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# Experimental results of the influence of residual stress on column strength

A. W. Huber

R. L. Ketter

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PROGRESS REPORT

EXPERIMENTAL RESULTS OF THE  
INFLUENCE OF RESIDUAL STRESS  
ON COLUMN STRENGTH

*(Not For Publication)*

by

Alfons W. Huber  
and  
Robert L. Ketter

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LEHIGH UNIVERSITY

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## I. INTRODUCTION

The purpose of this report is to present some of the experimental results of two residual stress studies, each of which includes a cross-section test, a set of residual stress measurements and coupon tests, and the correlating results of one full-size column test. One of the residual stress studies and the column test were carried out on as delivered material, while the other residual stress study involved annealed material. The column was allowed to bend about its "weak" axis.

These results have been obtained on the Pilot Investigation of the "Influence of Residual Stress on Column Strength" now underway at Lehigh. The study is sponsored jointly by the Column Research Council, the Pennsylvania State Highway Department and the Bureau of Public Roads. The column test was a part of a program on the "Strength of Welded Continuous Frames and Their Components" sponsored by the Welding Research Council and the Navy Department.

These preliminary data will be included in a complete report to be prepared at the conclusion of the Pilot Investigation. For information, reference is made here to the proposal for this study (Oct. 22, 1952).

## II. RESULTS

Figure 1 shows the location of the test specimens in both as delivered and annealed material. As shown, the materials for the column test, cross-section test, coupon tests, and residual stress measurements were selected from positions adjacent to one another.

Figure 2 shows the measured residual stress distribution in the as delivered material. Compare with the idealized distribution assumed for theoretical analysis in Fig. 4.

Figure 3 shows the stress-strain relation obtained on the as-delivered cross-section specimen and on a small coupon plotted in non-dimensional scale.

Figure 4 shows the column curve for the weak axis computed from the as-delivered cross-sectional stress-strain relation (solid line) and also shows the theoretical curve based on the idealized residual stress distribution (dotted curve). The two curves are in close agreement. The maximum strength of the as-delivered column ( $L/r = 82$ ) is also shown here.

Figure 5 shows the residual stress distribution on the annealed material. The magnitude of residual stress is very small. (Compare with Fig. 2 showing the distribution of residual stress in the as-delivered material.)

Figure 6 shows the stress-strain relation obtained from the annealed cross-section specimen and from a small coupon plotted in non-dimensional scale.

Figure 7 shows the column curve computed from the annealed cross-section stress-strain relation valid for both weak and strong axis. The column curve obtained from the as-delivered cross-section test is also plotted for comparison. The difference between the Euler curve of the annealed and as-delivered material is due to the difference in the values of  $E$  and  $\sigma_y$  of both materials. The difference of these two curves is marked in the region below  $L/r = 100$ .

Figure 8 shows the pattern of cold-bend yield lines present in the member prior to testing. As shown in the sketch the center and lower sections of the specimen were free of these lines. While it is possible to get columns of this length free of cold-bend yield lines, it must be assumed that columns invariably will have been deformed prior to use.

Figure 9 is the load deflection curve for the column test. Theoretically, a concentrically loaded, ideal column should not deflect until the tangent modulus load is reached. In the test, however, a slight deviation was noted from the start. Assuming this deflection due entirely to initial curvature, the initial "out of straightness" would need to be approximately 0.044" to produce the deflections recorded. Since rolling tolerances would allow 0.15", this factor could account for part of the deviation observed during the test. Assuming that the deviation was due to eccentricity alone,  $e$  would need to be 0.014" to cause this deflection.

As shown in the figure, the first yield lines were extensions of previous cold-bend lines. These lines, however, neither increased in size nor were additional zones formed after the first ones were observed. This is consistent with theory.

Yield lines due to cooling residual stress appeared in the column at the predicted load based on the residual stress measurements.

Figure 10 is a curve similar to that used by Shanley to illustrate that bending can occur without strain reversal. Gages 6 and 10 increased quite rapidly before gages 5 and 9 reversed.

Figure 11 shows the strain-distribution in the elastic and plastic stages. It shows, again, that bending occurred without strain reversal.

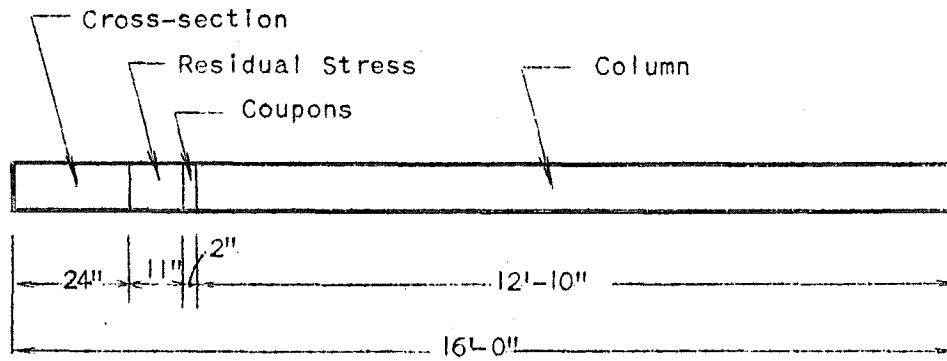
Gage 10 was located on the flange containing the greatest cooling residual stress (approximately 13 ksi see Fig. 2). Therefore gage 10 would be expected to increase more rapidly at an earlier load than the other gages. Such was the condition observed in the test.

### III. DISCUSSION

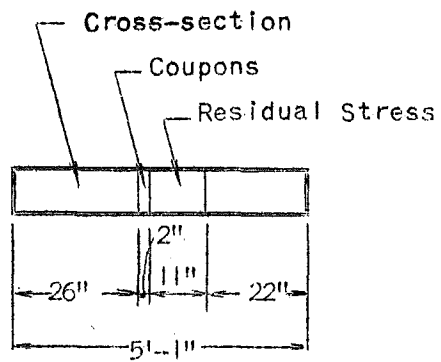
1. Good agreement was observed between the column test ( $L/r = 82$ ) and the column curves predicted by cross-section test and by residual stress measurements (Fig. 4).
2. The column curve computed from the cross-section stress-strain relation by application of tangent-modulus theory is in good agreement with the theoretical solution based on the residual stress measurements.
3. As would be expected from theory, the column curve for the annealed material as obtained from a cross-section test (Fig. 7) predicts strengths greater than does the column curve for as-delivered material. Column tests should be made in the region of greatest reduction using annealed material.
4. Since annealing did not remove all of the residual stress (Fig. 5), a part of the lowering of the corresponding column curve in Fig. 7 (solid line) is undoubtedly due to this residual stress.
5. Even though the first yield line produced during the column test was in a region of cold-bending, its effect was local (as shown by the flaking of mill scale). Once these several lines were formed, there was no further development. Cooling residuals, however, caused a marked change in behavior - as was expected.

6. The small reduction in load carried by the column below that predicted from the cross section test or the residual stress measurements can be attributed to the fact that perfect alignment and absolute straightness are impossible on tests and both cause a reduction in strength. It is expected that these reductions are of small amount.
7. The column curve obtained from the cross-section test is a function of the residual stresses present in the specimen. If there is an appreciable variation in these stresses along the member, the column strength predicted by the cross-section test will differ from column tests, even though the specimens may come from immediately adjacent locations. Therefore, the variation of residual stresses along a member should be investigated.
8. These results are in confirmation of the same tests upon which this investigation was based. The correlation between column test and cross-section test is good and, further, the cross-section test gives results which agree with those predicted on the basis of residual stress measurements and coupon tests. These results therefore furnish additional evidence that residual stresses due to cooling after rolling cause a reduction in column strength, a reduction that can be predicted by either cross-section tests or by residual stress measurements and coupon tests.





As-delivered 8WF31



Annealed 8WF31

Fig. 1 Location of Test Specimens

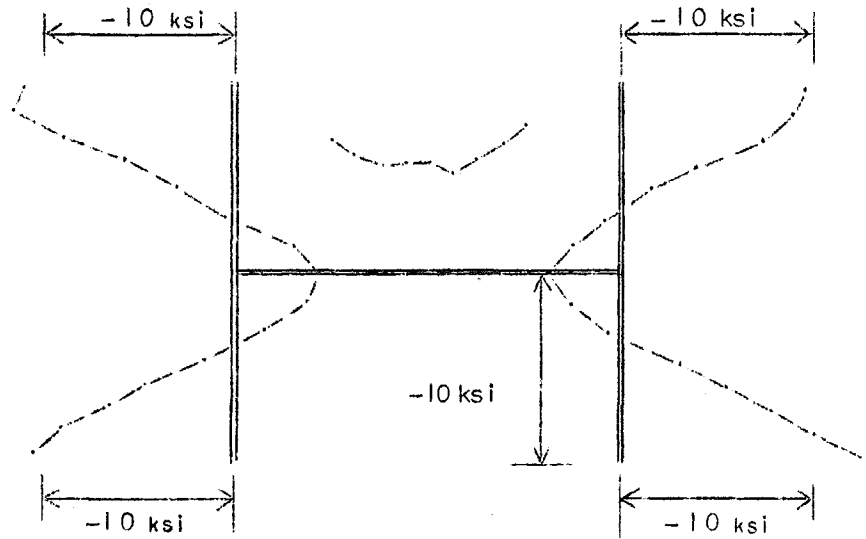


Fig. 2 Residual Stress Distribution (as delivered)

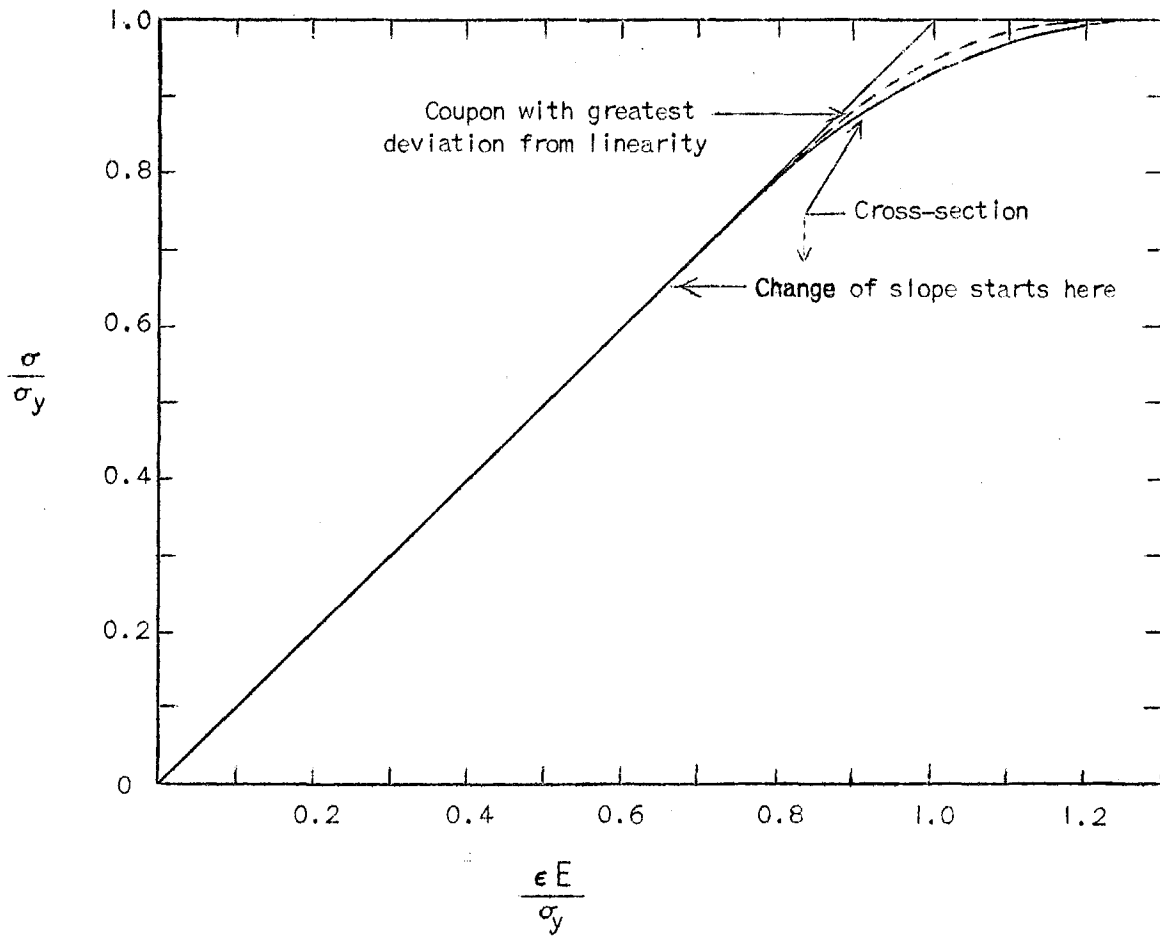


Fig. 3 Stress-Strain Curves (as delivered)

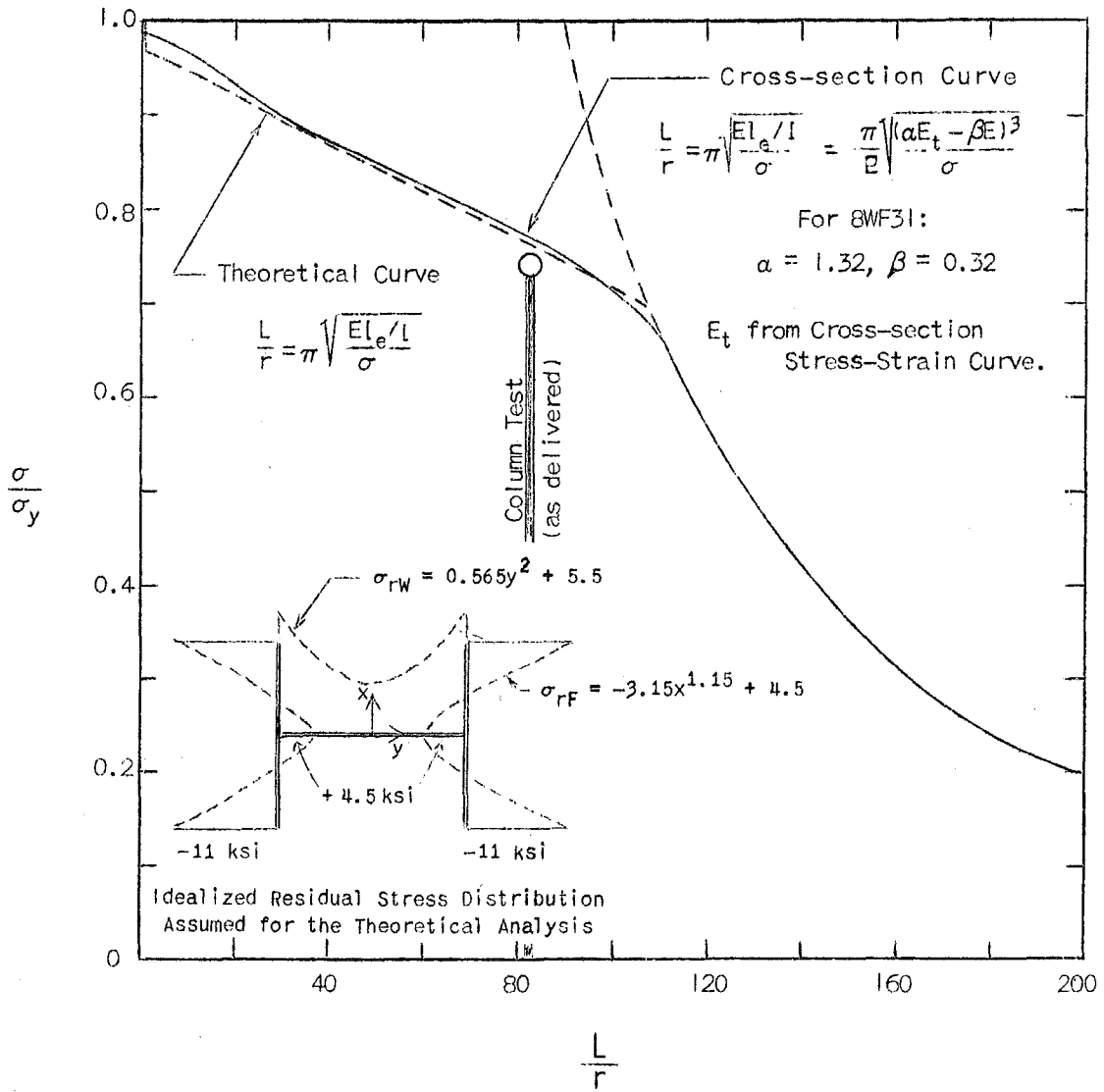


Fig. 4 Column Curves (weak axis, as delivered)

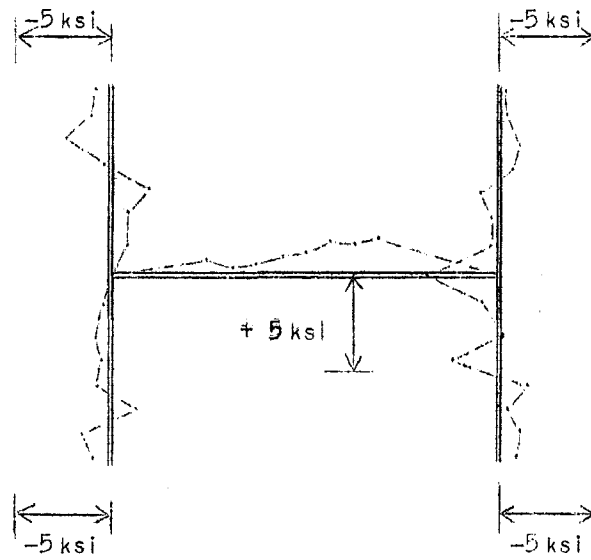


Fig. 5 Residual Stress Distribution (annealed)

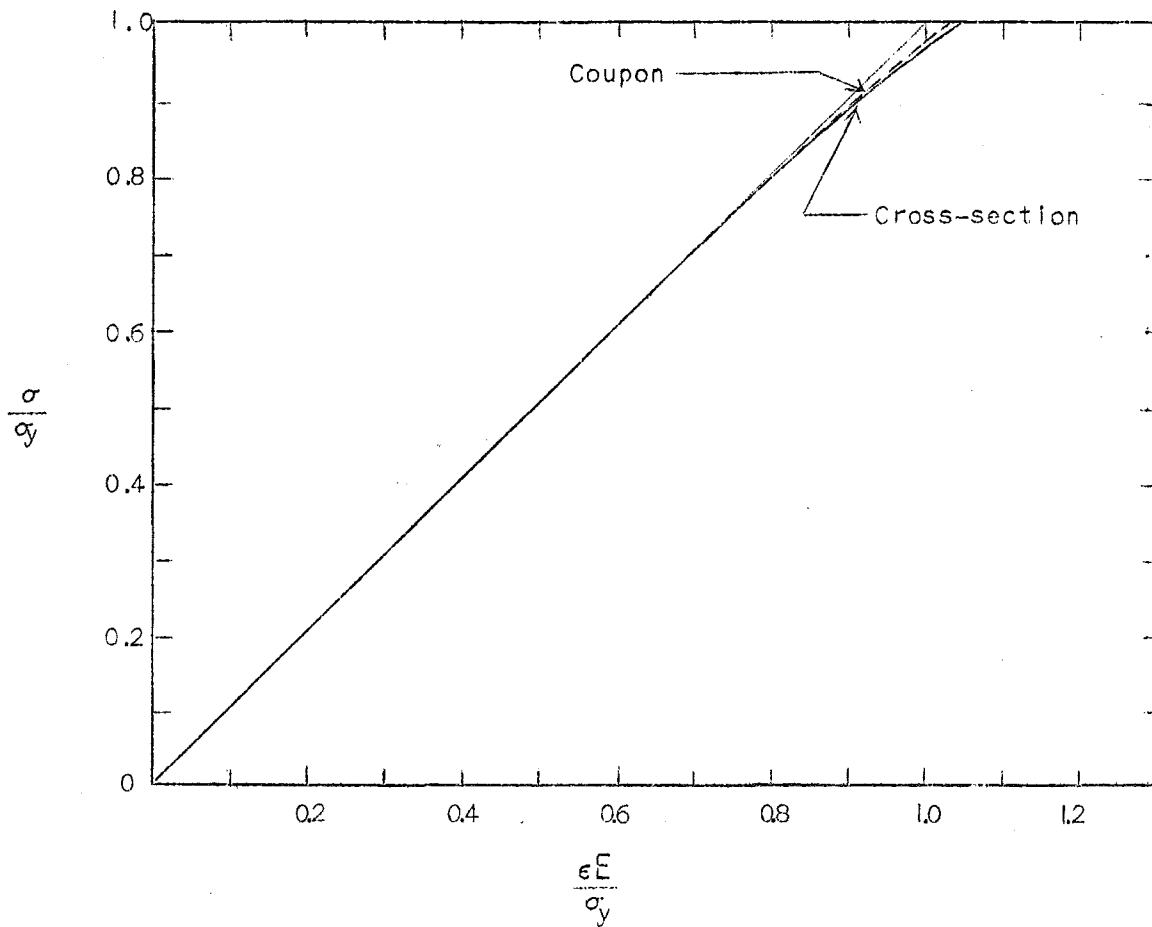


Fig. 6 Stress-Strain Curves (annealed)

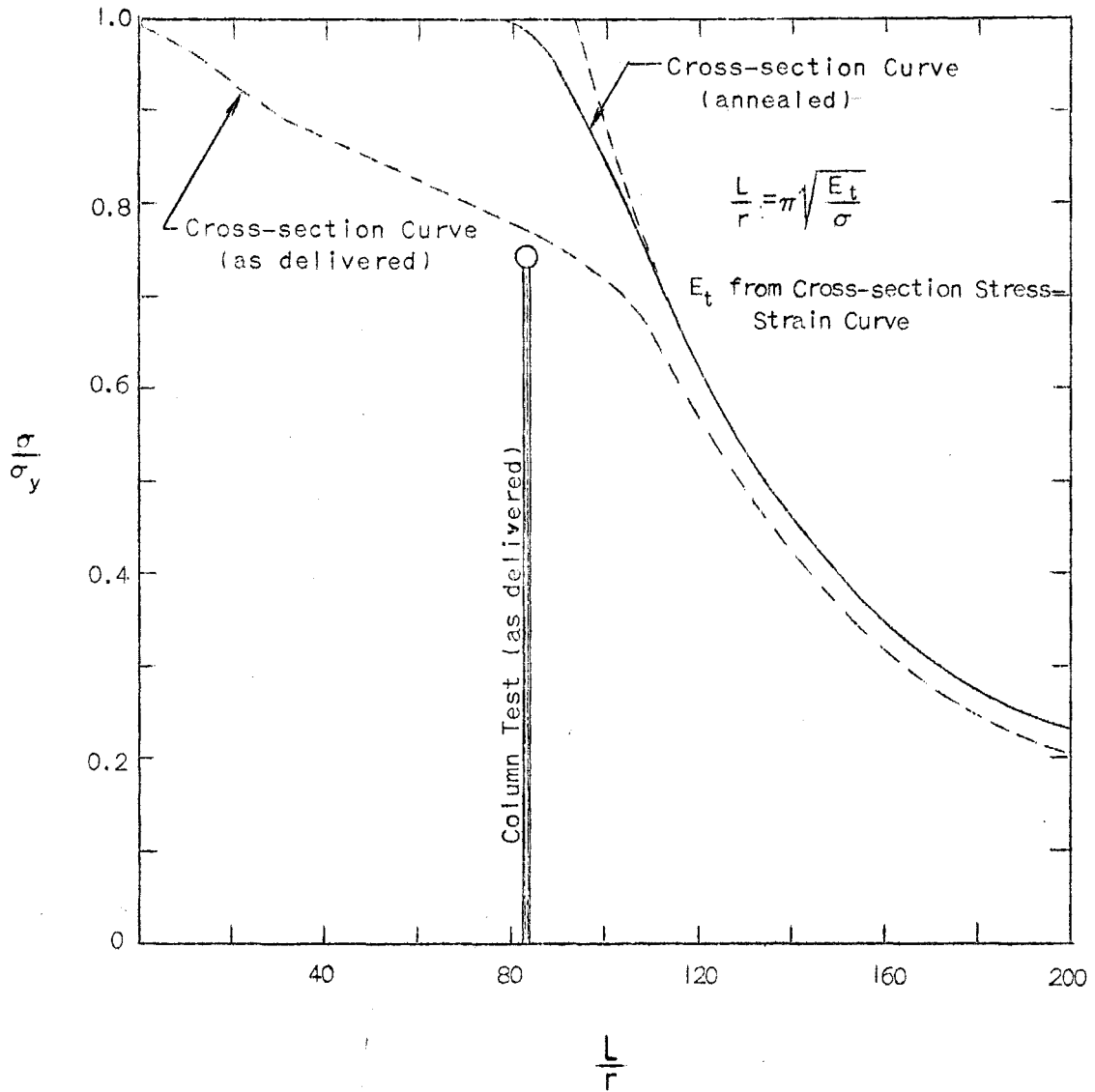


Fig. 7 Column Curve (annealed)

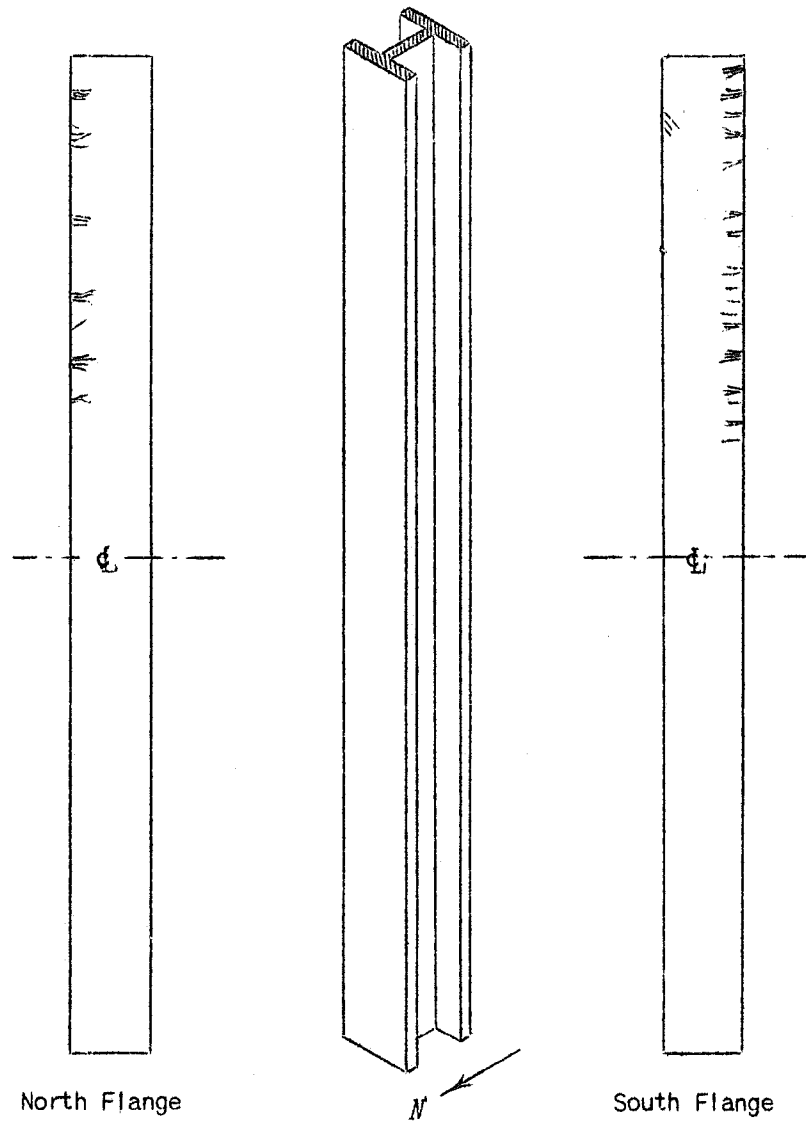
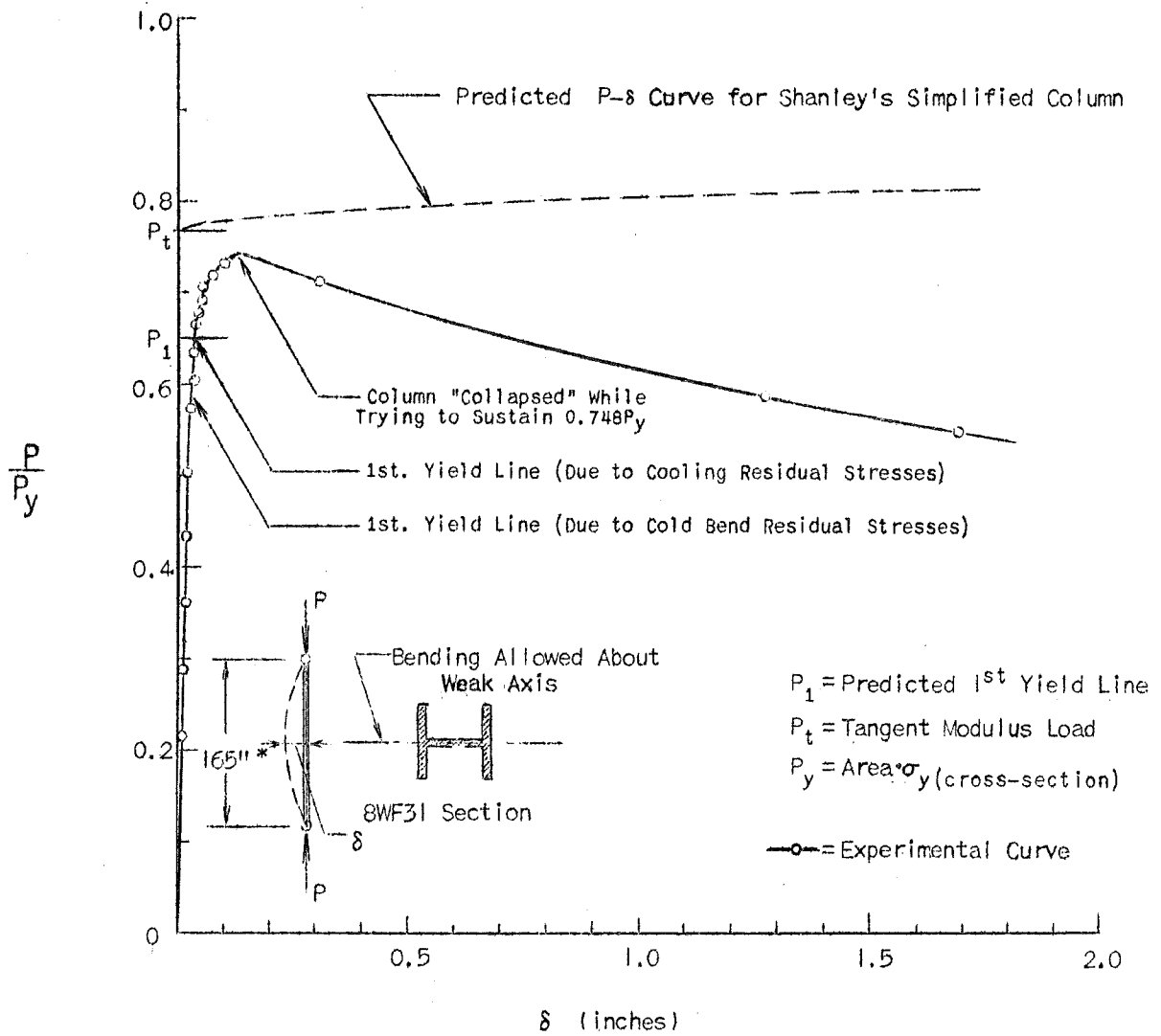


Fig. 8 Cold Bend Residual Stress Pattern



\* Subtract  $11\frac{1}{2}''$  to obtain actual length of column between base plates.

Fig. 9 Load-Deflection Curve

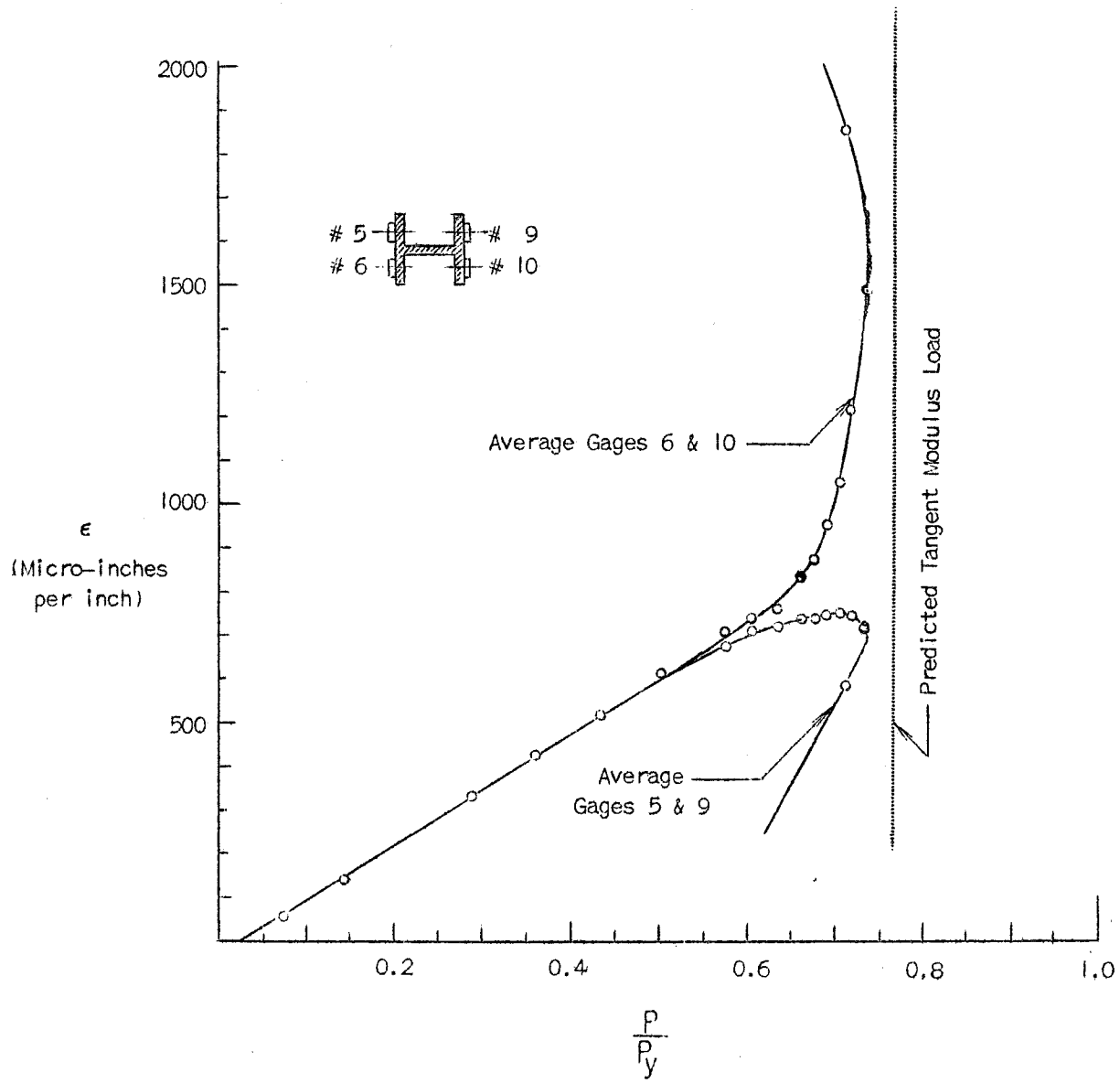


Fig. 10 Load-Strain Curves



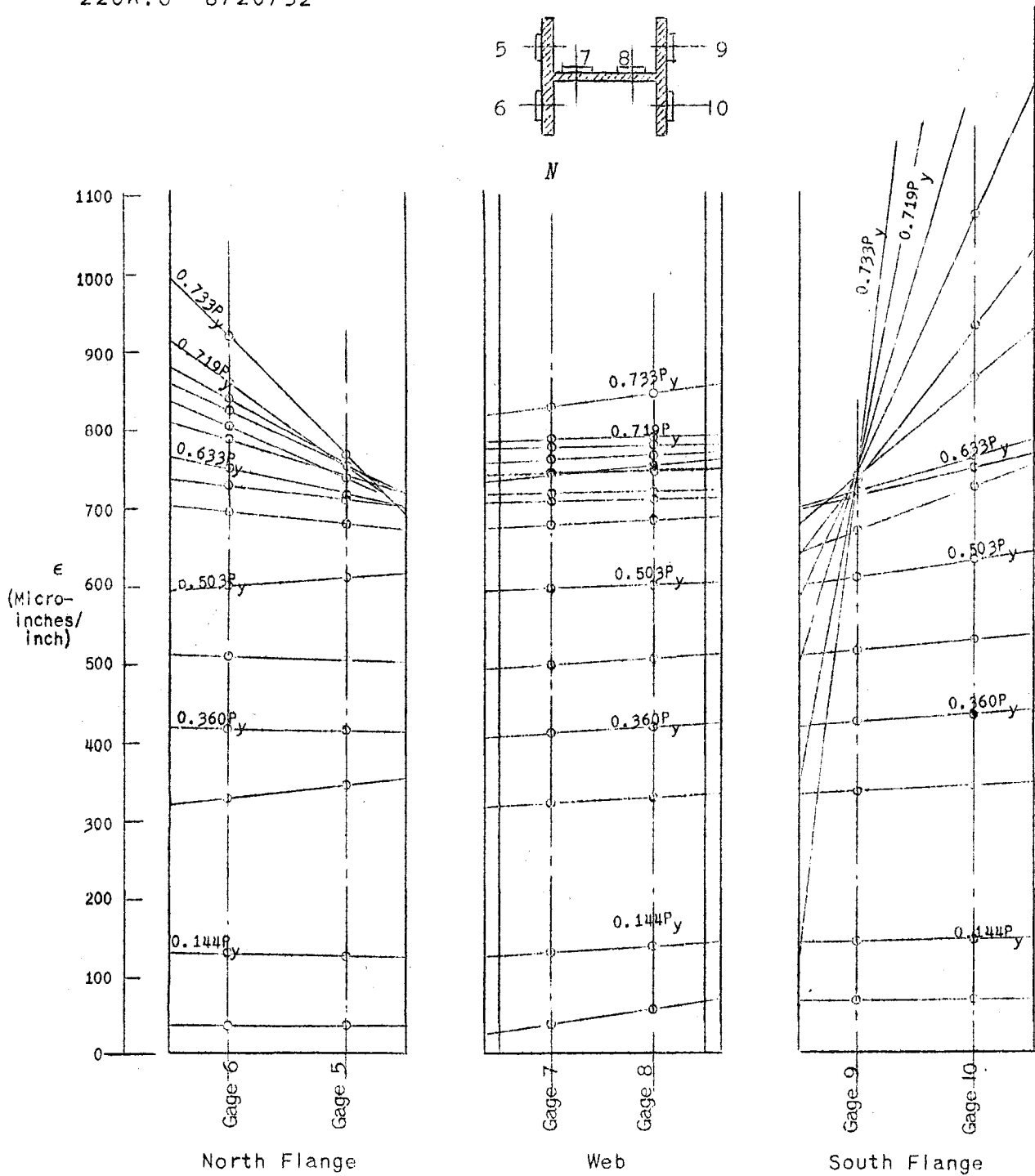


Fig. 11 Strain Distribution at  $\angle$  of Column