1953

Prestressed timber, June 1953

J. W. McNabb

June 8, 1953

Department of Civil Engineering and Mechanics
Lehigh University
Bethlehem, Pennsylvania

Attention: Professors W. J. Eney and J. O. Liebig

Gentlemen:

The following report is presented in fulfillment of the requirements for C.E. 404, Structural Research.

To the best of my knowledge, the investigation of the feasibility of prestressing timber is original research. All of the experimental work was performed at Fritz Engineering Laboratory under the auspices of the Lehigh University Institute of Research.

The efforts which you gentlemen and Fritz Engineering Laboratory personnel expended in making the project a success is sincerely appreciated.

Yours very truly,

John W. McNabb

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Introduction

This report presents the results of the Prestressed Timber Project conducted at the Fritz Engineering Laboratory, Lehigh University during the school year 1952-53.

Although this report is not intended to be a design manual, it is important to consider the factors which influence the selection of a working stress and to consider their relationship to any new factors introduced by prestressing.

"Working stresses are not derived directly from laboratory-test values but rather are based on determination of intermediate basic—stress values for defect-free wood. Values for basic stress are, in effect, working stresses for clear, straight-grained lumber."[1]

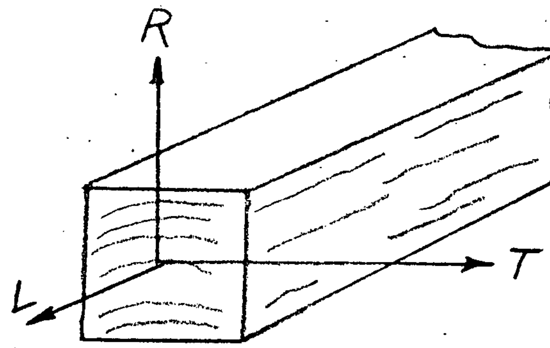
In the derivation of basic-stress values , consideration has been given to:

(1) Variability in the strength of clear wood—"consideration must be given not to the material of average strength but to the weakest piece that may be used". Tests have shown that a major fuctor contributing to the varialility in the modulus of rupture is the density of the wood and specifications now include a density criterion for southern pine and Douglas fir.

(2) Duration of load—"Tests have demonstrated that the load required to break beams in long time loading is about two-thirds of that required to break them under ordinary static loading in the laboratory. When the duration of stress is shortened still further, as in impact loading, the load required to break a timber is increased over that observed in static bending tests."[1]

1. Frederick F. Wangaard, "The Mechanical Properties of Wood", Part 3, p. 206.

(3). Accidental overloading——this provision is made for the possibility of small accidential overloads to which the structure might be subjected.



Timber does not have the same elastic properties in all directions but exhibits characteristics according to the direction of the applied force with respect to the grain and the annual growth rings.

The above notation is:

T = an axis tangent to the growth rings.

R = an axis radial with respect to the growth rings.

L = a longitudinal axis.

"Two principal theories have been advanced to account for the discrepancies among compressive, tensile and bending properties of wood."

1. Bach-Baumann Theory. - "The older theory, advanced by Bach and Baumann explains the bending behavior of a rectangular wooden beam by considering the stress-strain curves in direct tension and direct compression."[1] The direct tension curve and the direct compression curve is considered to represent the strain variation for the tension and compression fibers of the bent beam. The neutral axis shifts under this theory toward the tension side and the proper tension or compression value is obtained by equating area under the direct compression curve to area under the direct tension curve.

2. Newlin-Trayer Theory—"Newlin and Trayer advanced the theory that only by some supporting action among fibers could the variations in modulus of rupture and proportional limit with changes in depth and cross-section be explained."

"Briefly, the theory argues that the slender, hollow, tapering cells comprising the great mass of woody tissue act in compression somewhat like small Euler columns, restrained against buckling as a whole and partially restrained against buckling of the cell walls by their neighbors by means of the lignin encrustation which serves to bind the individual cells together."[1]

All test specimens used in these tests were Structural Grade Douglas fir (Coast Region) of nominal 2" X 6" cross section, surfaced on four sides to 1 5/8" x 5 5/8". Coupons used for making the test of small, clear specimens were sawed from the original stick used in each respective test. The timber used in these tests was obtained from the Brown-Borhek Lumber Company.

1. Albert G. H. Dietz, "Stress-Strain Relations in Timber Beams of Douglas Fir", p. 19

Notation

A	cross sectional area.
C	distance from neutral axis to extreme fiber.
e	end eccentricity of prestressing wire measured from the neutral axis.
ϵ	unit strain.
E	modulus of elasticity
I	moment of inertia of cross-sectional area.
K	radius of gyration
K_n	a buckling constant depending upon beam characteristics
l,L	span length.
M	bending moment
p, ρ	distance to a fiber on which stress is computed.
P	total transverse load; total force in prestressing wires.
Pcr	critical buckling load
S, S_ρ	mormal unit stress
T_H	horizontal component of total prestressing force
T_V	vertical component of total prestressing force.
Δ	deflection at centerline.

Notation used in section III-4 is defined as presented.

SECTION I

NON-PRESTRESSED BEAM TEST

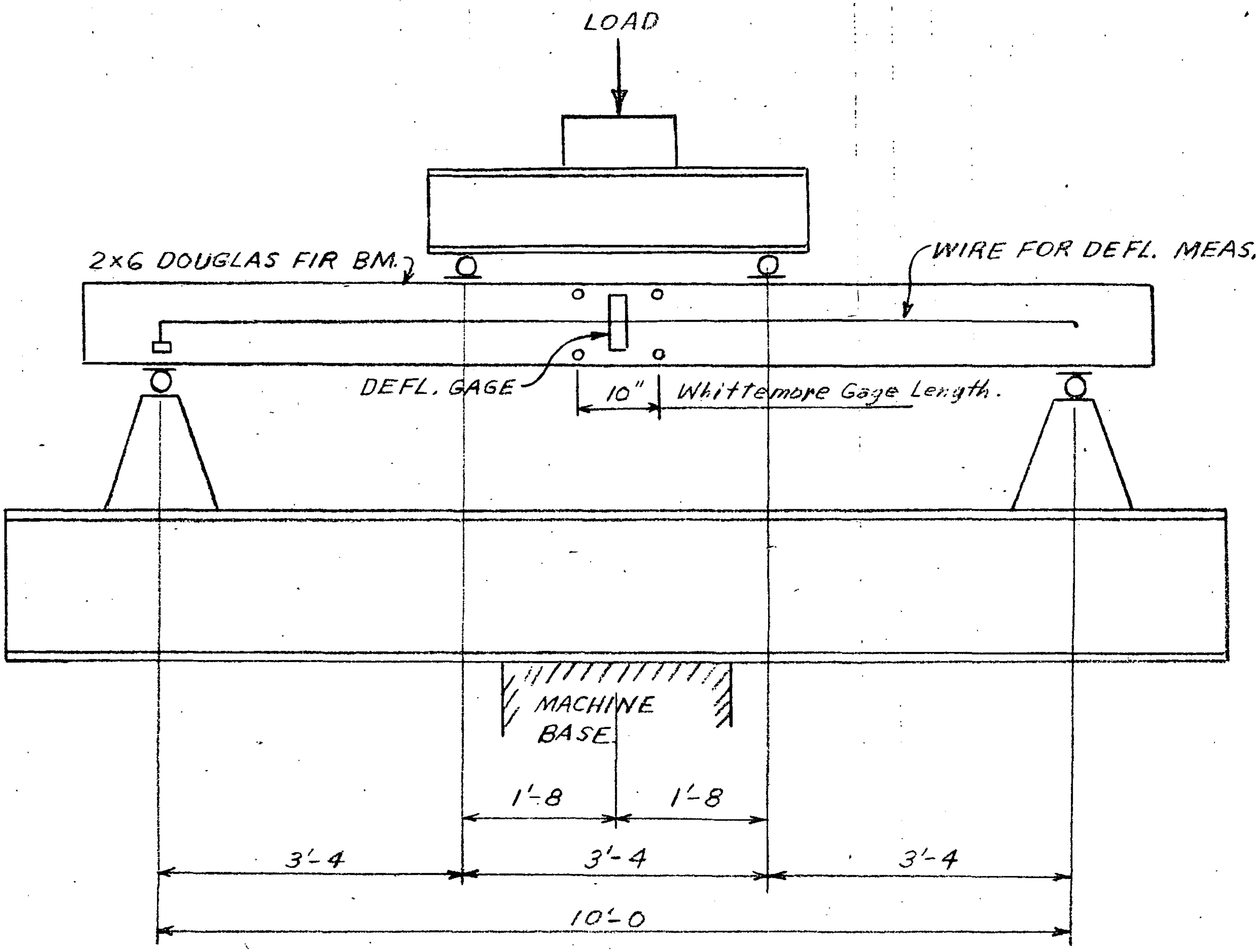
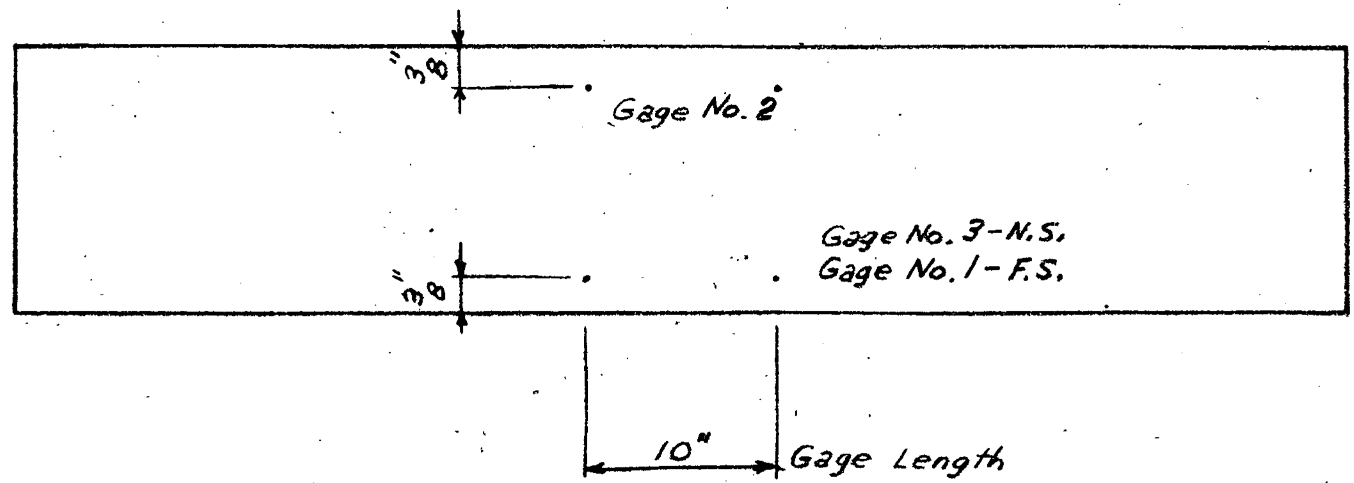


FIG. 1-1
TEST SET-UP



LOOKING SOUTH

WHITTEMORE GAGE POSITIONS

FIG. 1-2

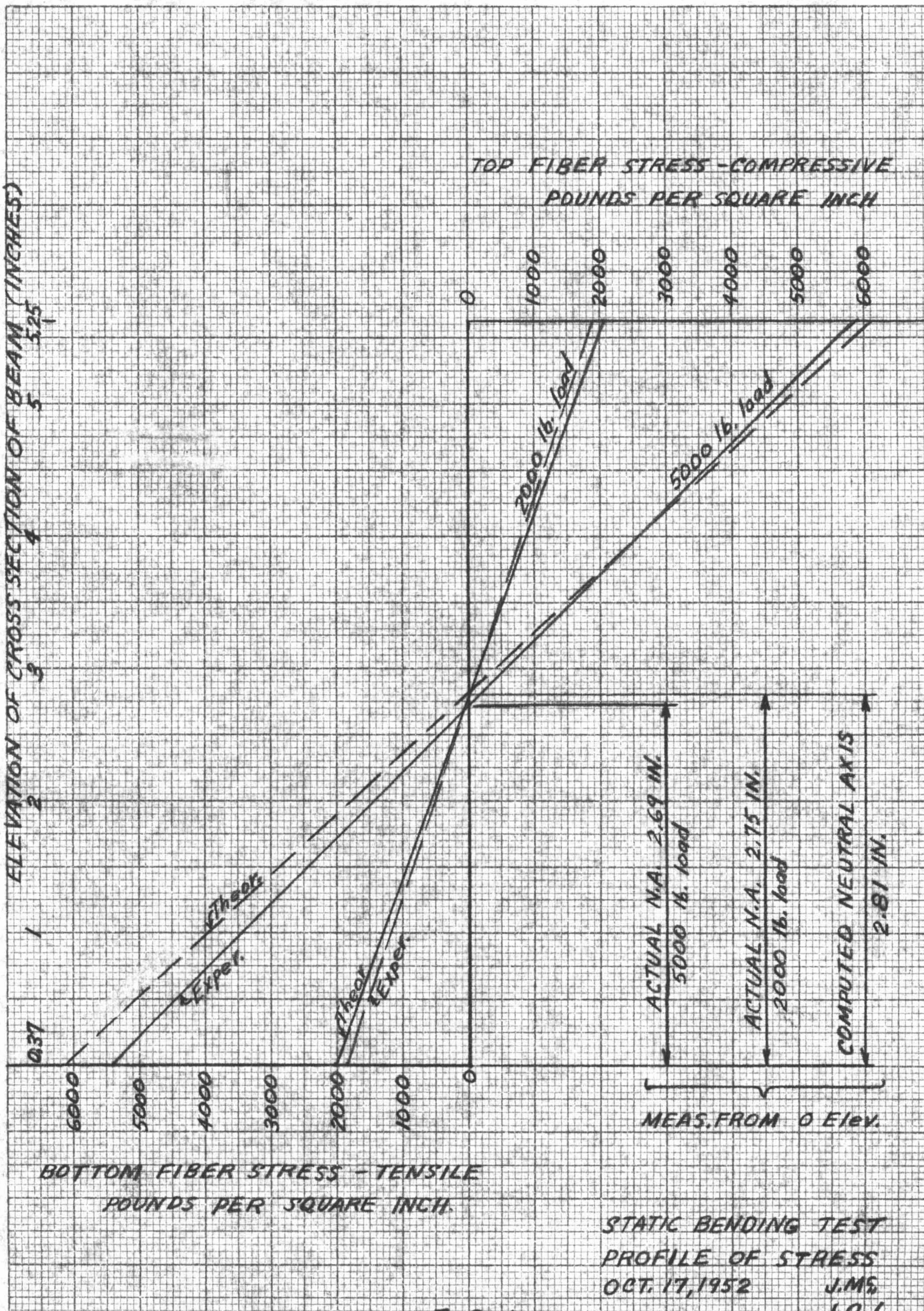

TOP FIBER STRESS - COMPRESSIVE
POUNDS PER SQUARE INCH
0
1000
2000
3000
4000
5000
6000
ELEVATION OF CROSS SECTION OF BEAM (INCHES)
5.25
5
4
3
2
1
0.37
2000 lb. load
5000 lb. load
℄ Theor.
℄ Exper.
℄ Theor.
℄ Exper.
ACTUAL N.A. 2.69 IN.
5000 lb. load
ACTUAL N.A. 2.75 IN.
2000 lb. load
COMPUTED NEUTRAL AXIS
2.81 IN.
MEAS. FROM 0 Elev.
6000
5000
4000
3000
2000
1000
0
BOTTOM FIBER STRESS - TENSILE
POUNDS PER SQUARE INCH.
STATIC BENDING TEST
PROFILE OF STRESS
OCT. 17, 1952
J.McC.
J.O.L.

FIG. 1-3

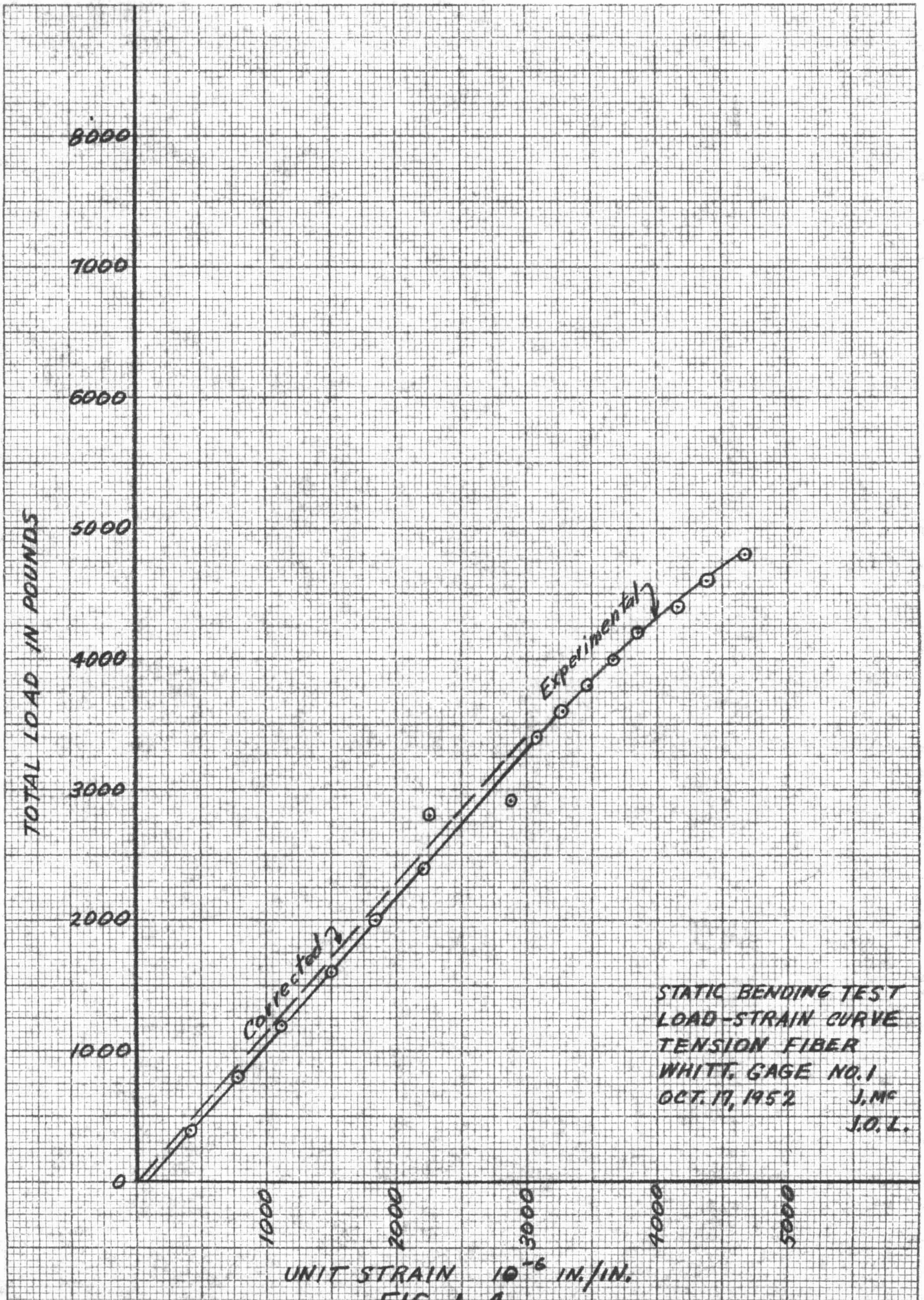

TOTAL LOAD IN POUNDS
8000
7000
6000
5000
4000
3000
2000
1000
0
1000
2000
3000
4000
5000
UNIT STRAIN 10^{-6} IN./IN.
Corrected
Experimental
STATIC BENDING TEST
LOAD-STRAIN CURVE
TENSION FIBER
WHITT. GAGE NO. 1
OCT. 17, 1952 J. Mc
J.O.L.

FIG. 1-4

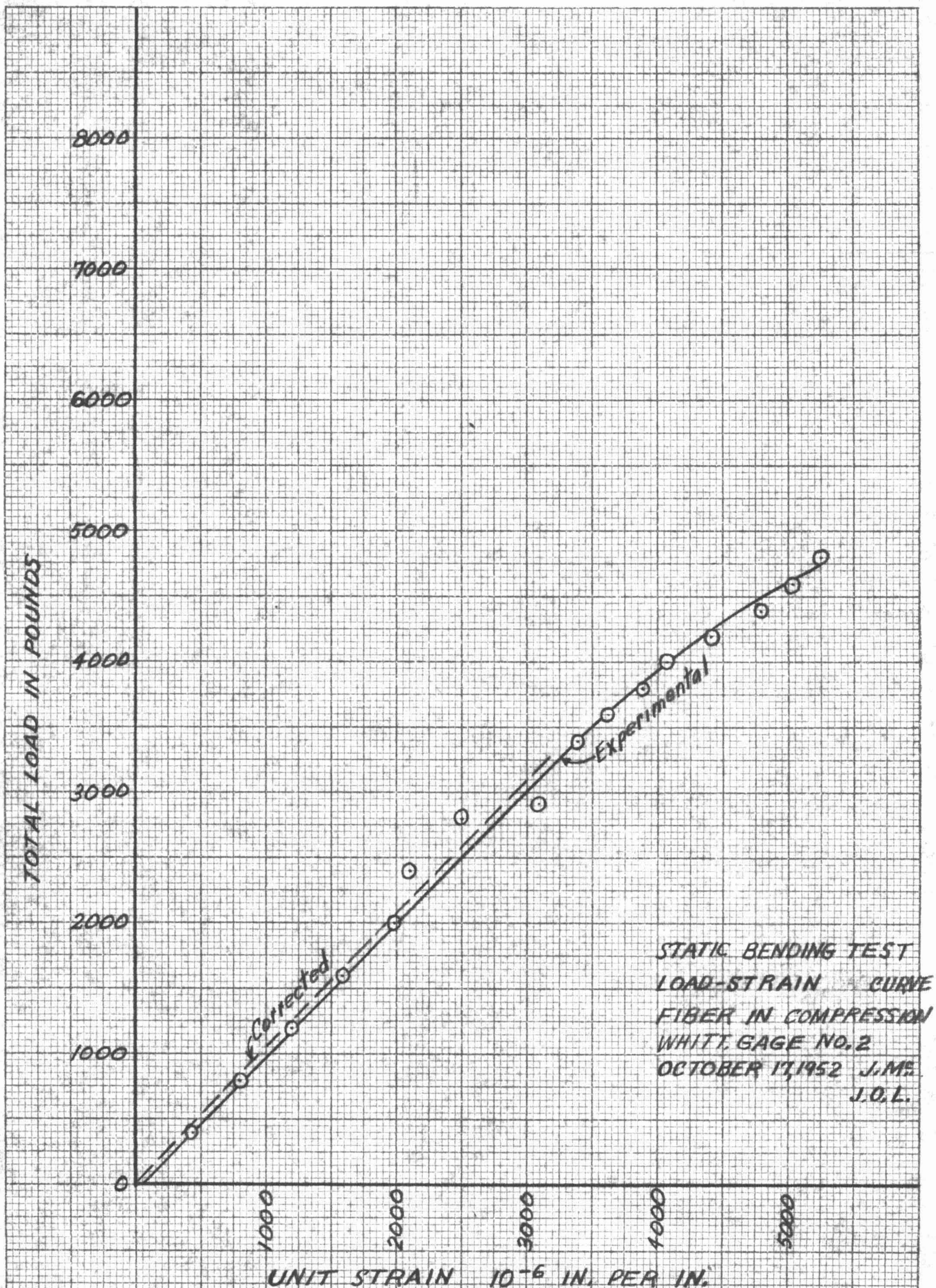

TOTAL LOAD IN POUNDS
8000
7000
6000
5000
4000
3000
2000
1000
0
1000
2000
3000
4000
5000
UNIT STRAIN 10^{-6} IN. PER IN.
Corrected
Experimental
STATIC BENDING TEST
LOAD-STRAIN CURVE
FIBER IN COMPRESSION
WHITT. GAGE NO. 2
OCTOBER 17, 1952 J. Mc.
J. O. L.

FIG. 1-5

7

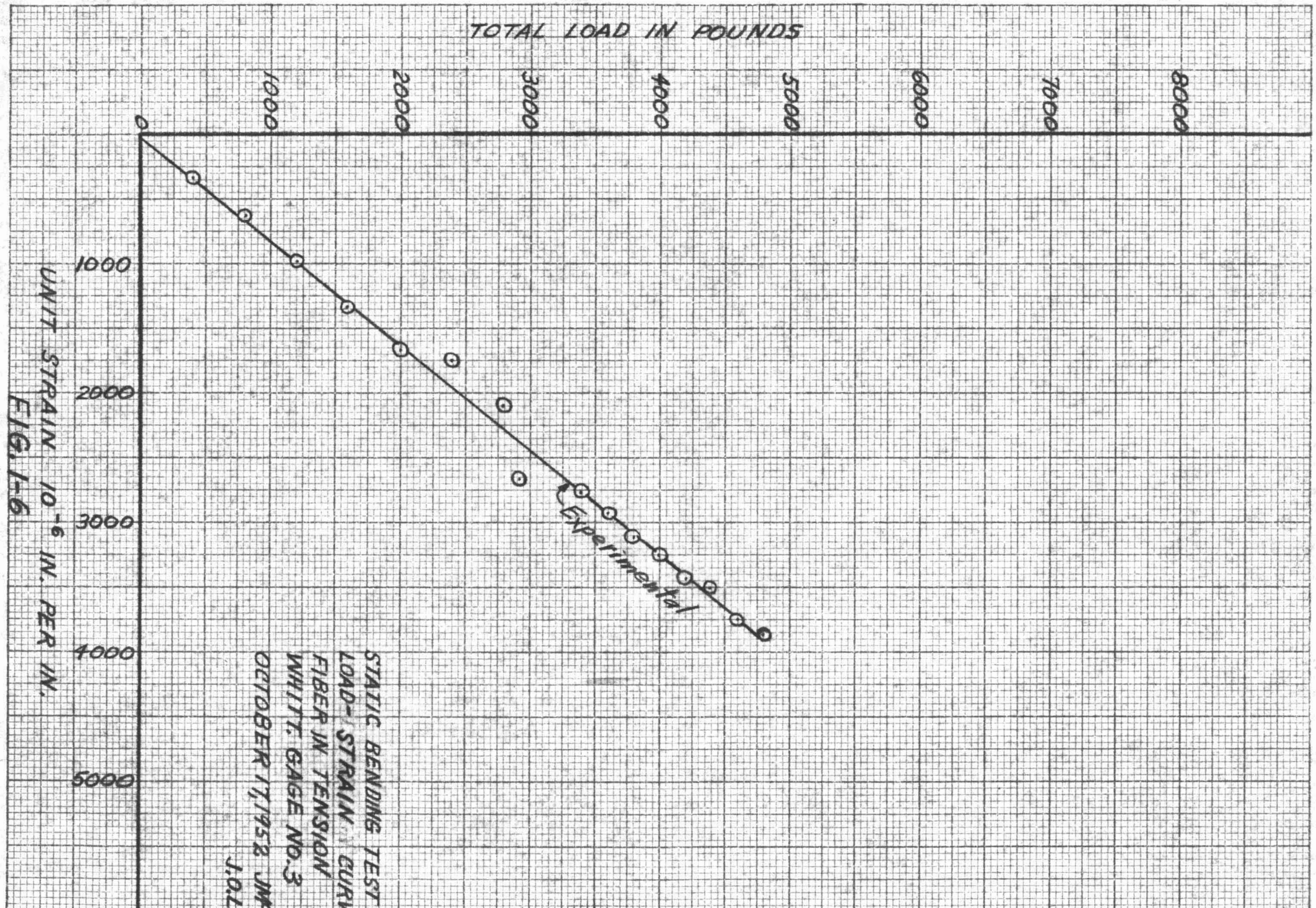
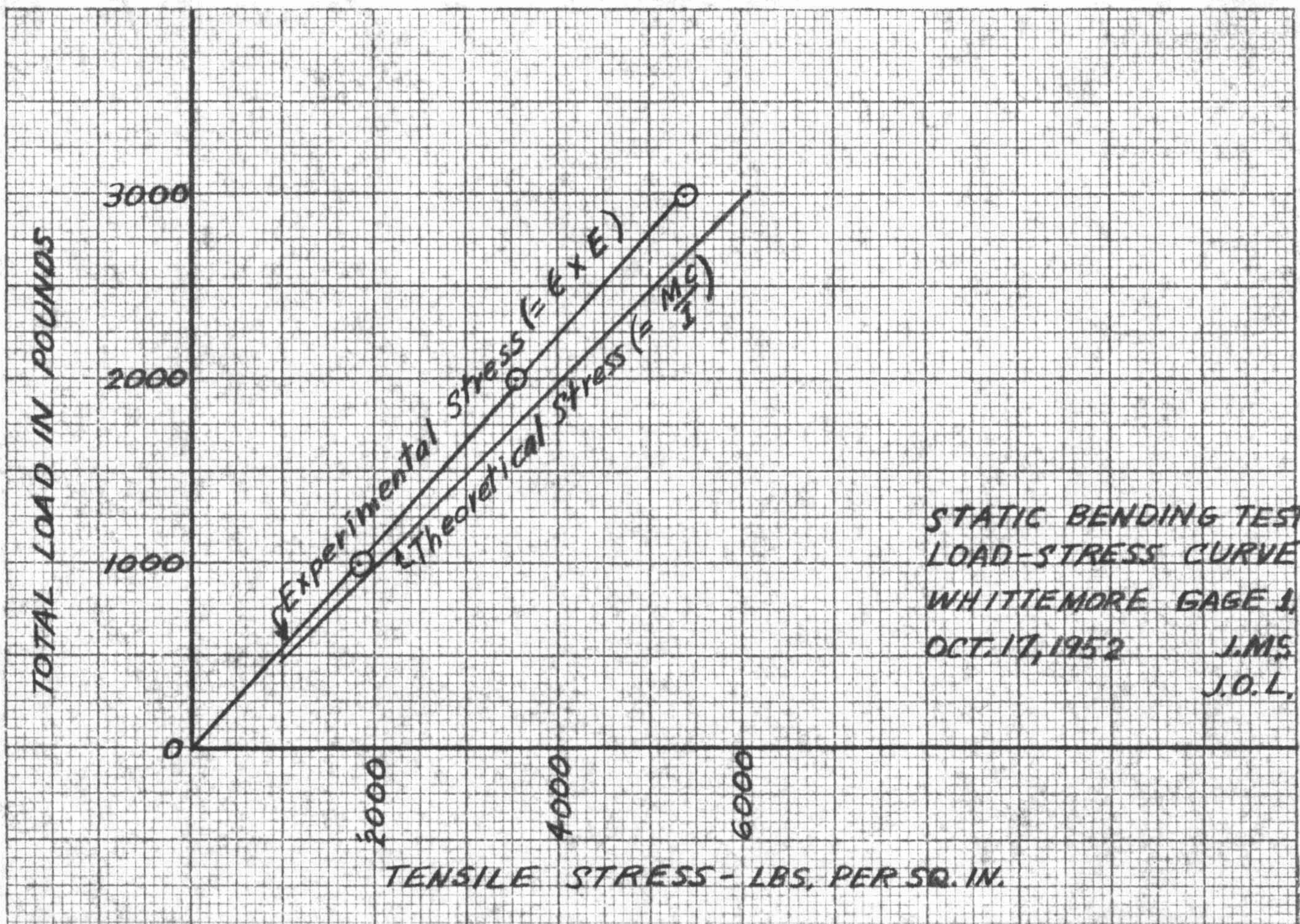

TOTAL LOAD IN POUNDS
0
1000
2000
3000
4000
5000
6000
7000
8000
UNIT STRAIN 10^{-6} IN. PER IN.
1000
2000
3000
4000
5000
Experimental
STATIC BENDING TEST
LOAD-STRAIN CURVE
FIBER IN TENSION
WHITT. GAGE NO. 3
OCTOBER 17, 1952 JMF
J.O.L.

FIG. I-6


TOTAL LOAD IN POUNDS
0
1000
2000
3000
2000
4000
6000
TENSILE STRESS - LBS. PER SQ. IN.
Experimental Stress (= ϵ x E)
Theoretical Stress (= Mc/I)
STATIC BENDING TEST
LOAD-STRESS CURVE
WHITTEMORE GAGE 1,
OCT. 17, 1952 J.M.S.
J.O.L.

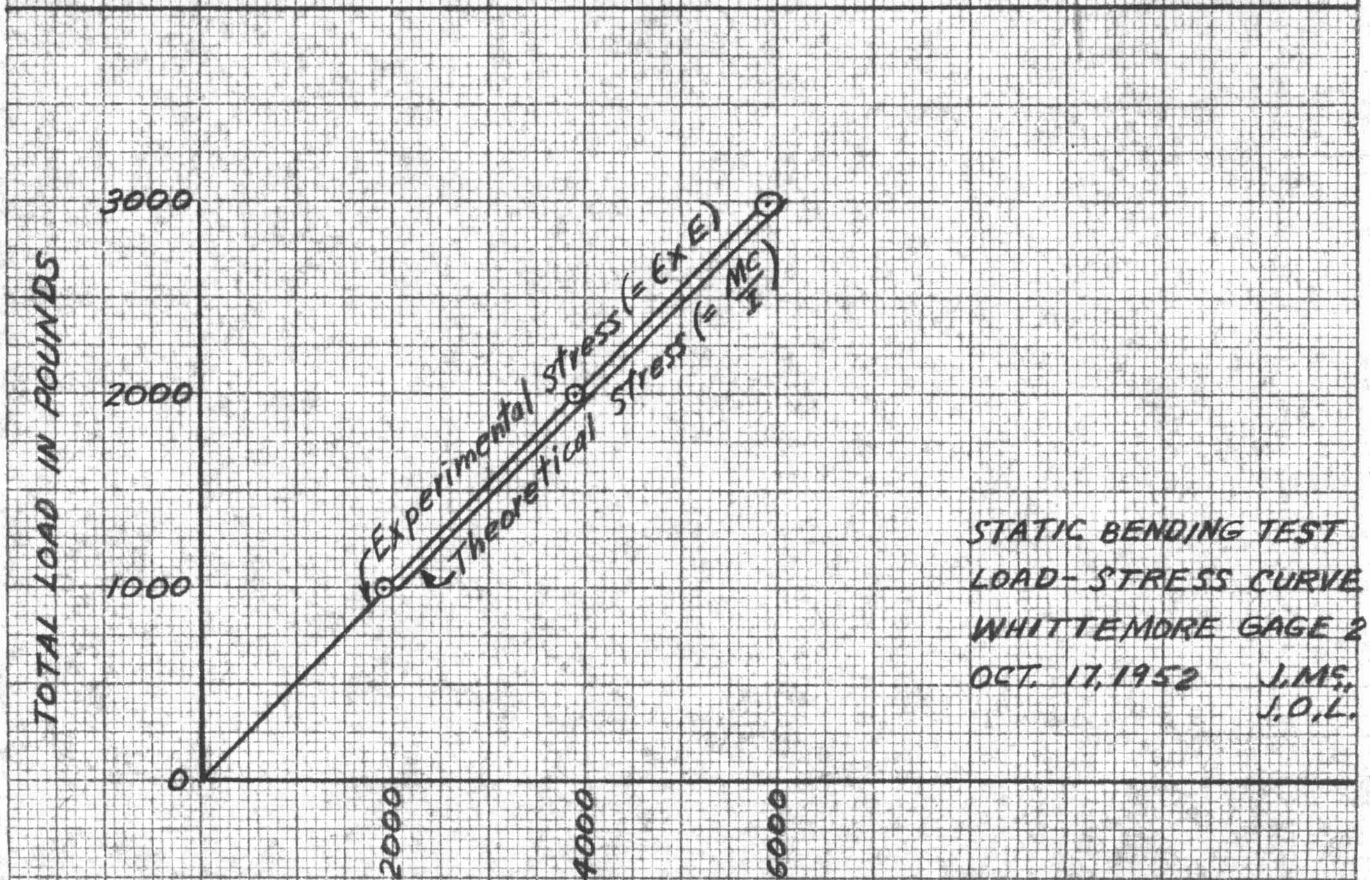

TOTAL LOAD IN POUNDS
0
1000
2000
3000
2000
4000
6000
COMPRESSIVE STRESS - LBS. PER SQ. IN.
Experimental stress (= ϵ x E)
Theoretical Stress (= Mc/I)
STATIC BENDING TEST
LOAD-STRESS CURVE
WHITTEMORE GAGE 2
OCT. 17, 1952 J.M.S.
J.O.L.

FIG. 1-7

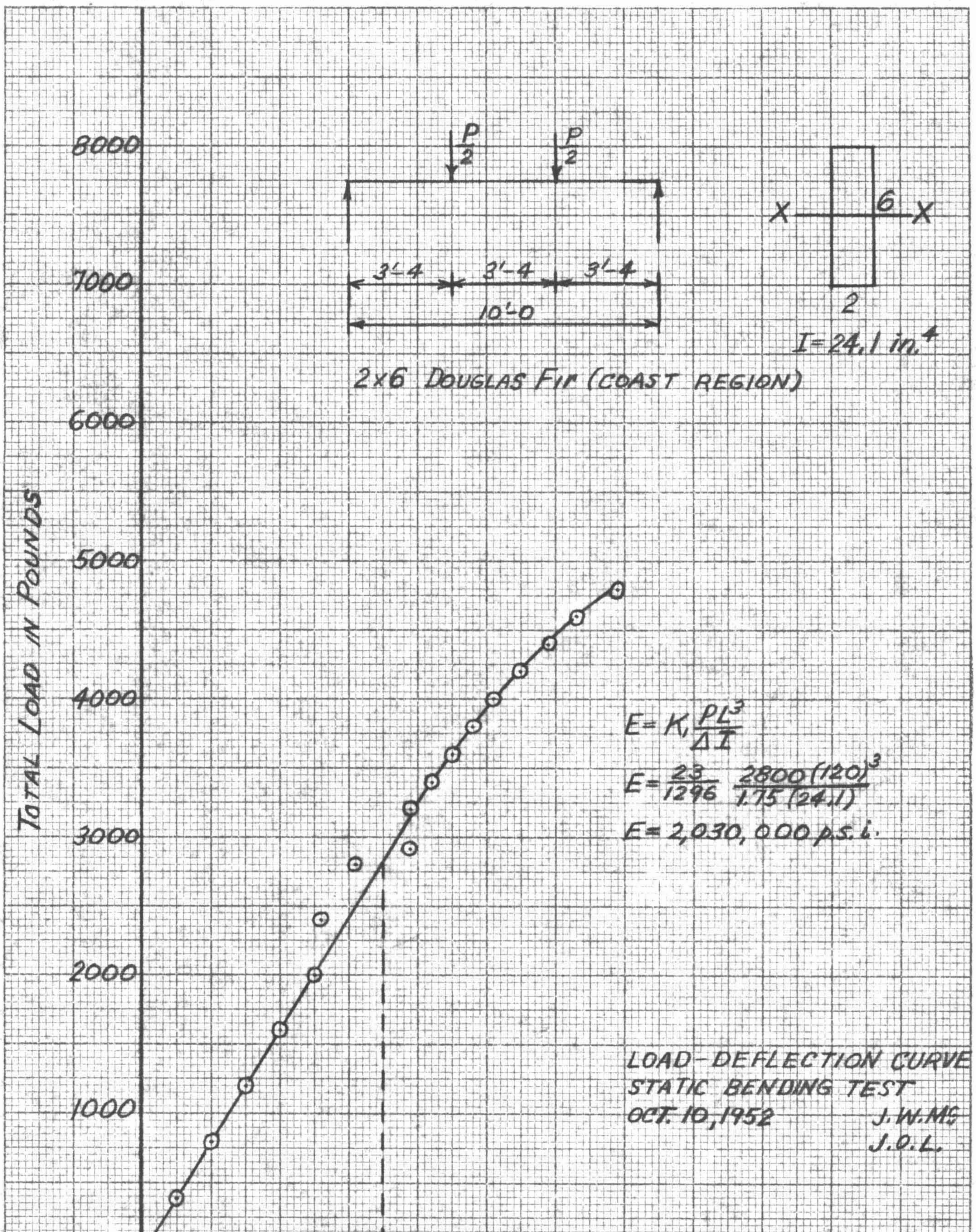

P/2
P/2
X
6
X
2
3'-4
3'-4
3'-4
10'-0
I=24.1 in.4
2×6 DOUGLAS FIR (COAST REGION)
8000
7000
6000
5000
4000
3000
2000
1000
0
TOTAL LOAD IN POUNDS
E= K, PL³/ΔI
E= 23/1296 2800(120)³/1.75(24.1)
E= 2,030,000 p.s.i.
LOAD-DEFLECTION CURVE
STATIC BENDING TEST
OCT. 10, 1952
J.W.Mc
J.O.L.
1.0
2.0
3.0
4.0
5.0
DEFLECTION AT CENTER IN INCHES.

FIG. 1-8

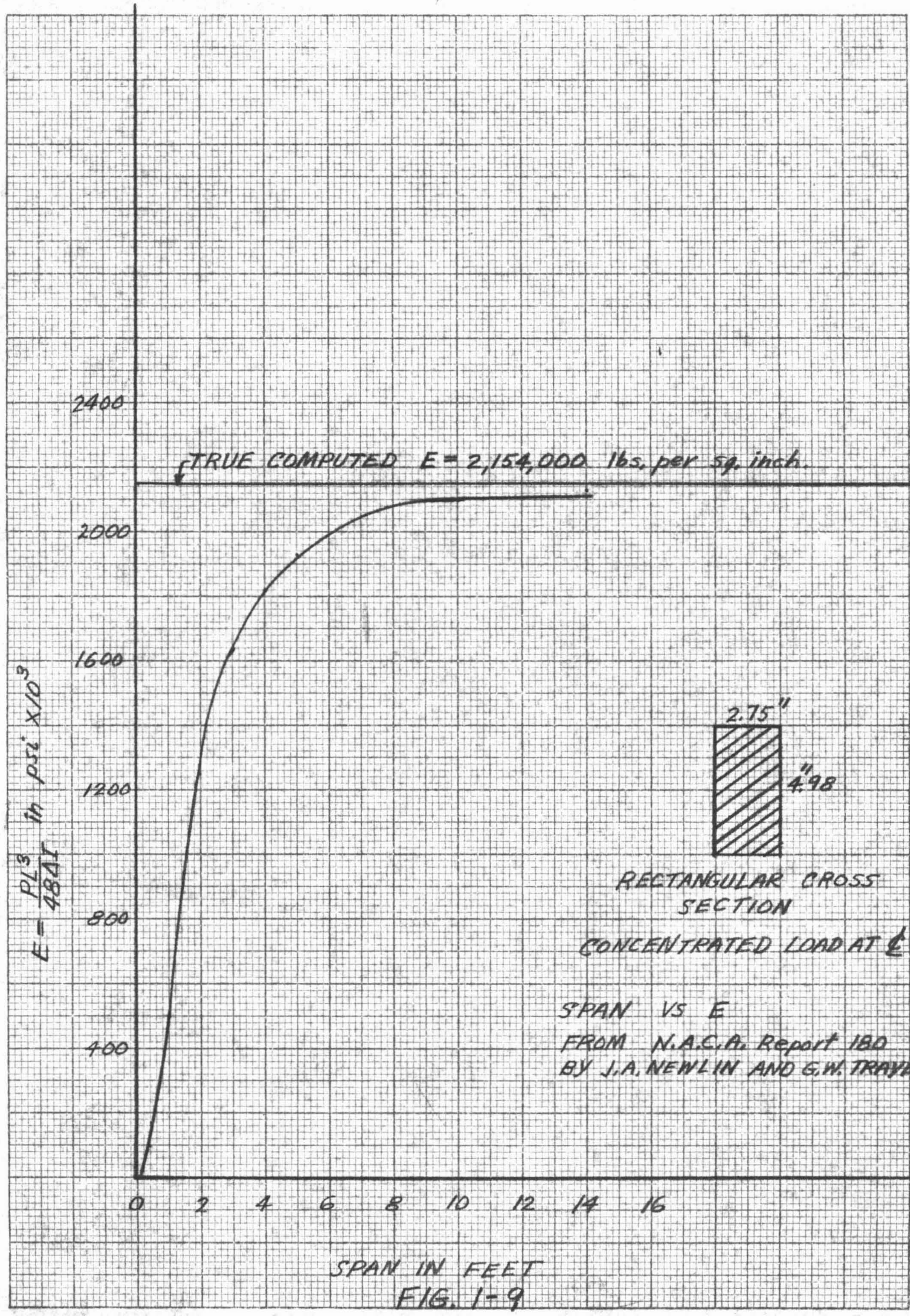
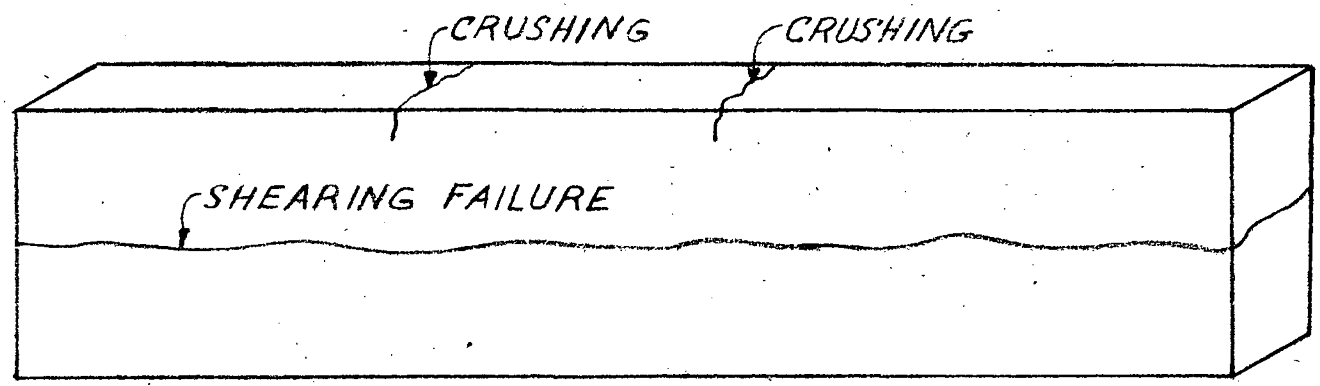

TRUE COMPUTED E = 2,154,000 lbs. per sq. inch.
2400
2000
1600
1200
800
400
E = PL³/48ΔI in psi x10³
2.75"
4.98"
RECTANGULAR CROSS SECTION
CONCENTRATED LOAD AT ℄
SPAN VS E
FROM N.A.C.A. Report 180
BY J.A. NEWLIN AND G.W. TRAYER
0
2
4
6
8
10
12
14
16
SPAN IN FEET

FIG. 1-9



SKETCH OF FAILURE

FIG. 1-10

Section I - Test of a Non-Prestressed Timber Beam

1. Object of the Test:

The object of this test was to test a beam of the same size as the pre-stressed beams under the same loading conditions for comparison with the results obtained on pre-stressed beams.

2. Test Procedure and Experimental Apparatus:

The test set-up for the static bending test is illustrated in Figure 1-1. A symmetrical, two point (or "third point") loading was selected since the bending moment distribution along the beam is similar to that for a uniform loading and the middle third of the beam is subjected to pure bending if we neglect the weight of the beam.

The rollers located at the ends and points of loading were free to move horizontally and the frictional forces at these points is negligible. Steel bearing plates were provided at the ends and points of loading to distribute the loads over a finite area and thus prevent the wood fibers from crushing locally. A 10" WF beam was placed across the testing machine base. The deflections of this steel beam were considered negligible since the loads which caused failure of the timber beam have small effect on a steel beam of this section.

The loads were applied by a 60,000 pound Baldwin-Southwark hydraulic testing machine. The lowest possible cross-head speed was used throughout the test.

Deflection measurements were made with a piano wire and a scale placed at the center of the span. The piano wire was attached to the beam at one end by means of a nail driven into the beam at the neutral axis and was hung over a nail at the other end. A weight attached at this end of the beam held the wire taut throughout the testing. The scale at the center of the span was divided into twenty divisions to the inch.

A Whittemore strain gage was used for strain measurements and 10" gage lengths were provided at the center of the span on both vertical faces at selected fibers as shown in Figure 1-2. Cylindrical steel Whittemore gage point receivers were attached to the timber beam with cement at the points mentioned above.

An initial load was applied to the beam and thereafter increments of load were applied as shown on page 76. When the machine load scale was changed from low to high range, there was a noticeable break in the readings. This can be attributed to poor initial adjustment of the scales.

3. Control Tests - small, clear specimens:

These tests were conducted in accordance with A.S.T.M. Standard Methods of Testing Small, Clear Specimens by Prof. J. O. Liebig and Mr. Howard Tchou with the results shown in Appendix A.

4. The Flexure Formula as Applied to Timber Beam Design or Analysis:

The following assumptions are generally made in deriving the flexure formula:

(a) The proportional limit is not exceeded.

(b) The modulus of elasticity in compression equals the modulus of elasticity in tension and is a constant.

(c) Strain is proportional to the distance of the fibre from the neutral axis.

(d) Plane section before bending remains a plane section after bending.

(e) The loads act in the plane which contains the centroidal axis of the beam.

(f) Shearing strains are neglected.

The flexure formula states: $S = \frac{Mp}{I}$

in which S = unit stress, due to bending, on a fiber at a distance p from the neutral axis of the cross-section.

I = moment of inertia of the cross-sectional area about the neutral axis.

M = bending moment at the section considered.

p = distance from the nuebral axis to the fiber on which the stress is desired.

The results of this test are analyzed at the end of this section and the effectiveness of the flexure formula discussed.

Hansen in "Modern Timber Design" says "Since the strength of wood in tension and compression along the grain is very different, being much greater in tension, it probably seems unreasonable that wood beams should behave in a manner similar to homogeneous or isotropic materials.[1]

Form factors have been devised to alter the flexure formula as applied to various cross sections in order that design and analysis results obtained more nearly approach experimental results. The reader is referred to "Form Factors of Beams Subjected to Transverse Loading Only", by J. A. Newlin and G. W. Trayer, Tech. Bull., 1310, U. S. Dept. Agr., 1941, for further information on form factors.

The Modulus of Rupture affords a means of comparison of the ultimate strength of beams. It is not, however, the stress in a fiber when the ultimate load was applied. For this particular beam, we have:

$$M.R. = \frac{M_{max.}C}{I} = \frac{2500(40)2.81}{24.1} = 11,650 \text{ psi.}$$

[1] Howard J. Hansen, "Modern Timber Design", p. 52

5. (a) Tabulation showing stresses computed from experimental data.

$S = E\epsilon$

Tensile Stress (Whittemore Gage No. 1)

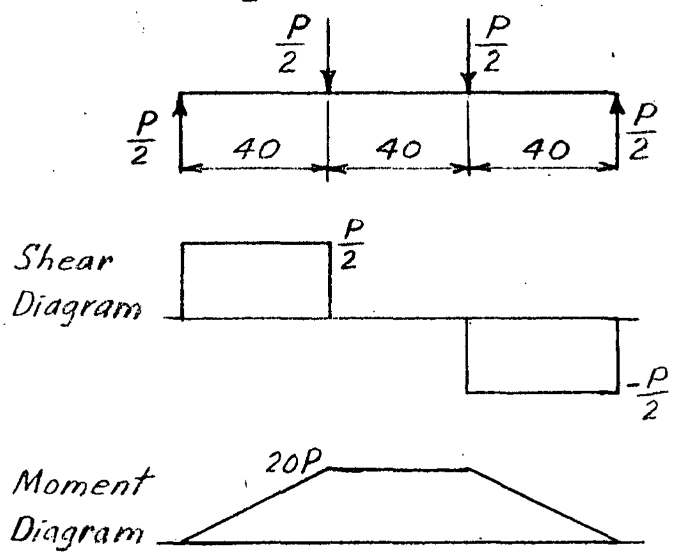
Beam Load	Unit Strain ($\times 10^{-6}$)	Modulus of Elasticity	Stress
1000 lb.	900 in./in.	2.03×10^6 psi.	1830 psi
2000	1750		3560
3000	2650		5400

Compressive Stress (Whittemore Gage No. 2)

Beam Load	Unit Strain ($\times 10^{-6}$)	Modulus of Elasticity	Stress
1000	950 in./in.	2.03×10^6 psi.	1920 psi
2000	1920		3900
3000	2900		5910

(b) Tabulation showing stresses computed by the flexure formula.

$S = \frac{Mc}{I}$ $M = 20P$ $c = 2.44$ $I = 24.1$ $S = \frac{20P(2.44)}{24.1} = 2.03P$



Beam Load	Tensile or Compressive Stress
1000	2030 psi.
2000	4060
3000	6090

6. Analysis of Data

The tabulations 5(a) and 5 (b) and Fig. 1-3 showing a profile of the stresses at the centerline of the beam verify rather closely the flexure formula as applied to a rectangular section with a form factor equal to unity. These data support the theory regarding a shift of the neutral axis toward the tension side of the beam. Each fiber on the compression side is considered to be a Euler column. The fibers at the extreme top of the beam are stressed more than those near the neutral axis. The theory is advanced that the less stressed fibers lend support to the most stressed fibers and that local compression failure by crushing can take place at the top of the beam with the result being a shift in the neutral axis toward the tension side of the beam.

Figs. 1-4, 1-5, and 1-6 show the variation of fiber unit strain with total external load in pounds. The location of these fibers is shown in Fig. 1-2. At a value of about 3500 lbs. of total external load the function becomes non-linear which indicates the proportional limit was reached.

Tensile or Compressive stress on each of two fibers is plotted versus total load in pounds in Fig. 1-7. Values up to 3000 lbs. were taken but values greater than 3500 were not taken since the stress-strain relationship is non-linear above this point. It can be observed that the theoretical and actual curves follow each other closely.

The values of the modulus of elasticity shown in the appendix obtained in the test of a small clear specimen of 28" span is 1.63×10^6psi. and the value obtained from the test of a 2" x 6" x 10'0" span as shown on Fig. 1-8 is 2.03×10^6psi. This discrepancy is largely due to the influence of shear. This variation of the modulus with the length of span is shown in Fig. 1-9 which is taken from

National Advisory Committee for Aeronautics Report 180 by Trayer and March.

7. Conclusion: Tho modulus of rupture for the simple beam was exactly equal to the modulus of rupture for Pre-stressed Beam Number One. A general conclusion cannot be drawn from such limited testing, but the decision was made to devise a better method of inducing the pre-stress. The revised method of pre-stressing is discussed in section III.

SECTION II

PRE-STRESSED BEAM NO. 1

Figure 2 - 1

Pre-stressed Beam Number One prior to test.

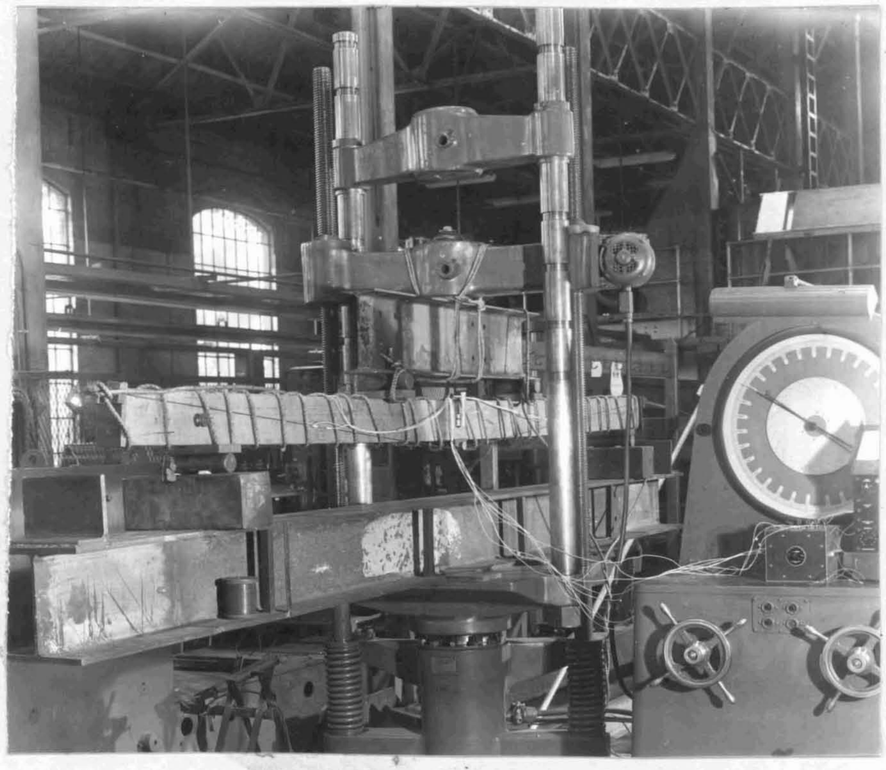


Figure 2 - 2

Pre-stressed Beam Number One in Testing Machine.

Figure 2 - 3

Pre-stressed Beam Number One in Testing Machine.

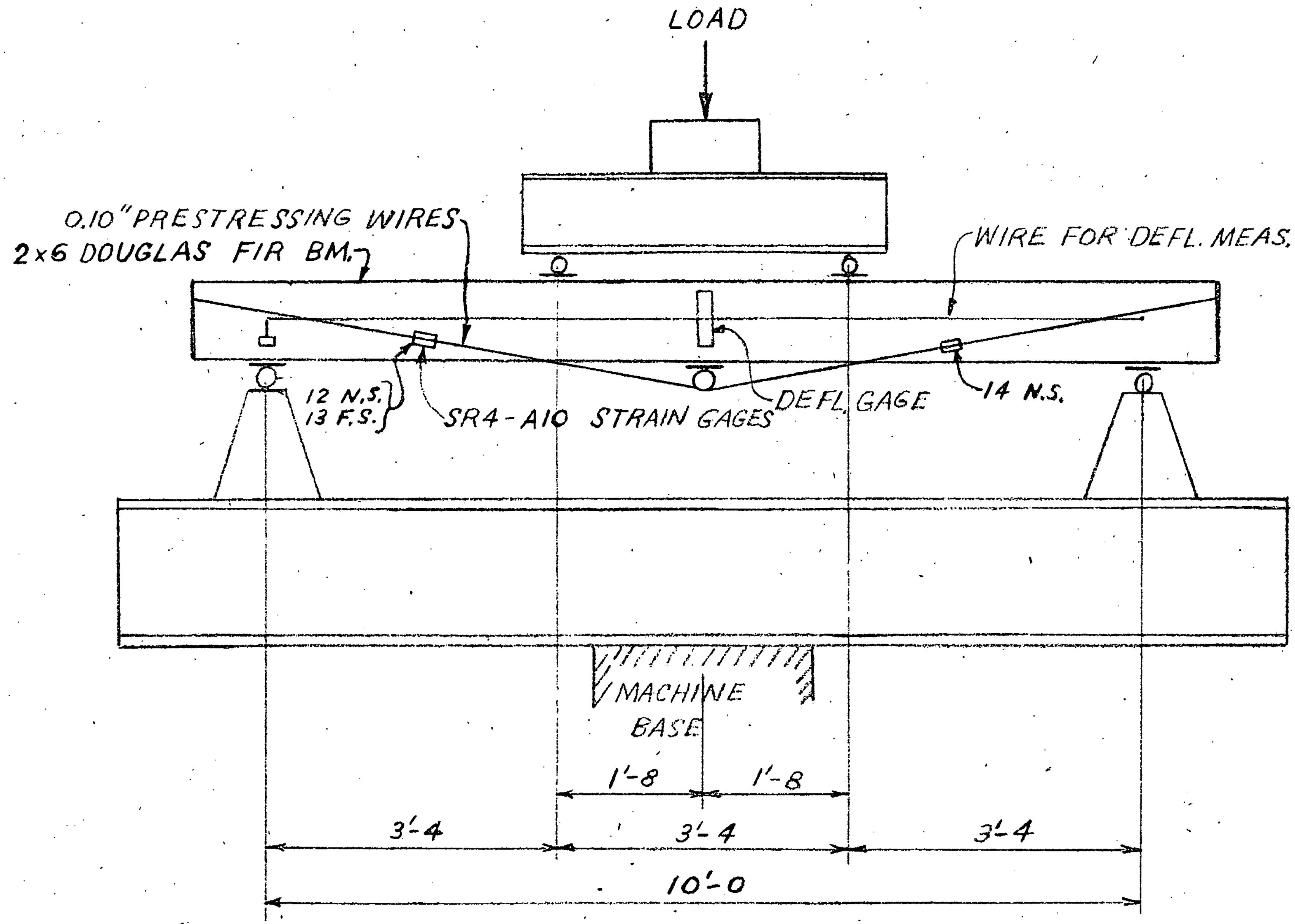


FIG. 2-4

TEST SET-UP PRE-STRESSED TIMBER BEAM

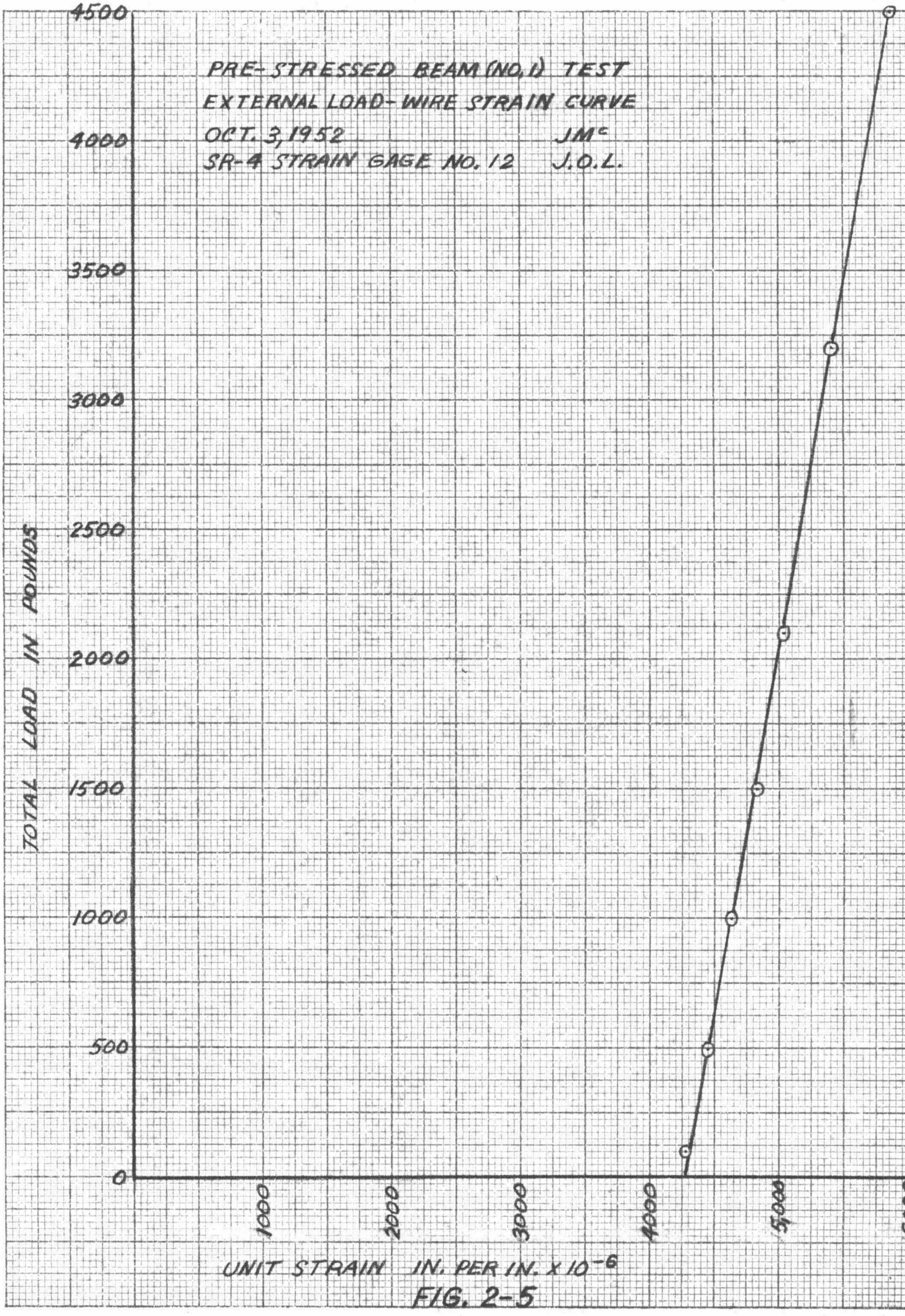

PRE-STRESSED BEAM (NO. 1) TEST
EXTERNAL LOAD- WIRE STRAIN CURVE
OCT. 3, 1952
JMc
SR-4 STRAIN GAGE NO. 12
J.O.L.
TOTAL LOAD IN POUNDS
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1000
2000
3000
4000
5000
6000
UNIT STRAIN IN. PER IN. x 10^-6

FIG. 2-5

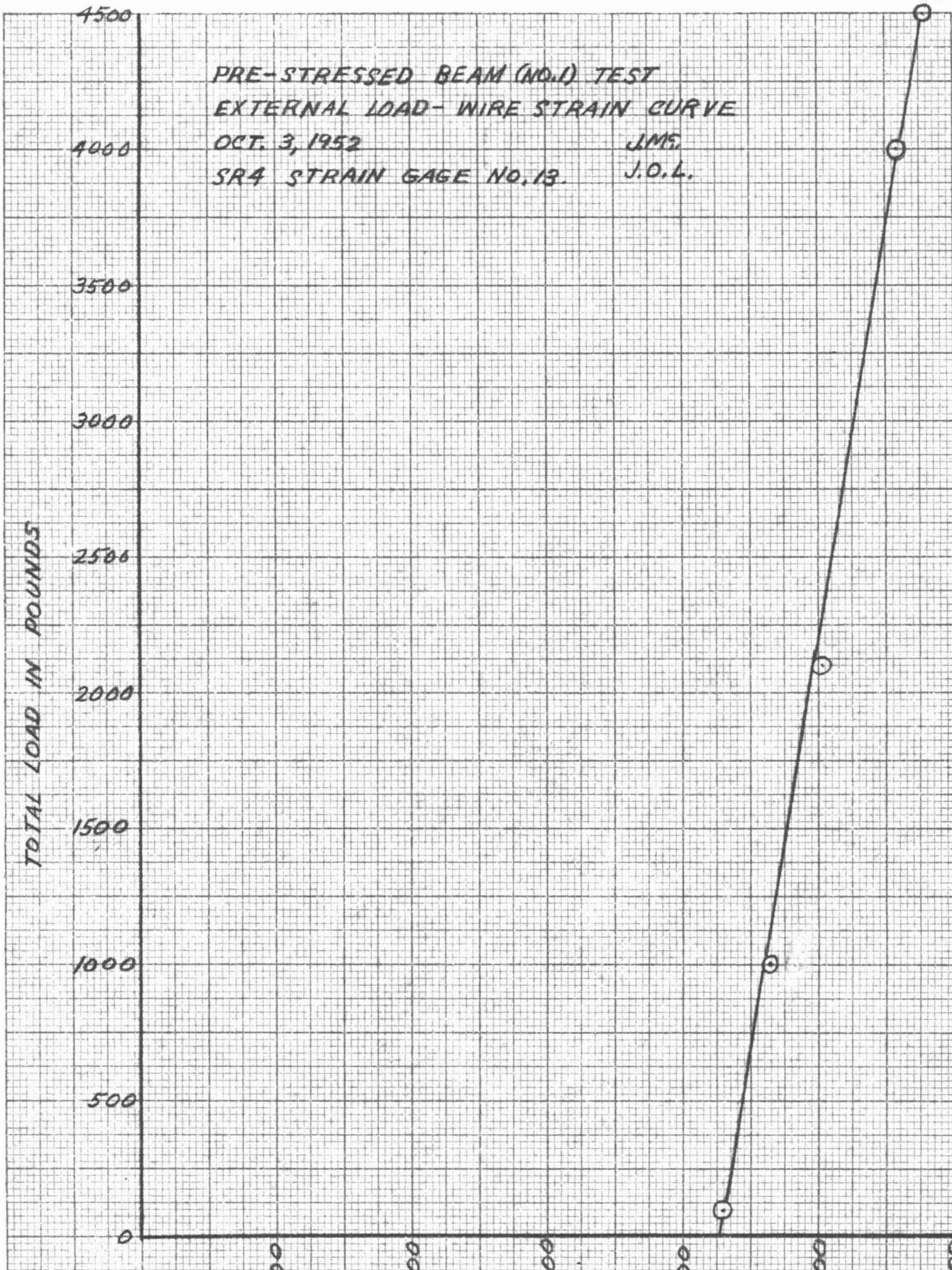

PRE-STRESSED BEAM (NO.1) TEST
EXTERNAL LOAD- WIRE STRAIN CURVE
OCT. 3, 1952
SR4 STRAIN GAGE NO. 13.
J.M.S.
J.O.L.
TOTAL LOAD IN POUNDS
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1000
2000
3000
4000
5000
6000
UNIT STRAIN (10^{-6}) IN. PER IN.

FIG. 2-6

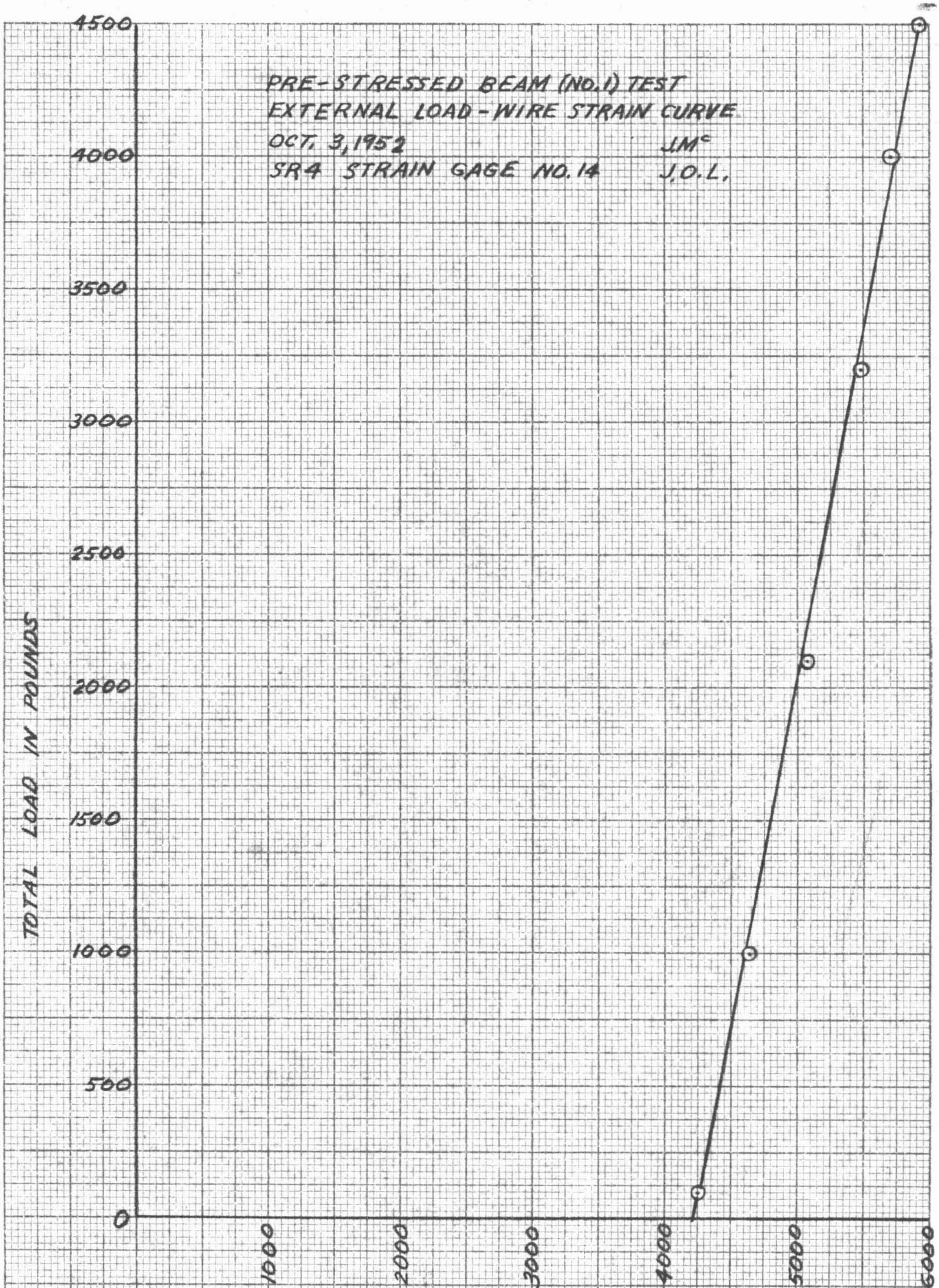

PRE-STRESSED BEAM (NO. 1) TEST
EXTERNAL LOAD-WIRE STRAIN CURVE
OCT. 3, 1952
SR4 STRAIN GAGE NO. 14
JMc
J.O.L.
TOTAL LOAD IN POUNDS
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1000
2000
3000
4000
5000
6000
UNIT STRAIN IN. PER IN X 10^-6

FIG. 2-7

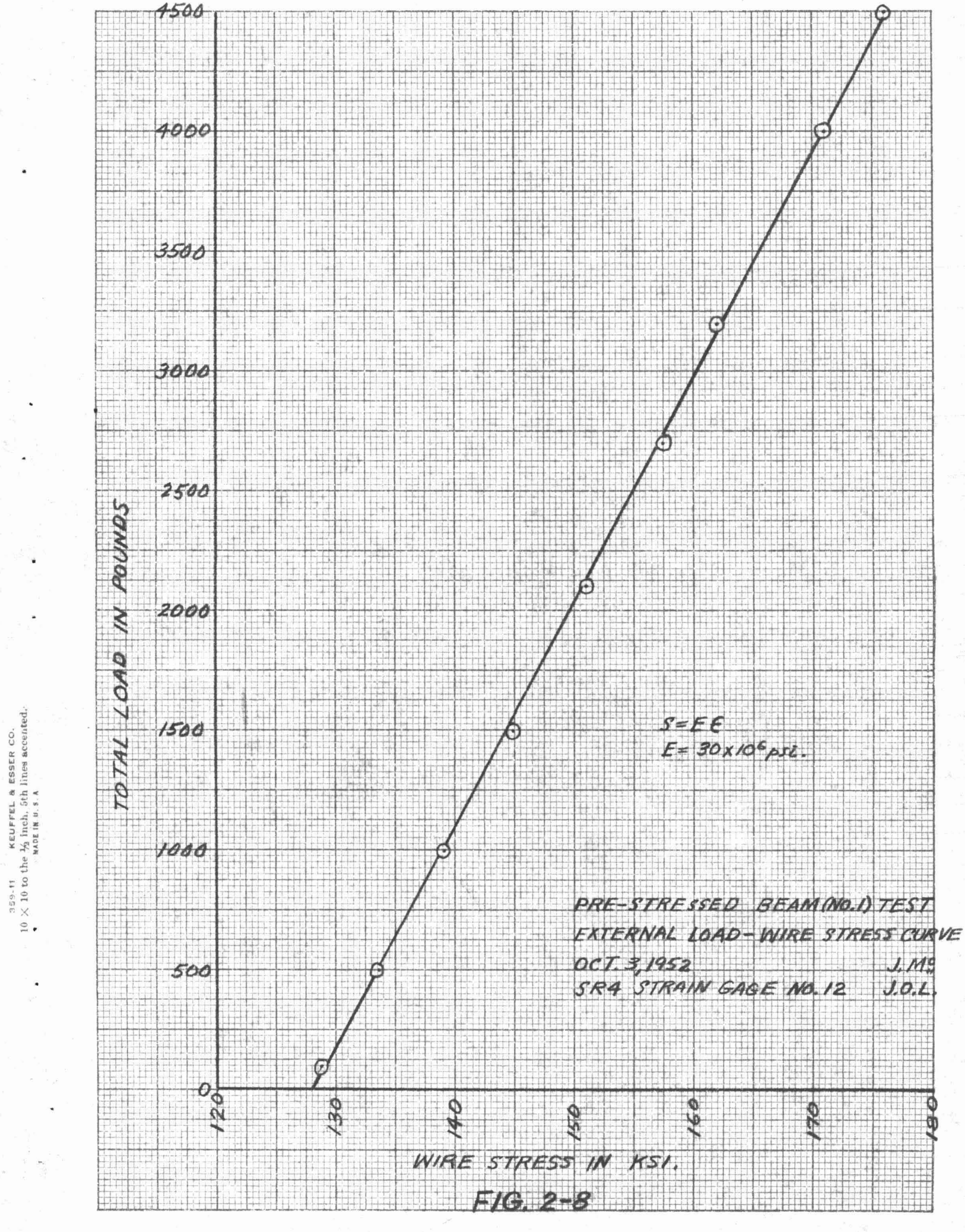

TOTAL LOAD IN POUNDS
4500
4000
3500
3000
2500
2000
1500
1000
500
0
120
130
140
150
160
170
180
WIRE STRESS IN KSI.
S=Eε
E= 30x10⁶ psi.
PRE-STRESSED BEAM (No. 1) TEST
EXTERNAL LOAD-WIRE STRESS CURVE
OCT. 3, 1952
J. Mc
SR4 STRAIN GAGE No. 12
J.O.L.
359-11 KEUFFEL & ESSER CO.
10 X 10 to the 1/2 inch, 5th lines accented.
MADE IN U.S.A.

FIG. 2-8

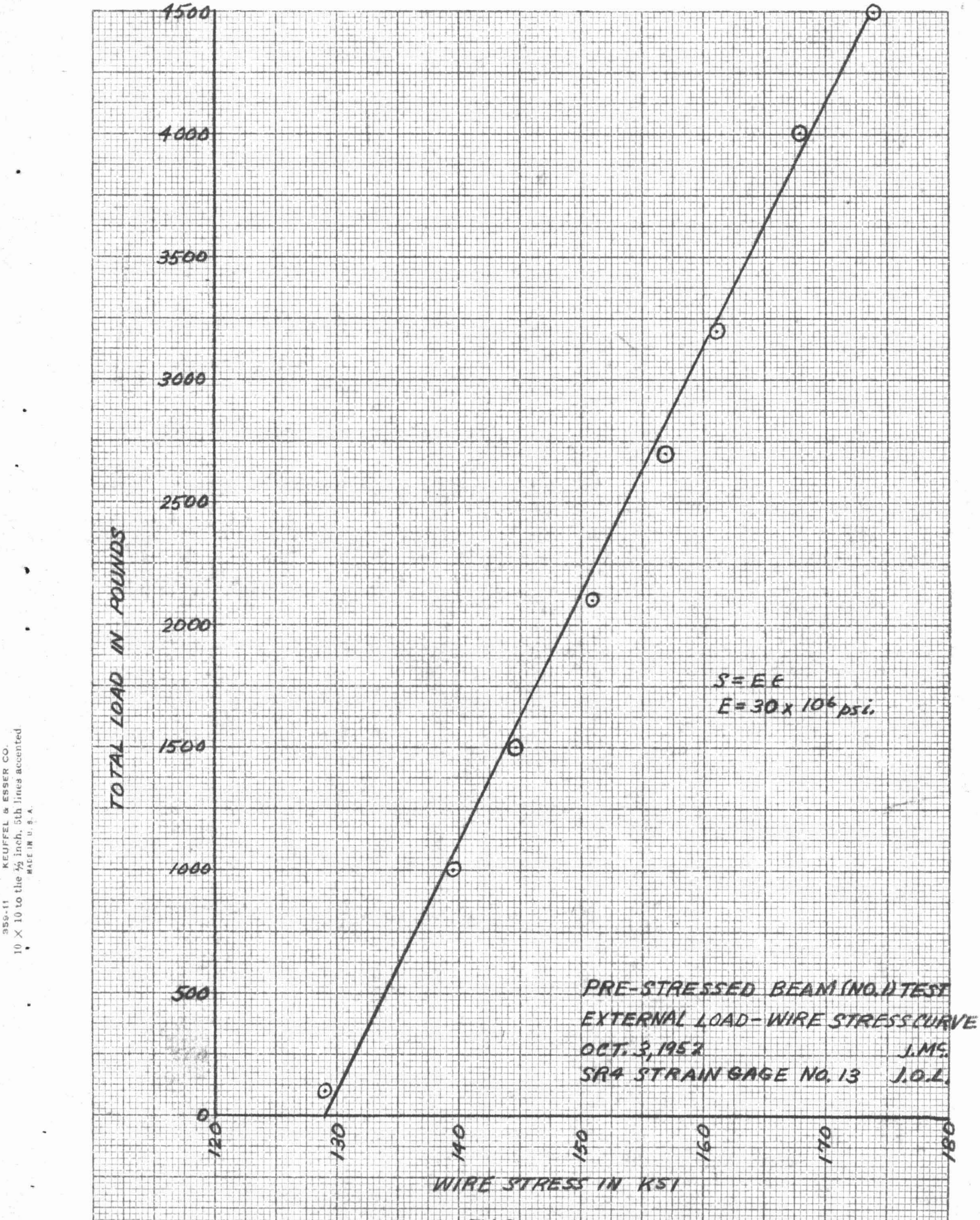

TOTAL LOAD IN POUNDS
4500
4000
3500
3000
2500
2000
1500
1000
500
0
120
130
140
150
160
170
180
WIRE STRESS IN KSI
S = E ε
E = 30 x 10⁶ psi.
PRE-STRESSED BEAM (NO. 1) TEST
EXTERNAL LOAD-WIRE STRESS CURVE
OCT. 3, 1952 J.Mc.
SR4 STRAIN GAGE NO. 13 J.O.L.
KEUFFEL & ESSER CO.
359-11 10 X 10 to the ½ inch, 5th lines accented
MADE IN U.S.A.

FIG. 2-9

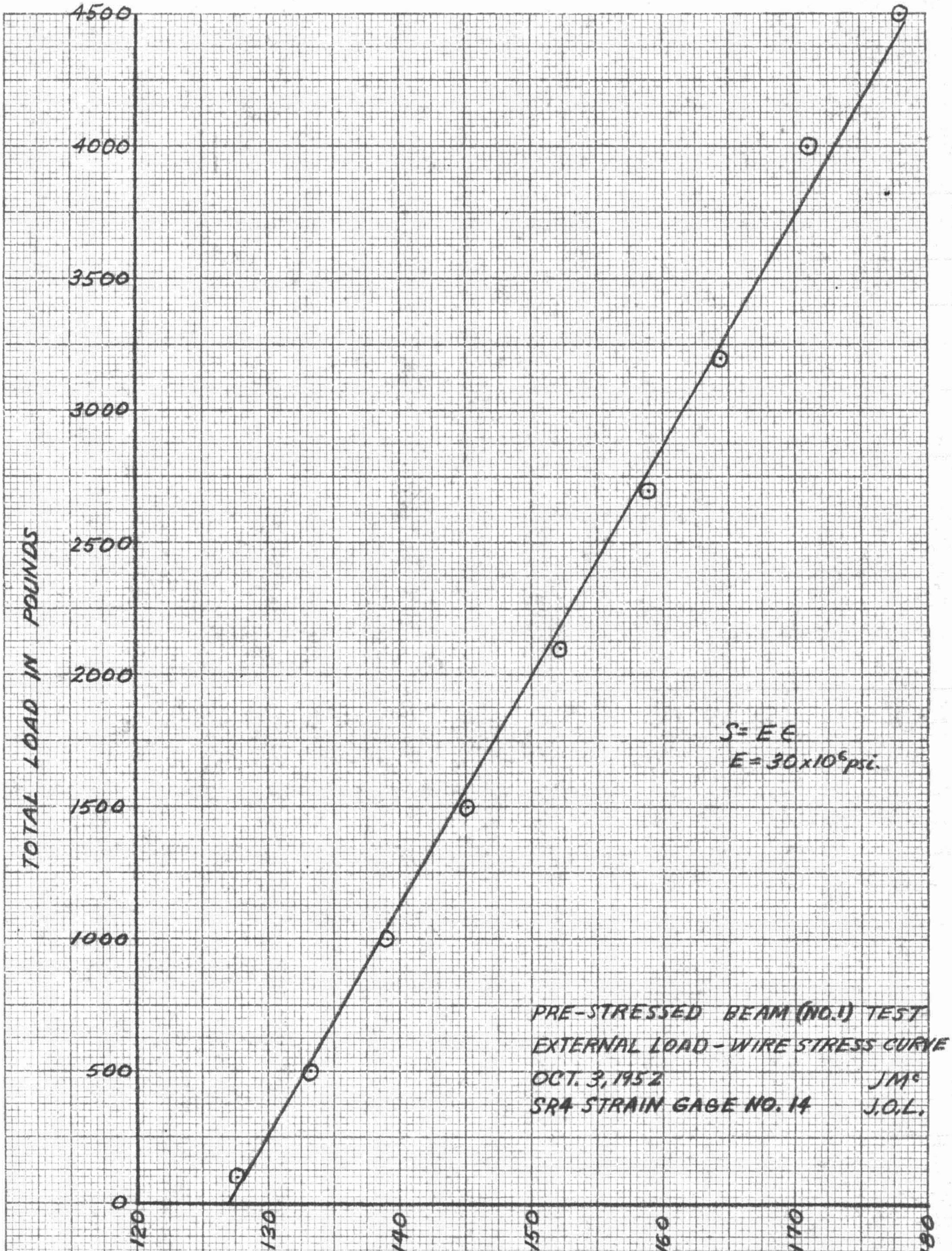
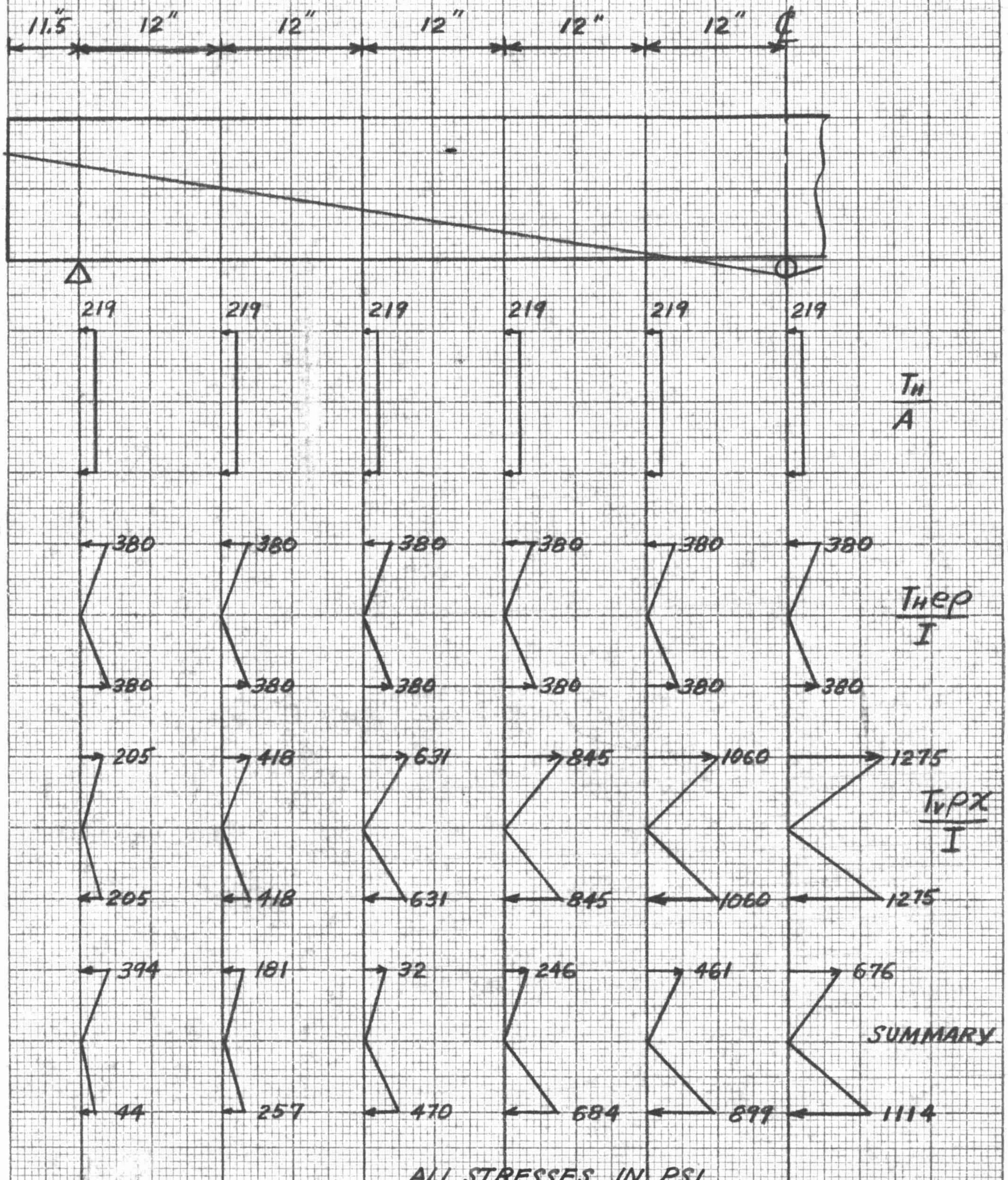

4500
4000
3500
3000
2500
2000
1500
1000
500
0
TOTAL LOAD IN POUNDS
120
130
140
150
160
170
180
WIRE STRESS IN KSI
S = E ∈
E = 30x10⁶ psi.
PRE-STRESSED BEAM (NO.1) TEST
EXTERNAL LOAD - WIRE STRESS CURVE
OCT. 3, 1952
JMc
SR4 STRAIN GAGE NO. 14
J.O.L.

FIG. 2-10



STRESSES DUE TO PRESTRESSING

FIG. 2-11

Keuffel & Esser Co. 359-11 10 × 10 to the ½ inch, 5th lines accented. Made in U.S.A.

FIG. 2 - 12

Manner of First Failure of Large Beams (From U.S.Forest Service Bulletin 108 p. 56)

Species	Total Number of Tests	Percent of Total Failing by Tension	Compression	Shear
Long Leaf Pine				
Green	17	18	24	58
Dry	9	22	22	56
Douglas Fir				
Green	191	27	72	1
Dry	91	19	76	5
Short Leaf Pine				
Green	48	27	56	17
Dry	13	54		46
Western Larch				
Green	62	23	71	6
Dry	52	54	19	27
Lollolly Pine				
Green	111	40	53	7
Dry	25	60	12	28
Tamarach				
Green	30	37	53	10
Dry	9	45	22	33
Western Hemloch				
Green	39	21	74	5
Dry	44	11	66	23
Redwood				
Green	28	43	50	7
Dry	12	83	17	
Norway Pine				
Green	49	18	76	6
Dry	10	30	60	10

These tests were made on beams ranging in cross-section from 4" x 10" to 8" x 16", and with a span of 15 ft.

Section II Pre-Stressed Timber Beam Number One.

1. Object of the Test: To determine the behavior of a pre-stressed timber beam in a static bending test and the feasability of further tests after comparison with results obtainable with an ordinary timber beam.

2. Test Procedure and Experimental Apparatus.

Figure 2-1 is a photograph of the beam taken prior to pre-stressing. The beam was placed in the testing machine as shown in Figs. 2-2 and 2-3 and the pre-stressing force was applied by turning nuts at the end of each of the two wires. The unit stress in each wire prior to application of the external load was approximately 127,000 psi.

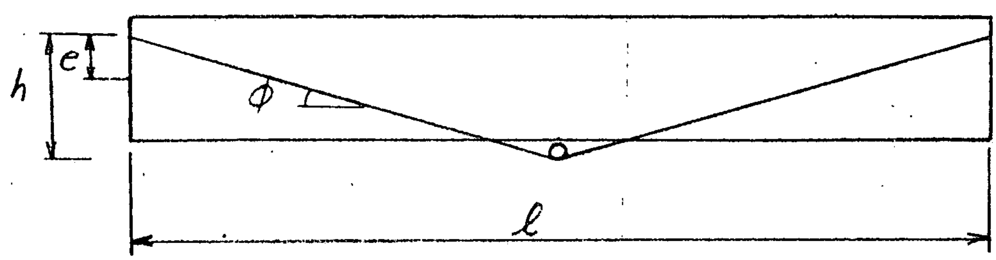
The external load was applied at the third points and the details at the points of support and loading were the same as those described in I-2 of this report.

Deflection measurements were made with a piano wire and a scale placed at the center of the span as shown in Fig. 2-4.

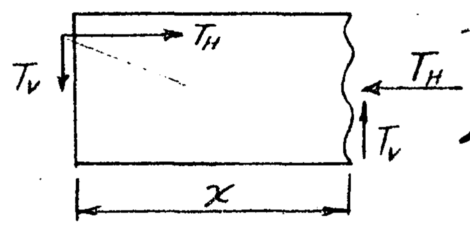
SR4-AID electrical strain gages were used to measure the strains in the pre-stressing wires. The location of these gages is shown in Fig. 2-4. Strains in the timber were not measured.

An initial load was applied to the beam and thereafter increments of load were applied as shown on page 77 .

3. Stresses due to pre-stressing.



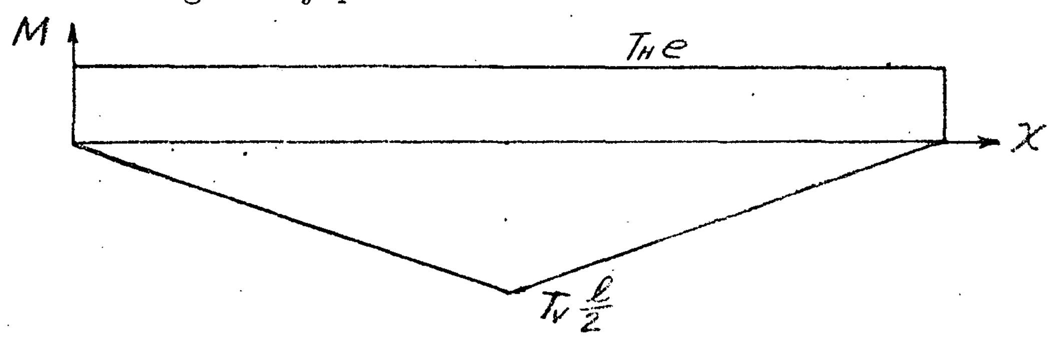
If we neglect, at first, the effect of deflection and consider that the tension T in both wires has a total horizontal component T_H less than the critical buckling load discussed in II-4, we can calculate the stresses due to the pre-stressing force as follows:



$M = T_V x - T_H e$ (When $T_V x > T_H e$)

$$S_\rho = \frac{T_H}{A} \pm \frac{(T_V x - T_H e)\rho}{I_x}$$

Drawing the moment diagram by parts we have:



<u>Calculations for Pre-stressing Stresses</u>

$$S_p = \frac{T_H}{A} \pm \frac{(T_V x - T_H e)\rho}{I}$$

Gage 12 128 ksi.
Gage 13 129 ksi.
Gage 14 127 ksi.
External Load = 0

Ave. 13 & 14 = 128 ksi.

T = 128,000 (2)(0.007854) = 2010 lbs. = (Total Pre-stressing Force)

$T_H = \frac{71.5}{71.7}(2010) = 2000$ lbs.

e = 1.63 in.
$I = 24.1$ in.^{4}

$T_V = \frac{5.44}{71.7}(2010) = 153$ lbs.

Stresses Computed for Outermost fibers $\rho = 2.81$

$\frac{T_H}{A} = \frac{2000}{9.14} = 219$ psi (Const. Compr. at all Sections) ← T_H/A

$\frac{T_H e \rho}{I} = \frac{2000\,(1.63)(2.81)}{24.1} = 380$ psi ← $T_H e \rho / I$

$\frac{T_V \rho}{I} x = \frac{153(2.81)}{24.1} x = 17.8x$ ← $x\, T_V \rho / I$

A method of successive approximation can be applied if the axial load is large enough to seriously affect the deflection. In applying this method to the following equation, the assumption that the deflection is a linear function of x is sometimes made and we would get the additional moment diagram shown below. A converging value for the deflection indicates that enough trials have been made.

$$S_\rho = \frac{T_H}{A} \pm \frac{\left(T_V x - T_H e + T_H \frac{2x}{\ell}\Delta\right)\rho}{I_x}$$

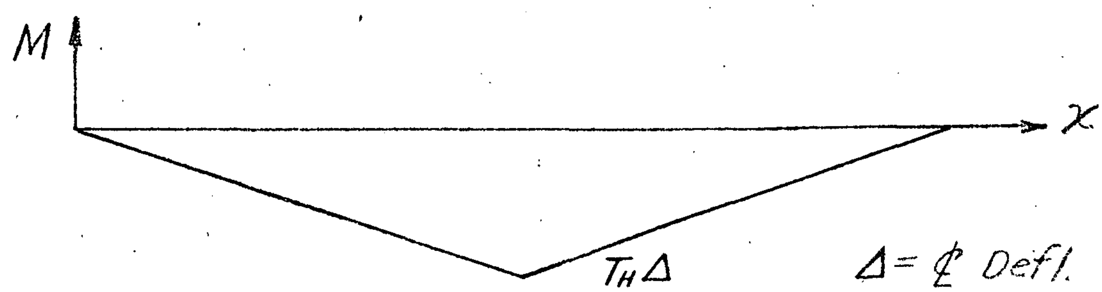


Fig. 2-11 shows the stresses induced in this particular beam prior to application of external load. Stresses in the beam due to the application of external load in addition to the pre-stressing load can be calculated provided simultaneous values of the external load and the tension T are known. The method of least work can be used to determine these simultaneous values.[1]

4. Critical Buckling Load

Professor E. R. Johnston of the Department of Civil Engineering and Mechanics has derived the following equation to determine the critical buckling load for a beam subjected to pre-stressing forces applied as previously discussed.

$$P_{cr} = (k_m L)^2 \frac{EI}{L^2}$$

For this particular case $k_n L = \pi$ or the above equation reduces to the familiar Euler value for a pin ended column.

$$P_{cr} = \frac{\pi^2 E I_y}{L^2} \qquad P_{cr} = \frac{\pi^2 (2.03 \times 10^6)(2.00)}{(120)^2} \qquad P_{cr} = 2790 \text{ lbs.}$$

$$I_y = \frac{1}{12}(5.62)(1.62)^3 = 2.00 \text{ in.}^4$$

1 Henry S. Jacoby and Roland P. Davis, "Timber Design and Construction" p. 172

5. Results of the Test.

Figures 2-5, 2-6, and 2-7 show values of total external load applied to the beam plotted versus the unit strain in each of the wires (gages 12, 13, and 14) indicated in Fig. 2-4.

The proportional limit of the 0.10 inch diameter wire used for the pre-stressing is about 165,000 psi. and only about 0.7% elongation occurs before reaching a tensile stress slightly over 220,000 psi.[1] The stress in the wires can be computed from the expression: $S = E\epsilon$ as long as this value is not exceeded. Figures 2-8, 2-9, and 2-10 show the total external load applied to the beam plotted versus the unit stress in each of the wires (gages 12, 13, 14) indicated in Fig. 2-4. The readings taken just prior to failure indicate that the total pre-stressing force was 2,765 pounds which is slightly less than the critical buckling load computed in II-4.

One of the wires failed at the root of the threads at one connection point, and the timber failed in tension. The modulus of rupture for this beam was exactly equal to the modulus of rupture of the non-prestressed beam. However, an eccentric application of the load due to poor placement of the loading beam probably contributed to early failure.

The wire used to indicate deflection was obstructed by the loading beam and hence a load-deflection curve is not included for this test.

1 H. J. Godfrey, "Steel Wire for Prestressed Concrete", _Proceedings of the First United States Conference on Prestressed Concrete_, 1951, p. 152

6. Conclusions for Pre-stressed Beam No. 1

a. Timber is from 2 to 5 times stronger in tension than in compression and Fig. 2-12 indicates that 76% of dry Douglas fir failed by comression in a series of 91 tests of large beams. The ideal method of prestressing timber would consist of applying a moment to the beam without applying an axial load. Any applied method will probably involve the axial load, however, and will thus lower the efficiency as can be noted in Fig. 2-11 where the axial stress is 32% of the total stress on the top fiber at the centerline.

b. Application of External load increases the pre-stressing force materially. Consider for example that we had started with a pre-stressing force 50% larger. This means that a <u>smaller</u> external load could be applied before the critical buckling load is reached.

c. Locating the wires eccentrically toward the top is erroneous. The horizontal component of the tension T then contributes a moment Te which is of the same sign as that introduced by the external loads.

SECTION III

PRE-STRESSED BEAM

NO. 2

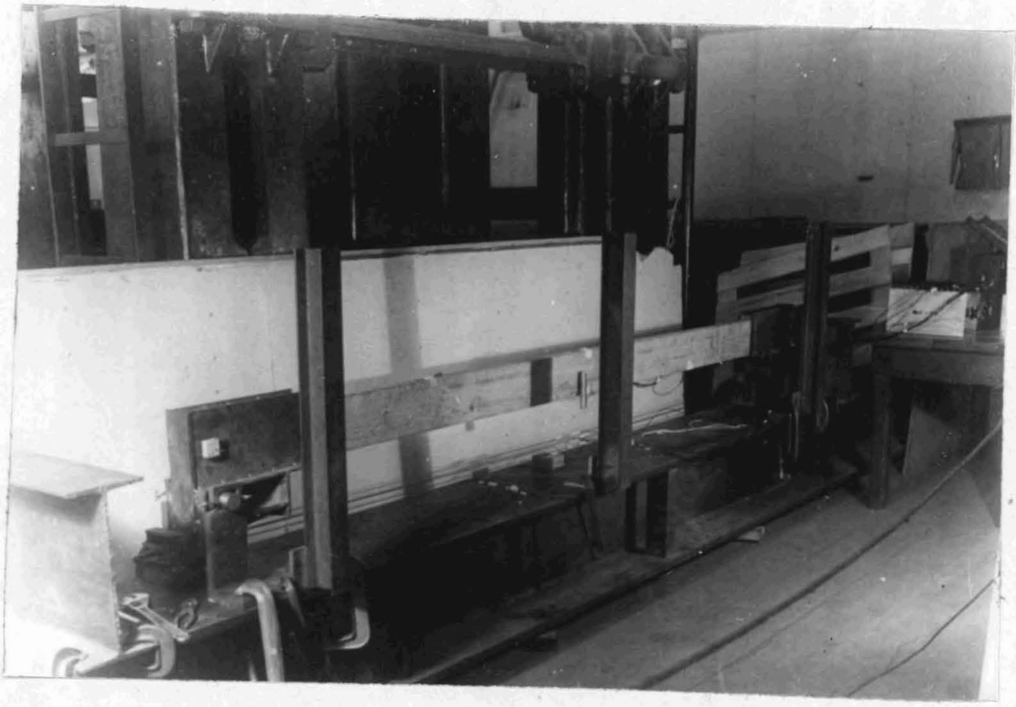
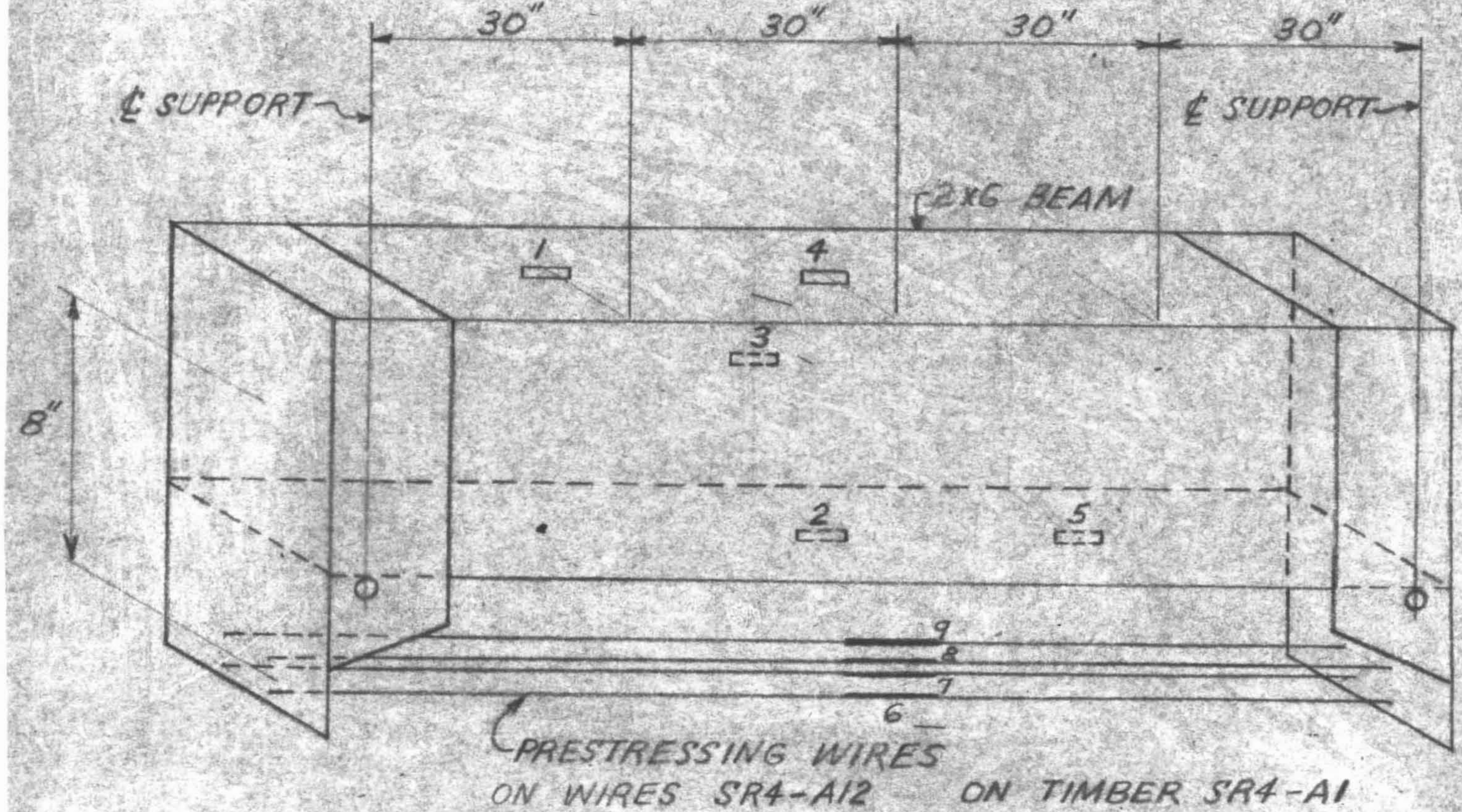


Figure 3 - 1

Test Set-up for Pre-stressed Beam Number Two - Tests A and B



PRESTRESSED BEAM NO. 2

FIG. 3-1a

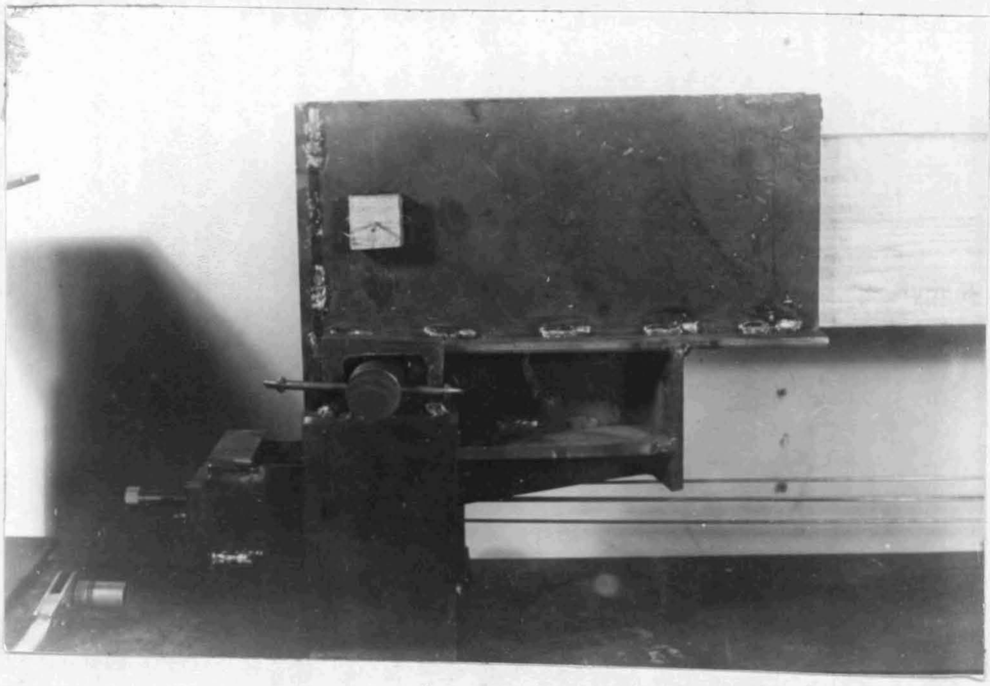
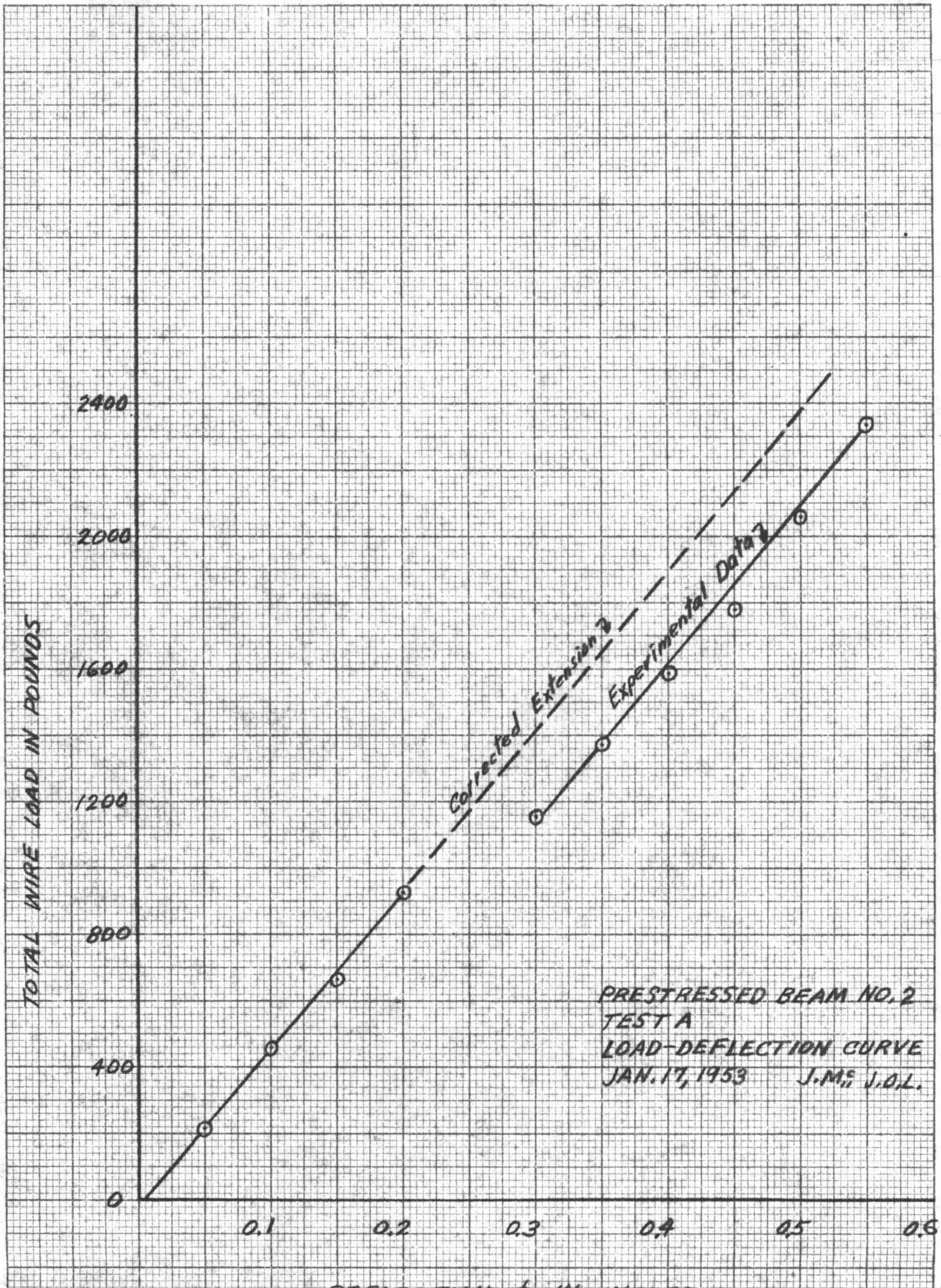


Figure 3 - 2

End Connection, Pre-stressing Device and End Support for Pre-Stressed Beam Number Two.



TOTAL WIRE LOAD IN POUNDS
2400
2000
1600
1200
800
400
0
0.1
0.2
0.3
0.4
0.5
0.6
Corrected Extension ℄
Experimental Data ℄
PRESTRESSED BEAM NO. 2
TEST A
LOAD-DEFLECTION CURVE
JAN. 17, 1953 J.Mc, J.O.L.
DEFLECTION ℄ IN INCHES

FIG. 3-4

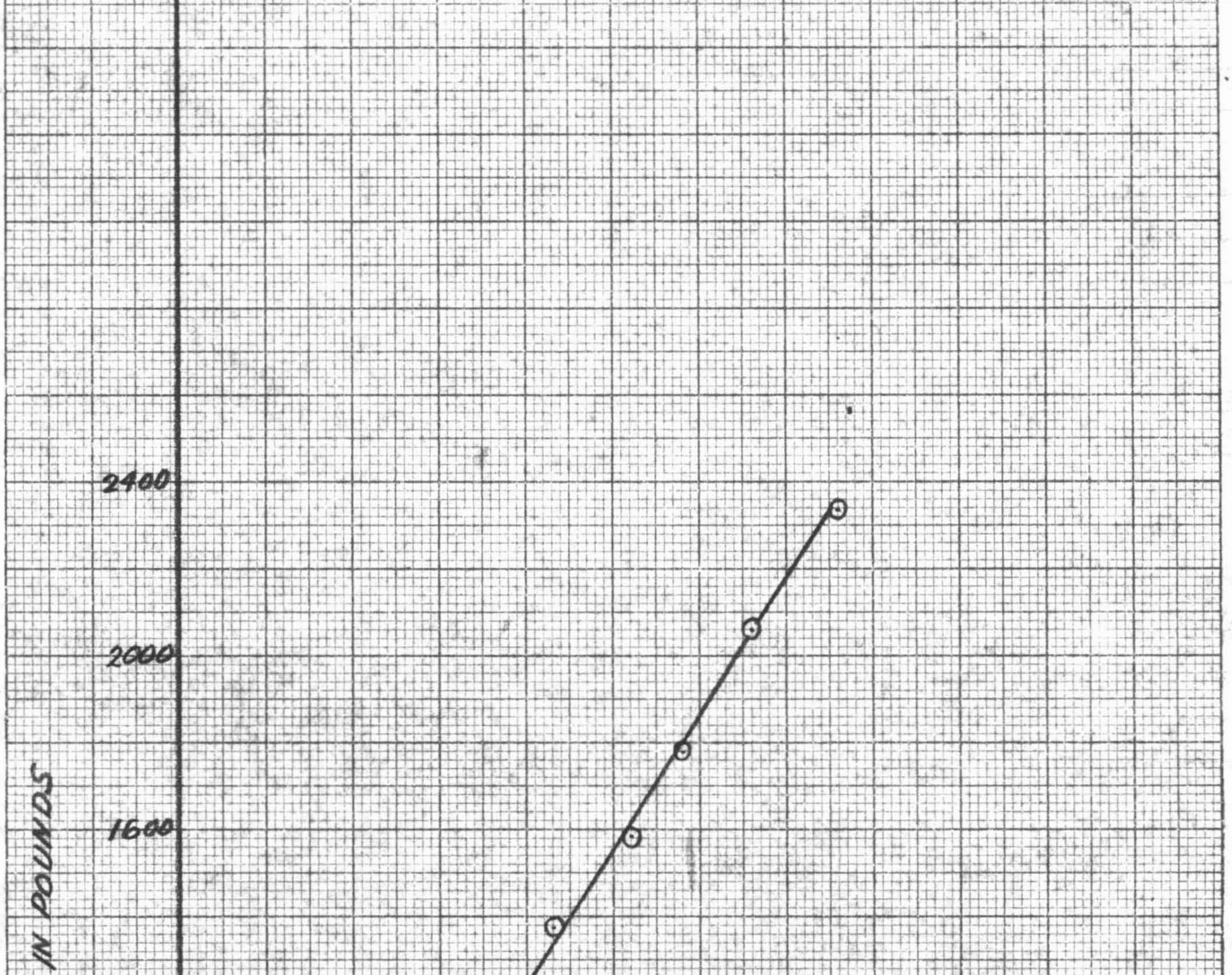

TOTAL WIRE LOAD IN POUNDS
2400
2000
1600
1200
800
400
0
200
400
600
800
1000
PRE-STRESSED BEAM NO.2
TEST A
LOAD-STRAIN CURVE
STRAIN GAGE NO. 1
JAN. 17, 1953 J.O.L. JMS.
UNIT STRAIN IN./IN. X 10⁻⁶ (TIMBER)

FIG. 3-5

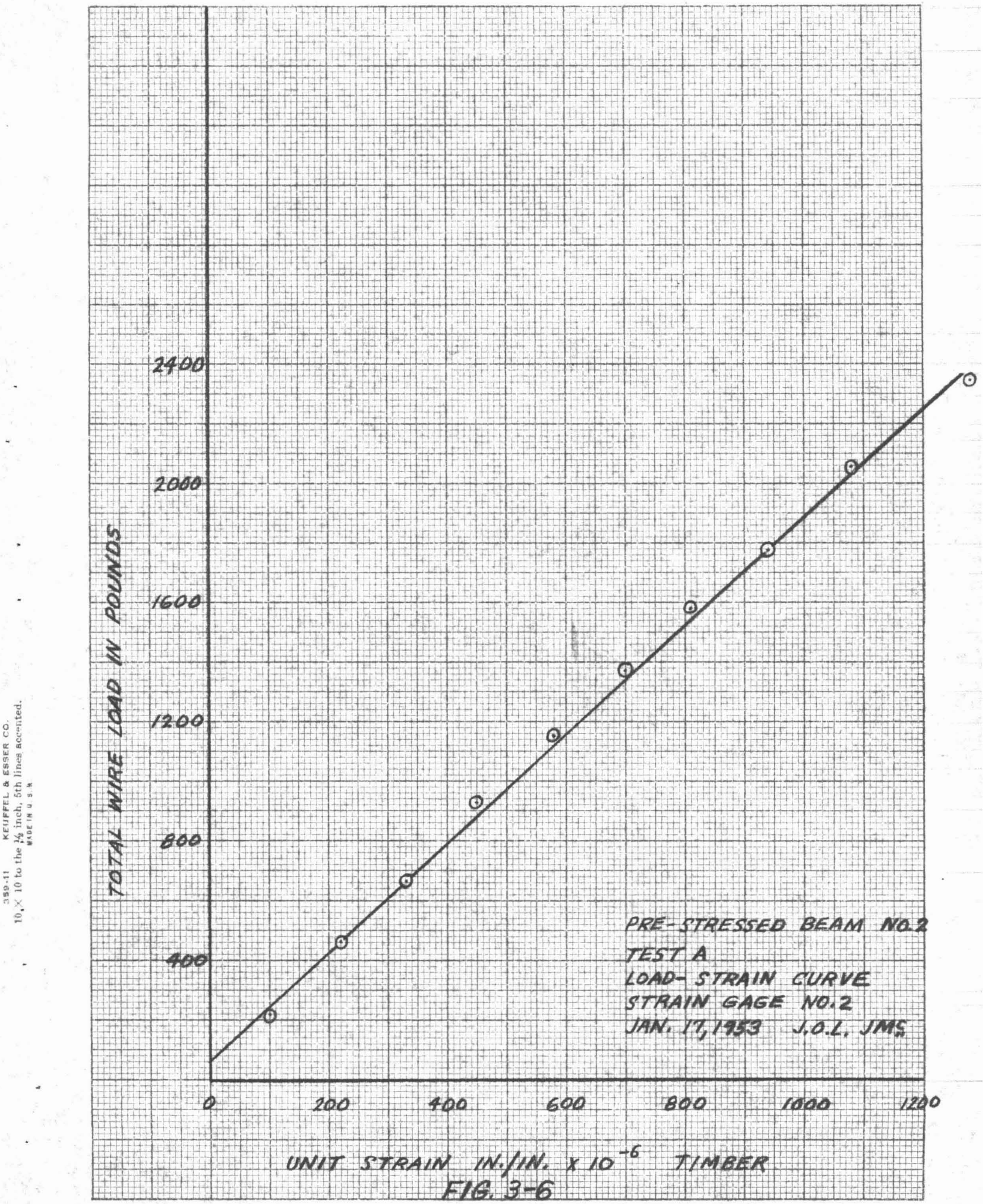

TOTAL WIRE LOAD IN POUNDS
2400
2000
1600
1200
800
400
0
200
400
600
800
1000
1200
UNIT STRAIN IN./IN. X 10^-6 TIMBER
PRE-STRESSED BEAM NO.2
TEST A
LOAD-STRAIN CURVE
STRAIN GAGE NO.2
JAN. 17, 1953 J.O.L. JMS
KEUFFEL & ESSER CO.
359-11
10 X 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

FIG. 3-6

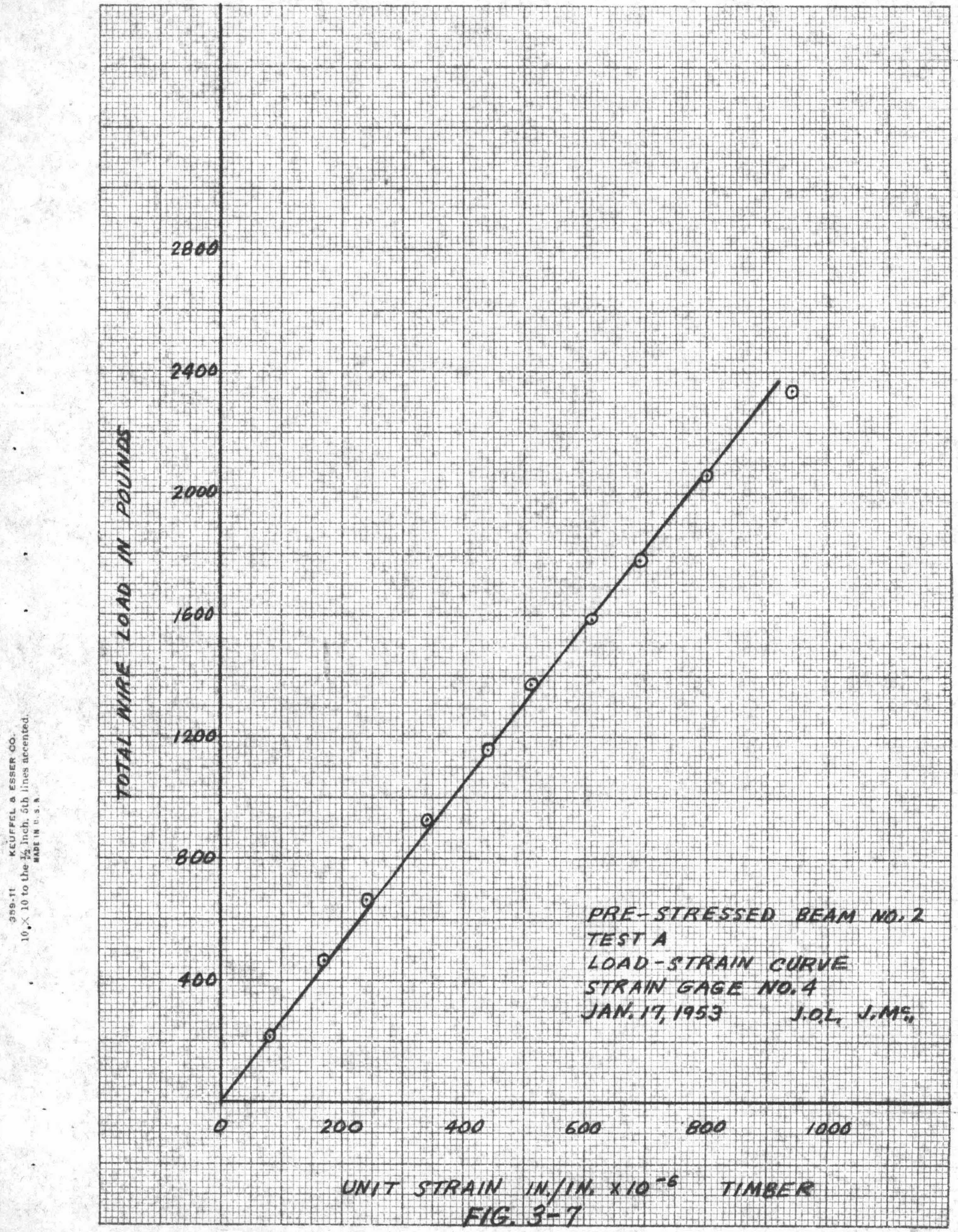
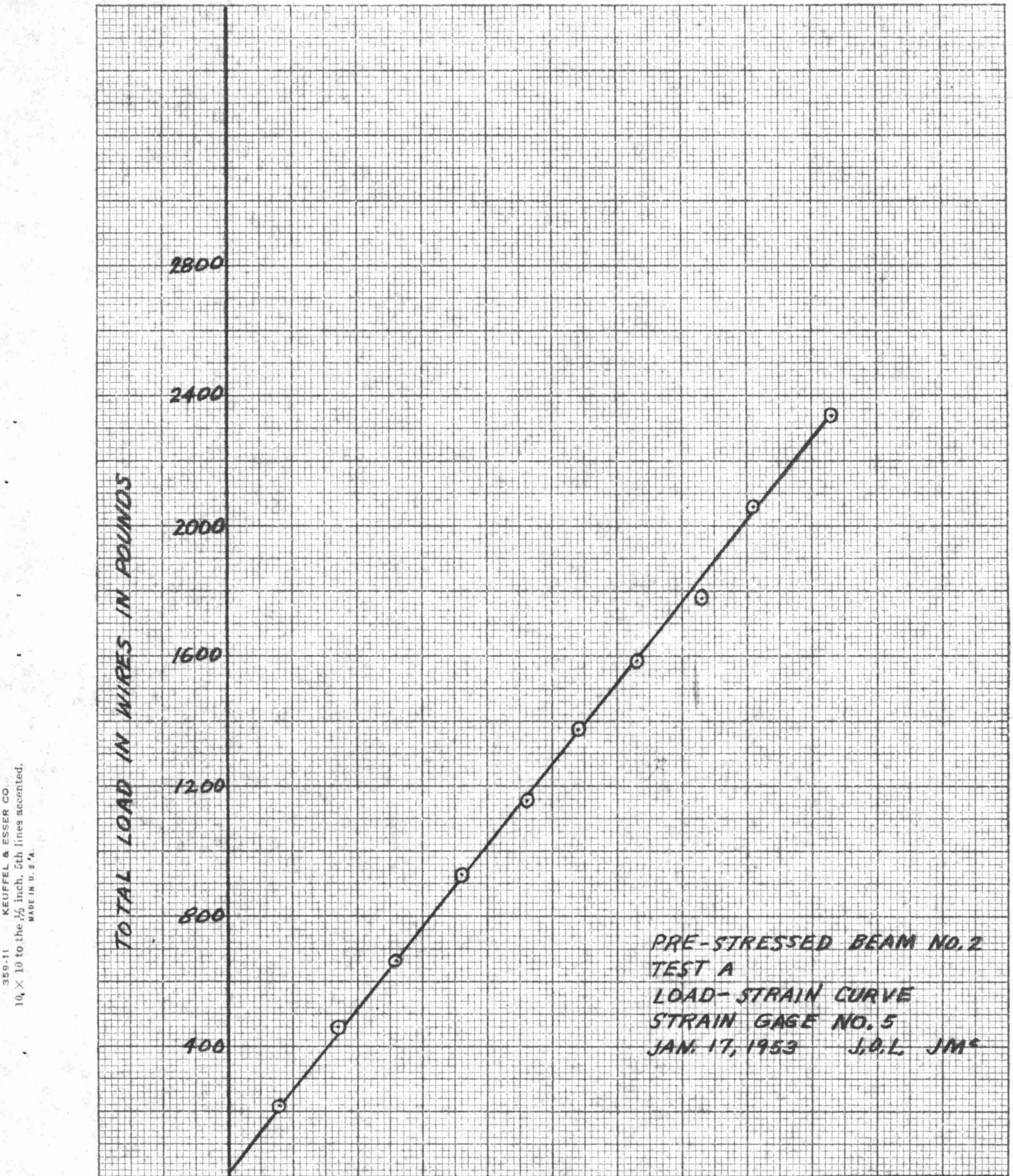

TOTAL WIRE LOAD IN POUNDS
2800
2400
2000
1600
1200
800
400
0
200
400
600
800
1000
UNIT STRAIN IN./IN. X10^-6 TIMBER
PRE-STRESSED BEAM NO. 2
TEST A
LOAD-STRAIN CURVE
STRAIN GAGE NO. 4
JAN. 17, 1953 J.O.L., J.Mc.
359-11 KEUFFEL & ESSER CO.
10 X 10 to the ½ inch. 5th lines accented.
MADE IN U.S.A.

FIG. 3-7



2800
2400
2000
1600
1200
800
400
0
200
400
600
800
1000
TOTAL LOAD IN WIRES IN POUNDS
UNIT STRAIN IN./IN. X10^-6 (TIMBER)
PRE-STRESSED BEAM NO. 2
TEST A
LOAD-STRAIN CURVE
STRAIN GAGE NO. 5
JAN. 17, 1953 J.O.L. JMc
359-11 KEUFFEL & ESSER CO.
10 X 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

FIG. 3-8

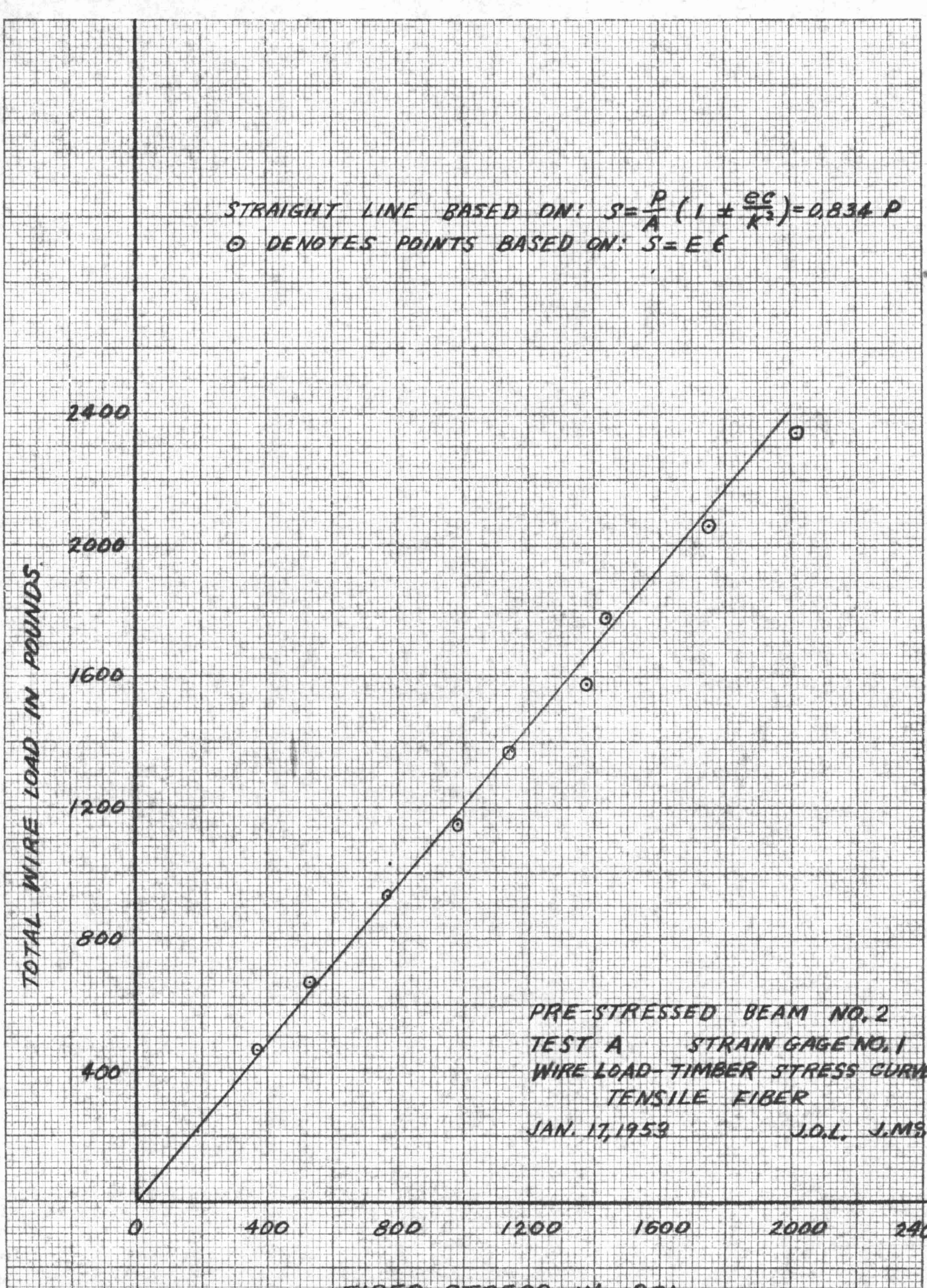
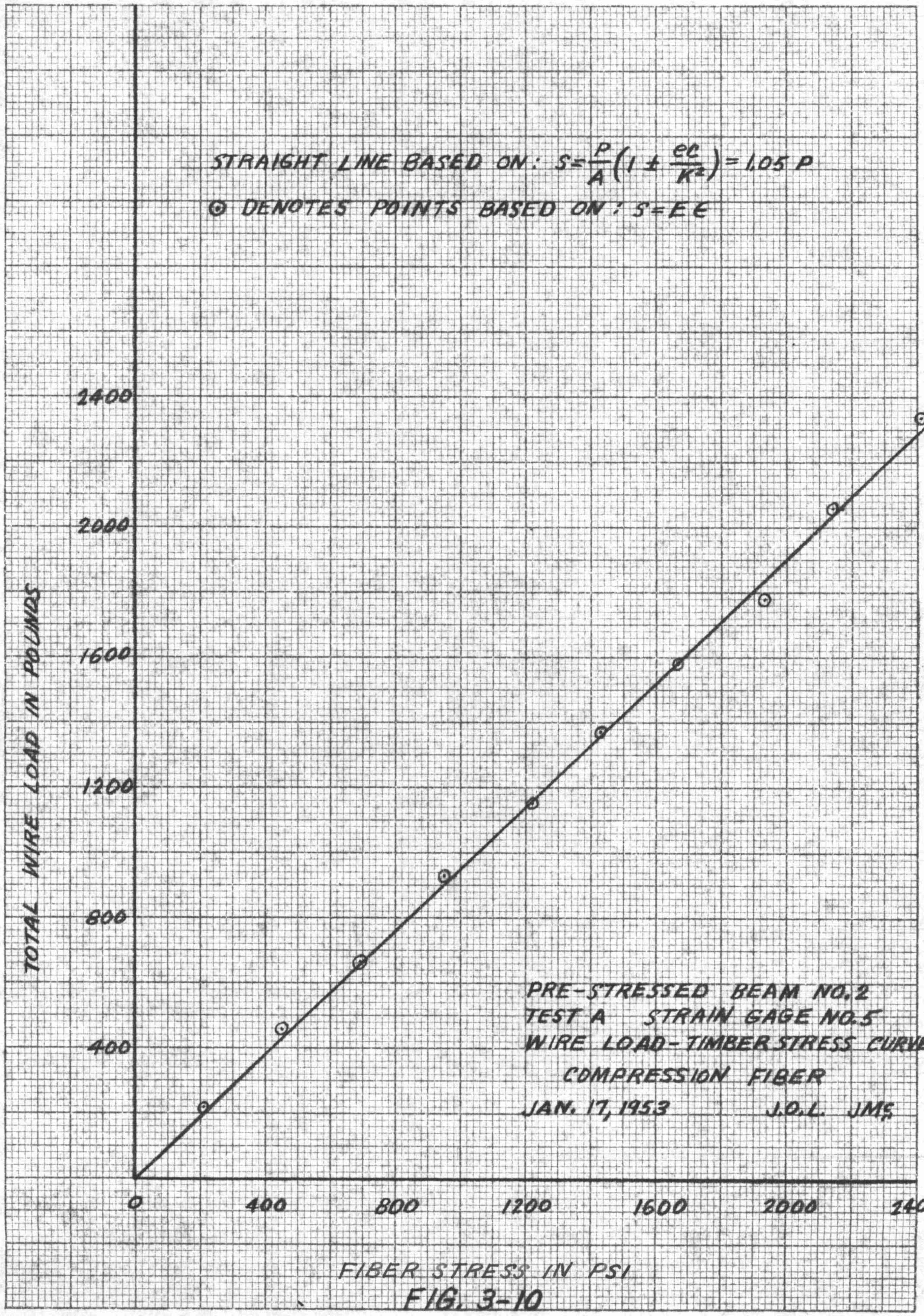

STRAIGHT LINE BASED ON: $S=\frac{P}{A}(1 \pm \frac{ec}{K^2})=0.834\ P$
⊙ DENOTES POINTS BASED ON: $S=E\epsilon$
TOTAL WIRE LOAD IN POUNDS
2400
2000
1600
1200
800
400
0
400
800
1200
1600
2000
2400
PRE-STRESSED BEAM NO. 2
TEST A STRAIN GAGE NO. 1
WIRE LOAD-TIMBER STRESS CURVE
TENSILE FIBER
JAN. 17, 1953 J.O.L. J.M.S.
FIBER STRESS IN PSI.

FIG. 3-9


STRAIGHT LINE BASED ON: $S=\frac{P}{A}\left(1 \pm \frac{ec}{K^2}\right)=1.05\,P$
⊙ DENOTES POINTS BASED ON: $S=E\epsilon$
TOTAL WIRE LOAD IN POUNDS
2400
2000
1600
1200
800
400
0
400
800
1200
1600
2000
2400
PRE-STRESSED BEAM NO. 2
TEST A STRAIN GAGE NO. 5
WIRE LOAD-TIMBER STRESS CURVE
COMPRESSION FIBER
JAN. 17, 1953 J.O.L. JMS
FIBER STRESS IN PSI
FIG. 3-10

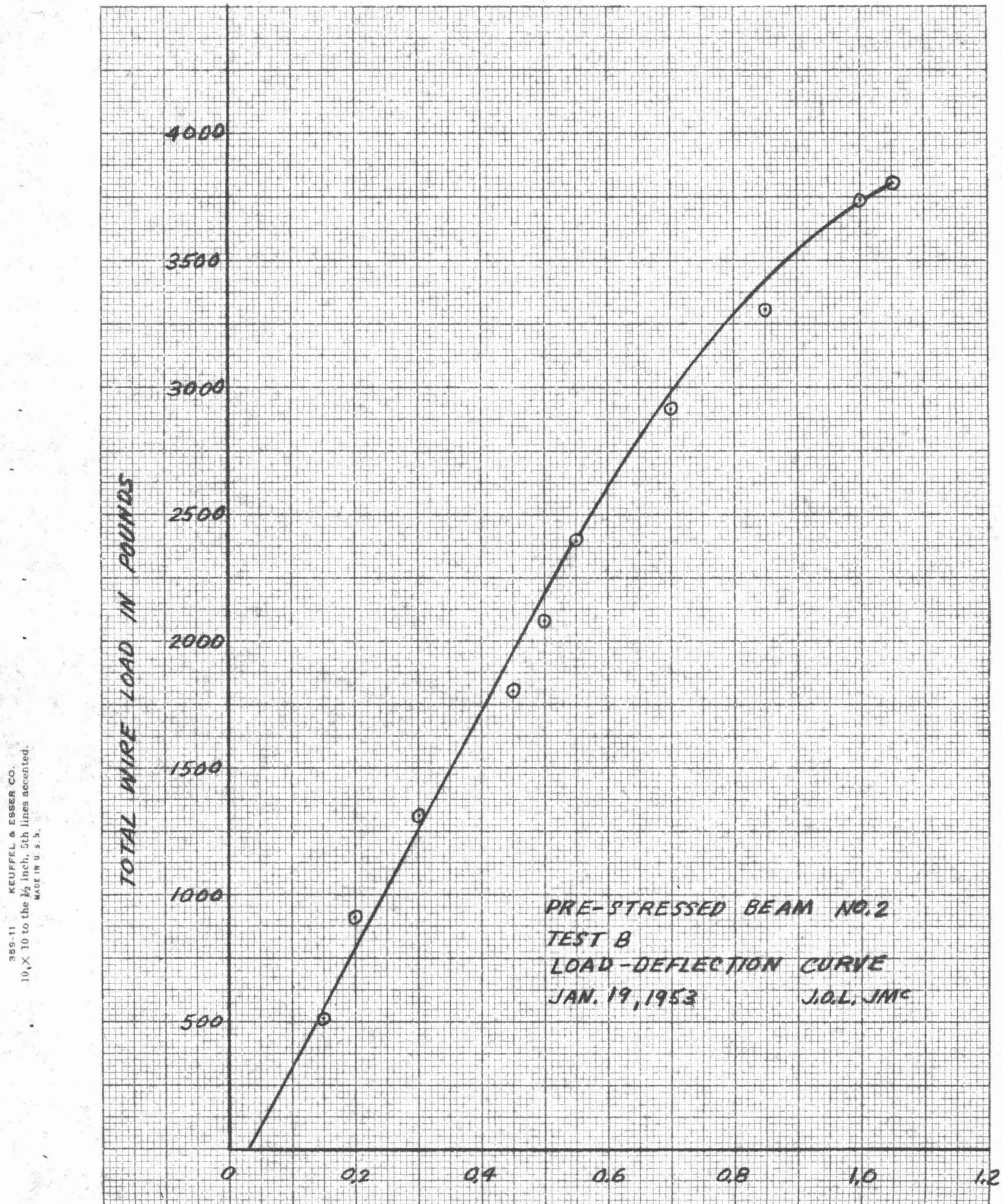

4000
3500
3000
2500
2000
1500
1000
500
TOTAL WIRE LOAD IN POUNDS
0
0.2
0.4
0.6
0.8
1.0
1.2
PRE-STRESSED BEAM NO. 2
TEST B
LOAD-DEFLECTION CURVE
JAN. 19, 1953
J.O.L. JMc
DEFLECTION IN INCHES (℄)
359-11 KEUFFEL & ESSER CO.
10 × 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

FIG. 3-11

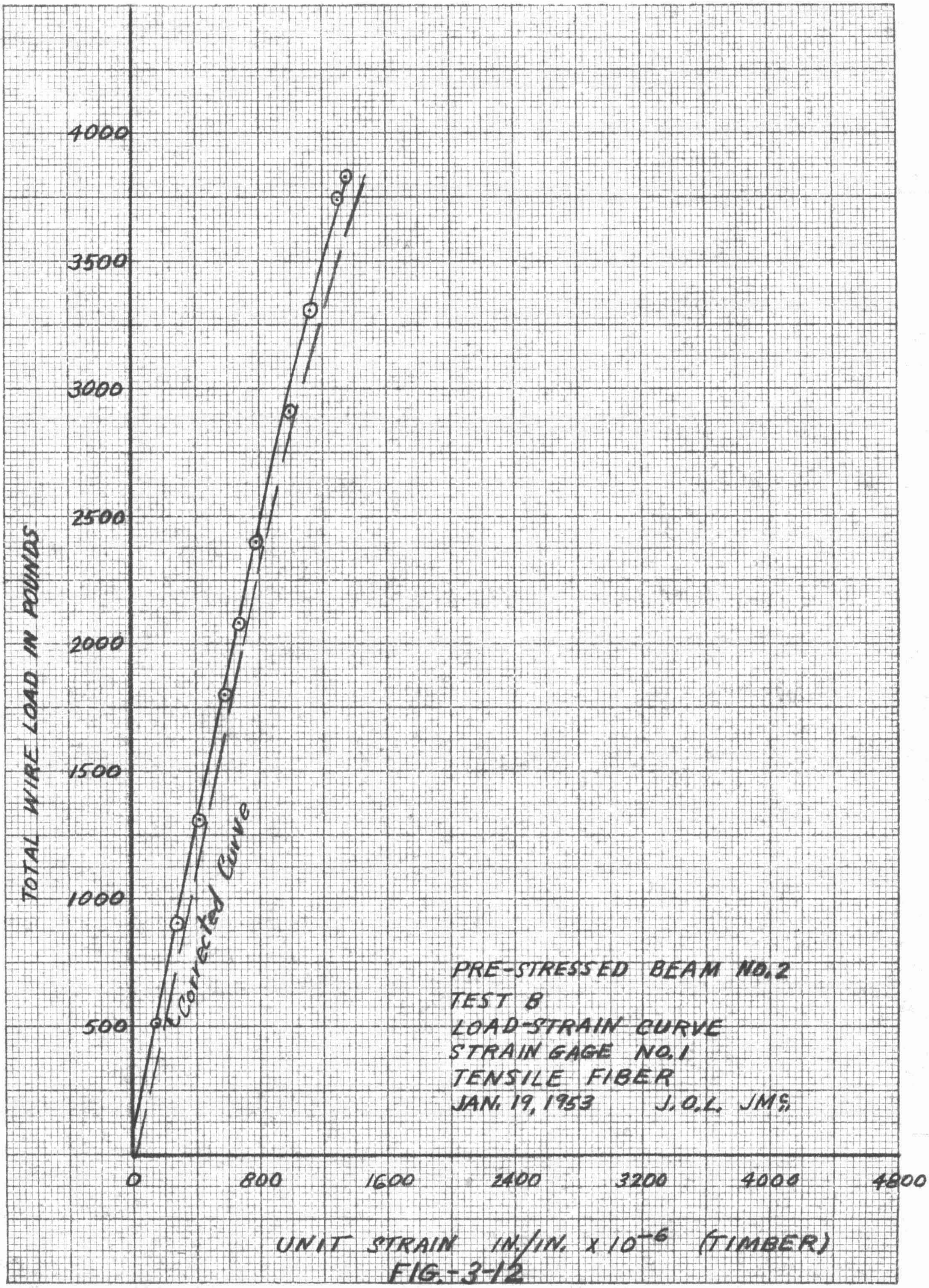
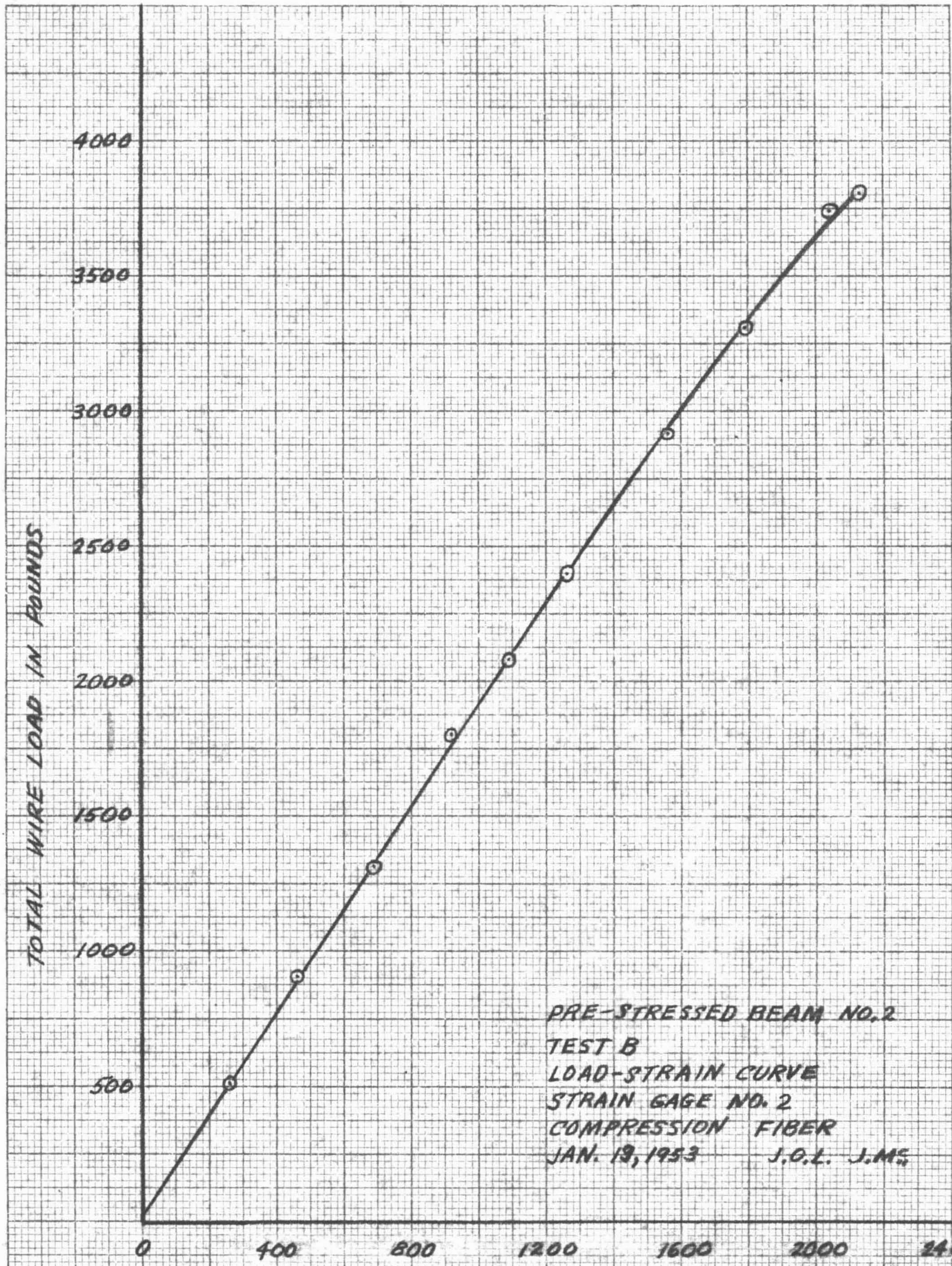

TOTAL WIRE LOAD IN POUNDS
4000
3500
3000
2500
2000
1500
1000
500
0
800
1600
2400
3200
4000
4800
Corrected Curve
PRE-STRESSED BEAM NO. 2
TEST B
LOAD-STRAIN CURVE
STRAIN GAGE NO. 1
TENSILE FIBER
JAN. 19, 1953 J.O.L. JMS
UNIT STRAIN IN./IN. X 10⁻⁶ (TIMBER)

FIG.-3-12


4000
3500
3000
2500
2000
1500
1000
500
TOTAL WIRE LOAD IN POUNDS
0
400
800
1200
1600
2000
2400
PRE-STRESSED BEAM NO. 2
TEST B
LOAD-STRAIN CURVE
STRAIN GAGE NO. 2
COMPRESSION FIBER
JAN. 13, 1953 J.O.L. J.McC.
UNIT STRAIN IN./IN. x 10⁻⁶ (TIMBER)
FIG. 3-13

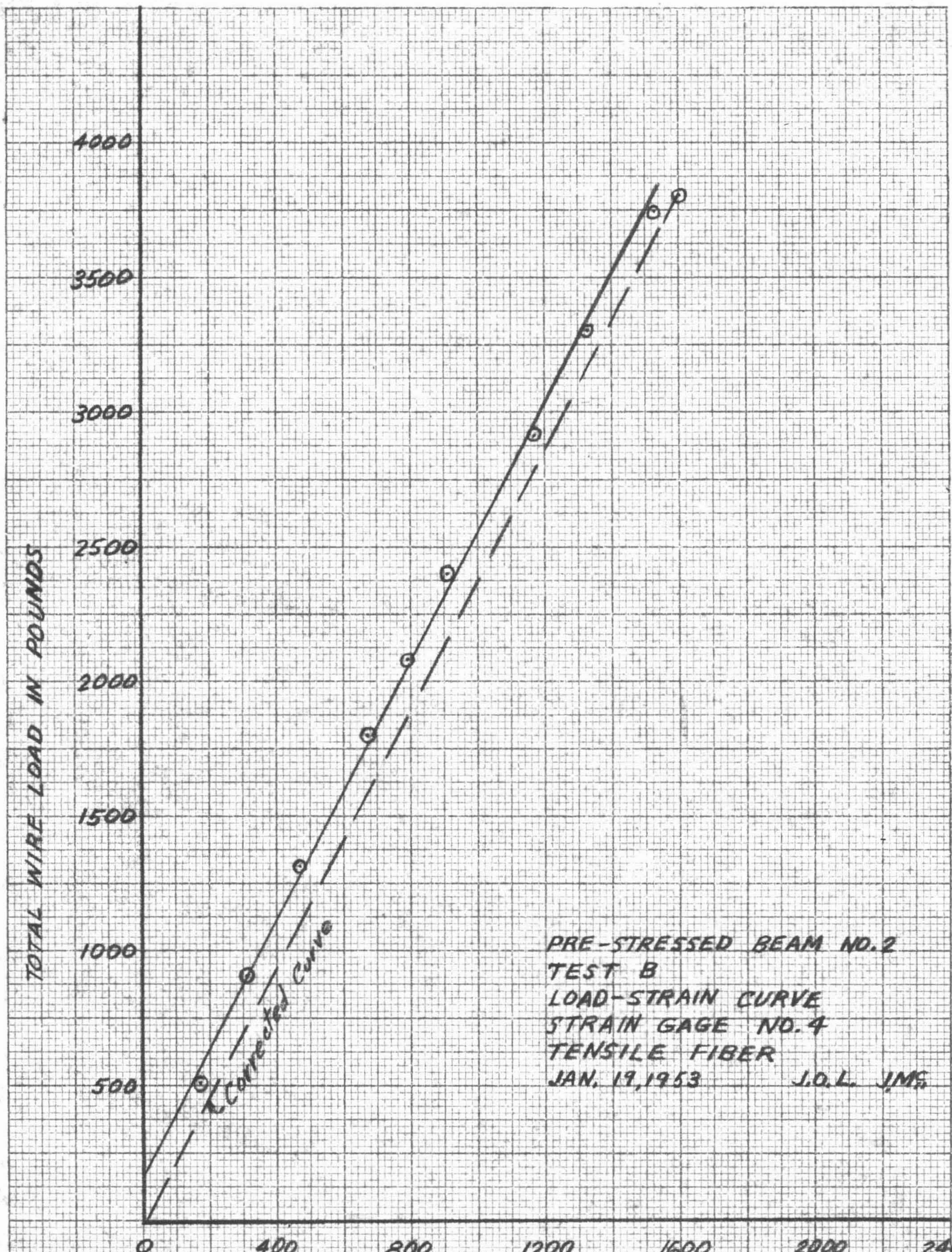
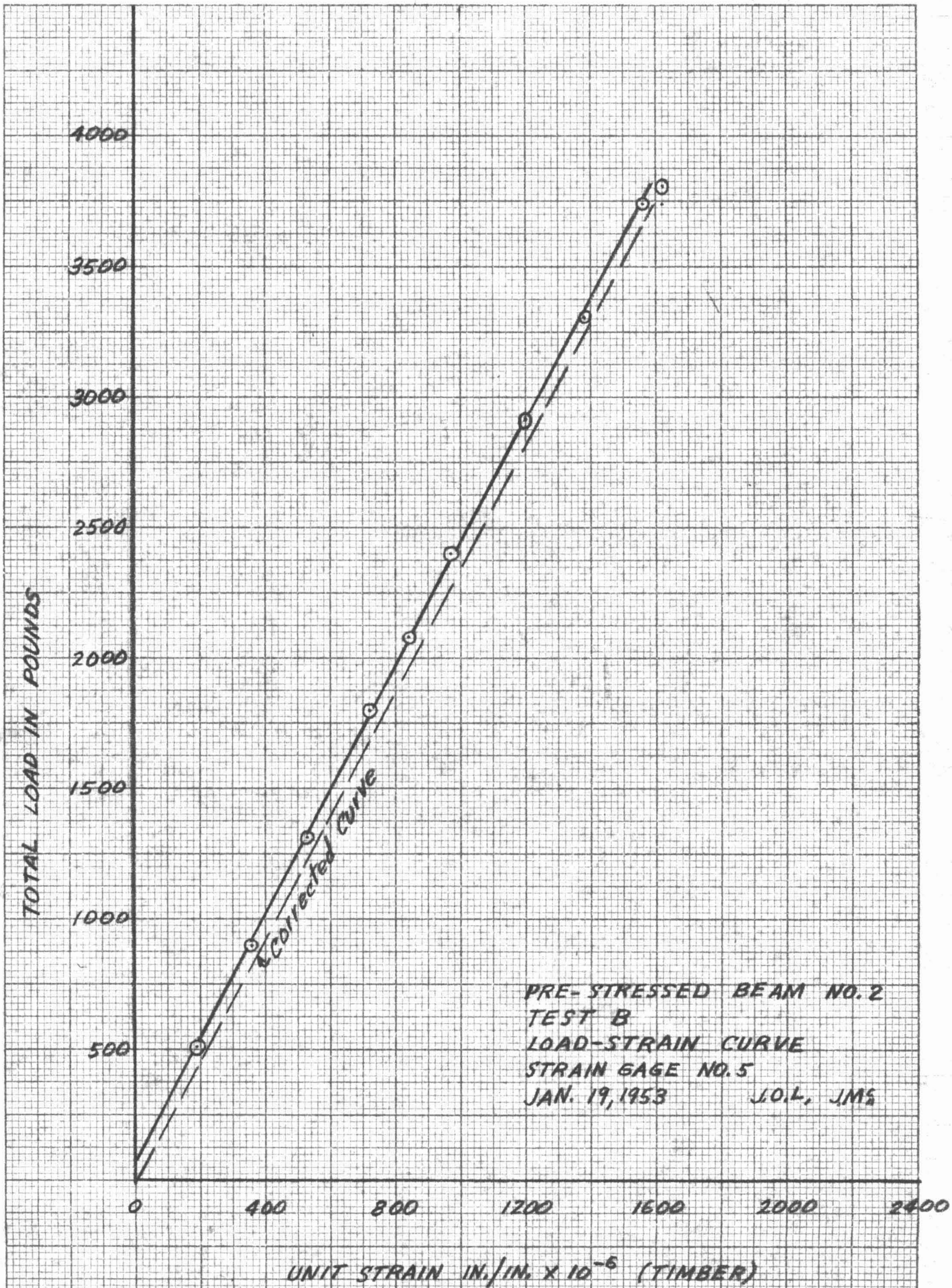
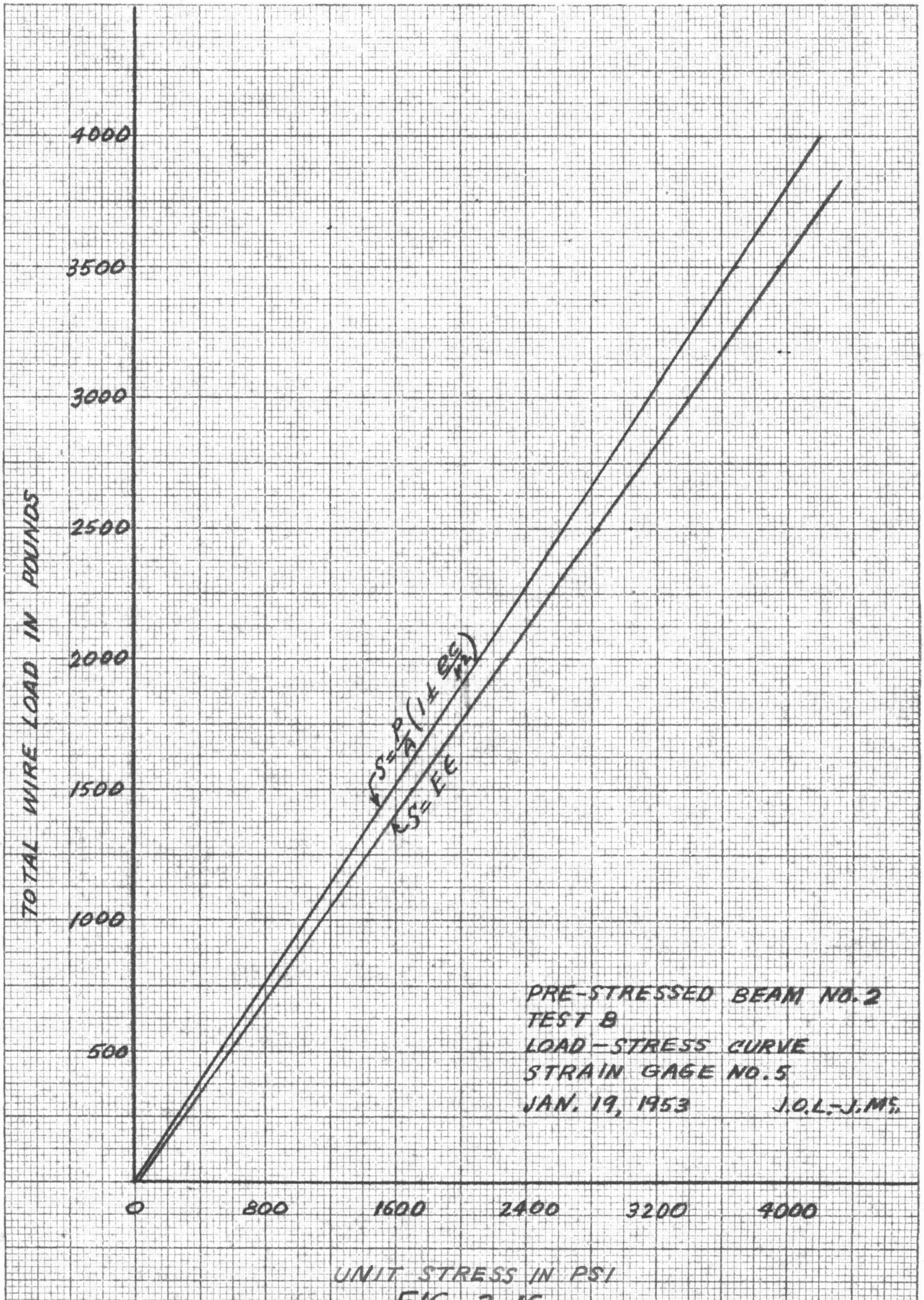

TOTAL WIRE LOAD IN POUNDS
4000
3500
3000
2500
2000
1500
1000
500
0
400
800
1200
1600
2000
2400
Corrected Curve
PRE-STRESSED BEAM NO. 2
TEST B
LOAD-STRAIN CURVE
STRAIN GAGE NO. 4
TENSILE FIBER
JAN. 19, 1953 J.O.L. J.McG.
UNIT STRAIN IN./IN. x 10^-6 (TIMBER)

FIG. 3-14



TOTAL LOAD IN POUNDS
4000
3500
3000
2500
2000
1500
1000
500
0
400
800
1200
1600
2000
2400
℄ Corrected Curve
PRE-STRESSED BEAM NO. 2
TEST B
LOAD-STRAIN CURVE
STRAIN GAGE NO. 5
JAN. 19, 1953 J.O.L, J.M.S.
UNIT STRAIN IN./IN. x 10⁻⁶ (TIMBER)

FIG. 3-15



4000
3500
3000
2500
2000
1500
1000
500
0
800
1600
2400
3200
4000
TOTAL WIRE LOAD IN POUNDS
UNIT STRESS IN PSI
S = P/A (1 ± ec/r²)
S = Eε
PRE-STRESSED BEAM NO. 2
TEST B
LOAD-STRESS CURVE
STRAIN GAGE NO. 5
JAN. 19, 1953
J.O.L.-J.Mc.
359-11 KEUFFEL & ESSER CO.
10 X 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

FIG. 3-16

1. Object of Test: To investigate the behavior of a timber beam subjected to an axial load and an end moment and to test the effectiveness of a device for transferring moment into a timber beam.

2. Test Procedure and Experimental Apparatus

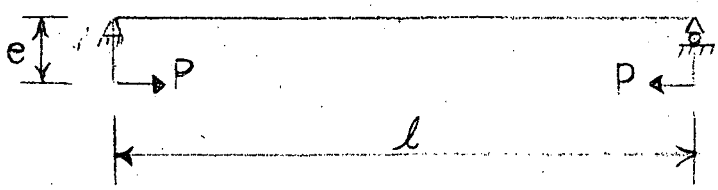
Figure 3-1 shows the test set-up for Prestressed Timber Beam Number Two-Tests A and B. Test A was performed without lateral support being provided and was terminated when the beam was about to buckle. Test B was started after lateral support was provided near the centerline and was terminated when difficulty was encountered with the prestressing device.

The end connection for transferring the prestressing load from the wires to the timber is shown in Figure 3 - 2. Provision was made at both ends for limited horizontal and vertical movement. The prestressing force was applied to all wires simultaneously through a plate. This plate contained a central threaded hole with a bolt attached. By turning the bolt head with a ratchet wrench the plate was moved away from the end connection thus stressing the wires.

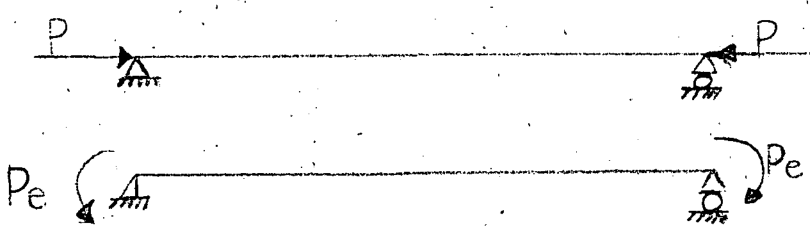
An SR4-A12 strain gage was provided on each of the four wires used for prestressing as shown in Figure 3-1a. Strains were measured at selected points along the timber beam as shown in Figure 3-1a.

Deflections were measured with a piano wire and a scale in a manner similar to that described in section I of this report.

3. Computation of Stresses in Timber - Test A



Neglecting deflections, we can consider superposition of the following cases.



$$\therefore \quad S = \frac{P}{A} \pm \frac{Pec}{I} = \frac{P}{A}\left[1 \pm \frac{ec}{k^2}\right]$$

Consider the fibers represented by strain gage number 1. The wire load-timber stress curve for these fibers is plotted in Figure 3-9.

$$S = \frac{P}{A}\left[1 - \frac{ec}{k^2}\right]$$

$$S = P\left(\frac{1}{9.14}\right)\left[1 - \frac{8(2.81)}{2.61}\right]$$

$$S = {}^{-}0.834\ P \quad (-\text{ indicates tension})$$

Assuming that the timber strains below the proportional limit vary linearly from the neutral axis and that Hooke's law holds, we may also write: $S = E\epsilon$. ($E = 2.65 \times 10^6$ psi)

Timber Stresses - Gage No. 1 - Tensile Fibers

$\Sigma\epsilon$ Wires in./in. x 10^{-6}	P Pounds	S = 0.834 P p.s.i.	ϵ Timber in./in. x 10^{-6}	S = Eϵ p.s.i.
930	219	183	70	186
1960	462	385	140	372
2830	666	555	200	531
3950	932	777	290	770
4910	1158	966	370	980
5840	1375	1148	430	1140
6740	1588	1325	520	1379
7560	1780	1485	580	1538
8740	2060	1720	660	1750
9920	2340	1955	760	2015

Consider the fibers represented by strain gage number 5. The wire load-timber stress curve for these fibers is plotted in Fig. 3-10.

$$S = P/A \left[1 + \frac{ec}{k^2} \right] = 1.053\ P \quad \text{(Compression Fibers)}$$

Timber Stresses - Gage No. 5 - Compression Fibers

P Pounds	S = 1.053P p.s.i.	ϵ Timber in./in. x 10^{-6}	S = Eϵ p.s.i.
219	231	80	212
462	486	170	451
666	702	260	689
932	981	360	954
1158	1220	460	1220
1375	1450	540	1431
1588	1675	630	1670
1780	1878	730	1933
2060	2170	810	2140
2340	2470	910	2410

Timber Stresses - Gage No. 2 - Compression Fibers

P Pounds	$S = 1.053P$ p.s.i.	ϵ Timber in./in. x 10^{-6}	$S = E\epsilon$ p.s.i.
219	231	120	318
462	486	255	675
666	702	370	982
932	981	510	1352
1158	1220	635	1685
1375	1450	755	2000
1588	1675	875	2320
1780	1878	978	2590
2060	2170	1130	3000
2340	2470	1290	3420

Timber Stresses - Gage No. 4 - Tensile Fibers

P Pounds	S = 0.834P p.s.i.	ϵ Timber in./in. x 10^{-6}	S = Eϵ p.s.i.
219	183	80	212
462	385	170	452
666	555	240	637
932	777	340	900
1158	966	440	1165
1375	1148	510	1352
1588	1325	610	1618
1780	1485	690	1830
2060	1720	800	2120
2340	1955	940	2490

4. The Lateral Buckling Problem.

"A mathematical analysis of the lateral elastic instability of deep rectangular beams leads to the following general expression:

$$P = F \frac{\sqrt{EI_2GK}}{L^2}$$

P = The critical buckling load

E = The modulus of elasticity along the grain

I_2 = The moment of inertia about the principal vertical axis

G = The modulus of rigidity in torsion

K = The torsion constant of the section

L = The span.

F = A constant depending upon the loading and fixity conditions."[1]

[1] George W. Trayer and H.W. March, "Elastic Instability of Members having Sections Common in Aircraft Construction". N.A.C.A. Report No. 382 p. 383.

For this particular set up we have: (Test A) "Case 10.- A thin, deep, rectangular beam subjected to a constant bending moment M and an axial thrust P^1, with its ends restrained."[1]

$$M_{cr.} = \frac{2\pi\sqrt{EI_2GK}}{L}\sqrt{1-\frac{P'L^2}{4\pi^2EI_2}}$$

Applying this equation to our particular beam we have:

$K = Bdb^3$

Where B=a const. depending upon the ratio of d to b.
$B = 0.269$
$K = 0.269\ (5.62)\ (1.62)^3 = 6.5$

Assuming $G = 1/16\ E = \dfrac{2.65\times10^6}{16} = 1.65\times10^5$ psi

Using $P^1 = Pcr$ (buckling about Y - axis) = 2790 pounds.

$I_2 = 1/12\ (5.62)\ (1.62)^3 = 2.02$ in ^{4}.

$$Mcr = \frac{2\pi\sqrt{2.65\ (10^6)\ (2.02)\ (1.65)\ (10^5)\ (6.5)}}{120}\sqrt{1-\frac{2790\ (120)^2}{4\pi^2(2.65)(10^6)2.02}}$$

Mcr= 113,000 in - #

However, in this case Mact.= 8 P^1 = 22,300 in —#.

Since Mact. < Mcr., lateral elastic instability is not critical for this beam. In fact a moment of this magnitude would put us well beyond the proportional limit. The above equation has meaning insofar as it reveals that buckling about the vertical axis is critical for this case and that lateral instability occurs in the plastic range.

Trayer and March in N.A.C.A. Report No. 382 have worked out and experimentally verified various cases of loading for lateral instability and state as one of their conclusions: "No arbitrary moment-of-inertia ratio can be used with certainty. Each particular case must be studied

1. George W. Trayer and H. W. March, "Elastic Instability of Members Having Sections Common in Aircraft Construction". N.A.C.A. Report No. 382 p.383.

individually and lateral support must be provided in accordance with the tendency of the beam to buckle laterally rather than to bend in a vertical plane."

5. Results of Test A.

Figures 3-5, 3-6, 3-7 and 3-8 show plots of the total wire load versus the unit strain in the timber. The unit strains vary linearly with the external load up to the point where the test was halted. A prestressing load-deflection curve is plotted in Figure 3-4.

Section III-3 shows the computations made for plotting the Wire Load-Timber Stress curves shown in Figures 3-9 and 3-10. The points selected for plotting were located at the quarter points of the beam and the two calculated stresses closely approach each other. However, the stresses computed for gages No. 2 and No. 4 do not check within reasonable experimental percentages. Even consideration of the added moment P $\triangle$ does not produce a satisfactory check.

6. Computation of Stresses in Timber - Test B.

If we make the same assumptions as for Test - A, we have:

S = 0.834P (for a tension fiber) and S = 1.053P (for a compression fiber).

Timber Stresses

	P Pounds	S = 0.834P p.s.i.	Timber in./in. x 10^{-6}	S = E ϵ p.s.i.
Gage No. 1 Tensile Fibers	500	417	200	530
	1000	834	380	1020
	1500	1250	520	1380
	2000	1670	700	1860
	2500	2080	880	2330
	3000	2500	1080	2860
	3500	2920	1200	3440
Gage No. 2 Compr. Fibers		S = 1.053P		
	500	547	260	689
	1000	1053	520	1380
	1500	1580	780	2070
	2000	2110	1040	2760
	2500	2640	1320	3500
	3000	3160	1600	4240
	3500	3690	1900	5030

Gage No. 4 Tensile Fibers	P Pounds	S = 0.834P p.s.i.	ϵ Timber in./in. x 10^{-6}	S = Eϵ
	500	417	220	583
	1000	834	430	1140
	1500	1250	640	1700
	2000	1670	850	2260
	2500	2080	1050	2790
	3000	2500	1260	3340
	3500	2920	1470	3900
Gage No. 5 Compression Fibers		S = 1.053P		
	500	547	220	583
	1000	1053	440	1170
	1500	1580	650	1725
	2000	2110	860	2280
	2500	2640	1070	2840
	3000	3160	1280	3390
	3500	3690	1490	3950

7. Results of Test B.

Figures 3-12, 3-13, 3-14 and 3-15 show plots of the total wire load versus the unit strain at selected points in the timber. This function is linear up to the conclusion of this test.

The total wire load-deflection curve is shown in Figure 3-11.

In section III-6 are shown the values of the timber fiber unit stress as computed by two methods. At the quarter points, these values are in fair agreement but, as for Test A, at the centerline the values are not satisfactory, even considering the added moment $P\Delta$.

Figure 3-16 shows a plot of total wire load vs. unit stress in the timber. (Gage No. 5).

8. Conclusions and Suggestions

a. The device which was used to transfer moment to the timber beam was satisfactory but details of the prestressing device would have to be altered to obtain a more uniform load in all wires and to allow more load to be applied. Future research could be aimed at devising a more satisfactory and economical moment connection for timber.

b. The wide percentage variations in the stresses computed in sections III-3 and III-6 are unexplained. A more exact solution yields values which are also unacceptable. Previous test results on ordinary beams would exclude an explanation based on the non-homogeniety of timber. Mr. A. G. H. Dietz has stated, "Until the bending proportional limit is reached, all fibers - tension, compression, outermost and innermost - exhibit linear stress-strain relations regardless of whether they have been stressed beyond the direct stress proportional limit or not and no hysteresis appears". [1]

c. The possibility of creep in the timber resulting in a loss of prestressing force has not been explored in these tests but could be a major factor in any application of the method.

d. Buckling presents a problem to be considered in each case depending upon the eccentricity, proportioning of the member and properties of the species to be used. Charts could be prepared which which would aid in determining critical loads for rectangular beams but this should follow work on a satisfactory moment connection.

e. This test did not include the effect of an external transverse load applied to the member but a future test is planned.

f. Any application of the method will have to weigh the cost of fittings and prestressing against the gain in load to be applied. However, we must always keep in mind that the gain is a net gain since the axial force is actually detrimental.

[1] Albert G. H. Dietz, "Stress-Strain Relations in Timber Beams of Douglas Fir" ASTM Bulletin No. 118, p. 27.

A P P E N D I X

Appendix

This Appendix contains data, calculations and curves pertaining to tests made on small clear specimens taken from the structural size timbers used in the testing program. The static bending, compression parallel to the grain, compression perpendicular to the grain and block shear tests were made substantially in accordance with the A.S.T.M. Standard Methods of Testing Small Clear Speciments of Timber. (A.S.T.M. Designation: D 143-50.)

Since the structural size employed in the program of tests was 5 5/8" x 1 5/8", the 2" x 2" size recommended for small, clear specimens was not used. Therefore, the results of these tests should not be compared with tests of 2" x 2" specimens.

A tensile test of the prestressing wire used in the beam tests is also included in this Appendix.

Tensile Test of 0.10 diameter steel pre-stressing wire.

A tensile test of the 0.10" diameter steel wire for pre-stressing was made to determine the value of the modulus of elasticity to use in other computations.

An attempt was made to measure strains with the Whittemore gage. A 10" gage was marked off on a length of wire and the wire was secured at each end by threading and placing nuts on each end. The strain measurements were difficult to make with the Whittemore gage and the curve is not as satisfactory as those obtained by using the SR4 strain gage.

Failure occured at the root of the threads and the strength was not affected by the impressions made for placing the Whittemore gage points.

The author, although not experienced in the use of a Whittemore gage, would not recommend the use of a Whittemore for measuring strains in a wire of this diameter.

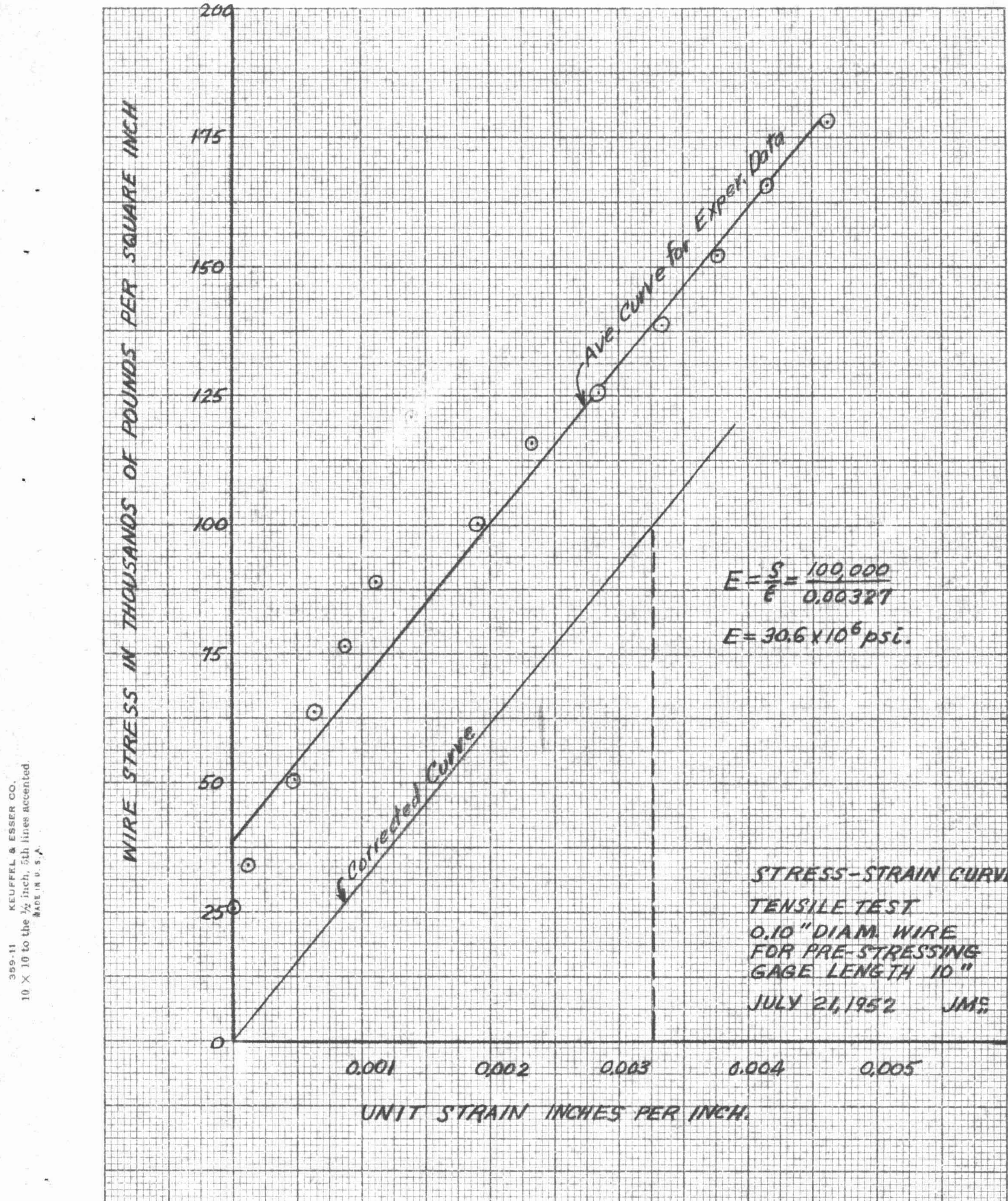

WIRE STRESS IN THOUSANDS OF POUNDS PER SQUARE INCH
200
175
150
125
100
75
50
25
0
0.001
0.002
0.003
0.004
0.005
UNIT STRAIN INCHES PER INCH.
Ave. Curve for Exper. Data
Corrected Curve
E = S/ε = 100,000/0.00327
E = 30.6 x 10^6 psi.
STRESS-STRAIN CURVE
TENSILE TEST
0.10" DIAM. WIRE
FOR PRE-STRESSING
GAGE LENGTH 10"
JULY 21, 1952 JMS.
359-11 KEUFFEL & ESSER CO.
10 X 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

FIG. A-1

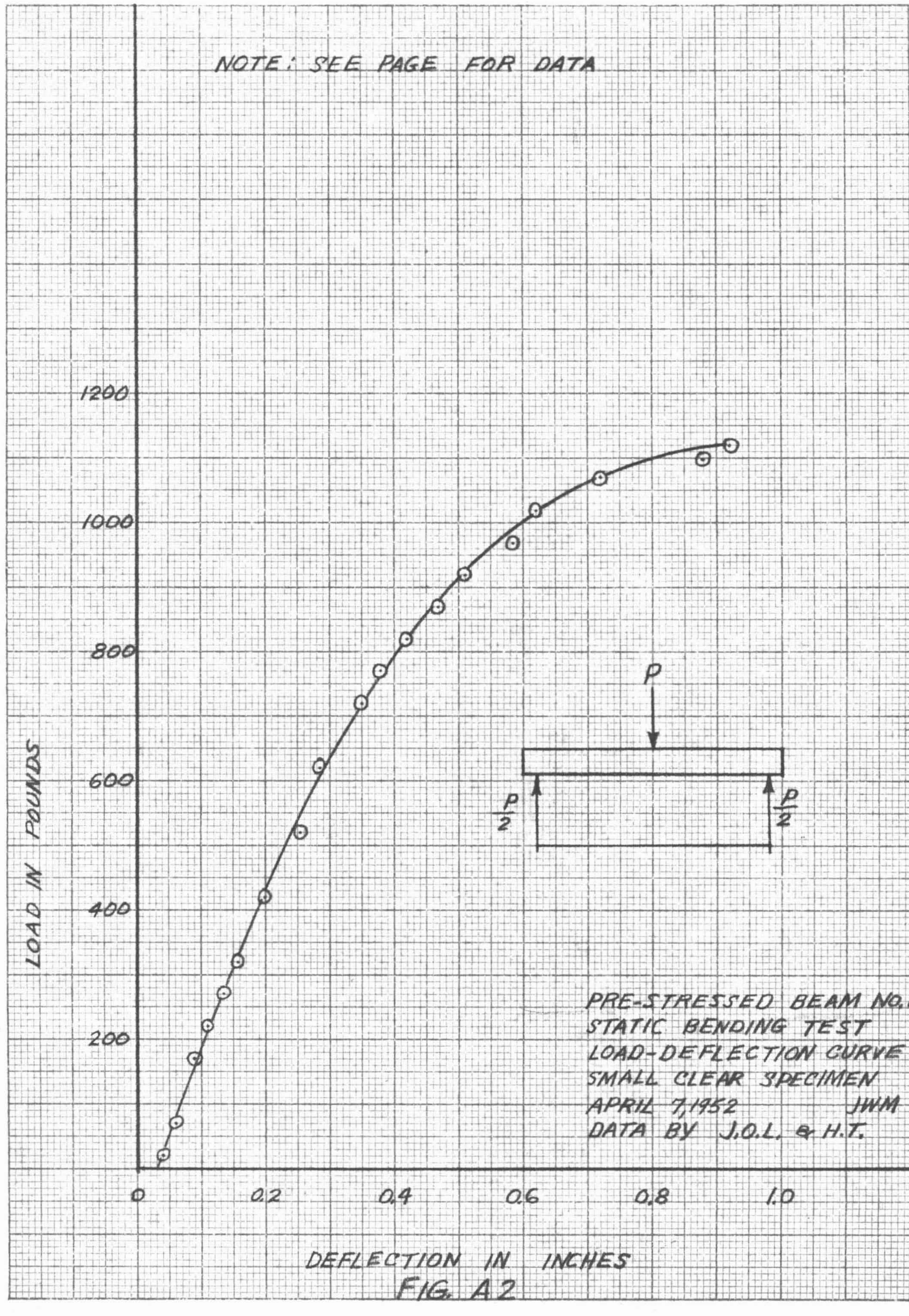

NOTE: SEE PAGE FOR DATA
1200
1000
800
600
400
200
LOAD IN POUNDS
0
0.2
0.4
0.6
0.8
1.0
P
P/2
P/2
PRE-STRESSED BEAM NO.1
STATIC BENDING TEST
LOAD-DEFLECTION CURVE
SMALL CLEAR SPECIMEN
APRIL 7, 1952 JWM
DATA BY J.O.L. & H.T.
DEFLECTION IN INCHES

FIG. A2

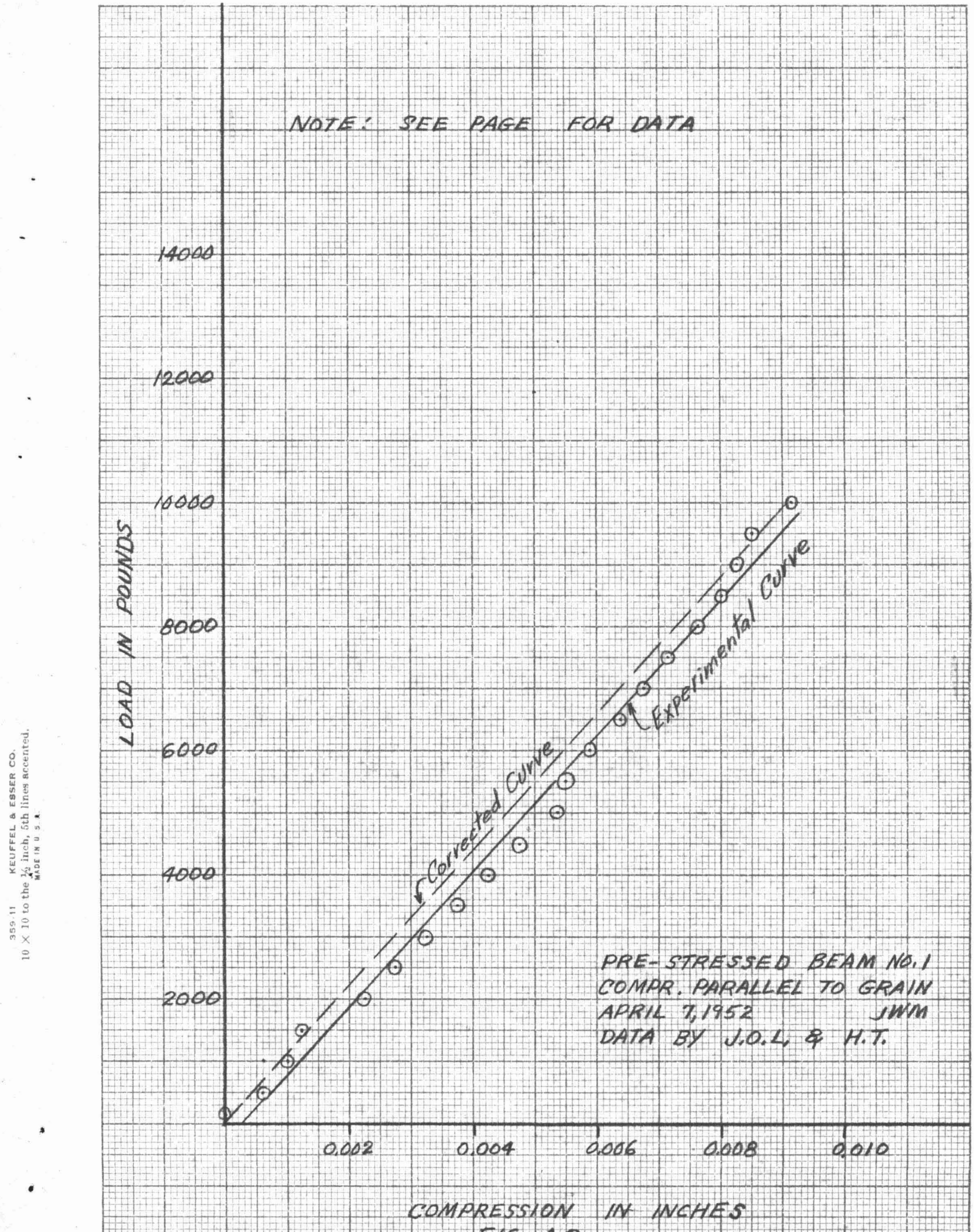

NOTE: SEE PAGE FOR DATA
LOAD IN POUNDS
14000
12000
10000
8000
6000
4000
2000
0.002
0.004
0.006
0.008
0.010
COMPRESSION IN INCHES
Corrected Curve
Experimental Curve
PRE-STRESSED BEAM NO. 1
COMPR. PARALLEL TO GRAIN
APRIL 7, 1952 JWM
DATA BY J.O.L. & H.T.
KEUFFEL & ESSER CO.
359-11 10 × 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

FIG. A3

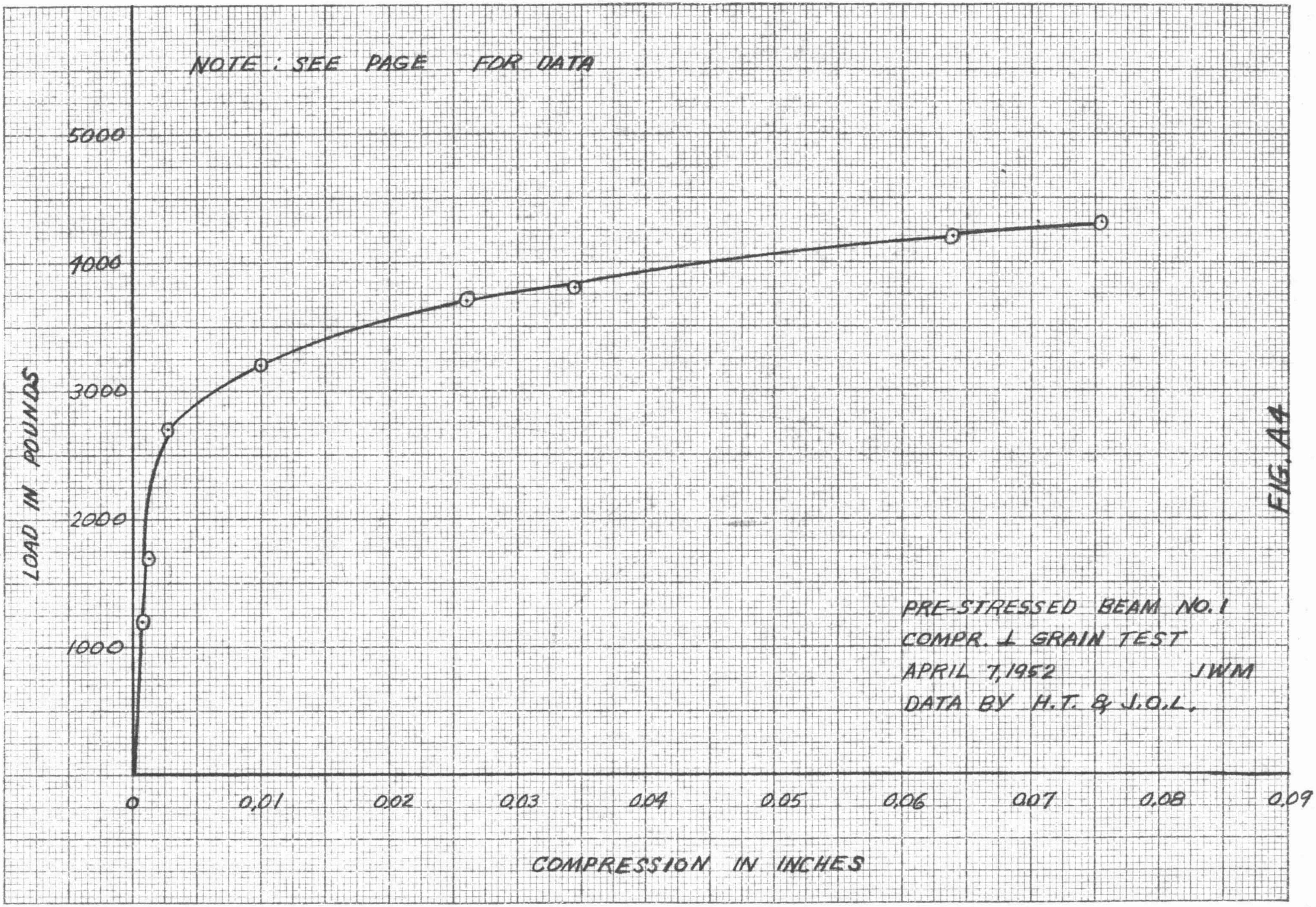

NOTE : SEE PAGE FOR DATA
5000
4000
3000
2000
1000
LOAD IN POUNDS
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
COMPRESSION IN INCHES
PRE-STRESSED BEAM NO. 1
COMPR. ⊥ GRAIN TEST
APRIL 7, 1952 JWM
DATA BY H.T. & J.O.L.

FIG. A4

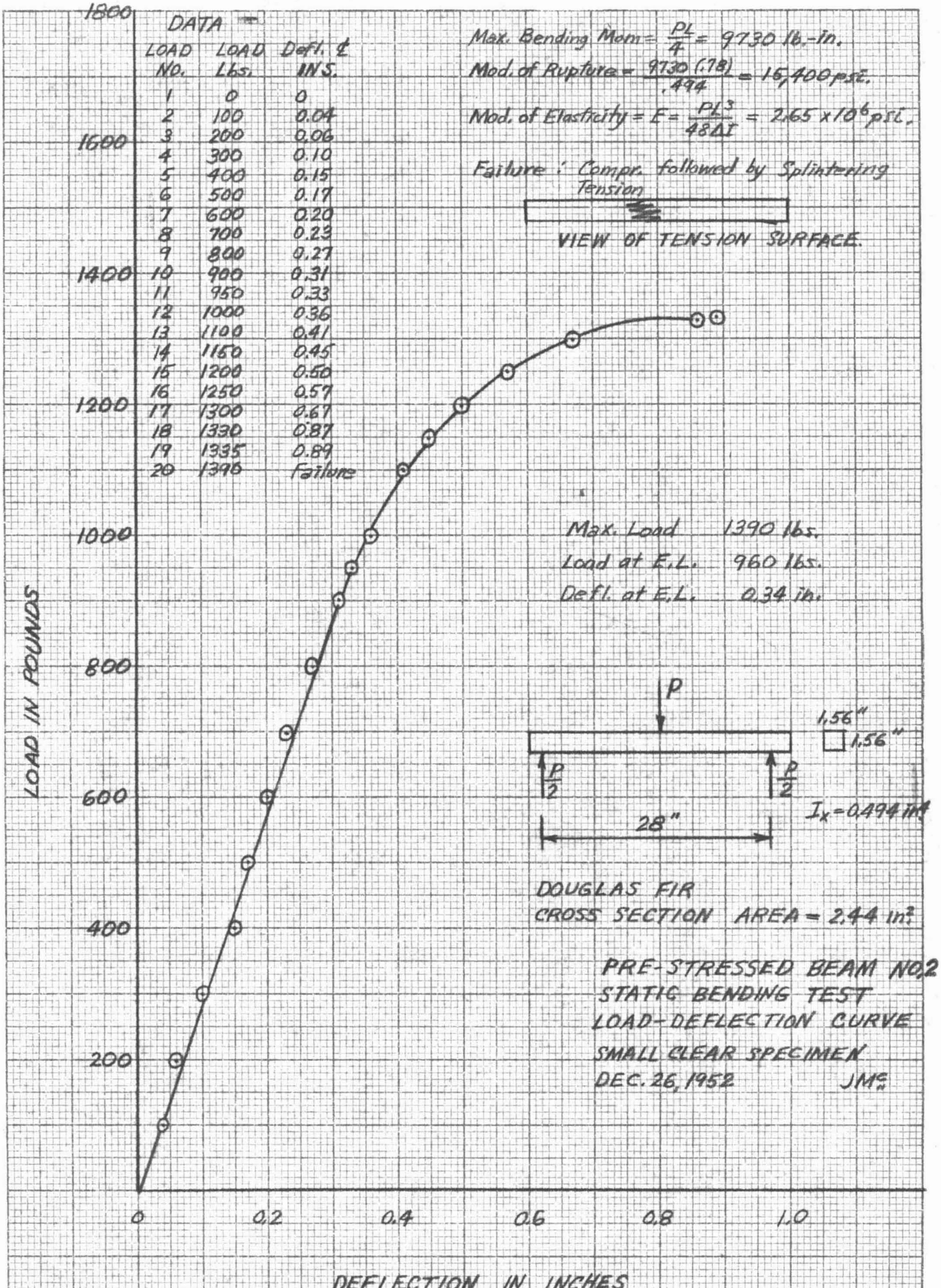
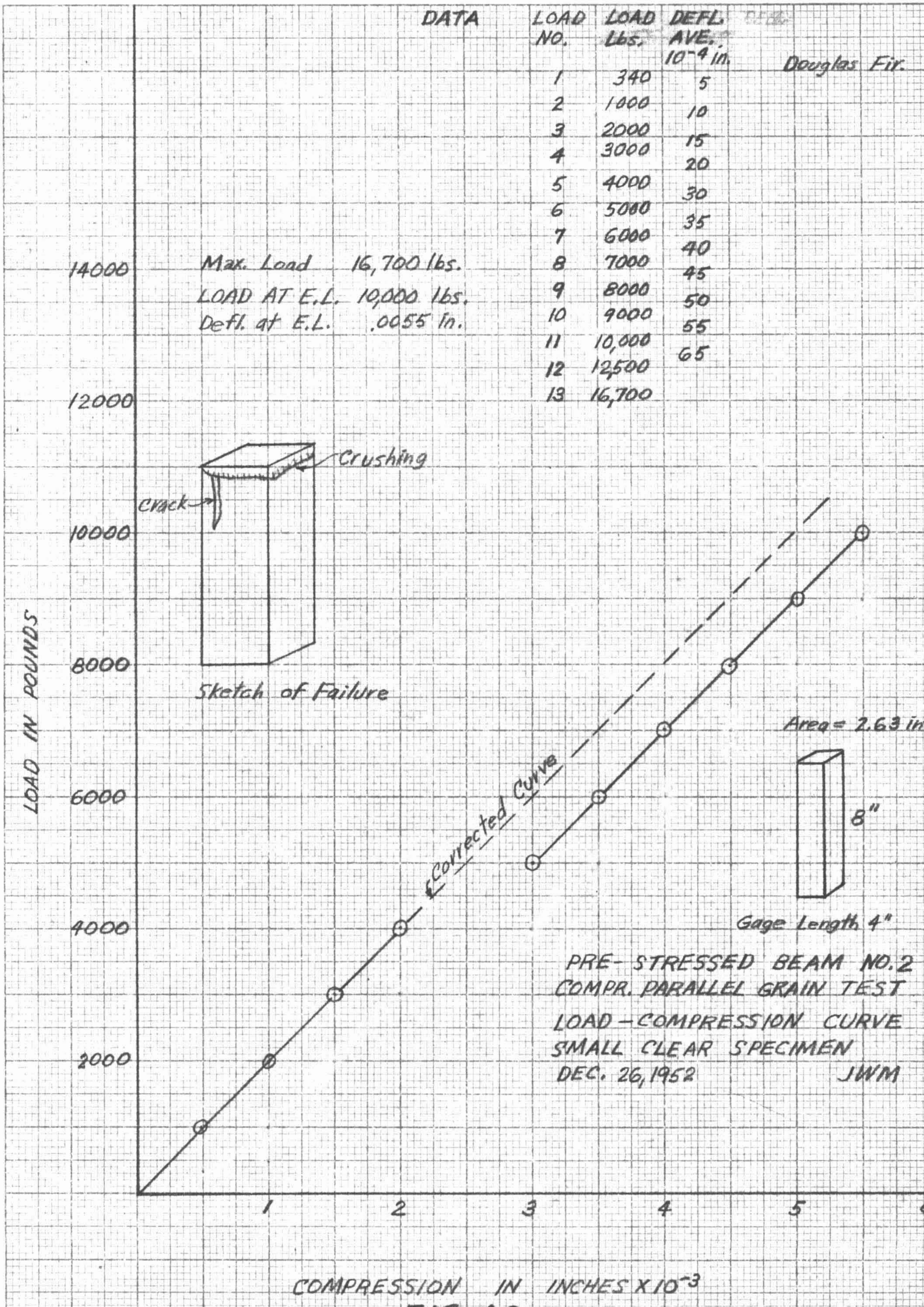

DATA
LOAD No. | LOAD Lbs. | Defl. ℄ INS.
1 0 0
2 100 0.04
3 200 0.06
4 300 0.10
5 400 0.15
6 500 0.17
7 600 0.20
8 700 0.23
9 800 0.27
10 900 0.31
11 950 0.33
12 1000 0.36
13 1100 0.41
14 1150 0.45
15 1200 0.50
16 1250 0.57
17 1300 0.67
18 1330 0.87
19 1335 0.89
20 1390 Failure
Max. Bending Mom = PL/4 = 9730 lb.-in.
Mod. of Rupture = 9730 (.78)/.494 = 15,400 psi.
Mod. of Elasticity = E = PL³/48ΔI = 2.65 x 10⁶ psi.
Failure: Compr. followed by Splintering Tension
VIEW OF TENSION SURFACE
Max. Load 1390 lbs.
Load at E.L. 960 lbs.
Defl. at E.L. 0.34 in.
P
P/2
P/2
28"
1.56"
1.56"
Iₓ = 0.494 in⁴
DOUGLAS FIR
CROSS SECTION AREA = 2.44 in²
PRE-STRESSED BEAM NO. 2
STATIC BENDING TEST
LOAD-DEFLECTION CURVE
SMALL CLEAR SPECIMEN
DEC. 26, 1952 JMc
LOAD IN POUNDS
1800
1600
1400
1200
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
DEFLECTION IN INCHES

FIG. A5



LOAD NO.	LOAD Lbs.	DEFL. AVE. 10^{-4} in.
1	340	5
2	1000	10
3	2000	15
4	3000	20
5	4000	30
6	5000	35
7	6000	40
8	7000	45
9	8000	50
10	9000	55
11	10,000	65
12	12,500	
13	16,700	

FIG. A6

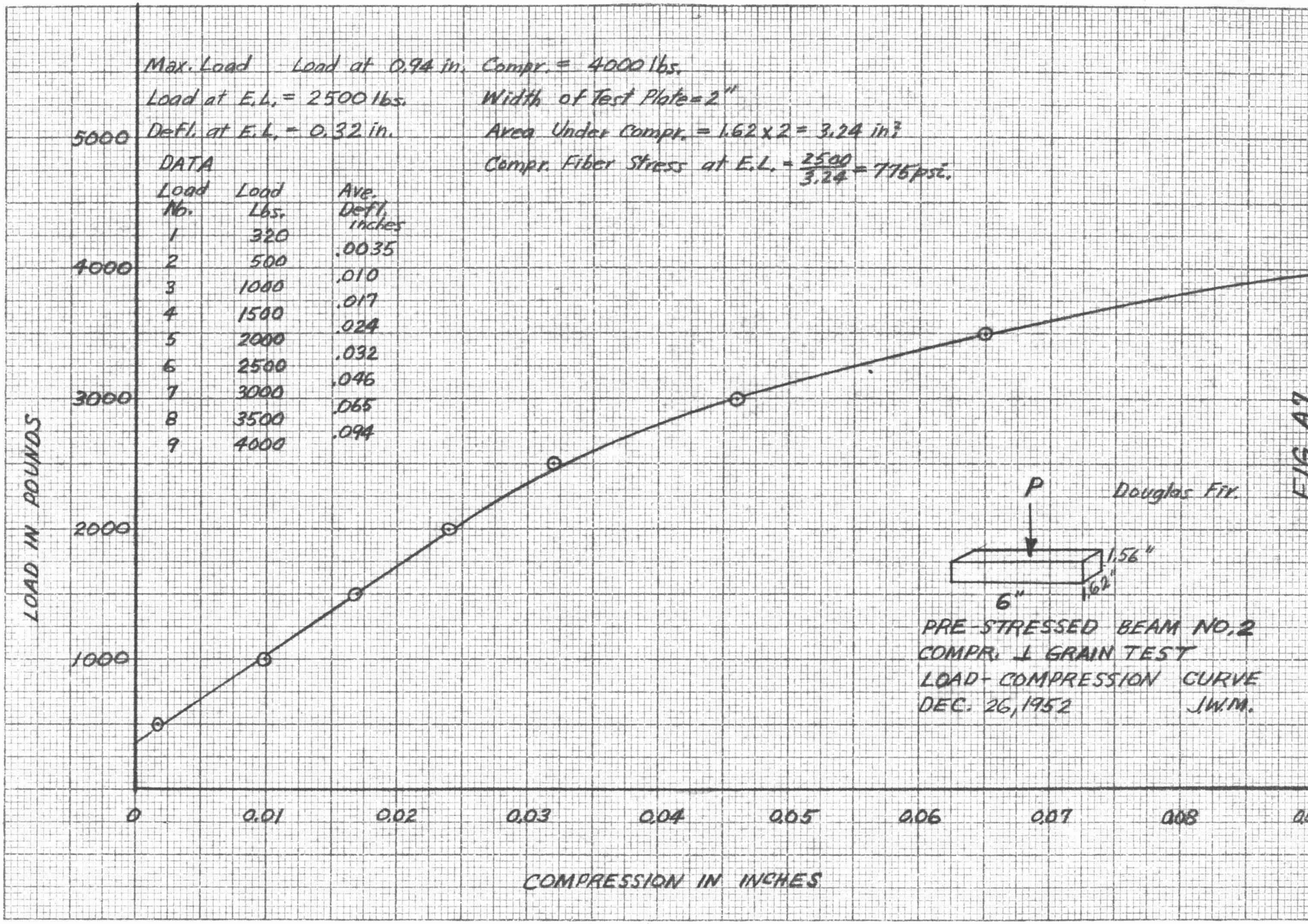

Max. Load Load at 0.94 in. Compr. = 4000 lbs.
Load at E.L. = 2500 lbs.
Defl. at E.L. = 0.32 in.
Width of Test Plate = 2"
Area Under Compr. = 1.62 x 2 = 3.24 in.²
Compr. Fiber Stress at E.L. = 2500/3.24 = 775 psi.
DATA
Load No. | Load Lbs. | Ave. Defl. inches
1 | 320 | .0035
2 | 500 | .010
3 | 1000 | .017
4 | 1500 | .024
5 | 2000 | .032
6 | 2500 | .046
7 | 3000 | .065
8 | 3500 | .094
9 | 4000
LOAD IN POUNDS
5000
4000
3000
2000
1000
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
COMPRESSION IN INCHES
P
1.56"
1.62"
6"
Douglas Fir.
PRE-STRESSED BEAM NO. 2
COMPR. ⊥ GRAIN TEST
LOAD-COMPRESSION CURVE
DEC. 26, 1952 J.W.M.

FIG. A7

Data for

Non-Prestressed
Timber Beam

10/17/52
J.O.L.
J.W.Mc.

Load No.	Total Load lbs.	Whit. Rdg. 1	Diff. in.	Whit. Rdg. 2	Diff. in.	Whit. Rdg. 3	Diff. in.	Defl. Rdg. 20 scale	Diff. 20 scale
1	32.5	.0489		.0499		.0508		16.7	
			.0041		.0044		.0033		0.5
2	400	.0530		.0458		.0541		16.2	
			.0077		.0080		.0064		1.0
3	800	.0566		.0419		.0572		15.7	
			.0112		.0120		.0099		1.5
4	1200	.0601		.0379		.0607		15.2	
			.0149		.0158		.0133		2.0
5	1600	.0638		.0341		.0641		14.7	
			.0184		.0198		.0166		2.5
6	2000	.0673		.0301		.0674		14.2	
			.0220						
7	2400	.0709							
			.0194		.0210		.0175		2.6
8	2400	.0683		.0289		.0683		14.1	
			.0230		.0251		.0210		3.1
9	2800	.0719		.0248		.0718		13.6	
			.0286		.0309		.0267		3.9
10	2925	.0775		.0190		.0775		12.8	
									3.9
*11	3200							12.8	
			.0306		.0339		.0277		4.2
12	3400	.0795		.0160		.0785		12.5	
			.0327		.0362		.0293		4.5
13	3600	.0816		.0137		.0801		12.2	
			.0346		.0388		.0311		4.8
14	3800	.0835		.0111		.0819		11.9	
			.0366		.0412		.0325		5.1
15	4000	.0857		.0087		.0833		11.6	
			.0386		.0441		.0343		5.5
16	4200	.0877		.0058		.0851		11.2	
			.0415		.0479		.0350		5.9
17	4400	.0904		.0020		.0868		10.8	
			.0436		.0503		.0375		6.3
18	4600	.0927		.0004		.0883		10.4	
			.0467		.0525		.0387		6.9
19	4800	.0956		.0026		.0895		9.8	
20	5000								ULTIMATE

*Switched to high range.

Data for Pre-Stressed Timber Beam No. 1

10/3/52
J.O.L.
J.W.Mc.

Load No.	External Load Pounds	Gage 12 in/in (10-6)	Diff. in/in x10-6	Gage 13 in/in x10-6	Diff. in/in x10-6	Gage 14 in/in x10-6	Diff. in/in x10-6	Defl. Rdg. 20 scale
E 1		5340		6110		4810		16.1
			430		420		520	
2		5770		6530		5330		16.1
			840		850		940	
3		6180		6960		5750		16.15
			2040		2230		2210	
4		7380		8340		7020		16.2
			3310		3490		3260	
W 5		8650		9600		8070		16.3
			3960		4020		3940	
6		9300		10130		8750		16.35
			4050		4100		4000	
7		9390		10210		8810		16.38
			4160		4150		4100	
8		9500		10260		8910		16.40
			4260		4270		4190	
9		9600		10380		9000		16.4
			4290		4300		4250	
10	100	9630		10410		9060		16.4
			4340		4350		4310	
11	200	9680		10460		9120		16.3
			4370		4390		4350	
12	380 300	9710		10500		9160		16.1
			4410		4420		4390	
13	400	9750		10530		9200		16.0
			4450		4460		4440	
14	500	9790		10570		9250		15.97
			4470		4490		4460	
15	573	9810		10600		9270		15.9
			4480		4500		4470	
16	600	9820		10610		9280		15.9
			4520		4540		4520	
17	700	9860		10650		9330		15.85
			4560		4570		4560	
18	800	9900		10680		9370		15.55
			4600		4600		4600	
19	900	9940		10710		9410		15.5
			4640		4650		4640	
20	1000	9980		10760		9450		15.4
			4670		4680		4680	
21	1100	10010		10790		9490		15.3
			4710		4710		4720	
22	1200	10050		10820		9530		15.2
			4750		4740		4770	

Load No.	External Load Pounds	Gage 12 in/in (10-6)	Diff. in/in x10-6	Gage 13 in/in x10-6	Diff. in/in x10-6	Gage 14 in/in x10-6	Diff. in/in x10-6	Defl. Rdg. 20 scale
23	1300	10090		10850		9580		15.0
			4830		4820		4840	
24	1500	10170		10930		9650		14.65
			4890		4880		4920	
25	1700	10230		10990		9730		14.5
			4960		4950		4990	
26	1900	10300		11060		9800		14.4
			5030		5020		5070	
27	2100	10370		11130		9880		14.3
			5100		5090		5150	
28	2300	10440		11200		9960		14.2
			5170		5150		5230	
29	2500	10510		11260		10040		14.0
			5250		5220		5300	
30	2700	10590		11330		10110		13.9
			5410		5370		5480	
31	3200	10750		11480		10290		12.2
			5640		5590		5700	
32	4000	10980		11700		10510		11.2
			5690		--		--	
33	4000	11030		--		--		
			5870		5790		5930	
34	4500	11210		11900		10740		10.5
			4440		4390		5410	
35	500	9740		10500		9210		15.1
			5030		4980		5080	
*36	2000	10370		11090		9890		14.0
			5400		5330		5470	
37	3000	10740		11440		10280		12.0
			5910		5830		5990	
38	4500	11250		11940		10800		10.8
39	5000	FAILURE						

*Reset 550 each scale

1/17/53
J.O.L.
J.W.Mc.

Pre-stressed beam No. 2 Test A

Units of all measurements ϵ in./in. x 10^{-6}

Load No.	Gage 1	$\Delta\epsilon$	Gage 2	$\Delta\epsilon$	Gage 3	$\Delta\epsilon$	Gage 4	$\Delta\epsilon$	Gage 5	$\Delta\epsilon$
1	5040		3380		5130		4000		4590	
2	5110	70	3280	100	5140	10	4080	80	4510	80
3	5180	140	3160	220	5130	0	4170	170	4420	170
4	5240	200	3050	330	5130	0	4240	240	4330	260
5	5330	290	2930	450	5130	0	4340	340	4230	360
6	5410	370	2800	580	5130	0	4440	440	4130	460
7	5470	430	2680	700	5130	0	4510	510	4050	540
8	5560	520	2570	810	5160	30	4610	610	3960	630
9	5620	580	2440	940	5160	30	4690	690	3860	730
10	5700	660	2300	1080	5210	80	4800	800	3780	810
*11	5800	760	2100	1280	5370	240	4940	940	3660	930
12	5550	510	2550	830	5170	40	4600	600	3960	630

Pre-stressed beam No. 2 Test A

Load No.	Gage 6	$\Delta\epsilon$	Gage 7	$\Delta\epsilon$	Gage 8	$\Delta\epsilon$	Gage 9	$\Delta\epsilon$	Rdg. Defl. (20 scale)	Defl. in.
1	6430		4820		4300		6140		8.90	
2	6640	210	5040	220	4540	240	6400	260	9.00	0.05
3	6870	440	5310	490	4790	490	6680	540	9.10	0.10
4	7080	650	5510	690	5030	730	6900	760	9.20	0.15
5	7340	910	5790	970	5310	1010	7200	1060	9.30	0.20
6	7570	1140	6040	1220	5550	1250	7440	1300	9.50	0.30
7	7780	1350	6270	1450	5790	1490	7690	1550	9.60	0.35
8	8000	1570	6500	1680	6010	1710	7920	1780	9.70	0.40
9	8220	1790	6770	1950	6250	1950	8210	1870	9.80	0.45
10	8440	2010	7030	2210	6470	2170	8480	2340	9.90	0.50
11	8640	2210	7410	2590	6680	2380	8880	2740	10.0	0.55
12	7920	1490	6470	1650	5930	1630	7910	1770	9.70	0.40

1/19/53
J.O.L.
J.W.Mc.

Pre-stressed Beam No.2 Test B

Units of all measurements ϵ in./in. x 10^{-6}

Load No.	Gage 1	$\Delta\epsilon$	Gage 2	$\Delta\epsilon$	Gage 3	$\Delta\epsilon$	Gage 4	$\Delta\epsilon$	Gage 5	$\Delta\epsilon$
1	5180		3410		5220		4160		4640	
		150		260		10		170		190
2	5330		3150		5210		4330		4450	
		280		460		30		310		360
3	5460		2950		5190		4470		4280	
		410		690		50		470		530
4	5590		2720		5170		4630		4110	
		580		920		50		670		720
5	5760		2490		5170		4830		3920	
		670		1090		30		790		840
6	5850		2320		5190		4950		3800	
		780		1260		40		810		970
7	5960		2150		5180		5070		3670	
		990		1560		50		1170		1200
8	6170		1850		5170		5330		3440	
		1120		1790		80		1330		1380
9	6300		1620		5140		5490		3260	
		1290		2040		90		1530		1560
10	6470		1370		5130		5690		3080	
		1340		2130		90		1600		1620
11	6520		1280		5130		5760		3020	

Pre-stressed Beam No. 2 Test B

Load No.	Gage 6		Gage 7		Gage 8		Gage 9		Defl. Rdg. (20 scale)	Defl. (inches)
1	6510		4930		4380		6270		9.00	
		530		510		590		560		0.15
2	7040		5440		4970		6830		9.30	
		920		920		1020		1000		0.20
3	7430		5850		5400		7270		9.40	
		1390		1170		1640		1390		0.30
4	7900		6100		6020		7660		9.60	
		1850		1890		1960		1950		0.45
5	8360		6820		6340		8220		9.90	
		2160		2090		2340		2220		0.50
6	8670		7020		6720		8490		10.0	
		2420		2530		2570		2640		0.55
7	8930		7460		6950		8910		10.1	
		3040		2820		3390		3150		0.70
8	9550		7750		7770		9420		10.4	
		3490		3460		3590		3540		0.85
9	10000		8390		7970		9810		10.7	
		3890		3820		4110		4030		1.00
10	10400		8750		8490		10300		11.0	
		3940		3800		4290		4140		1.05
11	10450		8730		8670		10410		11.1	

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Laboratory Tests of Specimen from Pre-Stressed Timber Beam
Static Bending Test

Rdg. No.	Load lb.	Defl. in.
1	0	0.010
2	20	0.040
3	70	0.060
4	120	0.060
5	170	0.090
6	220	0.110
7	270	0.135
8	320	0.156
9	370	0.178
10	420	0.200
11	470	0.225
12	520	0.255
13	570	0.275
14	620	0.285
15	670	0.325
16	720	0.350
17	770	0.380
18	820	0.420
19	870	0.468
20	920	0.510
21	970	0.585
22	1020	0.620
23	1070	0.720
24	1100	0.880
25	1120	0.920

$I = \frac{bd^3}{12} = 0.611$ in.^{4}

Section Modulus $S = 0.736$ in.^{3}

Max. Load $P = 1120$ lb.

Max. Bending Moment

$M = \frac{PL}{4} = 7840$ lbs.

Modulus of Rupture

$S = \frac{M}{S} = 10620$ Psi

Deflection @ E.L.

$= \frac{PL^3}{48EI} = 0.321$ in.

Modulus of Elasticity for Bending

$E = \frac{PL^3}{48\ \ I} = 16.3 \times 10^5$ Psi

Max. Horiz. Shear

S_h max. $= 3/2 \times \frac{V}{A} = 3/4 \cdot \frac{P}{A}$

Type of Failure

Compression followed by

Cross-Grain Tension

Laboratory Tests of Specimens from Pre-stressed Timber Beam

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Rdg. No.	Load lb.	Defl. @ Lt. in.	Δ in Defl.	Defl. @ Rt. in.	Δ in Defl.	Ave Defl.
1	0	0.0230	0	0.026	0	0
2	300	0.0235	0.0005	0.027	0.001	0.00075
3	600	0.0235	0.0005	0.027	0.001	0.00075
4	900	0.0235	0.0005	0.027	0.001	0.00075
5	1200	0.0235	0.0005	0.027	0.001	0.00075
6	1700	0.0240	0.001	0.0275	0.0015	0.00125
7	2200	0.0240	0.001	0.0275	0.0015	0.00125
8	2700	0.0255	0.0025	0.029	0.003	0.00275
9	3200	0.0330	0.0100	0.036	0.01	0.01
10	3700	0.0485	0.0255	0.052	0.026	0.026
11	3800	0.0580	0.035	0.060	0.034	0.0345
12	4200	0.0870	0.064	0.090	0.064	0.064
13	4320	0.1000	0.077	0.10	0.074	0.0755
14	4540	0.1260	0.103	0.129	0.103	0.103
15						

Area under Comp. 1.60" x 2.00" = 3.20 in.^{2}

Compression Fiber Stress @ E.L. 750 Psi

Strain @ E.L. 0.0001

Modulus of Elasticity 75×10^5 Psi

for Comp. Perpen. to Grain

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Laboratory Tests of Specimens from Pre-Stressed Timber Beam
Compression Parallel to Grain Test

Rdg. No.	Load lb.	Defl. @ Left	Defl. @ Right	Ave. Defl. in.
1	160	0	0	0
2	500	0.001	0.00025	0.0006
3	1000	0.0015	0.0005	0.001
4	1500	0.00225	0.001	0.00162
5	2000	0.00275	0.00175	0.00225
6	2500	0.00325	0.00225	0.00275
7	3000	0.00350	0.00300	0.00325
8	3500	0.00375	0.00375	0.00375
9	4000	0.0040	0.0045	0.00425
10	4500	0.0045	0.0050	0.00475
11	5000	0.0050	0.00575	0.00537
12	5500	0.0050	0.0060	0.00550
13	6000	0.00525	0.0065	0.00588
14	6500	0.00575	0.0070	0.00638
15	7000	0.0060	0.0075	0.00675
16	7500	0.0065	0.00775	0.00713
17	8000	0.00725	0.0080	0.00763
18	8500	0.0075	0.0085	0.0080
19	9000	0.00775	0.00875	0.00825
20	9500	0.0080	0.0090	0.0085
21	10000	0.00875	0.0095	0.00913
22	10500	——	——	
23	11000	——	——	
24	11500	0.010	0.010	0.010
25				

Type of Failure

Wedge Split

Max. Crushing Strength

11500 lb.

Max. Crushing Stress

4340 Psi

Max. Deflection

0.01 in.

Load @ P.L.

8980 lb.

Deflection @ P.L.

0.00785

Fiber stress @ P.L.

3390 Psi

Strain @ P.L.

0.00196

Modulus of Elasticity for Comp. Parallel to Grain

17.3×10^5 Psi

B I B L I O G R A P H Y

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