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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COMBINED BEAM-COLUMN STRESSES OF ALUMINUM-ALLOY CHANNEL SECTIONS

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SUMMARY

The results of a research program to obtain design data on the strength of open-channel aluminum-alloy sections subjected to combined column and beam action.

The results of the tests of about 70 specimens were graphed for stresses due to axial load and stresses due to bending load as functions of length to radius of gyration of the specimens. From these graphs a design chart was derived that is suitable for ready use.

INTRODUCTION

The research program reported in this paper was carried out in the engineering laboratories of the University of Maryland. The tests were supervised by Dr. John E. Younger and the funds and specimens were supplied by the National Advisory Committee for Aeronautics.

SPECIMENS

The test specimens were extruded 24ST aluminum-alloy channel sections 2.1 inches wide and 0.1 inch thick with legs (or flanges) varying from approximately 0.5 inch to 2 inches in depth. (See fig. 1.)

The specimens were produced by the Aluminum Company of America according to the following specifications:

1. The material shall be the Aluminum Company of America's No. 24ST aluminum alloy and shall conform in all respects to Navy Aeronautical Specification 46A9 (INT) of

July 1, 1937, except that:

2. To the chemical composition in Paragraph E-1 shall be added "chromium (maximum 0.25%)."

3. The words "excess of 0.00%" in the note in Paragraph E-1 shall be changed to read "excess of 0.03%."

4. The material shall have the following minimum physical properties:

Tensile strength: 57,000 pounds per square inch.

Yield strength: 42,000 pounds per square inch.

Elongation: 12 percent.

APPARATUS AND TESTS

Construction of Testing Jig

In figure 2 is shown a schematic sketch of the beam-column testing jig designed and used for these tests. The apparatus was designed and constructed by the three authors.

The jig is designed for the testing of airplane structural sections; first, subjected to simple column action, second, to simple beam action, and third, to the combination of both types of actions.

The column load is applied by means of a hand-screw jack bolted to a back plate, which in turn is bolted to the flange of the I-beam. For adjustment of the back plate to various lengths of specimen, holes were drilled in the flange of the I-beam at regular intervals. The jack head is held torque free by the jack-head clamp so that no torque is transmitted to a single pivoted-end knife edge that engages a V-grooved steel end plate on the specimen. This end plate prevents damage to the specimen and holds the knife edge on its neutral axis. The load is then transmitted through the specimen to a second V-grooved end plate in contact with a double pivoted-end knife edge. This second knife edge is maintained level. The lever arm, which is held in suspension by the load from this knife edge, is pivoted about the knife edge of the lever-arm fulcrum.

V-grooves are cut into the lever arm for the two knife-edge contacts. The lever arm is designed with a 15:1 ratio to transmit the load to the platform scale, where it is weighed. The platform scale rests in two channel sections bolted to the I-beam. (See also fig. 3.)

Calibration of Machine

After the machine was constructed, a careful calibration of actual loading in terms of indicated loading was made.

The column load was checked by the use of an Amsler compression block (fig. 4) and found to have a ratio of 1 pound indicated load (on platform scale) to 15 pounds actual load.

The bending load was calibrated by placing a platform scale under the harness straps. A calibration curve was drawn and the resulting line showed that 1 pound on the pan placed 10 pounds of bending load on the beam.

Specimen Preparation

After the determination of the length of the specimen on the basis of ratio of length to radius of gyration, the ends of the specimen were milled on a horizontal milling machine. A special jig was set up to hold the specimen. A vertical milling attachment was placed horizontally on the horizontal milling machine, in such a way that by advancing the feed and raising and lowering the table, the ends of the specimens were accurately milled.

TESTING FOR COLUMN AND BENDING LOADS

1. The specimen was placed as a simple beam on the two adjustable supports with the flanges (or legs) down.

2. The adjustable supports were raised so that the neutral axis of the specimen was directly in line with the axis of the jack.

3. The adjustable supports were clamped to the main beam with large C-clamps, which eliminated the possibility of moving the supports.

4. The jack head was moved up to the proper position for the individual specimen and bolted to the beam.

5. The lever arm on the platform scales was held in place and the horizontal knife edge was placed between the lever arm and the end plate. The end plate was used to fit against the specimen so that local stresses would not occur due to pressure of the knife edge directly on the specimen.

6. The knife edge at the jack end of the beam was then placed between the jack and the other end plate.

7. The jack was then screwed up until a small column pressure was exerted. This small pressure held the lever arm from falling out of place.

8. The harness straps were then placed on the specimen at predetermined loading points.

9. The harness and the lever were then hung on the straps.

10. The lever fulcrum was then clamped under the beam so that the lever would be in its uppermost position.

11. The pan was attached to the end of the lever and the desired side load was produced by placing known weights in the pan.

The specimen was then ready for testing. The column load was supplied by the jack through the specimen and the lever arm to the platform scale where the impressed load was read. By a continual balancing of the scale beam, the column load was always known. At the maximum column load, the scale arm would drop and no further increase in load would cause it to rise. This point was considered as the ultimate strength point.

DISCUSSION OF RESULTS

It was assumed in these tests that the channels as structural members of aircraft would be constrained to bend only in the direction of the open side; that is, so that the legs (or flanges) are in tension. (See figs. 5, 6, 7, and 8.) As a simple column (without side loads) the channels will fail by local wrinkling (sidewise) of the unsupported flanges. A small side load that will put tension in the flanges will obviously greatly strengthen the channel as a column. For example, in a certain test, a specimen failed as a pure column at an axial load of only 3,600 pounds; whereas a similar specimen to which a side load of only 68 pounds was applied failed at an axial load of 5,000 pounds.

The tests in this series extended only to the specimens that failed in bending in the direction of the open side. (See fig. 5.) This failure, of course, left the column end of the curves without any points. If the specimens are constrained to fail as assumed, the curves will apparently continue in a smooth curve to the intersection of the pure column axis. If the specimens are not constrained, however, the curves will drop sharply near the pure column axis as noted in figures 9 to 12.

In the tests covered in this investigation, the specimens quite generally failed in tension of the flange portion of the channel. No cases of the flanges buckling over sidewise occurred. In some of the shorter specimens, the back portion of the channel wrinkled slightly into approximately a sine curve.

Although the sections A, B, C, D, and E are not similar, the similar type of failure (tension in the flanges) seems to warrant plotting all the points for each ratio of length to radius of gyration on the same curve. The points for each section, however, are differentiated by particular symbols and are also given in the table of results (table I) so the separate curves may be plotted. It seems practical, however, within the variation limits of the material, the tests, and the design, to include all sections in the same design curves.

Figures 9 to 12 show the test data plotted as a function of axial and bending loads for L/ρ ratios of 110, 90, 70, and 50, respectively. For each L/ρ ratio, an average curve (fig. 13) and what seems to be a safe design curve (fig. 14) was drawn. From the curves of figure 14 the design chart of figure 15 was constructed. This chart gives the combined stress allowable for any combination of axial stress and bending stress.

It will be noted that the abscissas in each of the graphs is the tensile stress due to bending f_{bt} and that the P/A stress (f_c) is added to the tensile stress f_{bt} to obtain the so-called "total stress" f_{tot}. The explanation of this usage is based on the fact that the section is unsymmetrical about the axis of bending. Because of this characteristic and the assumed direction of bending, the tensile stress is about twice the compressive stress in pure bending. As the axial load is added, the tensile stress is reduced by the amount f_c but is increased by the additional bending moment represented by the product of the axial load and the deflection.

Written in the form of an equation, the tensile stress f_t is as follows:

$$f_t = \frac{Mc_t}{I} + \frac{Pyc_t}{I} - \frac{P}{A}$$

in which c_t is the distance from the neutral axis to the outer fiber in tension.

M, bending moment.

P, axial load.

A, cross-sectional area.

y, deflection.

I, moment of inertia of the cross-sectional area.

Writing ρ^2, the radius of gyration squared for I/A, the formula may be written:

$$f_t = \frac{Mc_t}{I} + \frac{P}{A}\left(\frac{}{\rho^2} c_t\ y - 1\right) = f_{bt} + f_c\left(\frac{c_t y}{\rho^2} - 1\right)$$

The bending compressive stress f_{bc} is

$$f_c = \frac{Mc_c}{I} + \frac{P}{A}\left(\frac{1}{\rho^2} c_c\ y + 1\right) = f_{bc} + f_c\left(\frac{c_c y}{\rho^2} + 1\right)$$

where c_c is the distance from the neutral axis to the outer fiber in compression. The dissimilarity between the two equations is in c_t and -1 in the first and c_c and $+1$ in the second.

University of Maryland,
College Park, Md., July 17, 1939.

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1. Tuckerman, L. B., Petrenko, S. N., and Johnson, C. D.: Strength of Tubing under Combined Axial and Transverse Loading. T.N. No. 307, N.A.C.A., 1929.

2. Wagner, Herbert: Remarks on Airplane Struts and Girders under Compressive and Bending Stresses. Index Values. T.M. No. 500, N.A.C.A., 1929.

3. Younger, John E.: Structural Design of Metal Airplanes. Ch. X - Beams and Struts. McGraw Hill Book Co., Inc., 1935.

TABLE I

Experimental Data from Beam-Column Tests of Aluminum-Alloy Channel Sections

Section	L/ρ	Column stress (Compression) f_c (lb./sq.in.)	Bending stress (Compression) f_{bc} (lb./sq.in.)	Bending stress (Tension) f_{bt} (lb./sq.in.)
A	110	0	45,000	83,700
A	110	1,450	35,200	65,500
A	110	2,775	27,500	51.200
A	110	4,420	18,400	34,100
A	110	8,630	2,080	3,865
C	110	4,830	18,300	36,450
C	110	6,180	12,200	24,300
C	110	7,400	7,100	14,150
C	110	8,140	4,530	9,000
D	110	6,610	6,640	14,870
E	110	0	31,800	73,200
E	110	1,550	24,000	55,300
E	110	2,050	19,500	45,000
E	110	4,640	11,700	27,150
E	110	8,250	6,200	14,300
E	110	8,360	2,020	4,630
A	90	0	47,900	89,300
A	90	2,300	31,500	58,800
A	90	6,000	19,600	36,500
A	90	10,150	10,000	18,500
A	90	11,750	5,950	11,100
B	90	3,470	32,500	61,200
B	90	5,830	24,600	46,400
B	90	10,300	12,700	24,000
B	90	10,580	9,900	18,600
E	90	0	31,000	71,500
E	90	1,800	23,100	53,300
E	90	3,150	19,300	44,600
E	90	6,310	12,800	29,550
E	90	7,810	7,700	17,880
E	90	9,370	4,530	10,450
A	70	0	49,000	91,100
A	70	3,370	37,100	69,300
A	70	8,130	28,500	53,200
A	70	12,000	20,000	37,200
A	70	15,300	11,400	21,300
A	70	17,500	5,720	10,650

TABLE I (Cont.)

Experimental Data from Beam-Column Tests of Aluminum-Alloy Channel Sections

Section	L/ρ	Column stress (Compression) f_c (lb./sq.in.)	Bending stress (Compression) f_{bc} (lb./sq.in.)	Bending stress (Tension) f_{bt} (lb./sq.in.)
D	70	0	35,800	79,700
D	70	3,600	29,000	60,100
D	70	8,870	18,700	41,600
D	70	20,700	4,620	10,300
E	70	0	30,200	69,800
E	70	2,350	24,300	56,200
E	70	9,080	19,800	46,000
E	70	15,050	13,000	30,100
A	50	0	44,508	83,300
A	50	4,470	39,400	73,500
A	50	8,000	31,800	59,300
A	50	14,020	22,400	41,800
A	50	19,700	17,600	32,900
B	50	8,030	35,000	66,000
C	50	8,960	30,600	60,800
D	50	0	36,300	81,000
D	50	8,250	32,000	71,300
D	50	12,900	23,600	52,800
D	50	17,450	18,500	41,200
D	50	22,200	12,600	28,200
D	50	27,300	5,740	12,800

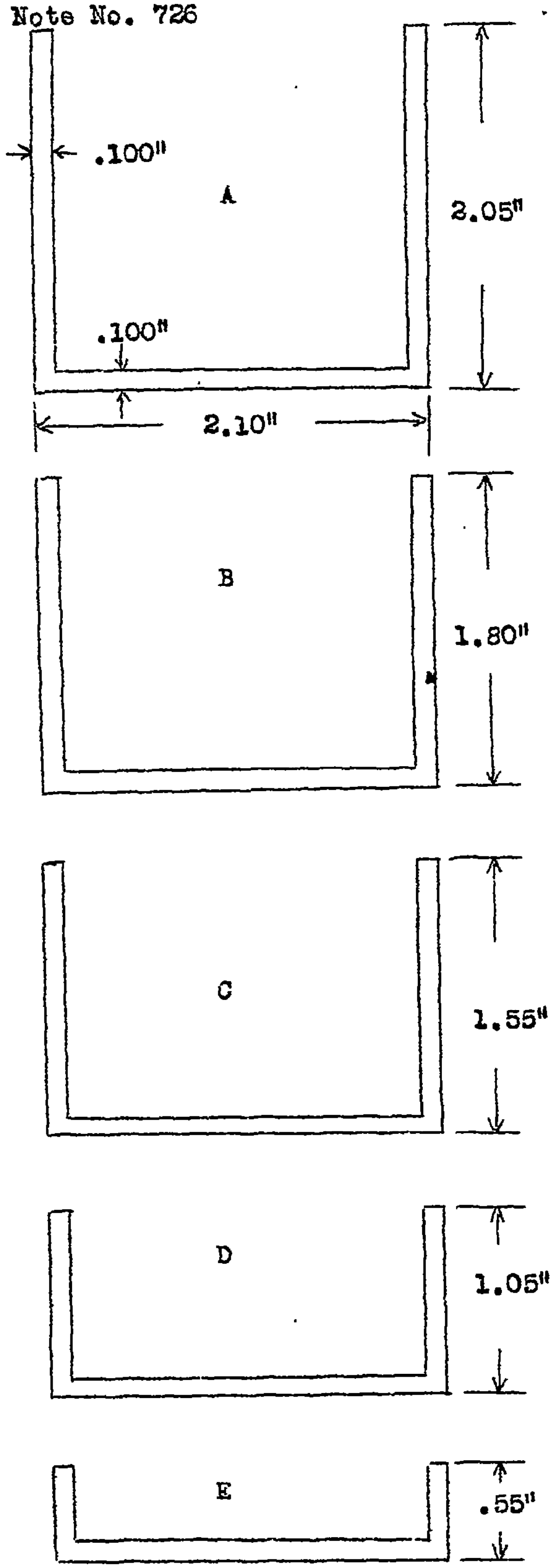

Figure 1.- Designation of sections.

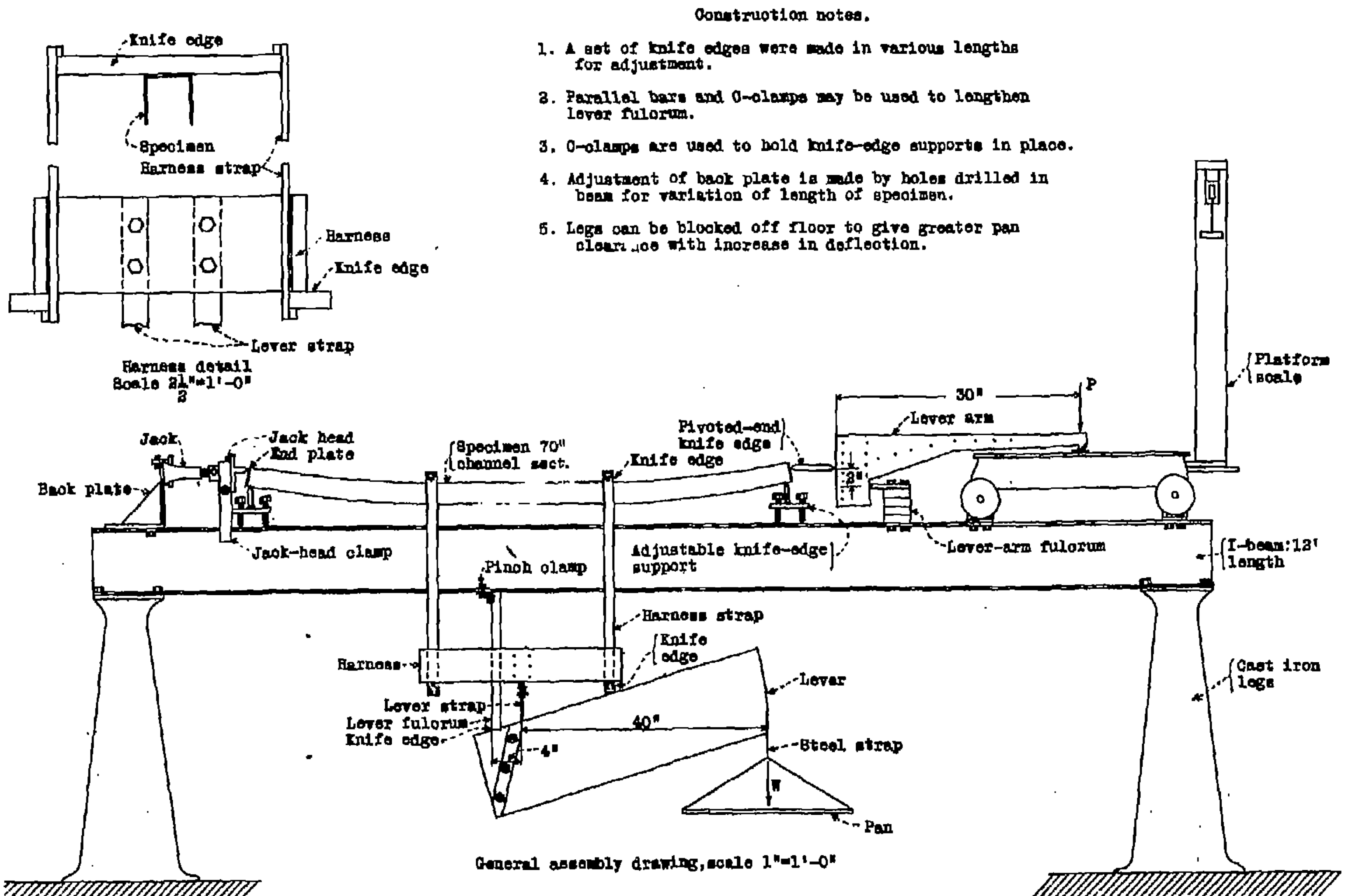

Figure 2.- Beam-column testing machine.

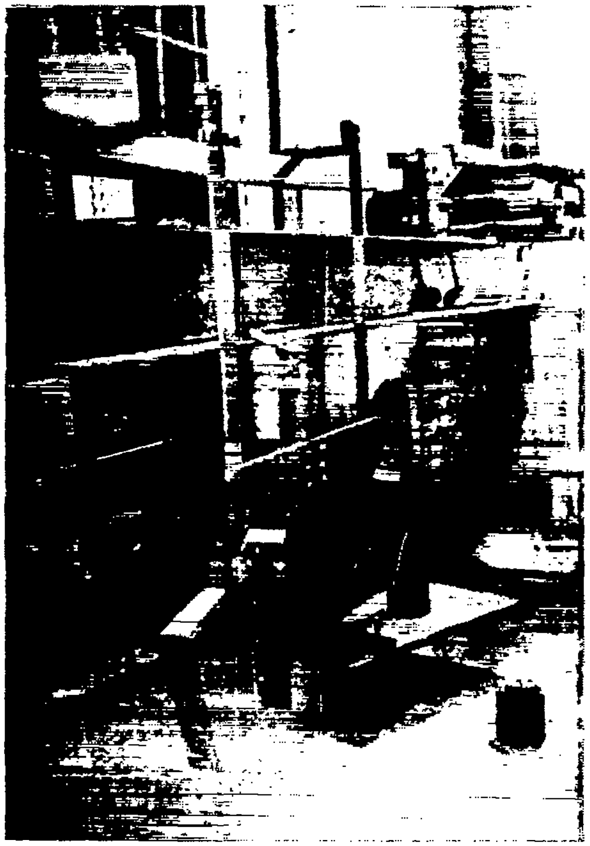

Figure 3.- General view of apparatus for applying side load, showing weights in pan, lever, harness, and harness straps.

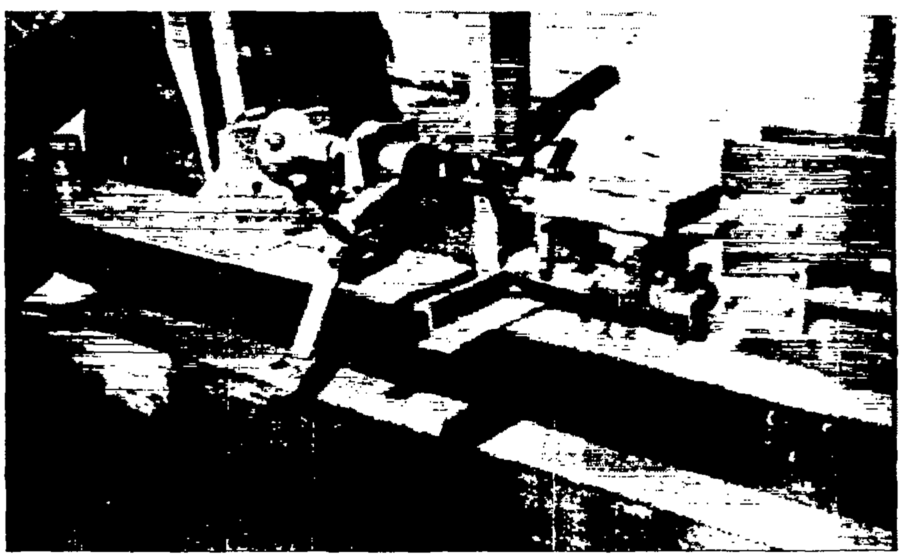

Figure 4.- Calibration of machine for compressive loads by use of Amsler block.

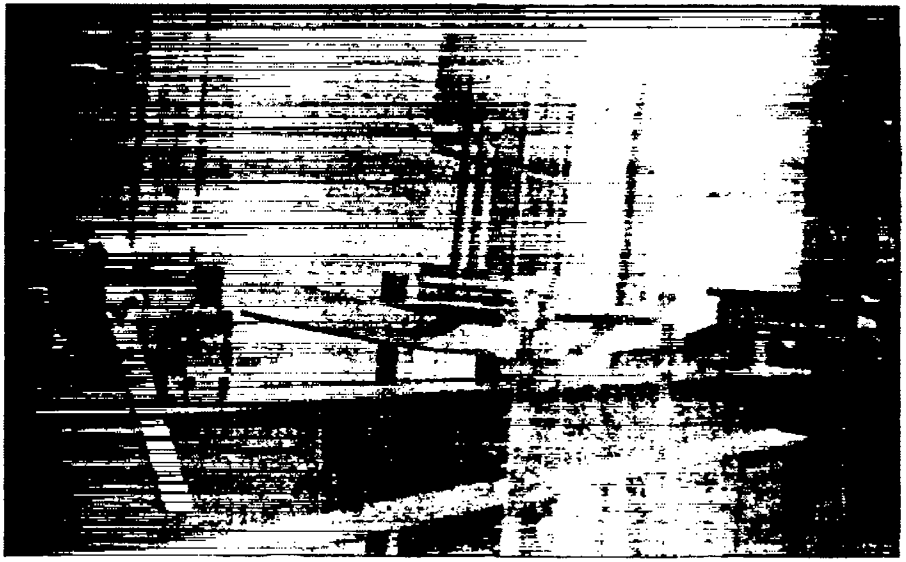

Figure 5.- Specimen bending under load applied through harness straps; no end load.

Figure 6.- View showing twisting and buckling of specimen during compression load alone.

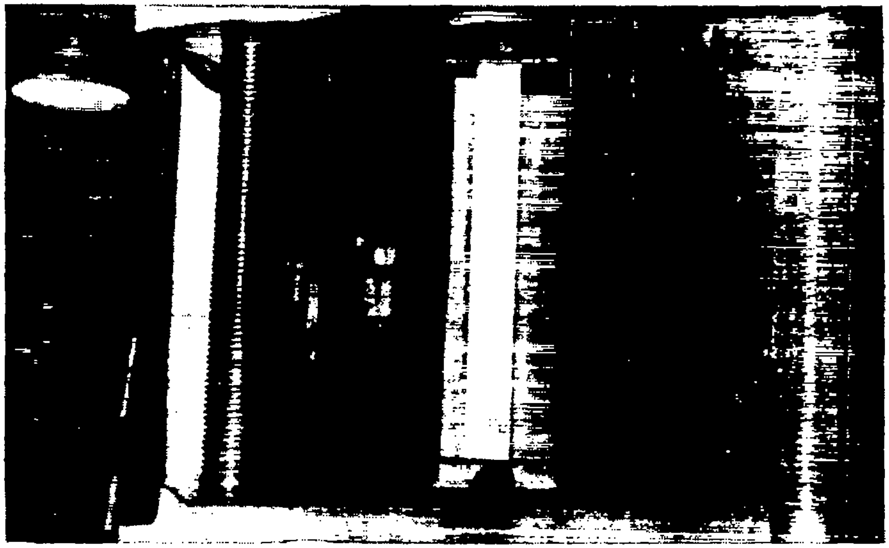

Figure 7.- Channel tested as pin-end column.

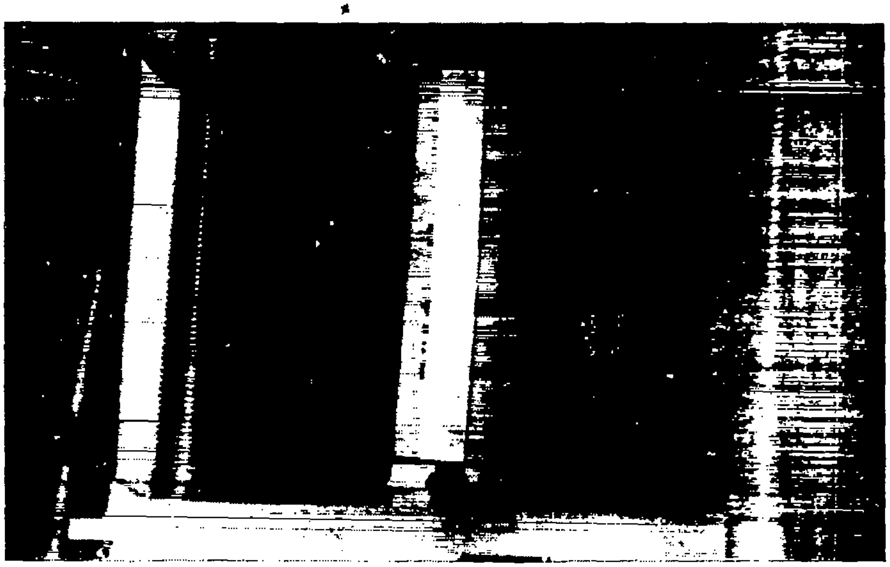

Figure 8.- A type of failure assumed impossible according to the structural characteristics on which the tests are based.

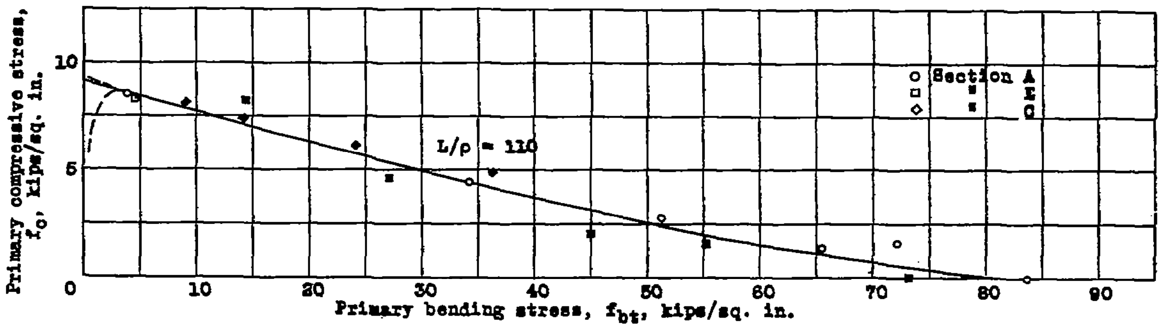

Figure 9.- Beam-column tests of open-channel sections. L/ρ = 110; 24ST aluminum alloy.

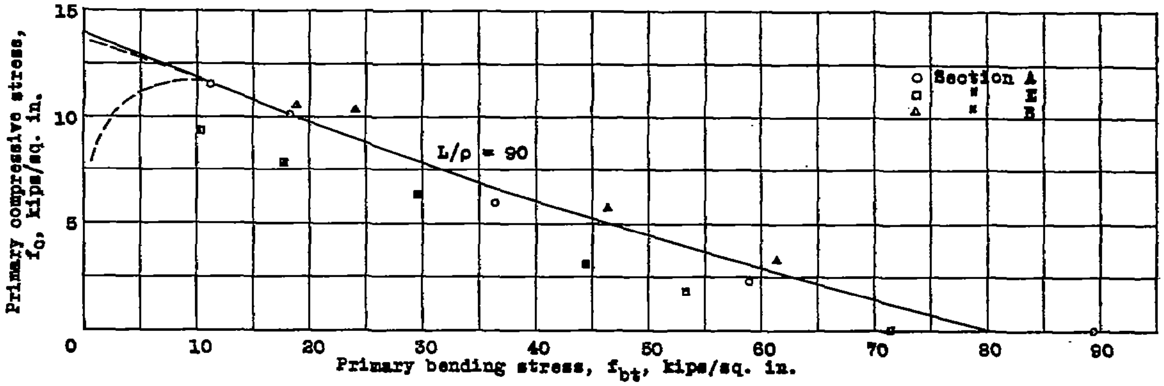

Figure 10.- Beam-column tests of open-channel sections. L/ρ = 90; 24ST aluminum alloy.

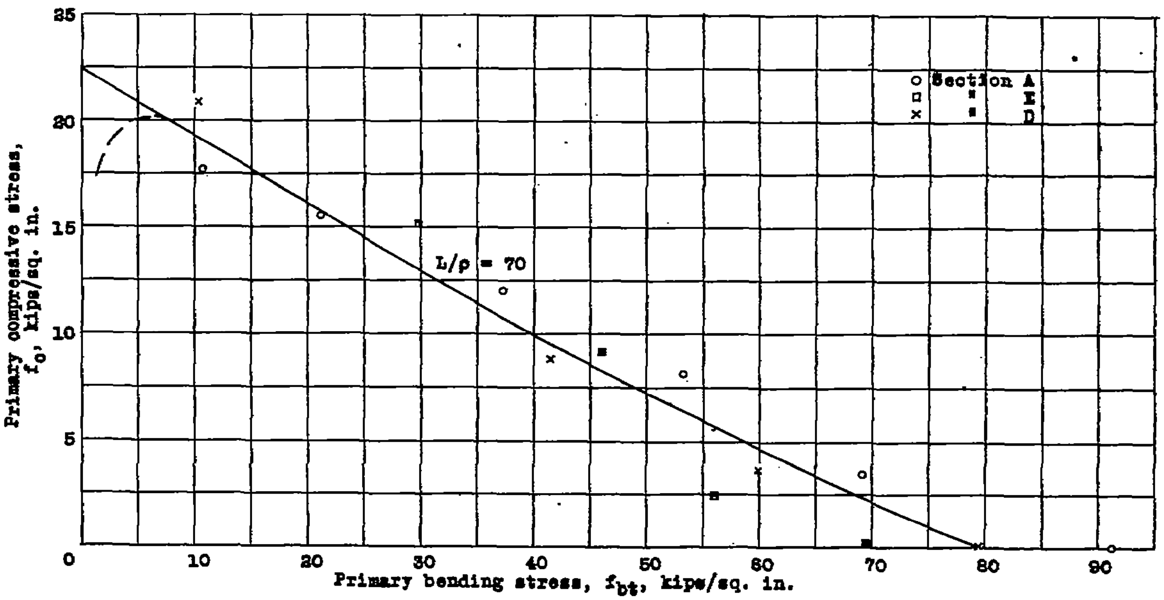

Figure 11.- Beam-column tests of open-channel sections. L/ρ = 70; 24ST aluminum alloy.

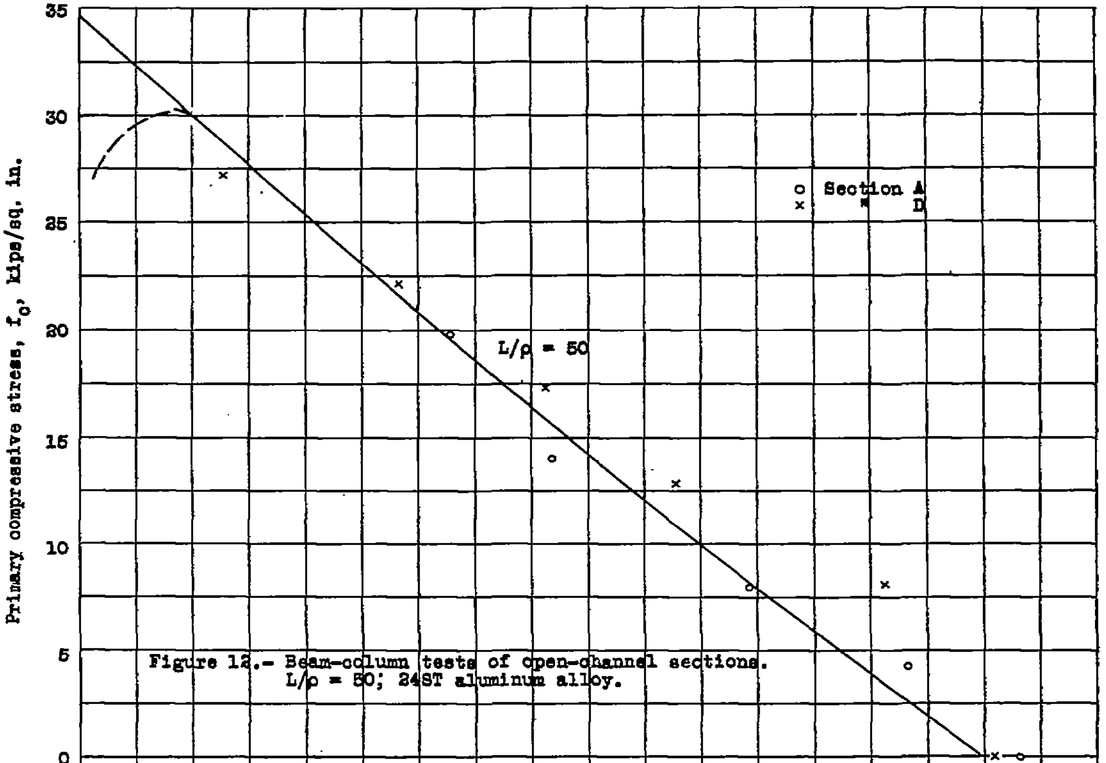

Figure 12.- Beam-column tests of open-channel sections. L/ρ = 50; 24ST aluminum alloy.

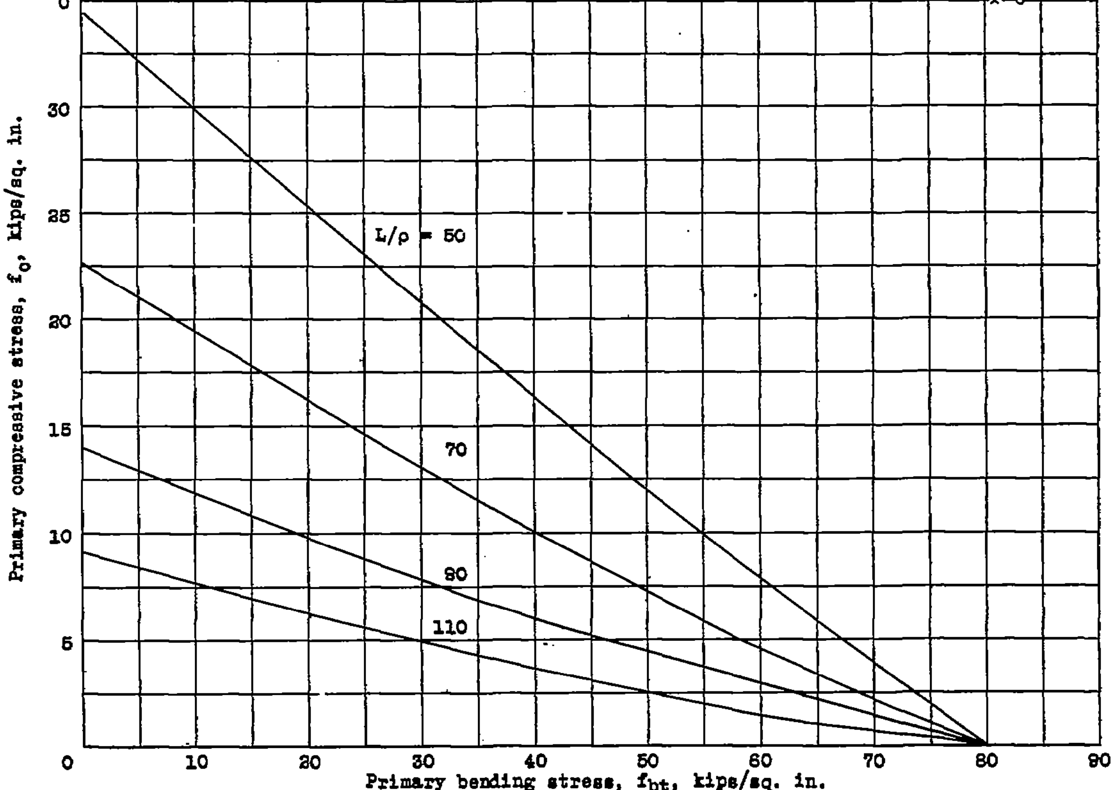

Figure 13.- Beam-column tests of open-channel sections for four L/ρ ratios. 24ST aluminum alloy.

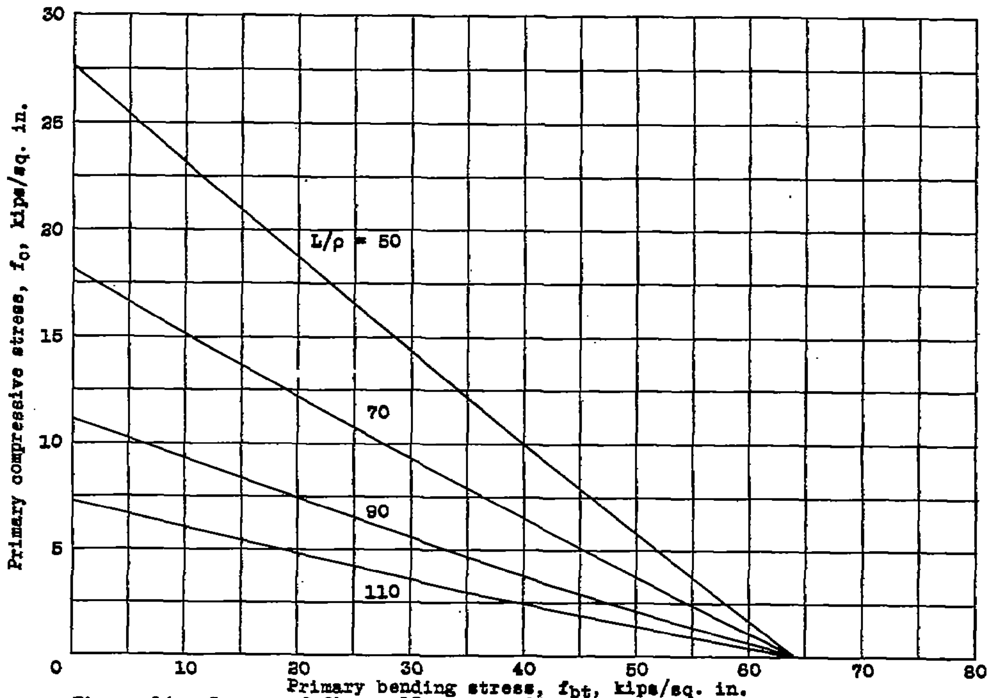

Figure 14.- Curves of figure 13 reduced 80 percent. 24ST aluminum alloy.

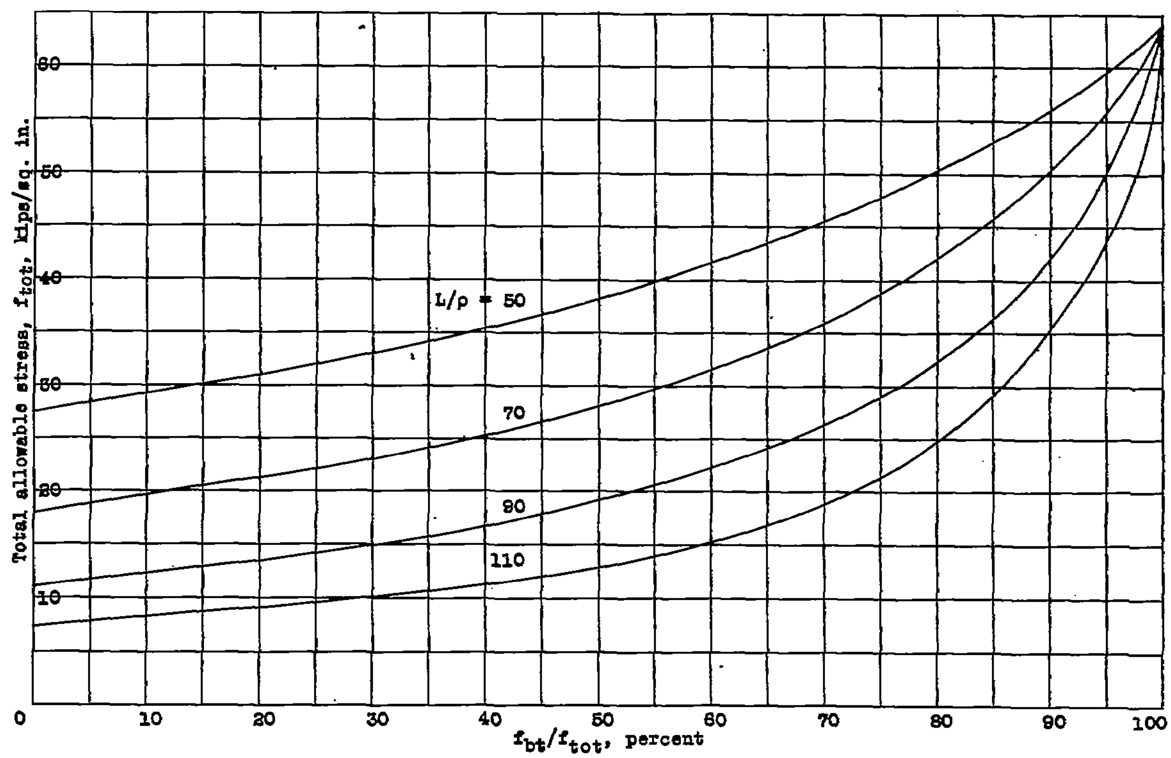

Figure 15.- Design chart for 24ST aluminum-alloy channel sections under axial load and transverse bending. Web of channel in compression during bending. f_{bt}= primary bending stress, f_c= compressive stress, f_{tot}= f_{bt} + f_c= combined stress.