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THE BAUSCHINGER EFFECT ON COLUMNS

by

Paul C. Paris*

Date 7/53

Introduction

Earthquakes or the passing shock wave of an atomic blast may cause tensile yield in members before collapse in compression. (1) In order to examine the effect of this reversal, the reduction of compressive properties of structural steel are analyzed after a variety of prestrains and these properties are applied to calculate collapse loads. The calculated maximum loads are then compared with test results to determine a practical method whereby they may be predicted.

Material Properties Tests

Three prestrains were chosen to examine the variation of compressive properties from a prestrain just greater than initial yield strain to a prestrain a little less than the strain at which strain hardening commences. The third prestrain was chosen to be a mean of the other prestrains.

The tensile prestrain was applied by putting a 24" long 1/2" square bar in the tension grips of a universal testing machine. A 2" Metzger strain gage was applied to the center of length of the bar. Its maximum strain

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reading in tension was recorded as the prestrain. It is worth noting that since the bars were slightly crooked due to stress relief in annealing that tensile yield usually started at the center of the bar. Since the prestrain criterion, the Metzger gage, was applied to the center of the bar, the prestrain in the end portions of the specimens was usually less than the recorded prestrain. In some cases yield started at the grips causing yielding to be greater in the end portions of the specimen. The effects of this uneven prestraining will be considered later in this paper.

Compressive properties were examined after prestraining by testing the center portion of the bar, using the same strain gage. This center portion (4" long) was cut from the prestrain bar and compressed between surface plates. The compressive properties for each level of prestrain are recorded on Fig. 1 to compare the gradient reduction of these properties.

Column Tests

Column specimens were prestrained in the same manner as in the material properties tests. The columns were then cut with the gaged part in the prestrain application comprising the central portion of the column. Cylindrical end fixtures were used to attain a pin end condition *as described elsewhere* (2,3) ~~(these fixtures are described in the author's previous~~ works (2,3)).

A variety of lengths was chosen for the column tests so as to cover the usual design L/r values for columns (L/r from 21 to 126 are covered). Results of column tests are shown in Fig. 2 and Fig. 3.

Theory and Comparison with Tests

The Engesser theory and the Kármán theory,⁽⁴⁾ the tangent modulus and reduced modulus formulas, respectively, have been discussed in length and are well known as criteria of column strength for materials of variable modulus.⁽⁵⁾ The conclusion of these discussions is that a column begins to deflect upon reaching the tangent modulus load and reaches its ultimate load between the tangent modulus and the reduced modulus loads. No simple theory for determining the exact ultimate load has been devised, though a complex method for finding it has been derived.⁽⁶⁾

The question of where the ultimate load lies in reference to the double modulus loads becomes of interest on inspecting the Figs. 2 and 3. The ultimate loads recorded in the column tests lie very close to the double modulus values. Where the test data shows scatter, the mean values seem to also indicate this fact. *As mentioned previously one cause* ~~has been mentioned previously and~~ *is* ~~the cause of the scatter~~ *is* ~~as the result of uneven yielding~~ *is* ~~during prestraining.~~ *?* This would cause scatter to be both positive and negative *thus mean* values should be close to the correct criterion. ~~The data therefore exhibits most~~

closely ultimate loads which correspond to the values of the reduced modulus theory.

Further Observations

Previous experimenters have tested aluminum columns in an effort to examine the tangent modulus and reduced modulus theories. Aluminum exhibits properties which reduce ultimate loads only for the mid-length columns (L/r of 40 to 60). The loads are reduced a small amount from the Euler theory. In the tests performed for this work the compressive properties showed effects which reduced the double modulus values to less than half of the Euler loads (see Fig. 2) for some cases. In all cases these values were much below those which would be expected on a similar plot for aluminum. This great reduction in ultimate load caused the ultimate to be obtained at a relatively large deflection. This deflection was visible to the eye in tests of L/r of 60 or greater. Due to these large deflections strain reversal obviously took place, so much so that in many cases the neutral axis was outlined in mill scale before collapse. This strain reversal indicates that the assumptions of the double modulus theory are more nearly satisfied than have been the case in tests on aluminum columns.

Discuss the
real conclusion
See BT ltr
Sept 24/52
L&P para.

ends at end

(X) friction at ends
(X) non-uniform yield

Acknowledgments

The author wishes to express his appreciation for the years of patient guidance of Dr. J.A. Van den Broek, Dr. T.H. Lin originally suggested tests of this nature to the

author. The program was initiated upon the further suggestion of Dr. B.G. Johnston, who also gave the benefit of his experience and time to laying out the initial test program. Thanks are also due to Dr. T.A. Hunter, Dr. B. Thürlimann, and Mr. John Rowley for many helpful suggestions.

✓
Test at
Nid.,
F.I.

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COMPRESSIVE PROPERTIES TESTS WITH A GIVEN % OF TENSILE PRESTRAIN

MATERIAL: HOT ROLLED
STRUCTURAL STEEL ANNEALED
AT 1600°F (4 HRS.) AND
FURNACE COOLED (34 HRS.)

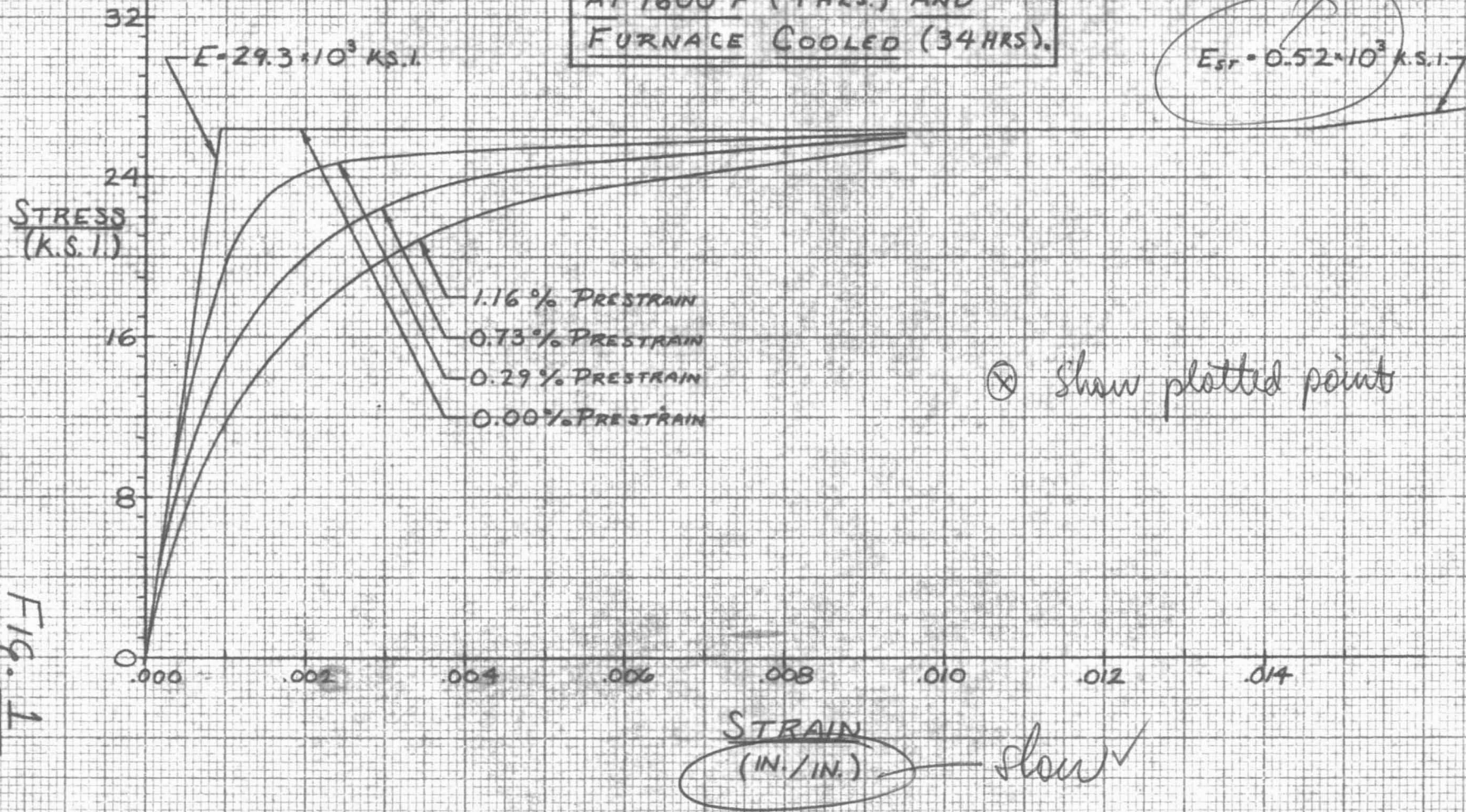


FIG. 1

THE BAUSCHINGER EFFECT ON COLUMNS - PAUL C PARIS - 7/2/53

COLUMN CURVES SHOWING
BAUSCHINGER'S EFFECT OF
TENSILE PRESTRAIN

- ELASTIC THEORY
- - - DOUBLE MODULUS THEORY
- TEST RESULTS
- - - TANGENT MODULUS THEORY (1.16% ONLY)

STRESS
 (K.S.I.)

32
24
16
8
0

L/r

% PRESTRAIN

0.00 %
 0.29 %
 0.73 %
 1.16 %

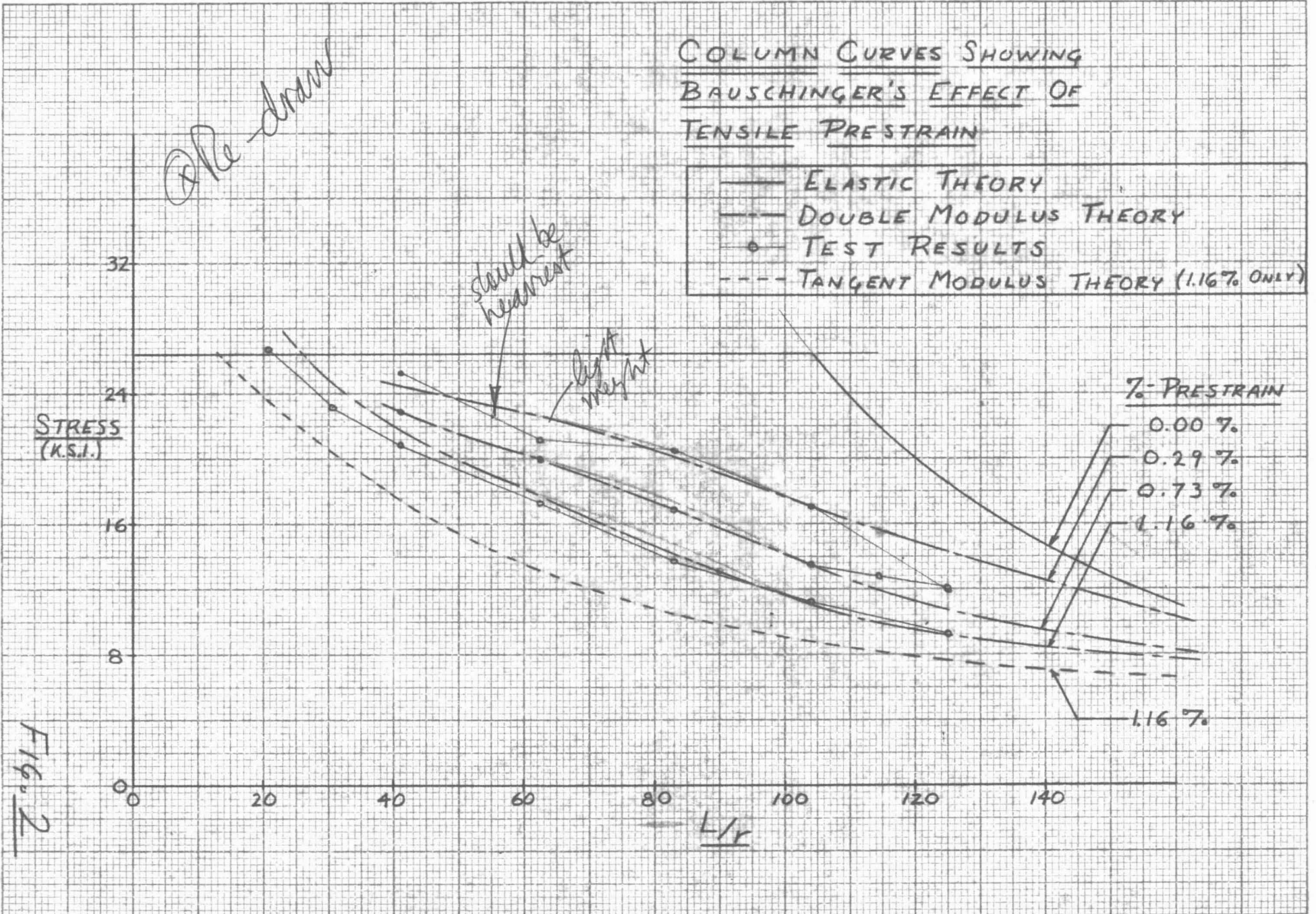
1.16 %

Re draw

should be nearest

light weight

FIG. 2



A COMPARISON OF
THEORIES & TESTS

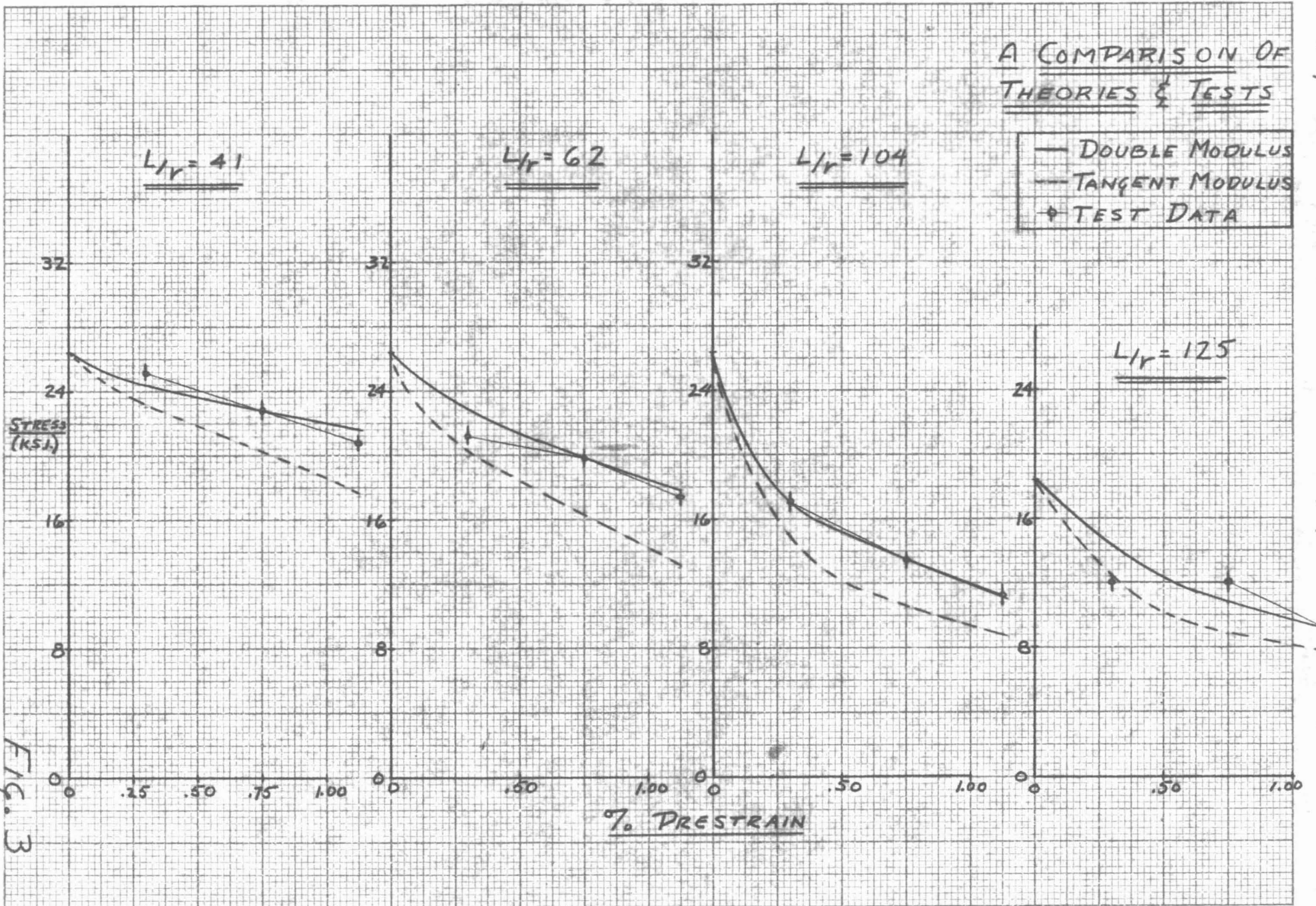


FIG. 3

THE BAUSCHINGER EFFECT ON COLUMNS - PAUL C. TRAVIS - 7/2/53