U. S. Department of Commerce National Bureau of Standards

RESEARCH PAPER RP754

Part of Journal of Research of the National Bureau of Standards, Volume 14
January 1935

FATIGUE PROPERTIES OF STEEL WIRE

By Stephen M. Shelton and William H. Swanger

ABSTRACT

Because of surface imperfections the fatigue limit of a structural member may be appreciably lower than the fatigue limit determined on machined and polished specimens of the material. This was shown by fatigue tests made by the rotating-beam method on galvanized heat-treated steel wire, Swedish valve-spring wire and cold-rolled mild steel wire: the fatigue limits of specimens with the original surfaces as produced by the manufacturers were 40, 60, and 82 percent, respectively, of the fatigue limits of machined and polished specimens of the same materials.

The development of a suitable gripping device made possible the determination of the limiting range of pulsating tensile stresses on unmachined (in the test length) specimens of wire in the Haigh alternating-stress testing machine.

The effect of variation of the mean stress between 50,000 and 200,000 lb/in.^{2} on the limiting ranges of pulsating tensile stresses was determined on cold-drawn and galvanized, and heat-treated and galvanized, steel suspension-bridge wires, and on a high-strength steel wire electroplated with zinc. The results showed that the limiting ranges of pulsating tensile stresses were practically independent of the mean stress within the range investigated.

CONTENTS

I. INTRODUCTION

For wrought metals, the tensile properties of test coupons are generally accepted as a criterion of the tensile properties of structural members. It has been found, however, that the fatigue limit of structural members is often less than that of machined and polished specimens of the same metal. As shown by many investigators, this is because the fatigue limit depends greatly upon the conditions at the surface, such as surface decarburization in steels, tool marks, notches, and some protective metallic coatings.[1] [2] [3] [4]

[1] D. J. McAdam, Jr. and R. W. Clyne, *Influence of chemically and mechanically formed notches on fatigue of metals*, J. Research NBS. **13** (1934) RP527.

[2] G. A. Hankins and M. L. Becker, *The effect of surface conditions produced by heat treatment on fatigue resistance of spring steels*, J. Iron and Steel Inst. **124**, pt. 2, 387 (1931).

[3] R. H. D. Barklie and H. J. Davies, *The effect of surface conditions and electrodeposited metals on the resistance of materials to repeated stresses*, Proc. Inst. Mech. Engrs., p. 731, pt. 1 (1930).

[4] W. H. Swanger and R. D. France, *Effect of zinc coatings on the endurance properties of steel*, BS J. Research **9**, 9 (1932) RP454.

There are few testing machines in which fatigue tests can be made on full-size structural members. Fatigue tests can be made, however, on wire in the condition in which it is used in some structures, such as suspension-bridge cables. It is not necessary to machine the surface of the specimens. Several investigators have devised methods for holding the wire so that failure does not occur in the grips.

One of the authors of this paper devised a rotating-beam fatigue-testing method for wire. The results obtained on low-carbon steel wire and on high-carbon steel wire were reported in 1931.[5] The portion of this paper on "Rotating-Beam Tests" describes the method and gives results of additional tests.

F. C. Lea [6] used several methods for gripping wires in a torsional fatigue-testing machine. A. Lindeberg tested wire under pulsating tensile stresses. His machine is particularly adapted for testing small wires. The results of an extended series of fatigue tests on steel wires from 1 mm to 1.37 mm (approximately 0.04 in. to 0.054 in.) in diameter, made on his machine in collaboration with A. Pomp and C. A. Duckwitz, were reported in a paper by Pomp and Duckwitz.[7] Their tests were limited to determinations of the stress ranges which did not produce failure in 5,000,000 cycles of pulsating tension.

A. V. de Forest and L. W. Hopkins [8] used a modification of the rotating-beam fatigue-testing machine. The specimens were bent to a constant radius of curvature by wrapping them around a sheave for one-quarter of the circumference under a constant tension and rotating the wire. Their machine was used for testing small wire to be used in wire rope.

The results of fatigue tests of wires and small wire ropes, having lengths up to 50 feet, under combined tensile and bending stresses, were reported by R. L. Templin.[9] Recently E. T. Gill and R. Goodacre [10] described a rotating-beam machine for short specimens of wire.

In structures wire is usually subjected to stresses which fluctuate from one tensile value to another tensile value. In order to test wire under such fatigue stresses, tests were made in the Haigh alternating-stress testing machine. The portion of this paper on "Tests Under Pulsating Tensile Stresses" describes the method of testing in the Haigh machine and gives the results on different wires.

II. ROTATING-BEAM TESTS

The specimen for a rotating-beam machine is a round rod supported at the ends and loaded at 2 intermediate points. The specimen is rotated by a suitable driving mechanism. To avoid failures in the grips it is usual to machine the specimen to a reduced diameter at mid-length. A specimen having a constant cross section can be used if the specimen is so long that its weight provides sufficiently increased stresses at mid-length to cause failures at or close to that point. A machine designed on this principle is shown in figure 1. The specimens were wire having the cylindrical surface in the condition in which the wire is used. The supports, A and B, were taken from an

[5] S. M. Shelton, Proc. Am. Soc. Testing Materials, **31**, pt. 2, 204 (1931).
[6] Proc. Inst. Mech. Engrs. **120**, 661 (1931).
[7] Mitt. K. W. Inst. f. Eisenf. z. Düsseldorf **13**, 79 (1931).
[8] Proc. Am. Soc. Testing Materials, **32**, pt. 2, 398 (1932).
[9] Proc. Am. Soc. Testing Materials, **33**, pt. 2, 364 (1933).
[10] Preprint no. 3, Iron and Steel Inst. (Sept. 1934).

R. R. Moore rotating-beam fatigue-testing machine.[11] The specimen, C, is attached to the rotating spindles of the supports by means of a spring collet shown in figure 2. The loads, $W/2$, are suspended over quadrants, of lightweight metal, whose centers coincide with the centers about which the supports, A and B, are free to rotate. A constant moment is thus applied to the supports regardless of the deflection of the specimen. The support, A, is mounted on the frame so that it is free to move longitudinally. The base, E, for the motor, D, is mounted on hinges so that the shaft of the motor can be brought into approximate alinement with the spindle in support, B. A flexible coupling, F, joining the spindle and shaft, adjusts minor misalinement.

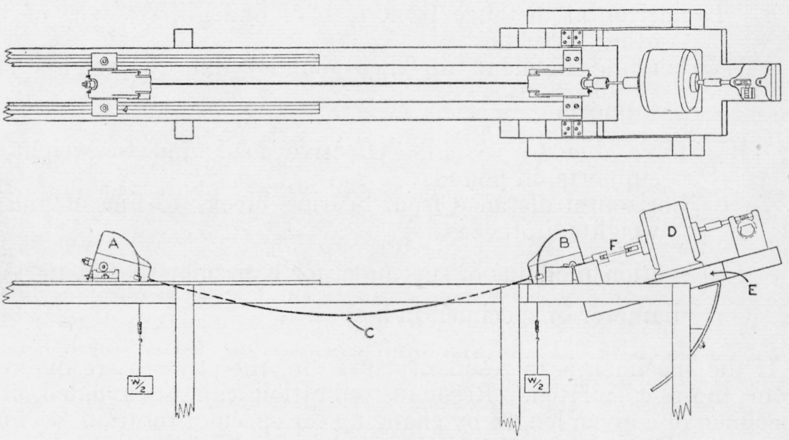

FIGURE 1.—*Long-span rotating-beam fatigue-testing machine.*

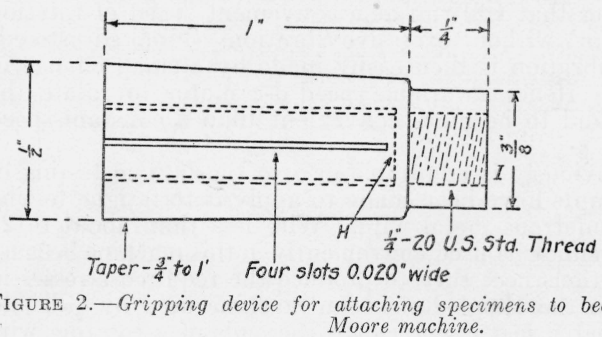

FIGURE 2.—*Gripping device for attaching specimens to bearing boxes of R. R. Moore machine.*

The specimen is inserted into the spring collet to the point, H (fig. 2). The collet is drawn into a tapered hole in the spindle of the support by means of a rod screwed into the collet at I, and anchored to the other end of the spindle. The specimen is gripped tightly by the tapered prongs of the collet as they are drawn into the spindle. The collet is lined with a bushing, G, to avoid seizing and galling on the surface of the specimen by the steel of the collet. Copper or several thicknesses of typewriter paper have been found suitable for this purpose.

[11] *Report of research committee on fatigue of metals,* appendix, Proc. Am. Soc. Testing Materials, **30,** pt. 1, 266 (1930).

The maximum fiber stress at the mid-length of the specimen can be computed from the formula:

$$S=\frac{(M_1+M_2)}{I/c}=\frac{W_1 l}{8}+\frac{W_2 a}{2}\div\frac{\pi}{32}d^3$$

where

S=maximum flexural stress, pounds per square inch.

M_1=bending moment (in inch-pounds) due to weight of specimen$=\frac{W_1 l}{8}$

W_1=total weight of specimen in pounds

l=horizontal distance from face of one grip to face of the other, in inches

M_2=bending moment (in inch-pounds) due to weights and supports$=\frac{W_2 a}{2}$

W_2=force due to weights+effective load due to weight of supports, in pounds

a=horizontal distance from bearing blocks to line of pull of weights, in inches

I/c=section modulus of specimen, for a circular specimen$=\frac{\pi}{32}d^3$

d=diameter of specimen in inches

If the specimen is in resonant vibration, the stresses are different from those calculated. Resonant vibration can be avoided in a specimen of a given length by changing the speed of rotation, or, for a given speed of rotation, by changing the length of the specimen. A few trials generally will show the proper length of specimen of wire of a given diameter that will run at a convenient speed of rotation (1,700 to 2,200 rpm) without excessive vibration. Final adjustment to eliminate all vibration is then easily made by a small change in speed of rotation. Hence a variable speed d-c motor to rotate the specimens was found to be more convenient than a constant-speed motor.

This method obviously is adaptable also to the fatigue testing of tubing. No attempts have been made to apply it to fatigue testing of soft iron or nonferrous metal wire. Wire less than about 0.125 inch in diameter cannot be used conveniently in this machine because of the large deflections necessary to produce the required stresses in the long span. In the Haigh-Robertson machine used by Gill and Goodacre,[12] an axial thrust is applied to the ends of a rotating wire so that the specimen becomes in effect an Euler strut. The mechanism is small, making operation at high speed (14,000 to 18,000 rpm) convenient, and can be used with wire 0.080 inch or less in diameter.

Fatigue tests were made with the long-span rotating-beam machine on 3 types of carbon-steel wire. Carbon and manganese contents and tensile properties are given in table 1. Material HG was a galvanized, oil-quenched and tempered, steel wire, 0.192 inch nominal diameter, manufactured for use in suspension-bridge cables; HGS was the same material with the zinc coating removed by solution in

[12] Preprint no. 3, Iron and Steel Inst. (September 1934).

Correction to page 20 of Research Paper RP754 of January 1935 Journal of Research of the National Bureau of Standards

---

For the formula to compute the maximum fiber stress at the mid-length of the specimen, as given originally, substitute the following:

$$S = \frac{(M_1 + M_2)}{I/c} = \left(\frac{W_2 a}{2} + \frac{W_1 l}{8} + \frac{W_1 b}{2} \right) \div \frac{\pi}{32} d^3$$

b = horizontal distance from face of grip to point of support

TABLE 1.—*Materials and results of fatigue tests*

Material	Carbon and manganese	Tensile properties				Endurance properties					
		Stress for permanent extension, in 8 inches, of—			Ultimate tensile strength	Rotating beam		Pulsating tensile stress			
		0.002%	0.003%	0.1%		Fatigue limit	$\frac{FL}{UTS}$	Mean	Maximum	Minimum	Fatigue limit
	Percent	lb/in.²	lb/in.²	lb/in.²	lb/in.²	lb/in.²	*Percent*	lb/in.²	lb/in.²	lb/in.²	lb/in.²
(HG) Heat-treated bridge wire, galvanized	0.75 C .50 Mn	82,000	100,000	198,000	225,000	50,000	22	49,000 68,000 88,000 107,000 133,000 153,000	75,500 92,500 111,000 130,000 158,000 177,000	22,500 43,500 65,000 83,500 108,000 129,000	±26,500 ±24,500 ±23,000 ±23,500 ±25,000 ±24,000
(HGS) Heat-treated bridge wire, stripped of zinc coating	.75 C .50 Mn	82,000	100,000	198,000	225,000	60,000	27	--------	--------	--------	--------
(HG) Machined and polished	.75 C .50 Mn	--------	--------	--------	--------	110,000	49	--------	--------	--------	--------
(CR) Cold-rolled steel rod	.13 C	60,000	63,000	--------	94,000	46,000	50	--------	--------	--------	--------
(CR) Machined and polished	.13 C	--------	--------	--------	--------	56,000	60	--------	--------	--------	--------
(WC) Swedish valve-spring wire	.65 C .55 Mn	104,000	119,000	190,000	221,000	76,000	34	--------	--------	--------	--------
(WC) Machined and polished	.65 C .55 Mn	--------	--------	--------	--------	126,000	56	--------	--------	--------	--------
(WO) Swedish valve-spring wire	.65 C .55 Mn	102,000	117,000	202,000	217,000	65,000	30	105,000	156,000	54,000	±51,000
(CD) Cold-drawn bridge wire, galvanized	.75 C .50 Mn	40,000	45,000	170,000	230,000	--------	--------	50,000 73,000 90,000 110,000 135,000 156,000	80,000 97,000 114,000 135,000 156,000 178,000	20,000 49,000 66,000 85,000 113,000 134,000	±30,000 ±24,000 ±24,000 ±25,000 ±21,500 ±22,000
(CD) Machined and polished	.75 C .50 Mn	--------	--------	--------	--------	118,000	51	--------	--------	--------	--------
(EG) Electrogalvanized wire	.71 C .97 Mn	--------	--------	188,000	246,000	--------	--------	50,000 107,000 113,000 150,000 200,000	87,000 135,000 140,000 180,000 226,000	13,000 79,000 86,000 120,000 174,000	37,000 28,000 27,000 30,000 26,000

hydrochloric acid;[13] CR was commercial "cold-rolled steel" rod 0.187 inch in diameter; WC and WO were "oil-tempered" valve-spring wires of Swedish manufacture, 0.162 and 0.148 inch nominal diameter.

The speed of rotation was approximately 2,000 rpm for the galvanized bridge-wire specimens, HG, and 1,900 rpm for the stripped specimens, HGS; the cold-rolled steel specimens, CR, were run at 1,700 rpm. The length of span between the grips for these 3 types of specimens was 60 inches plus or minus 1 inch. The maximum fiber stress at the middle of the span, due to the weight of the wire between grips, was approximately 6,000 lb/in.^{2} The valve-spring wires were run at approximately 2,200 rpm. The length of span for the 0.162-inch diameter specimens, WC, was 46 inches plus or minus 1 inch. The maximum fiber stress at the middle of the span due to the weight of the wire was approximately 4,200 lb/in.^{2} for the larger and 3,600 lb/in.^{2} for the smaller wire.

The increased fiber stresses due to the weights of the wires were sufficient to cause more than 90 percent of the fractures to occur within 12 inches of the middle of the span. Fractures which occurred more than 12 inches from the mid-point were not included in the results reported. Variation in the stress over the lengths of the wire 12 inches on each side of the center was no greater than the variation due to possible errors in measurement of the diameters. For the galvanized specimens the stresses were computed on the diameter of the stripped wires.

Results for the bridge wire specimens are given in figure 3. The fatigue limit of the galvanized wire, HG, was 50,000 lb/in.^{2} The endurance ratio (fatigue limit to ultimate tensile strength) was only 22 percent. Specimens of the same material with the zinc coating removed had a fatigue limit of 60,000 lb/in.^{2}, an endurance ratio of 27 percent. These fatigue limits are unusually low for materials with an ultimate tensile strength of 225,000 lb/in.^{2} That the cause can be attributed to surface imperfections was shown by the results obtained on specimens machined from the wire. These were tested in the R. R. Moore rotating-beam fatigue-testing machine. The specimens, 3 inches long, were machined from the original diameter of 0.192 inch to a diameter of 0.150 inch in the midsection, with a radius of curvature at the reduced section of 9⅞ inches. The machined surface was polished longitudinally with 0000 emery paper. The specimens were held in collets similar to those shown in figure 2. The fatigue limit of the machined and polished specimens was 110,000 lb/in.^{2}, an endurance ratio of 49 percent. The *S–N* curve for these specimens is shown in figure 3.

The *S–N* curves for the cold-rolled steel, CR, are shown in figure 4. For the specimens tested with the original surface intact the fatigue limit was 46,000 lb/in.^{2}, an endurance ratio of 50 percent. For the machined and polished specimens of this material (reduced diameter of 0.150 inch) the fatigue limit was 56,000 lb/in.^{2}, an endurance ratio of 60 percent. The higher endurance ratios of this material in comparison with that of the stripped heat-treated bridge wire may have been due to the lesser notch sensitivity of the softer and more ductile

---

[13] The specimens were stripped of zinc by immersion in HCl (sp gr 1.19) to which had been added 1.6 g of $SbCl_3$ per liter of HCl: *Standard method of determining weight of coating on zinc-coated iron or steel articles*, ASTM Standards, A 90-33, pt. 1, 317 (1933).

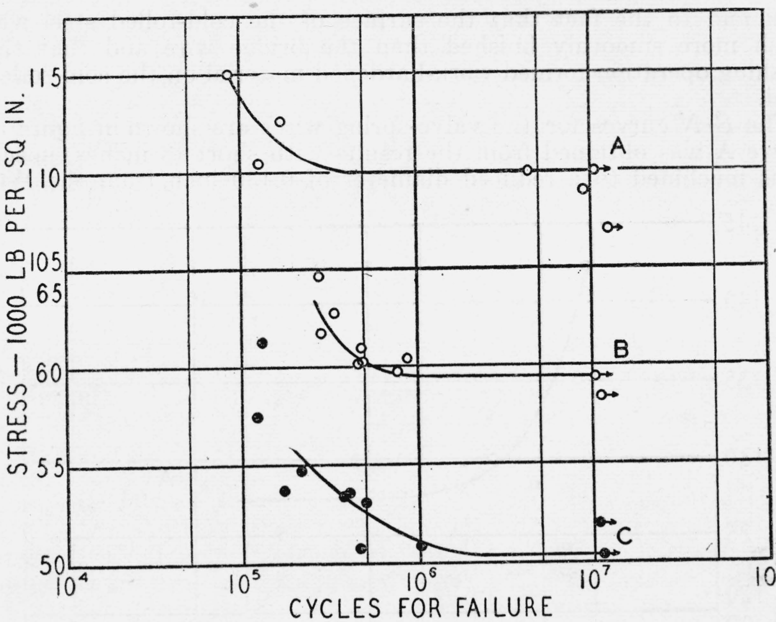

FIGURE 3.—*Results for rotating-beam fatigue tests on heat-treated bridge wire.*

Curve A, machined and polished specimens; curve B, specimens stripped of zinc; curve C, specimens of the galvanized wire.

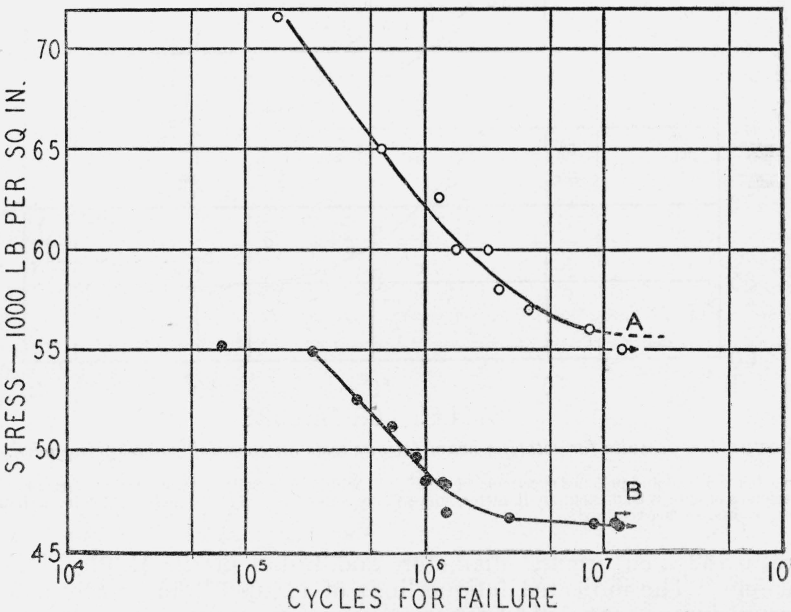

FIGURE 4.—*Results for rotating-beam fatigue tests on cold-rolled steel rods.*

Curve A, machined and polished specimens; curve B, specimens with original surface.

steel and to the fact that the surface of the cold-rolled steel was much more smoothly finished than the bridge wire and that the finishing operation formed work-hardened material on the cold-rolled steel.

The *S–N* curves for the valve-spring wires are shown in figure 5. Curve A was obtained from the results with short (3 inches) specimens machined to a reduced diameter of 0.130 inch from the WC

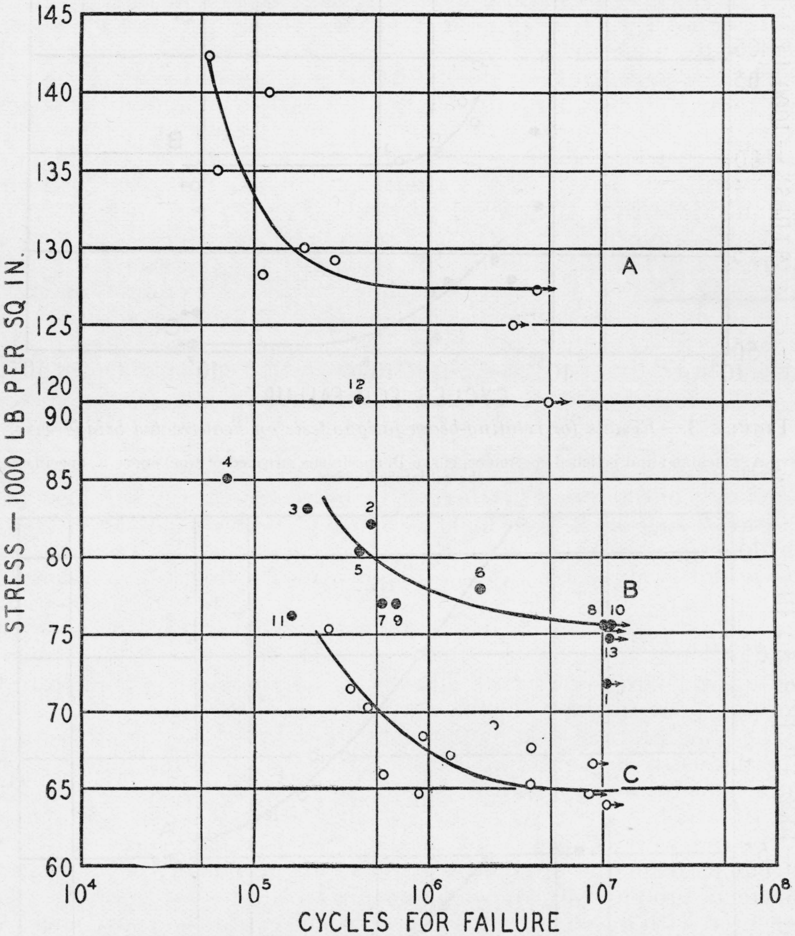

FIGURE 5.—*Results for rotating-beam fatigue tests on Swedish valve-spring wire.*

Curve A, machined and polished specimens of wire (WC, table 1) originally 0.162 in. in diameter; curve B specimens of wire WC, 0.162 in. in diameter; curve C, specimens of wire (WO, table 1) 0.148 in. in diameter, original surface retained.

wire, 0.162 inch original diameter, and tested in the R. R. Moore machine. The indicated fatigue limit of 126,000 lb/in.^{2} corresponds to an endurance ratio of 56 percent. For specimens with the original surface, tested in the long-span machine, a fatigue limit of only 76,000 lb/in.^{2} was obtained, an endurance ratio of 34 percent. It is noteworthy that in the latter group of tests, on each of the specimens that fractured at a number of cycles to the left of curve A, figure 5 (specimens 3, 4, 7, 9, and 11), the nucleus of fracture was located in a surface defect, a typical example of which is shown in figure 6 (A). One of the fractured surfaces of this specimen is shown in figure 6 (B). The nucleus of the fracture is indicated by the arrow. The appearance of the surface in the vicinity of the fractures typical of specimens 2, 5, 6, and 12, is shown in figure 6 (C). Figure 6 (D) shows the appearance of the fractured surface of one of these specimens. There is no indication of a surface defect in the nucleus of the fatigue fracture. Figure 6 (E) shows the appearance of the surface on the machined and polished specimens of this material, for which a fatigue limit of 126,000 lb/in.^{2} was indicated.

For the valve-spring wire, WO, 0.148 inch in diameter, a fatigue limit of 65,000 lb/in.^{2} was obtained on unmachined specimens tested in the long-span machine. The endurance ratio was only 30 percent. This wire was too small to permit tests of machined and polished specimens with the equipment available.

The *S–N* curve, C, figure 5, shows that there was less "scatter" in the results obtained with this wire than with the 0.162-inch diameter wire, WC. A reason for this was indicated by the examination of the surfaces of the fractured specimens adjacent to the fractures. No unusual surface defects at the nuclei of fracture were found; the surfaces of all the specimens were similar to that shown in figure 6 (C).

III. TESTS UNDER PULSATING TENSILE STRESSES

Fatigue tests under pulsating tensile stresses in the Haigh machine were made on materials HG and WO, listed in table 1, and also on 2 additional materials for which carbon and manganese contents and tensile properties are given in the table. Material CD was a suspension-bridge cable wire manufactured by cold-drawing ⅜-inch hot-rolled and "patented" rods through 5 passes to 0.192-inch nominal diameter. The drawn wire was galvanized by the hot-dip process, the coating being approximately 0.002 inch thick. Material EG was a cold-drawn wire coated with zinc by a commercial electrodeposition process. The thickness of the coating was 0.0035 inch.

The Haigh fatigue-testing machine permits a pulsating stress to be superimposed on an initial tensile stress on the specimens. The initial tension was applied to the specimen through a spring, the tension of which was regulated by a graduated nut. The graduations on the nut were calibrated by means of a specimen of the same wire as that used for the fatigue tests. The extensions of the calibration specimen, produced by known loads in a tensile-testing machine, were measured with a Ewing extensometer. The calibration specimen was then transferred to the Haigh machine and tension was applied by turning the nut. The resulting extensions measured with the same extensometer, were a direct measure of the tensile loads produced by turning the nut to the various graduated marks.

The upper end of the specimen for the fatigue test was attached to the fixed head on the machine and the lower end was attached to an armature which oscillated between the pole pieces of 2 electromagnets alternately excited by a 2-cycle generator. The maximum tensile stress is the sum of the initial stress imposed by the spring (attached to the armature) and half the range of pulsating stress imposed by the magnets. The minimum tensile stress is the initial stress minus half the range of pulsating stress. Equality of the increments of pulsating stress above and below the initial stress was maintained by means of a handwheel provided on the machine, which moved the specimen and armature, up or down, so that the armature attached to the lower end of the specimen was midway between the pole pieces. The midway point was indicated by a zero reading of a differential ammeter showing that the currents in both magnet circuits were equal. When this condition was maintained the initial stress set up in the specimen was the mean of the pulsating stresses.

The magnitude of the ranges of pulsating stresses used with different values of mean stress was indicated on a "stress meter" actuated by the magnets. The readings of the stress meter were also calibrated in terms of the load-extension relations of the calibration specimen of each type of wire.

During the tests at the higher values of mean stress the specimens acquired a permanent extension which disturbed the equality of oscillation of the armature about the midpoint between the pole pieces and lowered the initial stress imposed by the spring. It was necessary to readjust the load on each specimen at the beginning of a test because of the extension of the specimen and because of a small amount of yielding in the grips as they gradually seated themselves more firmly on the specimens. This readjustment by means of the handwheel was generally completed during the first 50,000 stress cycles, after which all the specimens appeared to assume a uniformly cylic state with no further permanent extension for the duration of the test.

It was found by measurement of the diameters of a number of permanently stretched specimens that the increase in stress due to the reduced diameter was well within the experimental error of the stress determinations, which is believed to be less than 5 percent. Accordingly, the stresses recorded in the test results are those calculated on the original diameters of the specimens and the limiting ranges given for the higher values of mean stress are on the "safe" side.

The 3 types of zinc-coated wires differed in thickness of coating. Hence, in order to have a more nearly common basis for comparison, the stress calculations were based on the diameters of the stripped wires.

With no reduced diameter in the portion of the test specimen between the grips, unavoidable clamping stresses would cause most of the fractures to occur within the grips. It was found that by grinding the zinc off the ends and polishing the exposed steel surface of the galvanized wires, or polishing the original surface of the ungalvanized wires, as far as they extended into the grips, the endurance strength of that portion of the specimen was increased sufficiently over the endurance strength of the portion between the grips so that fractures within the grips were avoided. The galvanized specimens were reduced in diameter as much as 0.008 inch in the gripped portions. The clamping stresses were distributed as uniformly as possible by the gripping device, a cross section of which is shown in figure 7.

A threaded fitting, A, was used to make the attachment to the machine, and as a seat for the tapered plug, C, which is essentially a spring collet. The hole in the collet through which the specimen, S, extended was drilled with a twist drill, and 4 radial slots were cut 90° apart to within about one-fourth inch from the smaller end.

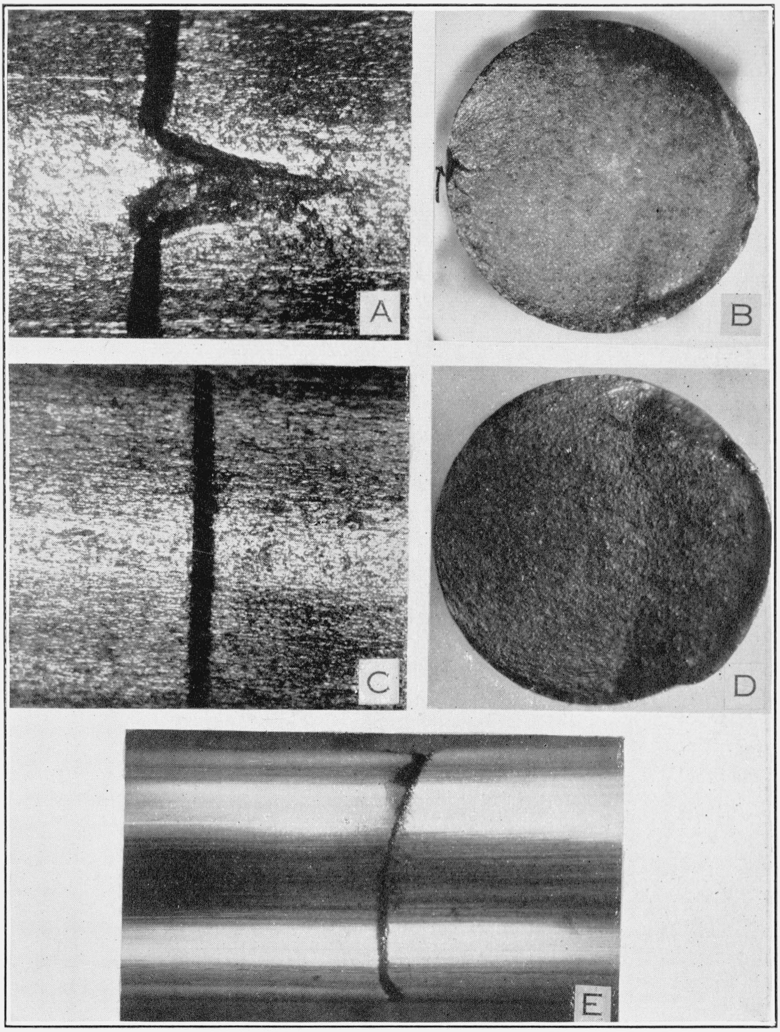

FIGURE 6.—*Conditions of the surfaces of specimens of Swedish valve-spring wire* WC, *table 1.*

A, Surface defect, specimen no. 4, from curve B, figure 5, X50. B, Surface of fracture of specimen no. 4; nucleus of fracture, indicated by arrow, located at surface defect shown in A, X16. C, Typical appearance of surface close to fractures which did not originate in major defects, X50. D, Appearance of fracture of specimen with no visible surface defect in nucleus of fatigue fracture, X16. E, Appearance of surface of machined and polished specimens, X16.

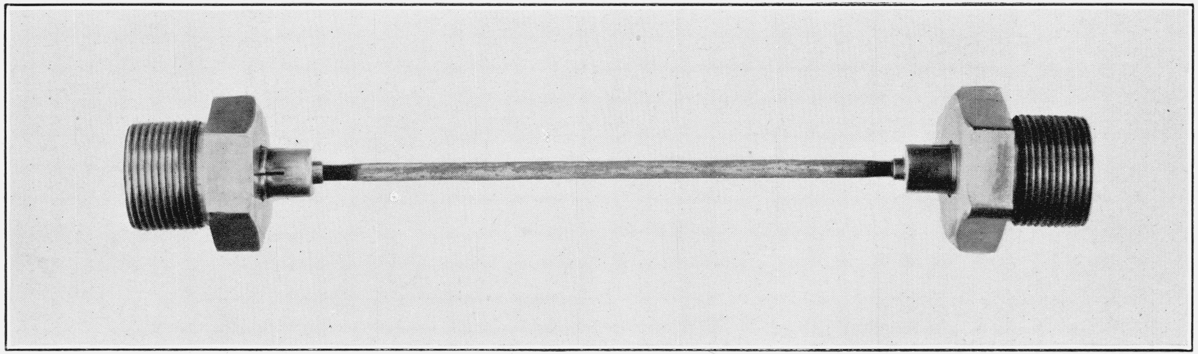

FIGURE 8.—*A galvanized-wire fatigue-test specimen with gripping device attached, as used in Haigh machine, ½ size.*

Parts A and C were made from machinery steel. A heat-treated steel nut, N, threaded on about one-half inch of the end of the specimen was seated on the larger end of the collet. A pull exerted on the specimen drew the collet through the tapered hole in the threaded fitting, A, and caused the collet to grip the polished end of the specimen. The specimen was thus held partly by the nut and partly by friction between the collet and the specimen. A soft metal bushing, B, slipped over the end of the specimen, aided in distributing uniformly the stresses caused by the pressure of the collet. Copper and brass tubing were tried, but proved to be unsatisfactory because both galled the steel surface of the specimen and frequently fatigue fractures radiated from the galled areas. This difficulty was practically eliminated with a bushing drilled from a rod of copper-lead bearing alloy containing approximately 25 percent lead, or by wrapping the ends of the specimens with several layers of typewriter paper.[14]

Figure 8 shows a specimen mounted in the grips. The length of the specimens was 10 inches. The machine operated at a rate of 2,400 cycles per minute.

Results of the determinations of the limiting range of pulsating tensile stress for the 4 types of wire at a mean tensile stress of approximately 110,000 lb/in.^{2} are shown in figures 9 to 12. Both the maximum and minimum stresses are plotted to show a clearer picture of the stress conditions than if only the semirange of stress were shown, as is usual for completely reversed stresses. Determinations were made at only one mean stress for the valve-spring wire.

The limiting ranges of pulsating tensile stress, determined in the same way, at 6 different mean stresses, are shown in figure 13 for the heat-treated galvanized bridge wire and in figure 14 for the cold-drawn galvanized bridge wire.

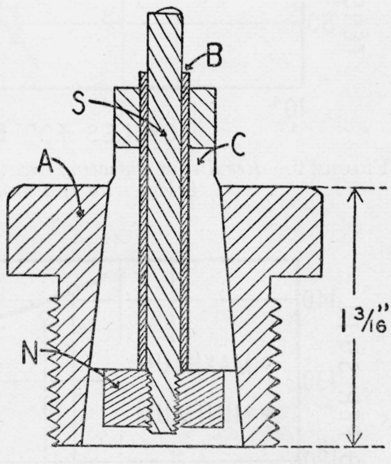

FIGURE 7.—*Gripping device for attaching specimens of wire to Haigh alternating-stress testing machine.*

The fatigue limits for complete reversal of stress, as determined by the rotating-beam method on the galvanized heat-treated bridge wire and on polished specimens machined from the wire, are also shown in figure 13. It was not possible to make rotating-beam tests on the cold-drawn galvanized bridge wire and on the electrogalvanized wire on the long-span machine because of the curvature of the wires, imparted in drawing as they were coiled on the take-up blocks. The rotating-beam fatigue limit obtained on short polished specimens machined from the cold-drawn bridge wire is shown in figure 14. In this figure are plotted also the maximum and minimum stresses of the limiting ranges of pulsating tensile stresses determined at 5 mean stresses for the electrogalvanized wire (EG, table 1.) Curves connecting the plotted points were not drawn, but it is evident that they would be practically parallel to those for the galvanized bridge wires.

[14] A much more elaborate method for gripping wire specimens for tests in the Haigh machine was described by R. Goodacre in Engineering, **137**, 503 (1934).

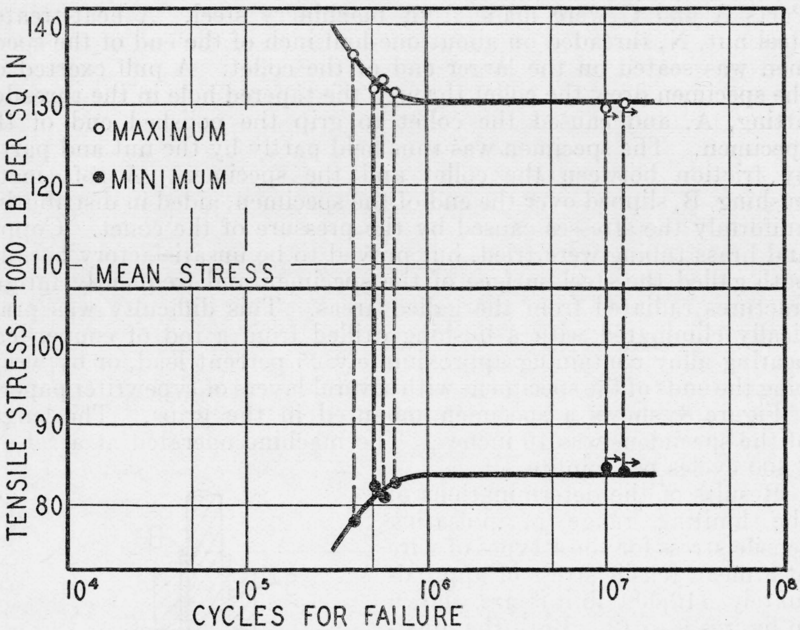

FIGURE 9.—*Results for pulsating tensile-stress fatigue tests on heat-treated galvanized bridge wire at a mean stress of 107,000 lb/in.*^{2}

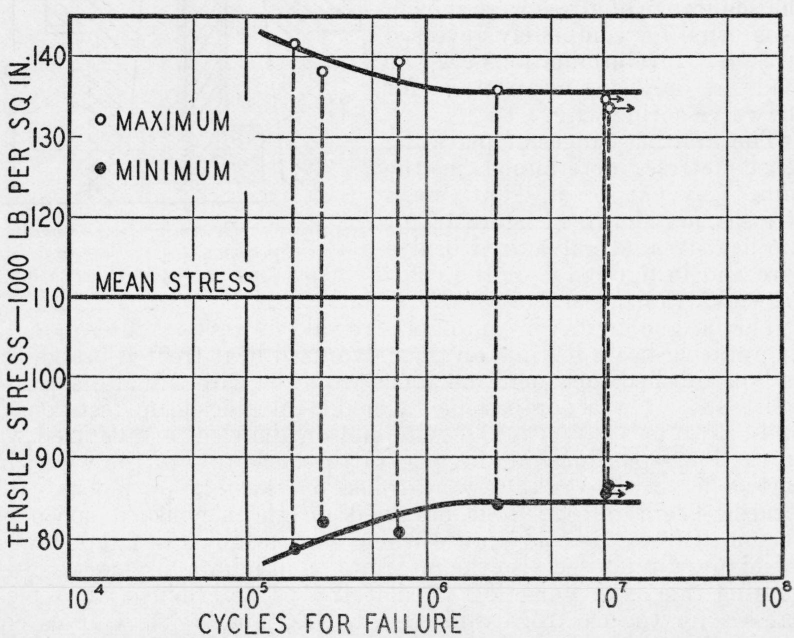

FIGURE 10.—*Results for pulsating tensile-stress fatigue tests on cold-drawn galvanized bridge wire at a mean stress of 110,000 lb/in.*^{2}

It was not practicable to make determinations of the limiting ranges of tensile stress on the galvanized wires at mean stresses much below the lowest value used, because it is necessary to maintain a minimum stress of about 10,000 lb/in.² to keep the wire straight. The capacity of the machine did not permit tests to be made on these wires at mean stresses higher than those used.

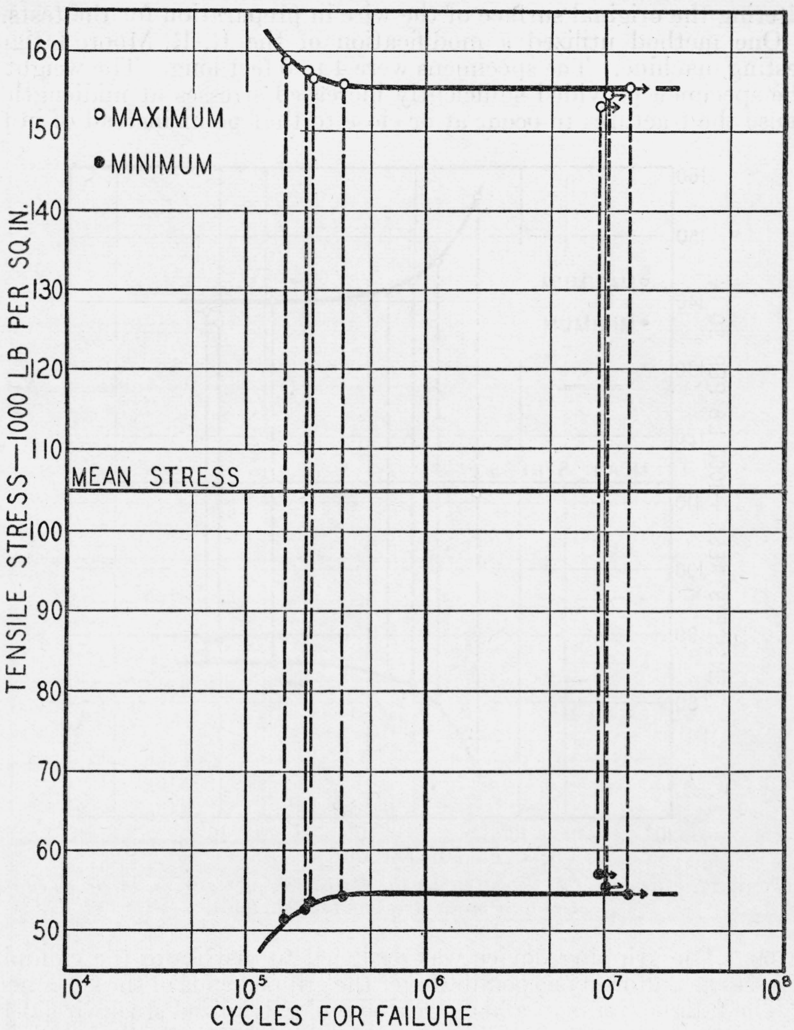

FIGURE 11.—*Results for pulsating tensile-stress fatigue tests on Swedish valve-spring wire at a mean stress of 105,000 lb/in.²*

For the 3 types of galvanized wire the limiting range of pulsating tensile stress was slightly greater at the lowest mean stress, 50,000 lb/in.², than at any of the higher mean stresses employed and was practically the same for all the mean stresses above 50,000 lb/in.² For the Swedish valve-spring wire the limiting range of pulsating tensile stress was about twice as great as those obtained on the 3 zinc-coated wires at approximately the same mean stress. By the rotating-beam tests the fatigue limit of this valve-spring wire was 30 percent higher than that obtained on the heat-treated galvanized bridge wire.

IV. SUMMARY

Two methods were devised for fatigue testing of steel wire without altering the original surface of the wire in preparation for the tests.

One method utilized a modification of the R. R. Moore fatigue-testing machine. The specimens were 4 to 6 feet long. The weight of the specimen provided sufficiently increased stresses at midlength to cause the fractures to occur at or close to that point instead of in the

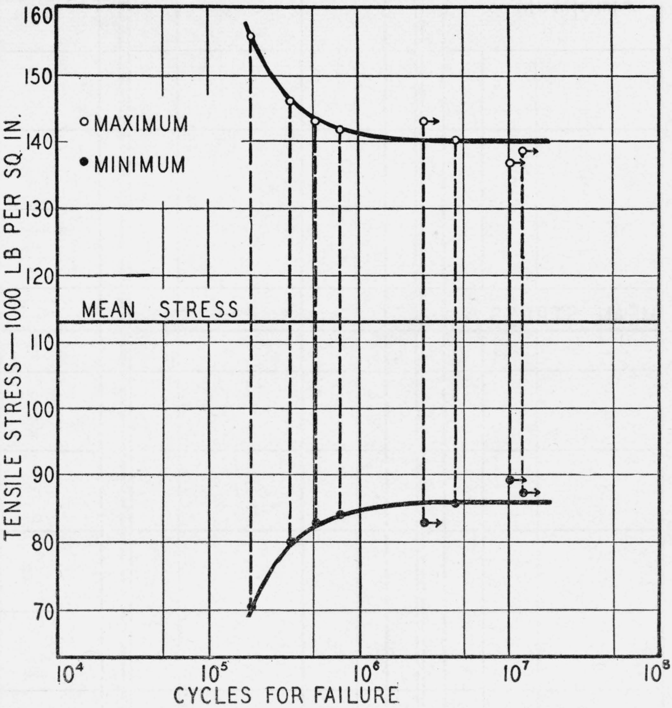

FIGURE 12.—*Results for pulsating tensile-stress fatigue tests on electrogalvanized wire at a mean stress of 113,000 lb/in.*[2]

grips. The gripping device was designed to distribute the clamping stresses as uniformly as possible over the gripped ends of the specimens.

The fatigue limits of a heat-treated and galvanized steel wire, 0.192 inch diameter, a Swedish valve-spring wire 0.162 inch diameter, and a cold-rolled mild steel wire 0.187 inch diameter were 45, 60, and 82 percent, respectively, of the fatigue limits obtained on short (3-inch length) machined and polished specimens of the same materials, with the diameters of the 2 larger wires reduced to 0.150 inch and that of the smallest to 0.130 inch.

With the use of a suitable gripping device it was found possible to make fatigue tests in the Haigh alternating-stress testing machine on specimens of wire with the original surface unaltered in the test

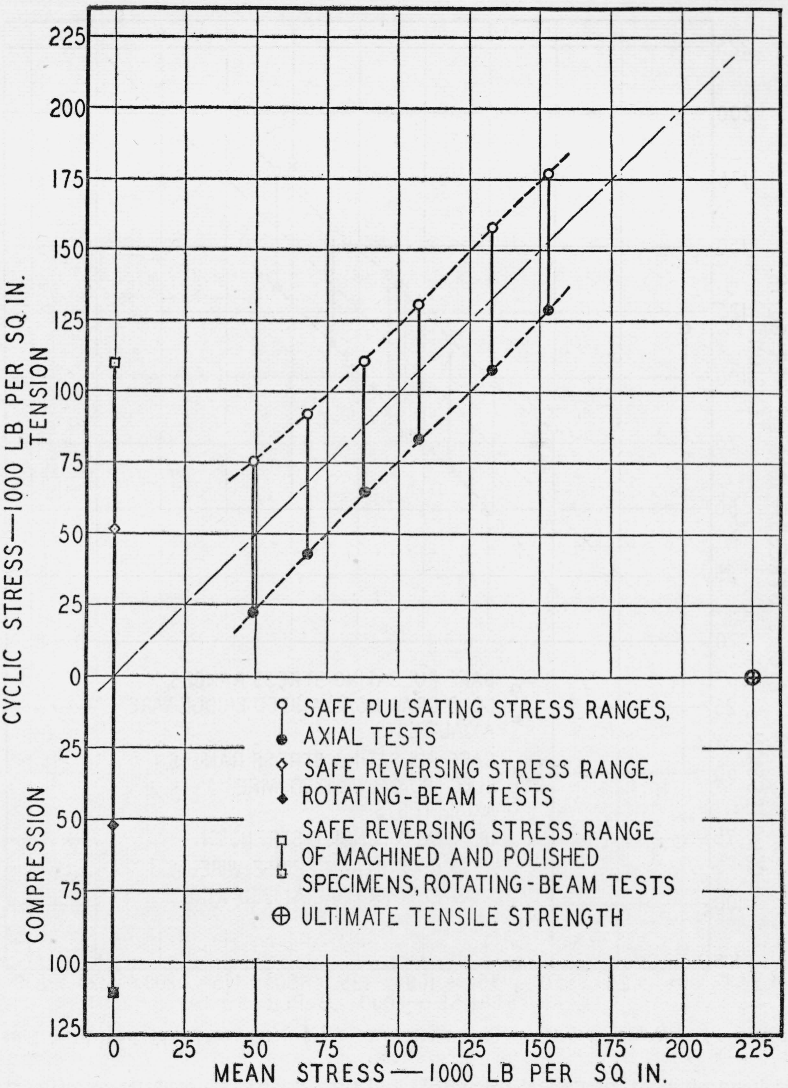

FIGURE 13.—*Relation between mean stress and limiting ranges of pulsating tensile stress.*

Heat-treated galvanized bridge wire

100452—35——3

length. The limiting ranges of pulsating tensile stresses were determined at various mean stresses between 50,000 and 200,000 lb/in.[2] on cold-drawn and galvanized, and heat-treated and galvanized, steel bridge wires, and on a high-strength steel wire electroplated with zinc.

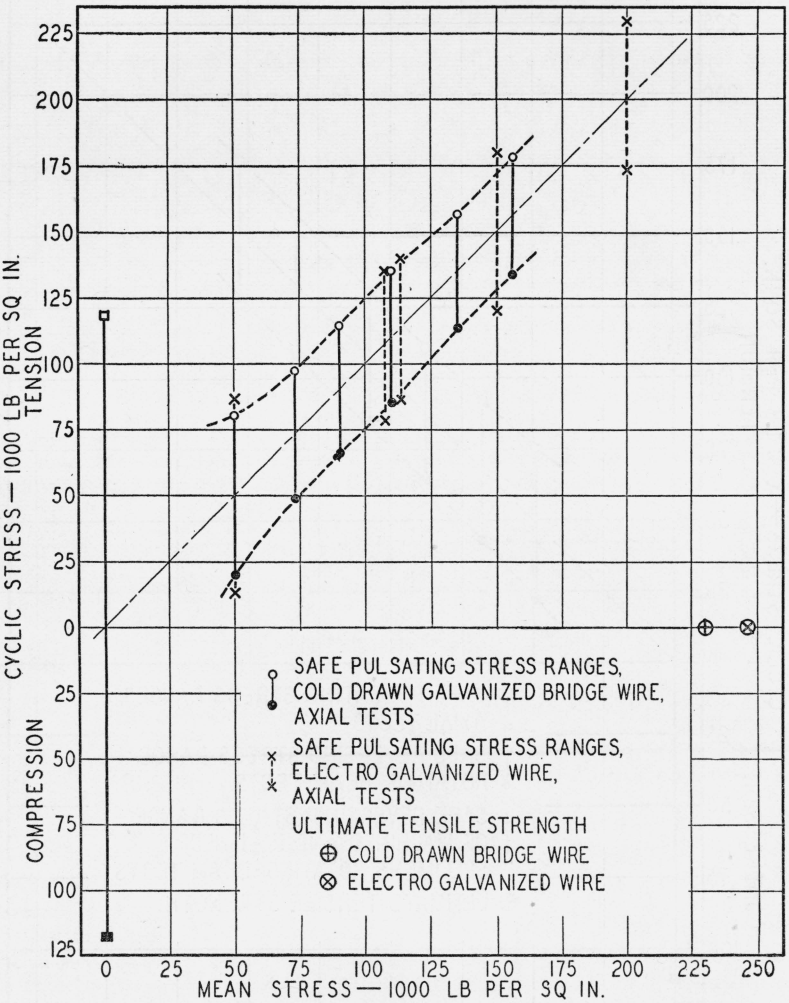

FIGURE 14.—*Relation between mean stress and limiting ranges of pulsating tensile stress.*

Cold-drawn galvanized bridge wire and electrogalvanized wire. Points on zero ordinate show safe reversing stress range of machined and polished specimens of cold-drawn bridge wire according to rotating-beam tests.

The results showed that the limiting ranges of pulsating tensile stresses were practically independent of the mean stress within the range investigated.

WASHINGTON, November 28, 1934.