NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE COLUMN STRENGTH OF ALUMINUM ALLOY 75S-T EXTRUDED SHAPES

By Marshall Holt and J. R. Leary
Aluminum Company of America

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INTRODUCTION

Because the tensile strength and tensile yield strength of alloy 75S-T are appreciably higher than those of the materials used in the tests leading to the use of the straight-line column curve, it appeared advisable to establish the curve of column strength by test rather than by extrapolation of relations determined empirically in the earlier tests. Typical properties of 75S-T extrusions are:

Tensile strength	88,000 psi
Tensile yield strength	80,000 psi
Elongation	10 percent in 2 inches

OBJECT AND SCOPE

The object of this investigation was to determine the curve of column strength for extruded aluminum alloy 75S-T. In addition to three extruded shapes, a rolled-and-drawn round rod was included. Specimens of various lengths covering the range of effective slenderness ratios up to about 100 were tested.

SPECIMENS AND MATERIAL

The specimens used in the column tests are described in table I. The actual average area of the angle was determined from the length and weight of a long piece and the nominal density of the material (0.101 lb per cu in.). The areas of the rectangular bars and the round rod were determined from the measured dimensions. The crookedness of the various specimens was measured by placing thickness gages between the specimen and a plane surface upon which it rested. The ends of the specimens were finished flat and parallel by turning the specimens on an arbor or in a steady-rest in a lathe.

The mechanical properties of the materials used are given in table II. The tensile tests were made in accordance with A.S.T.M. Standards for Tension Testing of Metallic Materials (E8-42). In the case of the angle, flat 1/2-inch-wide specimens were used. In the case of the rectangular bars and round rod, 1/2-inch-diameter round specimens were taken from the center of the section. The tensile properties of the extrusions given in table II are in fair agreement with the typical values and are therefore well above the specified minimum values. Etched cross sections of the bars showed uniform structure throughout the cross section.

Compressive stress-strain curves obtained with specimens of the full cross section are shown in figure 1. In the case of the angle and rectangular bars, the relative movement of the platens of the testing machine was interpreted into strains. The strains in the round rod were measured with a Ewing extensometer. A correction was applied to the indicated strains in order to obtain an initial slope of the stress-strain curve equal to the nominal value of compressive modulus of elasticity, 10,500,000 psi.

METHOD OF TESTING

The column tests were made using the conditions of flat ends. The fixed platens of the testing machine were alined parallel within 0.0003 inch in 12 inches, and the specimens were carefully centered on the platens. The ends of the specimens were thus restrained to the extent that the bearings did not tip. Experience has indicated that this method of testing is practically equivalent to the condition of fixed ends; thus the value of the coefficient describing the end conditions, K, has been taken equal to 0.50.

The tests were made in an Amsler hydraulic testing machine (type 150ZBDA, serial No. 5254) having a maximum capacity of 300,000 pounds and intermediate load ranges of 30,000, 100,000, and 200,000 pounds. The load range used was just sufficient to produce failure of the specimen so that maximum sensitivity and accuracy were obtained. The periodic calibration of this machine indicates that the errors in the load reading were less than ±1 percent for the load ranges used.

RESULTS AND DISCUSSION

The results of the column tests are given in table I and figures 2 to 5. In addition to the test results, these figures show four curves of column strength. One of these is the ordinary Euler curve representing the equation:

$$\frac{P}{A} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} \tag{1}$$

where

$\frac{P}{A}$ column strength (psi)

E compressive modulus of elasticity (psi) taken here as 10,500,000 psi for 75S-T (reference 1)

and

$\frac{KL}{r}$ effective slenderness ratio; for fixed ends, K = 0.50

This equation is based on the assumption of elastic action and is, therefore, valid only for stresses in the elastic stress range. There is fairly good agreement between the test data and the Euler curve for stresses in the elastic stress range.

The second curve is Engesser's interpretation of the Euler curve. Its equation is of the same form as that of the Euler curve, the difference being the use of an effective modulus of elasticity instead of the initial modulus in order to take into account the inelastic behavior of the material at average stresses above the proportional limit. Experience indicates that the effective modulus can be taken equal to the tangent modulus which is the slope of the stress-strain curve. The relations between the compressive stress and the tangent modulus are shown in figure 6. Although the tangent modulus column curve represents the test results fairly well, it is not suitable for general engineering use.

The third curve in figures 2 to 5 is simply a straight line drawn tangent to the Euler curve and is a type with considerable use in general engineering practice. The equation of the straight line is of the form:

$$\frac{P}{A} = B - C\left(\frac{KL}{r}\right) \quad \text{(reference 2)} \qquad (2)$$

where

B intercept at zero slenderness ratio, $CYS\left(1+\frac{CYS}{200000}\right)$

C slope of the straight line

and

CYS compressive yield strength, psi

These straight lines are those that would be predicted from an extrapolation of the rules established previously and are to be used in the range of slenderness ratios less than that at the point of tangency with the Euler curve. For these tests the straight line is generally conservative for stresses less than about 90 percent of the compressive yield strength, and at a slenderness ratio of about 40 the conservatism amounts to as much as about 10 percent. For slenderness ratios less than about 20 the straight line lies somewhat above the test results. The straight-line type equation does not fit these data as well as it did earlier data on lower strength alloys.

The fourth curve in figures 2 to 5 is a parabola tangent to the Euler curve and is of a type which is also common in general engineering practice. The equation is of the form:

$$\frac{P}{A} = F - G\left(\frac{KL}{r}\right)^2 \tag{3}$$

where

F intercept at zero slenderness ratio

and

G coefficient that makes the parabola tangent to the Euler curve

In general, this type of curve fits the data better than the straight line. It has the advantage that it does not rise excessively above the test results in the range of slenderness ratios less than about 20. As is the case with the straight line, the parabolic curve is to be used only in the range of slenderness ratio less than that at the point of tangency. For these comparisons the best value of F seems to be about 7.5 percent greater than the compressive yield strength. Possibly, a general relation between this intercept and the compressive yield strength can be developed later from a study of test results from materials covering a wider range of compressive yeild strengths. For material having a compressive yield strength equal to the typical tensile yield strength (80,000 psi) the equation of the parabola is:

$$\frac{P}{A} = 86,000 - 17.9\left(\frac{KL}{r}\right)^2 \tag{4}$$

Figure 7 gives a comparison of the column curves based on the tangent moduli for the four sections tested. The difference in mechanical properties is reflected in these curves.

CONCLUSIONS

The following conclusions have been drawn from the results of tests and discussion of flat-end column tests on 75S-T extruded shapes and rolled-and-drawn rod presented in this report:

1. For column strengths in the elastic stress range, the test results agree fairly well with the Euler column curve for columns with fixed ends.

2. For column strengths above the elastic stress range, the test results agree satisfactorily with the tangent modulus column curve for columns with fixed ends. The equation defining this curve is of the same form as the Euler column formula (equation (1)), the difference being that tangent-modulus rather than initial modulus is used.

3. The straight-line column curve tangent to the Euler curve using empirical constants based on previous tests on lower strength alloys lies below the test results for column strengths less than about 90 percent of the compressive yield strength of the material and lies above the test results for column strengths greater than this. The straight-line type of curve does not appear to represent the data satisfactorily.

4. The parabolic column curve tangent to the Euler curve agrees well enough with the test results that it might be used for general design purposes for slenderness ratios less than that at the point of tangency. In the case of the material tested, which had compressive yield strengths of 78,000 to 87,000 psi, the most satisfactory intercept on the axis of zero slenderness ratio seems to be 1.075 times the compressive yield strength. Additional data on other alloys having high compressive yield strengths will be useful in establishing a general relation between the compressive yield strength and this intercept.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Penna., April 24, 1945.

REFERENCES

1. Templin, R. L., and Hartmann, E. C.: The Elastic Constants for Wrought Aluminum Alloys. NACA TN No. 966, 1945.

2. Templin, R. L., Sturm, R. G., Hartmann, E. C., and Holt, Marshall: Column Strength of Various Aluminum Alloys. Tech. Paper No. 1, Aluminum Res. Lab., Aluminum Co. of Am., 1938.

TABLE I.- DESCRIPTION OF SPECIMENS AND RESULTS OF TESTS - COLUMN STRENGTH OF ALUMINUM ALLOY 75S-T

[Specimens tested as columns with flat ends]

Specimen number	Length L (in.)	Weight (lb)	Effective slenderness ratio, KL/r[1]	Measured crookedness, e (in.)	Ratio, L/e	Ultimate load, P (lb)	Column strength, P/A (psi)
Extruded Angle, 1 by 1 by 3/16 in. Die No. 79-B. (Area, 0.3574 sq in.)							
6-38	38.22	1.380	97.0	0.015	2,550	3,900	10,910
6-31	30.57	1.106	77.5	0.011	2,780	6,150	17,210
6-23	23.00	0.832	58.4	0.002	11,500	10,920	30,550
6-19	19.08	0.690	48.4	0.006	3,180	15,150	42,390
6-17	17.19	0.620	43.5	0.004	4,300	18,475	51,690
6-15	15.31	0.553	38.8	0.001	15,310	22,250	62,260
6-13	13.40	0.486	34.0	0.006	2,230	24,000	67,150
6-10	9.590	0.346	24.3	-	-	27,280	76,330
6-8	7.596	0.275	19.3	0.001	7,600	28,100	78,620
6-6	5.796	0.210	14.7	-	-	28,600	80,020
6-4	3.900	0.141	9.9	-	-	30,100	84,220
Extruded Bar, 5/8 by 2¼ in. (0.623 by 2.264 in.) Die No. 22513-EG. (Area, 1.410 sq in.)							
17-39	39.16	5.60	108.8	0.023	1,700	11,350	8,050
18-29	29.03	4.13	80.7	0.006	4,850	21,000	14,890
18-22	21.77	3.10	60.5	0.008	2,720	38,500	27,300
18-18	18.18	2.58	50.5	0.008	2,230	59,500	42,200
18-16	15.35	2.20	42.6	0.006	2,560	74,000	52,480
18-14	14.60	2.08	40.5	0.006	2,430	80,400	57,020
18-13	12.70	1.81	35.3	0.005	2,540	92,250	65,430
17-11	10.967	1.57	30.4	0.004	2,740	99,000	70,210
17-9	9.088	1.30	25.2	0.004	2,270	106,000	75,180
17-7	7.401	1.05	20.6	0.001	7,400	109,500	77,660
17-5	5.558	0.79	15.4	0.002	2,780	113,000	80,140
17-4	3.751	0.54	10.4	-	-	[2]121,000	[2]85,820
Extruded Bar, 1 by 2 in. (1.001 by 2.010 in.) Die No. 22513-EV. (Area, 2.012 sq in.)							
20-58	57.80	11.82	100.1	0.025	2,310	20,000	9,940
20-46	46.30	9.47	80.3	0.013	3,560	33,400	16,600
20-35	34.75	7.09	60.2	0.021	1,650	57,200	28,430
19-29	29.00	5.90	50.2	0.013	2,230	80,200	39,860
19-26	26.13	5.32	45.2	0.018	1,450	96,200	47,810
19-23	23.19	4.74	40.1	0.004	5,790	120,000	59,640
19-20	20.47	4.18	35.5	0.011	1,860	136,000	67,840
19-17	17.40	3.56	30.2	0.006	2,900	150,900	75,000
21-15	14.56	2.99	25.2	0.006	2,420	165,500	82,260
21-12	11.692	2.39	20.2	0.004	2,920	168,000	83,500
20-9	8.738	1.79	15.1	-	-	171,000	84,990
21-6	5.880	1.20	10.2	-	-	[2]180,500	[2]89,710
Rolled and Drawn Rod, 1 in. Diameter, (0.998 in.) (Area, 0.7791 sq in.)							
A-50	50.00	3.950	100.3	0.010	5,000	7,800	10,010
A-40	40.00	3.171	80.4	0.005	8,000	12,400	15,920
B-30	30.00	2.381	60.3	0.004	7,500	22,100	28,370
B-25	25.00	1.978	50.2	-	-	31,900	40,940
B-23	22.50	1.770	45.2	-	-	38,900	49,930
B-20	20.00	1.579	40.2	0.004	5,000	46,600	59,810
B-18	17.50	1.381	35.2	-	-	53,150	68,220
B-15	15.00	1.187	30.1	-	-	55,600	71,360
B-13	12.50	0.988	25.1	-	-	57,000	73,160
B-10	10.014	0.800	20.2	-	-	58,200	74,700
A-8	7.525	0.600	15.1	-	-	62,150	79,770
A-5	5.025	0.400	10.1	-	-	66,100	84,840

[1]K taken as 0.50.
[2]Maximum load applied, specimen did not fail.

TABLE II.- PROPERTIES OF MATERIAL - INVESTIGATION OF COLUMN STRENGTH OF ALUMINUM ALLOY 75S-T

[Tensile tests made on 1/2-in.-wide rectangular or 1/2-in.-diameter round specimens in accordance with A.S.T.M. Standards for Tension Testing of Metallic Materials (E8-42)]

[Compressive tests made on specimens of full cross section]

Shape	Dimensions (in.)	Tensile strength (psi)	Tensile yield strength (offset = 0.2 percent) (psi)	Elongation in 2 in. (percent)	Compressive yield strength (offset = 0.2 percent) (psi)
Extruded angle	1 by 1 by 3/16	85,400	77,100	10.5	80,300
Extruded bar	5/8 by $2\frac{1}{2}$	86,800	78,800	9.0	80,000
Extruded bar	1 by 2	87,700	80,800	11.0	87,000
Rolled and drawn rod	1-in. diam.	83,200	72,600	14.0	77,800

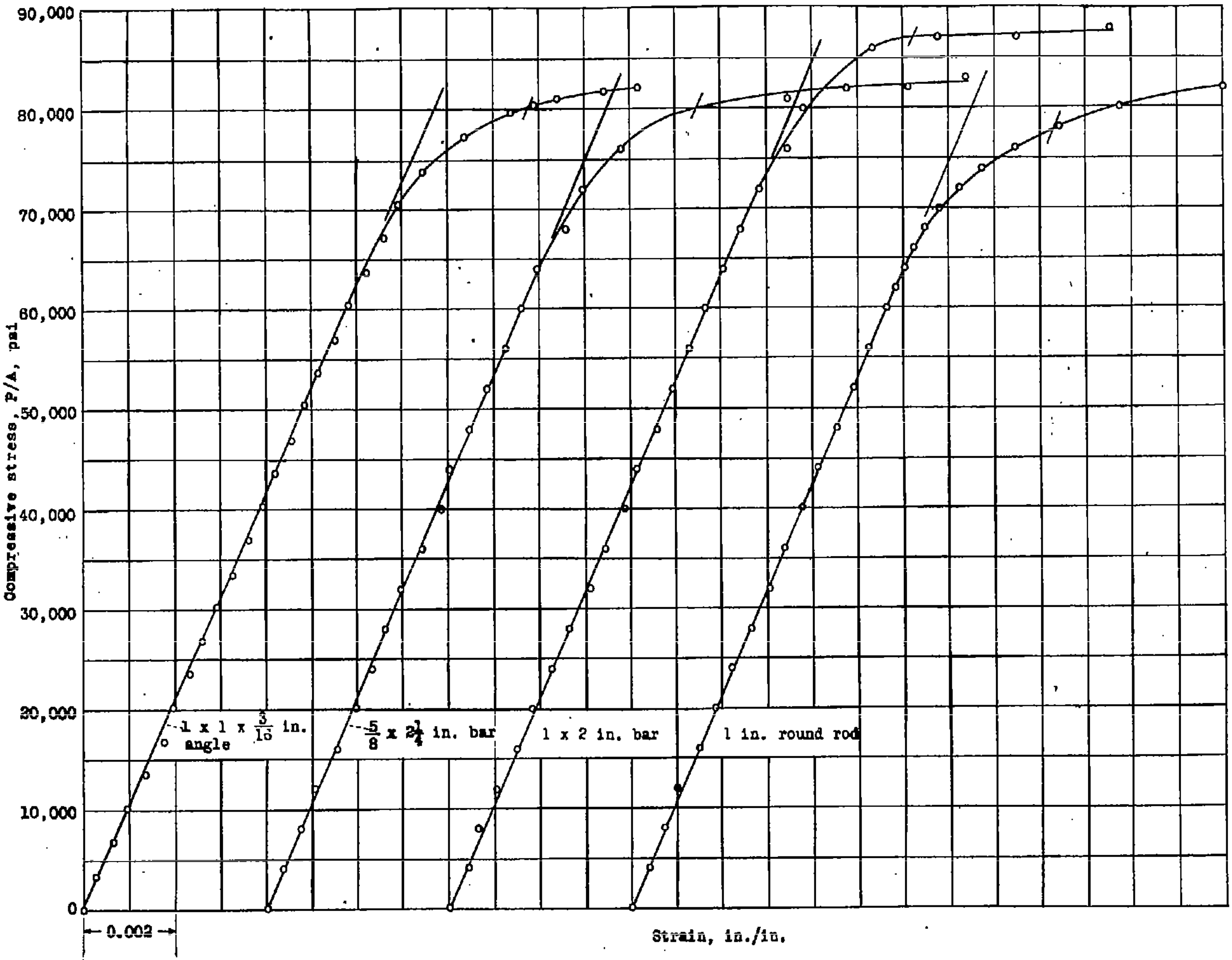

Figure 1.- Compressive stress-strain curves of 75S-T. The data shown were corrected to give an initial slope equal to that of the nominal modulus of the material.

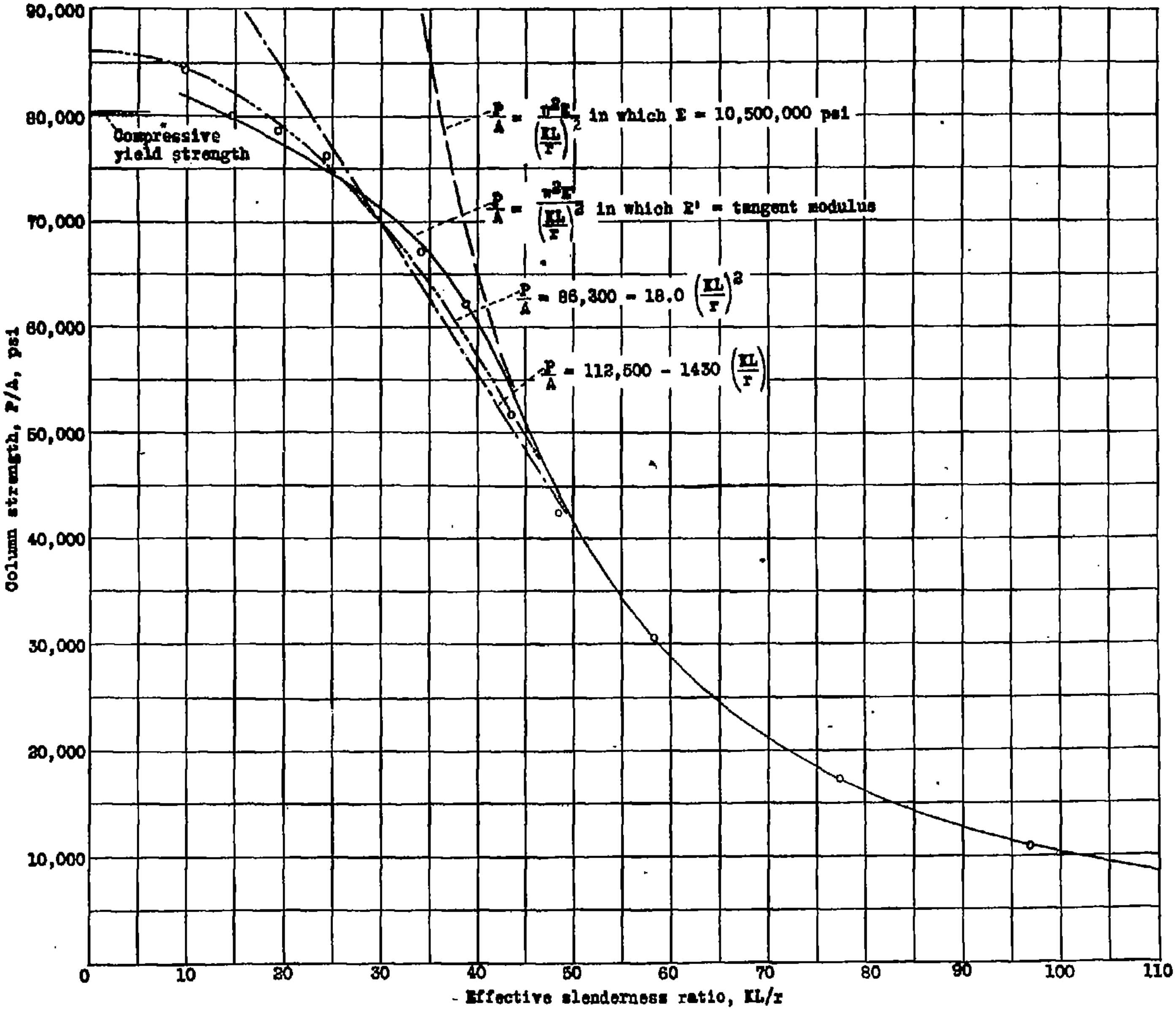

Figure 2.- Column strength of 75S-T 1 x 1 x 3/16 in. extruded angle. Specimens tested as columns with flat ends, K taken equal to 0.50.

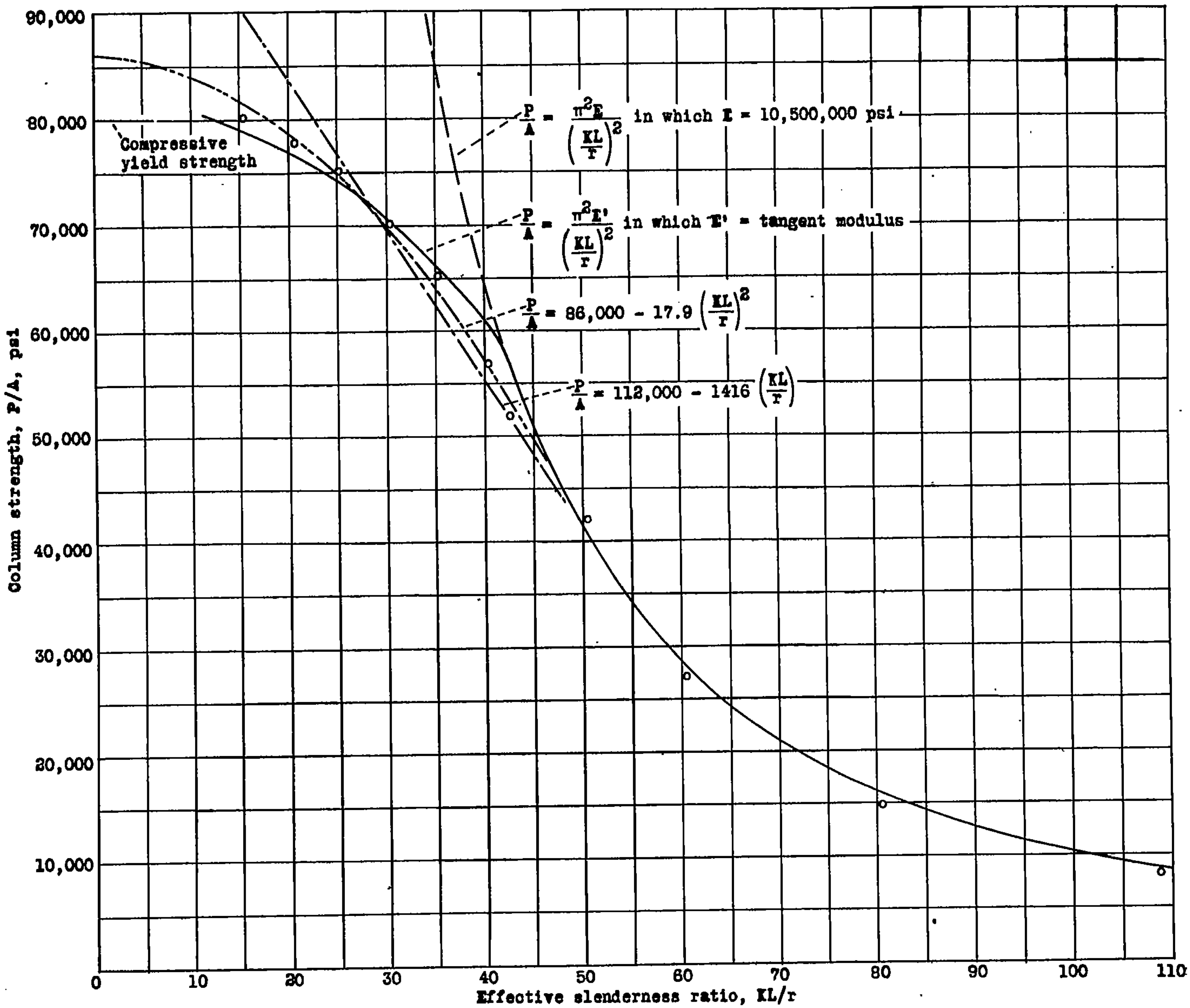

Figure 3.- Column strength of 75S-T 5/8 x 2-1/4 in. extruded bar. Specimens tested as columns with flat ends, K taken equal to 0.50.

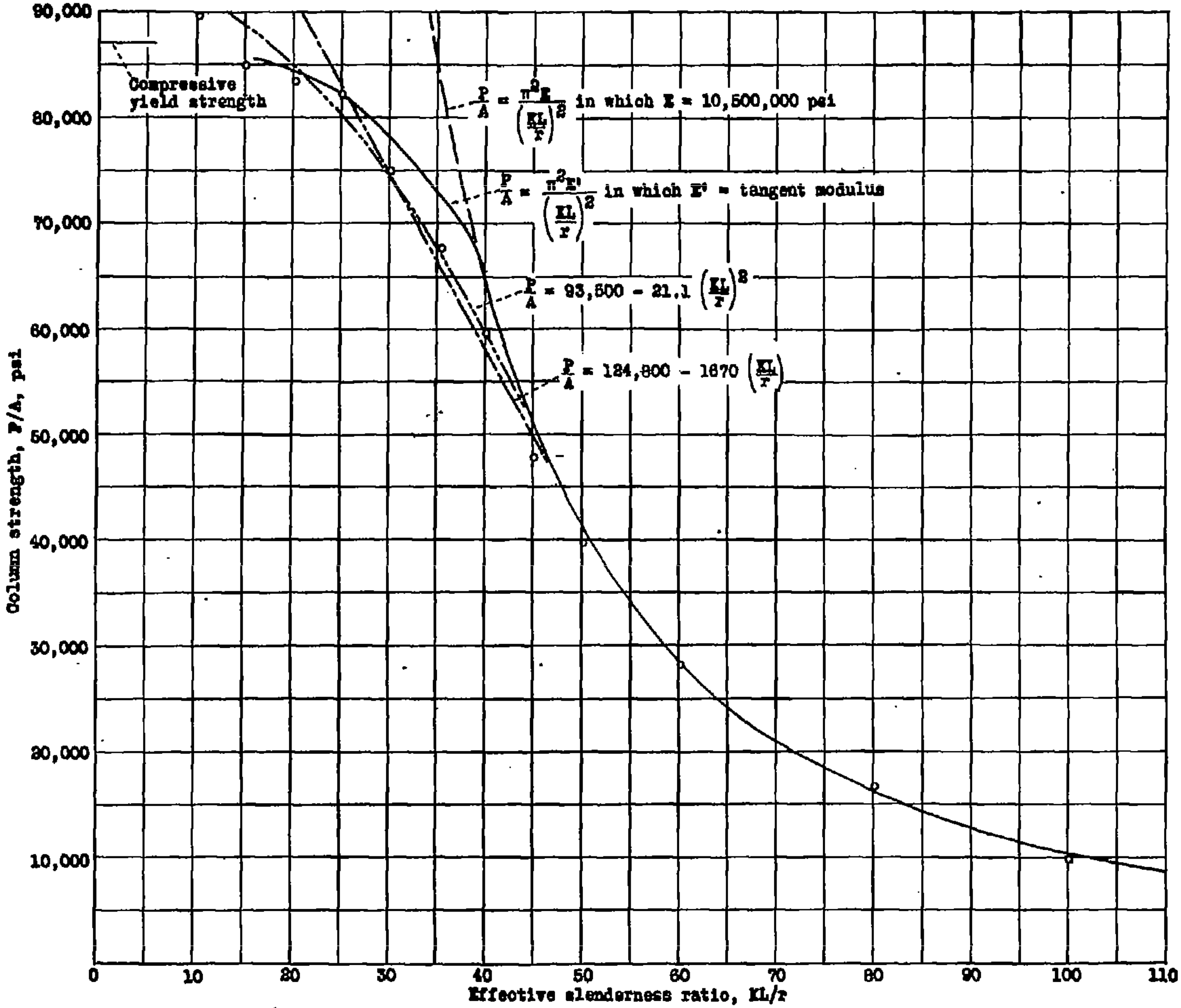

Figure 4.- Column strength of 75S-T 1 x 2 in. extruded bar. Specimens tested as columns with flat ends, K taken equal to 0.50.

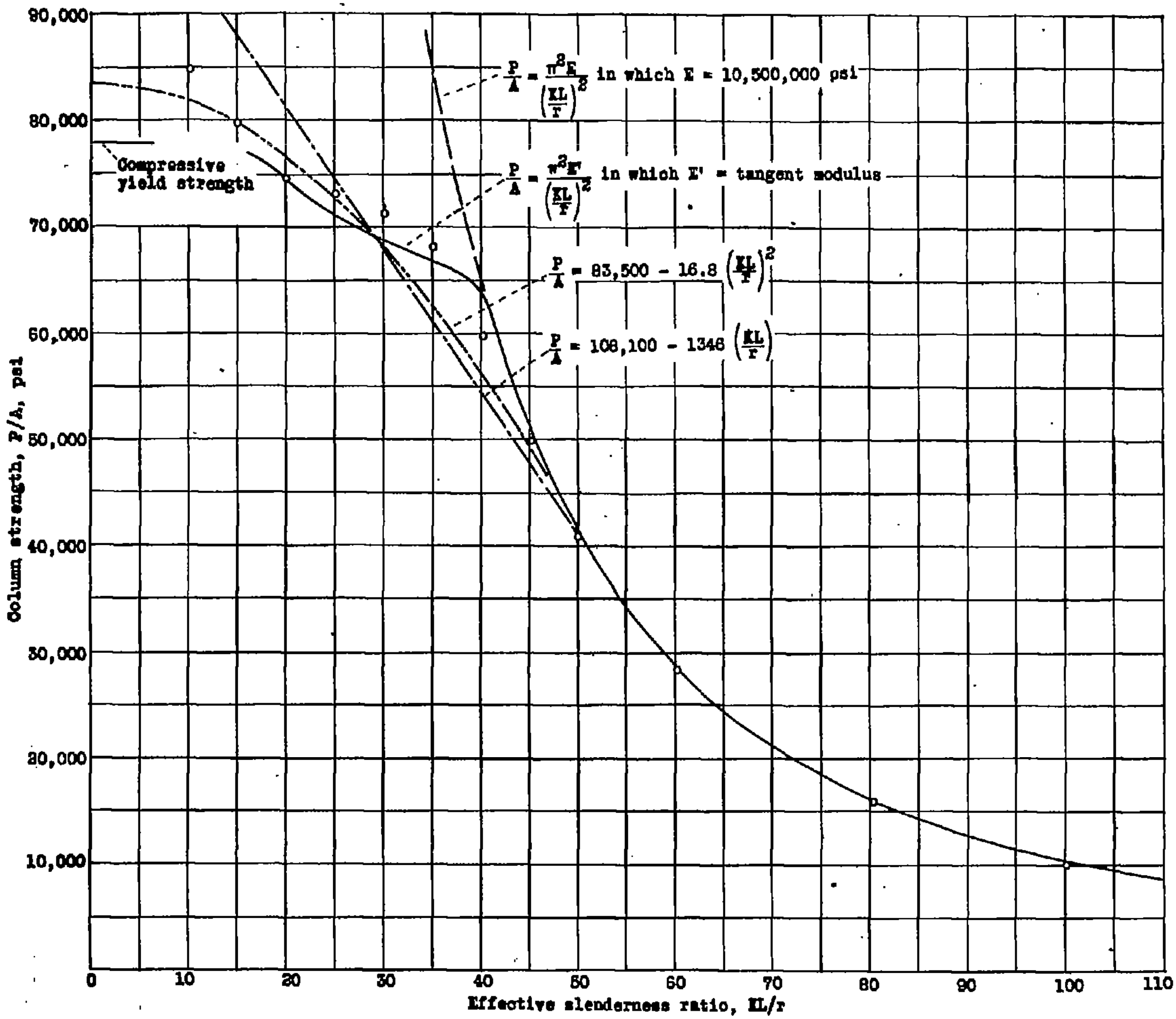

Figure 5.- Column strength of 75S-T rolled and drawn round 1 in. diameter rod. Specimens tested as columns with flat ends, K taken equal to 0.50.

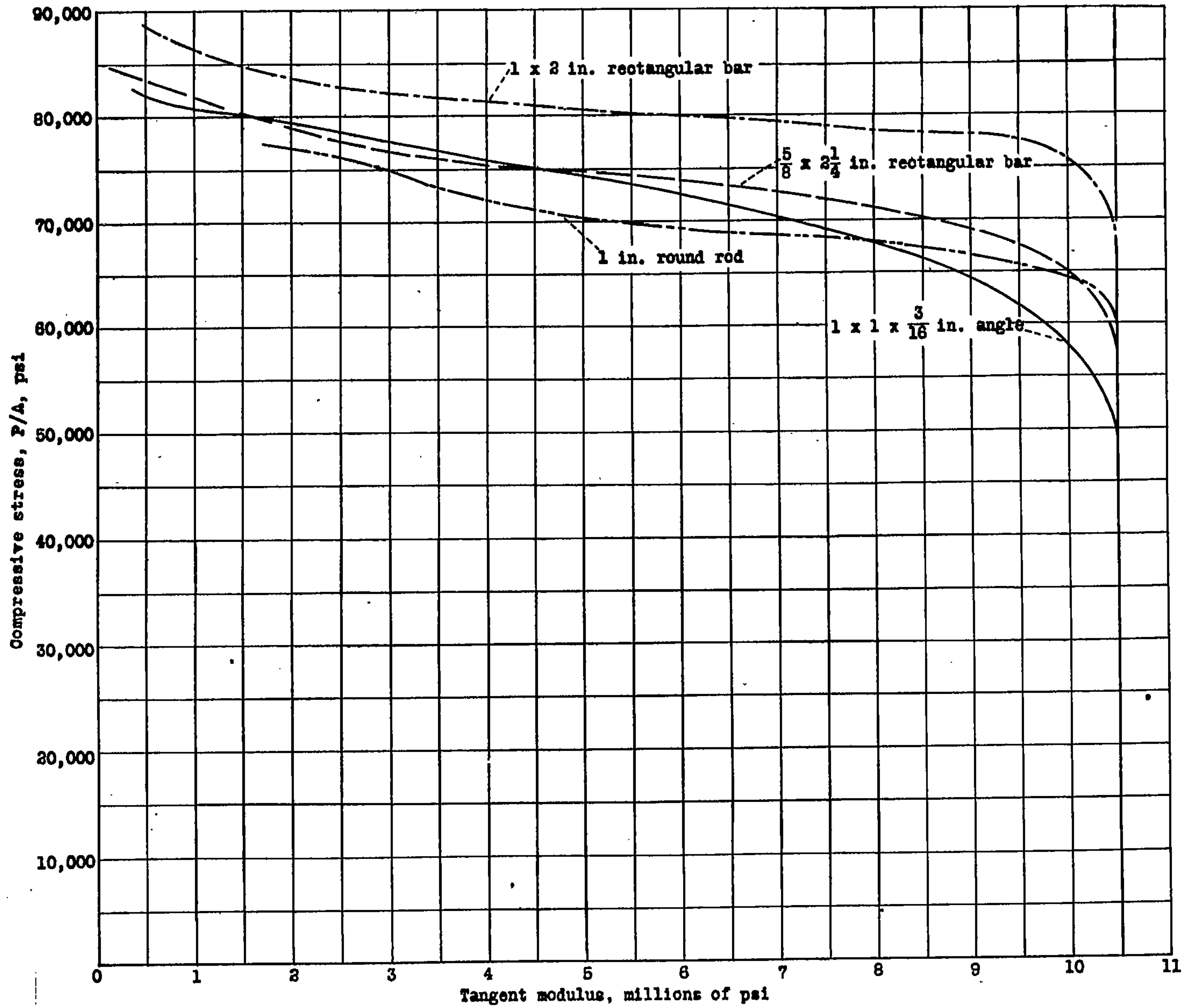

Figure 6.- Compressive stress tangent modulus curves for 75S-T extruded shapes and rolled and drawn rod.

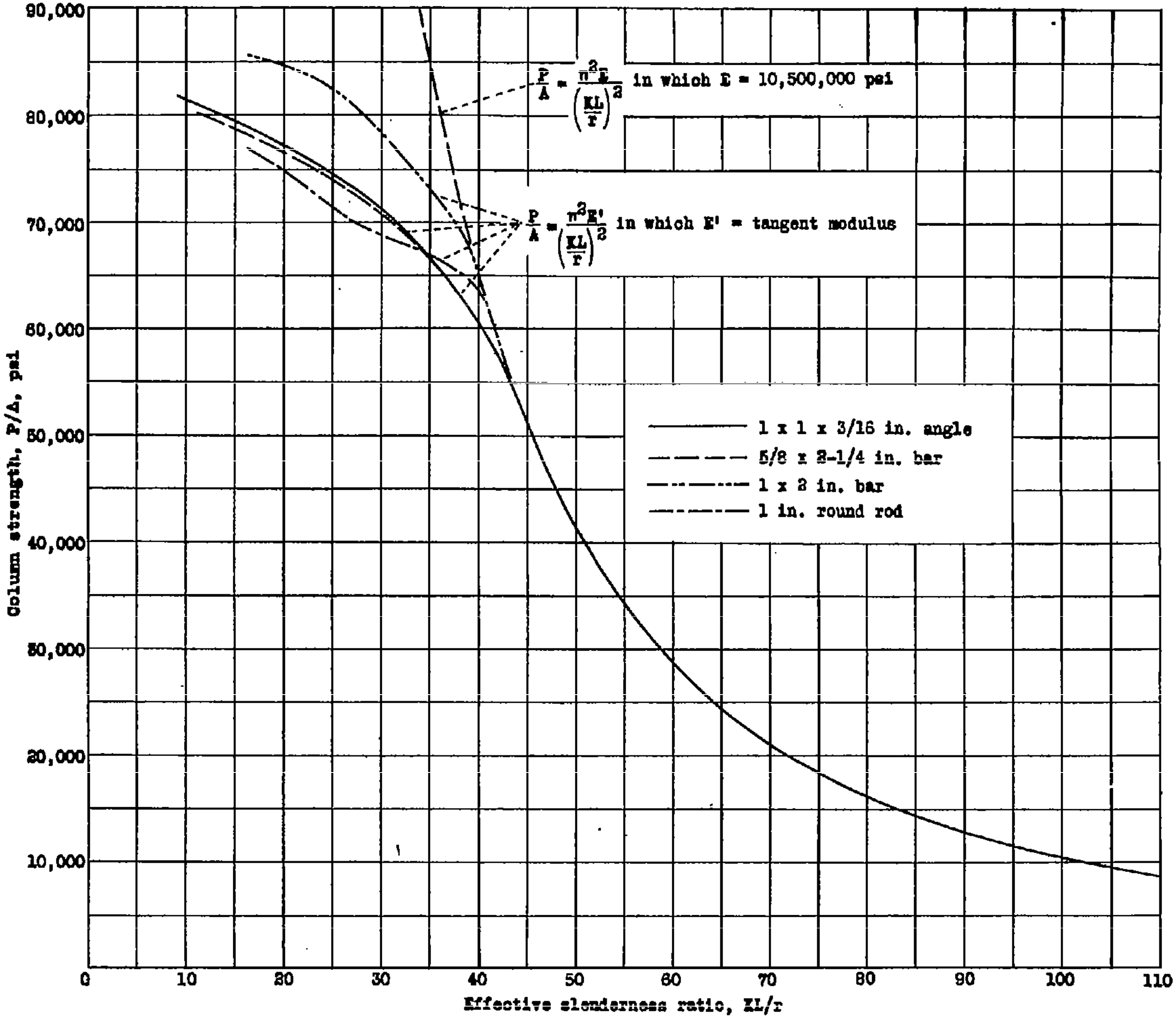

Figure 7.- Column strength of 75S-T. Specimens tested as columns with flat ends, K taken equal to 0.50.