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Compression tests on short steel columns of rectangular cross-section.

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205E.2b

ADDRESS REPLY TO:
FRITZ ENGINEERING LABORATORY

8 May 1953

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HYDRAULICS LAB. EXT. 279

To: Members, Research Committee C
of Column Research Council

Re: Project 0.8.C-
Lehigh University
Inelastic Instability

Gentlemen:

In view of the forthcoming meeting of Research Committee C, this letter is to report progress on part of our "Local Buckling" project, and on which you are giving us advisory support.

At the last meeting of the Committee, our Progress Report Q* was distributed for comment. There was considerable discussion as to the value of certain of the tests. You all received copies of later correspondence between the chairman (Dr. Winter), Dr. Osgood, and one of the undersigned (letters dated May, 1952, June 9, 1952, and August 21, 1952 (2 letters).

One of the principal suggestions made was that we should proceed with testing plate assemblies (rolled shapes) more rapidly than had originally been intended according to the outline in Report Q. This suggestion was followed with the result that work proceeded along two lines:

(a) Tests of Short Compression Coupons

The objective here was to obtain the basic compressive stress-strain diagram and to see if correlation were obtained between the strength of the short compression coupons and the tangent-modulus in the strain-hardening range.

(b) Tests of Short Columns of Rolled Shapes

By testing steel angles in which the boundary conditions are known and in which the flange width to thickness ratio is varied, it would be possible to see how well the available theories predicted the critical strength of rolled shapes.

The results of the angle tests (part (b) above) will be furnished separately at the committee meeting. The results of the short

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* "Inelastic Local Buckling of WF Sections", by Yang and Beedle, Fritz Laboratory Report 205E.1, May 1, 1952.

compression coupons are attached to this letter, the material having been prepared largely by Mr. Geerhard Haaijer, Research Assistant at the Fritz Laboratory.

Since correlation has been reasonably well established between the tangent-modulus load in the strain-hardening range and the critical load in the short compression coupons (point at which bending commences to increase rapidly), it is anticipated that the future work on the project will in the main be concerned with the testing of angles and wide-flange shapes.

Sincerely yours,

Bruno Thürlimann
Research Asst. Professor

Lynn S. Beedle
Assistant Director

LSB:
Encl.
cc: Members, Executive Committee
Messrs. J. Jones
F. Frankland
C. Yang
T.R. Higgins

Welded Continuous Frames and Their Components

COMPRESSION TESTS ON SHORT STEEL COLUMNS OF RECTANGULAR CROSS-SECTION

1. Summary of Theory

For slender columns, which buckle in the elastic range, the critical load is given by the Euler formula:

$$P_e = \frac{\pi^2 EI}{(KL)^2}$$

KL is the equivalent buckling length, the factor K depending on the end conditions.

In the plastic range we have to distinguish between two loads:

a. the tangent modulus load, obtained by replacing the modulus of elasticity E in Euler's formula by the tangent modulus.

$$P_t = \frac{\pi^2 E_t I}{(KL)^2}$$

b. the reduced modulus load, derived under the assumption that unloading occurs during buckling.

Then the modulus of elasticity is replaced by the reduced modulus;

$$E_r = \frac{4\ EE_t}{(\sqrt{E} + \sqrt{E_t})^2}$$

and $$P_r = \frac{\pi^2 E_r I}{(KL)^2}$$

Shanley cleared up the problem and came to the following principal conclusions:

1. Bending commences at the tangent modulus load with an increase in load.
2. The maximum load lies between P_t and P_r, P_r being the upper limit.

Shanley indicated that the formulas for computing the tangent-modulus load do not apply when $E_t = 0$, "since the limiting column load is then determined by the stress at which this occurs".

Yang (Progress Report Q) emphasized the application of the tangent-modulus theory to the strength of very short specimens (the above expression for P_t also applying to the strain-hardening range) and suggesting reasons for the increase in strength above the yield load without the necessity for lateral support.

Bleich discusses the problem on pages 21 and 22 of his book "Buckling Strength of Metal Structures".

2. Scope of Tests

The scope of these tests on short columns is to investigate the behavior of the column at and beyond the point at which bending starts, especially with regard to the tangent-modulus load, as computed from the stress-strain curve in the strain-hardening range.

3. Test Set-up and Procedure

The short compression specimens were cut from the flange of an 8WF40 section as sketched in Fig. 1. Dimensions are shown in Table 1:

Table 1

Specimen	b in	t in	L in	$\frac{L}{t}$	$\frac{KL}{r}$
C2	0.745	0.544	2.80	5.15	8.9
C3	0.745	0.543	3.20	5.90	10.2
C4	0.745	0.543	3.65	6.72	11.6
C5	0.745	0.545	4.33	7.94	13.9
C6	0.745	0.545	4.80	8.80	15.3
C7	0.750	0.527	5.65	10.91	18.9
C8	0.750	0.527	6.90	13.10	23.4

b = width, t = thickness and L = length of specimens.

Test conditions simulate fixed ends, therefore, K = 1/2

r = radius of inertia = $\sqrt{\dfrac{\frac{1}{12}\,b\,t^3}{b\,t}} = \dfrac{t}{\sqrt{12}}$

$\frac{KL}{r}$ = slenderness ratio

All specimens were precisely aligned by means of strain readings taken on two sides of the specimen with Huggenberger strain gages (1-inch gage length). At a load equal to one-half of the yield load the Huggenbergers were replaced by a Peter's gage (2-inch gage length) and a 5-inch long wire was attached connecting the centerline of the column with a $\frac{1}{1000}$ inch Ames dial in order to measure the lateral deflection of the centerline.

As the test proceeded continuously, simultaneous load, strain and deflection readings were taken.

4. Results

Fig. 1 shows a stress-strain curve which is an average curve obtained from the tests on specimens C2 and C3, giving practically the same results.

From this average stress-strain curve, tangent-modulus and reduced-modulus loads were computed and plotted in Fig. 2 as a function of the slenderness ratio. The lower curve giving the tangent-modulus and the higher giving the reduced-modulus loads. The plotted points indicate the ultimate strength of the specimens. In Fig. 3 curves giving the load as a function of the deflection of the centerline are plotted.

The arrows indicate the tangent-modulus load as computed from the strain-hardening range of the stress-strain curve.

5. Summary

From the load-deflection curves it is seen that bending starts immediately after reaching the yield point (except for specimens C7 and C8 which start to bend somewhat earlier). However, this is not the load at which bending commences to increase rapidly and is, thus, not a "critical load". Consistent with theory and with earlier tests the maximum loads are smaller than the reduced-modulus loads and greater than the tangent-modulus loads.

Considering the load vs. lateral deflection curves of Fig. 3, it is evident that up to the theoretical tangent-modulus load (see arrows) the lateral deflection remains quite small. In the region of this load however, the deflection starts to increase more rapidly. Thus, as nearly as can be determined in tests, bending in the critical sense starts at the tangent-modulus load, the tangent-modulus being determined in the strain-hardening range.

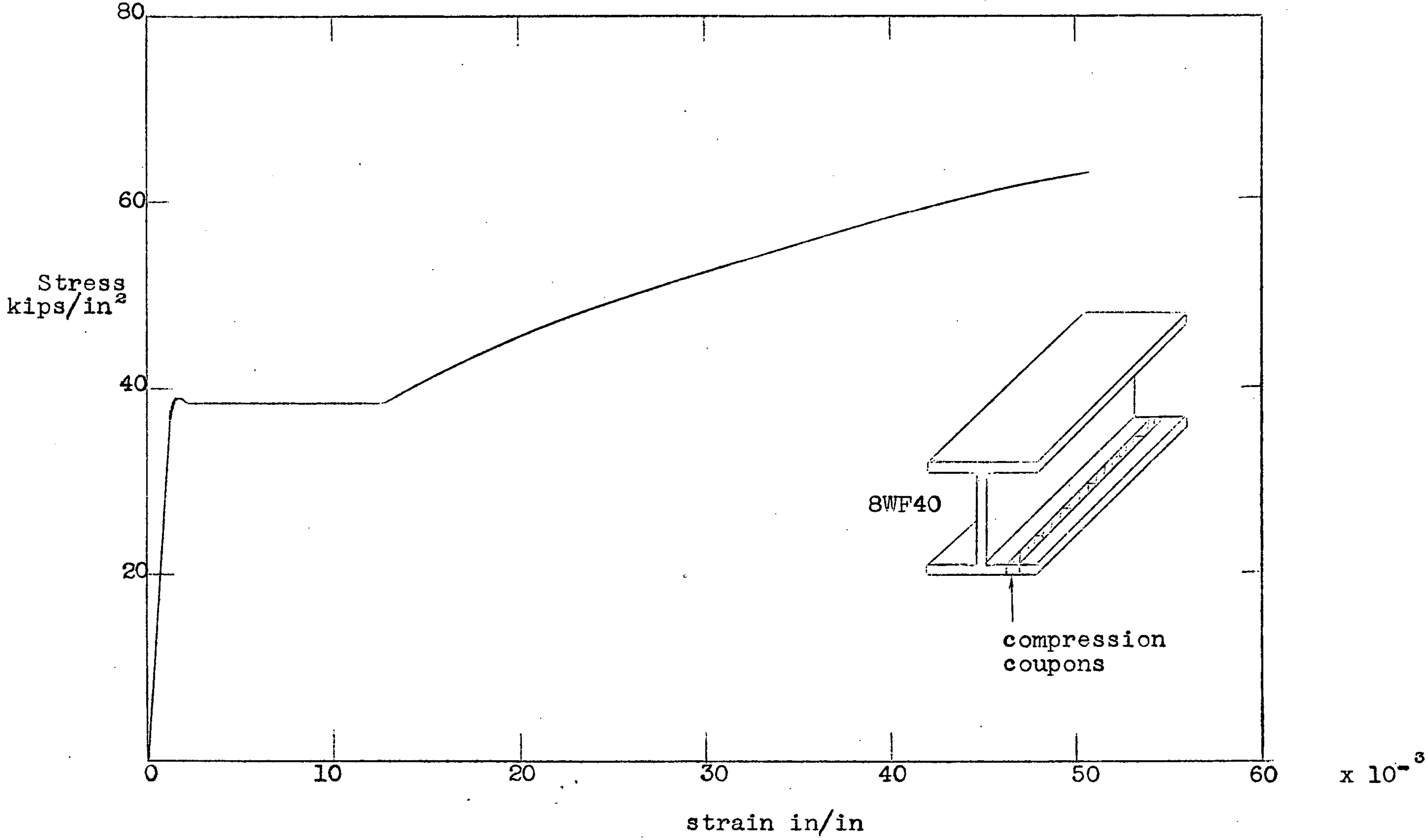

Fig. 1 Average Stress-strain Curve (Specimens C2 and C3)

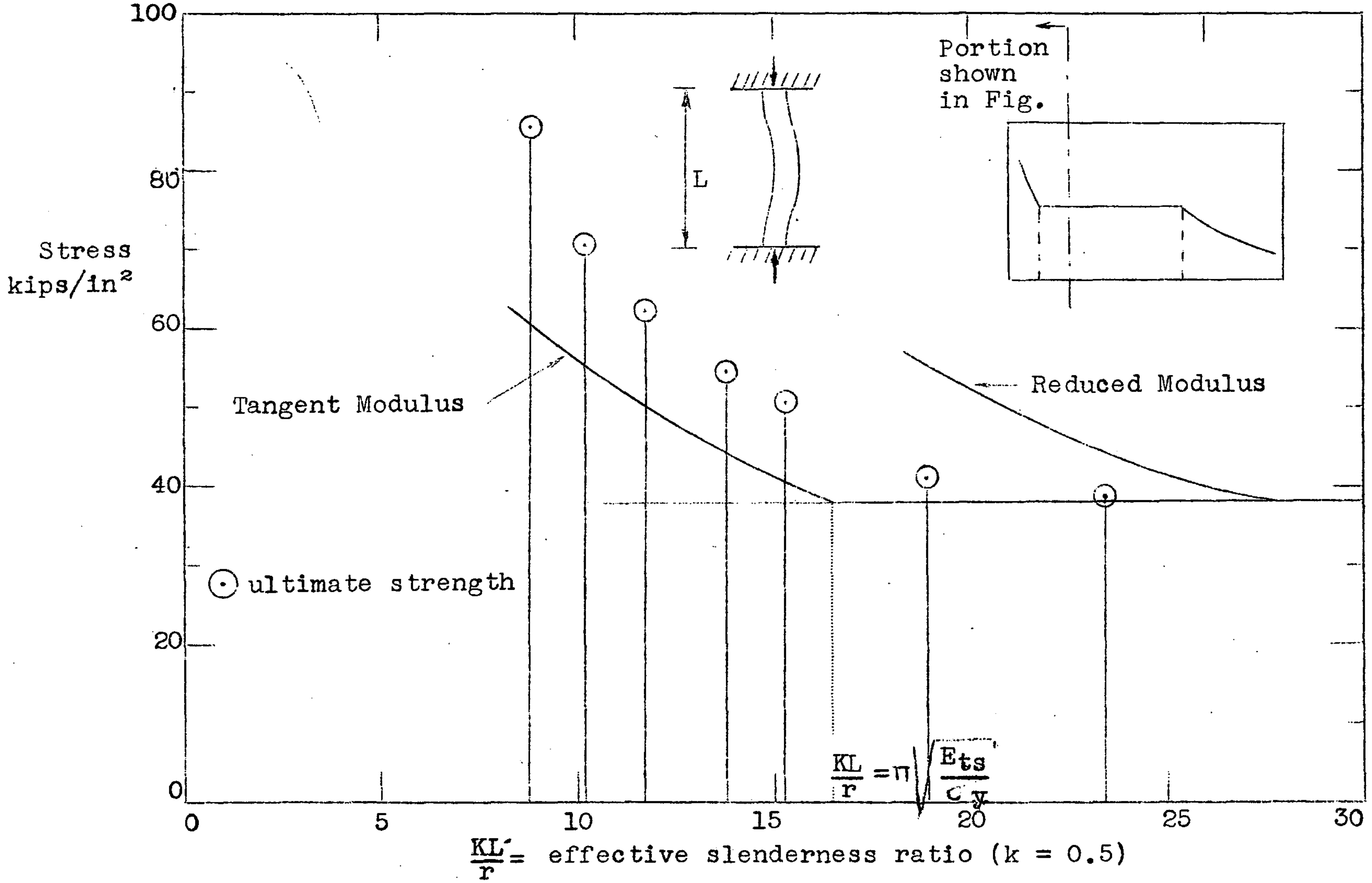

Fig. 2 Column Curve and Observed Ultimate Strength of Specimens (inelastic range)

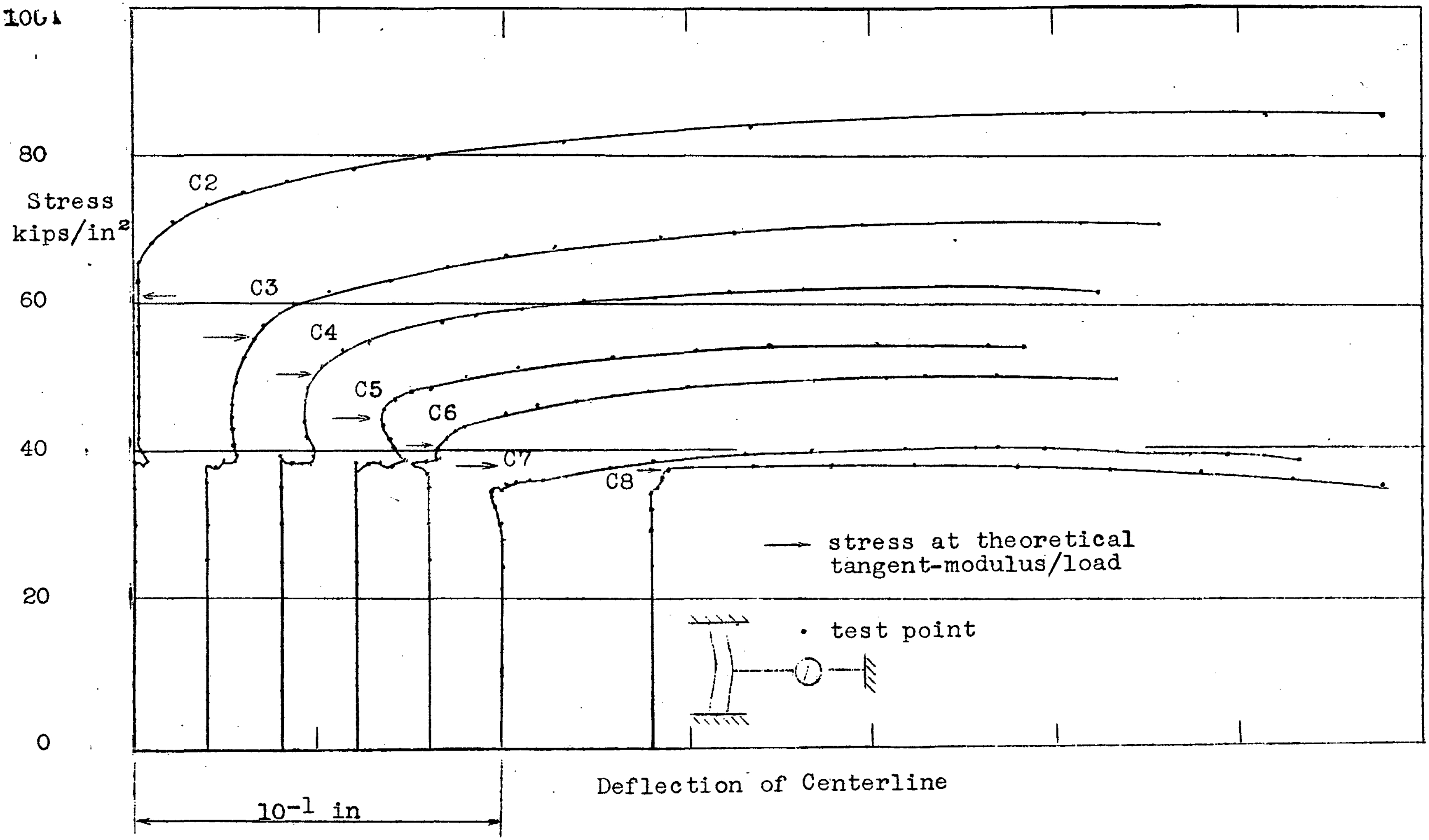

Fig. 3 Average Stress vs. Lateral Deflection Curves