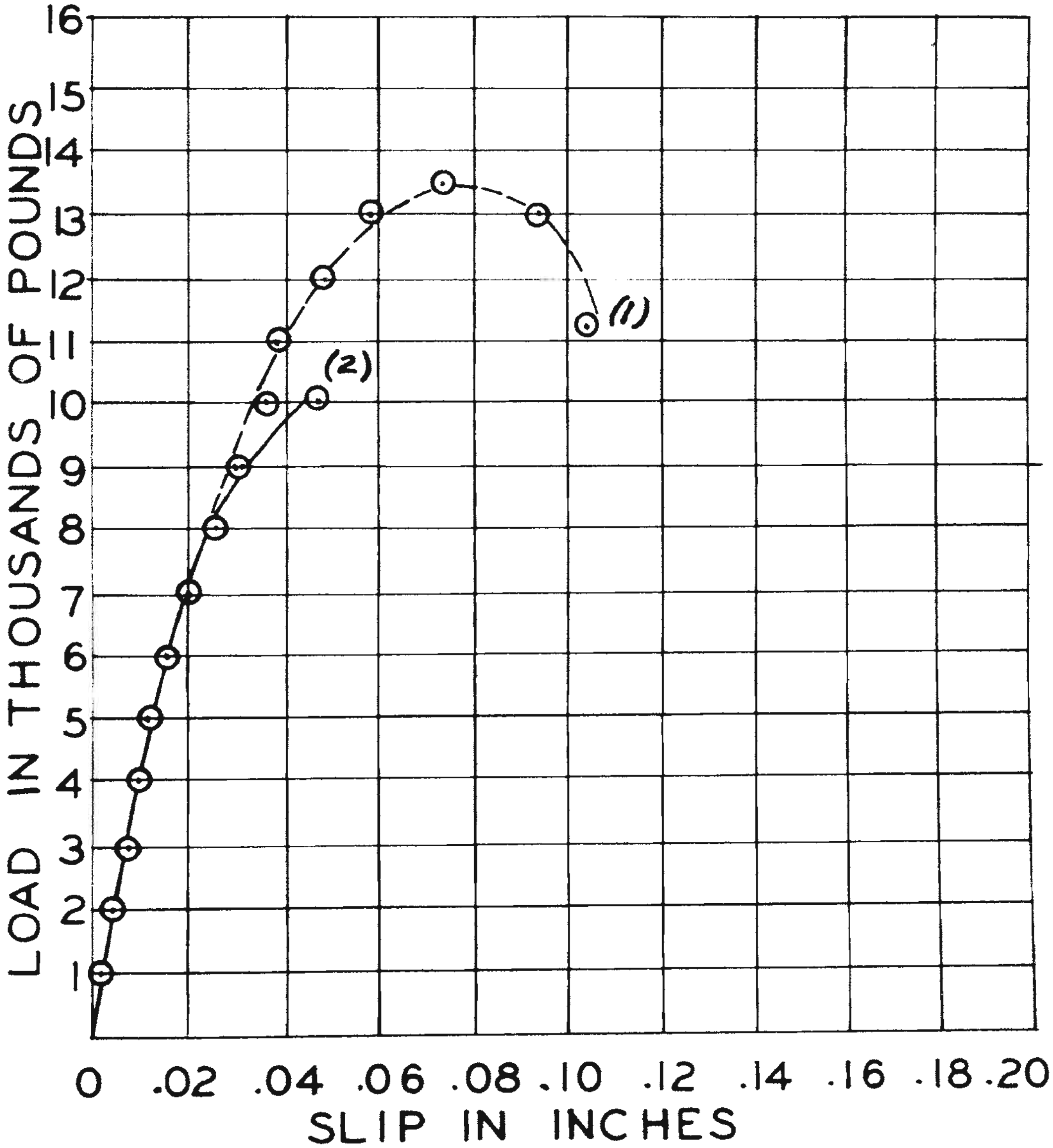


PLATE : 10

DATA SHEET 11

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.002	.002	.002	3080
1000	.002	.002	.004	6160
1500	.007	.002	.005	9240
2000	.003	.000	.006	12300
2500	.004	.000	.008	15400
3000	.002	.000	.009	18500
3500	.002	.000	.010	21600
4000	.002	.001	.0115	24700
4500	.002	.001	.0130	27000
5000	.002	.001	.0145	30900
5500	.002	.001	.0155	33900
6000	.001	.001	.0165	37000
6500	.001	.001	.0175	40200
7000	.002	.001	.0190	43200
7500	.001	.001	.0200	46200
8000	.002	.001	.0220	49300
8500	.001	.002	.0235	52400
9000	.002	.001	.0245	55500
9500	.002	.001	.0260	58600
10000	.002	.001	.0275	61700
10500	.002	.001	.0290	64800
11000	.002	.002	.0310	67900
11500	.002	.002	.0330	71000
12000	.003	.002	.0355	74000
12500	.004	.003	.0370	77100
13700	.030	.032	.0680	80200
11000	.040	.020	.0980	84600
11000	Failure by tension in long. wire			61700

Average Failure load 11,000 lbs.

Average Peak load 13,700 lbs.

Average Failure Stress 61,700 psi

Average Peak Stress 84,600 psi

Average total slip .010 inches

Beam Series DM-11 Longitudinal Wire #2 @ 4"

Transverse Wire #6 @ 6"

Average Stress represents stress in #2 long. wire

LOAD VS SLIP

DM-II BEAMS

LONG. WIRE: #2 @ 4" TRANS WIRE: #6 @ 6"

FAILURE: TENSION

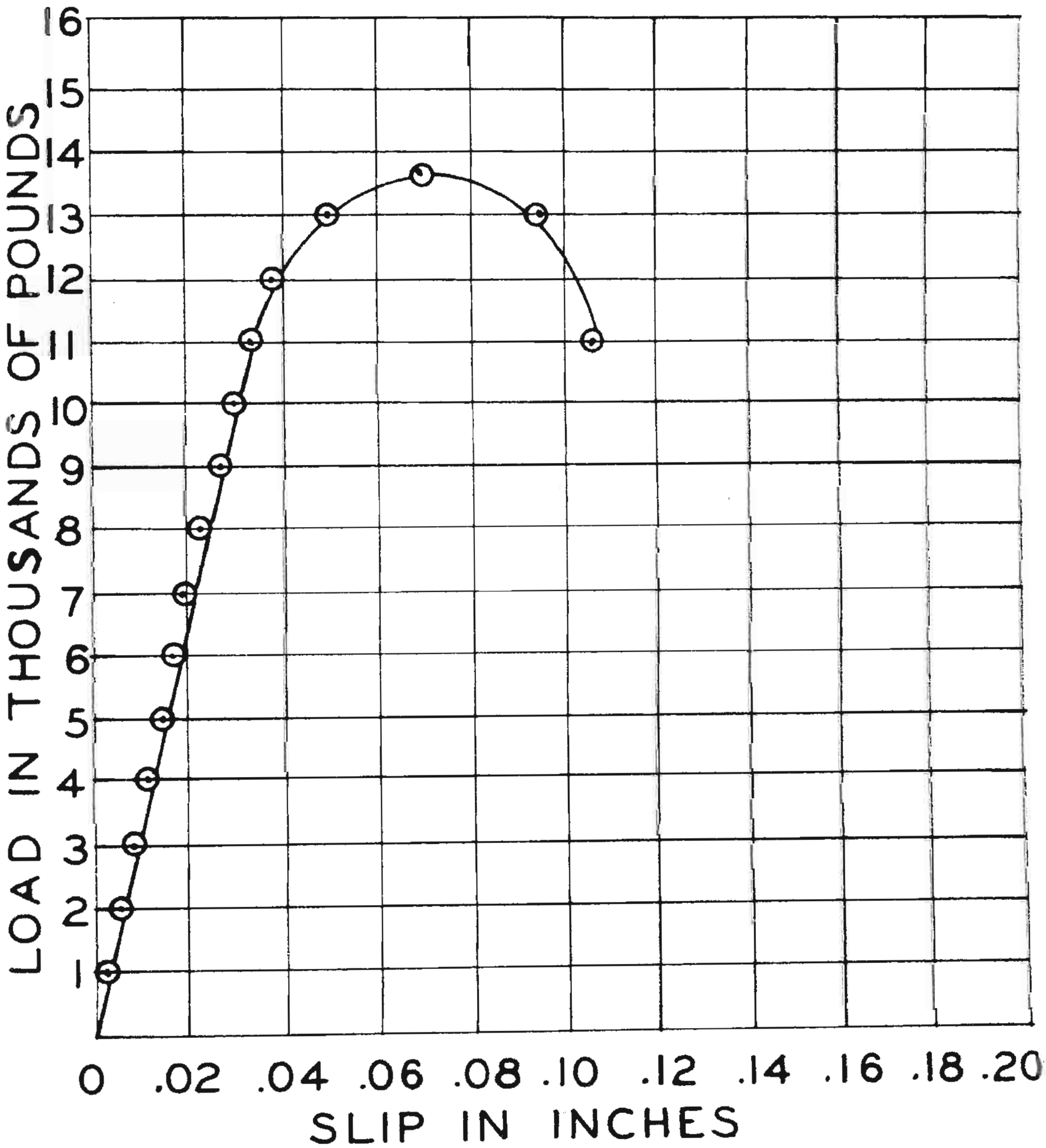


PLATE: II

DATA SHEET 12

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.000	.000	.000	3080
1000	.003	.001	.002	6160
1500	.000	.000	.002	9240
2000	.002	.001	.003	12300
2500	.001	.001	.0045	15400
3000	.001	.002	.0050	18500
3500	.001	.001	.0055	21600
4000	.001	.001	.0065	24700
4500	.001	.001	.0075	27800
5000	.001	.001	.0085	30900
5500	.002	.001	.0095	33900
6000	.001	.001	.0105	37000
6500	.003	.000	.0110	40200
7000	.001	.001	.0125	42300
7500	.002	.003	.0135	46200
8000	.002	.001	.0160	49300
8500	.002	.001	.0175	52400
9000	.003	.000	.0190	55500
9500	.002	.001	.0220	58600
10000	.003	.006	.0265	61700
10500	.002	.002	.0285	64800
11000	.004	.002	.0320	67900
11500	.002	.002	.0340	71000
12000	.006	.005	.0390	74000
12500	.011	.010	.0500	77100
11000	.041	.044	.0850	67900
11000	Failure by tension in long. wire			

Average Failure load (Tension) 11,000 lbs.

Average Peak load 12,500 lbs.

Average Failure Stress 67,900 psi

Average Peak Stress 77,100 psi

Average Total Slip .0850 inches

Beam Series DM-12 Longitudinal Wire #2 @ 2"

Transverse Wire #2 @ 6"

Average Stress represents stress in #2 long. wire

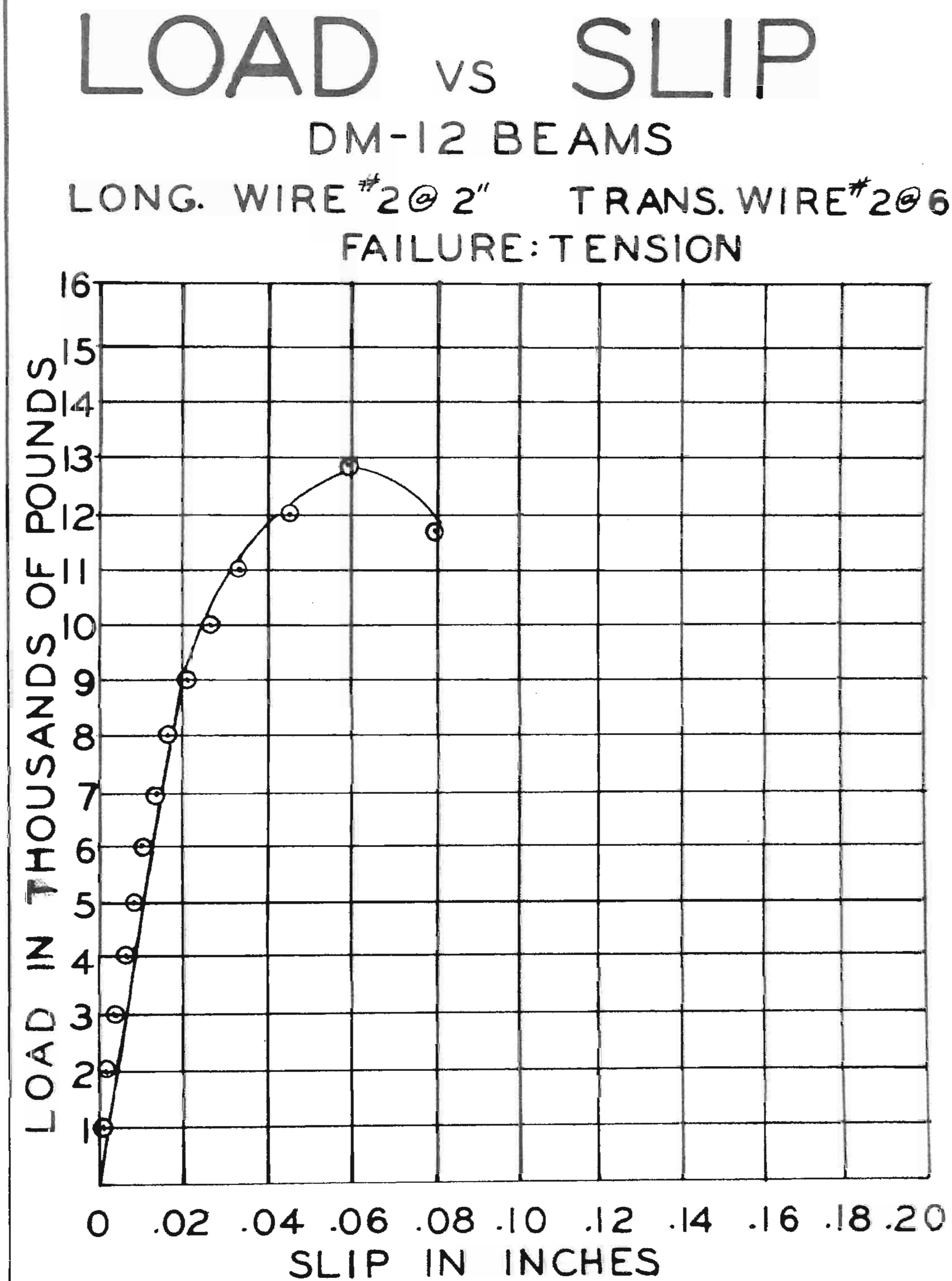

LOAD vs SLIP
DM-12 BEAMS
LONG. WIRE #2 @ 2"
TRANS. WIRE #2 @ 6
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0 .02 .04 .06 .08 .10 .12 .14 .16 .18 .20
SLIP IN INCHES

PLATE : 12

DATA SHEET 13

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.000	.000	.0000	3080
1000	.000	.000	.0000	6160
1500	.002	.000	.0010	9240
2000	.004	.002	.0020	12300
2500	.003	.001	.0030	15400
3000	.000	.001	.0040	18500
3500	.002	.000	.0050	21600
4000	.001	.000	.0060	24700
4500	.001	.000	.0070	27800
5000	,001	.001	.0080	30900
5500	.002	.000	.0090	33900
6000	.002	.000	.0100	37000
6500	.002	.001	.0115	40200
7000	.001	.001	.0125	43200
7500	.001	.001	.0135	46200
8000	.001	.002	.0150	49300
8500	.001	.002	.0165	52400
9000	.001	.003	.0185	55500
9500	.001	.002	.0200	58600
10000	.001	.002	.0215	61700
10500	.001	.002	.0230	64800
11000	.002	.001	.0250	67900
11500	.003	.000	.0265	71000
12000	.004	.003	.0300	74000
12600	.008	.011	.0395	77900
11000	.062	.022	.0715	67900
11000	Failure by tension in long. wire			

Average Failure load 11,000 lbs.

Average Peak Load 12,600 lbs.

Average Failure Stress 67,900 psi

Average Peak Stress 77,900 psi

Average Total Slip .0715 inches

Beam Series DM-13 Long. Wire #2 @ 3"

Trans. Wire #4 @ 6"

Average Stress represents stress in #2 long. wire

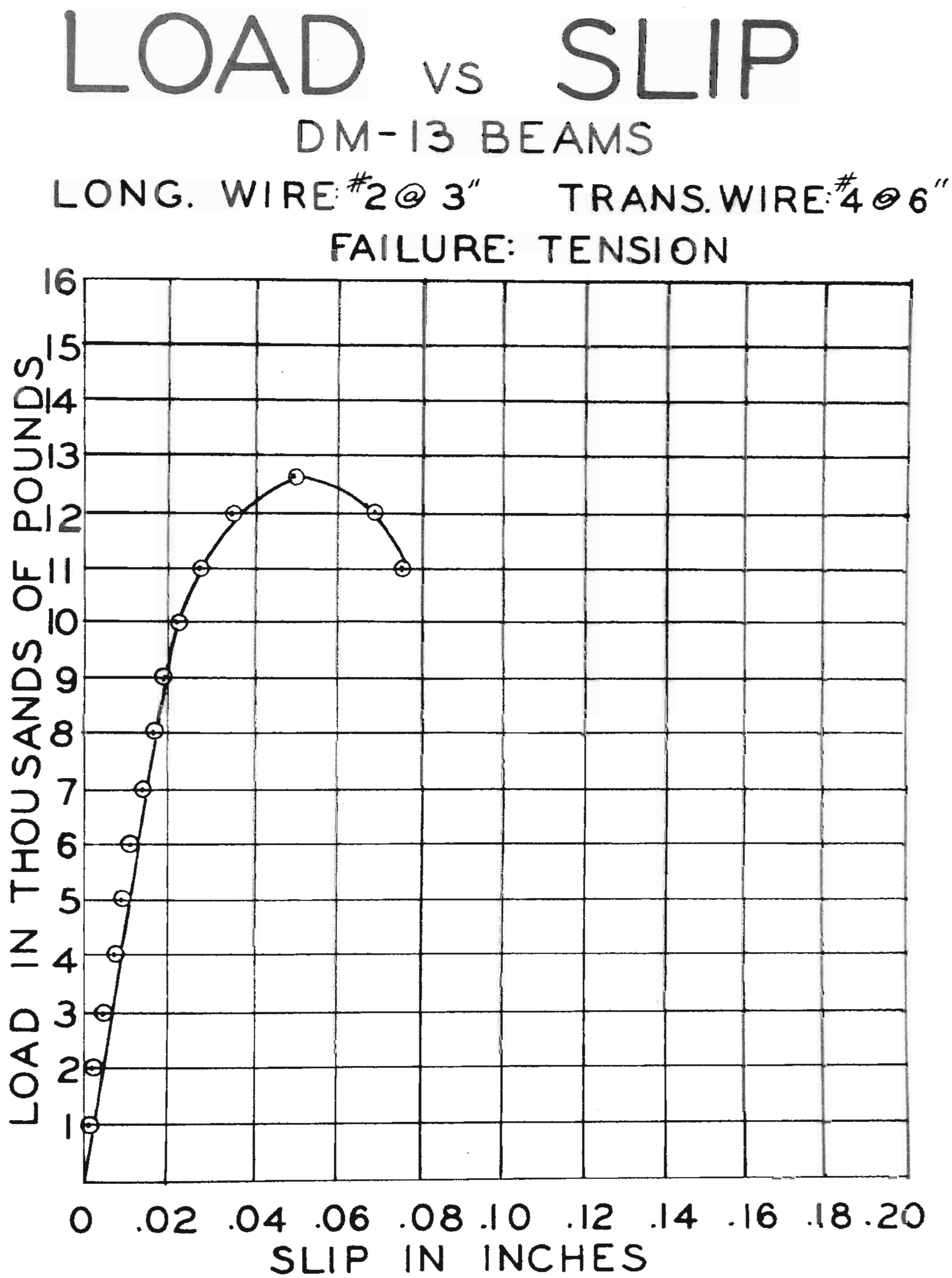

LOAD VS SLIP
DM-13 BEAMS
LONG. WIRE: #2 @ 3"
TRANS. WIRE: #4 @ 6"
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES

PLATE: 13

DATA SHEET 14

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.001	.001	.001	2900
1000	.003	.001	.003	5800
1500	.002	.002	.003	8750
2000	.003	.002	.004	11600
2500	.003	.003	.004	14500
3000	.002	.001	.005	17400
3500	.003	.000	.006	20300
4000	.001	.000	.007	23300
4500	.001	.001	.007	26100
5000	.002	.001	.009	29000
5500	.001	.003	.009	32000
6000	.000	.003	.010	34900
6500	.001	.004	.013	37800
7000	.002	.004	.015	40700
7500	.002	.003	.018	43600
8000	.002	.004	.021	46500
8500	.003	.004	.025	49400
9000	.006	.004	.028	52300
9500	.008	.004	.034	55200
10000	.006	.007	.041	58200
10100	.013	.019	.057	58700
10200	Failure by shearing of welds			

Average Failure load 10,200 lbs.

Average Total Slip .057 inches

Average Stress 59,300 psi

Beam Series OM-1 Longitudinal Wire #00 @ 6"

Transverse Wire #3 @ 6"

Average Stress represents stress in #00 long. wire

LOAD vs. SLIP

OM-1 BEAMS

LONG WIRE: #00 @ 6" TRANS. WIRE: #3 @ 6"

FAILURE: WELD SHEAR

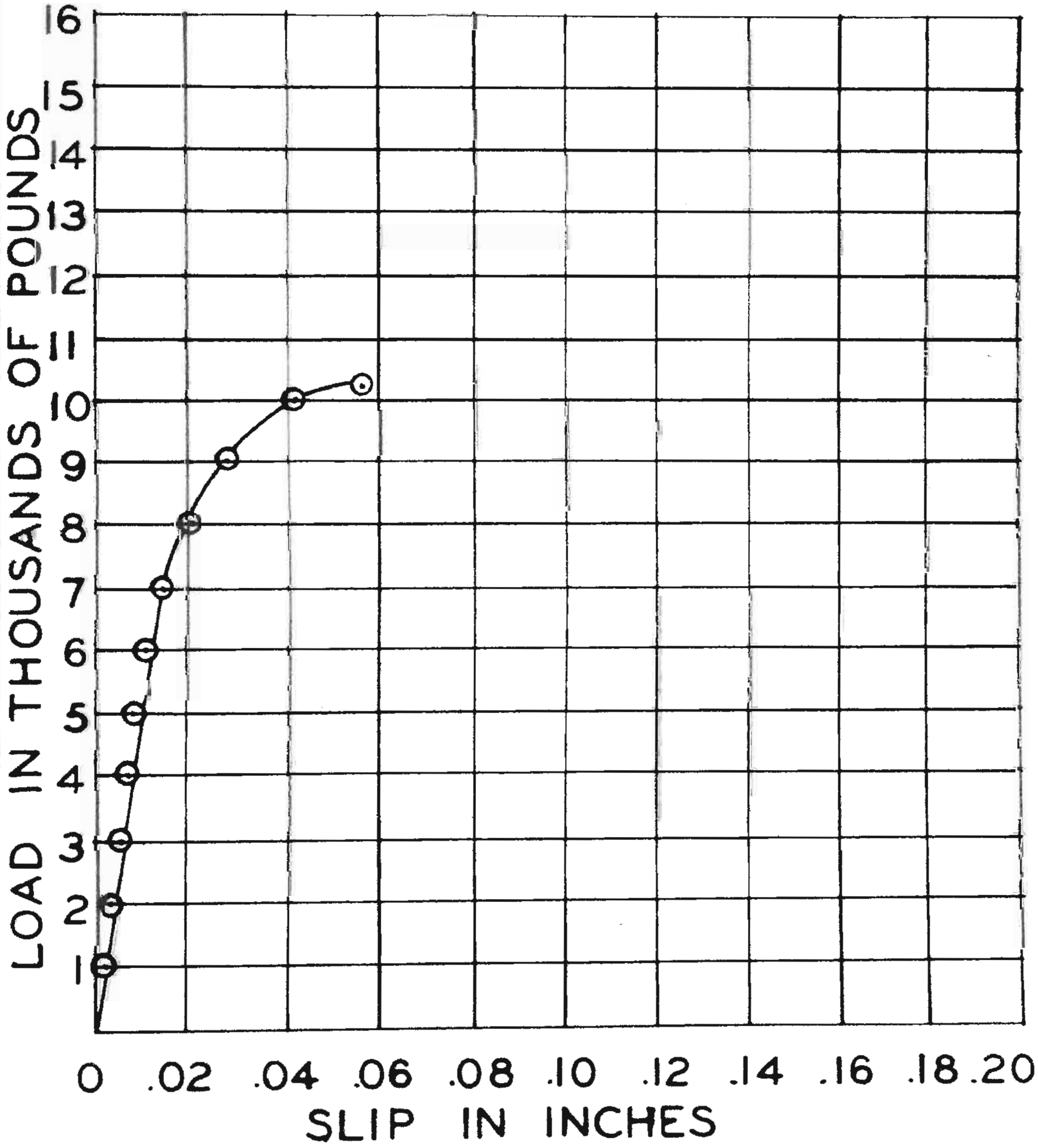


PLATE : 14

DATA SHEET 15

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.000	0
500	.001	.001	.0002	2900
1000	.001	.000	.0007	5800
1500	.004	.001	.0022	8750
2000	.003	.001	.0034	11600
2500	.002	.000	.0042	14500
3000	.001	.001	.0047	17400
3500	.001	.001	.0055	20300
4000	.001	.001	.0063	23300
4500	.002	.001	.0073	26100
5000	.001	.000	.0081	29000
5500	.001	.001	.0089	32000
6000	.002	.001	.0099	34900
6500	.002	.001	.0105	37800
7000	.003	.000	.0117	40700
7500	.002	.000	.0130	43600
8000	.001	.001	.0142	46500
8500	.002	.001	.0159	49400
9000	.002	.001	.0169	52300
9500	.001	.001	.0182	55200
10000	.003	.002	.0200	58200
10500	.002	.002	.0218	61000
11000	.002	.003	.0246	64000
11500	.002	.004	.0274	67000
12000	.010	.010	.0374	69900
12500	.012	.014	.0554	72800
12750	.019	.016	.0720	74000
10300	.038	.022	.0854	60000
10300	Failure by tension in long. wire			

Average Failure load 10,300 lbs.

Average Failure Stress 60,000 psi

Average Peak load 12,750 lbs.

Average Peak Stress 74,000 psi

Average Total Slip .0854 inches

Beam Series OM-2 Long. Wire #00 @ 6" Trans. Wire #3 @ 6"

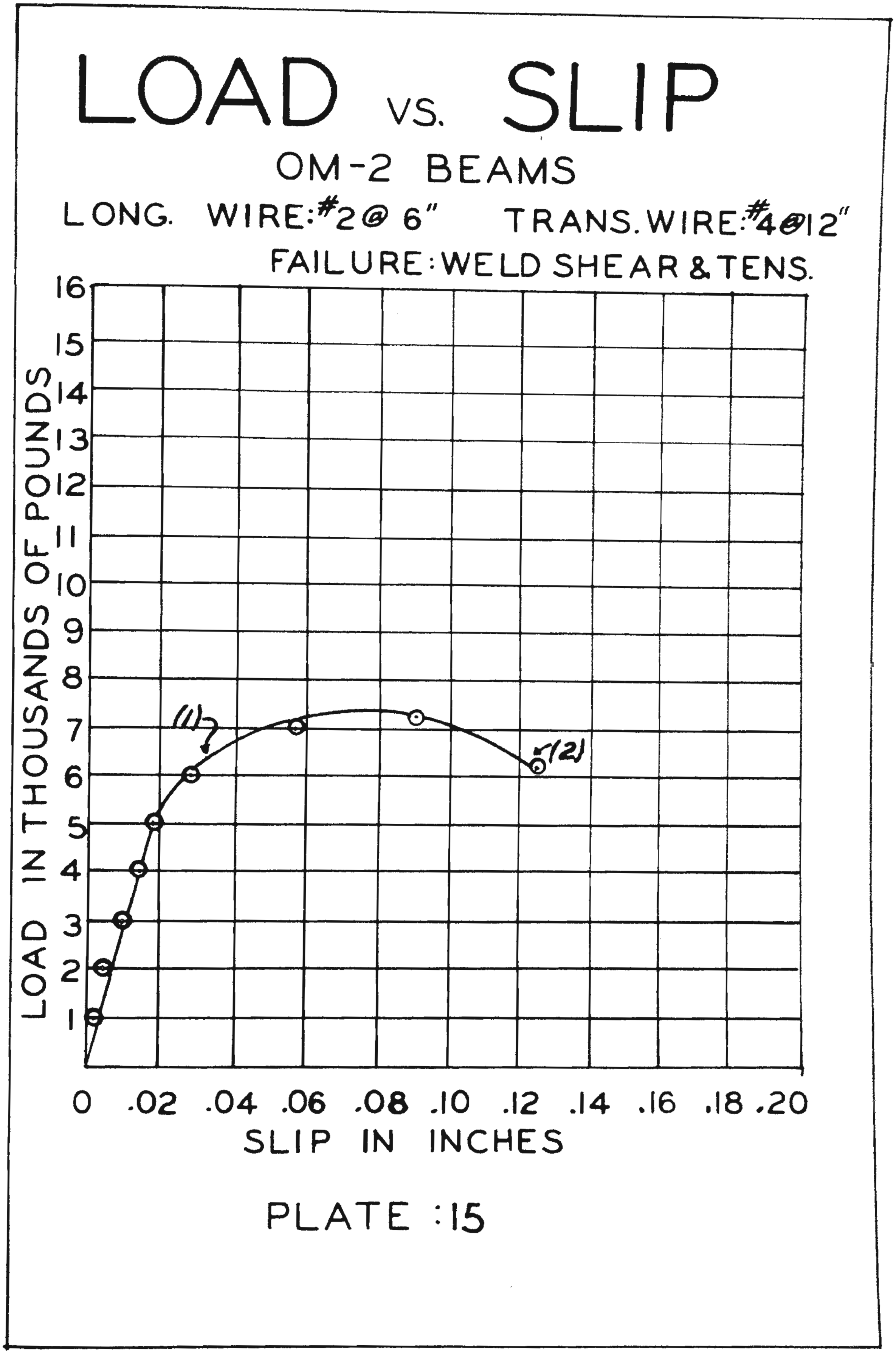

LOAD VS. SLIP
OM-2 BEAMS
LONG. WIRE: #2 @ 6"
TRANS. WIRE: #4 @ 12"
FAILURE: WELD SHEAR & TENS.
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES
(1)
(2)

PLATE : 15

DATA SHEET 16

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches		W.Dial Slip inches	Total Slip inches	Stress psi
0	.000		.000	.0000	0
500	.004		.001	.0015	4630
1000	.005		.001	.0035	9260
1500	.003		.001	.0055	13900
2000	.002		.001	.0070	18500
2500	.003		.001	.0090	23100
3000	.001		.003	.0110	27800
3500	.001		.001	.0120	32400
4000	.003		.002	.0140	37100
4500	.003		.001	.0165	41600
5000	.003		.002	.0190	46200
5500	.005		.003	.0230	51100
6000	.007	Weld	.005	.0290	55600
6500	.012	- Shear -	.008	.0390	60200
7000	.019	(1)	.018	.0580	64900
7300	.035		.032	.0920	67700
6400	.028		.038	.1250	59300
6400	Failure by tension in long. wire (2)				

Average Failure load tension 6400 lbs.

Average Failure load weld shear 6500 lbs.

Average Peak Load tension 7300 lbs.

Average Failure Stress tension 59,300 psi

Average Peak Stress tension 67,700 psi

Average Failure Stress weld shear 60,200 psi

Average Total Slip .1250 (T) .0390 (W.S.)

Beam Series DOM-2 Long. Wire #2 @ 6" Trans. Wire #4 @ 12"

Average Stress represents stress in #2 long. wire

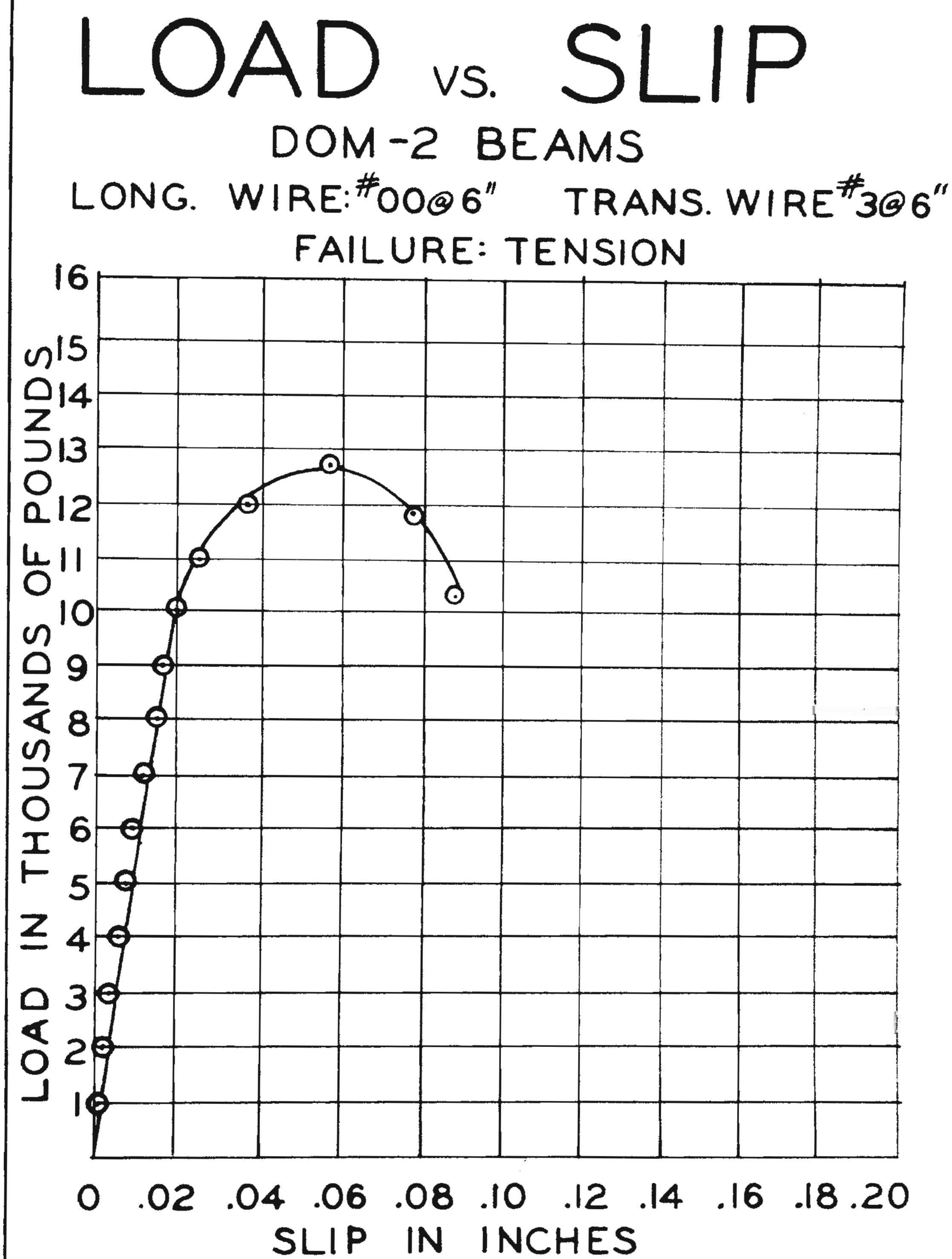

LOAD VS. SLIP
DOM-2 BEAMS
LONG. WIRE: #00@6"
TRANS. WIRE #3@6"
FAILURE: TENSION
LOAD IN THOUSANDS OF POUNDS
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
SLIP IN INCHES

PLATE :16

DATA SHEET 17

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.002	.000	.0010	4630
1000	.002	.001	.0010	9260
1500	.005	.000	.0015	13900
2000	.003	.001	.0020	18500
2500	.003	.001	.0027	23100
3000	.002	.000	.0032	27800
3500	.002	.001	.0042	32400
4000	.001	.002	.0055	37100
4500	.001	.002	.0070	41600
5000	.002	.001	.0095	46200
5500	.001	.002	.0107	51100
6000	.002	.002	.0129	55600
6500	.003	.003	.0159	60200
7000	.002	.002	.0184	64900
7500	.003	.003	.0217	69400
8000	.007	.007	.0285	74000
8200	.011	.009	.0385	76000
7100	.024	.017	.0585	65700
7100	Failure by tension in long. wire			

Average Failure Load 65,700 lbs. per sq. in.

Average Peak Load 8200 lbs.

Average Failure Stress 65,700 psi

Average Peak Stress 76,000 psi

Average Total Slip .0585 inches

Beam Series DOM-3 Long. Wire #2 @ 6"

Trans. Wire #4 @ 12"

Average Stress represents stress in #2 long. wire

LOAD VS. SLIP

DOM-3 BEAMS

LONG. WIRE: #2 @ 6"   TRANS. WIRE: #4 @ 12"

FAILURE: TENSION

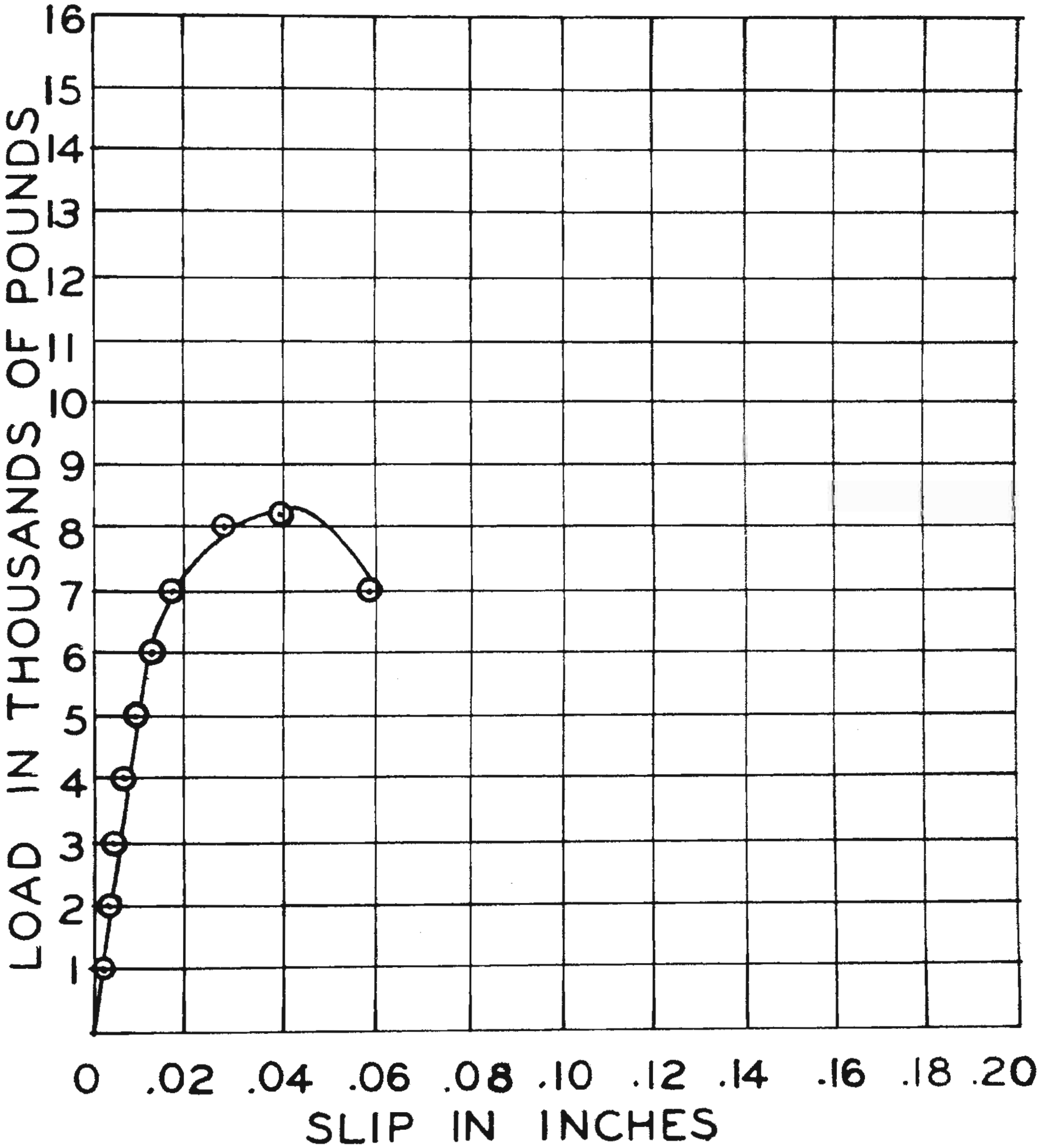


PLATE : 17

DATA SHEET 18

Investigation of Anchorage for 3/8" Round Reinforcing Bars

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
1000	.000	.000	.0000	4550
2000	.000	.001	.0005	9100
3000	.001	.001	.0015	13600
4000	.002	.001	.0030	18100
5000	.001	.001	.0040	22700
6000	.002	.001	.0055	27300
7000	.002	.001	.0070	31800
8000	.001	.002	.0085	36400
9000	.001	.001	.0095	41000
10000	.002	.001	.0115	45500
11000	.004	.001	.0140	50000
12000	.001	.001	.0150	54500
13000	.002	.002	.0170	59050
14000	.002	.002	.0195	63600
15000	.003	.003	.0225	68200
16000	.004	.005	.0270	72800
17000	.009	.012	.0375	77200
18000	.011	.013	.0495	81900
19000	.016	.017	.0660	86500
20000	.015	.021	.0835	91000
21000	.014	.015	.0980	95500
22000	.013	.014	.1115	100000
23000	.021	.021	.1330	104500
24000	.020	.020	.1530	109000

Failure by shearing of concrete block

Average Failure Load 24,000 lbs.

Average Failure Stress 109,000 psi

Average Total Slip .1530 inches

Failure by direct shear of concrete block

Beam Series C-1-2 Reinforcement: 3/8" Round Rods

DATA SHEET 19

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.000	.000	.0000	2310
1000	.002	.000	.0010	4620
1500	.002	.001	.0020	6950
2000	.001	.000	.0025	9250
2500	.002	.000	.0040	11600
3000	.003	.001	.0055	13900
3500	.002	.000	.0065	16200
4000	.002	.002	.0085	19400
4500	.002	.001	.0100	20800
5000	.001	.000	.0105	23100
5500	.002	.000	.0115	25500
6000	.002	.001	.0130	27800
6500	.001	.001	.0140	30000
7000	.002	.000	.0150	32400
7500	.001	.001	.0160	34700
8000	.001	.001	.0170	37000
8500	.001	.002	.0185	39300
9000	.002	.000	.0195	41700
9500	.001	.001	.0205	44000
10000	.002	.000	.0215	46300
10500	.001	.001	.0225	48600
11000	.001	.001	.0235	51000
11500	.001	.001	.0245	53300
12000	.003	.000	.0260	55600
12500	.002	.002	.0280	57900
13000	.002	.001	.0295	60200
13500	.002	.002	.0315	62500
14000	.002	.001	.0330	64800
14500	.002	.002	.0350	67100
15000	.003	.002	.0370	69500
15500	.003	.003	.0405	71800
16000	.007	.004	.0450	74000
16500	.005	.006	.0515	76300
17000	.014	.015	.0660	78800
15000	.054	.065	.1260	69500
15000	Failure by tension in long. wire			

Average Fail. Load 15,000 lbs. Stress 69,500 psi

Average Total Slip .1260 in.

Beam Series C-3-4 Long. Wire #2 @ 3" Trans. Wire #2 @ 6"

DATA SHEET 19-A (20)

Investigation of Anchorage For Welded Wire Reinforcement Fabric

Load in lbs.	E.Dial Slip inches	W.Dial Slip inches	Total Slip inches	Stress psi
0	.000	.000	.0000	0
500	.000	.001	.0005	2310
1000	.001	.000	.0010	4620
1500	.000	.000	.0015	6950
2000	.001	.000	.0015	9250
2500	.002	.000	.0020	11600
3000	.001	.000	.0030	13900
3500	.001	.001	.0040	16200
4000	.000	.001	.0045	19400
4500	.001	.001	.0055	20800
5000	.000	.000	.0055	23100
5500	.001	.001	.0065	25500
6000	.001	.000	.0070	27800
6500	.000	.002	.0080	30000
7000	.000	.001	.0085	32400
7500	.000	.001	.0090	34700
8000	.001	.001	.0100	37000
8500	.000	.001	.0105	39300
9000	.001	.001	.0115	41700
9500	.001	.001	.0125	44000
10000	.001	.001	.0135	46300
10500	.001	.001	.0145	48600
11000	.001	.000	.0150	51000
11500	.001	.001	.0160	53300
12000	.002	.001	.0175	55600
12500	.001	.001	.0185	57900
13000	.002	.001	.0200	60200
13500	.001	.002	.0220	62500
14000	.002	.001	.0235	64800
14500	.002	.002	.0255	67100
15000	.002	.002	.0265	69500
15500	.002	.001	.0280	71800
16000	.002	.003	.0305	74000
16800	.011	.014	.0425	77700
15700	.008	.010	.0515	72500
15700	Failure by tension in long. wire			

Average Failure Load 15,700 lbs. Stress 72,500 psi

Average Total Slip 0.0515 inches

Beam Series C-5-6 Long. Wire #2 @ 3" Trans. Wire #2 @ 4"

LOAD VS. SLIP

COMPARISON GRAPHS

M-I BEAMS & BEAM TESTS BY E. A. WEINEL

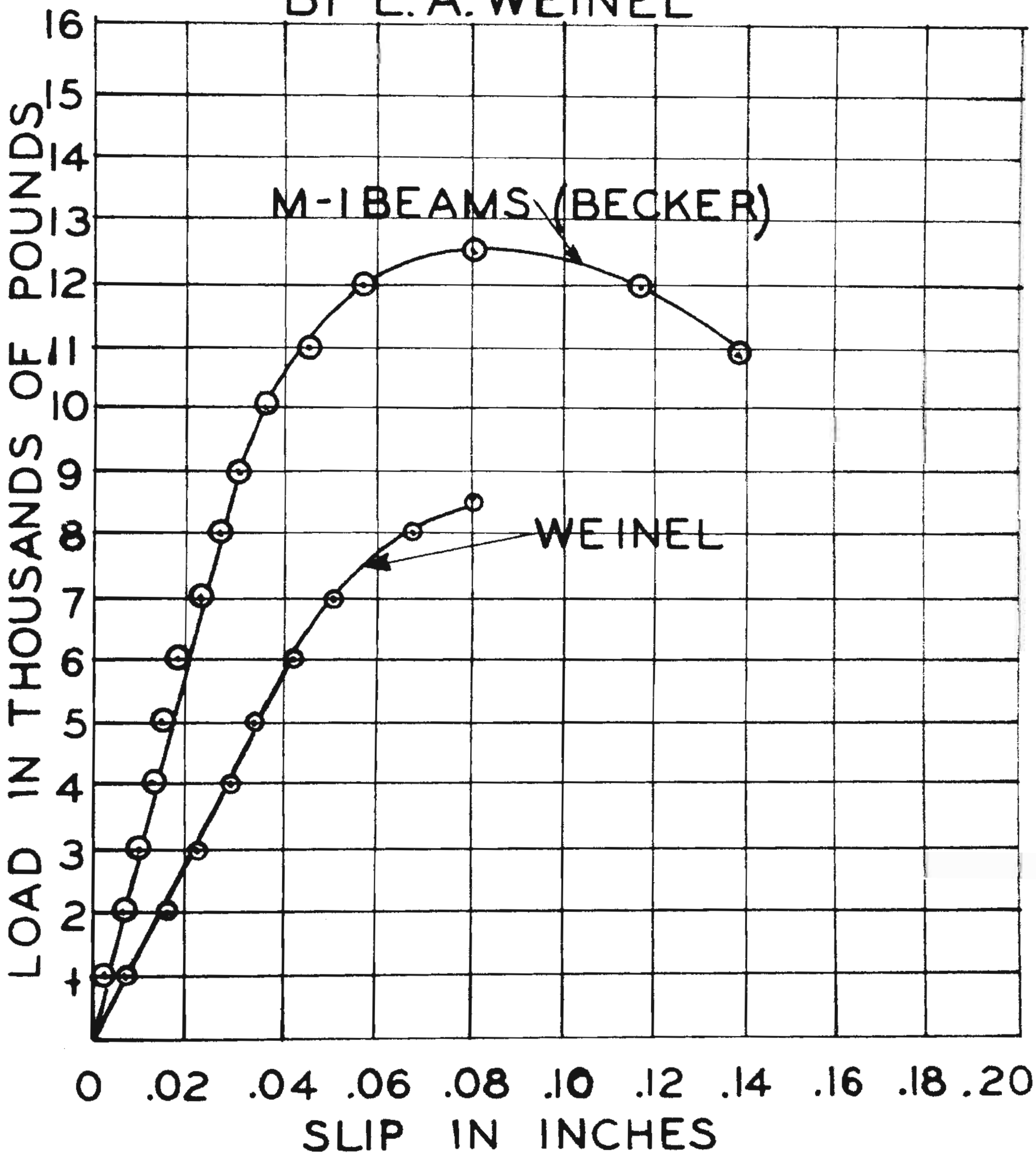


PLATE :18

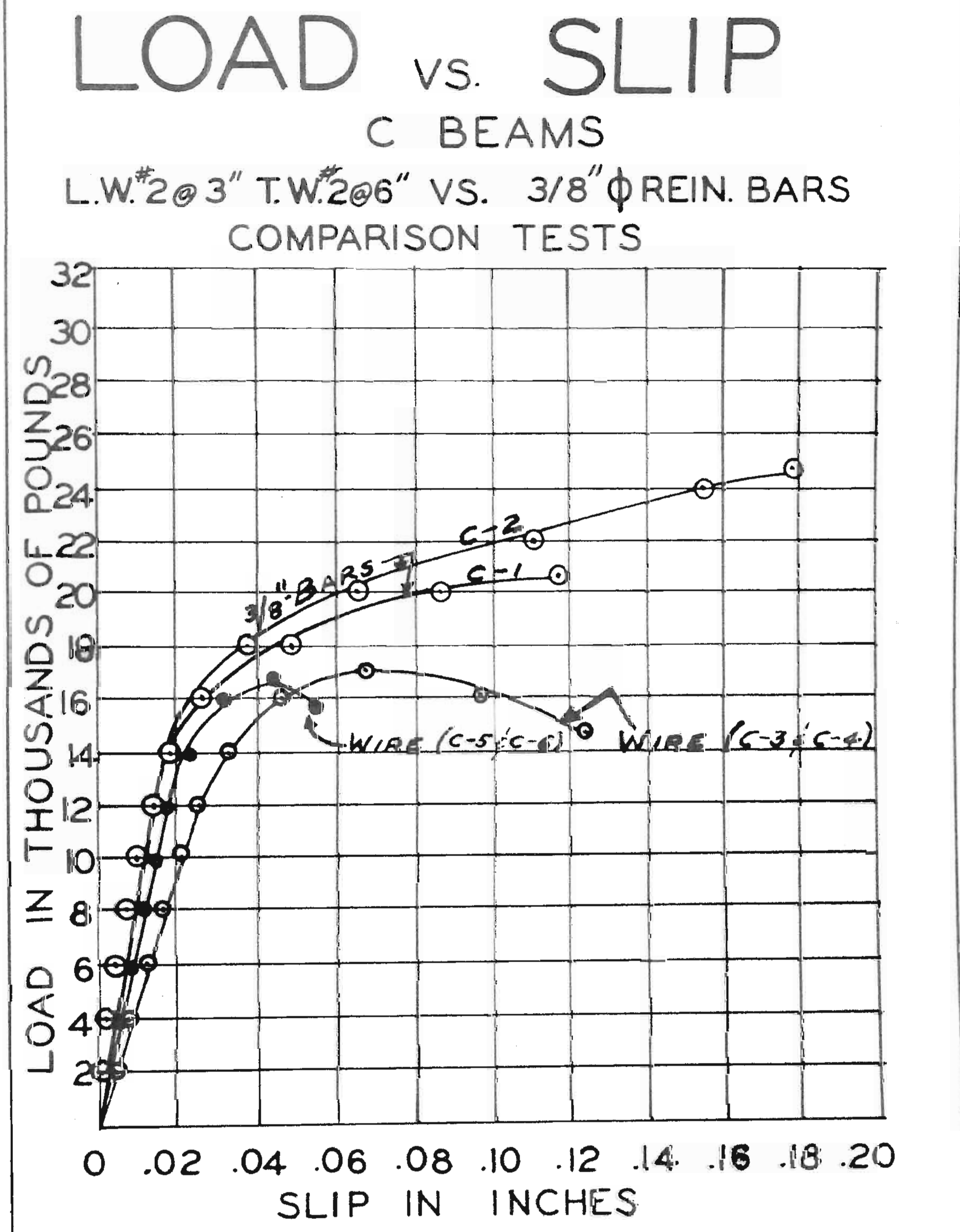
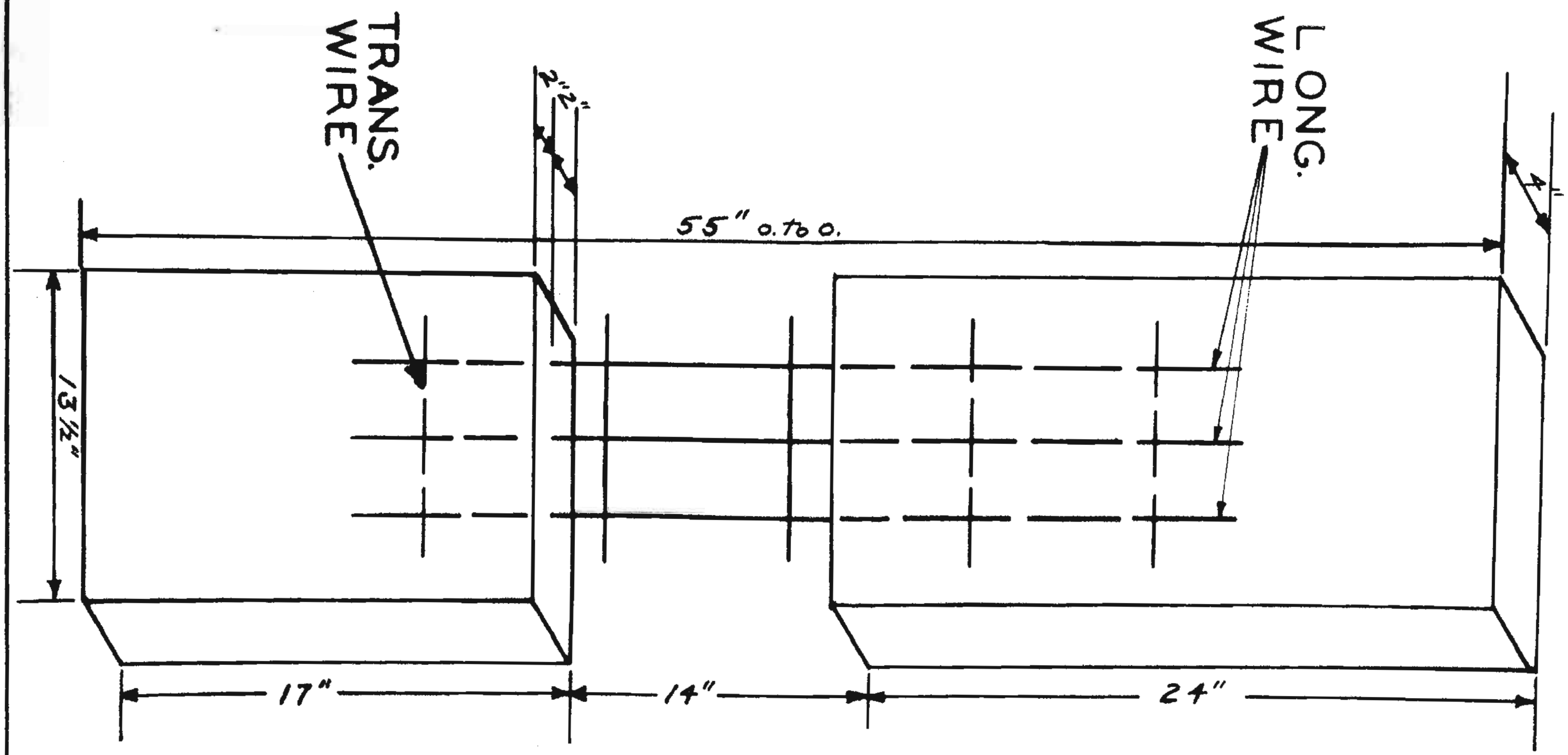

LOAD VS. SLIP
C BEAMS
L.W.#2 @ 3" T.W.#2 @ 6" VS. 3/8" ϕ REIN. BARS
COMPARISON TESTS
LOAD IN THOUSANDS OF POUNDS
SLIP IN INCHES
3/8" BARS
C-2
C-1
WIRE (C-5 & C-6)
WIRE (C-3 & C-4)
0 .02 .04 .06 .08 .10 .12 .14 .16 .18 .20
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

PLATE : 19

SUMMARY OF TESTS AND RESULTS

BEAMS	LONG.WIRE	TRS. WIRE	FAILURE	YIELD LOAD	YLD.STRESS	YIELD SLIP	FAIL. LOAD	FAIL.STRESS	FAIL.SLIP	REMARKS
M-2	#2@2″	#2@6″	TENS.	9500 LBS	58600 PSI	0.0405 IN	11350 LBS	70050 PSI	0.157 IN.	
DM-12	#2@2″	#2@6″	"	9500	58600	0.0220	11000	67900	0.085	
M-3	#2@3″	#4@6″	"	9000	55500	0.0380	10300	63800	0.1645	
DM-13	#2@3″	#4@6″	"	10000	61700	0.0215	11000	67900	0.0715	
M-8	#2@3″	#4@12″	"	8500	52400	0.0340	10000	61700	0.1425	
DM-9	#2@3″	#4@12″	"	10500	64800	0.0235	11300	70000	0.0820	1 WELD FAIL. 1 TENS. FAIL.
M-1	#2@4″	#6@6″	TENS. + W.S.	10000	61700	0.0355	10800	66700	0.1390	
DM-11	#2@4″	#6@6″	TENS.	11500	71000	0.0330	11000	67900	0.0980	2 TENS. FAIL. 1 WELD FAIL.
M-5	#2@3″	#6@12″	TENS.+W.S.	8000	49300	0.0435	9900	61200	0.1465	
M-4	#2@2″	#8@4″	WELD SHEAR	5000	30900	0.0340	5640	37000	0.0485	
DM-10	#2@2″	#8@4″	W.S. + TENS.	7000	43200	0.0200	10000	61700	0.0470	2 WELD FAIL. 1 TENS. FAIL.
				11000	67900	0.0380	11200	699[illegible]	0.0910	
M-7	#2@2″	#8@8″	W.S.	3500	21600	0.0185	4530	28000	0.0355	
M-6	#2@4″	#8@12″	"	5000	30900	0.0295	6580	40600	0.0565	
OM-1	#00@6″	#3@6″	"	7500	43600	0.0180	10200	59400	0.0570	ONLY TWO LONG. WIRES
DOM-2	#00@6″	#3@6″	TENS.	10500	64800	0.0218	10300	63600	0.0854	"
OM-2	#2@6″	#4@12″	"	5500	51100	0.0230	6400	59300	0.1250	"
DOM-3	#2@6″	#4@12″	"	7000	64900	0.0184	7100	65700	0.0585	"
C-1	2-3/8″ BARS	—	CONC. SHEAR	15000	68200	0.0225	24000	109000	0.1530	RE-ROLLED RAIL STEEL
C-2	#2@3	#2@6″	TENS.	13500	62500	0.0315	15000	69500	0.1260	4 LONG WIRES



ISOMETRIC VIEW SHOWING LOCATION OF WIRE
AND DIMENSIONS FOR A TYPICAL M-SERIES BEAM.
ONE MORE TRANSVERSE WIRE PLACED IN EACH SECTION
OF DM SERIES BEAMS

TABLE 21

Investigation of Bond by Direct Pull Out Test for Plain Wire and Wire With Two-Week and Four-Week Rust

Wire Guage	Bond Area	Surface Condition	Length Embedded	Ultimate Bond Failure Lbs.	Unit Bond psi
No.00	6.296	Plain	6"	1470	234
"	8.394	"	8"	1640	196
"	12.592	"	12"	2550	203
No.00	6.296	Two wk. rust	6"	3293	524
"	8.394	"	8"	3533	421
"	12.592	"	12"	4750	378
No.00	6.296	Four-wk.rust	6"	2780	443
"	8.394	"	8"	3255	388
"	12.592	"	12"	3487	277
No. 2	4.939	Plain	6"	1380	280
"	6.585	"	8"	1410	214
"	9.877	"	12"	1810	183
No. 2	4.939	Two-wk.rust	6"	2172	441
"	6.585	"	8"	2360	345
"	9.877	"	12"	3275	331
No. 2	4.939	Four-wk.rust	6"	1783	362
"	6.585	"	8"	2258	343
"	9.877	"	12"	2568	260
No. 6	3.619	Plain	6"	1170	323
"	4.826	"	8"	1240	257
"	7.283	"	12"	1670	231
No. 6	3.619	Two-wk. rust	6"	1922	532
"	4.826	"	8"	1956	405
"	7.283	"	12"	2380 **	327
No. 6	3.619	Four-wk.rust	6"	1363	377
"	4.826	"	8"	1785	370
"	7.283	"	12"	2182 **	300
No. 10	2.526	Plain	6"	630	249
"	3.368	"	8"	760	225
"	5.052	"	12"	1120	222
No. 10	2.526	Two wk.rust	6"	963	380
"	3.368	"	8"	1025	306
"	5.052	"	12"	All tension breaks	
No. 10	2.526	Four-wk.rust	6"	285	113
"	3.368	"	8"	755	224
"	5.052	"	12"	1125	222

** Two wires broke in tension

TABLE 22

Pull Out Test for Bond Stress on Wire With Two-Week Rust

Wire Guage	Embed.	Ultimate Bond Failure Lbs.	Avr. Ult. Bond Failure lbs.	Unit Bond psi
No. 00	12"	4730		
"	"	4640		
"	"	4900	4750	383
No. 00	8"	3510		
"	"	3300		
"	"	3790	3533	421
No. 00	6"	3430		
"	"	3330		
"	"	3120	3293	524
No. 2	12"	3315		
"	"	3760		
"	"	2750	3275	331
No. 2	8"	2320		
"	"	2350		
"	"	2410	2360	345
No. 2	6"	2525		
"	"	1800		
"	"	2190	2172	441
No. 6	12"	2380		
"	"	*2470		
"	"	*2440	2380	327
No. 6	8"	1975		
"	"	1790		
"	"	2110	1958	405
No. 6	6"	2050		
"	"	1840		
"	"	1875	1922	532
No. 10	12"	*1110		
"	"	*1105		
"	"	*1040	All tension breaks	
No. 10	8"	1130		
"	"	*1155		
"	"	940	1035	308
No. 10	6"	1065		
"	"	1120		
"	"	700	962	380

* Tension Breaks

TABLE 23

Pull Out Test for Bond Stress on Wire With Four-Week Rust

Wire Guage	Embed.	Ultimate Bond Failure lbs.	Avr. Ult. Bond Failure lbs.	Unit Bond psi
No. 00	12"	4200		
"	"	3125		
"	"	3135	3487	277
No. 00	8"	3310		
"	"	3200		
"	"	None	3255	388
No. 00	6"	2840		
"	"	2490		
"	"	3010	2780	443
No. 2	12"	2345		
"	"	3110		
"	"	2250	2568	260
No. 2	8"	3050		
"	"	1500		
"	"	2225	2258	343
No. 2	6"	1620		
"	"	1950		
"	"	1780	1783	362
No. 6	12"	2360		
"	"	1860		
"	"	2325	2182	300
No. 6	8"	2250		
"	"	1425		
"	"	1680	1785	370
No. 6	6"	1690		
"	"	1440		
"	"	960	1363	377
No. 10	12"	*1150		
"	"	1125		
"	"	*1250	1125	222
No. 10	8"	750		
"	"	715		
"	"	800	755	224
No. 10	6"	290		
"	"	415		
"	"	150	285	113

* Tension Breaks

Explanation of Symbols on Bar Graphs

P---Beneath each graph represents plain wire tested

2---Beneath each graph represents two-week rust wire tested

4---Beneath each graph represents four-week rust wire tested

Lengths of wire embedded are given as 6", 8", and 12",
grouped by arrows in each case

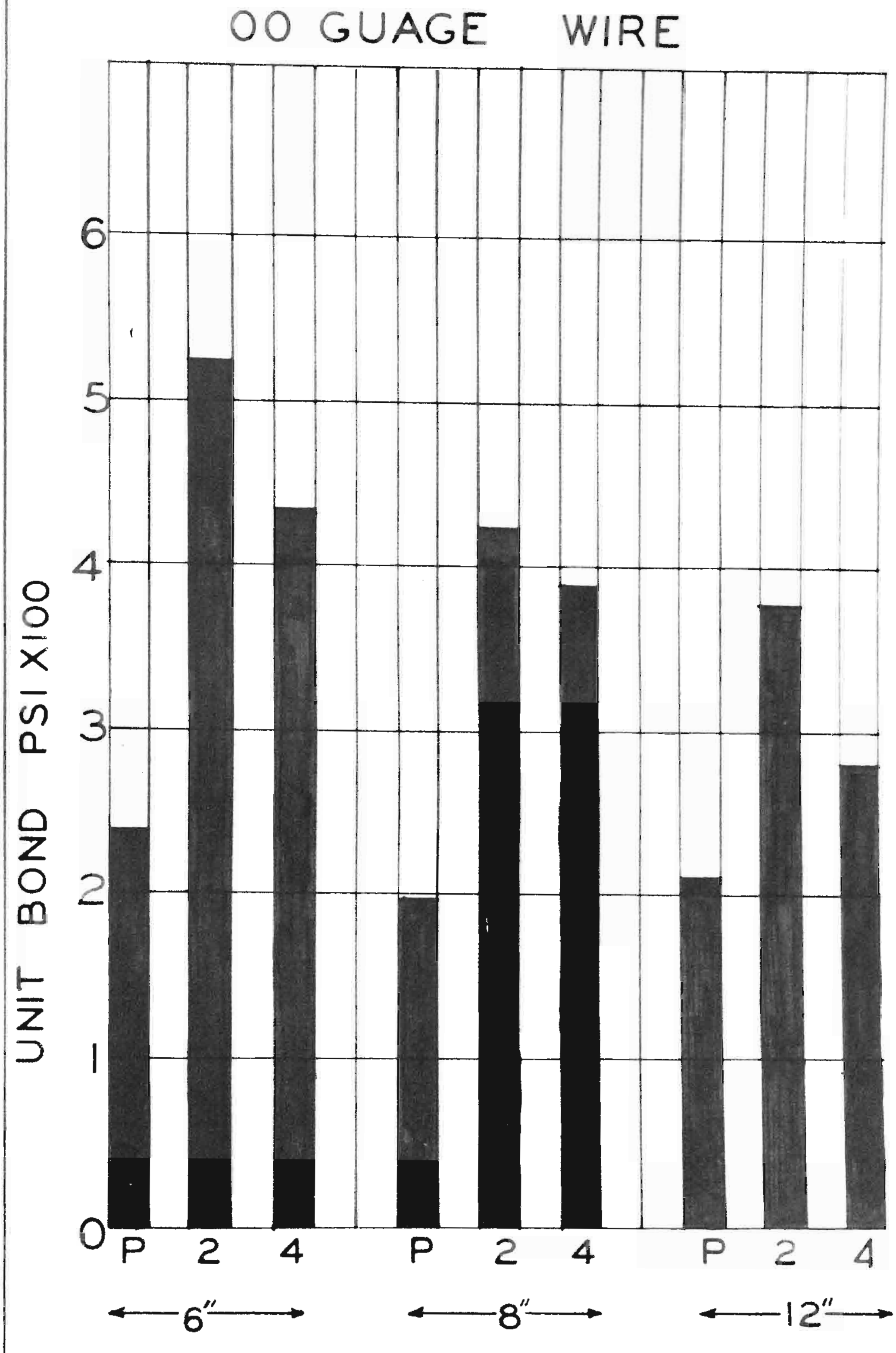


PLATE 20

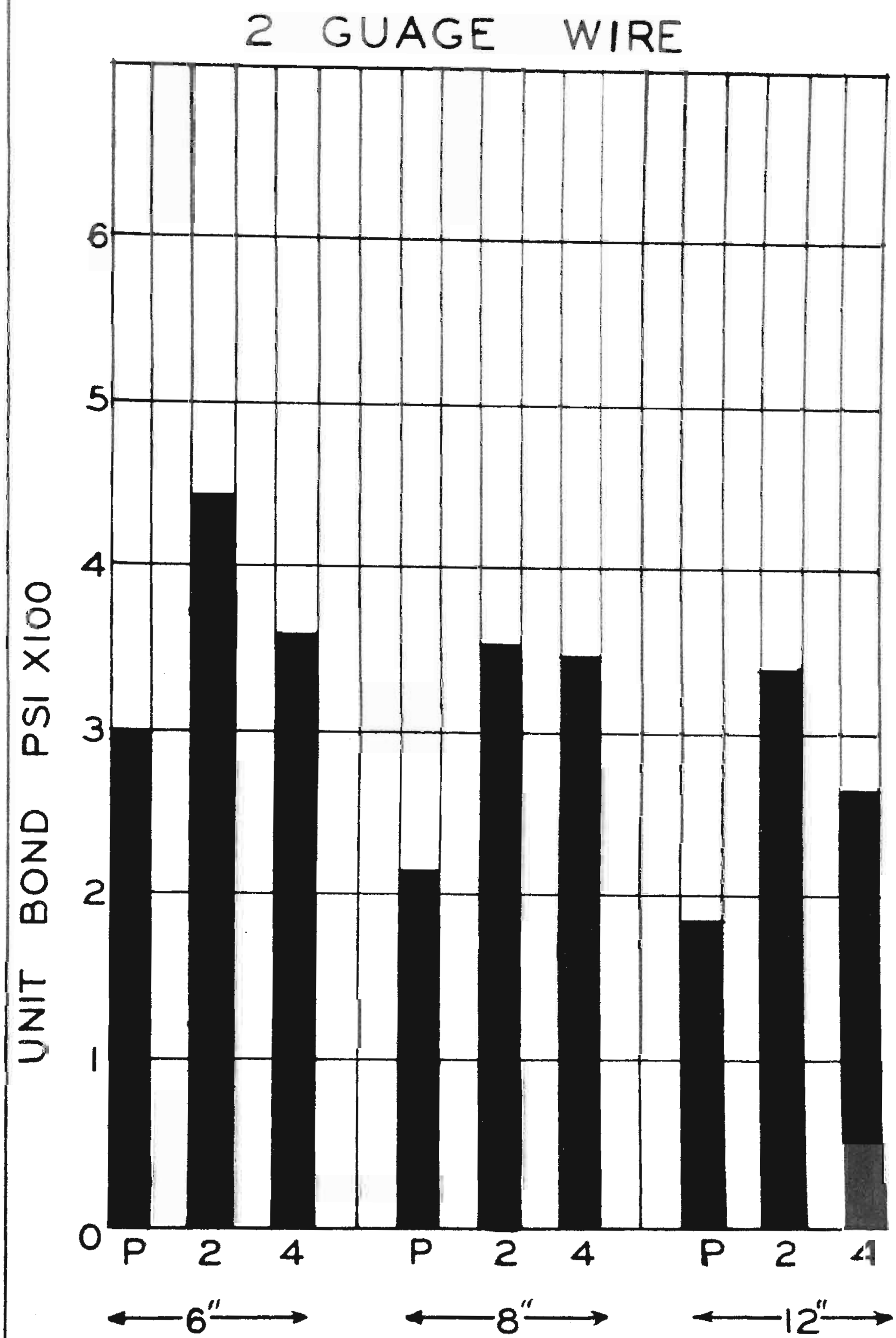


PLATE 21

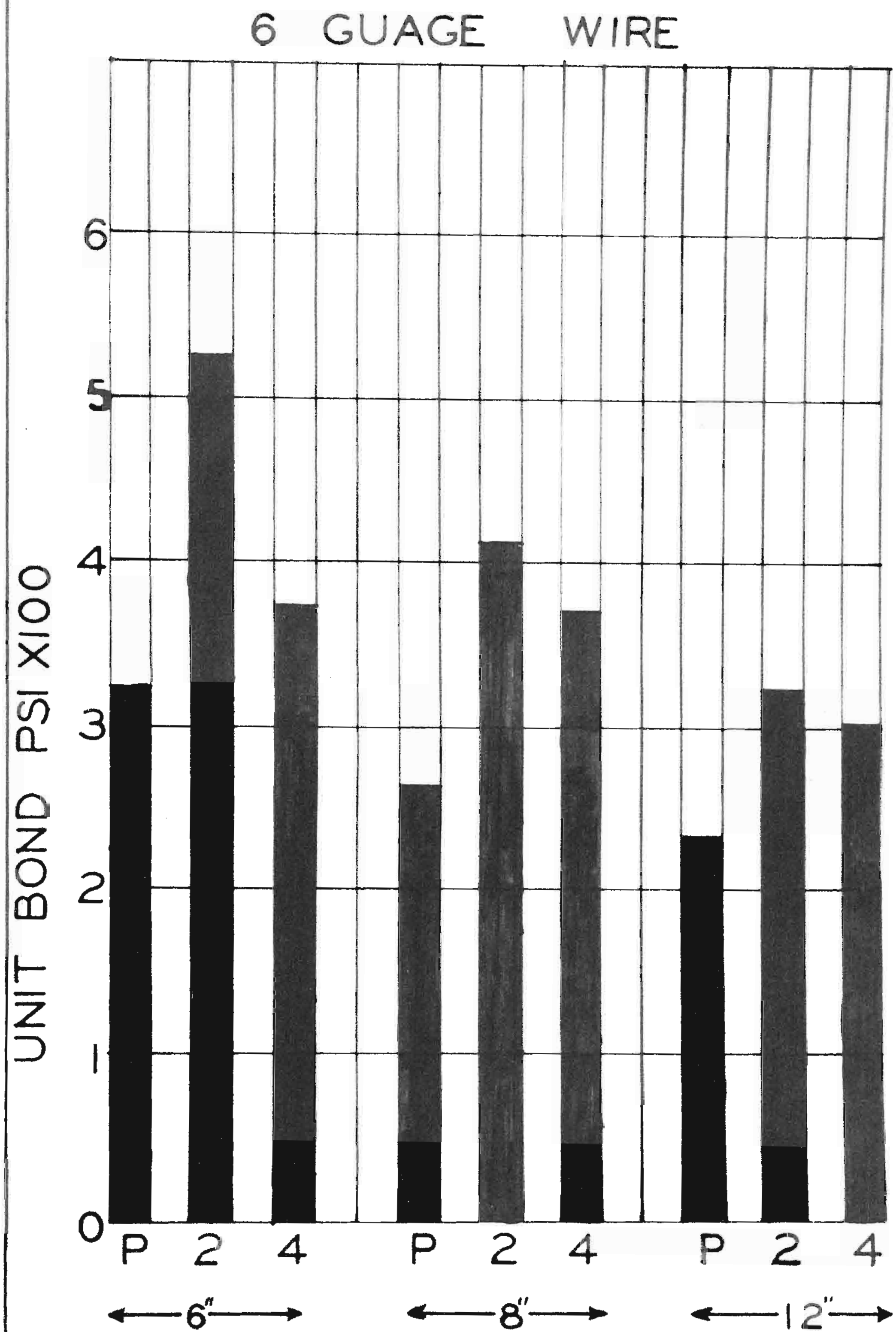
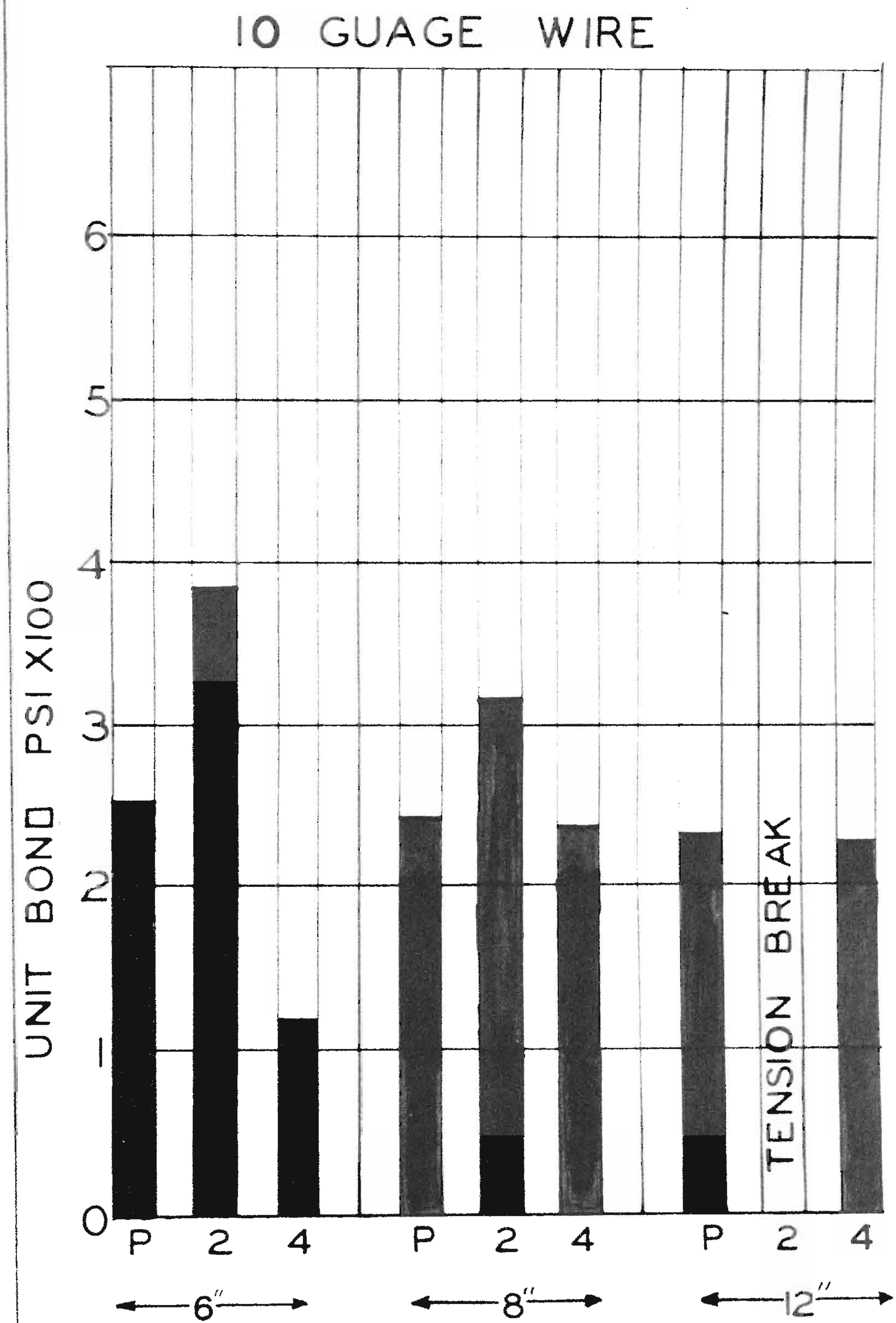


PLATE 22



10 GUAGE WIRE
UNIT BOND PSI X100
0
1
2
3
4
5
6
P 2 4
P 2 4
P 2 4
TENSION BREAK
6"
8"
12"

PLATE 23

RESULTS

The series of twenty tests of the welded wire fabric served to indicate that mechanical anchorage of the welds is the predominant factor in determining the resistance value of the fabric. Mr. Weinel proved in his investigation that a single weld was capable of developing from eighty-seven to ninety-three percent of the tensile strength of a single longitudinal wire. This was accomplished by performing a direct pull out test on a longitudinal wire with one transverse wire, embedded in a concrete cylinder. The longitudinal wire was greased, thus destroying all adhesive bond, and testing only the mechanical anchorage value of the weld. All longitudinal wires tested in this investigation were plain, except of course those used in the rust experiment. The results show that in all cases except that of the #8 guage transverse wire, the mechanical anchorage of the weld, plus the adhesive bond of the longitudinal wires is sufficient to develop at least the equivalent of the tensile strength of the longitudinal wire. In most cases the longitudinal wires failed in tension proving that the mechanical anchorage plus adhesive bond is considerably greater than the tensile strength of the longitudinal wires.

As a direct comparison, the comparison graph, page 72, was drawn using data from the beams tested by Mr. Weinel and the identical beams tested by the author. Mr. Weinel's beams, with the longitudinal wires greased, failed by shearing of the welds at approximately 8500 lbs. or 52,500 psi, with a total slip between the steel and concrete of 0.08 inches. The M-1 series beams, identical with Mr. Weinel's, except that the longitudinal wires were ungreased, failed in tension at a load of 10,800 lbs. (or 66,700 psi) and reached a maximum load of 12,400 lbs. (or 76,600 psi) with a total slip at failure of 0.14 inches and at maximum load of 0.08 inches--the same value as the failure slip in Mr. Weinel's beams. Thus the adhesive bond, added to the mechanical anchorage value of the welds, permitted almost 50% more load at peak, and 27% more load at failure. At 8500 lbs., the failure load of Mr. Weinel's beams, the slip was 0.0275 inches, or one-third of the value of the greased wires.

The results of the investigation tabulated on page 74 show values of yield load, stress, slip, and failure load, stress and slip for each series of tests performed. The "Yield" point is defined here as the load or stress at which the slip between the steel and concrete is no longer proportional to the load, and should not be confused with the usual definition of Yield point. The Yield stress of the wire of the M series beams failing in tension varied from 52,000 to 61,000 psi, and that of the DM series beams from 58,000 to 71,000 psi. The failure stress of the same M series beams varied from 62,000 to 70,000 psi and that of the DM series beams from 67,000 to 71,000 psi. The average slip at the yield point for the M series beams failing in tension varied from 0.034 in. to 0.043 in. and that of the DM series from 0.020 in. to 0.033 in. The average slip at failure for M series beams varied from 0.14 in. to 0.165 in., and for DM series beams from 0.07 in. to 0.098 in. The average total slip at failure in the DM series beams was roughly one half the total slip in similar M series beams.

Failures by shearing of the welds followed the same pattern as the tension failures, as can be readily seen by inspection of the summary table. Weld failures occurred only in beams consisting of #6 guage or #8 guage transverse wires in the M series and only in beams with #8 guage transverse wires in the DM series. The OM and DOM series beams followed the same pattern. Beams of the OM series failed in tension at approximately the same stresses as those of the M series, and the yield stresses of the DOM series considerably exceeded those of the OM series. The total slip at failure for the DOM series beams was also approximately one half the total slip of similar OM series beams.

The spacing of the longitudinal wires had no apparent effect on either the slip or the amount of load the wire could withstand. The total slip increased with an increase of spacing of the transverse wires in both the M and DM series beams, mainly due to the fact that all adhesive bond had to be released before the full mechanical anchorage of the welds could be developed. With an increase in transverse wire spacing, there was an increase of adhesive bond and hence the initial slip was slightly less than that of the same transverse wire spaced at closer intervals. Upon release of the adhesive bond the resistance was purely mechanical anchorage and the slip progressed at the same rate for all M series beams. The DM, OM, and DOM series followed this same pattern.

The slip progressed at a greater rate in M and OM series beams than in the DM and DOM series. The added adhesive bond played the minor part, while the mechanical anchorage of the welds (double for DM and DOM beams) had the effect of decreasing the slip considerably. This can be readily seen by inspection of the graphs.

Beams reinforced with #2 and #4 guage transverse wires all failed in tension. The #6 guage wires failed in both weld shear and tension in the M series, and tension only in the DM series. The #8 guage wires all failed by shearing of the welds in the M series, and by both weld shear and tension in the DM series. The OM series beams consisting of #3 transverse wires failed by shearing of the welds. The OM beams with #4 transverse wires and the entire DOM series all failed in tension.

Elongation of the longitudinal wire failing in tension was neglected as the amount of elongation was small, and unless failure occurred between the point of connection of the Ames Dial and the face of the concrete block the elongation had practically no effect on the slip. Failure did occur between these points in only one case, and hence was neglected in drawing the curves of load versus slip.

The values of the yield point and tensile strength differ from those obtained by a straight tension test on the steel due to the fact that the steel was pulling out of the concrete block throughout the test, thus decreasing the true load. This fact explains the difference in failure load for the M and DM series beams failing in tension. Considerably more anchorage was furnished by the steel in the DM series beams, and therefore the slip was decreased and the load greater than that of similar M series beams.

In a few cases failure occurred before any appreciable load was reached. Upon investigation the author discovered a faulty weld; that is, very little weld material joining the transverse and longitudinal wires. In these cases duplicate tests were performed. Upon further investigation the author found that a few welds could be broken by applying pressure to a joint of the fabric with the bare hands. This was rare, however, and in most cases the weld was sufficient to develop some load.

The results of the rust experiments are best explained by an inspection of the bar graphs, pages 80 to 83 . The plain wire tested at values ranging from 200 to 325 psi; the wire which had been subjected to two weeks of rusting from 325 to 525 psi, and the four-week rust wire from 250 to 425 psi. The average increase in bond stress for two-week rust wire was approximately 65%, and the average increase for four-week rust wire, 30%. In one case, namely the #10 guage wire, the wire exposed to four weeks rust tested at a lower value than the plain wire. The two-week rust wire of the #10 guage followed the same pattern as the #00, #2, and #6 guage wires.

The 3/8 inch round reinforcing bars tested in the comparison test were rolled from rail steel of high carbon content, and hence tested at higher values than low or medium carbon steel. Failure occurred in this test by shearing of the concrete block at approximately the maximum load that the two bars could withstand. This is evident from an inspection of the curves C-1 and C-2, page 73. Beams C-3--C-6 tested at greater values of slip at yield point (which was approximately the same in all cases) and lower values of maximum load. Beams C5 and C6 contained one extra transverse wire in each section thus decreasing the amount of slip and permitting slightly greater values of maximum load. The failure and yield point stresses were slightly higher than those for similar M and DM series beams due to the added anchorage of the extra welds. The average total slip at yield for the wire was approximately .027 inches, and for the 3/8 inch bars .022 inches. The average stress at failure was 109,000 psi for the bars (maximum load) and 69,500 psi for the wire, slightly higher than similar wire of the M and DM series beams.

The results can best be summarized as follows:

(1) The mechanical anchorage of the welds plus the adhesive bond of the longitudinal wires was equal to or greater than the tensile strength of the longitudinal wires in all cases except that of the #8 guage transverse wires.

(2) The addition of the adhesive bond of the longitudinal wires to the mechanical anchorage of the welds permitted 50% more load at peak and 27% more load

at failure with a lower rate of slip in the M-1 beams than identical beams with greased longitudinal wires. The beams failed in tension rather than by shearing of the welds.

(3) The yield stress of the wire of the M series beams varied from 52,000 to 61,000 psi, and the failure stresses varied from 62,000 to 70,000 psi. The average total slip was 0.034 to 0.043 inches and 0.14 to 0.165 inches respectively for beams failing in tension.

(4) The yield stress of the wire of the DM series beams varied from 58,000 to 70,000 psi and the failure stress from 67,000 to 71,000 psi. The average total slip was from 0.020 to 0.033 inches and 0.070 to 0.098 inches respectively for beams failing in tension.

(5) Weld failures occurred in beams consisting of #6 and #8 guage transverse wire in the M series, and only in beams consisting of #8 guage transverse wire in the DM series.

(6) Beams of the OM and DOM series failed at approximately the same stresses and in the same manner as those of the M and DM series.

(7) Slip progressed at a lower initial rate with an increase of spacing of transverse wires of the same guage. Total slip, however, was greater.

(8) Slip progressed at a considerably lower rate in the DM and DOM series beams than in the M and DM series.

(9) Beams reinforced with #2 and #4 guage transverse wires all failed in tension. No. 6 guage reinforcement failed in both tension and weld shear, and #8 guage failed by weld shear only, except in the DM series beams, in which cases all but #8 failed in tension.

(10) Elongation was negligible in all but one case, and hence was neglected in determining values of slip.

(11) When failure was the result of a faulty weld the failure occurred before load of any consequence was applied.

(12) The average increase in bond stress for wire rusted two weeks was 65%, and for wire rusted four weeks, 30%, in direct comparison with plain wire.

(13) Standard 3/8 inch round ribbed reinforcing bars developed 109,000 psi at maximum load as against 69,500 psi for an equivalent area of welded wire fabric.

(14) Slip between the reinforcing bars and the concrete progressed at a considerably lower rate than that of the welded wire fabric.

CONCLUSIONS

Although only a few guages of welded wire fabric were tested in this investigation, a definite consistent pattern has been indicated. Mechanical anchorage undoubtedly plays the major part of the resistance value of the fabric; however, adhesive bond does have some effect. The failure of the greater percentage of the beams by tension in the longitudinal wires leads to the conclusion that the mechanical anchorage afforded by the welds is sufficient to develop full tensile strength of the longitudinal wires. The #6 guage transverse wires seem to be the limiting size, since beams cast with this wire failed in both tension and weld shear. Beams reinforced with guages below #6 all failed in tension, and those reinforced with #8 guage transverse wires failed by shearing of the welds. Adhesive bond has its greatest effect on this particular guage of wire. This is proved by the comparison test of Mr. Weinel's beams and the M-1 beams tested by the author. By releasing the adhesive bond Mr. Weinel obtained failure by weld shear in all cases. The author found that the addition of this adhesive bond was sufficient to develop the tensile strength of the longitudinal wires in approximately half the beams tested. Beams reinforced with #8 guage transverse wires failed in tension in only one case, and by weld shear in all the rest. This would indicate that the #8 guage wires are incapable of developing sufficient load before failure. The author therefore recommends that #8 guage transverse wires be used only with the smaller guages of longitudinal wires.

The ability of the M-1 beams to carry 50% more load at peak and 27% more at failure than Mr. Weinel's beams with a considerably lower rate of slip, proves that adhesive bond has a definite limiting effect on the initial rate of slip between the steel and the concrete, and when coupled with the mechanical anchorage of the welds will cause a tension rather than a weld shear failure in some of the lower guages of wire. It would probably be safe to conclude, although no data is available, that this would hold true for only the limiting size wire, or in this case the #6 guage wire. With adhesive bond released in beams reinforced with #2 and #4 guage transverse wire, the slip would undoubtedly be increased; however, the author feels that failure would occur in the same manner as with the adhesive bond acting.

The tests performed on the DM series beams verify the results obtained from the M series. Failure of all but the #8 guage transverse wires by tension furnishes further proof that the anchorage of the welds is sufficient to develop full tensile strength of the longitudinal wires, and that the #8 guage transverse wire cannot carry load of any consequence without failure. Double reinforcement allows only approximately 5% more load before failure, but raises the yield point 15% with a decrease of 42% in slip at the yield point, and almost 85% at failure. This indicates that slip is directly proportional to the number of welds in the reinforcement, and that by doubling the number of welds the rate of slip is decreased almost 50% to the yield point, and the total slip to almost one half its original value at failure. These, of course, are average values.

Due to the limiting width of the beams only two longitudinal wires could be placed in beams of the OM and DOM series; however, these tests followed the same pattern as those of the M and DM series, and thus serve as a check on the conclusions previously drawn.

With an increase of spacing of transverse wires of the same guage a lower initial rate of slip occurs due to the added adhesive bond which must be completely released before the full mechanical anchorage of the welds may be developed. The total slip at failure, however, is greater than that with transverse wires of the same guage spaced at closer intervals. Since mechanical anchorage is the controlling factor in the resistance of welded wire fabric to load, and it is desired to limit slip to a minimum, the author concludes that a limiting spacing of six, or possibly eight inches for transverse wires would probably be desirable. A twelve-inch spacing of transverse wires allows considerably more total slip than a six inch spacing, and similarly six inch spacing allows more than four. The closer the transverse wires are spaced, the more mechanical anchorage is afforded by the additional number of welds, and it seems logical that a six or possibly eight inch limit on transverse wires would be most desirable. A further investigation, testing other combinations of longitudinal and transverse wires would be necessary to verify this conclusion.

Elongation of the longitudinal wires plays a very minor role, and can be neglected in all cases.

In a number of cases faulty welds were discovered. This should be remedied, as the faulty weld will cause failure before any significant load can be developed. The author found very little weld material joining the transverse and longitudinal wires in cases of faulty welds, and thus the welds sheared upon application of very small loads. This could be remedied in the fabrication of the welded wire reinforcement.

Wire which has been exposed to two weeks rust is capable of developing 65% greater bond stress than plain wire. Wire rusted four weeks will develop 30%

more bond stress. The increase in the two-week wire is due mainly to the roughened condition of the wire's surface. This wire exhibited a uniform scale throughout its length. After four weeks of rusting the scale becomes pitted and flaky, and hence the decrease from 65% to 30%. These values, of course, are averages for the entire series of tests.

The comparison tests of the welded wire fabric and standard 3/8 inch round reinforcing bars definitely indicates that reinforcing bars can withstand greater loads with a lower rate of slip than an equivalent area of welded wire reinforcement.

With a closer spacing of transverse wires, however, the total slip between the steel and concrete is reduced, and a further investigation, with transverse wires spaced at intervals of two or three inches might indicate that the rate of slip of the wire would be equal to or less than the slip of the reinforcing bars.

A summary of the conclusions drawn from the results of the investigation follows:

(1) Mechanical anchorage of the welds is the predominant factor in the resistance value of welded wire reinforcement.

(2) The mechanical anchorage of the welds is capable of developing full tensile strength of the longitudinal

wires with #2, #4, and #6 guage transverse reinforcement.

(3) The limiting size transverse wire in welded wire reinforcement fabric is the #6 guage wire.

(4) Adhesive bond added to mechanical anchorage enables the wire to carry 50% more peak load, and 27% more failure load with a lower rate of slip than greased longitudinal wires. (This is based on the comparison test only.)

(5) The #8 guage transverse wire is incapable of developing sufficient load before failure, (by weld shear), when welded to larger guages of longitudinal wire as transverse reinforcement.

(6) Multiple anchorage, i.e., two transverse wires embedded in the test section of the concrete beams, as in the DM series, increases failure load 5%, raises the yield point 15% and decreases slip approximately 42% at yield and 85% (total) at failure.

(7) An increase of transverse wire spacing (of the same guage) results in a lower initial rate of slip and a greater total slip at failure.

(8) A six or possibly eight inch limit on transverse wire spacing would be desirable to keep slip between the steel and concrete to a minimum.

(9) Faulty welds cause failure before any significant load can be developed. This is due to an insufficient

amount of weld material at the joint of the transverse and longitudinal wire.

(10) Average values (DM series beams) for welded wire fabric are as follows:

"Yield" Stress: 64,500 psi

Failure Stress: 68,500 psi

Av. Slip at Yield: 0.0265 inches

Av. Slip at Failure: 0.084 inches

(11) Wire exposed to two weeks rust develops an average of 65% greater bond stress than plain wire. Wire rusted four weeks shows an increase of approximately 30%.

(12) Standard round ribbed reinforcing bars will carry more load than an equivalent area of welded wire reinforcement fabric. Slip between the reinforcing bars and the concrete is less than that of the welded wire fabric. This, of course, depends upon the spacing of the transverse wires, and further investigation with closer spacing of transverse wires might lead to a better comparison.

(13) The final determination of the most desirable cross wire spacing would result from an economic comparison of the cost of welded wire fabric and ordinary reinforcing bars, of which the placing cost would be an important factor.

(14) The ease with which welded wire fabric can be adapted to varying combinations of spacing and wire sizes lends itself to almost ideal design possibilities. It is a known fact that smaller longitudinal steel and closer spacing results in increased bond values. Therefore, proper design of welded wire reinforcement may compare favorably with hi-bond bars, and may have an added advantage in properly distributing steel for balanced design.

DISCUSSION OF ACCURACY

The results of the entire investigation are, of course, subject to the limitations of experimental and human error. Average values were taken in all cases to eliminate the obviously inconclusive data furnished by a single experiment.

In a few cases it was observed that the concrete sections of the beams were slightly uneven, thus causing an eccentric load on the beam during the testing. This, of course, would cause a small percentage of error in the final average tabulation. The accuracy in reading the two Ames Dials probably accounts for the greatest percentage of error, as no attempt was made to read the dials to four decimal places. Since the dials were constantly moving, it would have been practically impossible to obtain four place accuracy, especially at points of maximum load and failure. The rapid movement of the dials particularly at failure enabled only an approximation of the exact failure slip, and the high points of the load-slip curves are probably the limit in accuracy of the dial readings.

Elongation would have a very minor effect upon the amount of probable error, as only one failure occurred between the Ames Dial connection and the face of the concrete block. This did occur, however, in the M-1 series beams, and might help explain why that particular series does not exactly follow the pattern set by the others.

Compression tests on standard concrete cylinders resulted in values as high as 3900 psi and as low as 2700 psi for the compressive strength of the concrete. Since bond is proportional to this value, the difference in the concrete of the various beams would have some effect on the adhesive bond values, and thus cause a small amount of error.

The efficiency of the testing machine and the human factor probably account for the remainder. The author endeavored to check all data twice before the final tabulation, and although the mathematical calculations are probably correct, some error in recording and listing data undoubtedly exists.

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VITA

Alan A. Becker was born on February 8, 1926, at New York City, N.Y., the son of Mr. and Mrs. Arthur A. Becker.

His early education was received in grade and high schools in New York City. He entered the Massachusetts Institute of Technology in June, 1943, and graduated in February, 1947, with the degree of Bachelor of Science in Civil Engineering.

In February, 1947, he was appointed Instructor of Civil Engineering at the Missouri School of Mines, and he acted in that capacity until June of the same year, at which time he accepted employment as a designer with the Missouri State Highway Department Bridge Office.

He returned to his duties as instructor in September, 1947, and enrolled as a part-time graduate student.

In February, 1948, he was married to Carolyn Frances Marr, daughter of Mr. and Mrs. William S. Marr of Jefferson City, Missouri.