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Welded plate girders proposal for a research program, June 20, 1955

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W E L D E D   P L A T E   G I R D E R S

Proposal for a research program on welded
plate girders, prepared for
Welding Research Council
June 20, 1955

I. I N T R O D U C T I O N

Welded plate girders have been designed and built for some decades. Although most of these bridges performed quite satisfactorily, failures also have been reported. Many problems related to welded plate girders have never been solved and it is considered that there is a need for further research.

Fritz Engineering Laboratory now offers facilities for large size static tests and dynamic tests on larger scales than have ever before been possible in this country. Large size static tests can be performed in a 5 million lbs. tension-compression-bending testing machine. For large scale dynamic tests a universal test bed is available with hydraulic jacks of a total capacity of 220,000 lbs. at 250 or 500 cycles per minute.

Before starting any actual testing program a preliminary study should be made to avoid duplication of any tests that already have been carried out and to investigate predictions of available theories. It might be advantageous to perform some tests concerning structural details next. These would furnish additional information for the design of a welded plate girder to be tested statically.

Thus, the research program outlined in this report suggests two phases:

Phase 1: Preliminary Study

A complete literature survey, statement of problems, and preliminary theoretical studies resulting in a detailed outline of the tests of Phase 2 and design of specimens.

Duration: 9 months

Phase 2: Static Tests on Large Scale, Thin Web, Welded Plate Girders

On the basis of the preliminary study (phase 1) a pair of plate girders will be designed and tested incorporating as many variables as possible in the one test assembly. The girders will be tested together, connected by cross and lateral bracing to prevent lateral buckling. In this way the behavior under static loading of splices, web to flange connections, stiffeners (horizontal and vertical, one- and two-sided) can be investigated and whenever possible compared with theoretical predictions.

Duration: 15 months

In this statement, major emphasis is given to the preliminary study and the large size static tests. In the next two sections these two phases will be discussed in more detail.

For the sake of completeness, the possibilities of large-scale fatigue tests are discussed in the Appendix to this statement. Aside from their value toward answering questions concerning the fatigue performance of such structures, results would be valuable in the design of details for the static tests.

II. PRELIMINARY STUDY (PHASE 1)

A literature survey undoubtedly will supply valuable information on problems encountered with the design and construction of welded plate girders. Quite a number of highway and even railroad bridges have already been constructed using welded plate girders. However, failures occurred in some of them as in the bridge across the "Hardenbergstrasse" in Berlin, built in 1935 and, after severe cracks were observed, replaced by a riveted structure in 1938(1). Another example is the "Three Rivers Bridge" in Canada(2). The structures failed in a brittle manner but it should be pointed out that there are two reasons for this type of failure which are basically completely different:

1. Brittleness of the material due to welding (Depends on the chemical composition of the steel).

2. Occurrence of three dimentional states of tensile stress (Details and welding procedure such that three dimensional states of stress are induced).

With the new ASTM specification A373-54T for structural steel for welding most of the concern about the first cause of brittle fracture is eliminated. Proper detailing and welding procedures are of vital importance to avoid brittle fracture due to the second cause (three-dimensional states of stress).

The "Tannvald" bridge(3) of the Swiss Railroads is a very good example of such proper detailing. Great care has been given to avoid fatigue failure. The bridge contains two three-span continuous girders with three equal spans of 118 ft. A cross-section of the girders and a shop splice is shown in Fig. 1. Except for the field splices the girders are welded.

The clear depth to thickness ratio of the web (d/w) is 222 and the web has been reinforced by a one-sided longitudinal stiffener.

When webs are welded against relatively thin flanges, the latter are known to deform as shown in Fig. 2a. However, thick flanges will deform and stresses are induced (Fig. 2b). Also in the longitudinal direction, large residual stresses may occur at the junction of web and flange (Fig. 3). Thus all conditions for brittle fracture are satisfied. Moreover welding of a thick web against a relatively thick flange will present its problems because of the difference in the amount of heat required for flange and web. Connecting the web to the flange by means of an angle as shown in Fig. 1 may solve some of these problems. Fillet welds of web-flange connections should be designed to transmit the shear forces between flange and web.

Due to restraint provided by the joined material, transverse tensile stresses in tension flanges will occur when the ends of vertical stiffeners are welded against the flange (Fig. 4). Welding of partial-length cover plates to the flanges has a similar effect. Fatigue tests will show the effect of these restraints and indicate whether or not such details must be avoided in design.

A detailed discussion on three-dimensional stresses in welded plate girders as a cause for brittle fracture is given by Hartmann(4).

Stability problems become important with the application of thin webs and deep girders as in new "Cologne-Deutz" bridge(5). The central span of this three-span continuous structure is 605 ft. High tensile steel was used for the girders which were assembled by automatic welding. The depth of the main girders varies between 10 ft. at the center of the span and 25 ft. 6 in. at the supports. In order to prevent the 5/8-in.-thick web from buckling, vertical and horizontal stiffeners have been provided. Some panels contain as many as four horizontal stiffeners. It is interesting to compare the total web depth-to-thickness ratio of the web (d/w = 487) of this bridge with the 1953 AASHO specifications which allow d/w = 270 with one horizontal stiffener. The three-span continuous riveted plate girders of the Hackensack River Bridge(6) satisfy these conditions. The AREA and AASHO specifications limit the clear depth-to-thickness ratio of webs to 170 thus avoiding horizontal stiffeners. Only when the stresses of the extreme fibers of the section are reduced, are slightly larger d/w ratios allowed in the AREA specifications.

The stability problem of plates reinforced by stiffeners has been treated theoretically by Timoshenko(7), Bleich(8), Moisseiff and Lienhard(9), and others. Some experimental work on web buckling has been carried out by Massonnet(10) but he states that further research is needed with regard to the actual behavior of stiffeners. This should include one-sided stiffeners as these may be used from an aesthetical point of view. Furthermore, for buildings it may be possible to depend on post-buckling strength of webs (tension field girders).

Summarizing, the following problems should be considered in the preliminary study:

A. Structural Details (avoid three-dimensional states of stress)

1. web-flange connections (shear transfer and problems of welding)
2. flange splices

3. flanges reinforced by additional plates (partial-length cover plates)
4. web splices
5. stiffener-web connections
6. stiffener-flange connections.

B. Stability Problems

1. vertical stiffeners (one and two-sided)
2. horizontal stiffeners (one and two-sided)
3. post-buckling strength (tension-field girders)
4. lateral-torsional buckling

III. STATIC TESTS ON A PAIR OF LARGE-SIZE GIRDERS (PHASE 2)

As part of the preliminary study (Phase 1) a pair of large size, welded plate girders will be designed to be tested statically. In the design a considerable number of variables should be included regarding web thickness, splices, stiffening details, welding procedure, etc. Some structural details may perform very well when subjected to static loading but may be very poor with regard to fatigue. In addition to these, details especially designed for fatigue loading should be included.

When testing a single girder, special consideration must be given to lateral supports to avoid lateral buckling. A simpler test set-up is obtained by testing two girders connected by cross and lateral bracing to prevent lateral buckling as schematically shown in Fig. 5. At the same time this scheme offers possibilities of loading the main girders in a realistic manner.

Fig. 6 shows an example of a 90 ft. long, 8 ft. deep welded plate girder. Flanges are 12 x 4 in.^{2}. Testing a pair of these girders requires a machine capacity of about 2,500,000 lbs.; thus only one half of the available capacity will actually be needed.

Such girders offer excellent opportunities to incorporate different kinds of web-flange connections, field and shop splices, stiffening devices, etc. Also the web thickness may be varied along the girders. In the example of Fig. 6, a thickness of w = 1/2 in. would give a clear depth-to-thickness ratio of 176; with w = 3/8 in., d/w = 235; and with w = 1/4 in.: d/w = 350. Testing procedure would be such that when part of the structure failed, the test would be interrupted for repairs. On further loading, another part would fail requiring, again, restoration. This sequence would continue until the final maximum load would be reached. In this manner the behavior of many details can be investigated in a single test, a procedure commonly used by aeronautical structural laboratories.

Webs loaded in shear can be allowed to buckle while the load is then carried by diagonal tension in webs and compression of the vertical stiffeners.

Furthermore, the difference in behavior of one and two-sided stiffeners can be investigated (see Figs. 4 and 6).

Two kinds of tests are anticipated with a pair of girders:

1. <u>Tests Within the Elastic Range</u>: By measuring deflections of webs and stiffeners, critical loads can be determined (for instance by plotting δ/P vs. δ (δ = deflection; P = load) according to a method proposed by Southwell).

Comparing these results with theoretical predictions will clear up the actual behavior of thin webs and of different kinds of one and two-sided horizontal and vertical stiffeners.

2. Destruction Tests: Allowing parts of the structure to fail and then interrupting the test for repairs will furnish information corresponding to many destruction tests.

Typical cross-sections are shown in Figs. 6d and 6e. Two possible web and flange splices are shown in Figs. 6b and 6c. Two web-flange connections are shown in Figs. 6d and 6e together with possible stiffener-web connections. Stiffener-flange details are shown in Figs. 4 and 6e.

IV. E V A L U A T I O N

By a comparison between theoretical predictions and the results of the tests that have been discussed, it will be possible to determine whether or not improvements may be realized in the design of welded plate girders.

Where possible, specific design procedures will be recommended, based on the results of the study.

V. R E F E R E N C E S

1. "Berliner Stadtbahnbrücken über die Hardenbergstrasse", ("Berlin Bridge Across the Hardenbergstrasse"), by Schaper, Die Bautechnik 1938 p. 651, by Kommerell, Die Bautechnik 1939 p. 161, by Schaechterle, Die Bautechnik 1939 p. 49.

2. "The Three Rivers Bridge" Engineering Journal Vol. 31, No. 1, January 1949.

3. "Tannwaldbrücke über die Aare bei Olten" ("Tannwald Bridge Across the Aare Near Olten"), Der Bauingenieur, Vol. 25, No. 8, August 1950, pp. 309 - 310.

4. "Stahlbrücken", ("Steel Bridges"), by Friedrich Hartmann, Franz Deuticke, Vienna, 1951.

5. "The Cologne-Deutz Bridge", Der Bauingenieur, Vol. 24, No. 1, 1949 pp. 17-20; The Engineer, Vol. 189, March 17, 1950, p. 328.

6. "Hackensack and Passaic River Bridges", Engineering News Record, January 17, 1952, pp. 30 - 33.

7. "Theory of Elastic Stability", by S. Timoshenko, McGraw Hill, New York, 1936, pp. 371 - 384.

8. "Buckling Strength of Metal Structures", by Friedrich Bleich, McGraw Hill, New York, 1952, pp. 358 - 385.

9. "Theory of Elastic Stability Applied to Structural Design", by L. S. Moisseiff and F. Lienhard, Transactions ASCE Vol. 106, 1941, pp. 1052 - 1091.

10. "Recherches sur le dimensionnement et le raidissage rationnels de l'âme des poutres a âme pleine, en tenant compte du danger de voilement", ("Research on the Rational Dimensioning and Stiffening of Webs of Plate Girders, Taking Into Account the Dange of Buckling"), by Ch. Massonnet. Annales de l'Institut Technique du Batiment et des Travaux Publics No. 71, November, 1953, pp. 1063 - 1080.

VI. ESTIMATED COSTS

Phase 1: Exploratory Study of Nine Months

1. Full-time Research Assistant	$ 3,000
2. Part-time help (drawing, etc.)	800
3. Supervision	1,500
4. Clerical help	400
Total of salaries	$ 5,700
5. Overhead 33 1/3 % * of salaries and wages	1,900
6. Preparation of reports, drawings	350
7. Miscellaneous, Travel, Meetings	500
Total	$ 8,450

**Phase 2: Static Test on Pair of Full-Size Girders (15 months)

1. Salaries and Wages (including overhead), consumable materials, reports, and miscellaneous	$ 30,000
2. Pair of girders and cross-bracing	15,000
3. Supports and loading structure	5,000
Total	$ 50,000

Total Program (2 years) $ 58,450

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* The current overhead rate for Lehigh University has been established by negotiation with the Army Audit Agency, Philadelphia, at 68.96% of salaries and wages. The acceptance of a nominal rate of 33 1/3 % represents part of the University's contribution to this research program.

** Tentative statement subject to revision during Phase 1.

APPENDIX

Fatigue Tests Concerning Structural Details

From small-scale fatigue tests carried out at the University of Illinois a wealth of information is already available with regard to the strength of welds. However, information on the behavior of complete structural details could be obtained from large-scale tests at Lehigh. Web and flange splices (field and shop), web to flange connections, stiffening details should be tested, showing the effect of three-dimensional states of stress.

The following types of tests can now be performed:

1. Tension Tests: Using the 220,000 lbs. Amsler Testing Machine plates of 7 in.^{2} cross-sectional area can be tested with stresses alternating from 0 to 30,000 psi. This offers possibilities for dynamic investigation of flange splices, flanges reinforced by additional plates, the effect of web-stiffeners welded against the flanges. Some examples of possible tests are shown in Fig. 7.

2. Bending Tests:

   a. Third Point Loading: An example is given in Fig. 8 where the center part of a 17 ft. long, 18 in. deep section with flanges of 8 x 1 1/2 in.^{2} is subjected to pure bending. During the loading cycle the stress of the extreme fiber varies between the dead load stress σ_o and σ_o + 25,000 psi (live load stress σ = 25,000 psi). This test set-up will give the opportunity to investigate:

splices

stiffening details

load application in different manners, etc.

b. Center Point Loading: An example is given in Fig. 9. The girder is 33 in. deep, 22 ft. 6 in. long with flanges of 8 x 1 1/2 in.^{2}. Live load stresses at the center section are again 25,000 psi.

3. Shear Tests: can be performed using either third-point or center-point loading. The total shear force in the end sections of the girders is 110,000 lbs. Taking a variation of the shear stresses from 0 to 17,000 psi gives a web area of 6 1/2 in.^{2}. Thus webs with dimensions 3/8 x 17 in.^{2}, 1/4 x 26in.^{2}, etc. can be tested.

The above examples have been computed on the basis of large stress variations during each loading cycle, corresponding to high live-load stresses. Smaller live-load stresses naturally will result in larger test specimens.

The fatigue tests would require about 12 months and cost about \$ 30,000.00.

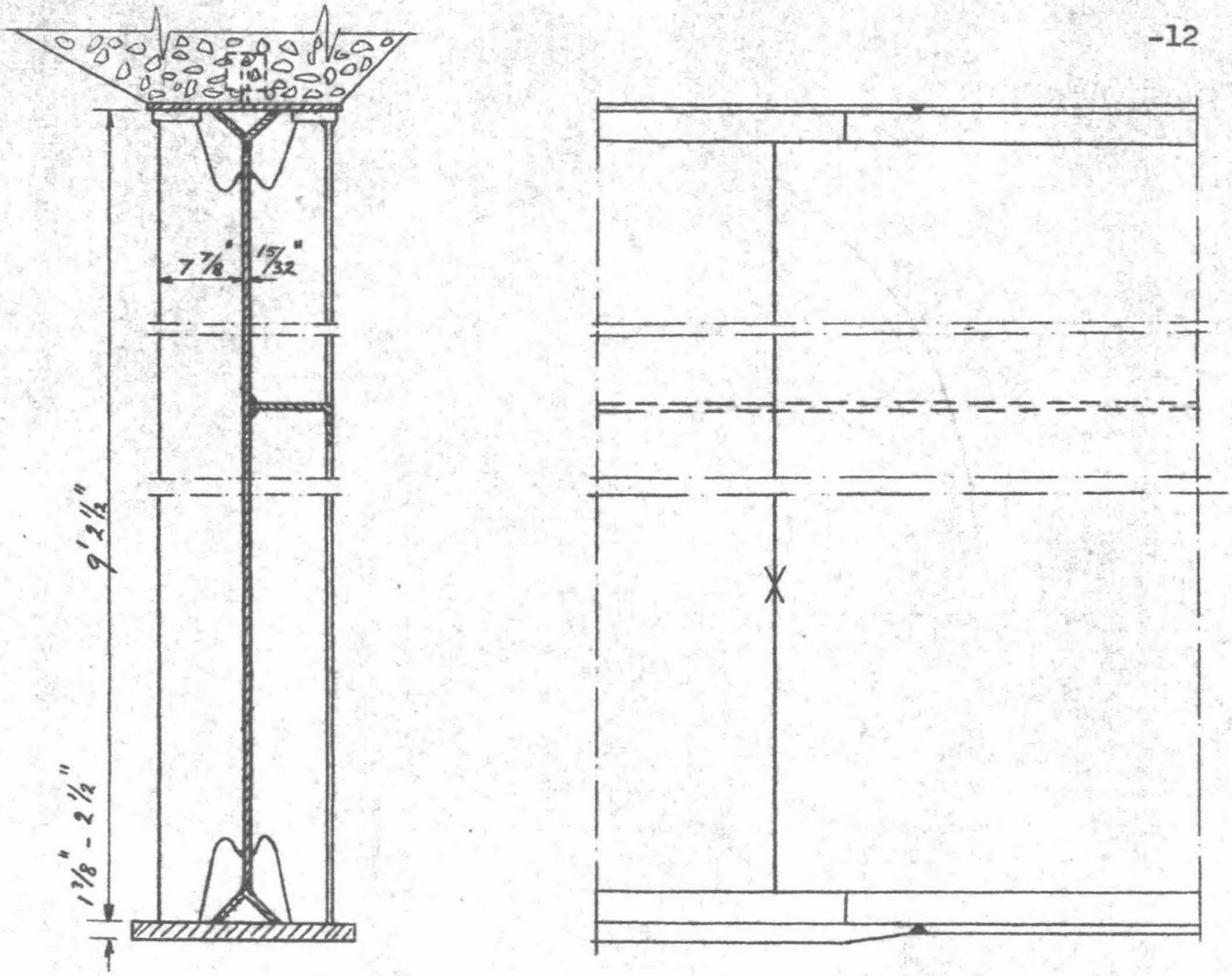

Fig. 1 Tannwald Bridge Details

Fig. 2 Web-Flange Connection
(Transverse Residual Stresses)

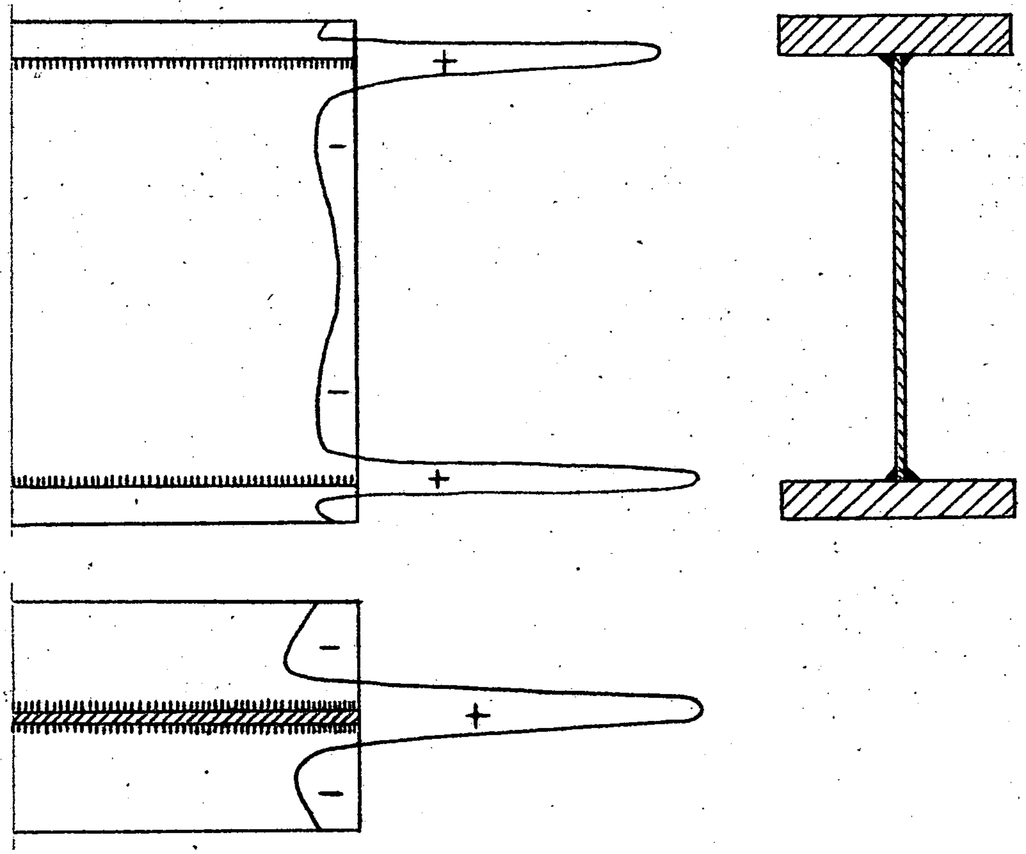

Fig. 3 Web-Flange Connection
(Longitudinal Residual Stresses)

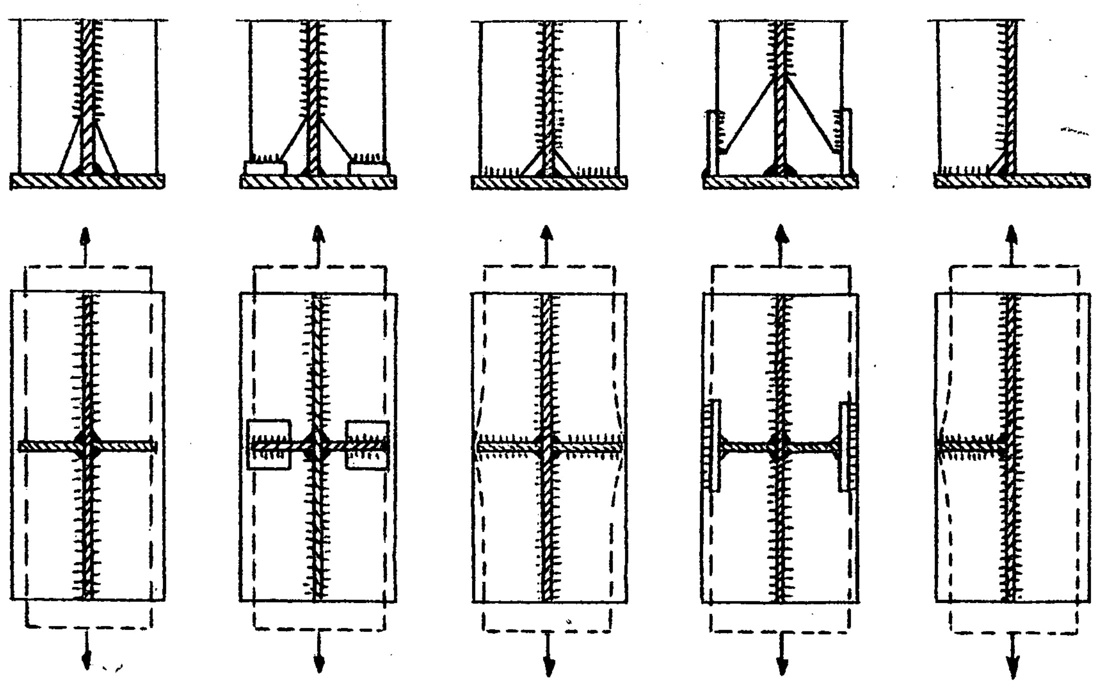

Fig. 4 Stiffener-Flange Connections

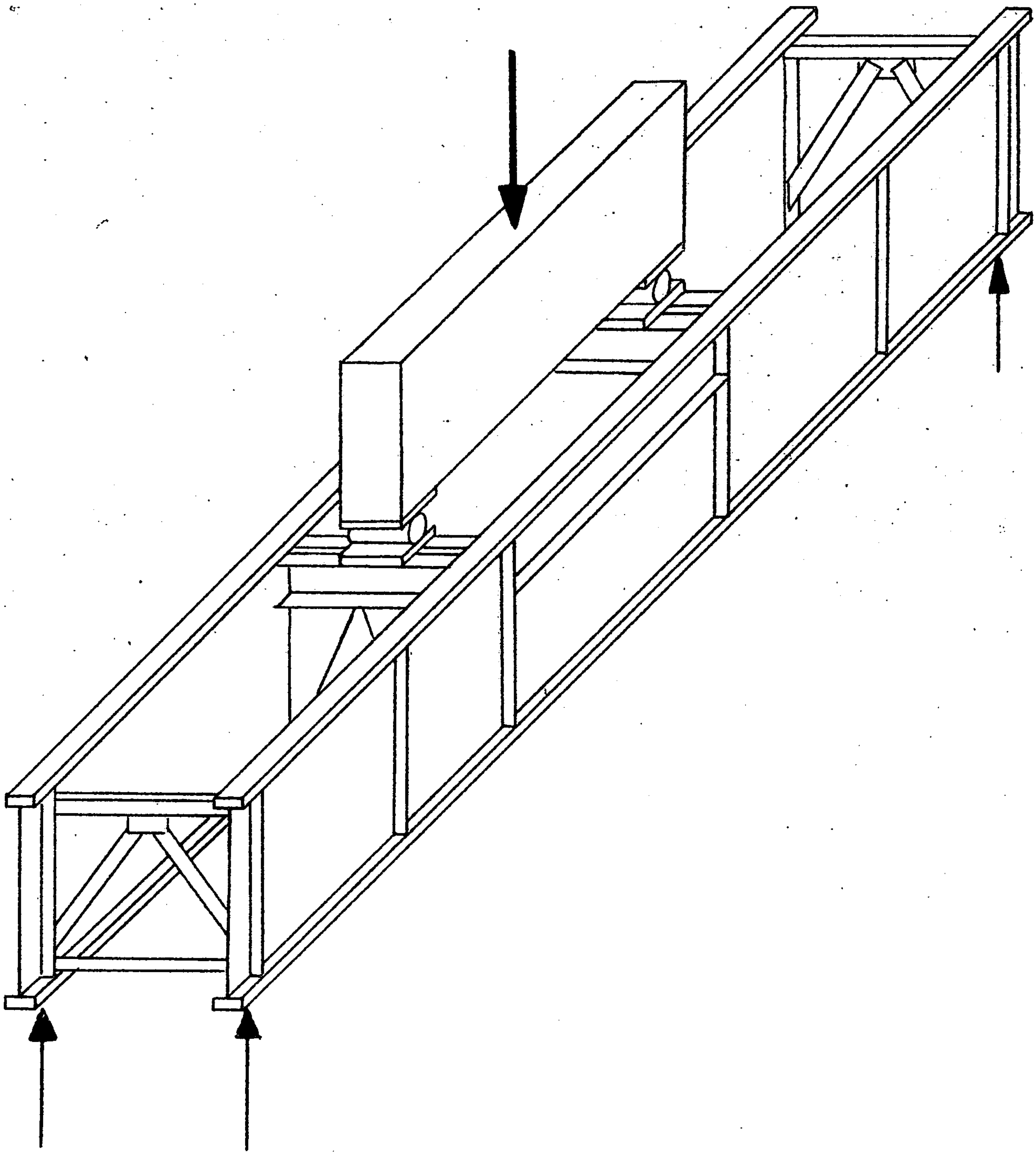

Fig. 5 Test Set-Up (Schematic)

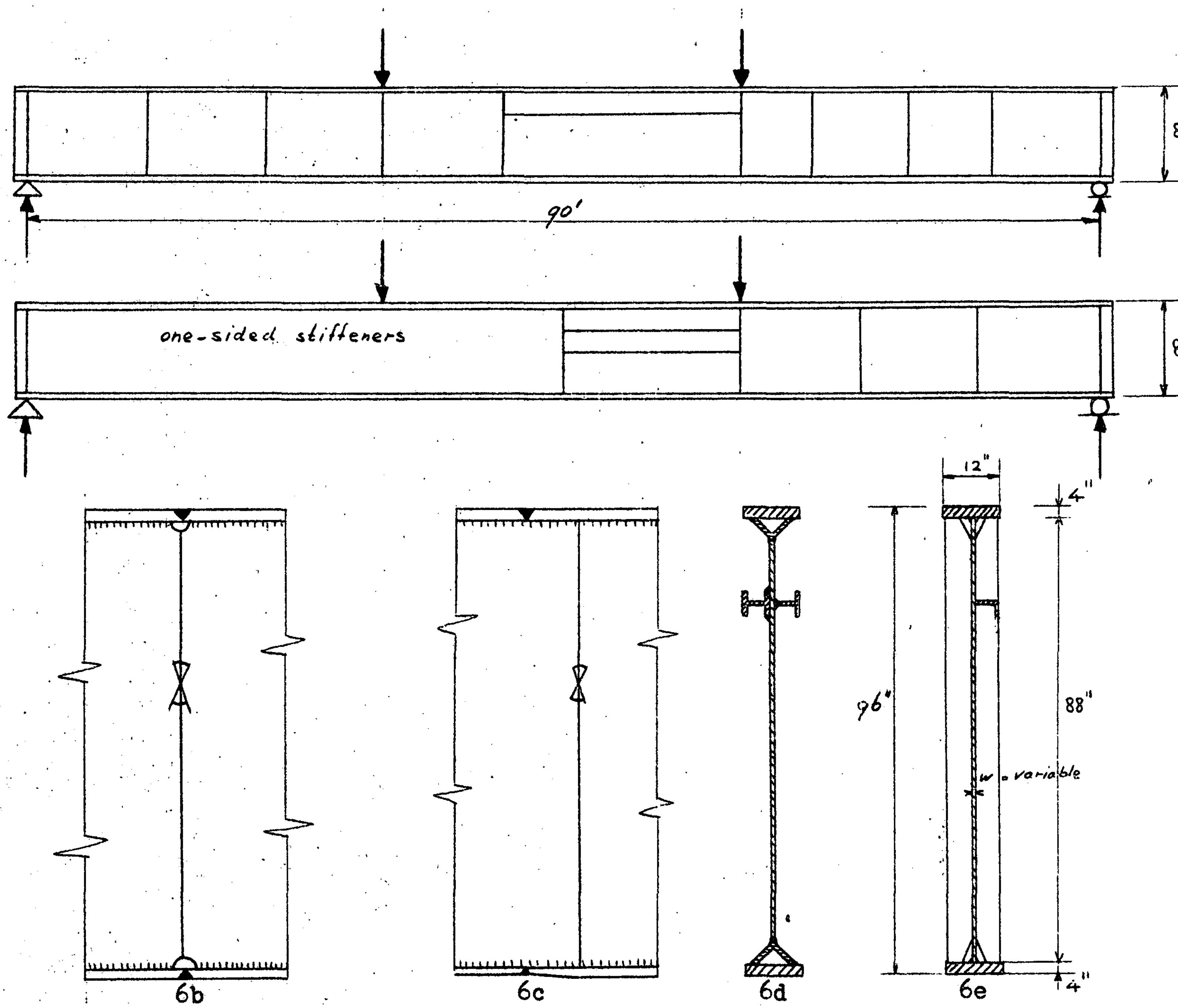

Fig. 6 Static Test

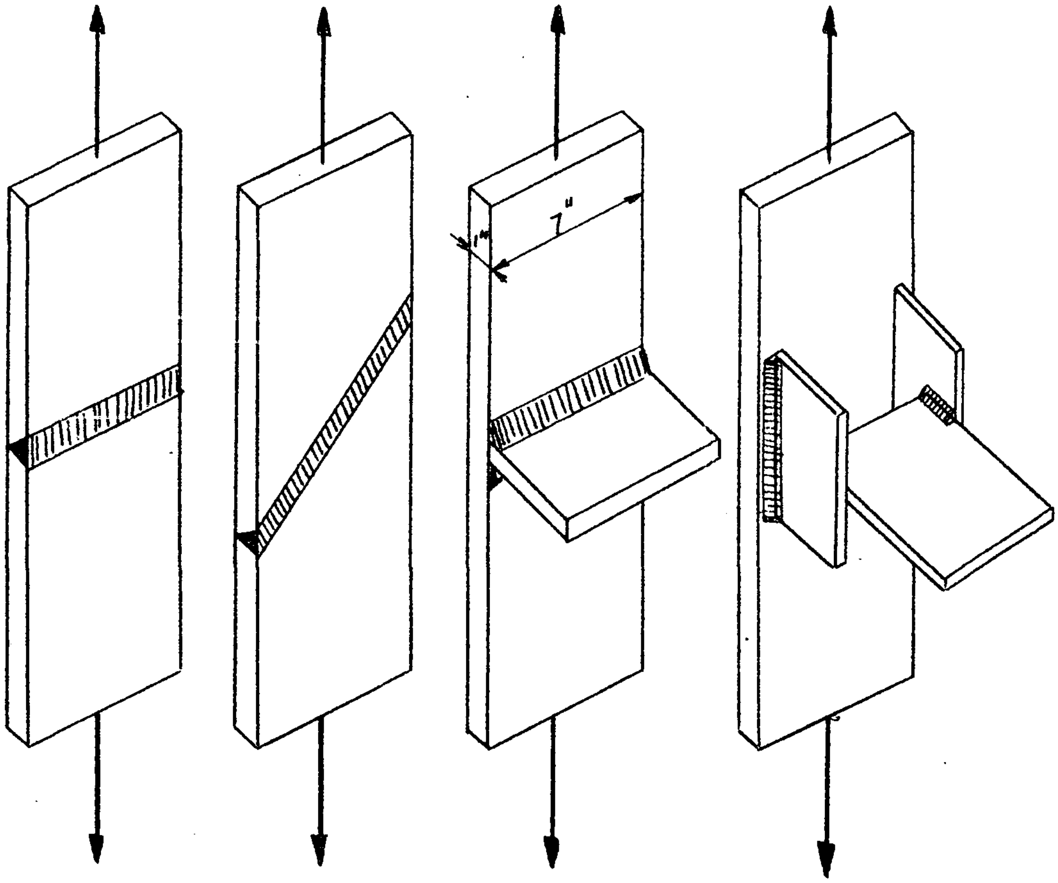

Fig. 7 Examples of Tension Tests

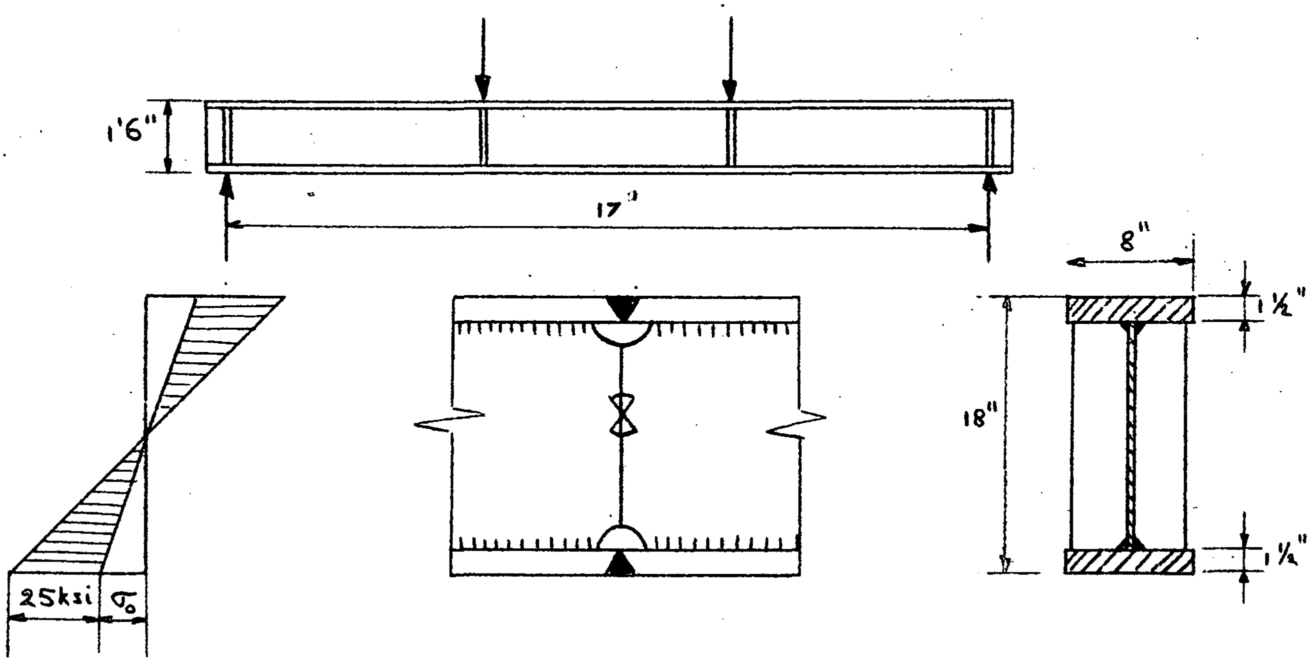

Fig. 8 Bending Test (Third-Point Loading)

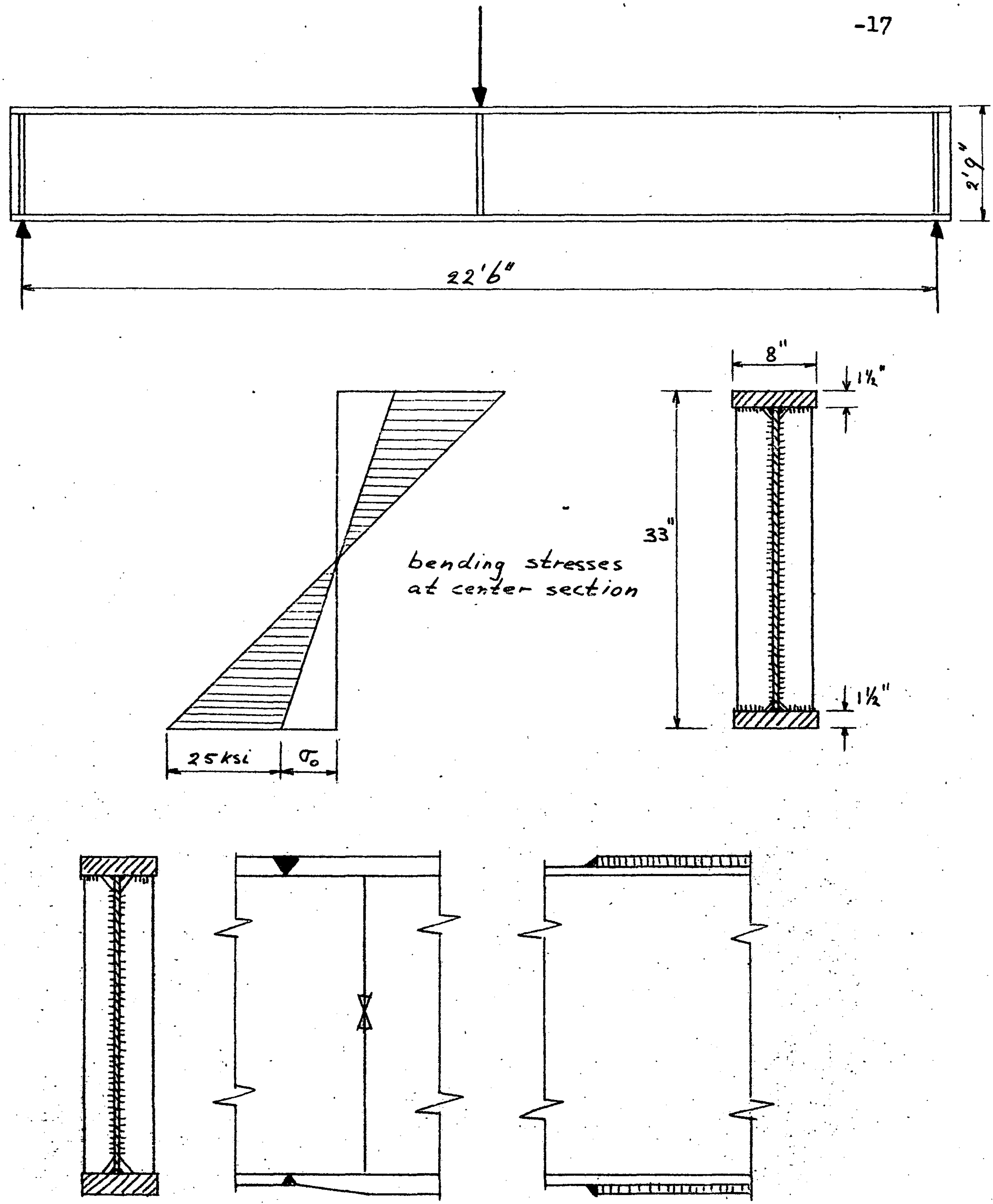

Fig. 9 Bending Test (Center-Point Loading)