NATIONAL BUREAU OF STANDARDS REPORT

2926

TESTS OF PRECAST GIRDERS WITH WELDED SPLICES

(Tee-Heads Nos. 2 and 3)

by

Leopold F. Skoda and D. Watstein

Report to

Bureau of Yards and Docks
Department of the Navy

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
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NBS PROJECT | **NBS REPORT**

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Contents

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Abstract

Two precast girders with welded splices were tested as simply supported beams to determine the resistance of the splices to shear. The girders consisted of thin web channels assembled by welding to produce members of a hollow section. The addition of six inclined bars on each side of the welded splices in Tee-Head No. 3 resulted in a marked increase in the shear resistance of the specimen as compared with Tee-Head No. 2 which contained no inclined stirrups.

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1. INTRODUCTION

The tests of the precast girders were made at the request of the Bureau of Yards and Docks for the purpose of evaluating the resistance to shear of the welded splices and the thin web of the hollow girder.

The following report presents the data obtained in tests of specimens which were designated as Tee-Head No. 2 and Tee-Head No. 3 by the Bureau of Yards and Docks:

2. DESCRIPTION OF TEST SPECIMENS

2.1 General Description of Specimens

The precast Tee-Heads were constructed in accordance with the Bureau of Yards and Docks plans and specifications. (Precast Tee-Head, Sketch B-1, dated January 12, 1953, for Tee-Head No. 2, and Precast Tee-Head Revised Joint Assembly, Sketch B-2, dated May 5, 1953, for Tee-Head No. 3). The Tee-Head consisted essentially of an assembly of two reinforced concrete channels with straight haunches. The two channels, 12 ft 6 in. long and 3 ft 6 in. deep at the mid section, were joined together with welded plate splices along the top and bottom legs of the channels. Each channel was stiffened with four ribs, one near each end and one 9 in. each side of the centerline of the specimen. The overall thickness of the assembled specimen was 12 in. and the web thickness was 2 1/2 in. for each channel throughout. Girder ends were constructed to match the ends of the Tee-Head simulating a girder suspended between two adjoining Tee-Heads as shown in figures 1 and 2.

2.2 Forms

In order to keep the cost of casting the specimens to a minimum, only one set of forms was made and one half of a Tee-Head was cast at a time. Tee-Head No. 2 was cast on May 20 and June 2. Tee-Head No. 3 was cast on June 18 and June 25.

The forms were fabricated of wood and so constructed that the sides were easily removed. A base of 4- by 4-in. timbers was topped by sheets of 1/2-in. plywood. Plywood panels were then bolted to the base to form the inside of the vertical stiffening ribs, the legs of the channels and the inside of the web. The end channel sections were cast in an additional set of two forms. Three coats of spar varnish were applied to all surfaces within the form and prior to casting a mixture of oil and asbestine powder was applied to facilitate stripping. The forms with reinforcing steel in place are shown in figures 3 through 6.

2.3 Concrete

The proportions of the concrete mix were 1:2.48:2.02 by weight. High-early-strength cement was used in order to expedite the curing of the specimens. The aggregates were White Marsh, Maryland sand and pea gravel, maximum size of the coarse aggregate being 3/8 in. Three batches of concrete

were mixed for each casting operation and the slump varied from 2 in. to 3 1/2 in. Six standard 6- by 12-in. control cylinders were cast to represent each half of a specimen and the average compressive strength realized at the time of test was 7900 psi for Tee-Head No. 2 and 8200 psi for Tee-Head No. 3. Stress-strain curves were determined for each set of concrete cylinders and are shown in figures 7 and 8. All concrete specimens were cured for two days under damp burlap; they were then transferred to a curing chamber where they were cured at 72° F and 100 percent relative humidity, until it was necessary to remove them for fabrication into Tee-Heads.

2.4 Reinforcement

The channels composing the Tee-Heads were reinforced with intermediate grade reinforcing bars and with welded wire fabric. Two No. 9 deformed reinforcing bars were located along the upper leg of each channel and a No. 4 deformed bar was located along the bottom leg of the channel. The extreme top and bottom reinforcing bars projected 4-in. beyond each end of the specimen. The purpose of extending the bars was to form a welded joint with the girder end sections. The webs of the channels were reinforced with 2- by 2-in. welded wire fabric of No. 6 gage. The fabric extended throughout the web and was bent at a 90° angle to extend into the upper end lower leg of the channel.

The girder end sections were similarly reinforced with a single No. 7 deformed reinforcing bar in the upper and lower legs and were so placed as to permit being welded to the bars projecting from the Tee-Head. Wire fabric of the size used in the Tee-Head was also placed in the same manner in the beam ends.

Each channel of Tee-Heads No. 2 and No. 3 was reinforced at the joint with a single hooked No. 4 deformed reinforcing bar to resist shear, as shown in the attached sketch. In addition to that, Tee-Head No. 3 was also reinforced against diagonal tension in the web on each side of the joint with three inclined No. 4 bars located as shown in the sketch.

The girder ends were reinforced the same way as their accompanying Tee-Heads.

(For details of reinforcing refer to enclosed sketch).

2.5. Assembly of Specimens

The two halves of the respective Tee-Heads were joined together at six points. Three of these points were located on the upper leg and the remaining three on the lower leg of the channels. These connections were made by welding 1- by 3- by 3/8-in. steel splice plates to the abutting 2- by 3- by 3/8-in. plates embedded into each half of the specimen. The embedded plates were anchored by being welded to a No. 5 reinforcing bar placed in the leg and web of the specimen. Similar welding plates were also cast into the girder ends at four points on the stiffening ribs.

After the channels and girder end sections were assembled, all three parts of the Tee-Head were aligned so as to form welded lap joints of the reinforcing bars projecting from the Tee-Head and the two girder ends as shown in the close-up in figure 2. The protruding No. 9 reinforcing bars of the Tee-Head were welded to the No. 7 bar of the girder end at the top of the specimen; in the same manner, the No. 4 bar of the Tee-Head was welded to the No. 7 bar in the girder end at the bottom of the specimens. In all cases the length of the welded lap joint was 3 inches ± 1/8 in. After the welding was completed, the gaps between the Tee-Head and the girder ends were filled with concrete of the same proportions as had been used in casting the specimens. At the time of test the compressive strength of this concrete was 8270 psi for Tee-Head No. 2 at 34 days and 6770 psi for Tee-Head No.3 at 15 days. Stress-strain curves for 6- by 12-in. cylinders of the concrete are shown in figures 7 and 8, respectively.

3. TESTING PROCEDURE AND RESULTS

3.1 Test Set-Up

Both Tee-Heads were tested in a similar manner to failure in a 600,000 lb capacity hydraulic testing machine. It was necessary to support the test specimen on a 20 ft length of I-beam since the length of the platen of the testing machine was only 12 ft, whereas a 13 ft 6-in. span was specified in the test of the Tee-Head. The supporting I-beam was 30-in. deep and was supported at points 12 ft apart by 4- by 4- by 12-in. steel blocks. The Tee-Head was then placed in an inverted position on top of the supporting I-beam as shown in figure 9. At the reaction points 6 ft 9 in. on either side of the centerline, the Tee-Head was supported by rollers. The top of the Tee-Head was capped with a 14- by 18- by 1-in. steel plate and a 10- by 12- by 4-in. steel

bearing block was interposed between the capping plate and the crosshead of the testing machine. The load was applied through a 3-in. diameter steel roller which was sandwiched between the two plates. Neat plaster of paris was used to assure intimate contact between all steel parts of the assembly.

3.2 Instrumentation

Deflection of the Tee-Heads was measured at the center of the specimen by a taut-wire mirror-scale device and also with micrometer dial gages. The taut-wire device consisted of .011 in. diameter wire stretched taut with weights suspended over anchor pins located directly above the reaction points. A scale calibrated in hundredths of an inch was cemented to a specimen along its centerline and readings were taken at the point on the scale intersected by the wire. The micrometer dial gages having one-thousandth inch divisions were placed at the centerline and bore against brass angles cemented to the sides of the specimen. The dial gages were mounted on tripods which rested on the platen of the testing machine. Another pair of dial gages mounted over the east and west ends of the test specimen directly over the supports measured the movement of the supports with reference to the platen of the testing machine.

In addition to these measurements, the angular rotation of the girder ends about the reaction points was measured during the testing of Tee-Head No. 3. This was accomplished with a horizontal clinometer with a gage length of 20 in. Direct and reverse readings were taken at increments of 25,000 lbs.

3.3 Test Results

The stress-strain curves obtained for the concrete and the grout used in the girder splices for Tee-Head No. 2 are shown in figure 7. The concrete in the first half of this Tee-Head was 61 days old at the time of test and the second half of the specimen was 48 days old. The compressive strengths of the cylinders representing the two halves of the specimen were 8165 and 7680 psi, while their tangent moduli were 4,600,000 and 4,700,000 psi, respectively. The concrete grout was 34 days old at the time of test and its compressive strength and tangent modulus were 8370 psi and 4,500,000 psi, respectively.

The stress-strain curves obtained for the concrete and the grout used in the girder splices for Tee-Head No. 3 are shown in figure 8. The compressive strength of the first and second halves of this specimen at age 50 and 43 days were 8370 and 8030 psi respectively, and the corresponding tangent moduli were 5,000,000 and 4,900,000 psi. The 15 day old grout attained a strength of 6,770 psi and its tangent modulus was 4,500,000 psi. In both Tee-Heads, 1 percent calcium chloride was added to the concrete grout to accelerate the strength.

The properties of the reinforcement used in both Tee-Heads are given in the table on Properties of Materials for each Tee-Head. All the bars were deformed reinforcing bars of intermediate grade and the welded wire fabric used as web reinforcement was 2- by 2-in. wire mesh of No. 6 gage.

Both Tee-Heads were tested in an inverted position as simple beams having a 13 ft 6-in. span with a concentrated load applied at the center. The load was applied in increments of 5,000 lb up to a load of 10,000 lb and then in increments of 10,000 lb until a maximum load was reached. The maximum load for Tee-Head No. 2 was 140,000 lb and for Tee-Head No. 3, 181,000 lb.

The first visible cracks observed during the test of Tee-Head No. 2 occurred at 26,000 lb and the total number of observed cracks was 88. Initial cracking of Tee-Head No. 3 was observed at 25,000 lb and the total number of cracks was 70. In both cases the observed cracks were carefully marked and numbered and the crack patterns are shown in figures 10 and 11. Load-deflection curves are shown in figures 12 and 13 for the two specimens and represent the averaged results of data obtained by the taut-wire and dial gage methods. There was good agreement between the data obtained by the two different methods.

The load-deflection relationship observed in the tests of the Tee-Heads as simply supported beams was in accord with similar results usually obtained with conventionally reinforced concrete beams. The relatively steep initial position of the curve corresponds to the load-deflection relationship observed prior to cracking which started at about 25,000 lb. As the number of cracks increased, the beams began to deflect more rapidly. The maximum value of deflection at the center of Tee-Head No. 2 was .392 in. at 140,000 lb, (maximum load), and the maximum deflection at the center of Tee-Head No. 3 was .370 in. at 180,000 lb (last set of readings prior to failure).

SR-4 strain gages were applied to the No. 9 bars in each Tee-Head at a point as near the centerline of the specimen as possible. Strain readings were taken at each increment of load and the data was reduced and plotted as observed stress versus the bending moment at the centerline. There was good agreement among the values of stress observed in individual bars in both Tee-Heads as well as between the average values of stress in both specimens. The maximum values of stress recorded during the test were 32.2 ksi and 40.0 ksi in Tee-Heads Nos. 2 and 3, respectively. These values of stress were observed at loads of 140,000 lb and 170,000 lb in the two specimens.

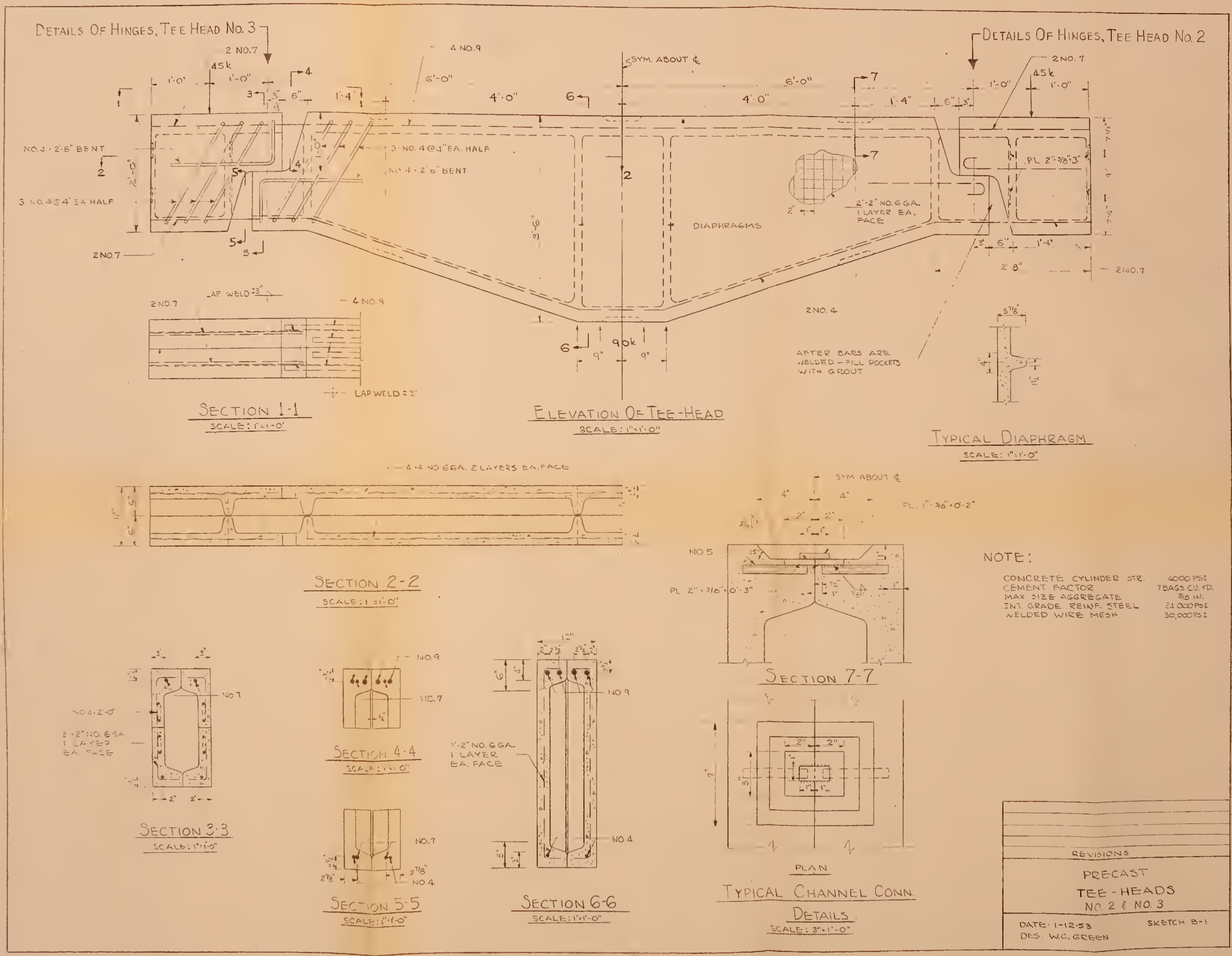
SR-4 strain gages were also applied to the hooked and bent bars in the joint assemblies of their respective Tee-Heads. Readings were taken but no uniformity was observed in either case. Figure 16 is a plot of the data obtained for Tee-Head No. 2 and shows machine load versus stress. A similar graph for Tee-Head No. 3 was eliminated from this report as it did not show anything significantly different and it was felt that the graph herein presented was representative of the erratic action of both Tee-Heads.

After the tests of the first two Tee-Heads had been completed, a request was made for a determination of rotation of the ends of the specimen. Accordingly, rotation was measured on Tee-Head No. 3 with a horizontal comparator and a graphic representation of the results appears in figures 17 and 18. Figure 17 shows the angular rotation of each end versus machine load. The similarity of these curves shows that the specimen was stressed equally at the ends. The last reading taken was at 150,000 lb and each end shows a rotation of .0061 radians. Figure 18 is a graph of the average end rotation versus the deflection as measured at the centerline of the specimen. This relationship is fairly linear. At the maximum measured rotation of .0061 radians, the deflection of the specimen at the centerline was .2475 in.

Tee-Head No. 2 failed at a load of 140,000 lb. Failure occurred at the east end by diagonal tension accompanied by spalling of the concrete on the inside of the joints. Spalling was caused by the outward bending of the eccentrically stressed lap welded connections. Breaks were observed in the horizontal and vertical wires of the welded wire fabric. Diagonal tension cracks in the concrete tended to extend into the compression zone merging into a plane of cleavage along the top of the specimen. The north welded joint failed in bending and a crack was observed extending into the smaller bar. Photographs showing the north and south sides of the east end failure are labeled figures 19 and 20.

Tee-Head No. 3 failed at a load of 181,000 lb. Failure occurred at the west end of the specimen as a crack formed in the weld of the eccentrically stressed welded splice. This was accompanied by diagonal tension failure in the web. The principal tension crack was just inside the region reinforced with the inclined bent bars. Tensile failure of the welded wire fabric occurred in horizontal and vertical directions and can be seen in the photographs labeled figure 21 and 22.

The addition of inclined stirrups on each side of the welded splices in Tee-Head No. 3 resulted in a marked increase in the shear resistance of the specimen. It is noted that the shear strength of Tee-Head No. 3 was sufficient to produce a stress in the longitudinal reinforcement (No. 9 bars of intermediate grade steel) in excess of 40,000 psi, whereas the maximum recorded stress in the longitudinal reinforcement of Tee-Head No. 2 was about 32,000 psi.



DETAILS OF HINGES, TEE HEAD No. 3
DETAILS OF HINGES, TEE HEAD No. 2
SYM. ABOUT ℄
4 NO.9
2 NO.7
45k
3 NO. 4 @ 4" EA. HALF
NO. 4 · 2'-6" BENT
3 NO. 4 @ 4' EA. HALF
2'-2" NO. 6 GA. 1 LAYER EA. FACE
DIAPHRAGMS
PL 2" · 3/8" · 3"
2 NO. 4
90k
AFTER BARS ARE WELDED — FILL POCKETS WITH GROUT
LAP WELD = 3"
SECTION 1-1
SCALE: 1"=1'-0"
ELEVATION OF TEE-HEAD
SCALE: 1"=1'-0"
TYPICAL DIAPHRAGM
SCALE: 1"=1'-0"
4·4 NO. 6 GA. 2 LAYERS EA. FACE
SECTION 2-2
SCALE: 1"=1'-0"
SYM ABOUT ℄
PL. 1" · 3/8" · 0'-2"
NO 5
PL 2" · 3/8" · 0'-3"
SECTION 7-7
NOTE:
CONCRETE CYLINDER STR. 4000 PSI
CEMENT FACTOR 7 BAGS CU. YD.
MAX SIZE AGGREGATE 3/8 IN.
INT. GRADE REINF. STEEL 21,000 PSI
WELDED WIRE MESH 30,000 PSI
SECTION 3-3
SCALE: 1"=1'-0"
SECTION 4-4
SCALE: 1"=1'-0"
SECTION 5-5
SCALE: 1"=1'-0"
SECTION 6-6
SCALE: 1"=1'-0"
PLAN
TYPICAL CHANNEL CONN. DETAILS
SCALE: 3"=1'-0"
REVISIONS
PRECAST
TEE-HEADS
NO. 2 & NO. 3
DATE: 1-12-53
SKETCH B-1
DES. W.C. GREEN

PROPERTIES OF MATERIALS TEE HEAD NO.2

MATERIAL	AVERAGE DIAMETER IN.	AREA SQ.IN.	YIELD STRENGTH PSI	TANGENT MODULUS PSI x 10^6	ULTIMATE STRENGTH PSI
NO. 3 REINFORCING BAR	.375	.11	46,700	29	72,900
NO. 4 REINFORCING BAR	.500	.20	47,400	29	73,100
NO. 7 REINFORCING BAR	.875	.60	39,800	29	71,500
NO. 9 REINFORCING BAR	1.000	.79	41,800	29	b
a NO. 4 WELDED TO A NO.7 BAR	.500	.20	47,600	29	73,000
a NO. 7 WELDED TO A NO.9 BAR	.875	.60	39,100	29	63,600
2"x2" WELDED WIRE MESH GAGE NO. 6	.1900	.0284	—	29	73,900
FIRST HALF CONCRETE	6	28.27	—	4.6	8,165
SECOND HALF CONCRETE	6	28.27	—	4.7	7,680
GROUT CONCRETE	6	28.27	—	4.5	8,270

a—In all cases yield strength and ultimate approximated that of the smaller bar.
b—Machine capacity not great enough to determine.

TABLE I

PROPERTIES OF MATERIALS TEE HEAD NO. 3

MATERIAL	AVERAGE DIAMETER IN.	AREA SQ. IN.	YIELD STRENGTH PSI	TANGENT MODULUS PSI×10^6	ULTIMATE STRENGTH PSI
NO. 3 REINFORCING BAR	.375	.11	46,700	29	72,900
NO. 4 REINFORCING BAR	.500	.20	47,400	29	73,100
NO. 7 REINFORCING BAR	.875	.60	39,800	29	71,500
NO. 9 REINFORCING BAR	1.000	.79	41,800	29	b
a NO. 4 WELDED TO A NO. 7 BAR	.500	.20	47,600	29	73,000
a NO. 7 WELDED TO A NO. 9 BAR	.875	.60	39,100	29	63,600
2"X2" WELDED WIRE MESH GAGE NO. 6	.190	.0284	——	29	73,900
FIRST HALF CONCRETE	6	28.27	——	5.0	8,370
SECOND HALF CONCRETE	6	28.27	——	4.9	8,030
GROUT CONCRETE	6	28.27	——	4.5	6,770

a – in all cases yield strength and ultimate approximated that of the smaller bar.

b – Machine capacity not great enough to determine.

TABLE 2

NBS

Fig. 1 - View of Tee-Head with girder ends attached.

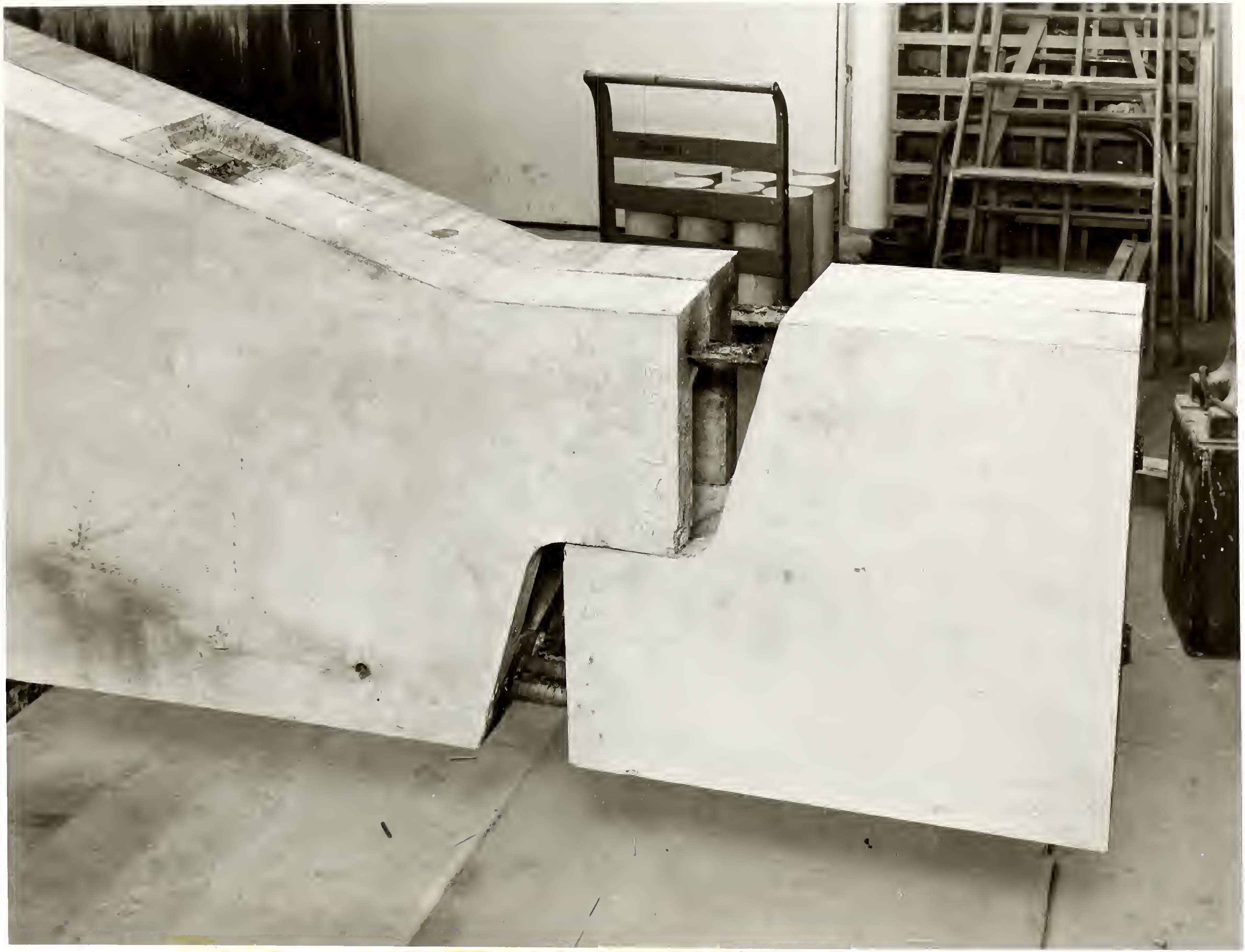


Fig. 2 - Close-up of girder splice.

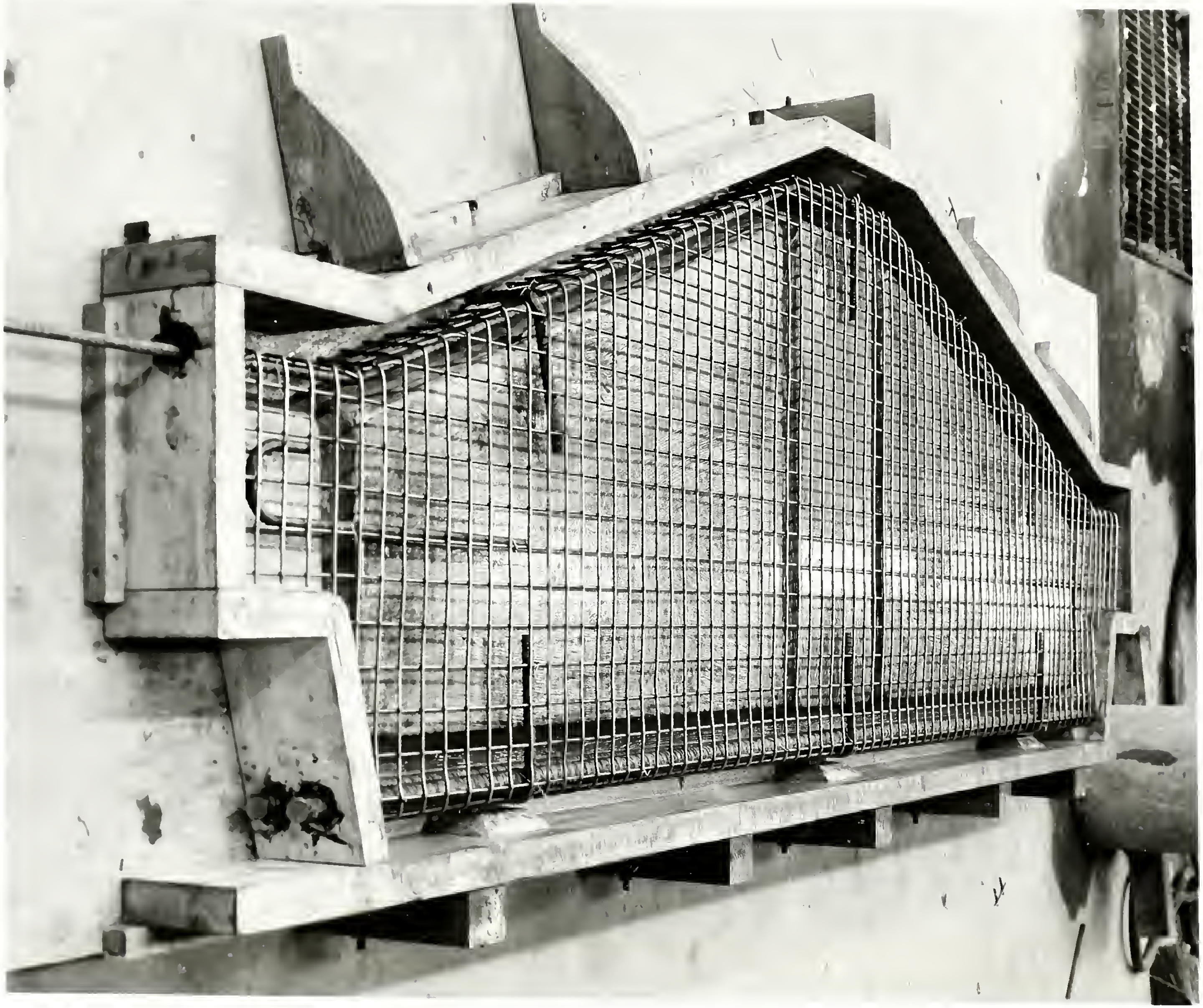


Fig. 3 - Form for center portion of Tee-Head No. 2, with steel in place.

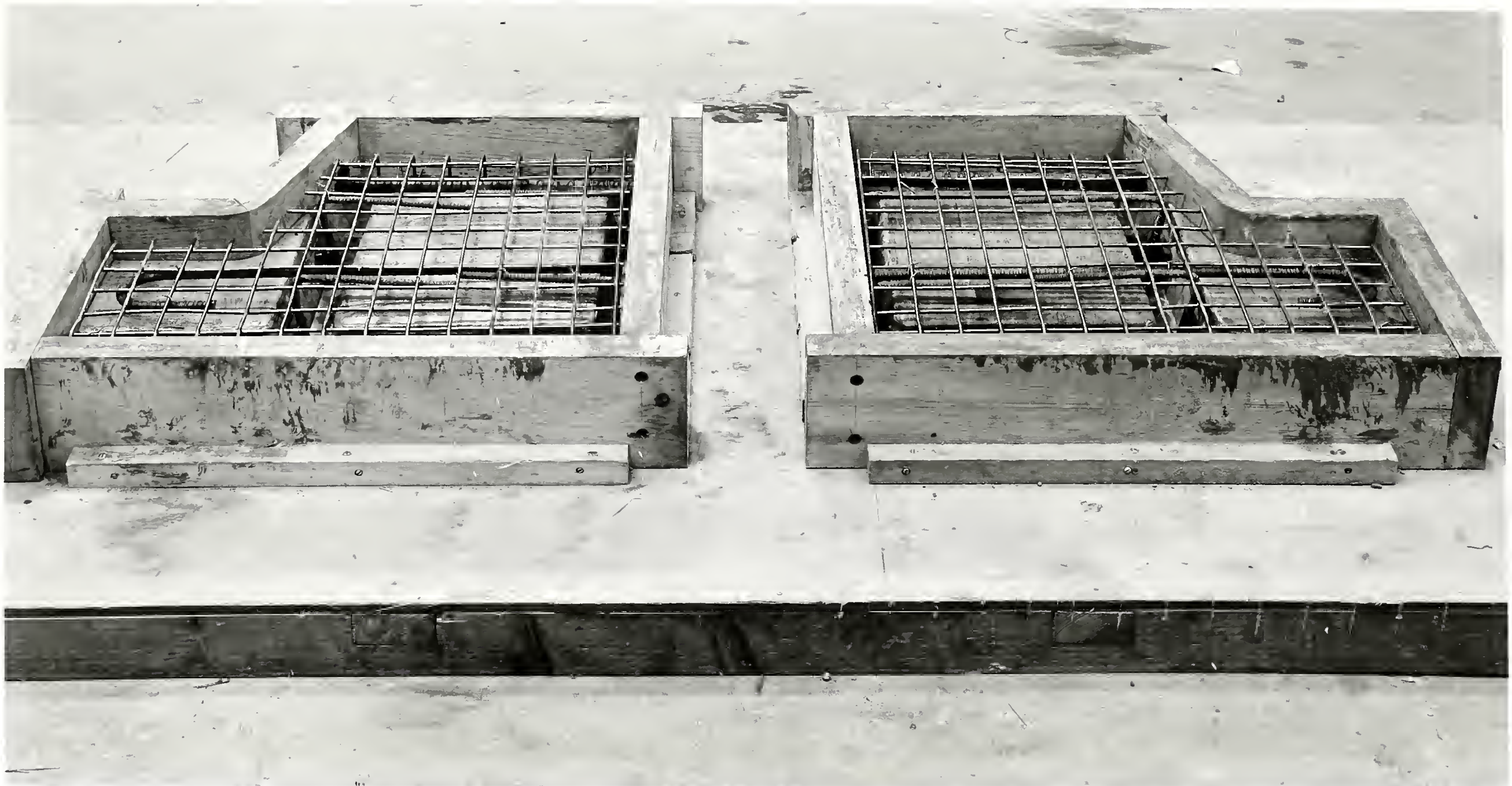
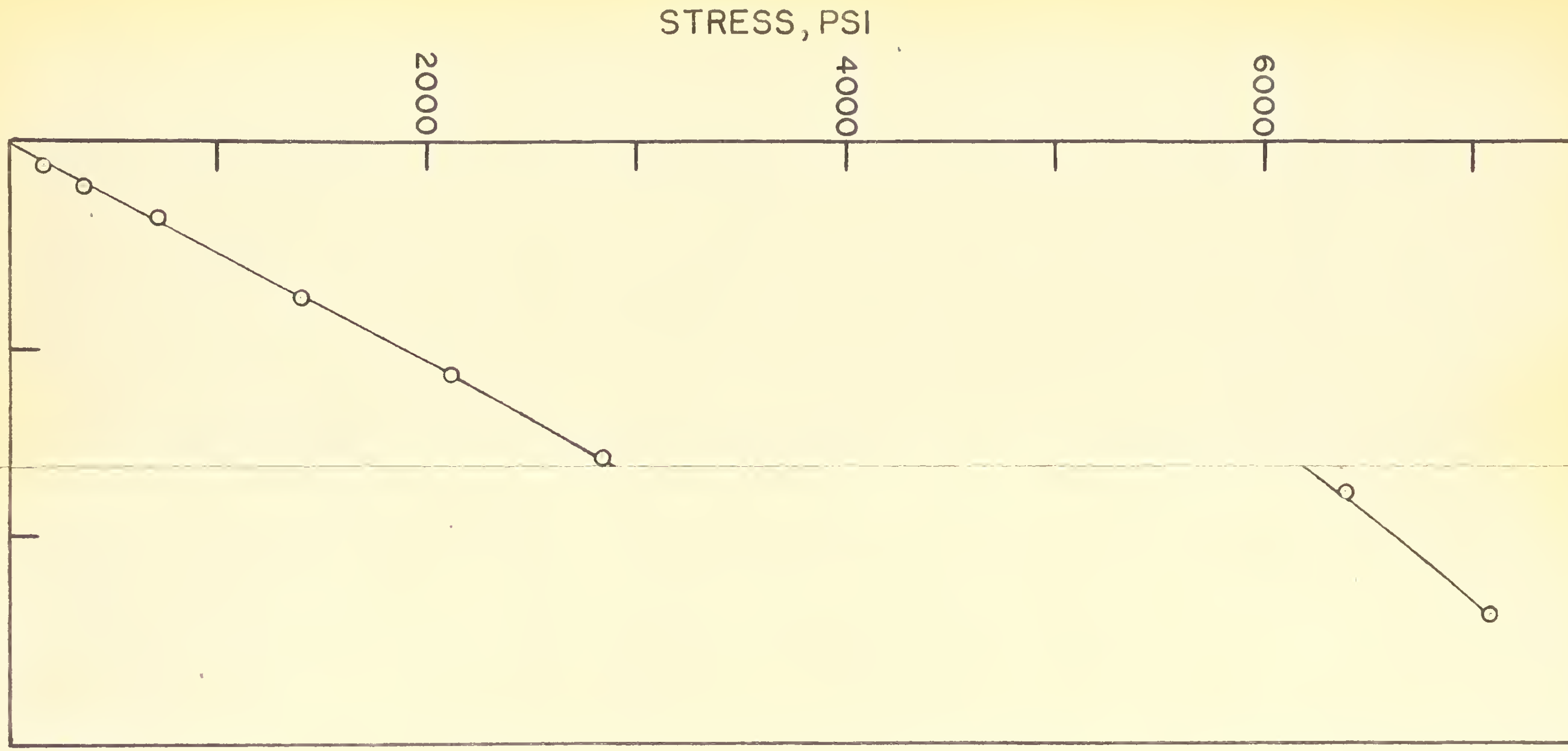


Fig. 4 - Forms for girder ends of Tee-Head No. 2, with steel in place.

Fig. 5 - Form for center portion of Tee-Head No. 3, with steel in place.

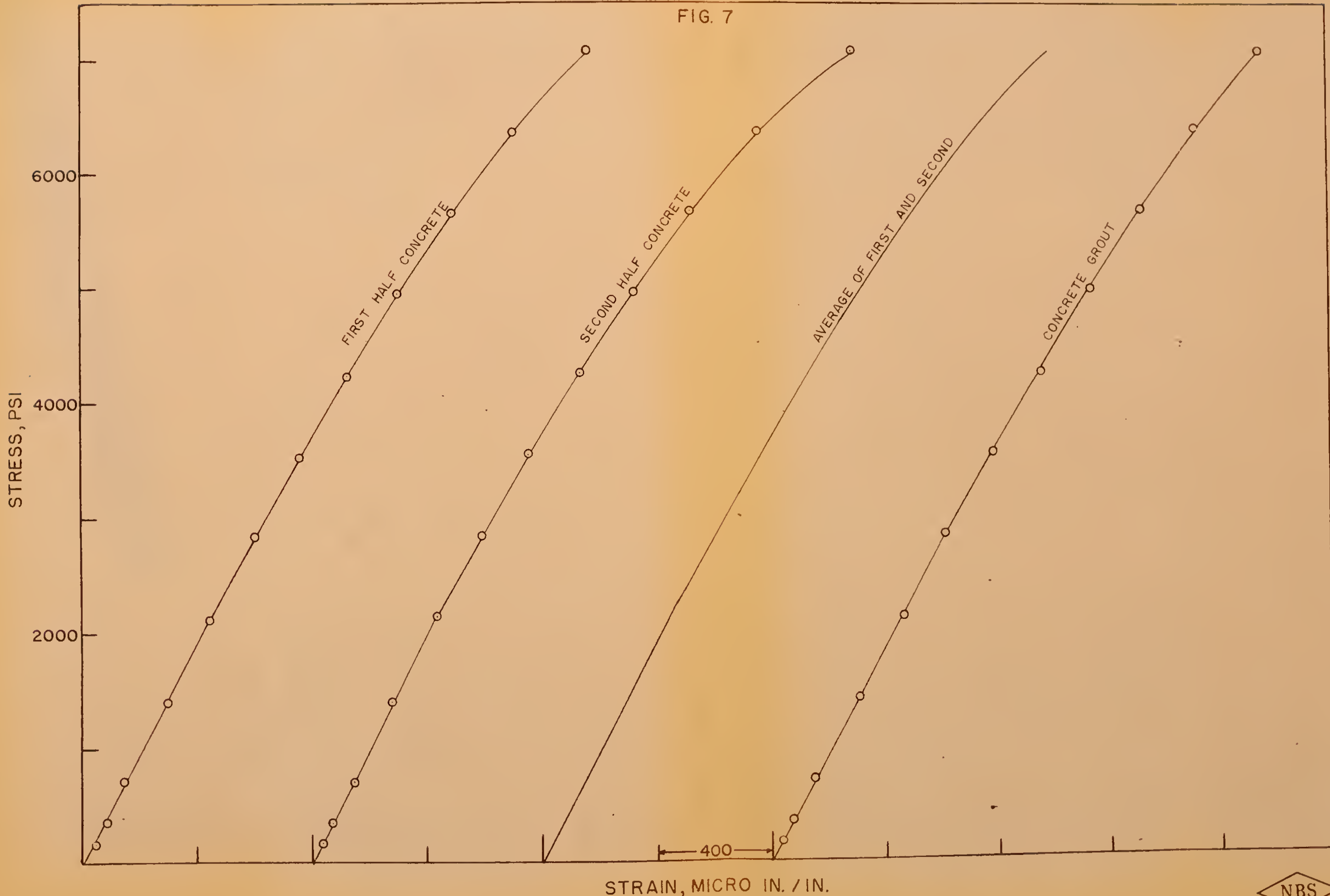
Fig. 6 - Forms for girder ends of Tee-Head No. 3, with steel in place.


STRESS, PSI
2000
4000
6000

STRESS-STRAIN CURVES TEE HEAD NO.2

COMPRESSIVE TESTS OF CONCRETE AND GROUT CONTROL CYLINDERS

FIG. 7



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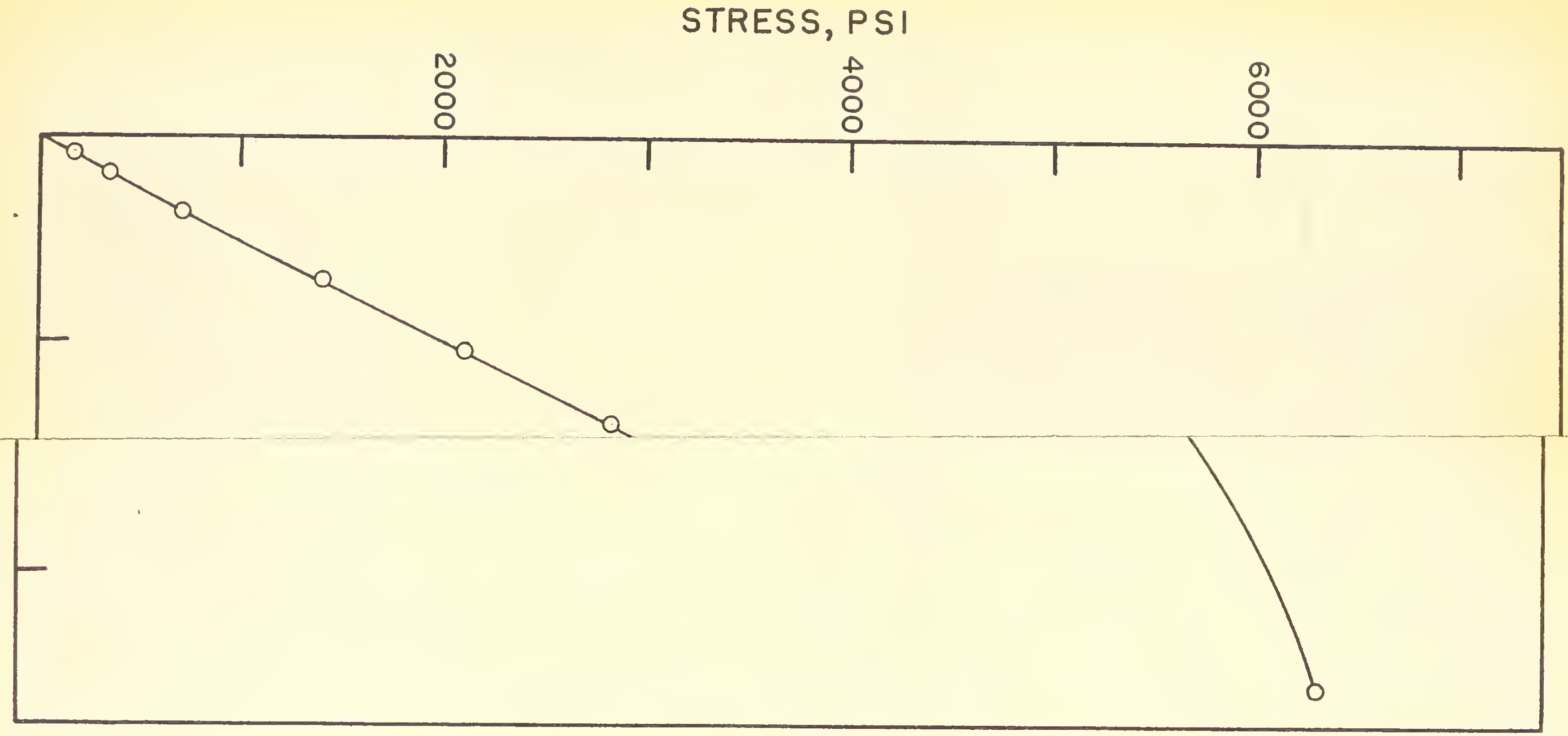
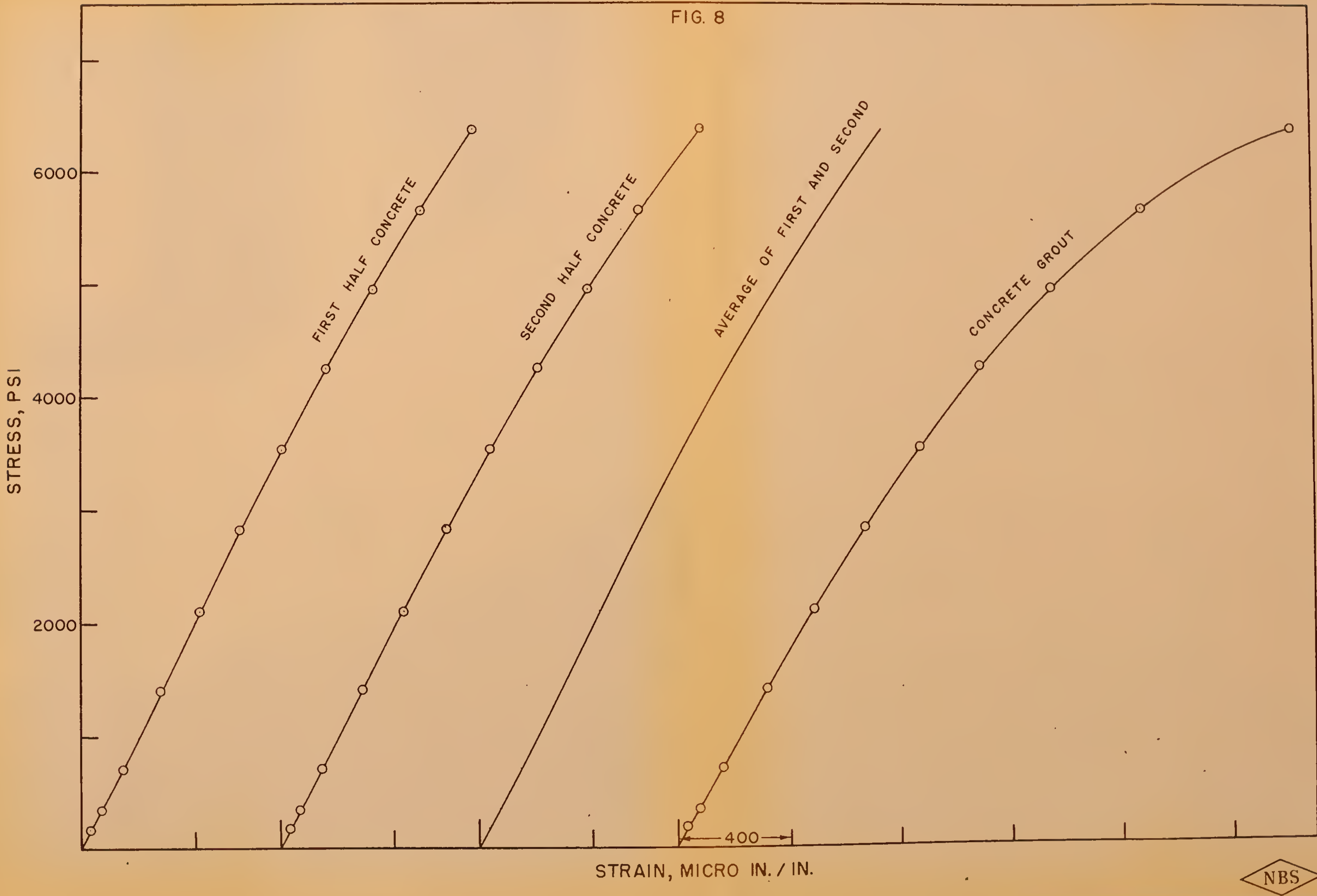

STRESS, PSI
2000
4000
6000

STRESS - STRAIN CURVES TEE HEAD NO. 3

COMPRESSIVE TESTS OF CONCRETE AND GROUT CONTROL CYLINDERS

FIG. 8



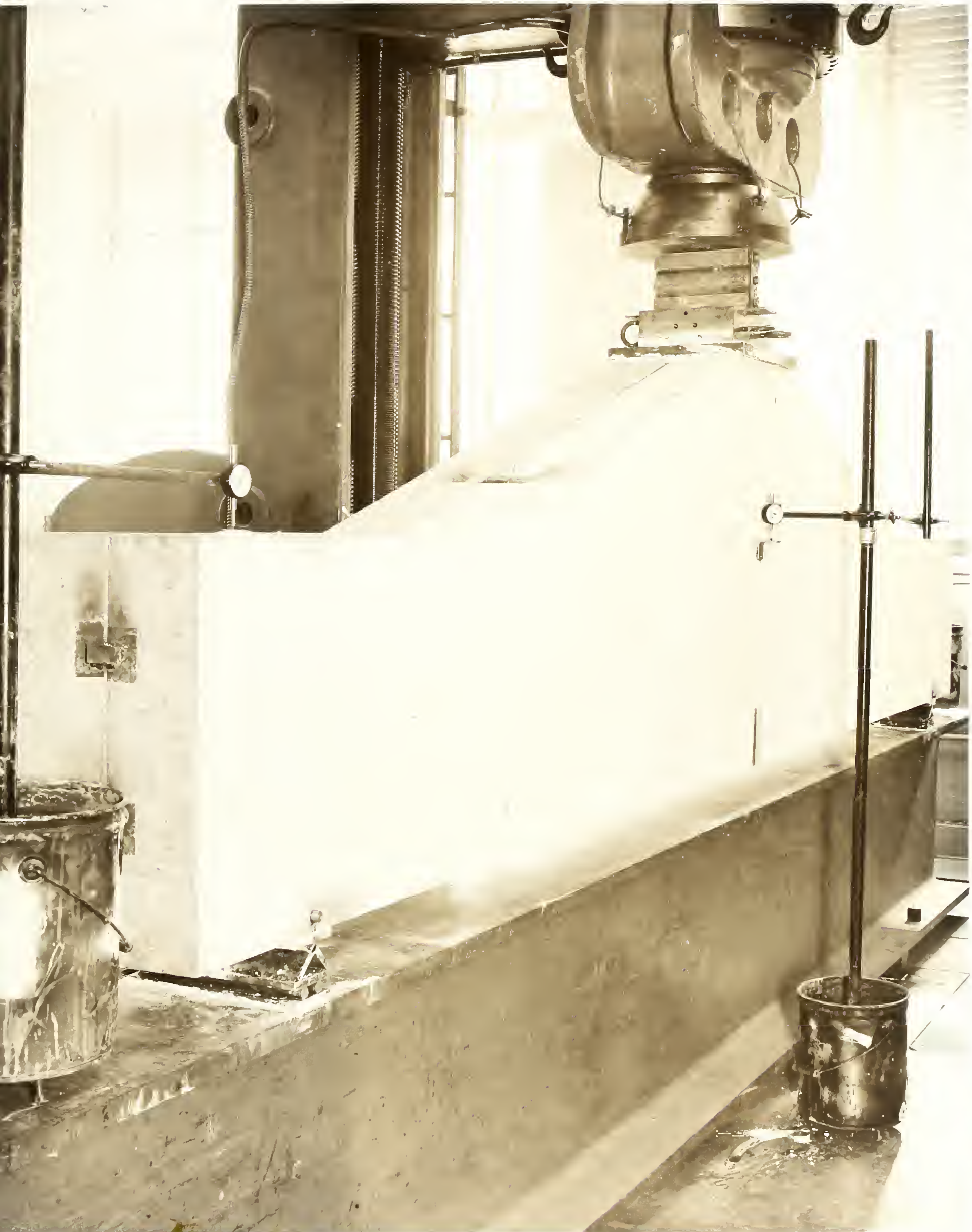
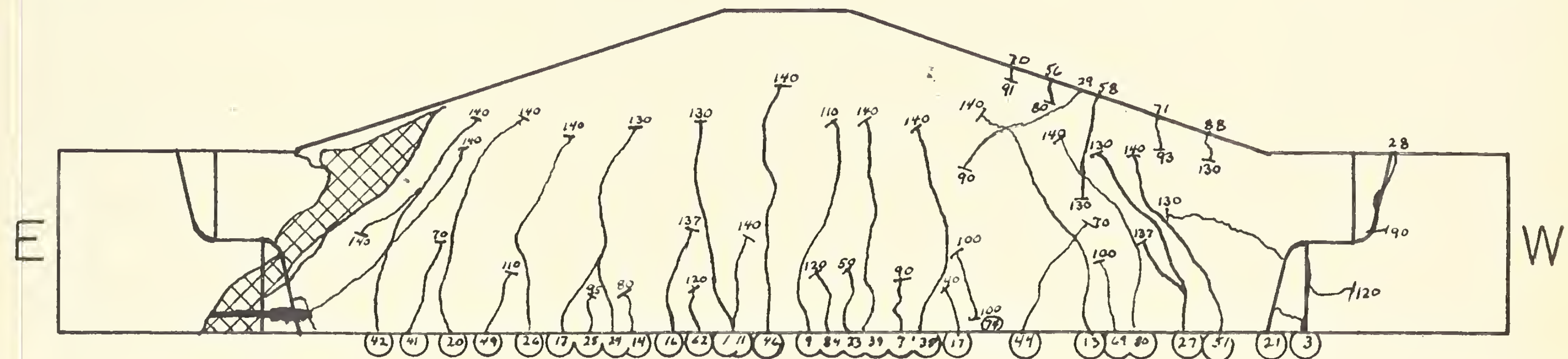


Fig. 9 - View of Tee-Head in testing machine.

CRACK PATTERNS TEE HEAD NO.2

FIG. 10

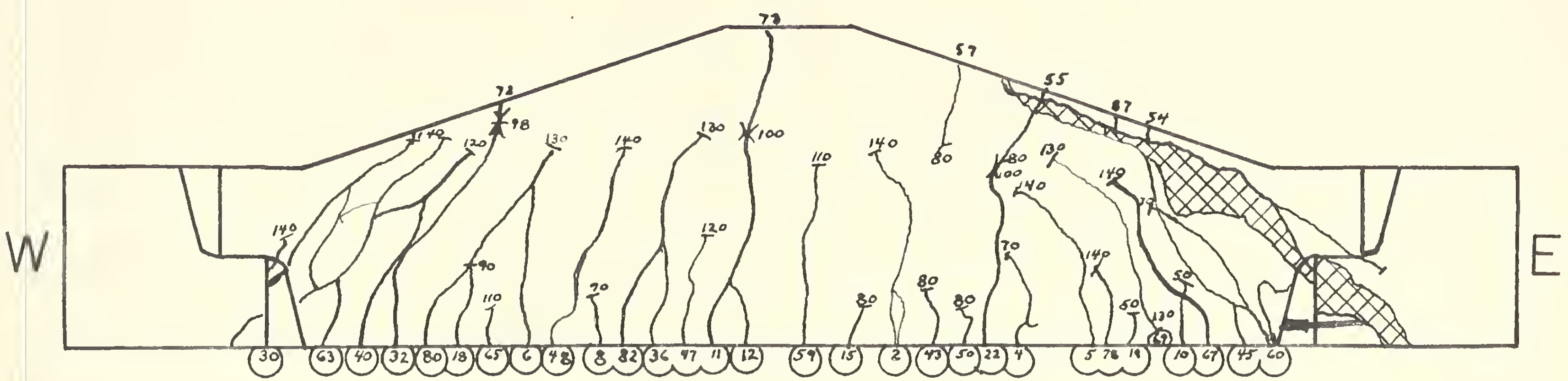


NORTH ELEVATION

CIRCLED NUMBERS INDICATE ORDER OF APPEARANCE

PLAIN NUMBERS INDICATE MACHINE LOAD IN KIPS

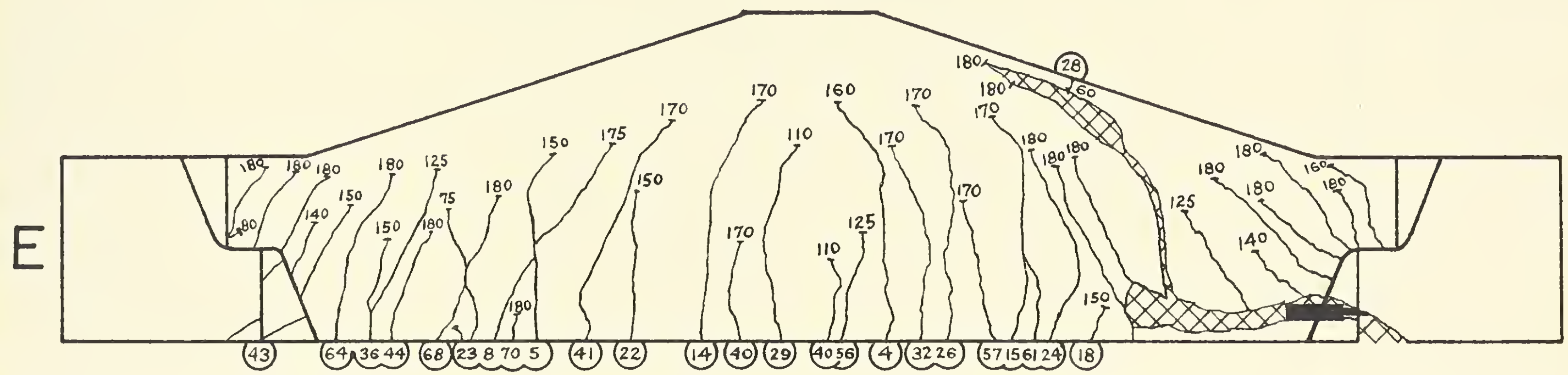
CROSS - HATCHED LINES INDICATE EXPOSED MESH



SOUTH ELEVATION

CRACK PATTERNS TEE HEAD NO. 3

FIG. 11

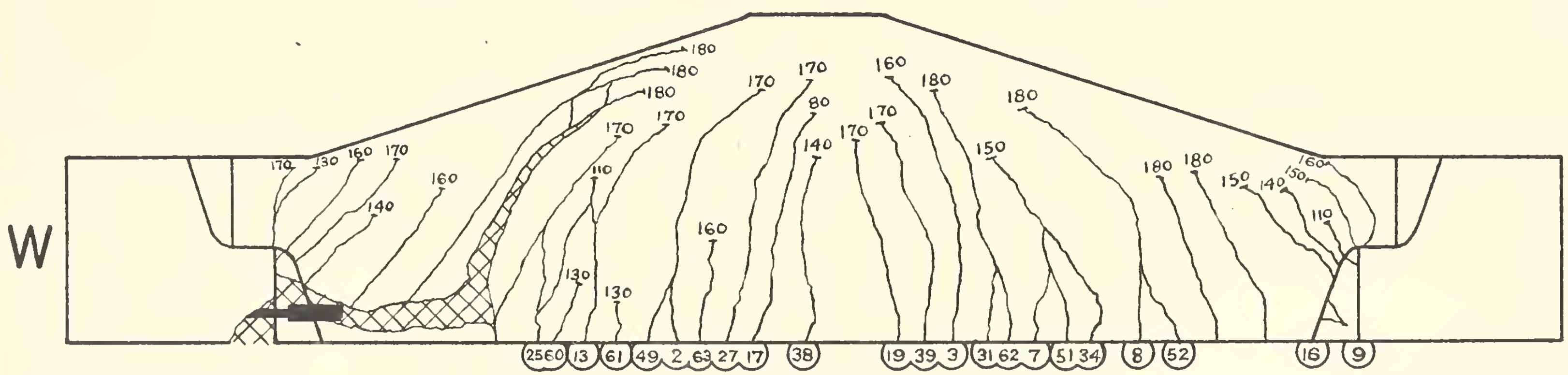


NORTH ELEVATION

CIRCLED NUMBERS INDICATE ORDER OF APPEARANCE

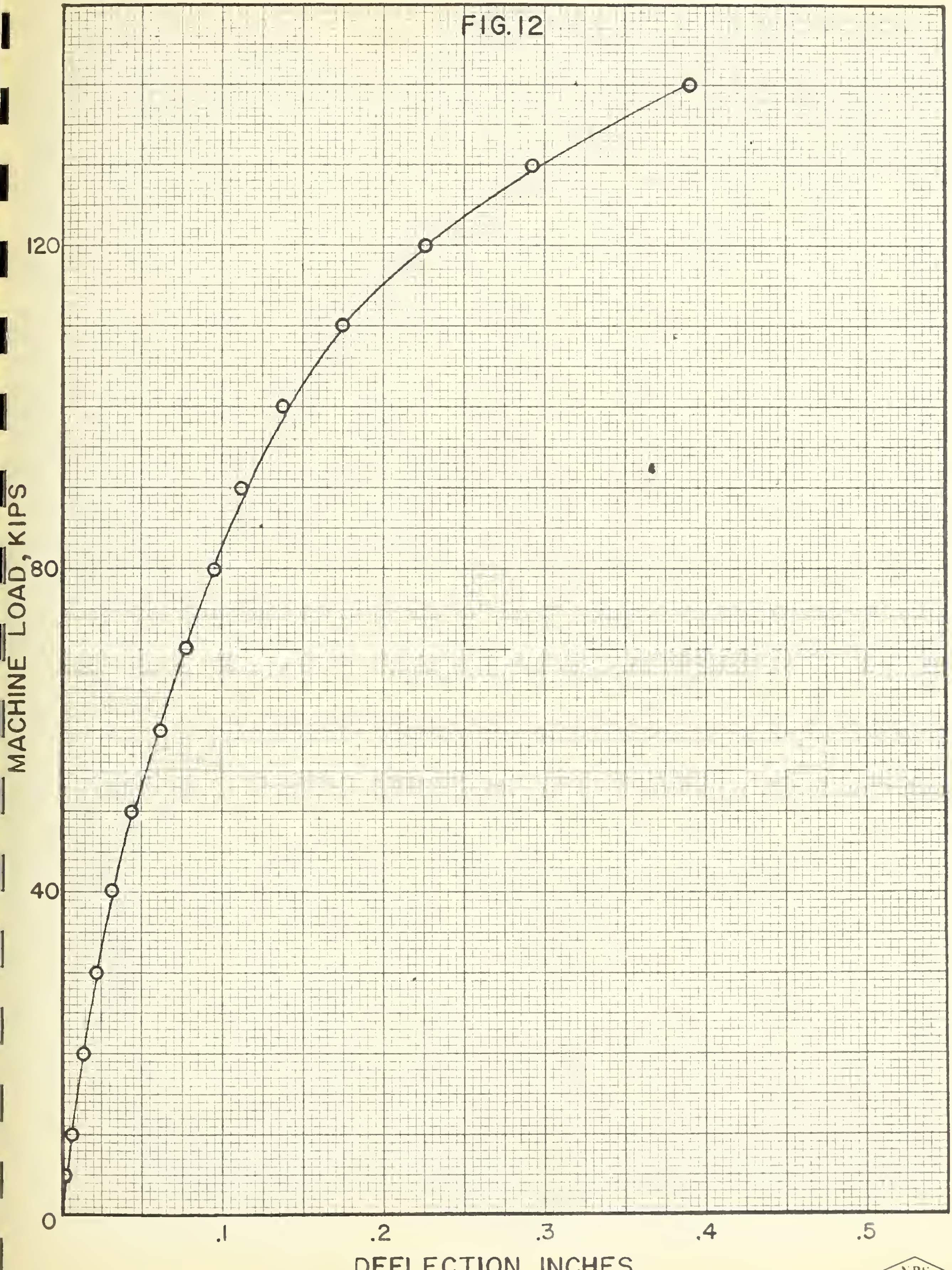
PLAIN NUMBERS INDICATE MACHINE LOAD IN KIPS

CROSS - HATCHED LINES INDICATE EXPOSED MESH



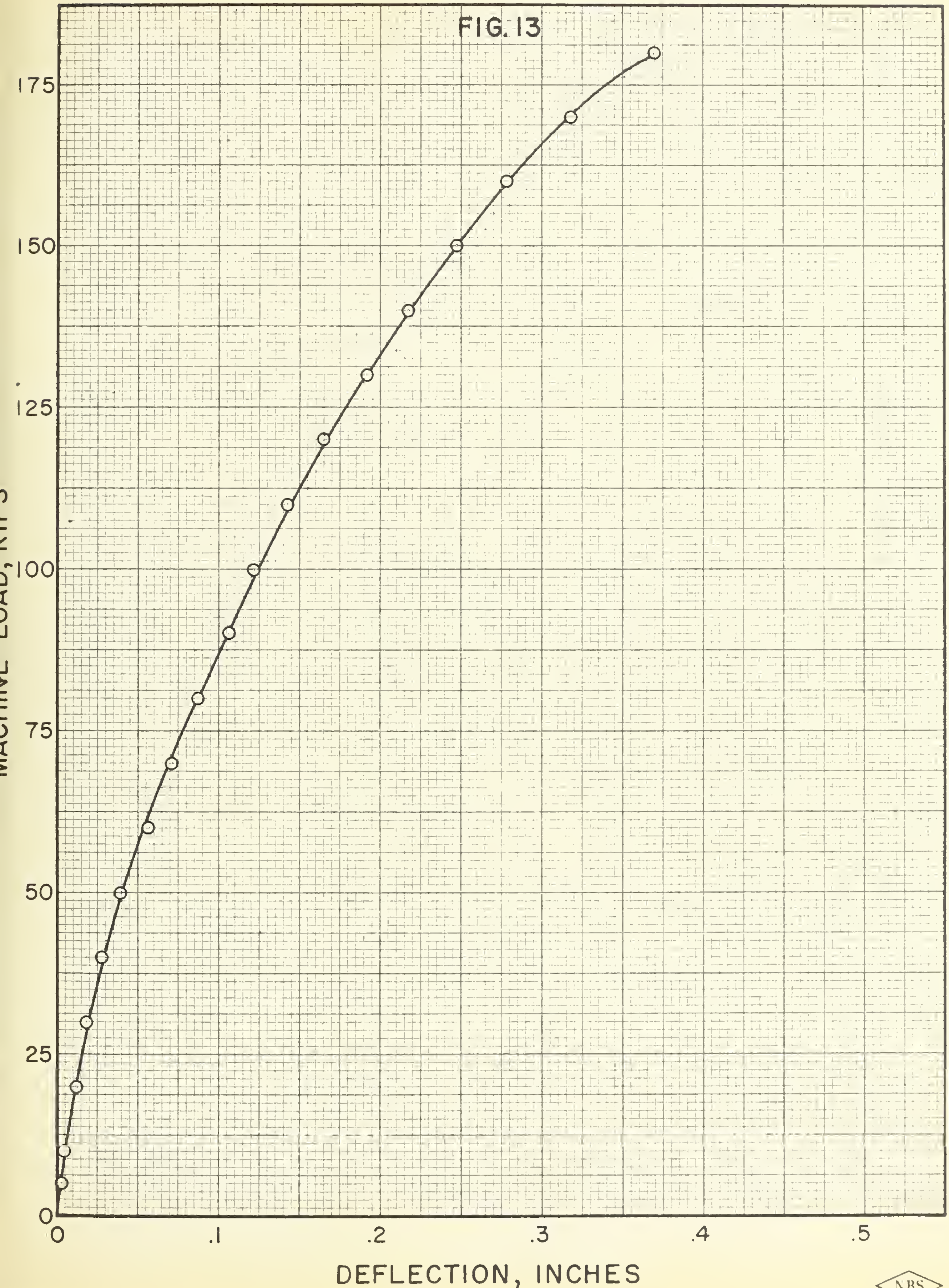
SOUTH ELEVATION

LOAD DEFLECTION CURVE TEE HEAD NO. 2
AVERAGE OF TAUT WIRE METHOD AND DIAL GAGES

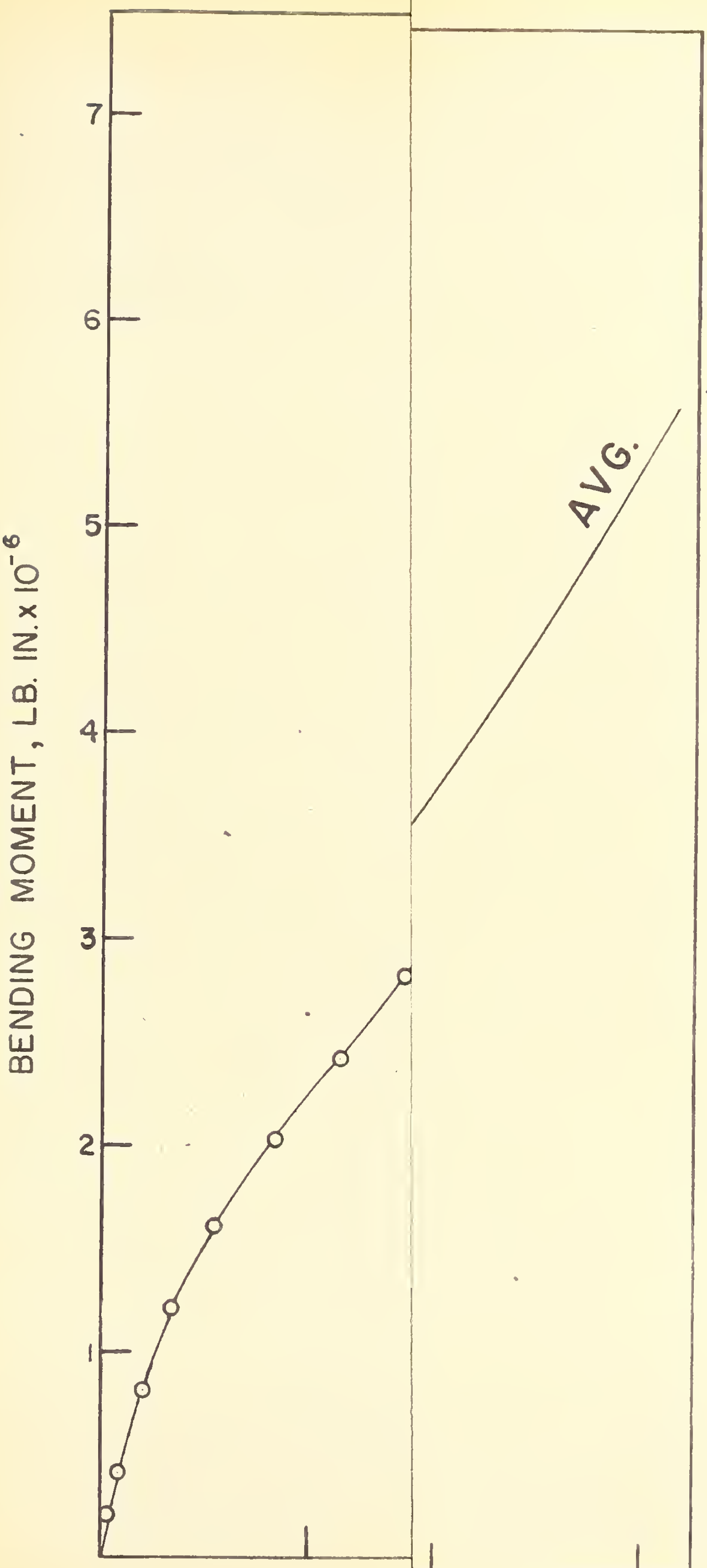


NBS

LOAD DEFLECTION CURVE TEE HEAD NO. 3
AVERAGE OF TAUT WIRE METHOD AND DIAL GAGES

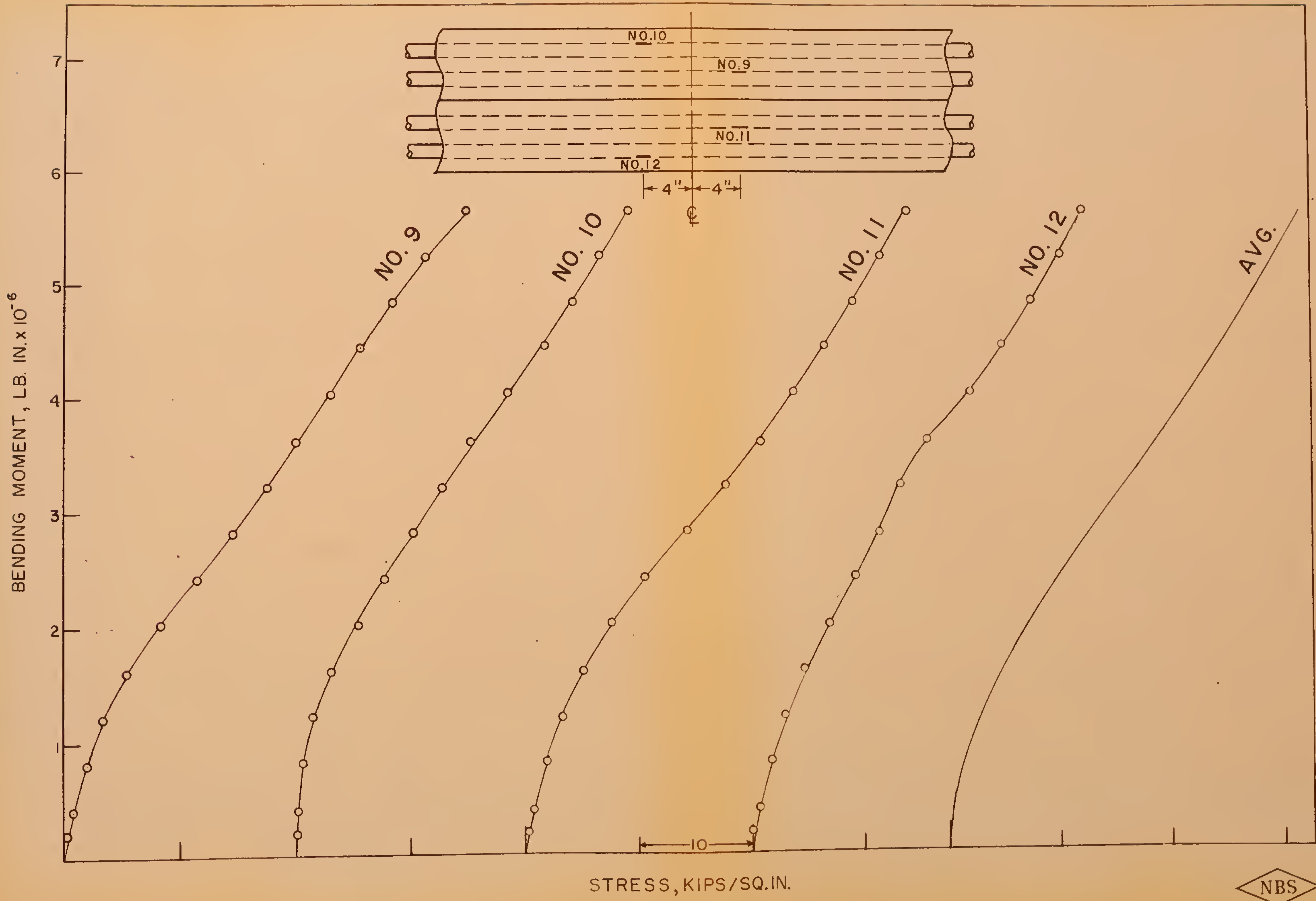


D NO. 2

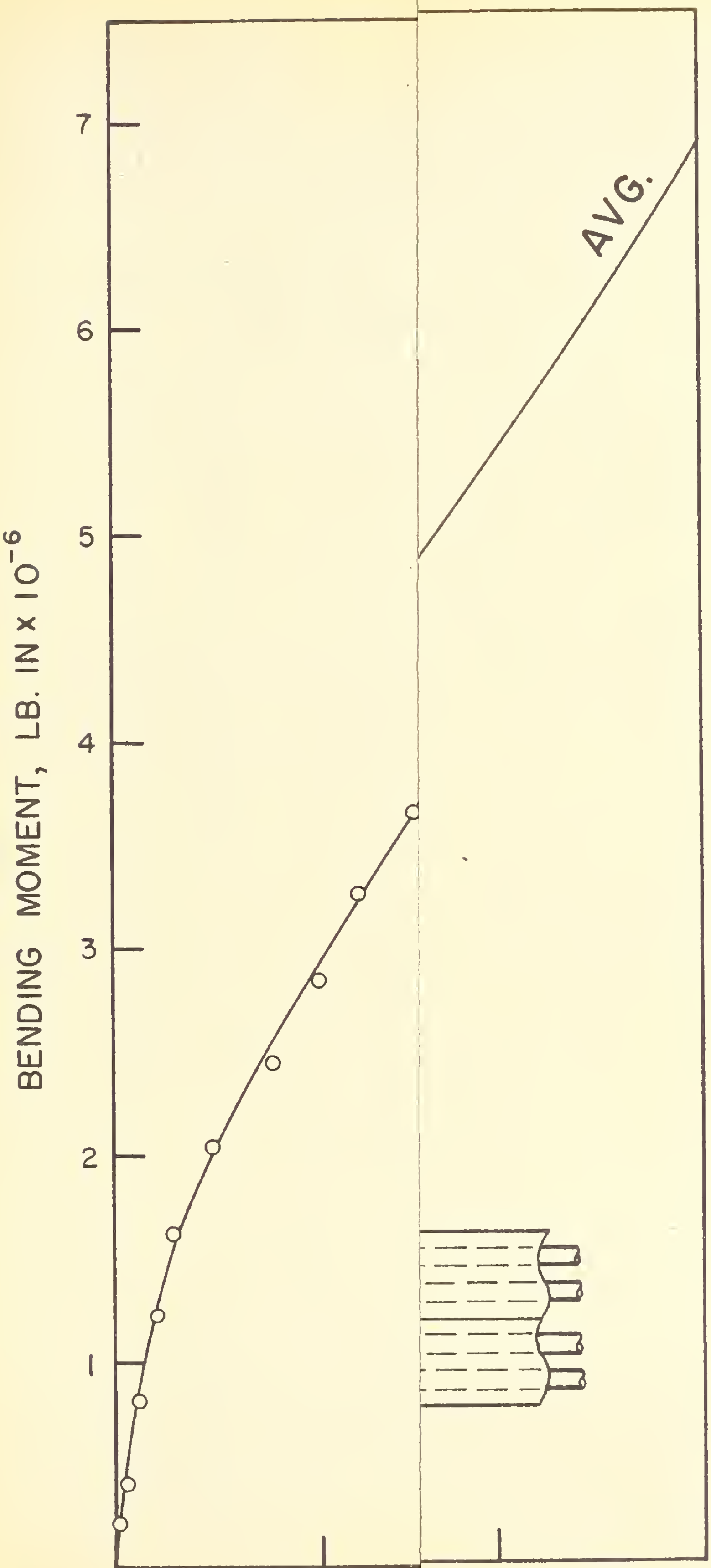


BENDING MOMENT VS. OBSERVED STRESS AT CENTER SECTION, TEE HEAD NO. 2

FIG. 14



BEN 3



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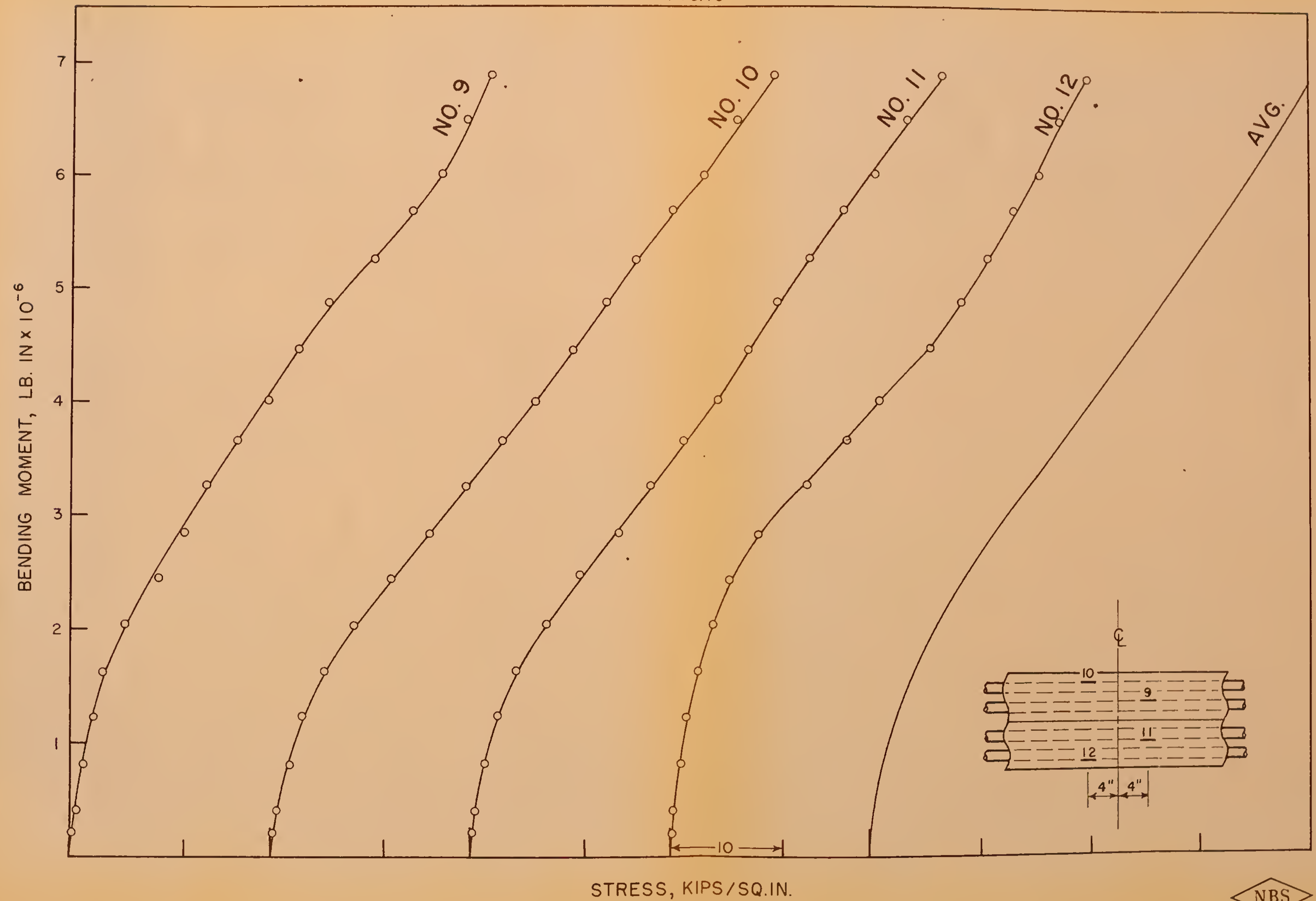
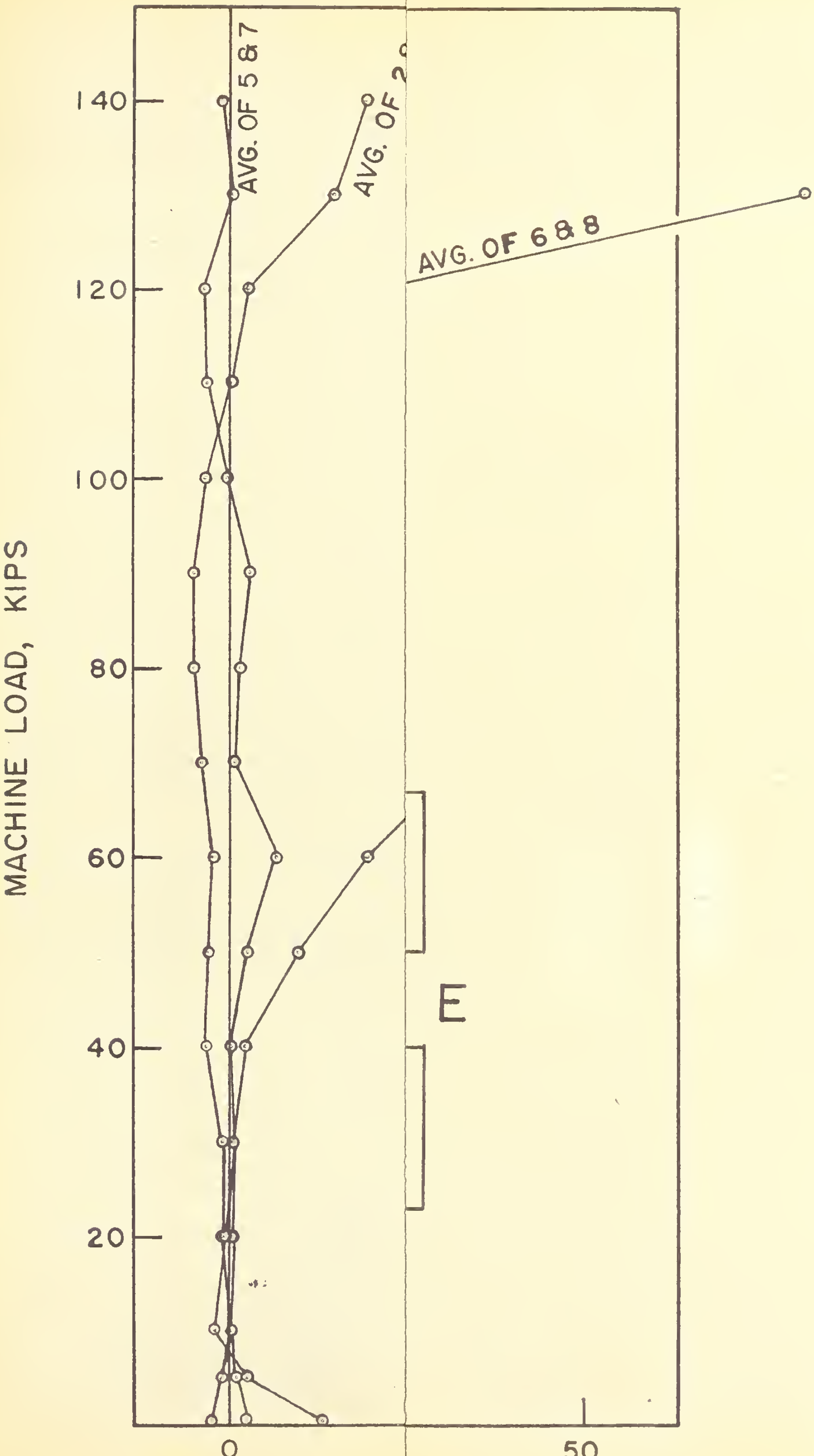
BENDING MOMENT VS. OBSERVED STRESS AT CENTER SECTION, TEE HEAD NO. 3

FIG. 15



MA. 2



AVG. OF 5 & 7
AVG. OF 2
AVG. OF 6 & 8
E
140
120
100
80
60
40
20
MACHINE LOAD, KIPS
0
50

MACHINE LOAD VS. OBSERVED STRESS AT JOINT ASSEMBLIES, TEE HEAD NO. 2

FIG. 16

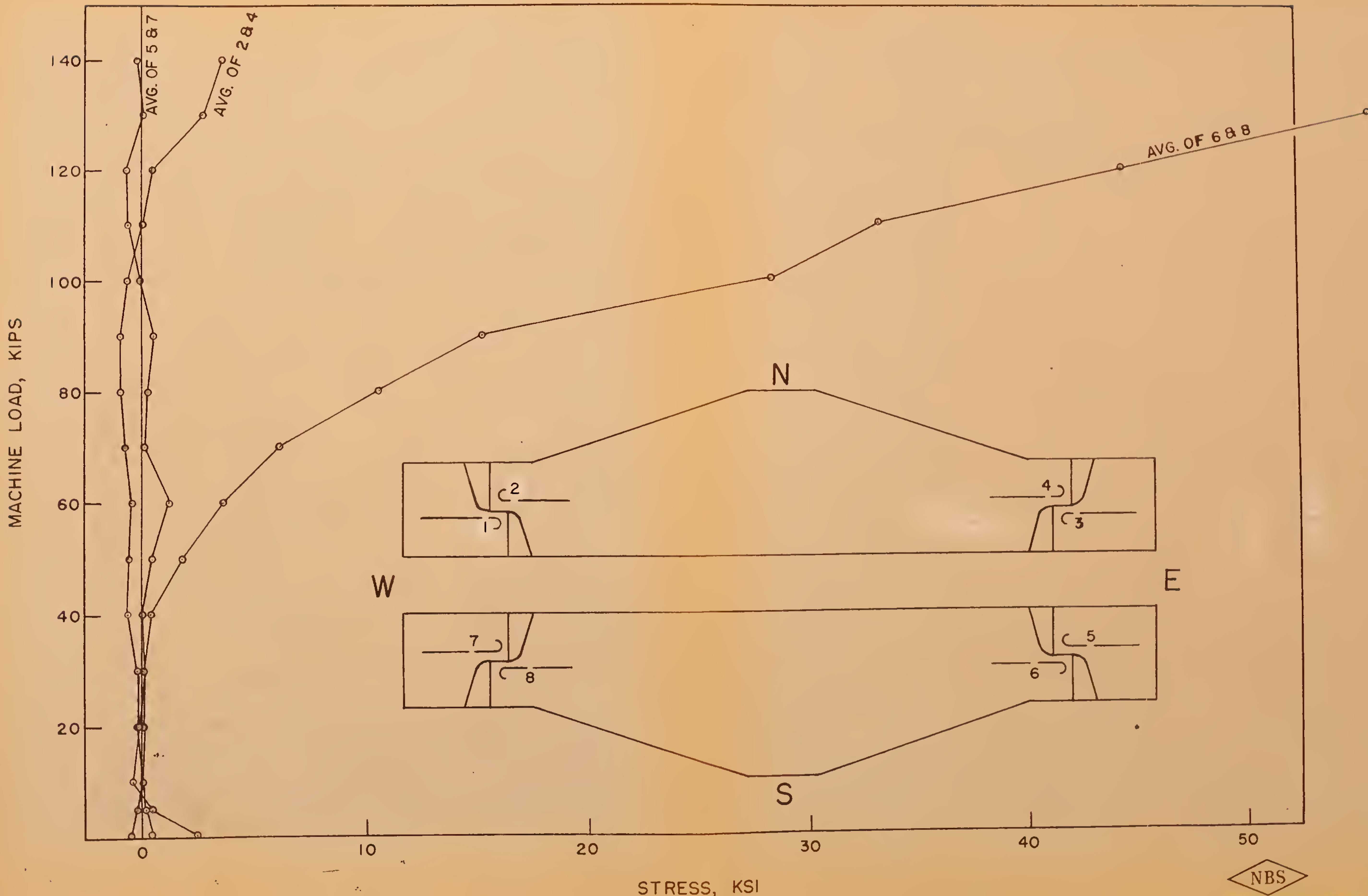
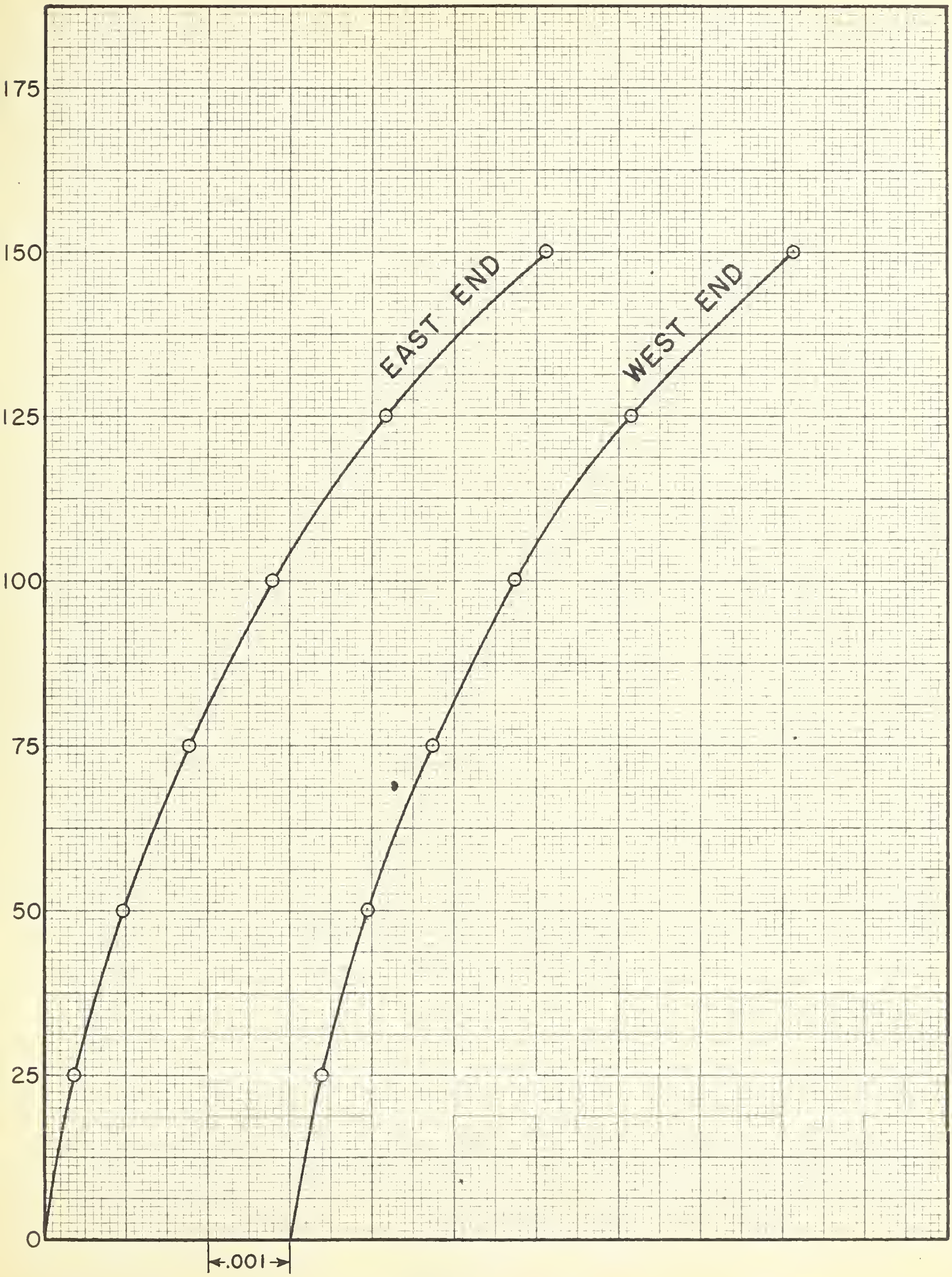


FIG. 17

ANGULAR ROTATION OF ENDS VS. MACHINE LOAD
TEE HEAD NO. 3



ROTATION, RADIANS

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FIG. 18

ANGULAR ROTATION OF ENDS VS. DEFLECTION AT CENTER LINE, TEE HEAD NO. 3

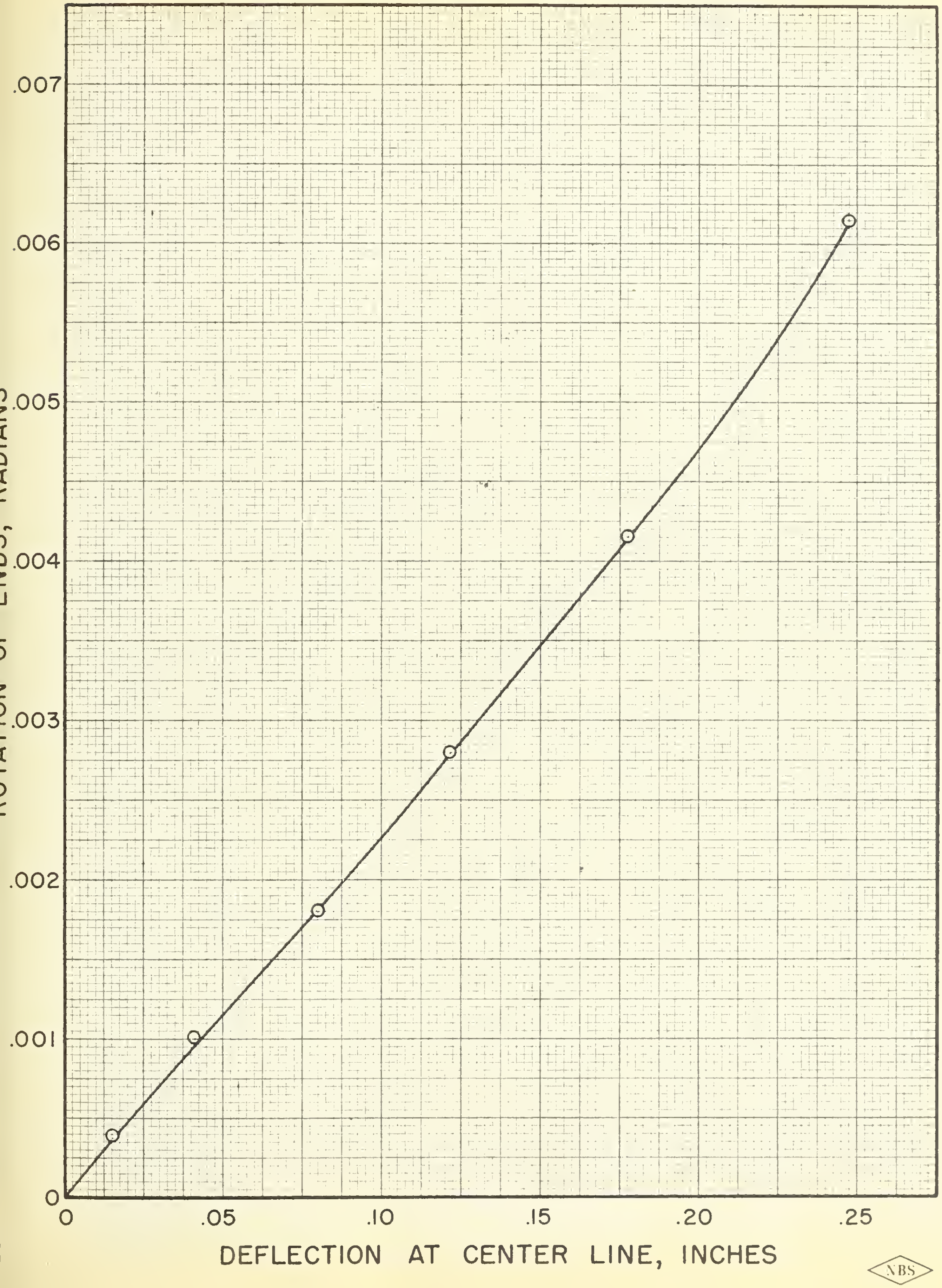

Fig. 19 - Close-up of failure at east end (north side)
Tee-Head No. 2.

Fig. 20 - Close-up of failure at east end (south side)
Tee-Head No. 2.

Fig. 21 - Close-up of failure at west end (north side)
Tee-Head No. 3.

Fig. 22 - Close-up of failure at west end (south side)
Tee-Head No. 3.

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