1949

A torsion machine of 2,000,000 IN-LB capacity, ASTM Bulletin No. 160, pp. 49-52, 1949, Reprint No. 68 (49-5)

F. K. Chang

K. E. Knudsen

B. G. Johnston

TORSION TEST MANUAL

---USING THE 2,000,000 POUND-INCH TORSION TESTING MACHINE---

April 6, 1949

FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY

BY F. K. Chang

Contents

Designation of Test Specimens

P-1 .... Single plate, no holes

P-2 .... Single plate with holes

P-3 .... 4 plates

T-1 .... 20" girder, no cover plate, bolted and riveted

T-2 .... 20" girder, 1 cover plate, bolted riveted

T-3 .... 20" girder, 2 cover plates, bolted

T-4 .... 20" girder, 2 cover plates, riveted

T-5 .... 20" girder, 3 cover plates, bolted and riveted

T-6 .... 50" girder, bolted & riveted,

T-7 .... 20" girder, welded

T-8 .... 50" girder, welded

T-9 -------- 18" WF 77 lbs

Preparation of the Specimens

(1) Mount the SR4 gages on the specimen according to the sketch. The Baldwin instructions should be strictly followed.

(2) Weld-on the level bar seats according to sketch. The vertical post of the seats must be perpendicular to the longitudinal axis of the specimen.

(3) Drill holes for Whittemore gages:

i) The holes should be approximately 0.05 in. in diameter and normal to the gage line and to the surface of the specimen.

ii) The holes should be of sufficient depth to leave clearance below the conical point of the leg of the gage and they should be carefully reamed to remove small irregularities in their surface. (use #54 drill)

iii) The holes should be carefully spaced so as to remain well within the working range of the instruments.

(4) White wash if desired.

(5) Prepare the fixture plates.

Set-up of the Specimens on the Machine

(1) Choose proper torquemeter

Torquemeter A 0 → 2,000,000 Pound-inch
Torquemeter B 0 → 500,000 Pound-inch
Torquemeter C 0 → 100,000 Pound-inch

(2) Lock the trolley in position according to the length of the specimen. When 2 positions are possible, always use the one which gives more allowance for specimen shortening.

(3) Move the travelling head of the Riehle Machine (RN) to the top position with 1/8" clearance. Fix the two rope sockets in positions and turn the large wheel in counterclockwise direction until:

i) the rotating head is approximately in a horizontal position with the south side slightly higher,

ii) the rope is tight,

iii) we can insert all 3 pins to look the wheel in position.

(4) Bolt the 2 fixture plates on the rotating head and the stationary head respectively.

(5) Set up the specimen carefully, making sure to avoid any externally applied load.

(6) Properly fit the fixture plates at both ends. Use shim plates if necessary.

(7) Attach dial gages between the trolley and the stationary head to measure the shortening of the specimen under twist.

(8) Wiring of SR4 gages.

Operating of the Machine

(1) Be sure that the specimen is under no torque. Set the scale of the Riehle Machine (RM) to register zero and take readings of the torquemeter, strain gages, level bars, dial gages and extensometers.

(2) Be sure that the rope is in a center position on the large wheel and all the 6 pulleys.

(3) Remove the hand-wheel and turn on the switch if the driving motor will be used as stated in (5).

(4) Pull out all 3 pin. (Jack may be used on the wheel or a small load applied to ease the pull.)

(5) Apply the load using either the hand-wheel or the driving motor at slow gear (west position) <u>after</u> all three pins are taken out

i) Using hand-wheel: for small increment of load.

ii) Using driving motor

TOP BUTTON (FORWARD)	HEAD MOVES DOWN APPLYING LOAD
MIDDLE BUTTON (REVERSE)	HEAD MOVES UP RELEASING LOAD
BOTTOM BUTTON (STOP)	STOP

iii) Keep the arm of the RM scale either in floating balance or touching the bottom of the end opening. It is on dangerous side for the arm to come in contact with top of the end opening.

(6) Although slow gear is preferred in most cases, sometimes fast gear (Eastpposition) is required for unloading or rapid loadings For one stroke on the Riehle Machine, the slow gear takes 1 1/2 hrs. while the fast gear takes only 20 minutes. When change the gears, the clutch should be disconnected first.

(7) Take the following readings for each corresponding load:

i) Torquemeter readings setting first the gage factors & correct compensating gage switches.
ii) SR4 readings setting first the gage factors & correct compensating gage switches.
iii) Level bar readings.
iv) Whittemore gage readings.
v) Dial gage readings.

(8) Use smaller increment of load for the first few readings. When the load approaches the yield strength of the specimen, smaller increment must be used again.

(9) The load applied on the RM should never exceed 45,000 lbs. (50,000 lbs. in exceptional cases.

Change of Rope Socket Positions when Total Angle of Twist $> 30°$

(1) At the end of each stroke of the Riehle Machine (RN), insert the three pins whenever possible to lock the large wheel in position. Take all readings immediately.

(2) Move the travelling head of the RM to the top position with 1/8" clearance.

(3) Move the south-side sockets one spacing up and then, move the north-side socket one space down thus stretching the rope.

(4) Pull out all 3 pins (apply small load to case the pull).

(5) Apply the load to the last previous magnitude and take all the readings again.

(6) Twist 30° more.

Taking the Level Bar Readings

(1) Check the alignment of the level bar seat.

(2) Apply a small load to eliminate the loose play factor of the specimen.

(3) Make the top plate of the level bar seat (LBS) level, or vertical, by setting the micro-reading to .515 for horizontal level bar and .425 for vertical level bar respectively.

(4) When taking a reading, the point of the stationary leg should coincide with the small drill. The point of the micro-meter should coincide with the bottom line of the slot. Keep the level bar in a vertical positioh always.

(5) Before the level bar is out of range, turn the top pbece of the LBS to a level position. Be sure to take the level bar readings at the same load before and after the turning.

(6) Take 3 independent readings for each point at each load.

Whittemore Gage Readings

(1) Three independent readings for each gage line at each load are required. No 2 readings over the same gage line should be taken successively as the operator is unconsciously prejudiced in estimating the last place of reading.

(2) The instrument should have the points perfectly clean of grit, etc. at all times.

(3) All sets of readings should have at least 1 out of every 25 as a check on the standard bar.

(4) All gage holes should be perfectly clean.

(5) All sets of observations should have a temperature record accompanying it.

(6) Keep dial plunger clean at all times.

(7) Be sure that the instrument is "unlocked" when take the readings.

Routine Test Prodedures

(1) Apply and release load up to 1/3 elastic strength several times before test. Plot curves if desired. (Fig. 1)

(2) Be sure that the specimen is under no torque and take all zero readings before test being started.

(3) Use small increment of load for first few readings and readings near the yield strength of the specimen.

(4) For each load, the sequence of taking readings is as follows:

Man A.
- i) first set of level bar readings
- ii) " " " Whittemore readings
- iii) " " " Ames readings
- iv) second set of level bar readings
- v) " " " Whittemore "
- vi) " " " Ames readings
- vii) third set of level bar readings
- viii) " " " Whittemore "

Man B
- i) torquemeter reading
- ii) all gage readings
- iii) torquemeter reading again

Man C
- i) take record for man A
- ii) plot curves, see (5)
- iii) record stress lines on white wash, see (6)

(5) Plot curves Load vs Twist and
Load vs Shear Stress
as the test proceeds

(6) Mark the corresponding load when the stress lines occur at the white wash.

(7) Ceriterion in plastic range test -- decide for individual test.

(8) Release and apply loads again to previous magnitudes in plastic range and determine permanent sets. (Fig. 2)

(9) Prepare to take some photos at any time.

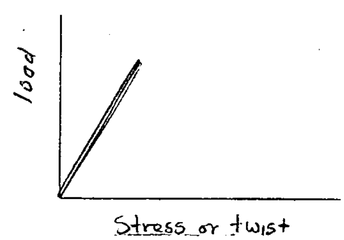


Fig. 1

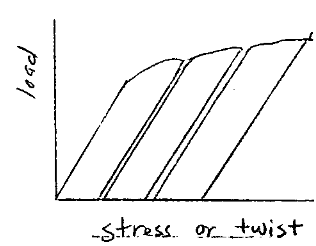


Fig. 2

Procedure for Calibrating Torsion Machine

A. Torquemeters

1. Use 200 inch lever arm (16'-8").

2. Weight hanger at end.

3. SR-4 gage leads (AD-1; GF 2.036) go in the following pairs

   B 2 & B 31

   B 23 & B 34

   One pair connected to compensating gage terminals and one pair to measuring gage terminals.

4. Apply weights in increments taking readings of SR-4 gage hookup vs. applied load.

5. Data sheet

   Torquemeter No.

   Gage factor setting (2.036)

   Max. Load Max. Moment

Load	Rdg.	$R_{before} - R_{this}$	$R - R_{original}$

This procedure has only been carried up to 400,000 in-lbs. because of limitations of amounts of weights which can be fit on weight hanger.

6. Plot calculated moment vs. change in SR-4 reading.
7. Extrapolating this curve will give the values up to 2,000,000 in-lb. without too much inaccuracy expected.

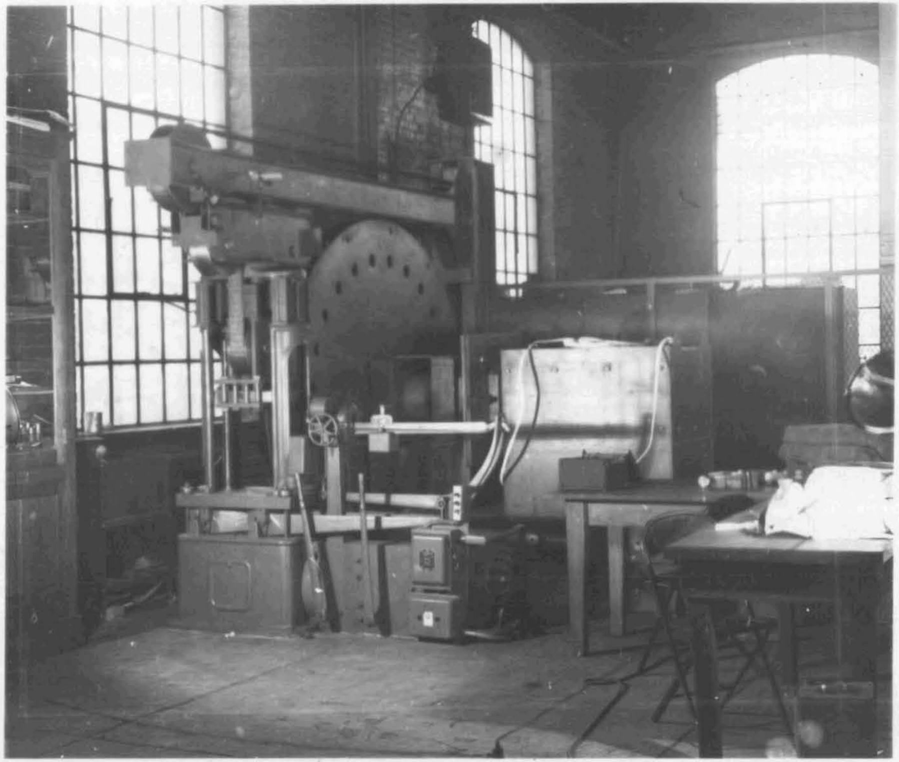
B. <u>Balance Lever</u>

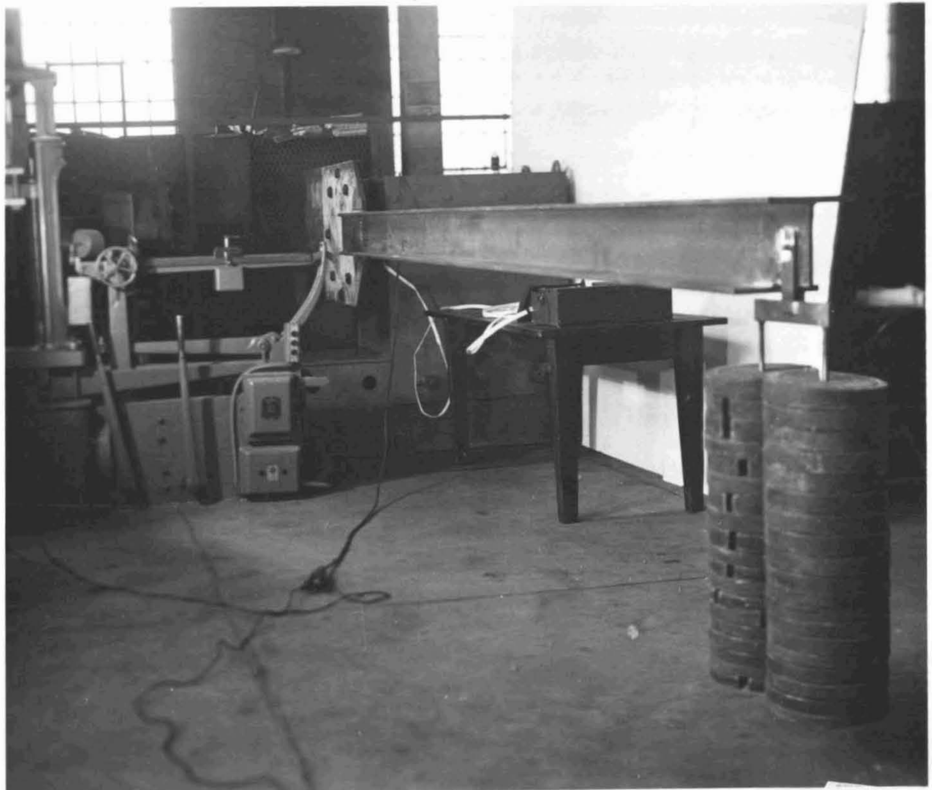
1. Bolt Trolley End fixture plate to the fixed End fixture plate. (see photo)
2. Connect up already calibrated torquemeter to Baldwin type K indicator.
3. Reading machine load vs. SR-4 indicator reading. A rough idea of torque can be gotten for purposes of operating the machine.

(Max. load for 2,000,000 in-lb. is about 30,000 lb. reading on the 50,000 lb. lever balance scale.)

Where information about calibration of Torsion Machine can be found

1. Old Calibrations 1948-1949, X 211 file.
2. Most recent calibration
   Engineer of Tests has a calibration book.
3. Photos of calibration setup, 211 photo file.
4. Tracing of torque lever & hangers. Tracing No. 211-31.
5. Reprint "A Torsion Testing Machine of 2,000,000 Inch Pound Capacity".





800 FL 209.1

A Torsion Testing Machine of 2,000,000 Inch-Pound Capacity

By F. K. Chang[1], K. Endre Knudsen[1], and Bruce G. Johnston[2]

SYNOPSIS

A torsion testing machine of 2,000,000 in-lb. capacity has been designed and constructed at the Fritz Engineering Laboratory of the Lehigh University Civil Engineering Department. This machine can test specimens up to 4 ft. 4 in. in diameter, 16 ft. long, and can apply twists through any desired angle. The torque is applied by turning an 88-in. diameter rotating head by means of a 4 by ¼-in. flat wire rope, using an old model standard Riehle testing machine as the power source. To measure the applied torque accurately, aluminum torque tubes mounted with SR-4 gages are inserted at one end of the stationary head. These are of various ranges to give desired sensitivity. The head, in turn, rests on rollers which permit longitudinal movement when the specimen shortens during the twist.

The machine consists largely of weldments, made up from standard rolled bars and plates. The apparatus is self-equilibrating under the load; only a few foundation bolts are needed to keep it in place.

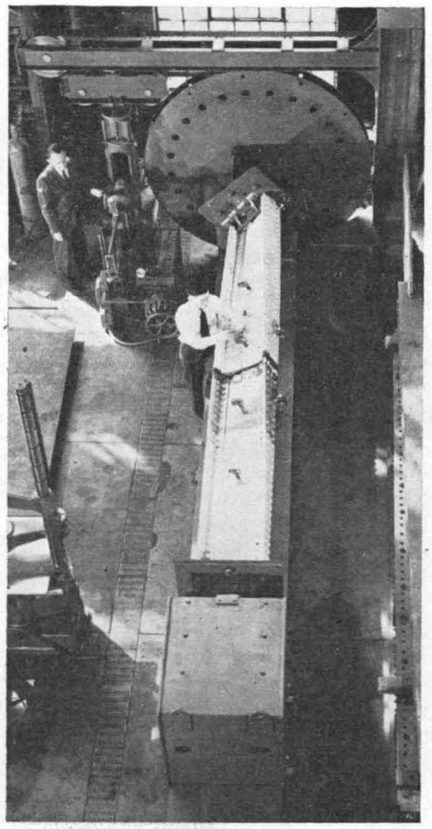


Fig. 1.—General View of the Machine.

A RESEARCH program on torsion was resumed at the laboratory in October, 1947, under the sponsorship of the Research Corporation of New York, N. Y. It was planned to test to destruction full size bolted, riveted and welded plate girders.

The available 24,000 in-lb. and the previously constructed 750,000 in-lb. torsion testing machines[3] in the laboratory were not capable of meeting the requirements of capacity or specimen dimensions, and the construction of a torsion testing machine of larger capacity became a requisite. Ten different alternative designs were studied, and the present one was adopted as being most economical and convenient. The present machine was completed on December 15, 1948, through the financial assistance of the Institute of Research of Lehigh University, Pennsylvania Department of Highways, in cooperation with the Public Roads Administration, and Research Corporation, principal sponsor of the program.

The authors also acknowledge the generous donations made by the John A. Roebling's Sons Co., Trenton, N. J., and the Aluminum Company of America, Pittsburgh, Pa., in the forms of the flat wire rope and aluminum tubes, respectively, used in the construction of the machine. The Lehigh Structural Steel Company has contributed the initial series of test specimens.

The Requirements of the Machine

In developing the design the following requirements were set up:

Capacity.—2,000,000 in-lb. Reasonably large box girders and full size plate girders may be tested with a machine of this capacity.

Maximum Size of Specimens.—The machine was to be capable of accommodating specimens up to 16 ft. in length and at least 4 ft. in diameter.

Angle of Twist.—Any angle desired.

Speed.—Assuming that a 45-deg. twist will cause failure and that the minimum time required to reach this condition be ½ hr., the rotating head was to have a maximum speed of

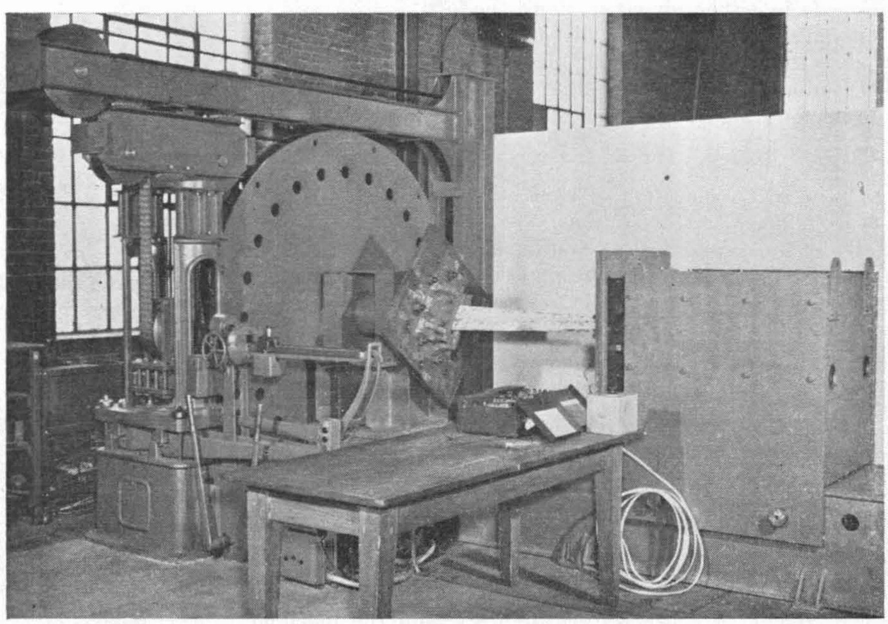


Fig. 2.—Close-up View of the Machine.

NOTE.—DISCUSSION OF THIS PAPER IS INVITED, either for publication or for the attention of the author. Address all communications to A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa.

[1] Research Fellows at Lehigh University, Bethlehem, Pa.

[2] Director, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.

[3] Bruce G. Johnston, "Torsion Testing Machine of 750,000 in-lb. Capacity," *Engineering News Record*, Vol. 114, No. 9, p. 310, February 28, 1935.

Authorized Reprint from the Copyrighted ASTM BULLETIN No. 160, September, 1949

approximately $\frac{1}{240}$ rpm. In order to reach this condition in a longer period of time or to apply a small increment of load in an appreciable period of time, several slower speeds down to at least $\frac{1}{5000}$ rpm. were to be provided.

Accuracy in Measuring the Applied Load.—The probable error of measurement was to be less than 0.5 per cent of the applied torque at any load within the range of any particular test.

Shortening Arrangement.—The grips should permit the specimen to shorten without developing appreciable longitudinal stresses during twist.

Design of the Machine

The machine, illustrated in Figs. 1 and 2, is approximately 9 ft. high and 24 ft. long. Its gross weight is 15 tons. The centerline of the machine is 46 in. above the floor level. Details of the various components are as follows:

Method of Gripping:

In Figs. 3 and 4, the specimen, *G*, is held at both ends by the fixture plates, *F*, which in turn are bolted to the rotating face plate, *D*, and the stationary face plate, *H*. Two rings of holes are drilled in the fixture plates and the face plates in the same pattern. The use of eight bolts in either ring will develop 2,000,000 in-lb. torque. Angles and lugs are welded to the fixture plates to apply the torque and to hold the specimen, care being taken to permit longitudinal movement and provide thereby a free-end condition. To accept various lengths of specimens, the trolley, *K*, may travel along the total length of the base beam, *M*, and be locked by two 3-in. diameter pins to the base beam in positions varying by one-foot steps. The intermediate length adjustments may be made by rolling the stationary head, *I*, in either direction along the four rails, *L*, fastened rigidly to the trolley, this same device providing free longitudinal shortening of the entire specimen during test.

Method of Applying Torque:

During the application of twist, the fixture plate, *F*, at the stationary head end remains practically stationary, while the fixture plate at the opposite end rotates as it transmits the torsional moment from the main wheel, *B*. Torque is applied to the 88-in. diameter main wheel by using an old 50,000-lb. Riehle machine already available at the laboratory, supplemented by a belt and pulley arrangement as shown in Fig. 4. The arrangement induces no bending in the Riehle machine and also enables one to weigh the force applied on the rope, *A*, by means of the testing machine scale.

When the traveling head, *S*, moves down, the main wheel is turned in a clockwise direction. The stroke of the traveling head is 24 in., which will rotate the main wheel through an arc of 30 deg. In case the required angle of twist is greater than 30 deg., the wheel can be locked to the end of the base-beam by inserting 3 pins in the holes of the inner ring of the main wheel which are spaced 15 deg. apart. The holes in the outer ring, spaced 30 deg. apart, are used to fasten both ends of the rope to the main wheel.

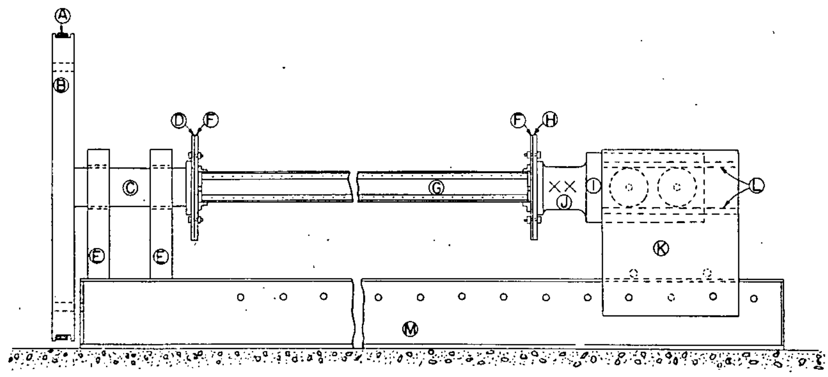


Fig. 3.—Front View Schematic Diagram of the 2,000,000 in-lb. Torsion Testing Machine.

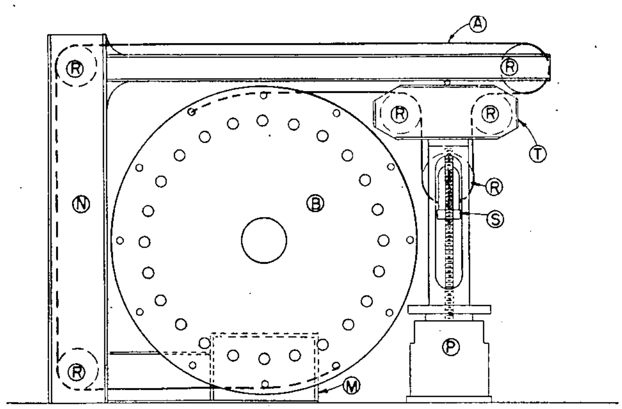


Fig. 4.—End View Schematic Diagram of the 2,000,000 in-lb. Torsion Machine.

By moving the traveling head to its uppermost position, the two rope sockets can be moved one hole, respectively, in a counterclockwise direction, thus taking up on the rope. The three pins can then be pulled out and another stroke of the testing machine head applied. By repeating this process, any desired angle of twist may be obtained.

In addition to the two different speeds on the machine, it is also possible to operate it by a hand wheel for very small increments of load.

The various possible speeds of the torsion machine corresponding to the twists of the specimens meet the requirement set up before.

Method of Measuring the Applied Torque:

The applied torque can be calculated approximately from the given diameter of the main wheel and the tensile load in the flat rope. The force in the flat rope is equal to one-half of the load recorded on the Riehle machine scale. Due to the friction created at the pulley bearings and the bending of the rope, the applied torque is not measured directly by this method.

To measure the applied torque directly, an aluminum alloy torquemeter tube mounted with SR-4 gages, Fig. 5, is inserted at the stationary head end. The gages on the torquemeter are

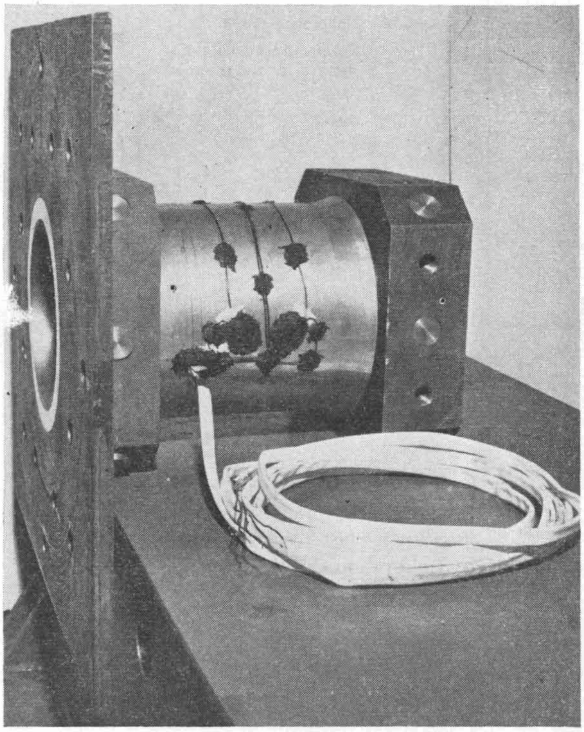


Fig. 5.—The Torquemeter.

arranged in such a way that gages *a* and *b* are subject to tension and gages *c* and *d* to compression during the twist, and are connected to the type *K* indicator in such a manner that the bridge output is doubled, Fig. 6.

Another advantage in using this type of connection is that strains in the torquemeter, due either to bending or vertical shear, caused by the dead weight of the specimen, do not record on the indicator. All four gages are located along the mid-depth of the tube where the average strain in each gage due to bending equals zero. The shear stress due to vertical load produces strain in gages *a* and *b* equal in magnitude and opposite in sign; therefore, being connected in series, they cancel out automatically. The same applies to gages *c* and *d*. The torquemeter also compensates strains due to temperature. Therefore, only the strain due to torque on the tube will be recorded on the indicator. The increment in the torquemeter strain readings should be directly proportional to the torque applied, if the torquemeter is stressed below its proportional limit, and the relation can be found by the method of calibration as described later. Three torquemeters of different range are used.

	Load Range Within Which the Probable Error of Load is Less Than 0.5 per cent
Torquemeter A (0 to2,000,000 in-lb.	100,000 to 2,000,000 in-lb.
Torquemeter B (0 to 500,000 in-lb.	40,000 to 500,000 in-lb.
Torquemeter C (0 to 100,000 in-lb.	10,000 to 100,000 in-lb.

Shortening Arrangement:

Specimens usually will shorten when torque is applied, especially in the plastic range, and longitudinal stresses will be set up if both ends of the specimen are held firmly in a longitudinal direction. In order to avoid such restraint, the stationary head rests on four rollers mounted on self-aligning roller bearings. Free movement is thereby permitted along the four rails fastened rigidly to the trolley, Figs. 3 and 7. The amount of shortening is measured by the Ames dials attached to the trolley. This arrangement also provides means for fractional adjustment for different specimen lengths as described before. High bearing stresses will be developed between the rails and the rollers; therefore special alloy steel is used.

Self-Equilibrium Under Twist:

The machine reaches self-equilibrium under the load. The total torque is transmitted by the base beam, Fig. 3, which is a 20- by 30-in. box beam 24 ft. in length, and built up of four $\frac{5}{8}$-in. plates welded at the four corners with stiffeners at 2-ft. intervals. When the specimen is under twist, a clockwise torque is applied to the base beam through the stationary head and the trolley. This is balanced by the counterclockwise torque applied at the end of the base beam, through the pulley frame, *N*, by the force in the flat wire rope, as shown in Fig. 4. When the wheel is locked to the end of the base beam and no tension is introduced in the rope during take-up, the latter torque is supplied by the reaction of the pins and the horizontal reaction on the main shaft, *C* (Fig. 3). No foundation is necessary. However, regularly spaced bolts are used to keep the machine in place and provide some additional rigidity from the floor.

Operation of the Machine

The operation of the machine is very simple, as follows:

First, the main wheel is locked to the end of the base beam by means of the three pins. The traveling head of the Riehle machine is moved to its topmost position. After choosing the proper position for the rope socket, in order to make the rope tight, the properly prepared fixture plates are bolted on and the specimen is set in position. The three pins locking the main wheel to the end of the base beam must be removed before the load can be applied.

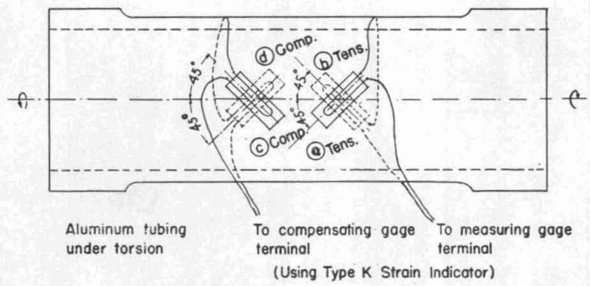


Fig. 6.—Location of SR-4 Gages on the Torquemeters.

The applied torque may be measured approximately by the Riehle machine and accurately from the torquemeter readings, as stated previously. It is essential that the proper range torquemeters be selected for each specimen.

Proof-Test and Calibration

The machine has been proof tested to its maximum capacity, 2,000,000 in-lb. by bolting the face plate of the rotating head directly to the face plate of the stationary head and then applying the load. No appreciable permament set was developed in any part of the machine.

The torquemeters were calibrated independently by the use of dead weight and a cantilever arm.

The relation between the increments in the torquemeter strain readings and the applied torque obtained by using the method of calibration checks very closely with the result using the tensile load in the rope multiplied by the distance between rope centers to obtain the applied torque. Both these results also check closely with theoretical relations based on the dimensions of the torquemeters and the known elastic constants of the material given in the *ALCOA* handbook. However, the calibrated value is used. The calibration curve of the torquemeter *B* is shown in Fig. 8 for illustration.

Initial Research Projects

A study of the shearing stress distribution, torsional stiffness, and useful

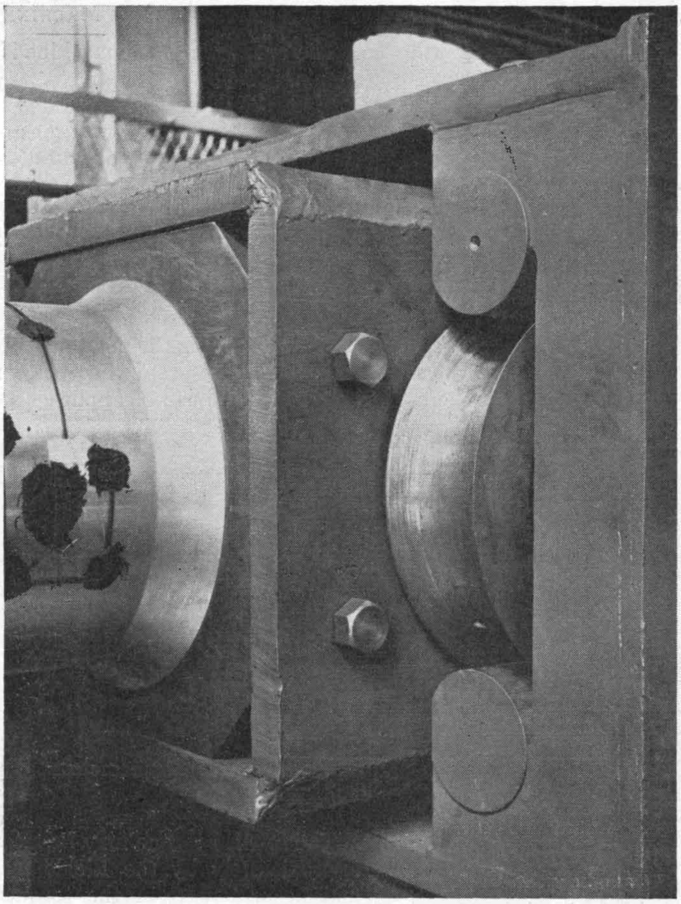


Fig. 7.—Stationary Head on Rollers.

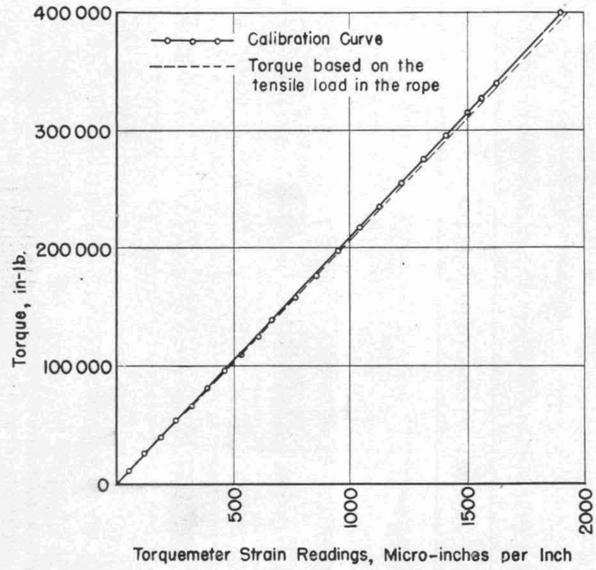


Fig. 8.—Calibration Curve of Torquemeter *B*.

and ultimate torsion capacity of riveted and welded plate girders under uniform torsion is now in progress, under sponsorship of Research Corporation of New York City and the Pennsylvania Department of Highways.

Formulas will be developed for calculating the pitch of rivets or bolts, or the sizes of welds, for the riveted, bolted, or welded plate girders, respectively, in order to approach the solid-section behavior under torsion. When the pitch of the rivets or bolts or the sizes of welds are given or determined by conventional methods, it should be possible to predict the torsional stiffness of the plate girders.

In the initial program, tests will be made of 15 full-size specimens. The specimens consist of three built-up plate specimens, along with five bolted, five riveted, and two welded plate girders, with a variable number of cover plates, variable rivet pitch, with or without stiffeners, variable tension in bolts for the bolted type, and a variety of girder sizes up to 4 ft. deep and 16 ft. long.

The investigation also includes a study of stress concentrations and over-all effects of transverse holes on built-up structural members under torsion.

Later investigations will include tests on riveted and bolted box sections.