NATIONAL BUREAU OF STANDARDS REPORT

4286

TESTS OF PRECAST CONTINUOUS SPLICED GIRDERS

by

L. F. Skoda and J. O. Bryson

Report to
Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Process Technology. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services.

Radio Propagation Engineering. Frequency Utilization Research. Tropospheric Propagation Research.

Radio Standards. High Frequency Standards. Microwave Standards.

- Office of Basic Instrumentation
- Office of Weights and Measures

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 1001-10-4811

August 15, 1955

NBS REPORT 4286

TESTS OF PRECAST CONTINUOUS SPLICED GIRDERS

by

L. F. Skoda and J. O. Bryson

To

Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

TESTS OF PRECAST CONTINUOUS SPLICED GIRDERS

by

L. F. Skoda and J. O. Bryson

Abstract

The rigidity and strength of two precast girders with welded splices of two different designs were determined in tests of the girders as beams continuous over three supports. The girders consisted of three reinforced concrete box sections welded and grouted together to form a beam 1- by 2-ft in cross section and 25 ft long.

The splices located at points of inflection were formed by lap welding suitable lengths and amounts of positive and negative reinforcement projecting from the ends of adjoining sections and then grouting the pockets.

The designs of the splices of the two girders were identical, except that girder No.2 contained an additional amount of reinforcement consisting of three inclined stirrups of No. 4 bars on each side of the splice. The addition of the inclined stirrups resulted in an increase of 67 percent in load carrying capacity of girder No. 2 as compared with girder No. 1.

---

1. INTRODUCTION

At the request of the Bureau of Yards and Docks, two precast continuous spliced girders were tested to evaluate the structural strength of proposed welded splices.

The following report presents observations and data obtained during the construction, fabrication and testing of two such girders.

2. PREPARATION OF THE SPECIMENS

2.1 Description of the specimens

Each girder consisted of three sections approximately 8 ft long joined together to form a girder 24.5 ft long. The sections were joined by lap welding suitable lengths and amounts of positive and negative reinforcement projecting from the ends of adjoining sections and then grouting the pockets. Each girder section was fabricated by welding together two channels which formed a box girder having a 1- by 2-ft cross section. The flange of the channel was 6 in. in breadth and its thickness varied from 6 in. at the base to 4 3/4 in. where the channels joined. The web thickness was 2 1/2 in. Each channel had three stiffening ribs, one at each end and one at the center. Steel plates, welded to bent No. 5 bars for anchorage, were embedded in the concrete at the time of casting. They were placed at the edge of the flanges, both on top and bottom, 2 ft 4 in. from the ends and 2 ft 4 in. from the center line of the joints. This provided each pair of channels with four points of attachment. Details of the girder and the reinforcement are shown in figure 1.

2.2 Forms

The symmetrical design of the girders made it possible to construct forms for only one-half of the specimen. To keep the cost of casting at a minimum, each girder was made from two casting operations.

The forms, made at the National Bureau of Standards carpenter shop, had a base of 3/4 in. plywood braced with 2- by 4-in. timbers. The pans were made of 3/4-in. plywood. The sides of the forms were made of 2- by 6-in. white pine and were removable. The heavy side pieces prevented warping. This resulted in an excellent duplication of the channels and a precise fit. The forms received three coats of waterproof spar varnish and, prior to each casting, oil and asbestine powder was applied as a separator. The forms with reinforcement in place are shown in figures 2 and 3.

2.3 Concrete

The proportions of the concrete were 1:2.48:2.02, by weight. High-early-strength cement was used to expedite-curing. The aggregates were sand and pea gravel, with a maximum size of 3/8 in., from White Marsh, Maryland. Three batches of concrete, with slump from 3 to 4 in., were mixed for each casting operation.

Two 6- by 12-in. control cylinders were cast from each batch and gave the following average results:

	Compressive strength	Tangent modulus
	psi	psi
Girder No. 1	7,560	4.5 by 10^6
Girder No. 2	8,130	4.4 by 10^6

Stress-strain curves for the concrete in each specimen are shown in figures 4 and 5.

Both specimens were kept under damp burlap for two days and then transferred to a curing chamber where they were moist-cured for periods ranging from 1 to 4 months. The concrete was then air-dried until tested at an age of about 8 months.

2.4 Reinforcement

Reinforcement in the upper flanges of the end sections of each girder consisted of four No. 8 deformed bars. The two inner bars were completely embedded while the outer bars extended 5 in. beyond the joint end. The upper flange of the middle section was reinforced with two No.4 deformed bars. These bars extended 5 in. from the middle section to lap the No. 8 bars from the end sections. The lower flanges were reinforced conversely: four No. 8 bars in the middle section and two No. 4 bars in the end section.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

The web reinforcement in the portion near the joint was different for the two girders. In girder No. 1 there was a single, hooked No. 4 bar while girder No. 2 had a bent No. 4 bar tied to three inclined stirrups of No. 4 bars on each side of the welded splice, as shown in figure 1.

All of the deformed reinforcing bars were of intermediate grade steel. The girders were further reinforced throughout their webs and flanges with 4- by 4-in. welded wire fabric, No. 6 gage.

2.5 Assembly, welding, and grouting

After curing, the channels were dried for two days before being assembled.

Each pair of channels was welded together with 1- by 3/8- by 2-in. connector plates, centered over the embedded steel plates (2.1). Small cracks, 1-in. to 2-in. long, adjacent to and radiating from the embedded plates, resulted from the heat produced by welding. These cracks were negligible in width, however,. Another crack appeared in girder No. 1 parallel to the embedded No. 5 anchorage bar, but it seemed to have no effect on the results of the test.

The joined channels were then put in position for welding with the protruding reinforcement overlapping 4 in., (see figure 1). To reduce heat transfer to the concrete

as the lap welding was done, each weld was allowed to cool after only half of the bead was complete. All welding was done by a qualified Navy welder.

After the welding was completed, forms were constructed around the pocket at each joint and filled with concrete having the same proportions as the concrete used in the specimen. The average compressive strength of 6- by 12-in. control cylinders was 8,400 psi.

3. TESTING PROCEDURE

3.1 Test setup

To simplify the testing procedure, the girders were tested in an inverted position. A mechanical testing machine with a 600,000 lb capacity was used.

The girder was supported on three rockers, one of which was at the center and one at each end 12 ft from the center. The load was applied to the girder through a loading beam at two load points 16 ft apart on top of the inverted girder. The machine load was applied to the loading beam through a spherically seated compression block.

The load was to be so distributed that the sum of the end reactions equaled the center reaction. To insure such a distribution, it was necessary to adjust the end reactions as each increment of load was applied by the machine. This was accomplished by means of hydraulic jacks which

served as end reactions for the girder. Calibrated load cells were placed between the jacks and the girder. As each increment of load was applied, the end reactions were adjusted to equal one-fourth of the load. A diagram of the loading arrangement is shown in figure 6. Figure 7 shows a close-up of the end reaction and figure 8 shows girder No. 1 in the testing machine.

3.2 Instrumentation

The instruments employed to measure the strains of the girders were 0.001-in. dial gages and SR-4 electrical resistance strain gages.

The dial gages were placed opposite the three reactions and the two points of load application, and measured the displacements of these points relative to the platen. It was necessary, therefore, to measure also any possible deflection in the platen of the testing machine in respect to the laboratory floor. The SR-4 gages were placed on all of the reinforcing bars at the points of maximum bending moments (see figure 6). A complete set of readings was taken at each machine load increment of 20,000 lb.

4. RESULTS

The girders were tested as beams continuous over three supports with the loads applied at points 4 ft from each end of the girder. This arrangement of supports and loads, shown in figures 1 and 6, was devised in order to have the welded splices at the third points coincide with points of inflection in the continuous girder.

Both girders failed by diagonal tension. Girder No.1 failed at a total applied load of 151,000 lb and girder No. 2 at 253,500 lb. Thus, the addition of six inclined stirrups of No. 4 bars on each side of the welded splices resulted in an increase of 67 percent in resistance to shear of the girder No. 2 as compared with girder No. 1. The loads given here are the applied machine loads and do not include the weights of the specimen and the loading fixtures.

The load deflection diagrams for the two girders are given in figures 9 and 10. The values of the deflections in the diagrams are the displacements of the center and the ends of the girders with respect to a straight line passing through the points of application of load. Negative values of deflection indicate downward displacements of the girder in its actual position in the structure.

Girder No. 1 reached a center deflection of 0.314 in. at a load of 139 kips, at which load the last deflection reading was obtained prior to failure. The end deflections at this load averaged 0.135 in.

Girder No. 2 reached a center deflection of 0.395 in. at 220 kips, the last observed deflection prior to failure. The end deflections at this load averaged 0.242 in.

The relation between the observed strain in the reinforcement and applied load is illustrated in figures 11 and 12. The strains were observed at the center of each girder and the points of application of load in both compressive and tensile reinforcement.

The strain in the reinforcement was also plotted in figures 13 and 14 to show the distribution of strain along the length of the girder and to check the theoretical location of the points of inflection. It can be seen that as the loads increased and cracks in the concrete became wider and more closely spaced, the sections of zero bending moments shifted somewhat toward the center of the girder. This was indicated, in general, by both the tensile and compressive strain measurements in the reinforcement.

Close-up views of the sections of the girders where failure occurred are shown in figures 15, 16, and 17, and the general crack pattern is shown in figure 18. It can

be seen that the shear failure in girder No. 1 was sudden and complete, as is usually the case with shear failures in reinforced concrete beams containing little or no web reinforcement. The major diagonal tension crack in girder No. 1 which ran from the point of application of load to the mid-section of the welded splice was wide enough to cause tensile failure in the 4- by 4-in. welded wire fabric of No. 6 gage which was present in the webs of the girder.

The diagonal tension crack at which failure developed in girder No. 2 was considerably steeper than that in girder No. 1. As can be seen in figures 16 and 17, the diagonal tension crack ran from the point of application of load to a section about midway between the splice and the load point. The splice itself, as seen in the close-up of figure 17, appeared to be substantially intact after the test, even though crossed by several cracks.

The distribution of cracks illustrated in figure 18 shows substantially the same crack pattern in both girders in the vicinity of supports and applied loads. However, on account of its greater load carrying capacity, girder No. 2 developed extensive tensile cracking in the vicinity of the splices which was absent in girder No. 1.

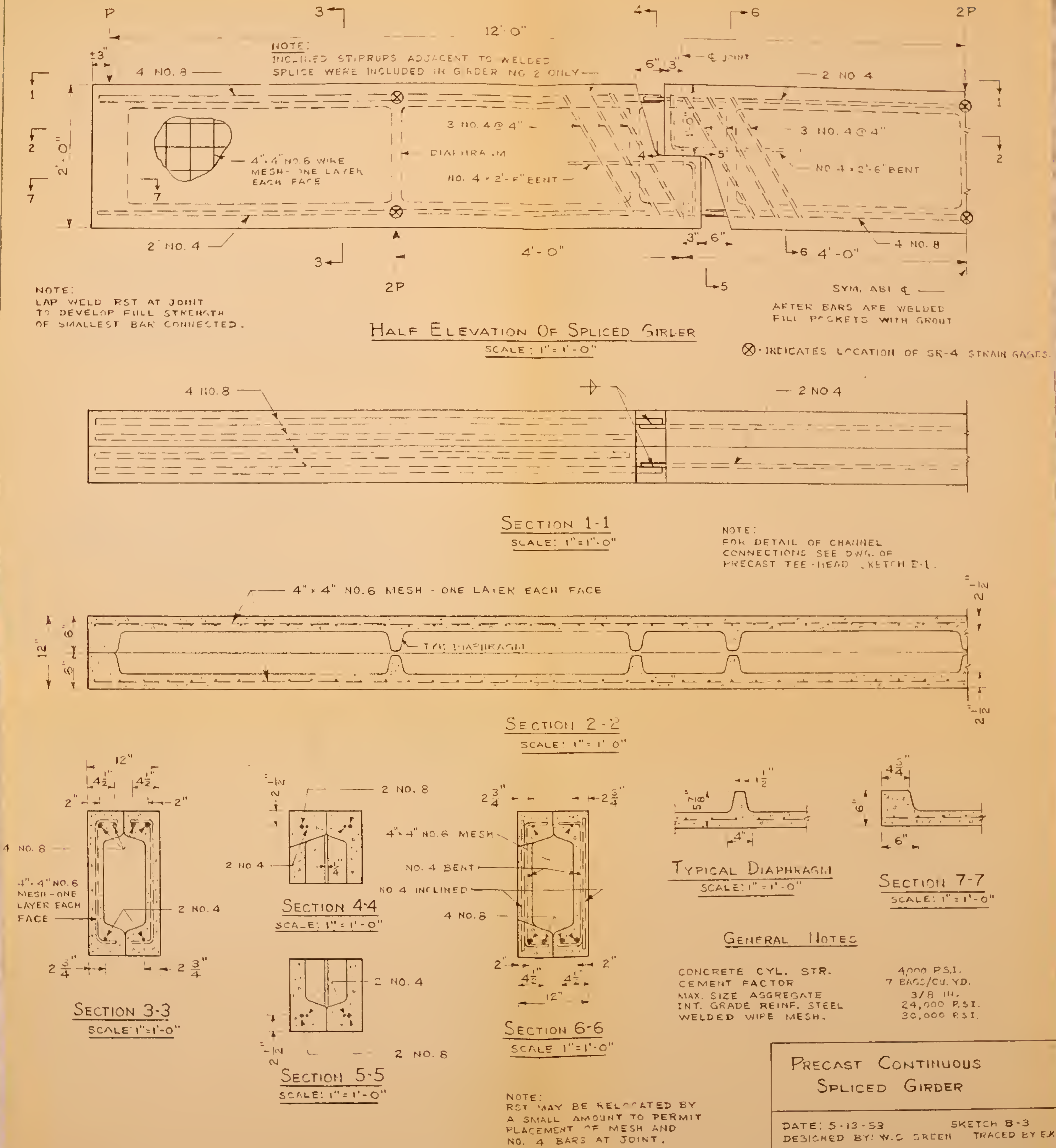

NOTE:
INCLINED STIRRUPS ADJACENT TO WELDED SPLICE WERE INCLUDED IN GIRDER NO 2 ONLY
12'-0"
4 NO. 8
2 NO 4
3 NO. 4 @ 4"
DIAPHRAGM
4"x4" NO.6 WIRE MESH - ONE LAYER EACH FACE
NO. 4 x 2'-6" BENT
2' NO. 4
4'-0"
℄ JOINT
NOTE:
LAP WELD RST AT JOINT TO DEVELOP FULL STRENGTH OF SMALLEST BAR CONNECTED.
SYM. ABT ℄
AFTER BARS ARE WELDED FILL POCKETS WITH GROUT
HALF ELEVATION OF SPLICED GIRDER
SCALE: 1"=1'-0"
⊗ - INDICATES LOCATION OF SR-4 STRAIN GAGES.
SECTION 1-1
SCALE: 1"=1'-0"
NOTE:
FOR DETAIL OF CHANNEL CONNECTIONS SEE DWG. OF PRECAST TEE-HEAD SKETCH B-1.
4" x 4" NO.6 MESH - ONE LAYER EACH FACE
TYP. DIAPHRAGM
SECTION 2-2
SCALE: 1"=1'-0"
SECTION 3-3
SCALE 1"=1'-0"
2 NO. 8
2 NO 4
SECTION 4-4
SCALE: 1"=1'-0"
SECTION 5-5
SCALE: 1"=1'-0"
4"x4" NO.6 MESH
NO. 4 BENT
NO 4 INCLINED
SECTION 6-6
SCALE 1"=1'-0"
TYPICAL DIAPHRAGM
SCALE: 1"=1'-0"
SECTION 7-7
SCALE: 1"=1'-0"
GENERAL NOTES
CONCRETE CYL. STR. 4,000 P.S.I.
CEMENT FACTOR 7 BAGS/CU. YD.
MAX. SIZE AGGREGATE 3/8 IN.
INT. GRADE REINF. STEEL 24,000 P.S.I.
WELDED WIRE MESH. 30,000 P.S.I.
NOTE:
RST MAY BE RELOCATED BY A SMALL AMOUNT TO PERMIT PLACEMENT OF MESH AND NO. 4 BARS AT JOINT.
PRECAST CONTINUOUS SPLICED GIRDER
DATE: 5-13-53
SKETCH B-3
DESIGNED BY: W.C GREEN
TRACED BY E.K.

FIG. 1

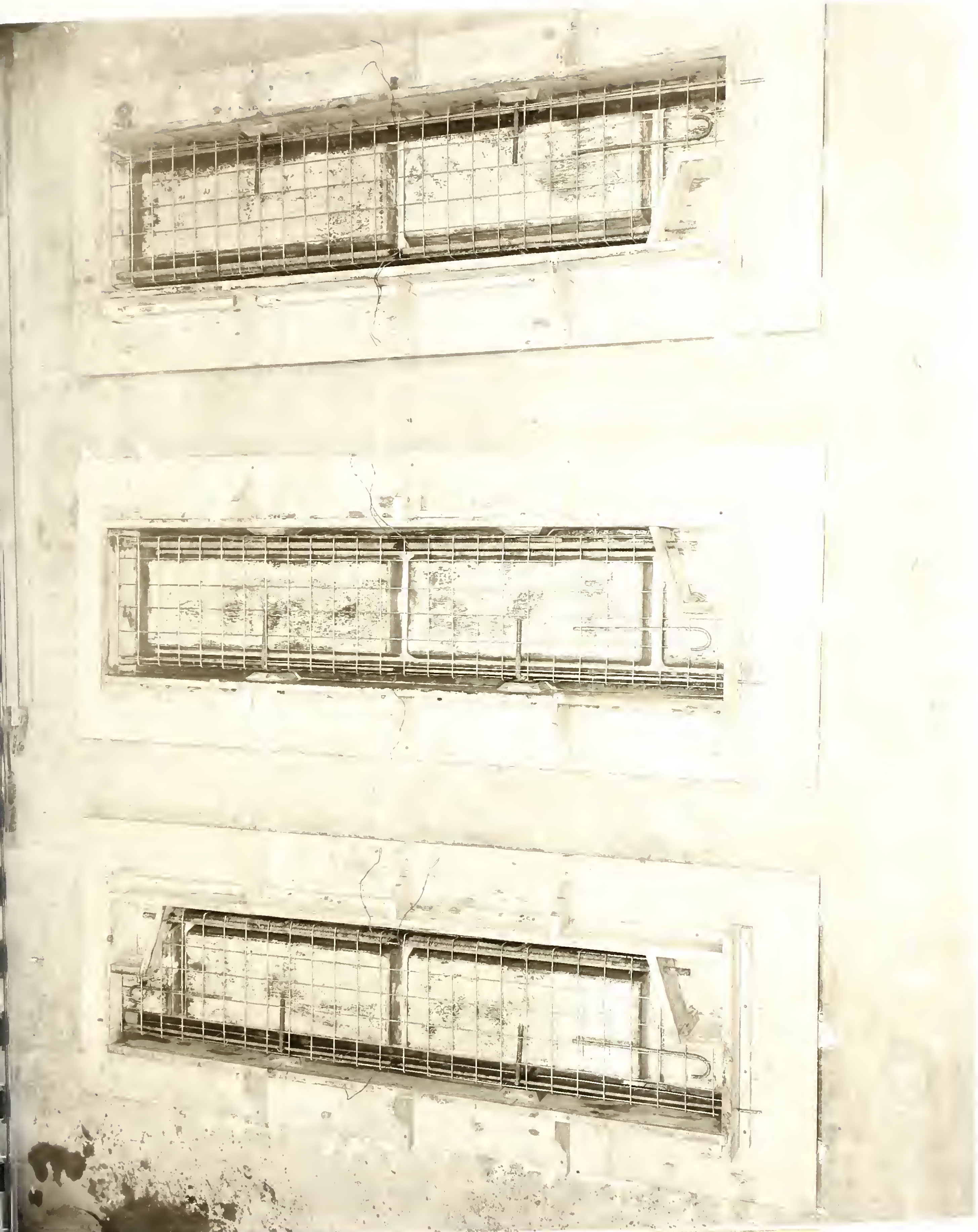


Fig. 2. Reinforcement and forms, girder No. 1.

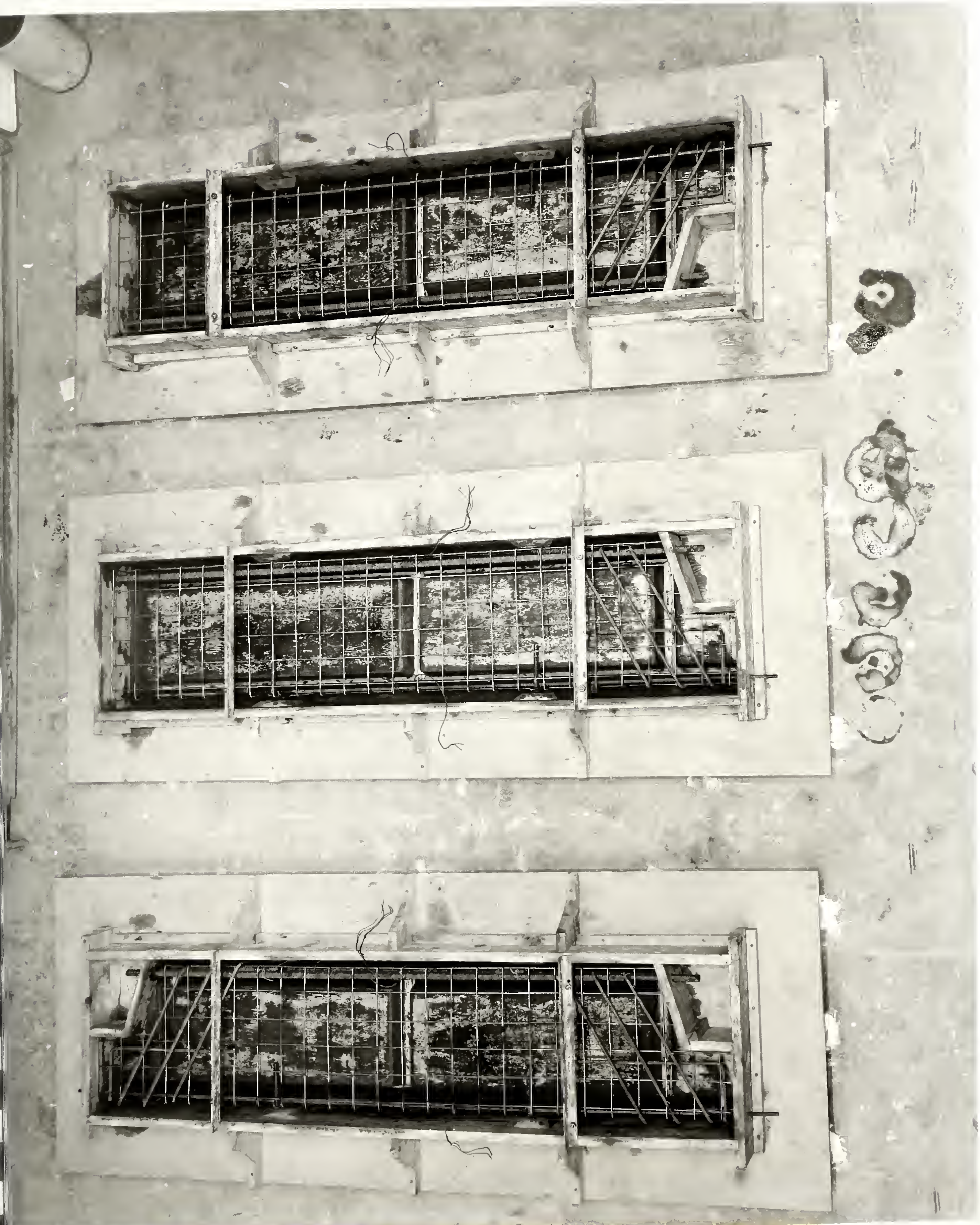


Fig. 3. Reinforcement and forms, girder No. 2.

CONTINUOUS GIRDER NO. I

STRESS-STRAIN CURVE OF 6"X12" CONCRETE CONTROL CYLINDER

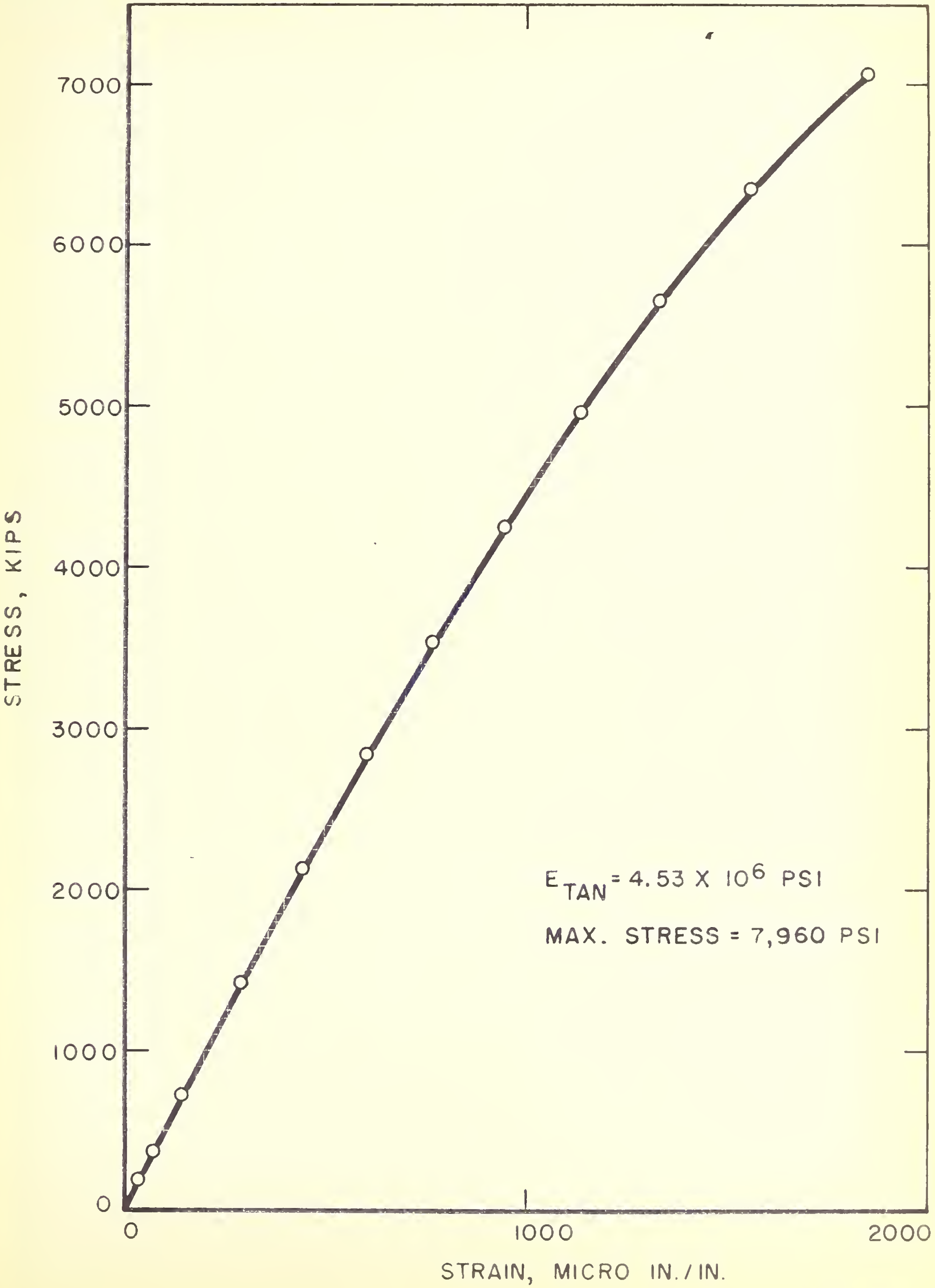


FIG. 4

CONTINUOUS GIRDER NO. 2

STRESS-STRAIN CURVE OF 6"X12" CONCRETE CONTROL CYLINDER

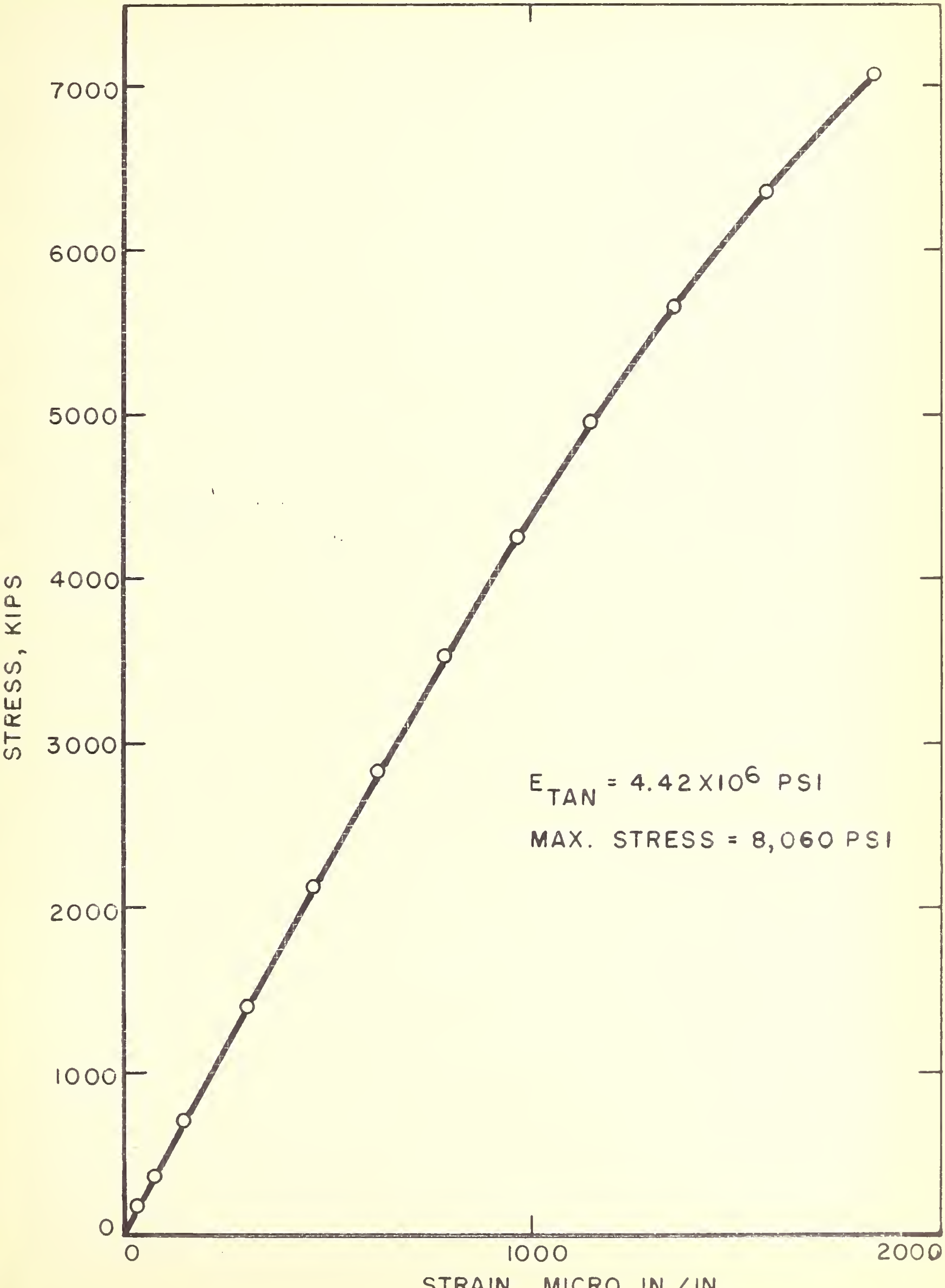
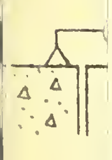
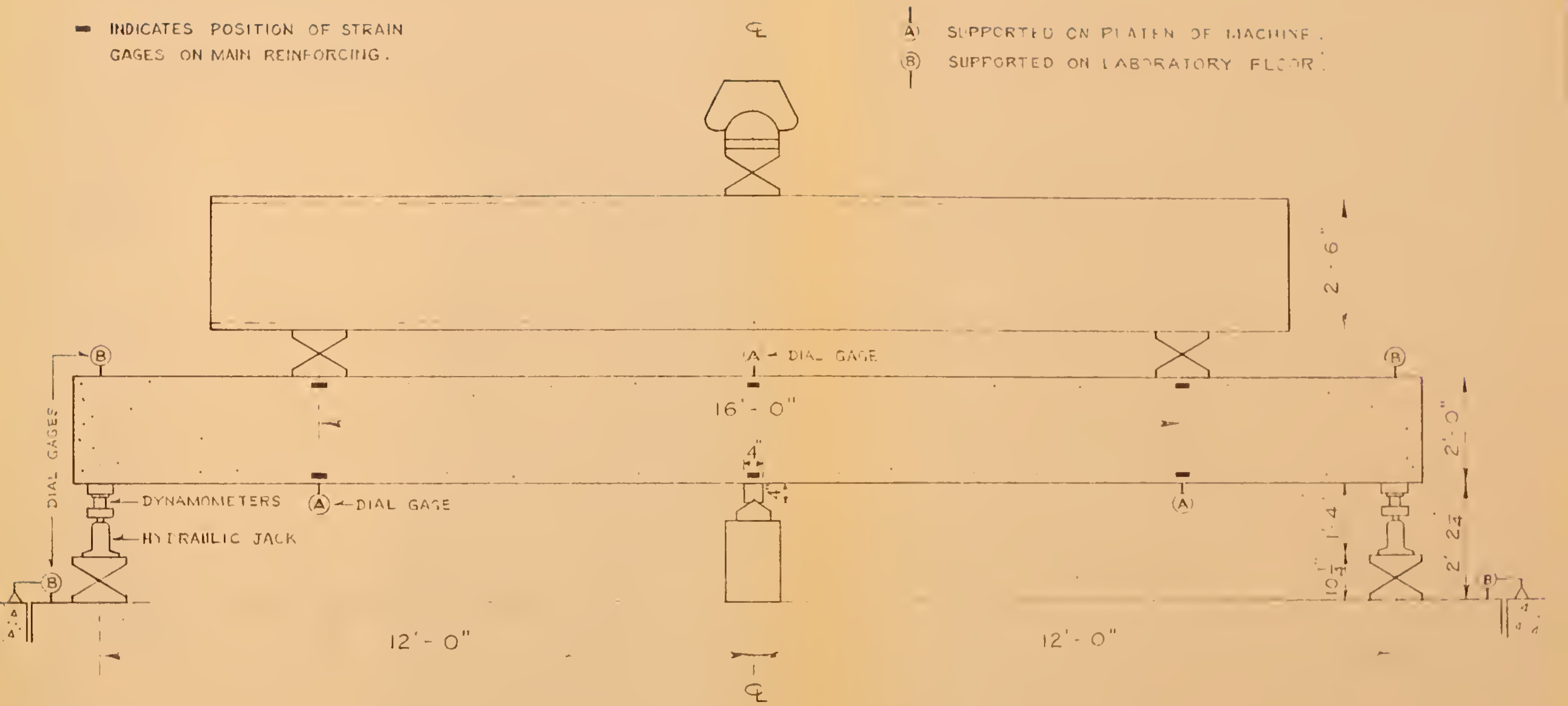


FIG. 5





LOADING ARRANGEMENT & LOCATION OF GAGES

SCALE: 1/2" = 1'-0"

NBS

8-13-54

EK

FIG. 6

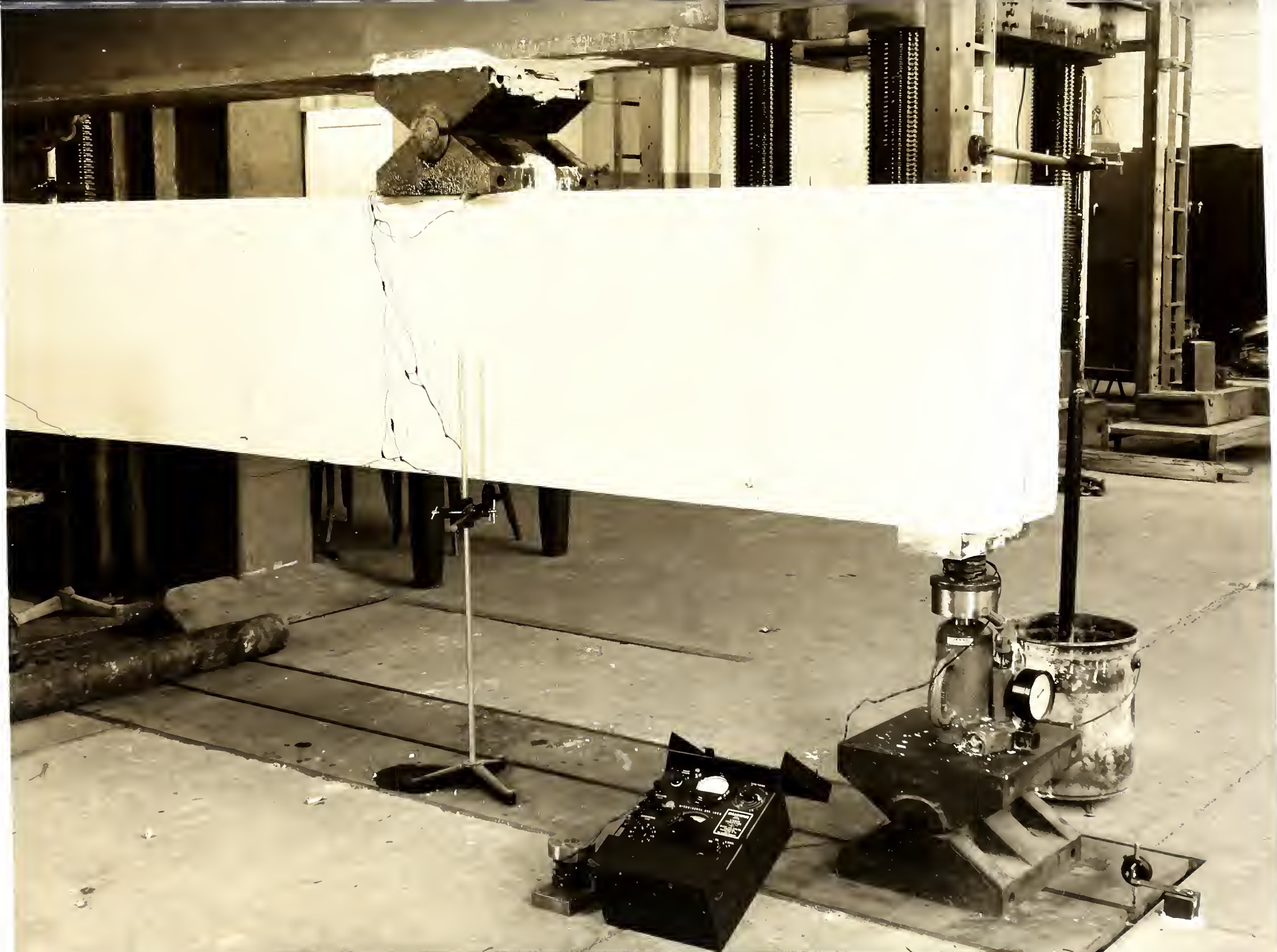


Fig. 7. Close-up of end reaction showing jack and load cell.

[illegible]

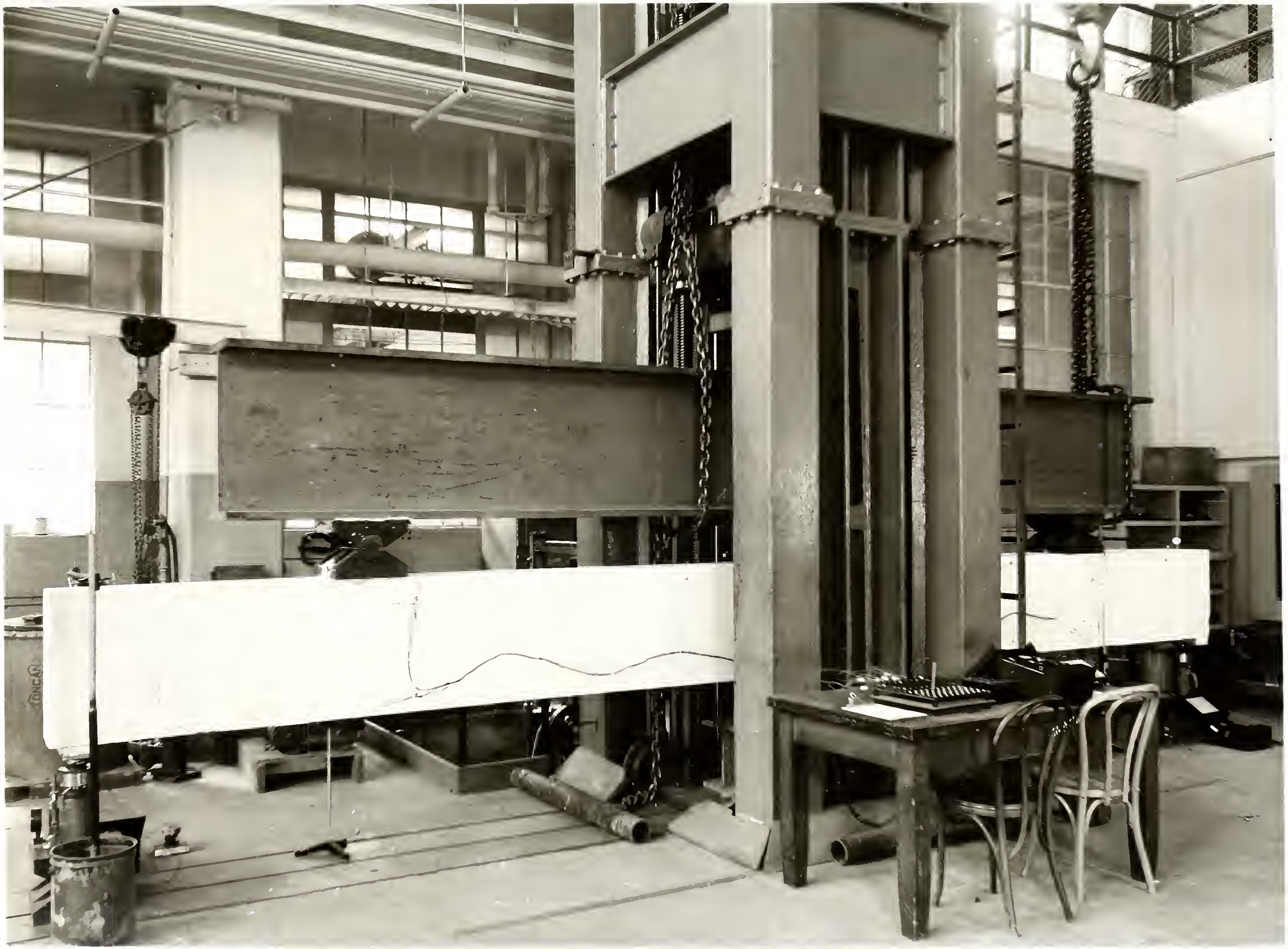


Fig. 8. Girder in 600,000 lb testing machine.

[illegible]

MACHINE LOAD VS. DEFLECTION C. G. NO. 1

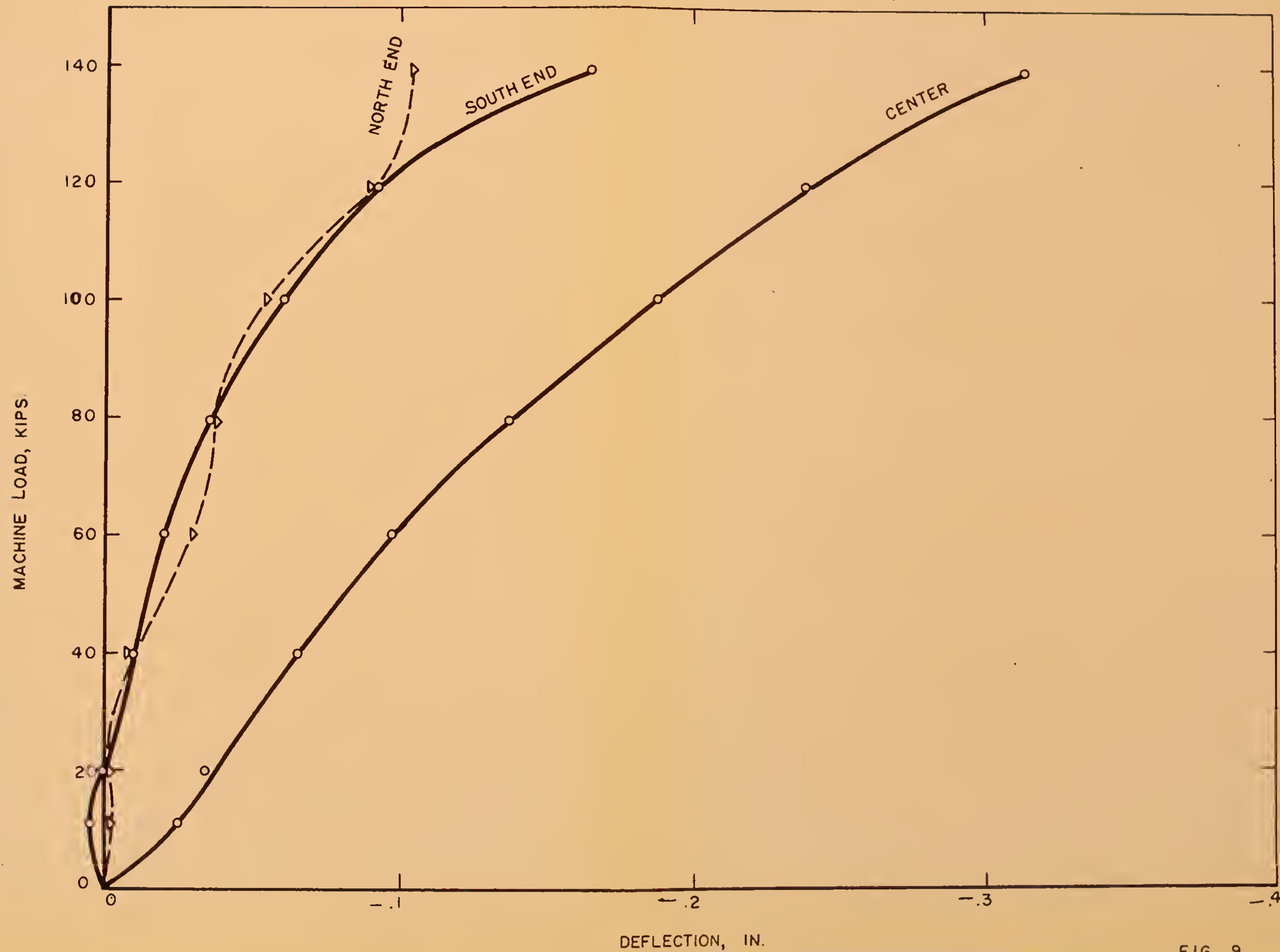
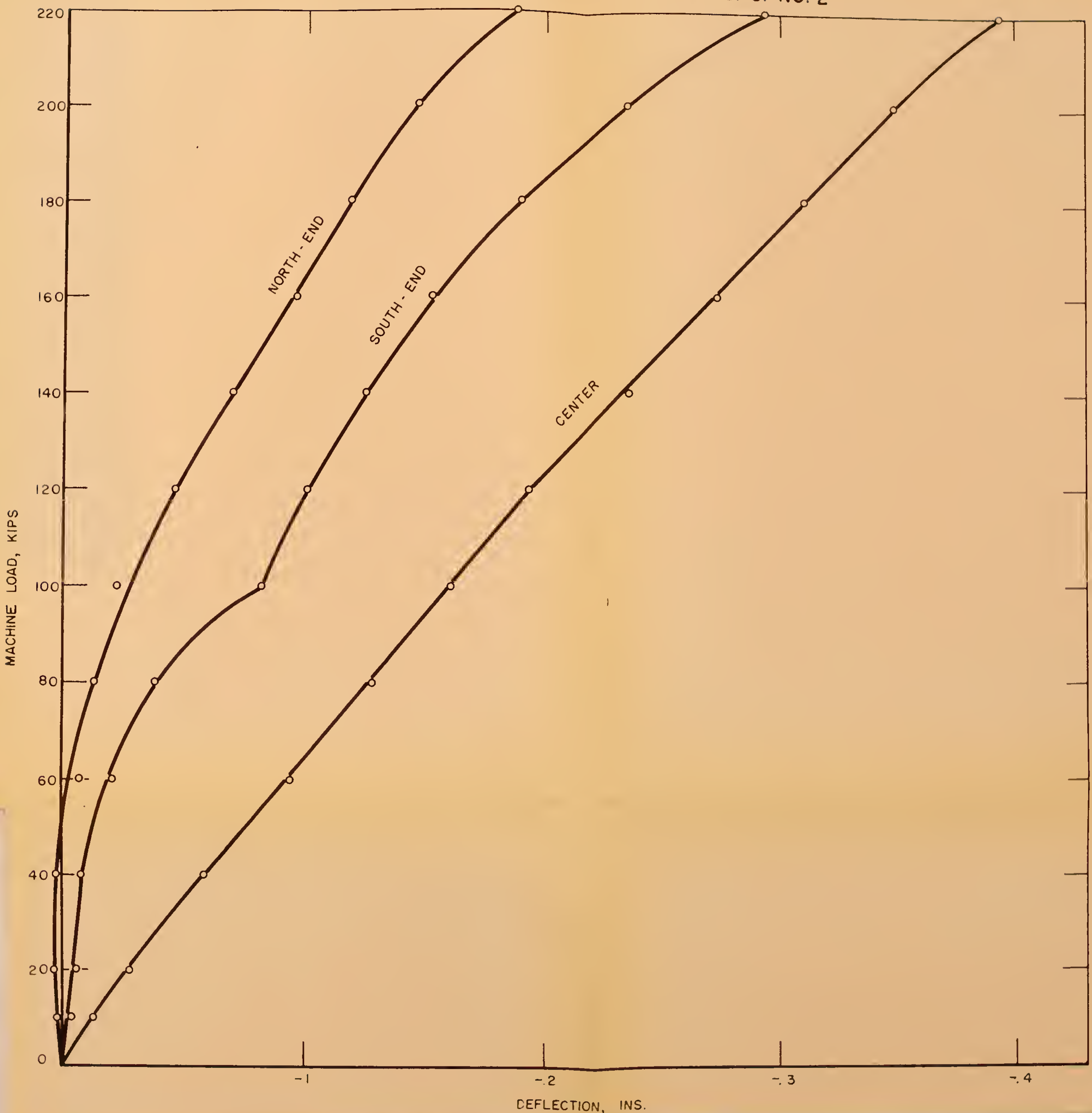


FIG. 9

MACHINE LOAD VS. DEFLECTION C. G. NO. 2



MACHINE LOAD, KIPS

OBSERVED STRAIN VS. MACHINE LOAD C. G. NO. 1

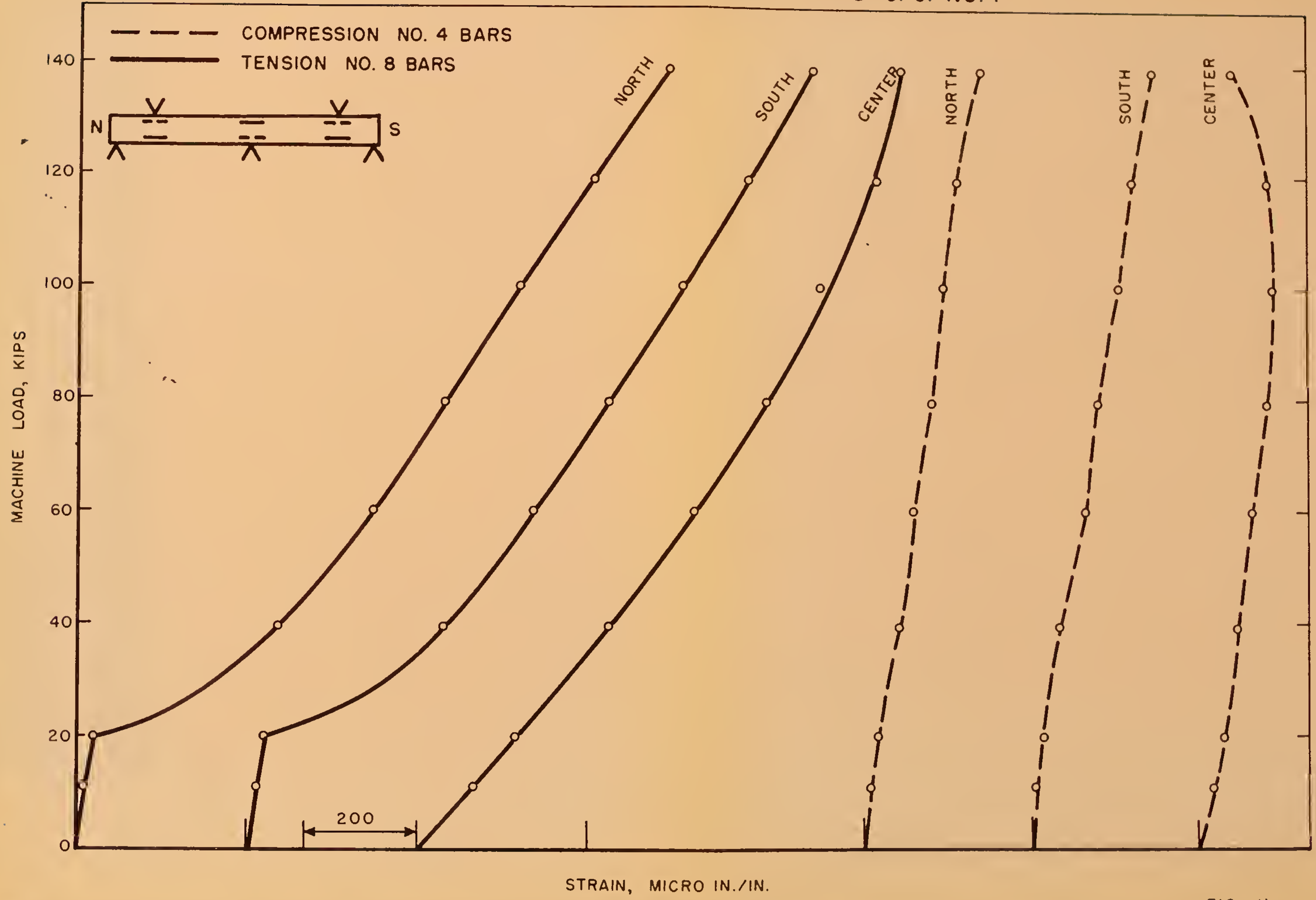


FIG. 11

MACHINE LOAD, KIPS

OBSERVED STRAIN VS. MACHINE LOAD C.G. NO. 2

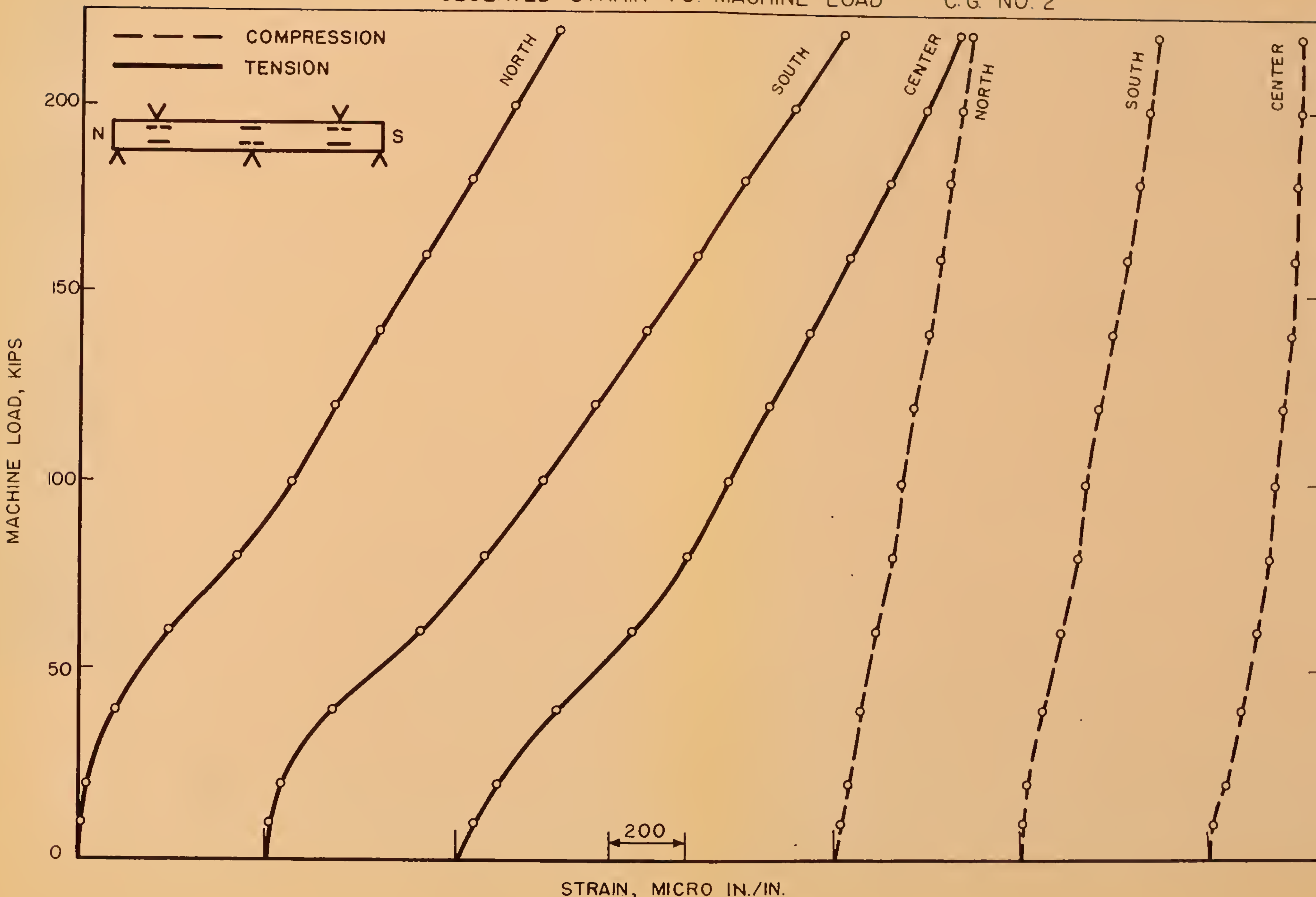
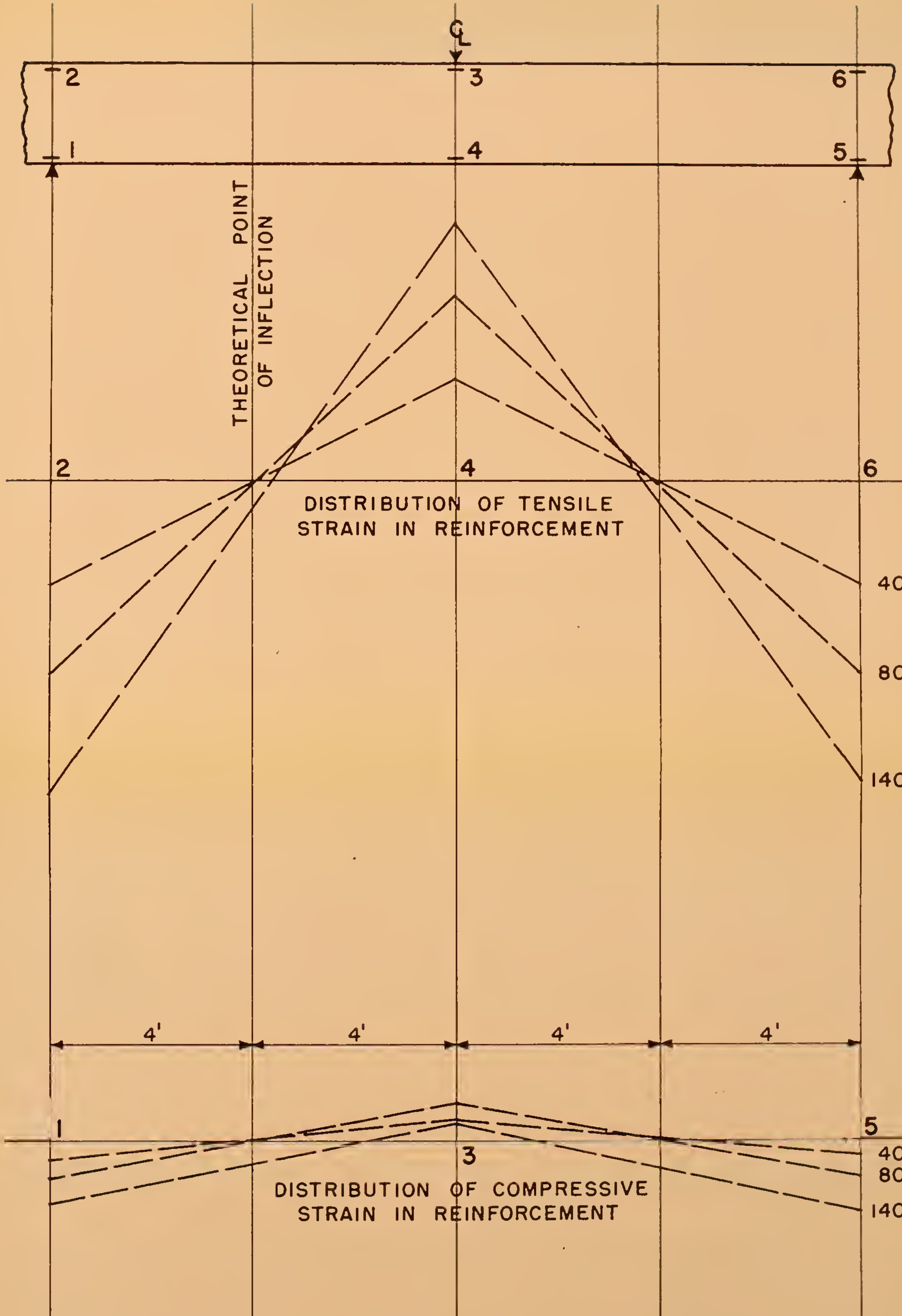
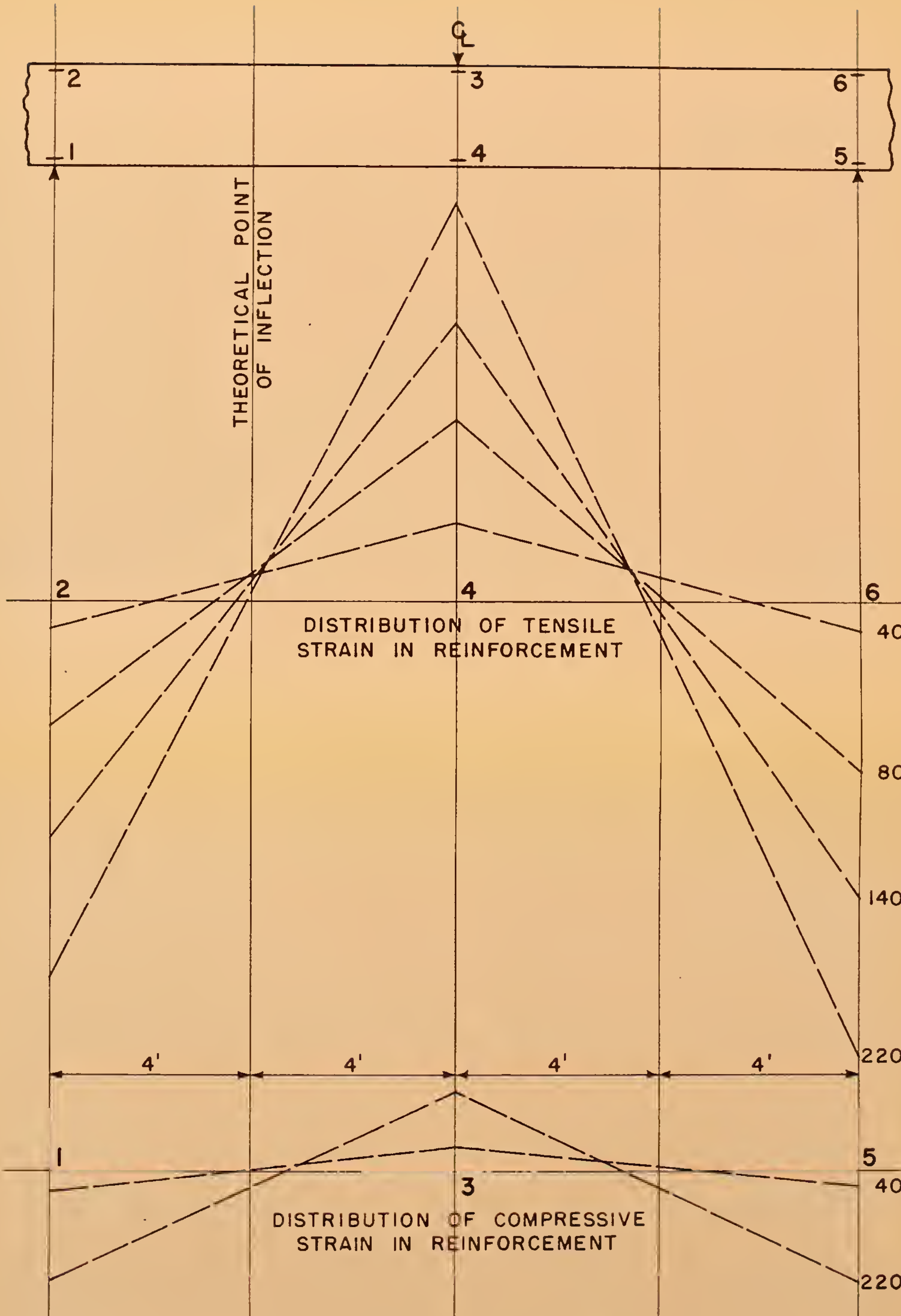


FIG. 12



STRAIN DISTRIBUTION IN REINFORCEMENT — C.G. NO. 1

FIG. 13



STRAIN DISTRIBUTION IN REINFORCEMENT — C.G. NO. 2

FIG. 14

Fig. 15. Failure of girder No. 1.

Fig. 16. Failure of girder No. 2, view of east side.

Fig. 17. Failure of girder No. 2, view of west side.

CRACK PATTERNS OF CONTINUOUS GIRDERS NO. 1 & 2

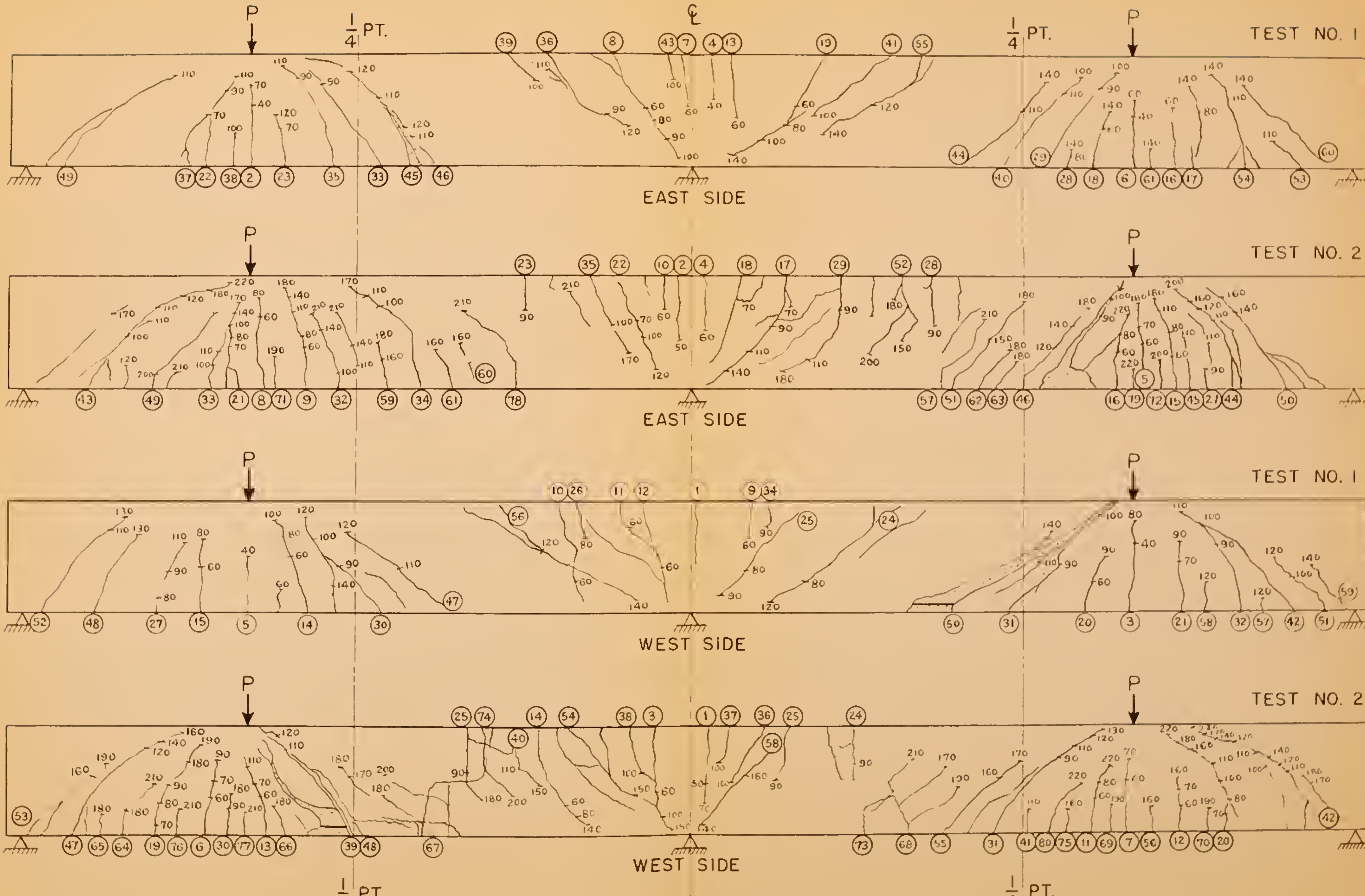


FIG. 18

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS