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157.2 Revised Ms.

SHEARING PROPERTIES AND POISSON'S RATIO OF STRUCTURAL AND ALLOY STEELS

By Inge Lyse[1] and H. J. Godfrey[2]

Synopsis

The paper describes the results of tests of different grades of structural and alloy steels to determine shearing properties (modulus of elasticity, yield point and ultimate strength) and their relation to the corresponding tensile properties. Poisson's ratio was also determined. Shearing properties were determined from slotted plate specimens tested in tension and from solid and hollow cylindrical torsion specimens.

The results showed considerable variation in the ratio of yield point in shear to yield point in tension for the different steels. Shearing modulus of elasticity determined by direct measurement agreed reasonably well with values calculated from values of tension modulus and Poisson's ratio. The values of Poisson's ratio did not vary greatly for the different steels.

Introduction

During a recent investigation of web buckling in steel beams, carried out at the Fritz Engineering Laboratory, Lehigh University, it was found that the ratio between the yield points in shear and in tension varied considerably for different grades of structural steel. In order to study the shearing properties more fully, the investigation reported in this paper was carried out, in which yield point, ultimate strength and modulus of elasticity in shear and tension were determined and compared for a number of different grades of structural steel and ten heat-treated alloy steels. Poisson's ratio for these steels was also deter-

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mined by direct measurement of lateral deformation of specimens under tension.

Since the shearing properties of steel are more difficult to determine than its tensile properties, several different methods of test were used as described hereafter in determining yield point and ultimate strength in shear. Shearing modulus of elasticity (G) was determined by the usual torsion test, and by computation from the tension modulus of elasticity (E) and Poisson's ratio (μ) using the following equation:

? o.k.

$$\underline{G} = \frac{E}{2\,(1+\mu)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

which is theoretically true for homogeneous, isotropic materials.

Materials

The several grades of structural steel comprised rolled I-beams, soft steel plates, tank steel plates, and $1\frac{1}{2}$-in. rolled rod. There were also included some soft, medium and hard steel rods of "structural" grade and a structural nickel steel.

The ten alloy steels included manganese, nickel, chromium, molybdenum, vanadium and tungsten steels. Nine were tested in the form of $\frac{7}{8}$-in. diameter specimens in annealed and quenched-and-drawn conditions. The tenth was tested in the "as-rolled" condition on 5/8" in. diameter specimens. Chemical compositions and heat treatments are given in Table II.

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(Size?)

The Bethlehem Steel Co., Bethlehem, Pa., supplied all materials for this investigation, with the exception of one of the alloy steels which was furnished by The Lukens Steel Co., Coatesville, Pa.

Specimens, Methods and Apparatus

Specimens from the I-beams were taken in all cases from the webs. Since these were in most cases only about $\frac{3}{8}$ in. thick and the plates only about $\frac{1}{4}$ in. thick, the usual cylindrical torsion specimens could not be used for determining shearing properties and slotted plate specimens described below were used. Plates S-1 and S-2 were 5/8" thick and both slotted plates and solid torsion specimens were made from these plates. For the remaining structural material and for all the alloy steels, shearing properties were determined on cylindrical torsion specimens. For reasons of economy, solid specimens were used, they being considerably less expensive than the hollow cylindrical specimens; however, ~~the~~ ~~[illegible]~~ both solid and hollow specimens were used in testing three grades of steel, soft, medium and hard steels. These tubular specimens were 1~~[illegible]~~ in. in outside diameter with $\frac{1}{8}$ in. wall thickness.

Values given in attached Table Solid and Hollow Torsion Tests.

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Note.— Which ones? There is nothing to identify them, and no values are given that can be identified from the data.

Tension and shearing tests were also made on ½- and 1-in. diameter bars machined from a rolled 1½-in. bar of structural steel, to determine any effect of size of specimen.

The shearing properties on cylindrical specimens were determined in a 24,000 in-lb. capacity Olsen torsion machine. The deformations were observed by means of a specially constructed instrument, built upon the same principle as that used by Seely and Putnam (6). The instrument, which is illustrated in Fig. 1, consists of two steel collars attached to the specimen and so constructed that their relative rotation may be measured by an Ames dial graduated to 0.0001 in. The instrument was calibrated against observations by mirrors and telescopes.

The slotted plate specimen, first used by Moore and Wilson (5), is 4 in. wide by 9 in. long, ~~½ in. thick~~, the thickness equal to that of material. and is prepared by cutting two parallel $\frac{1}{16}$-in. slots, at an angle of 45 deg. to the longitudinal axis, extending from points on that axis ½ in. apart to opposite edges of the specimen. When such a specimen is placed under tension, as shown in Fig. 2 (to be supplied) the shearing stresses are distributed fairly evenly over the ½ in. section. (See attached photo-elastic picture of a similar slotted plate specimen) Huggenberger tensometers were used for detemining the yield point but <u>not</u> the modulus of the slotted plate specimens. The ultimate strength of the slotted plate specimens was also obtained.

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Answered

Note.—Insert here a description of nature of stress in ½ in. section, how deformation is measured by Huggenberger tensometer, and what gage length is used. This is place to bring out that tensometer was used only to measure deformation for yield point, and not for modulus. Apparently slotted specimen was used for ultimate shearing strength.

Tensile deformation was measured by a Ewing extensometer. In determining Poisson's ratio, lateral deformation was measured by means of Huggenberger ~~Ex~~tensometers attached to a specially constructed circular collar of spring steel. As shown in Fig. 3, the collar was attached to the specimen by two screws placed diametrically. The pressure exerted by the screws was sufficient to allow the lateral deformation to take place without loosening the collar. The multiplication ratio of the collar as determined by direct calibration was 2.16. This simple rig proved very successful in the measurement of lateral deformations both below and above the yield point. Lateral strains were measured directly with this apparatus to ~~5 millionths~~ 0.000005 for 1-in. diameter specimens.

Tension and Torsion specimens of same size.
Bars were, 1, 7/8, - 1½, 5/8 and ½'' in diameter.
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Trained operator can read Huggenberger Tensometers to 1/10 division, which corresponds to 2.5 millionths. Anyone can read to 1/5 division or 5 millionths.

Note.—Were tension bars on which μ was determined 1 in. in diameter? Also why was accuracy changed from 2.5 to 5 millionths? Would it not be desirable to indicate multiplication ratio of tensometer? Where is reading to 1/200 in. made?

OK
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yes

Many of the stress-strain diagrams, both in shear and tension, particularly for the alloy steels (see Fig. 5), did not show a sharp break at the yield point. In such cases, the yield point was determined as the stress at which the tangent to the stress-strain curve has a slope (ratio of stress to strain) one-half of the slope ~~that~~ of the initial straight-line portion.

Results of Tests

The results of the tests on structural steels are given in Table I, and those on alloy steels in Tables II, III and IV. Typical stress-strain curves are shown in Figs. 4 and 5.

Effect of Shape and Size of Test Specimen:

Comparative stress-strain curves in shear obtained with slotted plate specimens and solid cylindrical specimens from the same material are shown in Fig. 4. It is noted that these two types of specimens gave very nearly the same yield point in shear. However, at a given stress the measured strains of the slotted plate specimens were less than those for the solid torsion bars. The slotted plate specimens gave a more definite yield point than did the torsion bars, and in general the results were more consistent. The ultimate shearing strength was less when determined on a plate specimen than when determined on a torsion bar, and the fracture of the former indicated a pure shear failure.

> Note.—Was G determined in any case by the slotted plate specimen, e.g. values of S-1 and S-2 on Table I. What materials were tested for shear on both solid bar and slotted plate specimen?

No.

on solid torsion specimens.

Plates S-1 and S-2

The average yield point in shear determined on the hollow cylindrical specimens (values not reported here) averaged about 90 per cent of that determined on solid bars. Enclosed table gives values for both hollow and solid torsion tests. Only yield point and ultimate stress determined on hollow specimens. Values in Table (enclosed) are average of 2 or more specimens.

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> Note.—Are any data at all given for hollow cylindrical specimens? Was G determined for any hollow specimens? There is so little given for hollow specimens that one questions including them at all.

The tests to determine effect of size of specimen show that the smaller specimens (½ and 1 in. in diameter) machined from 1½-in. bars gave lower strengths in both tension and shear than did the 1½-in. specimens, due probably to the effects of rolling during manufacture. The moduli of elasticity and Poissons Ratio, however, were very nearly the same for the several sizes of specimens. (See Table I.)

Properties of Structural Steels:

Referring to Table I, the shearing yield point for ordinary structural steels varied from 16,500 to 29,200 lb. per sq. in.; the yield point in tension varied from 26,900 to 51,300 lb. per sq. in. for the same materials. Steels containing nickel gave shearing yield point as high as 41,700 lb. per sq. in.

The ratios between the yield points in shear and in tension, given in the last column of the table, vary greatly. For rolled I-beams the ratio varied from 0.505 to 0.634; for tank steel plates, from 0.509 ~~and~~ to 0.534; for rolled soft steel plates, from 0.527 ~~and~~ to 0.671; and for rolled $1\frac{1}{2}$-in. bars the average ratio was 0.629. It should be noted that a number of the structural grade steels had shearing yield points when determined on slotted/plate specimens, considerably less than 60 per cent of the yield point in tension. If the stress developed by a hollow torsion specimen is considered to be correct, these ratios would be correspondingly lower.

P)

(contained only 0.9 % Cr., Ni content = 2.85 %)

OK - The addition of nickel raised the ratio of yield points in shear and tension to as much as 0.869.

Poisson's ratio for the different types of structural steel varied only between 0.271 and 0.302. For design purposes, the use of a value of 0.3 seems to be justified.

The shearing modulus of elasticity show~~s~~ed a high degree of uniformity when calculated from the observed longitudinal and lateral strains. However, the modulus obtained by direct measurements on the torsion specimens showed considerable variation.

Typical stress-strain diagrams for longitudinal, lateral and torsional deformations of structural steel are shown in Fig. 5. It is noted that the lateral deformation indicated a sharp yield point at the same stress as did the longitudinal deformation.

Properties of Alloy Steels:

The hardness and ductility of the alloy steels are given in Table III, together with a description of the tension test fracture. Attention is called to the laminated fractures of the quenched-and-drawn specimens.

Tensile and shearing properties and Poisson's ratio are presented in Table IV. The yield point in tension varied from 37,500 to 53,000 lb. per sq. in. for the steels in the annealed condition, and from 55,000 to 124,000 lb. per sq. in. for those in the quenched condition. The yield point in shear as determined on solid torsion specimens varied from 33,500 to 43,750 lb. per sq. in. for the annealed condition and from 44,100 to 93,000 lb. per sq. in. for the quenched condition. In general, the ratios between the yield points in shear and in tension were greater for the annealed than for the quenched specimens, ranging from 0.774 to 0.894 for the former and from 0.662 to 0.809 for the latter. The alloy steels, both in annealed and quenched conditions, showed considerably greater ratios between yield points in shear and tension than the structural steels.

A number of the annealed solid torsion specimens gave ultimate strengths in shear in excess of the corresponding tensile strengths. This is due to the use of the ordinary torsion formula to determine ultimate strength, notwithstanding that the formula does not hold after the stress has exceeded the proportional limit of the material.

Poisson's ratio varied from 0.272 to 0.320 for these ten alloy steels. With the exception of the tungsten steel (No. 7) there was little difference between Poisson's ratio for the steel in the annealed and quenched conditions.

Typical stress-strain diagrams for longitudinal, lateral and torsional deformations of one of the alloy steels are shown in Fig. 5. Attention is called to the gradual transition from a straight line to a curve in all three cases. After the proportional limit was reached the relative rate of lateral deformation increased over that of the longitudinal deformation so that Poisson's ratio approached 0.5.

Summary

The following summary and conclusions may be presented from this investigation:

1. The apparatus developed for measuring lateral and torsional strains

proved very successful, based on accuracy and consistency of results and calibration against other instruments.

2. Slotted-plate specimens and solid torsion specimens gave approximately the same yield point in shear.

3. The average yield point in shear of a hollow bar was about 90 per cent of that of a solid bar.

4. The size of the test specimen had no effect upon the observed Poisson's ratio.

5. Steel of structural grade showed a wide variation in the ratio of yield point in shear ~~and~~ to yield point in tension. In general the ratio was below 0.60 for specimens from rolled plates and structural sections.

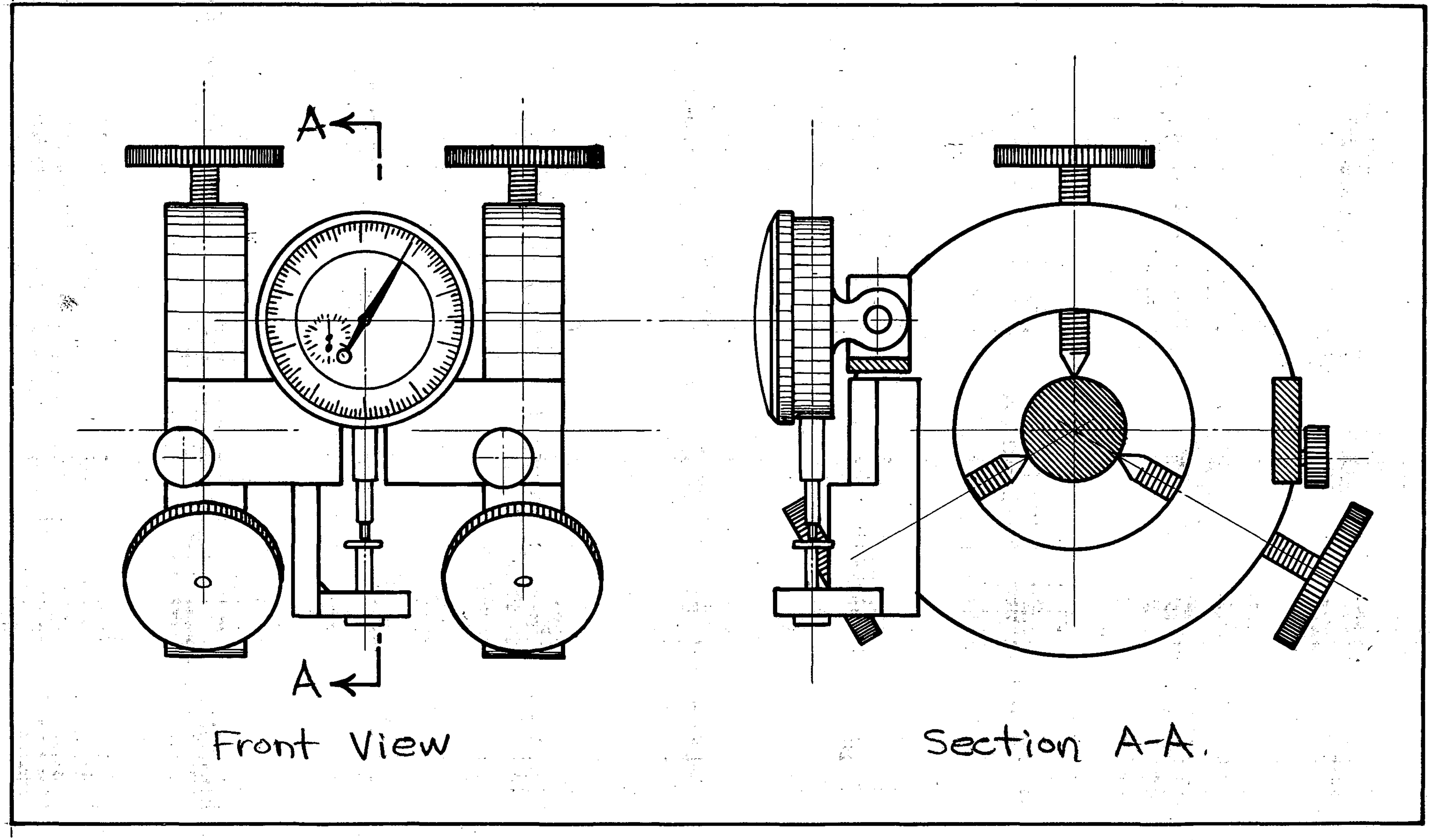
6. Poisson's ratio for structural steel varied from 0.271 to 0.302.

7. For alloy steels the ratio of yield points in shear and in tension varied between 0.774 and 0.894 for annealed condition and between 0.662 and 0.809 for quenched-and-drawn condition.

8. Poisson's ratio for alloy steels varied between 0.272 and 0.320.

Bibliography will be inserted.

Type



Front View

Section A-A.

Fig. 1. Apparatus for Measuring Torsional Deformation.

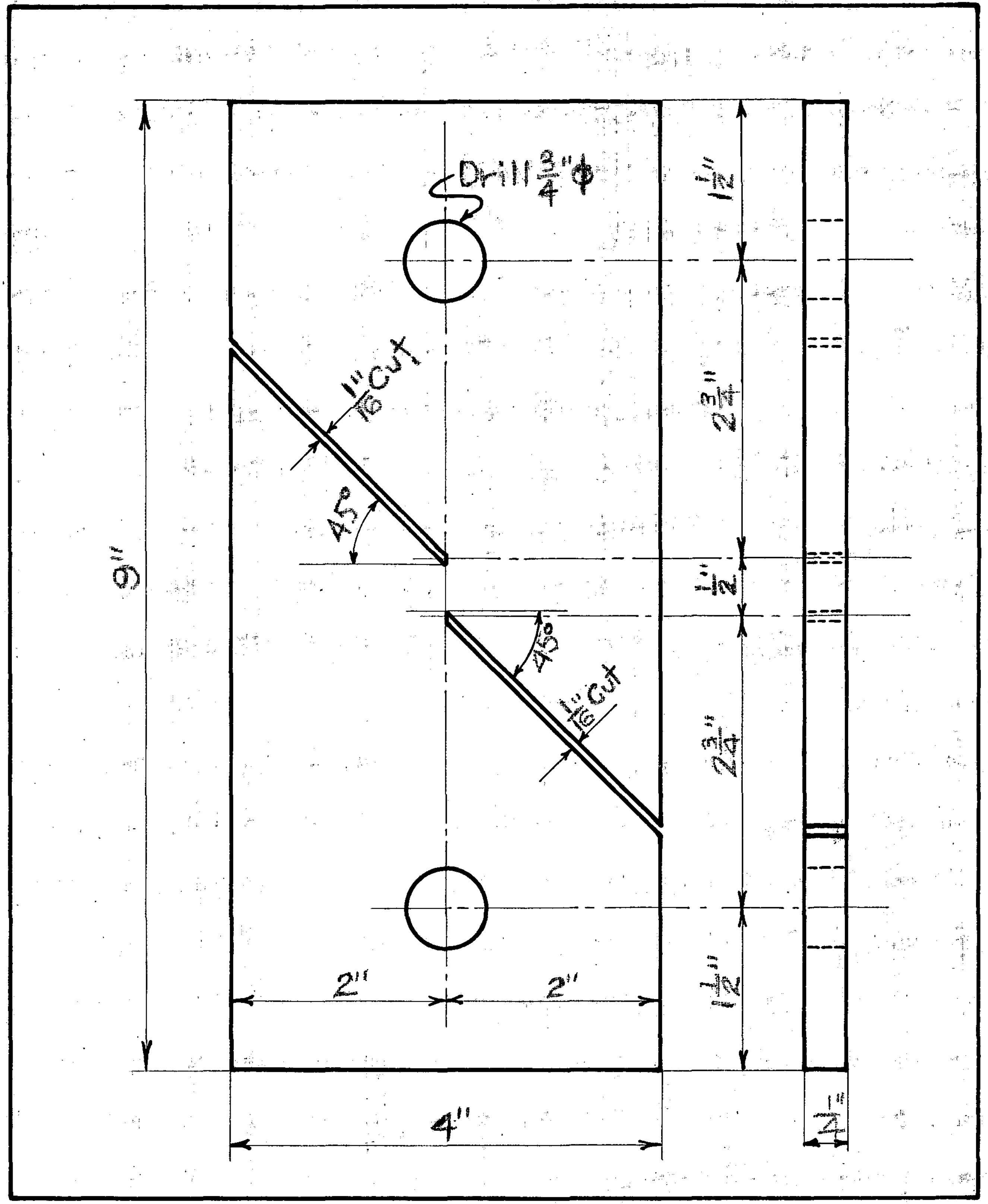


FIG. 2a - TYPICAL SLOTTED PLATE SPECIMEN

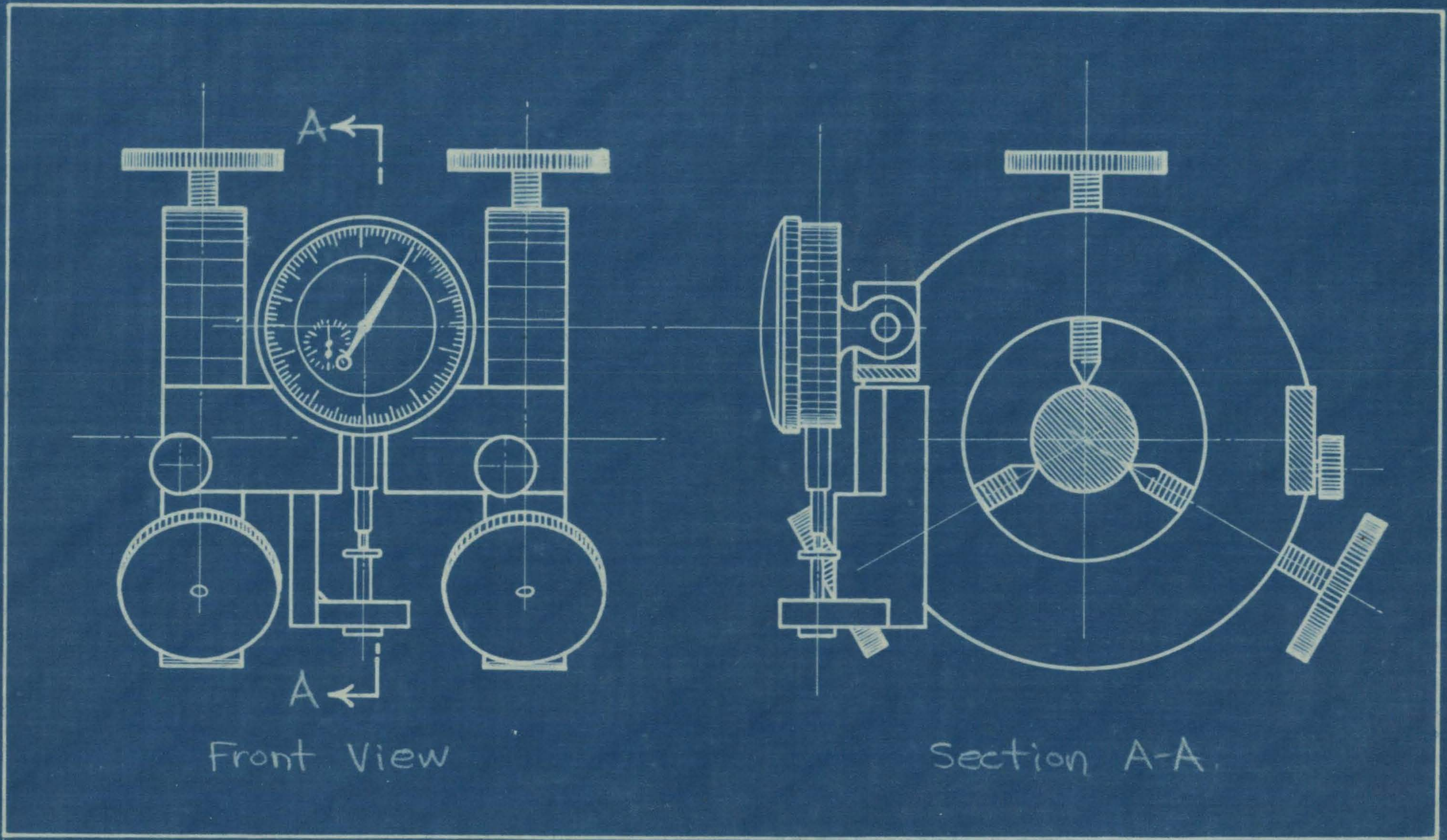


Fig. 1 Apparatus for Measuring Torsional Deformation.