1957

An experimental investigation of the strength of a riveted, built-up column, Lehigh University, (December 1957)

G. C. Lee

Recommended Citation
Lee, G. C., "An experimental investigation of the strength of a riveted, built-up column, Lehigh University, (December 1957)" (1957). *Fritz Laboratory Reports.* Paper 1685.
http://preserve.lehigh.edu/engr-civil-environmental-fritz-lab-reports/1685

Compressive Properties of Built-up Columns

Progress Report
December 1957

AN EXPERIMENTAL INVESTIGATION OF THE STRENGTH OF A RIVETED, BUILT-UP COLUMN

by

George C. Lee

Fritz Laboratory Report No. 249.3

CONTENTS

I. INTRODUCTION

This work covers a part of the experimental investigations of Project 249 (Built-up Column Strength). In the original program, six columns were scheduled to be tested. Three of these were riveted. This report describes the experimental study of the longest (28 ft.) riveted column which was tested such that failure occured about the strong axis of the section. In addition, correlation between these test results and those previously obtained will also be made. Table 1 gives the geometric properties of the six columns. The results of the previous work~~s~~ ~~are~~ is given in Reference 1.

II. DESCRIPTION OF SPECIMEN

The column section investigated was composed of four 5 x 3-1/2 x 1/2 angles and one 10 x 5/16" plate having a total length of member equal to 28' - 0". The material was mild structural (ASTM A-7) steel. The rivets were 3/4" in diameter and had a pitch of six inches. (Total 112 rivets). The holes for riveting were 13/16" in diameter. Fig. 1 shows a detailed plan of the cross-section. The slenderness ratios are 79.3 and 152.2 for strong and weak axes respectively.

It should be mentioned that there was an initial imperfection (a lamination) in the web plate of the column. The lamination was present only at one end and extended about two feet into the column along the line of one of the rivets. It was approximately 1/16" thick and 2" wide. Because of this situation particular attention was paid to this region of the column. No visible detrimental effects were observed.

Prior to the test the initial condition of straightness was examined. The column was for all intents and purposes in a straight condition. The maximum initial deflection with respect to the ends was 1/4" in 28 ft.

III. DESCRIPTION OF TEST SET-UP

The column investigated was allowed to bend in its strong direction due to pin-ended conditions. It was, however, restrained at two locations by a bracing system to prevent buckling in the "weak" direction. The loading was a concentric, axial, compressive thrust. The machine used was an hydraulic type universal testing machine of 5,000,000 lbs. capacity.

In Reference 2, a detailing description of the end fixtures and test set-up using them is given. The column ends were essentially simply supported in the strong direction and restrained against rotation in the weak direction.

Since the slenderness ratios of the total length column in the two directions were markedly different, it was necessary to prevent bending in the weak direction, as was pointed out earlier. On investigation it was determined that one lateral support at the mid-height of the column would just be sufficient to prevent the column from failing in the weak direction. However, two lateral supports were used for reasons of safety, and to ensure the desired failure type. In Fig. 4 the bracing system is shown. This system consisted of two brackets 8 ft. apart and 10 ft. from both ends which were attached after the alignment was completed.

Show why critical .. how determined

The deflections were measured by the following means: 1) 1/100" scales attached to the column were read by a transit fixed in position; and 2) Deflections were also obtained from three 1/10,000" dial gages of 2" range. These were located at the center section of the column and at sections 5 ft. from the ends. The gages were attached to a vertical rod suspended from the cross head of the machine which was guided at the bottom to move only vertically. This can also be seen in Fig. 5

Strains were measured by means of a series of SR-4 type A-1 strain gages (nominally one inch gage length) located at the center section and at positions near both ends of the column. The majority of the gages were attached near the flange tips and were used primarily in the alignment of the specimen.

The column was also whitewashed such that the yielding process could be observed during the test.

IV. ALIGNMENT

As in certain of the previous column tests, the alignment was considered satisfactory when at each section where measurements were made the maximum deviation of any of the strain readings is less than 5% at the maximum alignment load. The maximum alignment load was chosen as one-third of the anticipated proportional limit load to eliminate any possibility of yielding.

In the alignment series of trials, the average value of the three measured sections was obtained just within 5%. The load-deflection curve, however, indicated that the alignment was not perfect since there was an early deviation of the curve from the vertical axis (Fig. 9). It was none-the-less considered satisfactory.

unavoidable

V. TEST RESULTS IN COMPARISON WITH THE PREDICTED DATA

Testing started as soon as possible after the alignment was obtained. The load increments were determined from a load-deflection graph plotted during the test and decreased as the maximum load was approached. Also when approaching the maximum load, criterion measurements were made to determine when the member "settled down" and to avoid appreciable changes of load during any set of readings. Strains and deflections were taken at each load interval. The nominal stress-strain curves and the load-deflection curves for the member as a whole are shown in Fig. 7, 8, 9. A comparison of the load-deflection curves obtained from the transit-scale readings and the dial gages is also given in Fig. 10.

In Reference 1, the results of the previous investigations are given. A stub column test was conducted and the result is shown in Fig. 2. Also, a set of residual stresses measurement for the cross section was carried-out with the results being those shown in Fig. 3. Column curves based on the stub column curve and the residual stress measurement are given in Fig. 6 in a non-dimensionalized form.

Generally speaking, if a material (or cross-section) has an effective nonlinear stress-strain relationship, the tangent modulus prediction of the buckling load will be

$$\sigma_t = \frac{\pi^2 E_t}{(\frac{L}{r})^2}$$

or

$$P_t = \frac{\pi^2 E_t I}{L^2}$$

Because this load (or stress) represents the point of first possible deviation from a straight configuration, it represents a lower limit to the true carrying capacity of the member. Sections which contain residual stresses do exhibit this non-linear behavior. This is primarily because of the manner in which they yield. As shown in Reference 7, the tangent modulus load for such a case is then reduced to

shown in 205 PR #5

$$P_t = \frac{\pi^2 E I_e}{l^2}$$ use L

or

$$\sigma_t = \frac{\pi^2 E}{(\frac{l}{r})^2} \frac{I_e}{I}$$

For riveted columns, however, the residual stress pattern of each member is not at the present time known, and there is reason to suspect that a large variation will exist on both its magnitude and pattern. Because of this each column will be a different situation. A general theoretical derivations would therefore not actually be significant.

The predicted maximum load based on the tangent modulus curve determined from the stub column test was 582 kips. The actual maximum load the member carried was 572 kips. Together with the previous two columns (R-I, R-II), the results are indicated in Fig. 10 as is the predicted column strength. The results R-I and R-II (weak axis failures) have relatively higher maximum capacities than R-III (srrong axis failure) as predicted by theory. (It should be noted that this is opposite to that found for rolled shapes.)

VI. CONCLUSIONS AND SUGGESTIONS

This column test gives a result which essentially confirms the theoretical analysis given in Reference 1.

In general, the following can be concluded:

(1) For riveted built-up columns, the residual stress of the member as a whole is the same as the residual stress of the component parts. At present there seems to be a greater variation in these stresses than those measured on the WF shape. Therefore, to be able to predict the strength of any one given member it is necessary to know the magnitude and distribution in each of the individual parts.

(2) For cases where the residual stresses in compression are higher in the web (Fig. 3) near its edges, the columns will have greater maximum capacities for weak axis bending than for strong axis. This is due to the fact that

the rate of reduction of the effective moment of inertia about the strong axis is faster when the edges of the web reach the yielding condition first. The three column test results confirm this conclusion.

(3) In Reference 3 it is stated that the strong axis tangent modulus curve is a satisfactory approximation for column strength. Consequently, the statement that the tangent modulus curve can represent a good design standard is therefore further demonstrated.

In accordance with the second conclusion given above, it is recommended that the residual stress patterns for certain rolled shapes other than WF or I should be investigated. This would make it possible to predict the strength of built-up members, fabricated by riveting, with a greater degree of certainty. A confirmation of the column strengths for various composite cross-sectional forms should also be carried out.

Studies of the slip of riveted members subjected to tensile loads have been made. However, in the case of an eccentrically loaded column, the effect of the possible slip might become appreciable and thus influence the behavior of the member as a whole. It is therefore suggested that an investigation should be made of the effect of this variable. Other problems, such as edge preparation of plates (flame cut, rolled, etc.) and method of obtaining holes for riveting should also be considered.

VII. REFERENCES

1. Fujita Y.,
   "BUILT-UP COLUMN STRENGTH"
   Dissertation for Ph.D., Lehigh University, 1956

2. Huber, A. W.,
   "FIXTURES FOR TESTING PIN-ENDED COLUMNS"
   Fritz Lab. Report No. 220A.24, Lehigh University, July 1956

3. Fujita, Y.,
   "PRELIMINARY REPORT ON WELDED AND RIVETED MEMBERS"
   Fritz Lab. Progress Report No. 249-1, May 1956

4. Lee, G. C., and Ketter, R. L.,
   "THE EFFECT OF RESIDUAL STRESS ON THE COLUMN STRENGTH OF MEMBERS OF HIGH STRENGTH STEEL"
   Fritz Lab. Report No. 269-1, 1957

5. Shanley, F. R.,
   "INELASTIC COLUMN THEORY"
   Journal of Aeronautical Science, Vol. 14, No. 5, p. 261, May 1947

6. Bleich, F.,
   "THE BUCKLING STRENGTH OF METAL STRUCTURES"
   McGraw-Hill Book Company, 1st. edition, 1952

7. Huber, A. W.,
   "THE INFLUENCE OF RESIDUAL STRESS ON THE INSTABILITY OF COLUMNS"
   Dissertation for Ph. D., Leghigh University, 1956

VIII. ACKNOWLEDGEMENTS

This work is a part of the experimental investigations of Project 249 (Built-up Column Strength) under the original supervision of Dr. L. S. Beedle, carried out at the Fritz Engineering Laboratory, Lehigh University of which Professor W. J. Eney is director.

Hearty appreciation is expressed to Dr. R. L. Ketter, who gave the author many valuable guidances and suggestions throughout the investigation.

Mr. K. R. Harpel, foreman of Fritz Laboratory with his mechanics and technicians, prepared the specimen and test set-up. Messrs. B. T. Yen, A. Nitta, T. V. Galambos, J. Santos and L. Tall assisted the test. Mr. B. T. Yen also helped in the preparation of the figures. Their cooperation is sincerely appreciated.

TABLE I - SUMMARY OF COLUMN TEST RESULTS

(1) Specimen	(2) Length	(3) Slenderness Ratio	(4) Cross Sectional Area	(5) Yield Stress	(6) Maximum Load Capacity	(7) Axis of Failure
No.	L	$\frac{L}{r}$	(in2)	σ_y (ksi)	(kips)	
R-I	14'-6"	80	19.13	37.1	602	Weak
R-II	11'-0"	60	19.13	37.1	627	Weak
R-III	28'-0"	79.3	19.23*	37.1	572	Strong

* This area was measured about 18 months later than the first two. and by a different investigator.

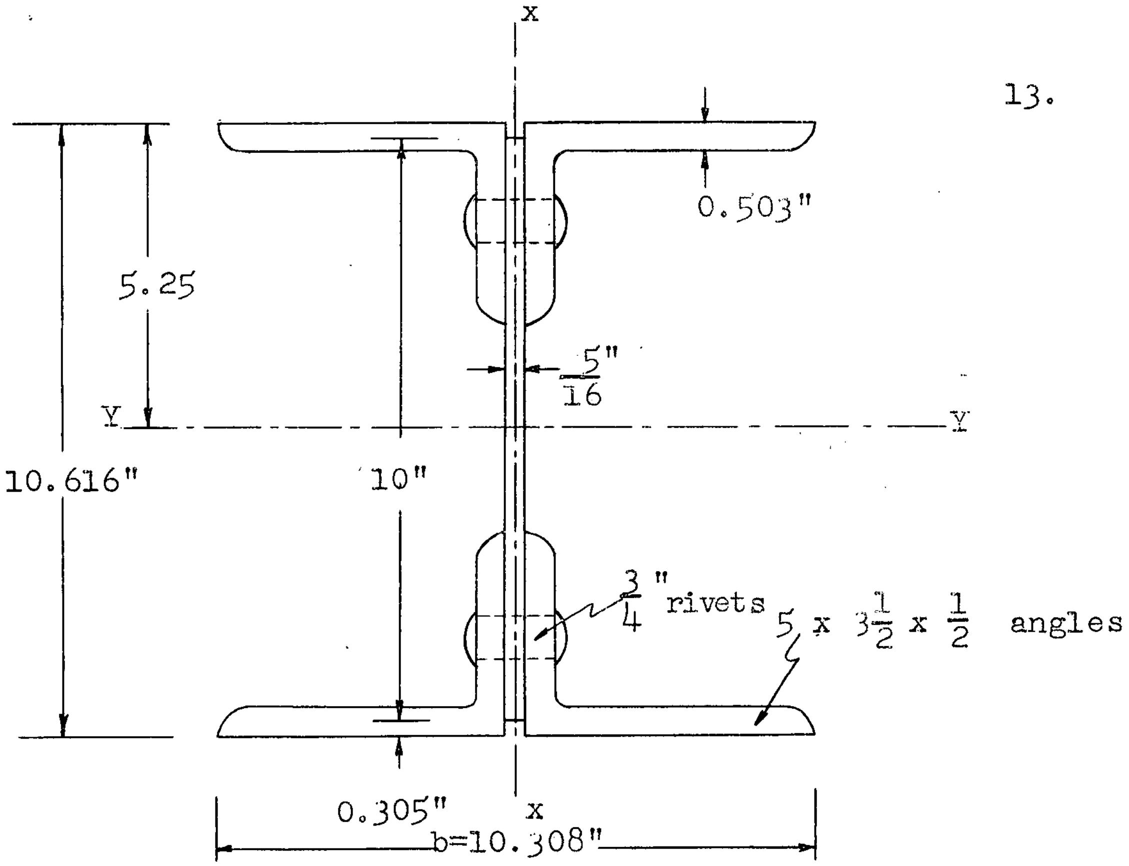


FIG. 1 CROSS SECTION DETAILS

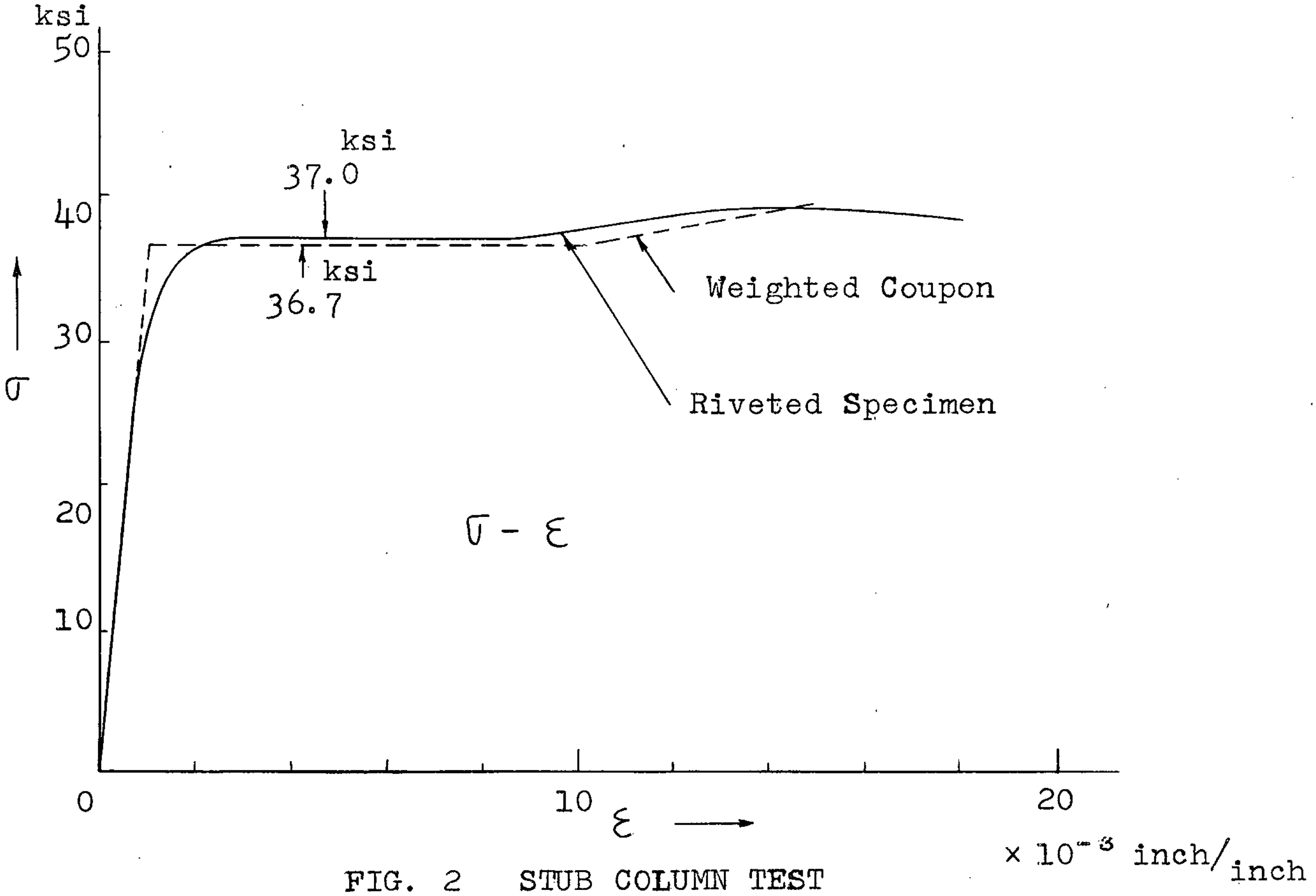
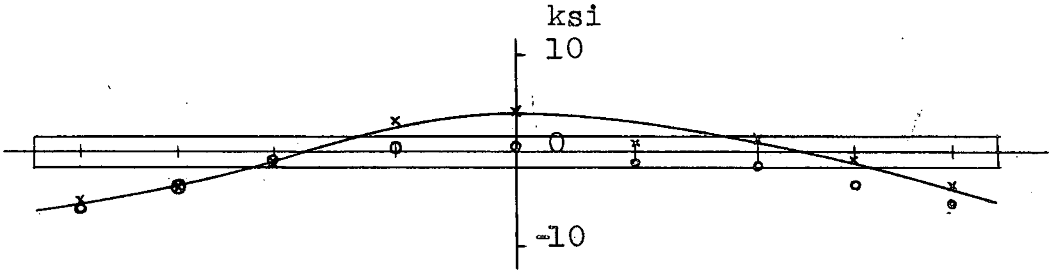
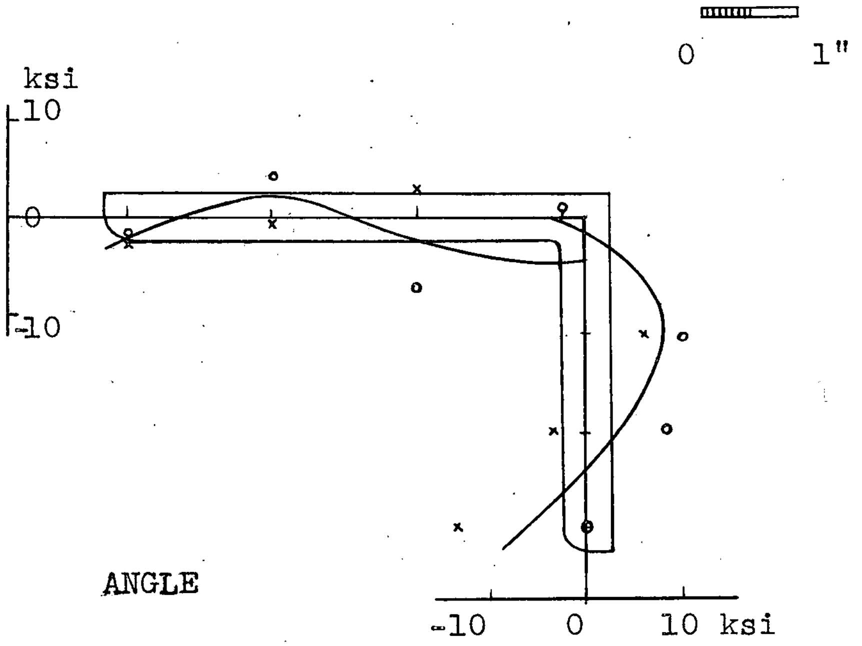


FIG. 2 STUB COLUMN TEST



WEB PLATE
(Universal Plate)



ANGLE

FIG. 3 RESIDUAL STRESS PATTERNS

FIG. 4 R-III COLUMN TEST IN PROGRESS

more detailed view available of restraining device?

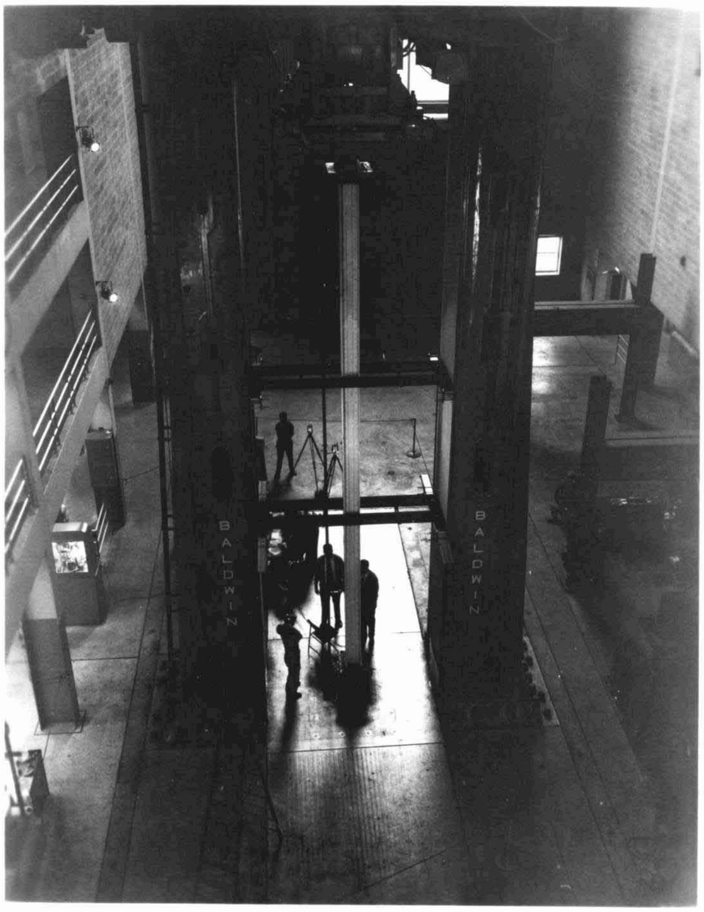


FIG. 5 A VIEW OF THE LATERAL SUPPORTS

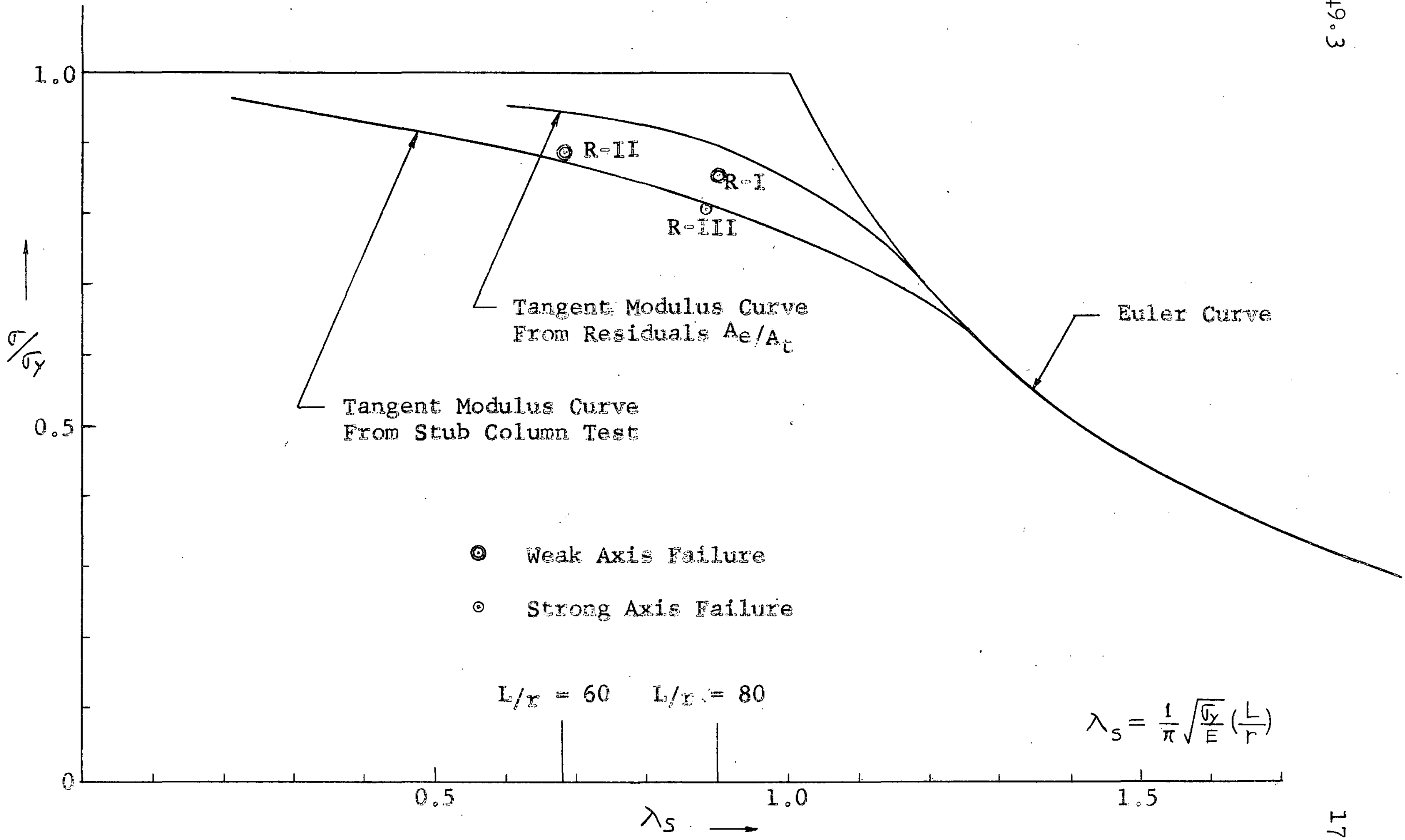


FIG. 6 NON-DIMENSIONAL COLUMN CURVES (Strong Axis)

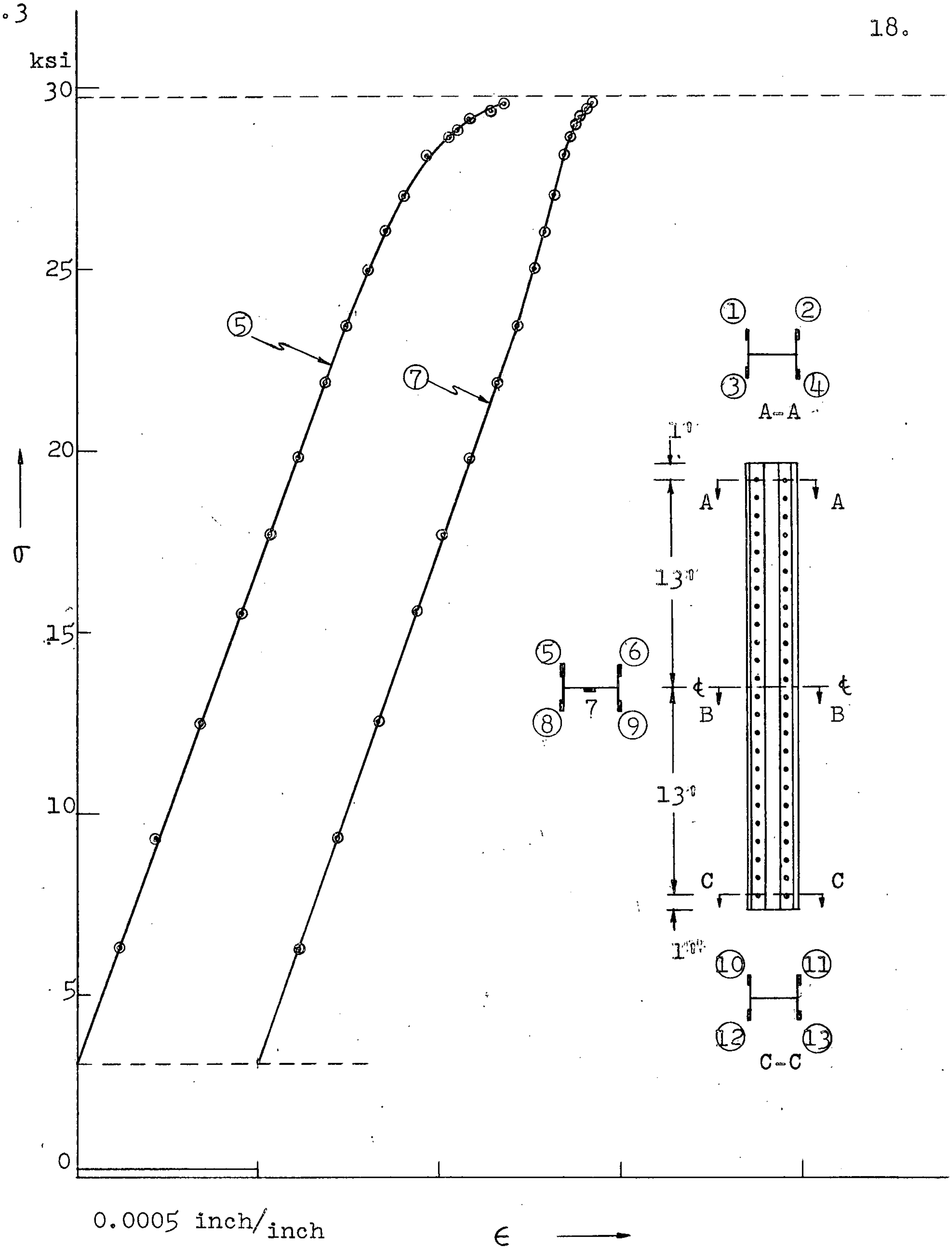


FIG. 7 STRESS-STRAIN CURVES (SR-4 Gages)

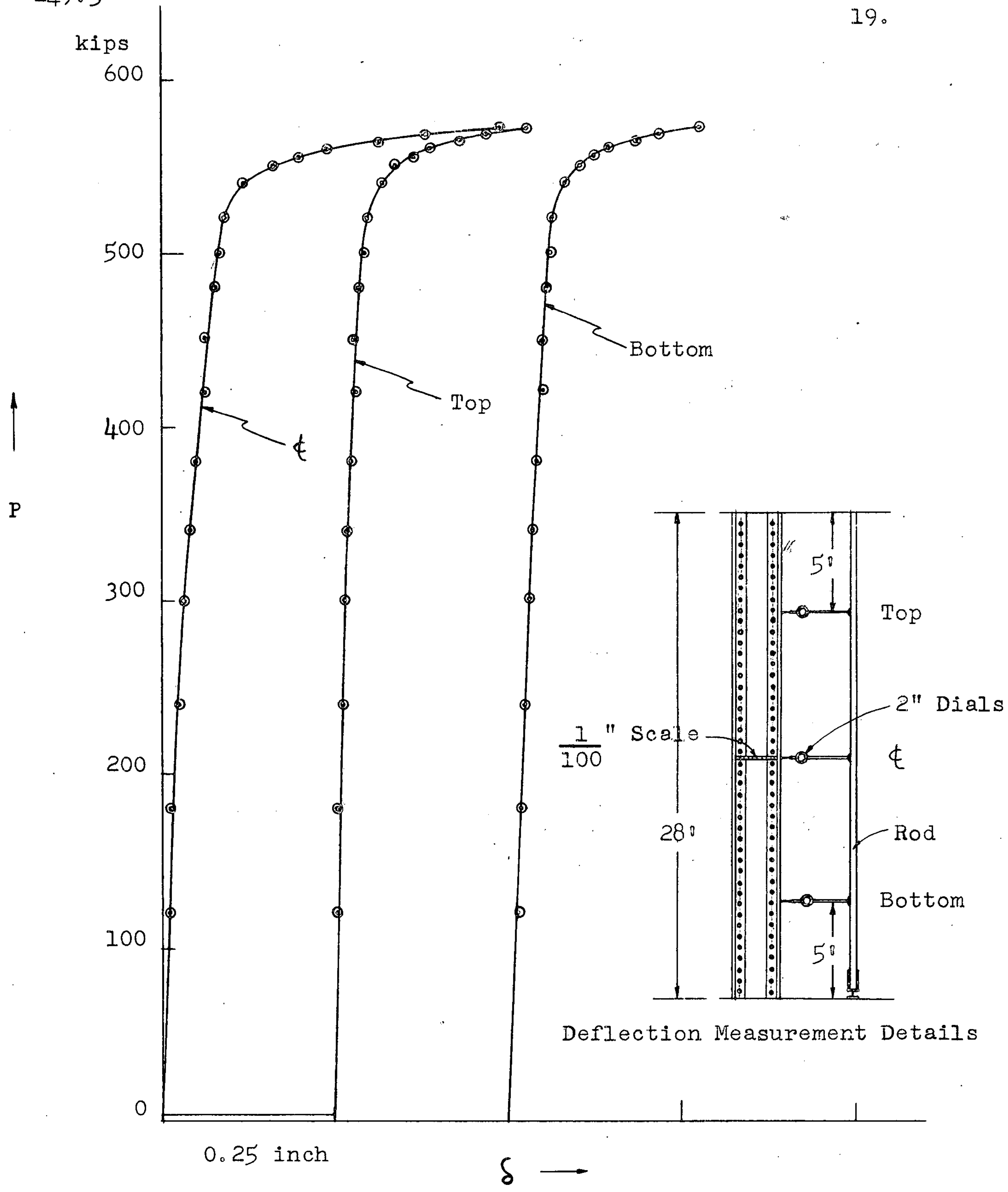


FIG. 8 LOAD-DEFLECTION CURVES (DIAL GAGES)

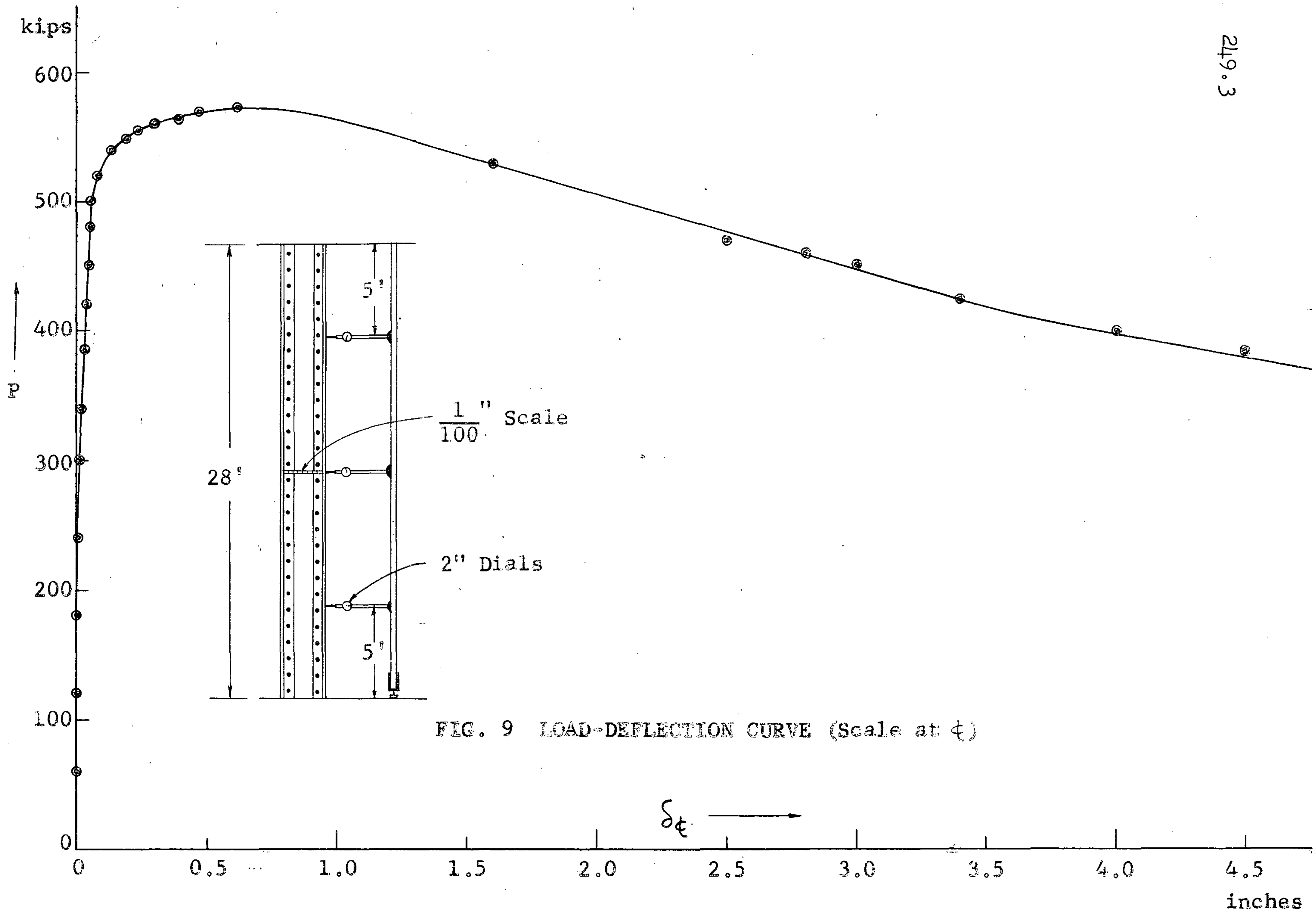


FIG. 9 LOAD-DEFLECTION CURVE (Scale at ℄)

show predicted value

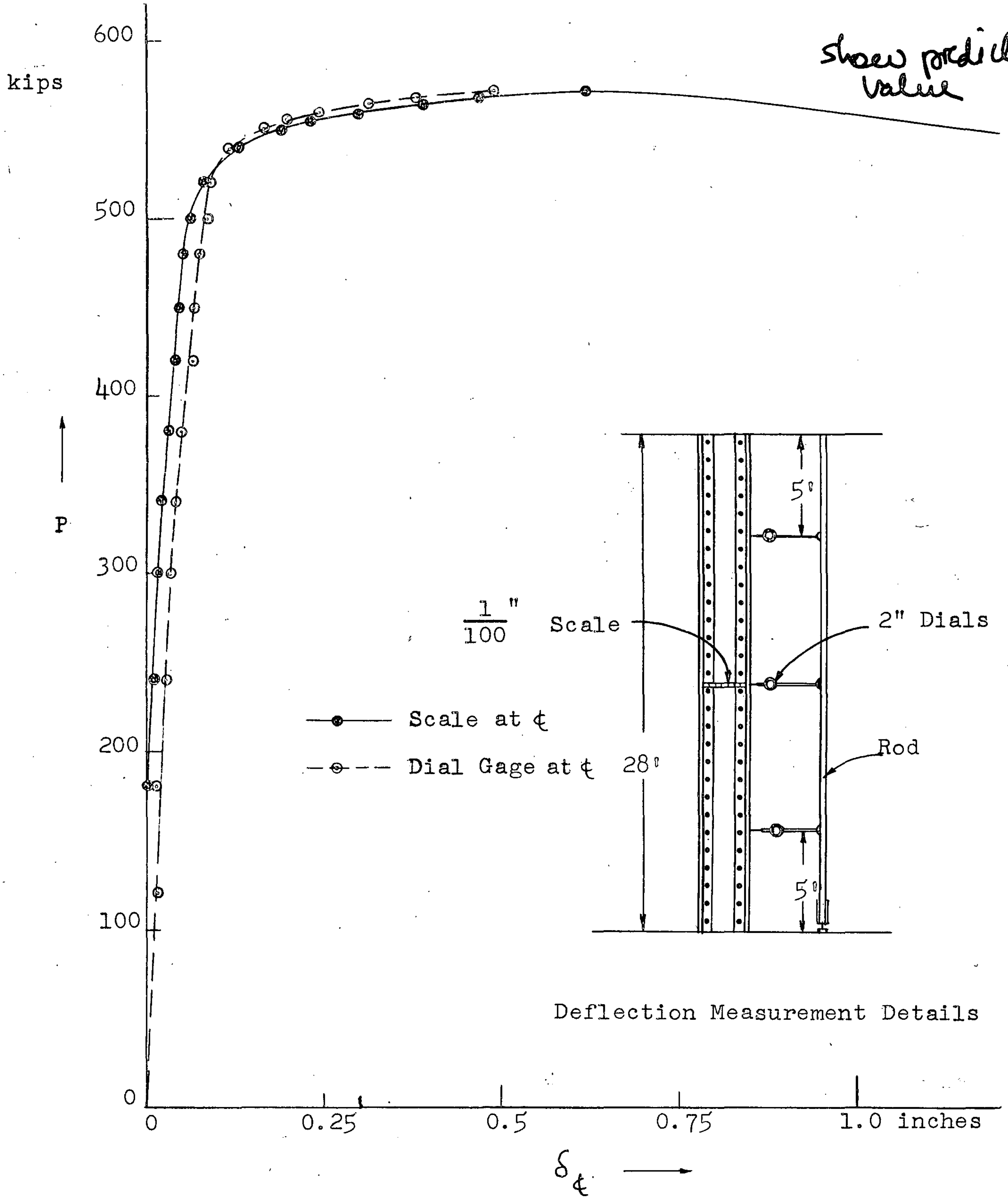


FIG. 10 COMPARISON OF LOAD-DEFLECTION CURVES OBTAINED FROM DIAL GAGE AND SCALE AT ℄