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Progress Report S

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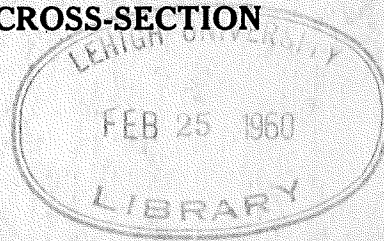
WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS

PROGRESS REPORT S

COMPRESSION TESTS ON SHORT STEEL COLUMNS

OF RECTANGULAR CROSS-SECTION

By

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(Not for publication)

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T A B L E   O F   C O N T E N T S

COMPRESSION TESTS ON SHORT STEEL COLUMNS
OF RECTANGULAR CROSS-SECTIONS

I. Introduction

Since 1947 a research program on "Welded Continuous Frames and Their Components" has been under way at Fritz Engineering Laboratory. Multiple tests on beams, columns and connections showed that some members reached the calculated plastic hinge value and sustained it for a considerable rotation. In contrary, other specimens failed prematurely due to local buckling.

The seriousness of such premature failure was emphasized in Progress Report Q[*] and a study was proposed on local inelastic buckling of structural steel members. The original program was modified following the suggestions of Research Committee C of the Column Research Council. Hence, tests on plate assemblies were included from the beginning.

Testing proceeded along two lines:

(a) Tests of short compression coupons as proposed in Report Q

(b) Tests of angle specimens

In this present report the results of tests (a) are presented and compared with theoretical predictions.

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[*] Progress Report Q, "Inelastic Local Buckling of WF-Sections", by Ching Huan Yang and Lynn S. Beedle
Fritz Laboratory Report 205E-1

II. 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 length, the factor K depending on the end conditions. (For pin ends K = 1.0; for fixed end K = 0.5)

In the plastic range the critical strength has been described, theoretically, by two loads:

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

$$P_t = \frac{\pi^2\,E_tI}{(KL)^2}$$

(b) the reduced modulus load, derived under the assumption that unloading occurs on some fibers of the cross-section 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 $P_r = \dfrac{\pi^2\,E_rI}{(KL)^2}$

Shanley cleared up the problem and came to the foloowing 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 (above expression for P_t also applying to the
strain-hardening range) and suggesting reasons for the in-
crease 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".

III. Scope of Tests

The scope of these tests on short columns is to inves-
tigate 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.

IV. 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.

All specimens were precisely aligned by means of
strain readings taken on two sides of the specimen with Hug-
genberger strain gages (1-inch gage length). At a load equal
to one-half of the yield load the Huggenberger gages were re-

placed by a Peter's gage (2-inch gage length) and a wire was
attached to the specimen connecting the centerline of the col-
umn with an 0.001 inch Ames dial in order to measure the lateral
deflection of the centerline.

This set-up is shown in Fig. 4.

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

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=0.5

$$r = \text{radius of gyration} = \sqrt{\frac{\frac{1}{12} b t^3}{b t}} = \frac{t}{\sqrt{12}}$$

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

V. Results

Fig. 1 shows a stress-strain curve which is an average curve obtained from tests on the shortest specimens (C2 and C3) which showed practically identical results. These specimens were sufficiently stocky so that the stress-strain diagram would not be affected significantly by the length.

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 gives the tangent-modulus and the higher one is a plot of the reduced-modulus relationship. 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.

Fig. 5 shows the specimens after being tested.

VI. 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.
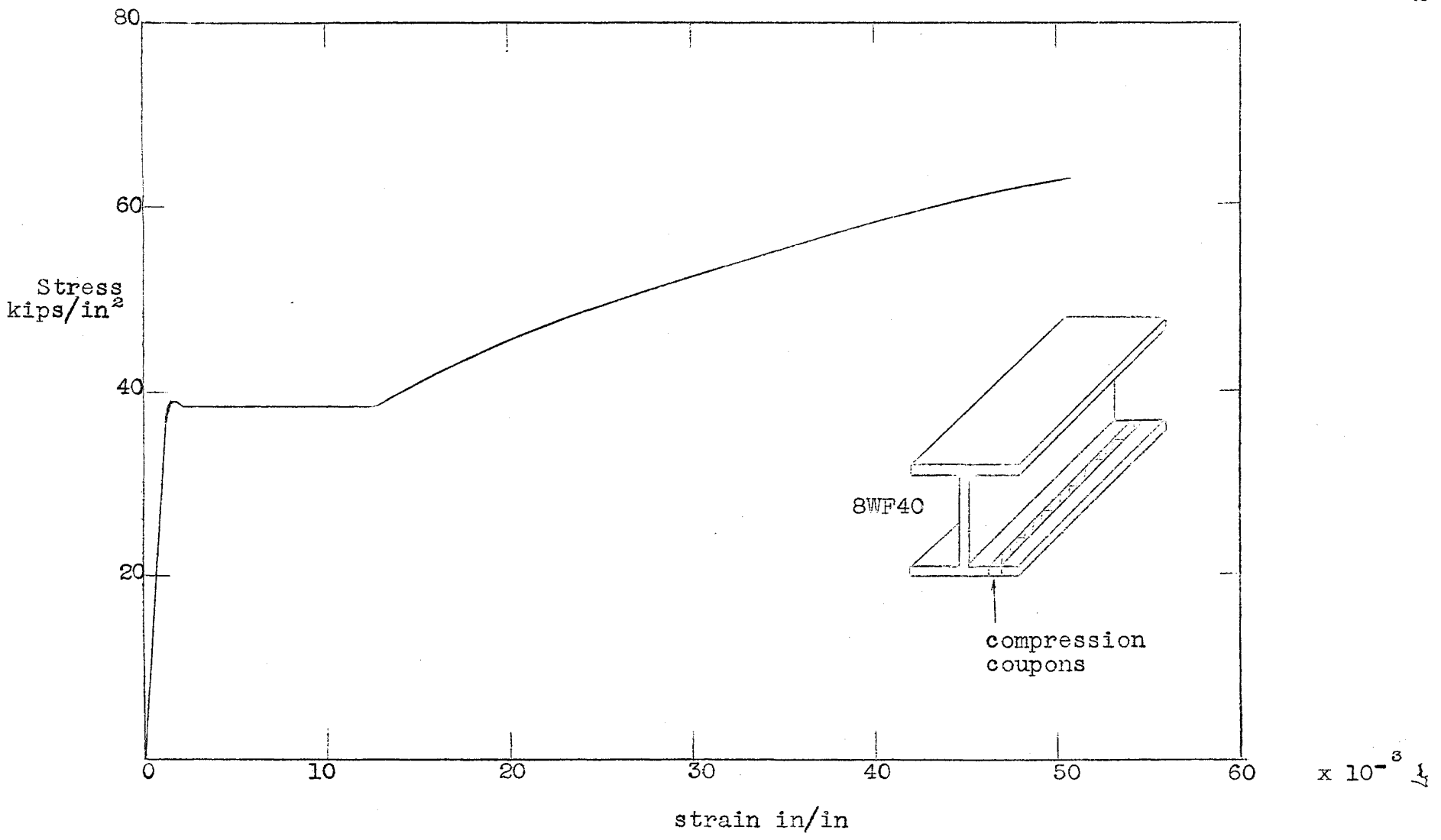

Fig. 1   Average Stress-strain Curve (Specimens C2 and C3)
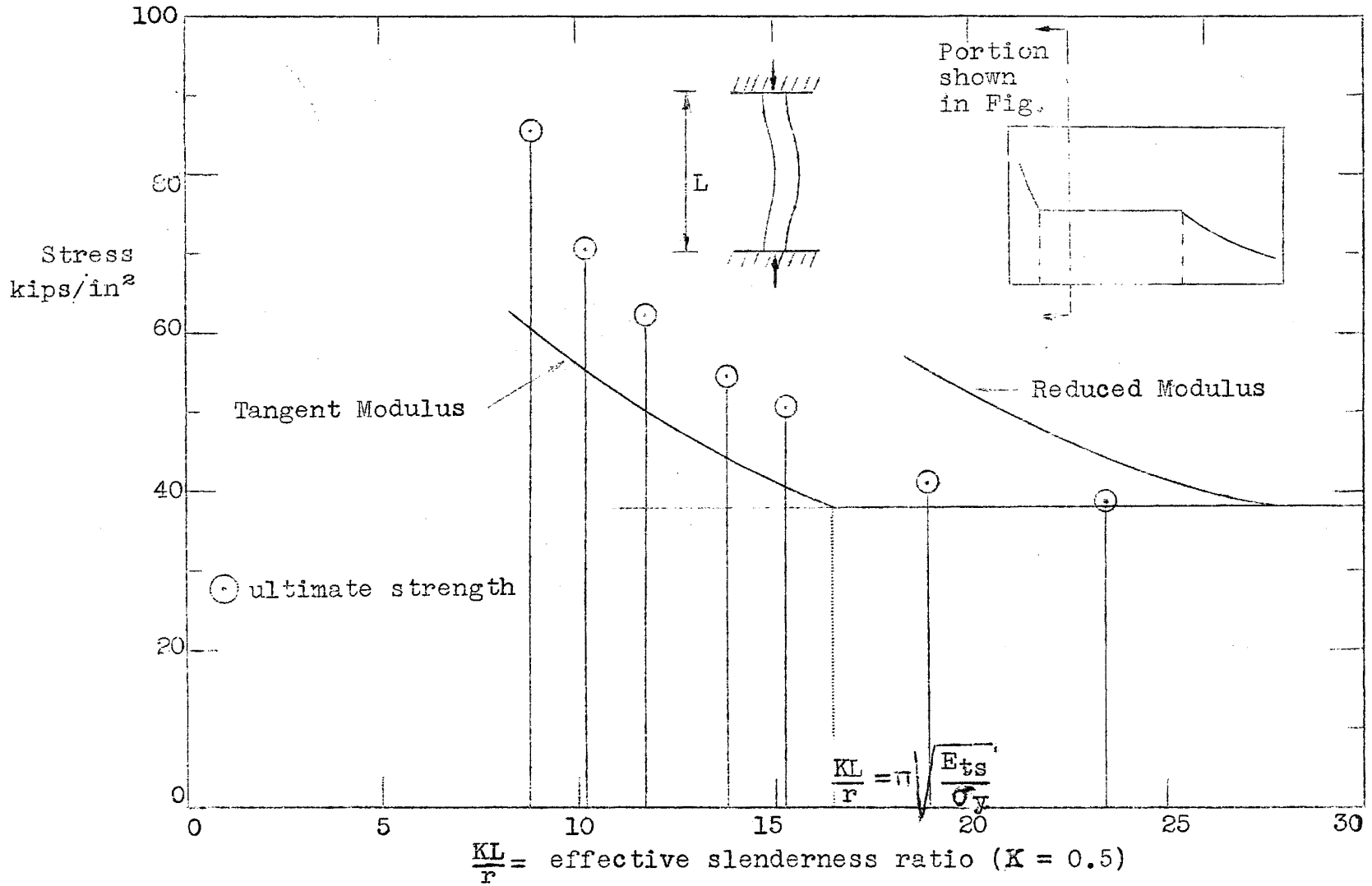
Fig. 2 Column Curve and Observed Ultimate Strength of Specimens (inelastic range)

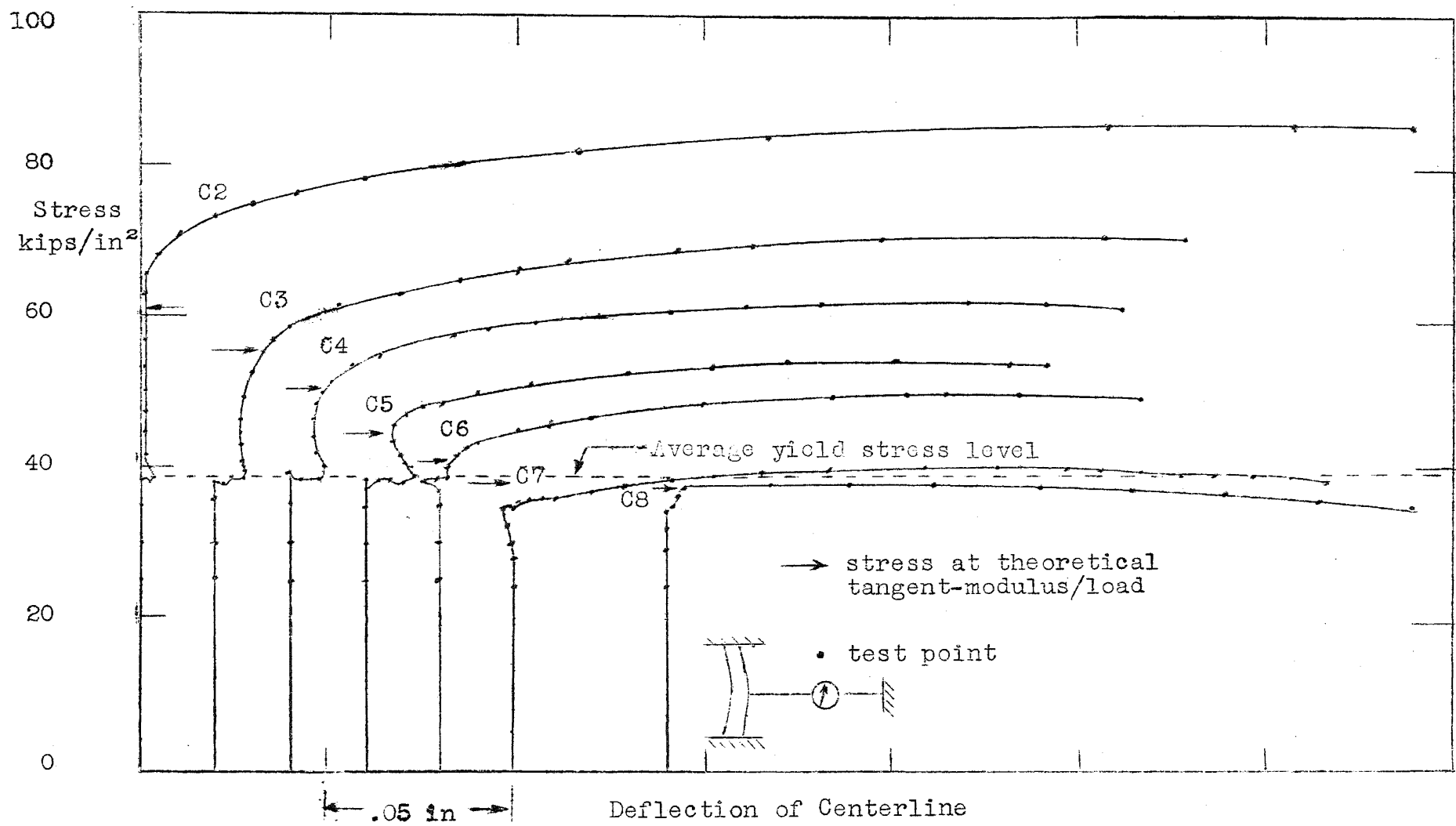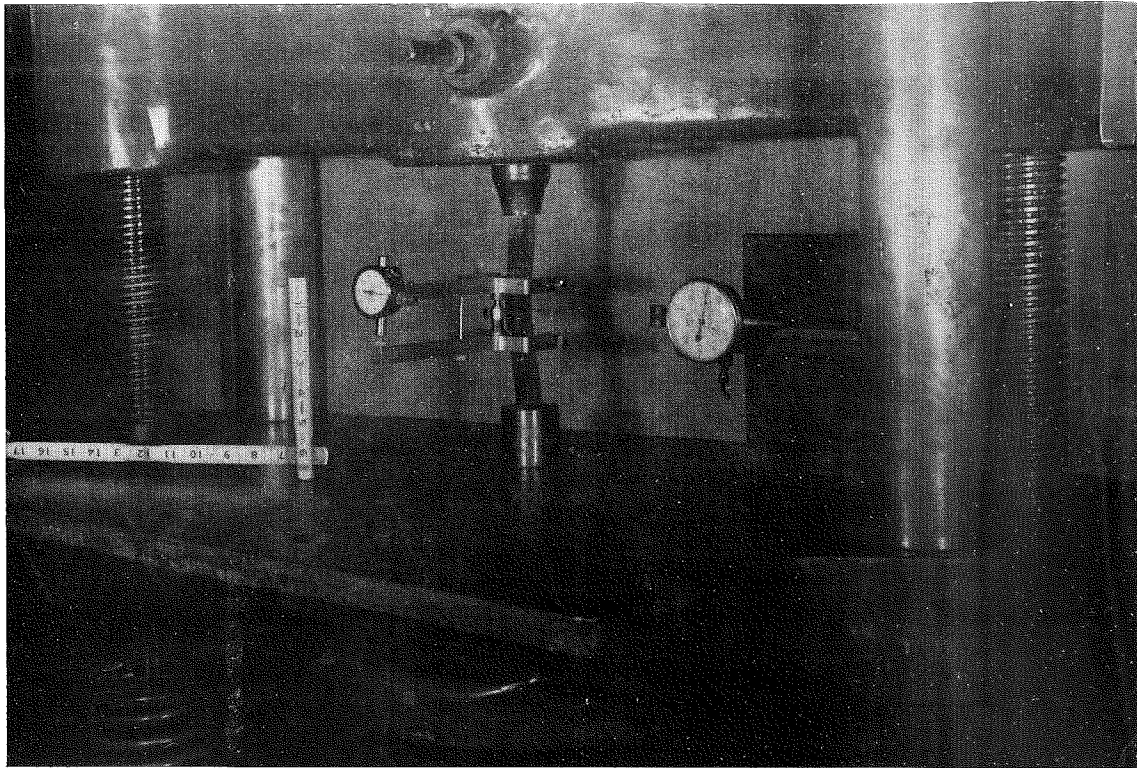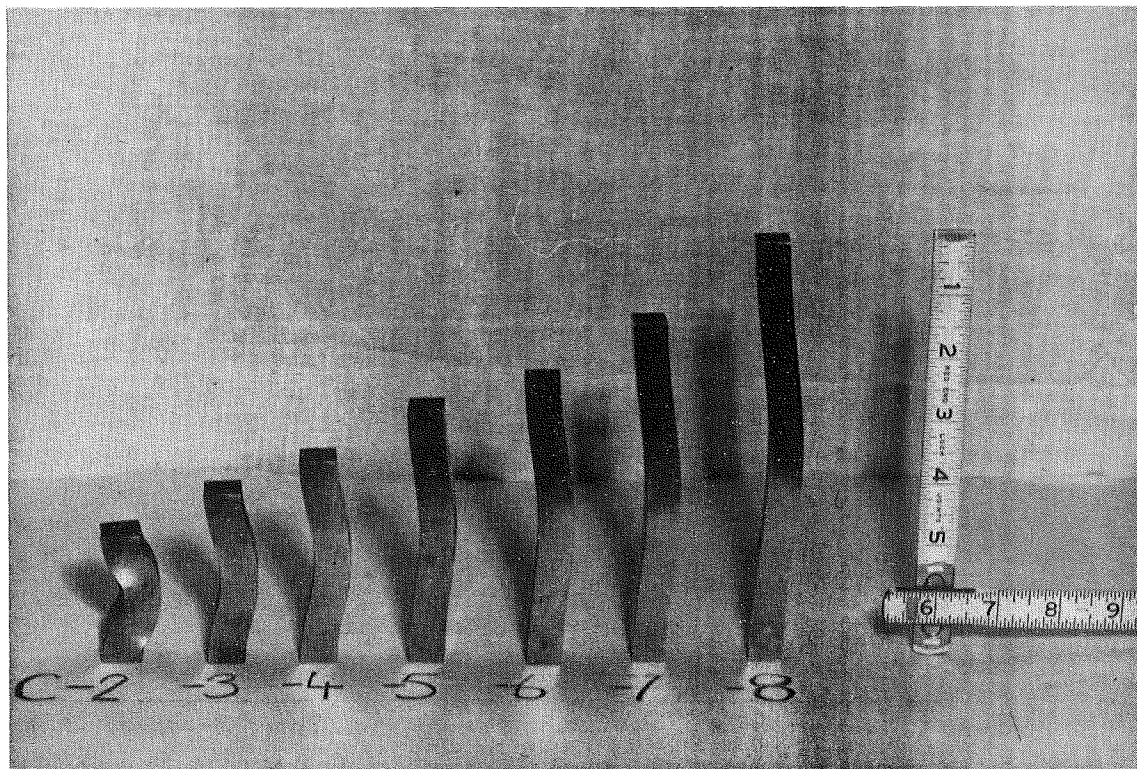Fig. 3   Average Stress vs. Lateral Deflection Curves

Fig. 4 Test Set-up (specimen C8)

Fig. 5 Specimens after testing