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RESIDUAL STRESS AND THE COMPRESSIVE PROPERTIES OF STEEL

Progress Report

FIXTURES FOR TESTING PIN-ENDED COLUMNS

by

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This work has been carried out as a part of an investigation sponsored jointly by the Column Research Council, the Pennsylvania Department of Highways and Bureau of Public Roads, and the National Science Foundation.

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I. A B S T R A C T

A description is given of the design and the performance of column end fixtures with cylindrical bearing surfaces. These fixtures were designed for heavy loads (maximum 2,000,000#) and simulate a pin-ended condition in one direction and fixed-ended condition in a direction at right angles to the first.

The fixtures can be used for axial or eccentric column tests with equal end eccentricities. Adjustments to compensate for uneven bearing and to correct for accidental eccentricity can be made.
2. INTRODUCTION

In order to test columns under known end conditions, special fixtures are required. In general the ideal end conditions assumed in theory must be simulated experimentally.

The experimental part of an investigation carried out at the Fritz Engineering Laboratory, Lehigh University, on "Residual Stress and the Compressive Properties of Steel", called for axial tests of a variety of wide-flange columns.\(^{(1)}\) The column end fixtures described in this report were designed for this purpose.

A knife edge assembly previously had been used at the laboratory for the test of axially loaded columns and of columns under combined thrust and moment.\(^{(2)}\) However, the knife edges did not have sufficient capacity for the heavier sections to be tested in the program. In reference \(^{(3)}\) an interesting design of hydraulically supported end fixtures is presented. These, too, were limited in application to rather low loads. Another design of end fixtures is described in reference\(^{(4)}\) for the testing of very heavy built-up columns under axial load (Capacity of more than 3,000,000#). End bearing is provided by approximate line loading through an assembly of plates of subsequently reduced widths. The application of these fixtures is limited to columns that carry high loads, otherwise the accuracy of the test results will be influenced by the end conditions.
The main requirements for the fixtures were a wide load range with a maximum capacity of 2,000,000#, low cost, simplicity, the possibility of adjusting for column imperfections, and finally to simulate pin-ends for the direction of desired buckling of the columns. A solution that satisfies these requirements was obtained by the adoption of a cylindrical bearing surface within an assembly of plates and wedges which could be used for adjustments.

A description of the design and the performance of the fixtures follows below.
3. DESCRIPTION OF COLUMN END FIXTURES

Cylindrical fixtures have been used previously for testing model columns under pin-ended condition. Such fixtures simulate a pin-end condition by rolling on the platens as the column bends. (Figures 1, 3, and 10). The cylinder radius is made such that its center is at the end of the column. Thus the line of force will always pass through the same point (Fig. 1).

Figure 3 shows the fixtures in place for an axial column test of a WF in an 800,000# testing machine. A close-up of the bottom fixture is shown in Fig. 2. Top and bottom fixtures are identical in design. The top fixture is held by screws against the cross-head of the testing machine while the bottom fixture just rests on the testing machine platform. The total weight of both fixtures is 4,538#. All material used is A7 Steel with exception of the cylindrical surface and the bearing blocks.

The following elements make up the fixture assembly. They are identified and dimensioned in Fig. 4. An exploded view is given in Fig. 5.

(a) **Column Base Plate:** The plate has slots in the interior for the bolts that fasten it to the fixture platen. At two opposite sides are cut-outs that serve as anchorage for four
bars which permit a relative movement of the column base plate with respect to the platen (control of eccentricity). The test column is welded to this base plate.

(b) **Fixture Platen**: This platen has a series of drilled and tapped holes for fastening the bolts that hold the column base plate. The cylindrical bearing surface is also attached to it by two screws. At two opposite sides are four small plates which serve as anchorages for the bars that permit relative movement of the column base plate. (See Fig. 4·d)

(c) **Main Cylindrical Bearing**: This consists of steel, heat treated to 70/80 Shore Soleroscope surface hardness. The radius of the bearing surface is located at the center of the column base plate. This, then, is also the location of a hypothetical pin and the actual column length can then be used in calculation.

(d) **Bearing Block**: This block bears on the cylindrical bearing and serves to distribute the load between the wedges and the small cylindrical bearings. It was also heat treated to the same hardness as the main cylindrical bearings.

(e) **Adjusting Assembly**: This assembly consists of wedge blocks, small cylindrical bearings, a base plate, spacers, tees and angles for fixing the location of the various elements.

The adjusting assembly permits the correction of uneven
bearing or out of squareness of the column for the direction normal to the direction of buckling. This is done by moving the wedges with tie bars that are anchored to stiffened tees; the bearing block thus pivots about the small cylindrical bearing until proper alignment is achieved. The column can be considered fully fixed for this direction. This end condition is desirable because no lateral bracing will then be required for a majority of column sections for a buckling test about the strong axis.

The fixture assembly is held together by side plates (Fig. 2). The lower side plate in Fig. 2 holds the adjusting assembly together. The upper side plate in Fig. 2 is necessary for the column set-up. The upper screws in the slotted holes are removed during the test and the cylindrical bearing can roll on the bearing block. A stud in the center of a circular cut-out on the upper side plate limits the total movement of the cylindrical bearing. This prevents the column from tipping over when the load is accidentally released.
The fixtures were designed for a maximum load of 2,000,000#. The main cylindrical bearing and the bearing block in contact with it were heat treated to 70/80 Shore Scleroscope Surface hardness in order to sustain high bearing stresses elastically. All other parts were made of untreated A-7 steel.

The bearing stresses along the area of contact of the cylindrical and horizontal surface were calculated by the equations of Hertz(6) (Both contacting surfaces are assumed to have equal modulus of elasticity, E, and Poisson's ratio equal to 0.3).

$$\sigma_{\text{max}} = 0.591 \sqrt{\frac{pE}{2r}} = 209,000 \text{ psi}$$

where $p$ is the pressure per linear inch ($\frac{2,000,000}{24}$), $r$, the radius of the cylindrical surface ($r = 10"$) and $E$, the modulus of elasticity (assumed as 30,000 Ksi).

The width of the bearing area is given by

$$b = 2.15 \sqrt{\frac{2pr}{E}} = 0.506"$$
5. TEST SET-UP AND ALIGNMENT

The set-up and alignment of the fixtures and test specimens is as follows. First, the upper fixture is positioned on the testing machine platform, after which the movable cross-head of the testing machine is lowered, the fixture is attached to it and the head is taken to the desired position. Next, the column test specimen with base plates welded in position is brought in vertically, is rolled under the upper fixture, and by means of the upper base plate is attached to this fixture with bolts. Finally, the bottom fixture is rolled underneath, and is set on the testing machine table, and the column is lowered and bolted at the bottom. (Fig. 6)

The alignment is first done geometrically and then checked by loading within the elastic limit of the material. This check is made by strain readings, deflections and rotation measurements and plumb bob or theodolite. The following adjustments can then be made on the top and/or bottom fixtures:

(1) Plumbness: (a) In the direction of buckling: The cross-head is raised with the test specimen and the line of contact is relocated between the cylindrical surface and the bearing block on the lower fixture.
(b) In the normal direction:
The wedges are either raised or lowered as required.

(2) **Eccentricity:** The column base plates are moved in relation to the fixture platens. (This can be done under a low load of a few thousand pounds).

(3) **Uneven Bearing:** This can be corrected by the adjustments listed under (1). (Here also it is not necessary to remove completely the load on the specimen).

Typical column test set-ups are shown in Figs. 3 and 7. Fig. 3 shows the test in progress on an eccentrically loaded column in an 800,000# testing machine while Fig. 7 shows a test of a 30 foot column(14WF111)in the 5,000,000# testing machine at Fritz Laboratory.
6. TESTS OF THE COLUMN END FIXTURES

The object of these preliminary tests was to find out if any appreciable end restraint is provided by the fixtures as they roll on the platens during column deflection. This restraint should be so small that it can be safely neglected. Two different tests were made to check the performance of the fixtures.

(a) For a check of the lower range of loading, a test on an eccentrically loaded column was performed in the elastic range (Fig. 3). The test results are compared with theoretical predictions in Fig. 8. The load-deflection relation at midheight is shown in Fig. 8a. The rotations of the lower column base plate is shown as a function of the load in Fig. 8b. (Due to elastic deformations of the base plate it is necessary to retighten the screws holding the base plate to the platen. If this is done at 100k load intervals the relative rotation is negligible between the column base plates and the fixture platens.)

The results of this test indicated that no appreciable restraint is provided by the fixtures. A restraint would have reduced the magnitude of the deflections and end rotations.

(b) To test the fixtures to 75% of their theoretical design capacity a second test was performed. The set-up is shown in
Fig. 9 and schematically in Fig. 10. A short specimen was centered between the fixtures. A jack connected to a dynamometer for measuring the force was fixed eccentrically between the fixtures. Thereby an additional axial force and a moment could be applied and the deformations (end rotations and bending strains) determined. Measurements were made by level bars attached to the fixtures and dial gages between base plates (Fig. 9). The test results are shown in Fig. 11. The axial load is plotted versus the axial strain (calculated from the dial gages) in Fig. 11a. The moment (calculated from the jack load) is shown as a function of bending strain, $\Delta \varepsilon$, and end rotation for various values of axial load ($450, 800, 1150, 1500$ Kips) on Figs. 11b and 11c. The theoretical curves (under the assumption of a perfect pin) are also shown.

While the experimental results show some scatter, there is little difference between the curves for the different axial loads and the theoretical curves for small deformations. Deformations were observed immediately upon application of moment. In order to obtain a numerical estimate of the resisting moment a parallel to the theoretical curve is drawn in Fig. 11b and 11c. For the maximum test load of $1,500$ kips this resisting moment was about $25$ k-in. If this result is interpreted in terms of axial and bending strain of a $10 \times 10$ inch section, the bending strain amounts to $1\%$ of the axial strain. The actual resistance was less for all loads and small deformations. In addition, the test condition was more
severe because of the shortness of the specimen. A slender column is expected to exhibit even less resistance to rotations of the ends.

An inspection of the bearing blocks after the test did not indicate any permanent set.

Finally, it is concluded that the fixtures have negligible end restraint for all practical purposes.
7. ACKNOWLEDGEMENTS

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8. BIBLIOGRAPHY


FIG. 1  END FIXTURE ACTION

FIG. 2  BOTTOM END FIXTURE
FIG. 3  ECCENTRIC LOAD TEST OF 12 WF 50 COLUMN
Note: Bottom Fixtures are identical with the Top Fixtures except for the bolt attachment of the Base Plate.
FIG. 5 EXPLODED VIEW OF BOTTOM END FIXTURES
FIG. 6 COLUMN TEST SET-UP (SCHEMATIC)

FIG. 7 AXIAL LOAD TEST OF 14WF111 COLUMN
FIG. 8 RESULTS OF ECCENTRIC LOAD TEST OF 12WF 50 COLUMN
FIG. 9 TEST OF END FIXTURES

FIG. 10 TEST OF END FIXTURES (SCHEMATIC)

Hydraulic Jack
Dynamometer
FIG. 11 RESULTS OF END FIXTURE TESTS