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Welded Built-Up Columns

THE TESTING OF PINNED-END COLUMNS

by

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and

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Lehigh University
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ABSTRACT

A procedure for the testing of pinned-end columns is presented in detail. The typical basic types of end fixtures which provide ideal pinned-end conditions are illustrated and evaluated. An end fixture, designed to carry an axial load of two million pounds, is discussed in connection with column tests conducted at Lehigh University. A procedure for data analysis and the evaluation of the results is presented.

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I. INTRODUCTION

This report presents a procedure for testing columns under ideal pinned-end conditions. The scope of the procedure is applicable to columns of rolled shapes as well as to columns of riveted and welded shapes with an estimated ultimate carrying capacity of up to 2,000,000 pounds. The limit is set only by the capacity of the end fixture and of the available testing machine.

Generally, either of two methods are used at present for preparing the column specimen for column testing. The first method requires the careful alignment of the axis of the column cross section with the axis of the loading heads of the testing machine. Preliminary strain readings are taken to ensure that the column specimen is centrally loaded. A preliminary measurement of residual stress distribution and initial out-of-straightness is taken and recorded. The data are then used to obtain a theoretical prediction of the strength of the column, which will be the basis of comparison with the experimental value.

In the second method, no special attention is given to the alignment of the axes of the column and the testing machine, except for a careful geometrical alignment. As a result, the influence of the variables affecting column strength cannot be separated distinctly. The test results from this type of a set-up may be analyzed statistically giving an empirical type formula for the ultimate carrying capacity of columns.

In this report, particular attention is given to the first method which was used extensively at the Fritz Engineering Laboratory of the

Department of Civil Engineering, Lehigh University. The tests were conducted in connection with several research studies on column strength under the guidance of Task Group 1 of the Column Research Council. The subsequent discussions of testing and testing techniques are based on the procedures used in the different research projects conducted at Lehigh University.

II. THE PINNED-END COLUMN

1. DEFINITION

A compression member with its length considerably larger than its cross-sectional dimension may be defined as a column. Columns have varying conditions of end restraint, ranging from the fixed-end condition to the pinned-end condition. Under both types of end conditions, no linear translation of the end of the column occurs relative to the load. The difference between the two conditions exists in the provision of restraint against angular rotation. For the fixed-end column, there is a complete restraint against angular rotation at the end of the column. As a result, the slope of the elastic curve at the fixed end is zero. On the other hand, under the pinned-end condition, no restraint exists and the column end is free to rotate.

2. APPLICATION

The end action of columns used in practice lies between the two limiting conditions of full restraint (fixed end) and zero restraint (pinned end). In testing column specimens, there is a need to isolate the effects of such factors as end conditions, residual stresses, initial out-of-straightness, eccentricities of load, and transverse loads. Most tests on columns did not isolate these various factors so that test results with a wide scatter band were obtained instead of a well-defined relationship between strength and slenderness ratio.

With regard to the effect of end condition, the choice may be reduced to the two limiting conditions of end restraint. In testing column shapes under the fixed-end condition, a degree of doubt exists as to whether full restraint is provided in the entire range of the test loads. This doubt is due to the indeterminate nature of the stress distribution at the end, particularly at the range of loads where the material starts to flow. When compressive residual stresses exist in the cross-section, the flow of the material is non-uniform.(1) Under the pinned-end condition of testing, the maximum conditions of stress will exist at about the mid-height section, which is the critical section under study. Thus, the stress distribution at the section of interest is not influenced by the St. Venant end effect. For this reason as well as other reasons such as the shorter column length required for pinned-end specimens, most column strength investigators have used the pinned-end condition for column testing.

Although the pinned-end column is an idealized column not existing in actual structures, an extensive study of its behavior is relevant to the problem of column design. The pinned end column must be regarded as the basic column, since all column specifications throughout the world are defined in terms of such a column. Until methods for the design of structures as a whole come into use, the design of columns will continue to be based on the strength of the simple pinned-end column.

The analysis of the behavior of a pinned-end column represents the most fundamental column instability problem. Each of the factors influencing column strength may be studied separately in the light of its effect on the column strength characteristics of the pinned-end column.

One such study, which was conducted at Lehigh University, successfully showed that in rolled WF shapes of A7 steel:(2)

(1) Residual stress is the most important influencing factor for column strength and

(2) The column strength may be calculated by the tangent modulus theory, taking into account the effect of residual stresses.

As a result of this study, there is a more realistic insight into the behavior of columns, particularly as influenced by the presence of residual stresses. The investigation has proven that for perfectly straight, centrally-loaded pinned-end columns, the transition curve is entirely due to the presence of residual stresses in the cross-section.(3)* The success of this study hinged on the isolation of the effect of residual stresses on the behavior of the pinned-end column.

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*The Column Research Council Basic Column Curve is based on this concept and is the result of the work done at Lehigh University.(2) In turn, the allowable stress given by the AISC Specifications is based on the CRC Basic Column Curve.(4)

III. TEST PROCEDURE

1. OBJECT

To obtain a load vs. deflection curve for an experimental column of a given slenderness ratio.

2. PREPARATION

a. The column specimen is cut from a straight portion of the fabricated column length to minimize the initial out-of-straightness of the specimen.

b. The outside dimensions of the specimen are checked at different points along the column length to ensure that there is no appreciable difference from the specified nominal dimensions.

c. The length of the column and the thicknesses of the flanges and web are measured. The actual cross-sectional area is calculated. The actual measured values are used in the final calculations.

d. Column specimens are usually white-washed with hydrated lime. During testing, the white-wash cracking pattern gives an indication of the progression of yielding in the cross section (the cracking reflects the flaking of the mill scale at yielded areas).

e. The initial out-of-straightness of the column is measured at several points along the length of the column. These values are used later in the evaluation of the results of the test.

3. END FIXTURES

Several schemes have been used to provide the required pin condition at the ends of the column specimen. The different basic types of end fixtures used by column strength investigators are shown in Fig. 1.(5) The examples given are representative only of what have been used and may not illustrate all possible types of fixtures which have been used by other investigators.

The first known reliable tests on columns were conducted in 1887 by Bauschinger.(6) He made use of conical end fixtures (Fig. 1a) which allowed free rotation of the column ends and also ensured central application of the load. A variation to this scheme was used by Von Karman in his column tests of 1910. The load was applied through a knife-edged bar bearing on a plane surface as shown in Fig. 1b.(7) Another type which is quite similar to the knife-edged fixture is shown in Fig. 1c. In place of a knife-edge bar, a small diameter roller is used to bear on a flat surface. In some cases, a half cylinder, with a radius of about 3 to 5 inches, is used to bear on the flat surface.

In using the fixtures discussed above, the effective column length can be approximated only by the distance between the tip of the knife edges or the distance between the bearing edges of the roller. A cylindrical type of end fixture, as shown in Fig. 1d, gives a more accurate value of the column length. Such fixtures are designed so that the center of the cylinder is located on the center line at the end of the column. As a result, the effective column length is equal to the actual length of the column specimen. To eliminate friction between the movable cylinder and the fixed block, oil is supplied under pressure between their contact surfaces.

The cylindrical type fixture used in tests at the University of

Washington (1926) is slightly different.(8) Rollers are used to overcome friction. A cross section of the end fixture is shown in Fig. 1c. Due to the rollers inserted between the contact surfaces, the friction is minimized considerably. This particular end fixture has a capacity of 500,000 pounds.

Another type of end fixture, which was used in testing round columns at the Aluminum Research Laboratories, is shown in Fig. 1f. The fixture is spherically seated and has a capacity of 300,000 pounds. The essential features of this fixture are: the supporting block a, in which a recess b has been provided to allow oil under pressure to seep through to the spherical bearing surface c of the platen d. Provision is made for collecting oil after passing between the spherical surfaces, and for returning it to the suction tank of the pump.(9)

A schematic diagram of the end fixtures used at Fritz Engineering Laboratory is shown in Fig. 2. The fixtures have a maximum capacity of 2,000,000 pounds. For load application, the main cylindrical bearing is on line contact with a bearing block for minimum friction resistance. A short description of the fixture is given below. This description is summarized from Reference 10 which presents the design, testing and adjustment of this end fixture.

The fixture is made up of a column base plate, a fixture platen, the main cylindrical bearing, the bearing block, and an adjusting assembly. Identical fixtures are used for both the top and bottom ends of the column. The geometrical center of the main cylindrical bearing is located at the mid-point of the end of the column. As shown in Fig. 3, the line of action of the applied force will always pass through the same point as the column goes through its deformation. Thus, the actual length of the column is the effective column length.

The adjusting assembly allows the correction for uneven bearing and for initial out-of-straightness of the column. This is done with the wedge blocks and the smaller cylindrical bearings of the adjusting assembly. The procedure of adjusting the fixture is described in section 3.5.

A photograph of the end fixture as used in testing is shown in Fig. 4. The fixture assembly is held together with side plates. The lower side plates hold the adjusting assembly together. The upper side plates provide lateral restraint to the main cylindrical bearing. The upper bolts in the slotted holes are removed after alignment and the cylindrical bearing can roll freely on the bearing block during the test. A stud at the center of a circular cutout in the upper side plate limits the total movement of the cylindrical bearing. This prevents the column from tipping over when the load is released accidentally.

4. INSTRUMENTATION

The instrumentation for a pinned-end column test consists of level bars to measure the end rotation, SR4 resistance gages to measure the strain and a 1/1000 in. accuracy dial gage to measure the lateral deflection at mid-height. Secondary instrumentation used both as a check and for additional data consists of three sets of 10 in. length gage holes for mechanical measurement of strain at mid-height section

(Fig. 5) and strip scales at quarter points (or at sixth points for longer columns) to be read with a transit or a theodolite to obtain deflection readings along the length of the column. To obtain load stabilization data in hydraulic testing machines, an additional 1/1000 in. accuracy dial gage is used to measure vertical crosshead movement.

The level bars are mounted on support brackets welded to the base plate and the top plate of the column (Fig. 4). Angle changes are measured by centering the level bubble by adjusting the micrometer screw. A vertical dial gage attached to the end of the level bar gives an indication of the rotation of the bar over a gage length of 20 inches.

SR4 strain gages are attached at different levels of the column, four at each end and eight at the mid-height level. For long columns, it may be necessary to attach four more strain gages each at the quarter- and three-quarter points.

The dial gage for lateral deflection measurement is fixed to the testing machine at about the mid-height of the column. A thin wire is attached to its plunger and connected to a small screw tapped in at the centerline of the column width or connected to a strong magnet attached to the column at the centerline. The set up is shown in Fig. 6.

The layout of the complete instrumentation of the column is shown in Fig. 7.(11)

5. TEST SET UP AND ALIGNMENT

To set up the test column, first the top fixture is placed in position on the base of the testing machine. The movable cross-head is lowered to the fixture, bolted, and taken up to a sufficient height to accommodate the column. Next, the column specimen with its base plates welded on, is brought in vertically and by means of the upper base plate, is attached to the fixture with bolts. Finally, the bottom fixture is placed in position on the machine base. The column is lowered and its lower base plate is bolted to the bottom fixture. At this point a geometrical alignment of the column is made with a plumb bob or with a transit. Necessary adjustments can be made by moving the bottom fixture to make certain that the corners of the fixture plates are directly over each other.

This is the first trial position in the alignment of the column. The next step is to load the column in increments up to a predetermined maximum alignment load. This load must be less than the proportional limit* of the column specimen to ensure that premature yielding of the cross section does not occur prior to testing. A certain degree of judgment is required in determining the maximum alignment load. The value depends on the proportional limit of the cross section, its maximum carrying capacity, and the degree of accuracy of the alignment.

The alignment is based on the four corner strain gages at each end of the specimen and at mid-height. The alignment is considered satisfactory if the deviation of any of the four corner gage readings does not exceed 5% of their average value at maximum alignment load. This criterion is applied at each of the three control sections.

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*The proportional limit is determined from the result of the stub column test (Ref. 11).

To adjust for plumbness and uneven bearing in the direction of buckling, the crosshead is raised with the test column and the line of contact between the cylindrical surface and the bearing block of the lower fixture is relocated. In the normal direction, the wedges are either pushed in or out as required. To adjust for the initial out-of-straightness of the column, the column base plates are moved in relation to the fixture platens.

Column specimens almost always have some initial out-of-straightness which makes it necessary to check the lateral deflection of the mid-height section during alignment. It is usually necessary to balance the eccentricity between the ends and the mid-height level to attain a position where the column is uniformly loaded and the deflection is negligible up to the maximum alignment load.

Similar techniques may be used in aligning columns with other types of end fixtures. This example is given to illustrate some of the techniques and to familiarize column strength investigators with some details of the problem of column alignment.

6. TESTING

The test is started with an initial load of about 1/15 to 1/10 of the calculated ultimate load capacity of the column. All the dial gages are adjusted for initial readings and readings are taken on the strip scales, the SR4 strain gages and the 10-in. gage holes. Besides recording the data, a point by point plot of the load-deflection curve and the load strain diagram should be made as the testing proceeds. The load is applied in appropriate increments as determined by the load deflection curve. This usually amounts to about 3% to 5% of the expected ultimate load of the column. The plot of load versus strain at the mid-section gives the value of the proportional limit and indicates the occurrence of yielding in the cross-section. The progression of yielding may be observed also from the whitewash cracking pattern, if the column has mill scale.

Above the proportional limit, readings should be taken when the load and the strain are stabilized. The criterion for load stabilization is dependent on the type of testing machine used:

(1) For a mechanical testing machine, the criterion is for no further decrease in load, and

(2) For the hydraulic testing machine, the criterion is for no further movement of the sensitive crosshead with the loading valve closed, provided the hydraulic system of the machine does not have any leak. (When leakage is suspected, the criterion is a simulation of that used for a mechanical testing machine; that is, for no movement of the crosshead controlled by the loading valve, the load is allowed to stabilize until there is no further decrease in load.)

These criteria are best used by plotting the load change or crosshead movement on graph paper, and noting the value corresponding to the asymptote (Fig. 8). The test data is recorded when (a) the asymptotic load is approached (for the case of the load criterion) or (b) the asymptotic crosshead movement is approached (for the case of the crosshead movement criterion).

Readings should not be recorded until the asymptote is definite. Experience will indicate the time intervals required in plotting the criterion readings. An interval of three to five minutes is usually satisfactory.

IV. RESULTS

1. PRESENTATION OF THE DATA

For each load increment, the following readings are taken:

(1) Mid-height dial gage)
) for deflection
(2) Strip scales)

(3) 10-in. gage holes at mid-height)
) for strain
(4) SR4 strain gages)

(5) Level bars for rotation

The whitewash is observed also and any cracking is noted. A checklist is kept to make sure that all readings and observations have been made. It should be noted that before any of these readings are taken, the load should be checked to see that it has stabilized.

The results of the test are best presented in diagrammatic form. These plots are shown in Figs. 9 through 13.

In Fig. 9, a plot of the initial deformed shape of the column specimen is shown. This data is used in the further evaluation of the reduction in column strength due to initial out-of-straightness.

During the test, a plot is made of the load and the average of the three strain readings taken with the Whittemore-type mechanical strain gage. This plot is compared with the stub column test result to detect any unusual behavior of the column. For presentation in the report on the column test results, the data is given as shown in Fig. 10. The individual readings on the gage holes at the concave and convex side and at the center line of the cross section are given and also compared with the stub column test results. These readings must be verified to be in agreement with the SR4 gage data. The plot may also be given as a stress-strain relationship by dividing each load by the actual measured cross-sectional area.

Fig. 11 shows the load-deflection curve of the column specimen. This curve is plotted during testing and is used to control the increments of loading. The load-deflection curve gives the most important data of the column test as it reflects the actual behavior of a pinned-end column specimen under load.

The progression of yielding of the cross-section is detected from the cracking of the whitewash*. A sample of a recording of the whitewash cracking pattern is shown in Fig. 12. From this figure, we see that yielding occurred approximately at Load No. 5 which corresponds to a certain load in the data record. The subsequent development of whitewash cracks indicating the yielding pattern can be traced further in the figure.

Another figure which can be obtained is the distribution of stress at different load levels (Fig. 13). The diagram is not obtained directly from the column test data, but it can be derived by superimposing the stress computed from the SR4 strain readings to the previously measured residual stress distribution in the cross section.(11) It should be noted that the total stress at any point (original residual stress plus applied stress) can not exceed the yield stress of the material at that point.

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*Cracking of the whitewash is not observed with "T-1" steel, which has no mill scale to crack under load.

2. EVALUATION OF TEST RESULTS

The report of the column test should give all the information obtained from the data analysis. An evaluation of the results can be made also by comparing the experimental value of the maximum load with the theoretical prediction, if a theoretical analysis was made, or with the results of tests on other cross-sections or shapes. The occurrence of local buckling or any other phenomena during the test should be noted also.

V. SUMMARY

The pinned-end column test is an important step in the study of column behavior. Through a knowledge of its behavior, a basic concept of the strength of columns as affected by such factors as end conditions, residual stresses, initial out-of-straightness, eccentricities of load, and transverse loads may be formulated.

To attain the ideal pinned condition at the ends, a special fixture is necessary to provide (1) free rotation of the ends of the column, and (2) no relative linear translation between the column ends and the applied load. Several schemes are presented in this report. Of particular interest is the end fixture designed to allow load applications of up to two million pounds.

The latter end fixture is used extensively at Fritz Engineering Laboratory, Lehigh University. Also described in this report is a standard column test procedure adopted by the Laboratory. The description of the procedure includes recommendations on the following:

(1) The adjustment of the end fixtures to obtain a centrally loaded, pinned-end column.
(2) The instrumentation of the column for deflection, strain, and end rotation.
(3) The actual testing procedure.
(4) The presentation of the data, and
(5) The evaluation of the test results.

VI. ACKNOWLEDGEMENT

This report presents a method for testing pinned-end columns in connection with a general study of the strength of welded built-up columns.

The investigation was conducted at Fritz Engineering Laboratory of the Department of Civil Engineering of Lehigh University in Bethlehem, Pennsylvania. The Pennsylvania Department of Highways, the U. S. Department of Commerce-Bureau of Public Roads, the National Science Foundation, and the Engineering Foundation through the Column Research Council jointly sponsored the research program.

Special thanks is given to Lynn S. Beedle, Director of Fritz Engineering Laboratory for his many helpful comments and suggestions in the course of the general study. The Column Research Council Task Group I under the Chairmanship of John A. Gilligan also provided valuable guidance.

Acknowledgement is also due to the authors' colleagues for their assistance in many parts of the investigation.

FIGURES

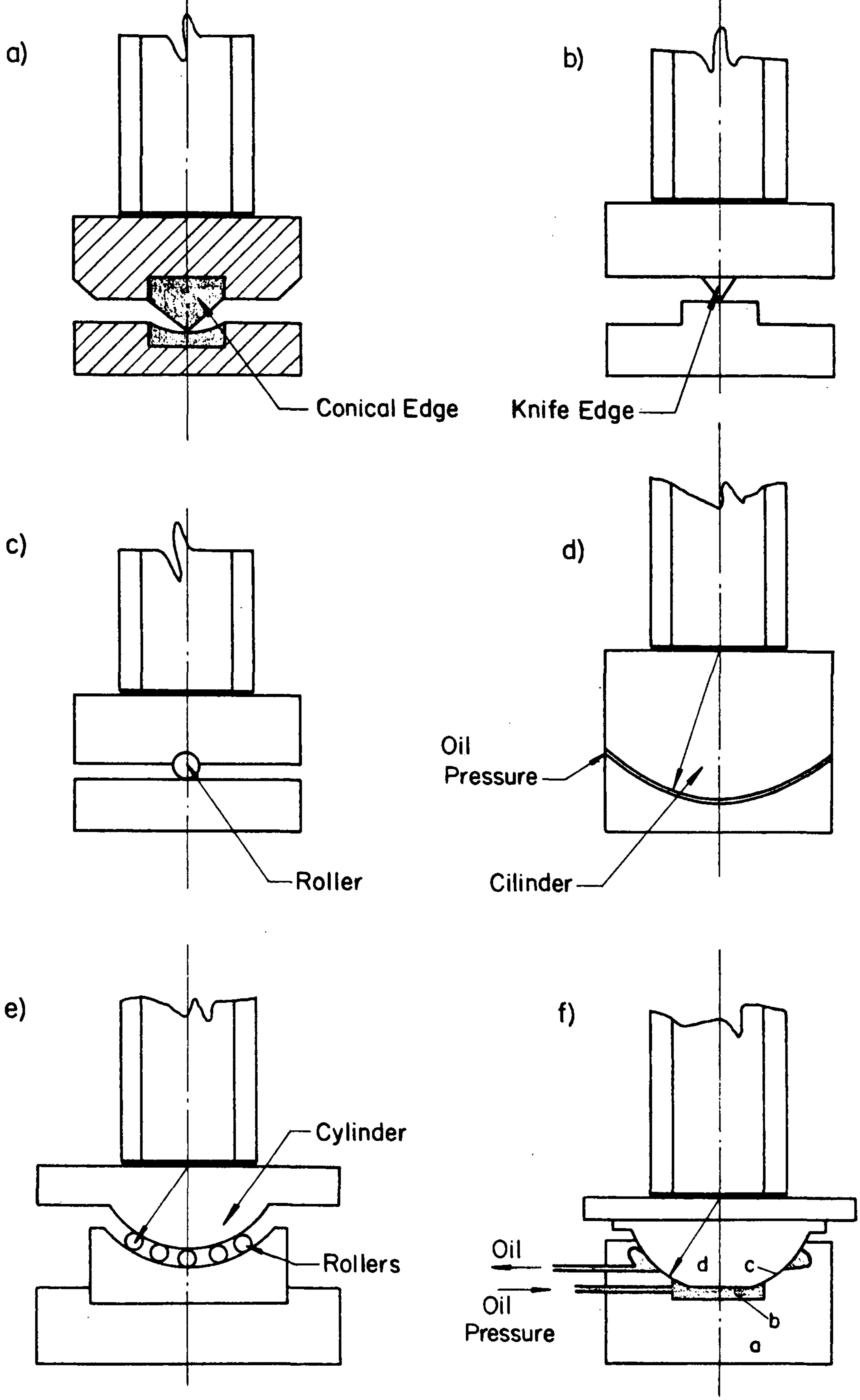

FIG. 1 BASIC TYPES OF END FIXTURES

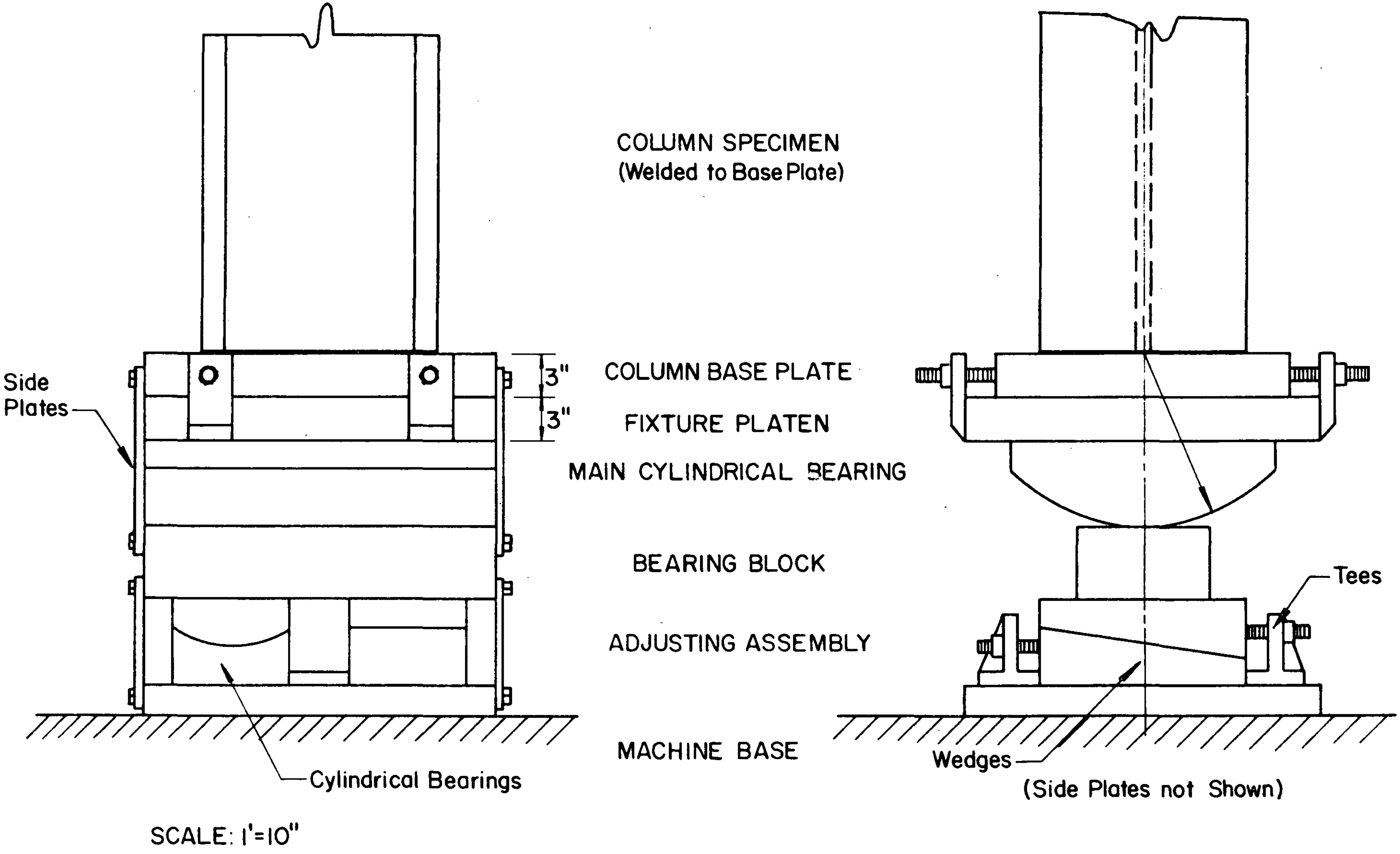

FIG. 2 STANDARD COLUMN END FIXTURE AT FRITZ ENGINEERING LABORATORY

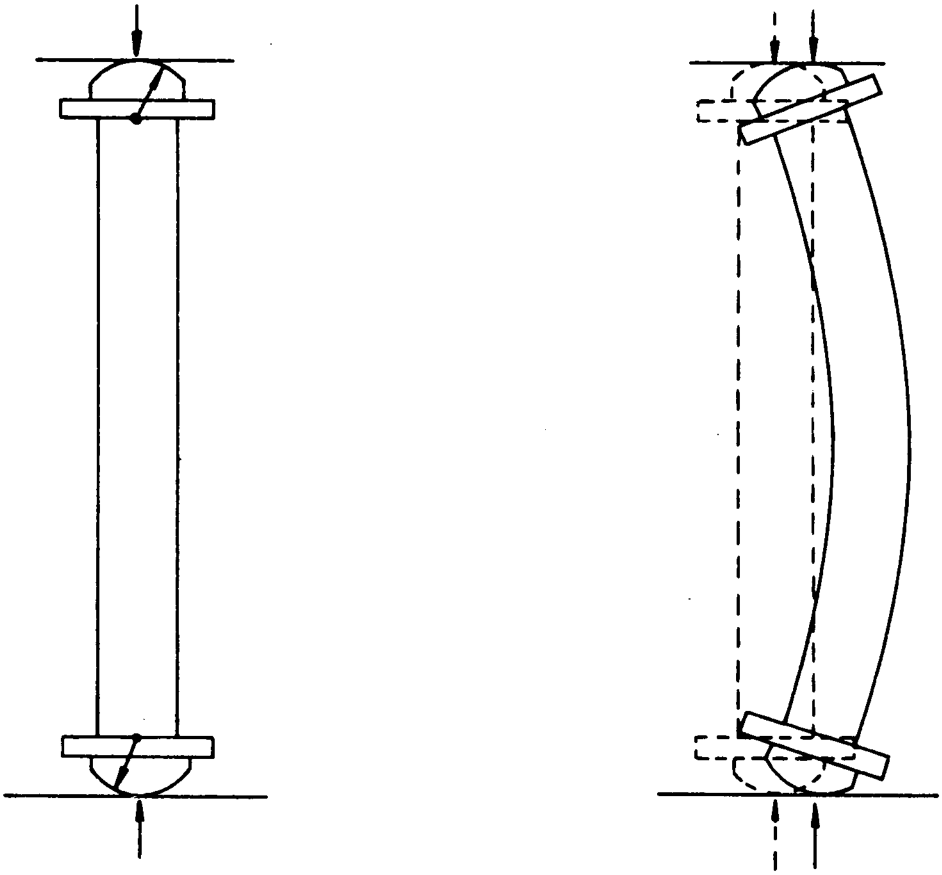

FIG. 3 END ACTION OF STANDARD END FIXTURES

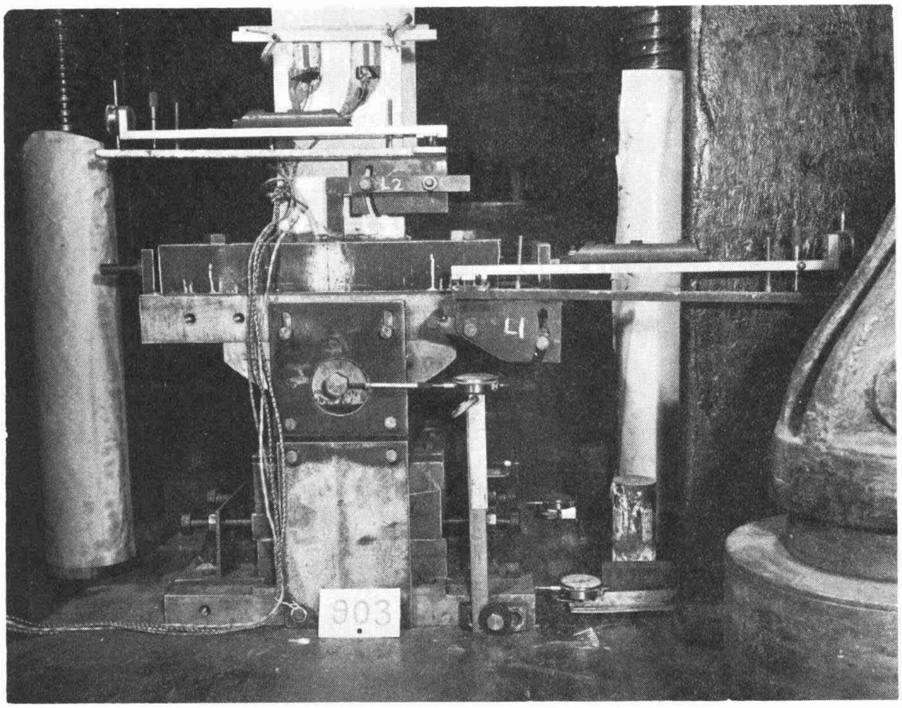

FIG. 4 DETAIL PICTURE OF STANDARD END FIXTURE

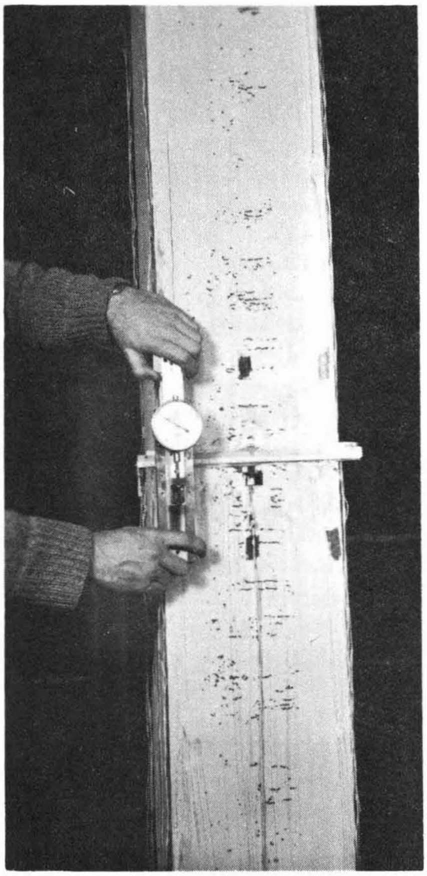

FIG. 5 MECHANICAL MEASUREMENT OF STRAIN AT MID-HEIGHT

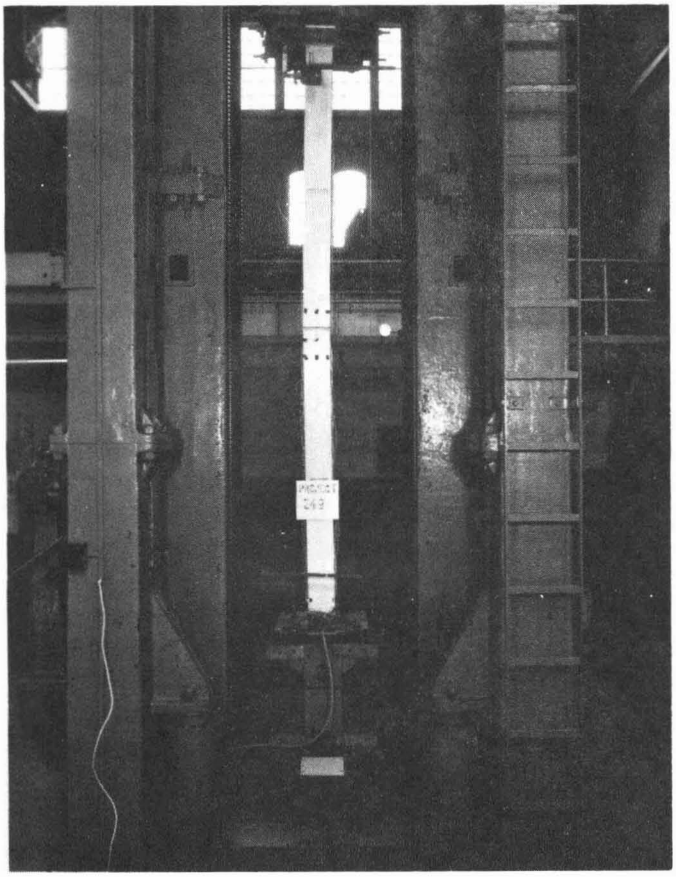

FIG. 6 DIAL GAGE SETUP AT MID-HEIGHT

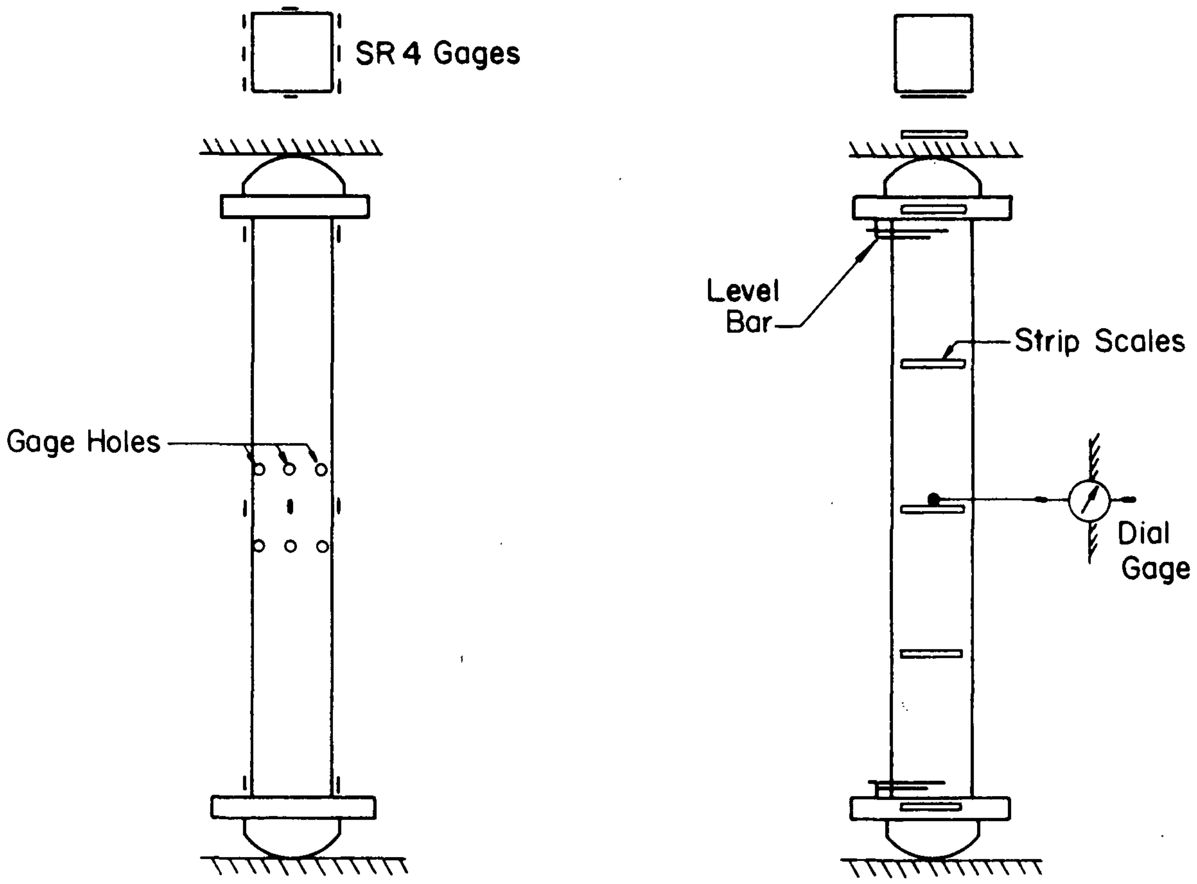

FIG. 7 SCHEMATIC DRAWING OF INSTRUMENTATION

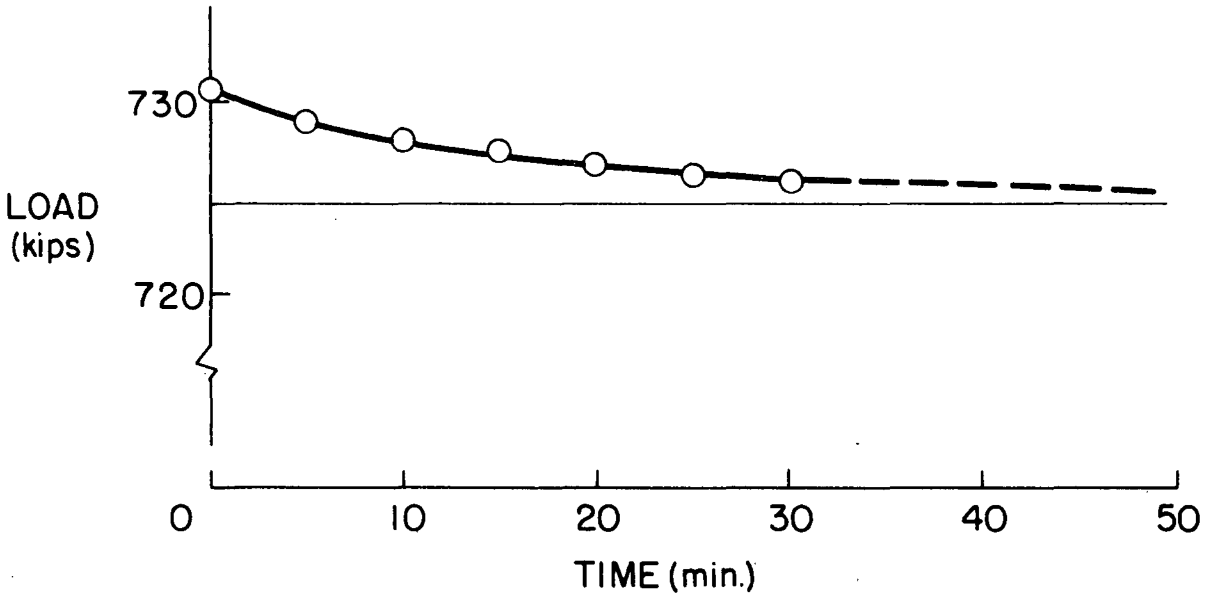

FIG. 8 TYPICAL LOAD RELAXATION DIAGRAM

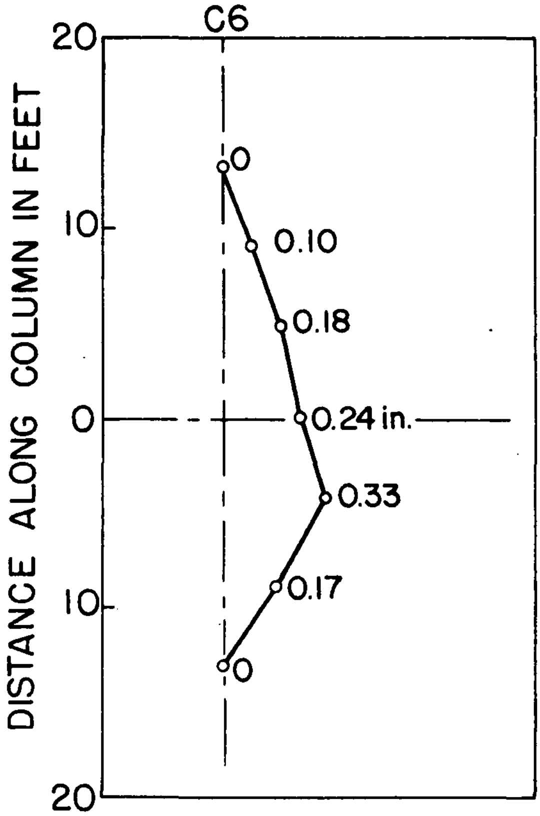

FIG. 9 INITIAL SHAPE OF COLUMN SPECIMEN

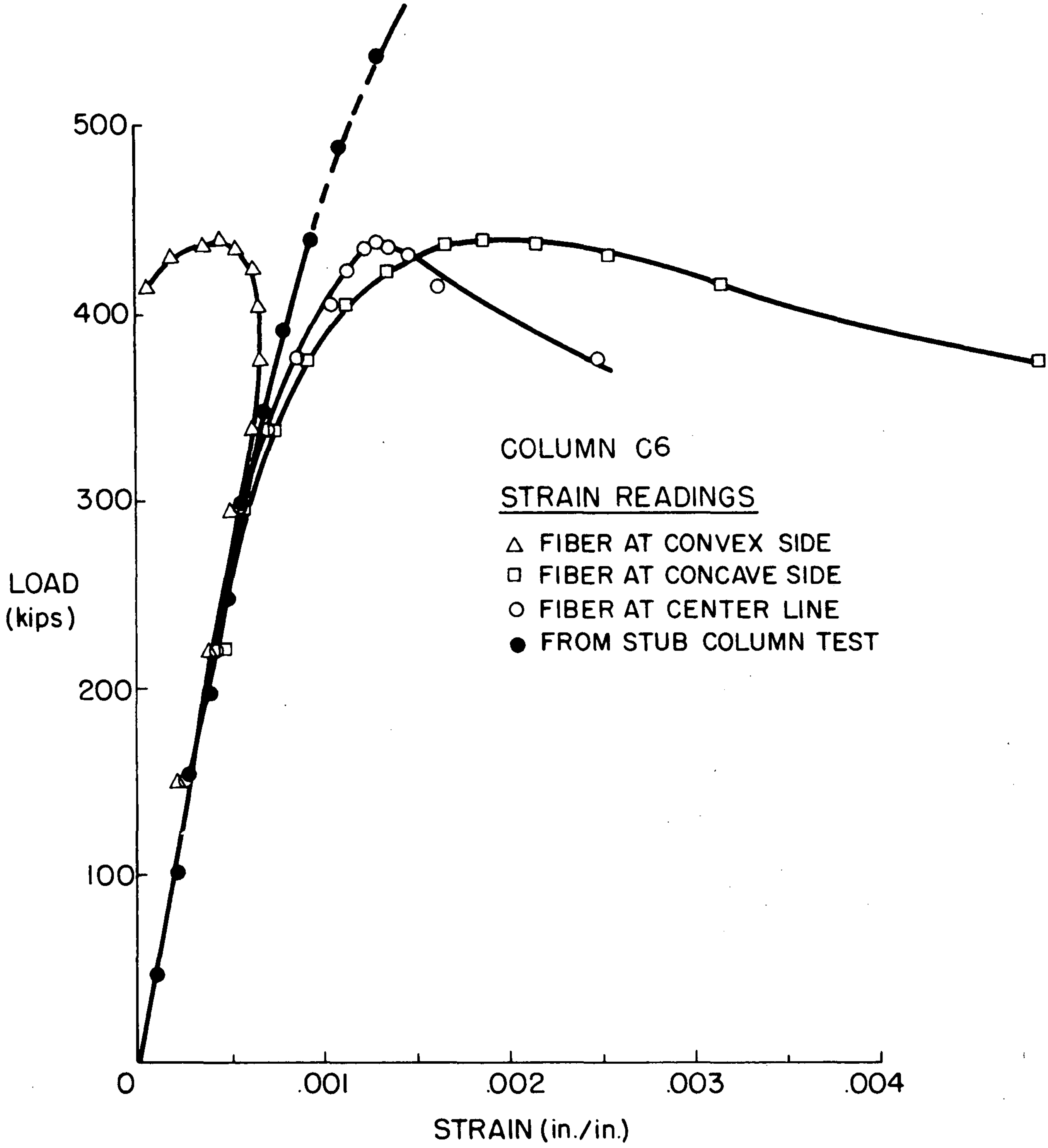

FIG. 10 FIBER STRAINS

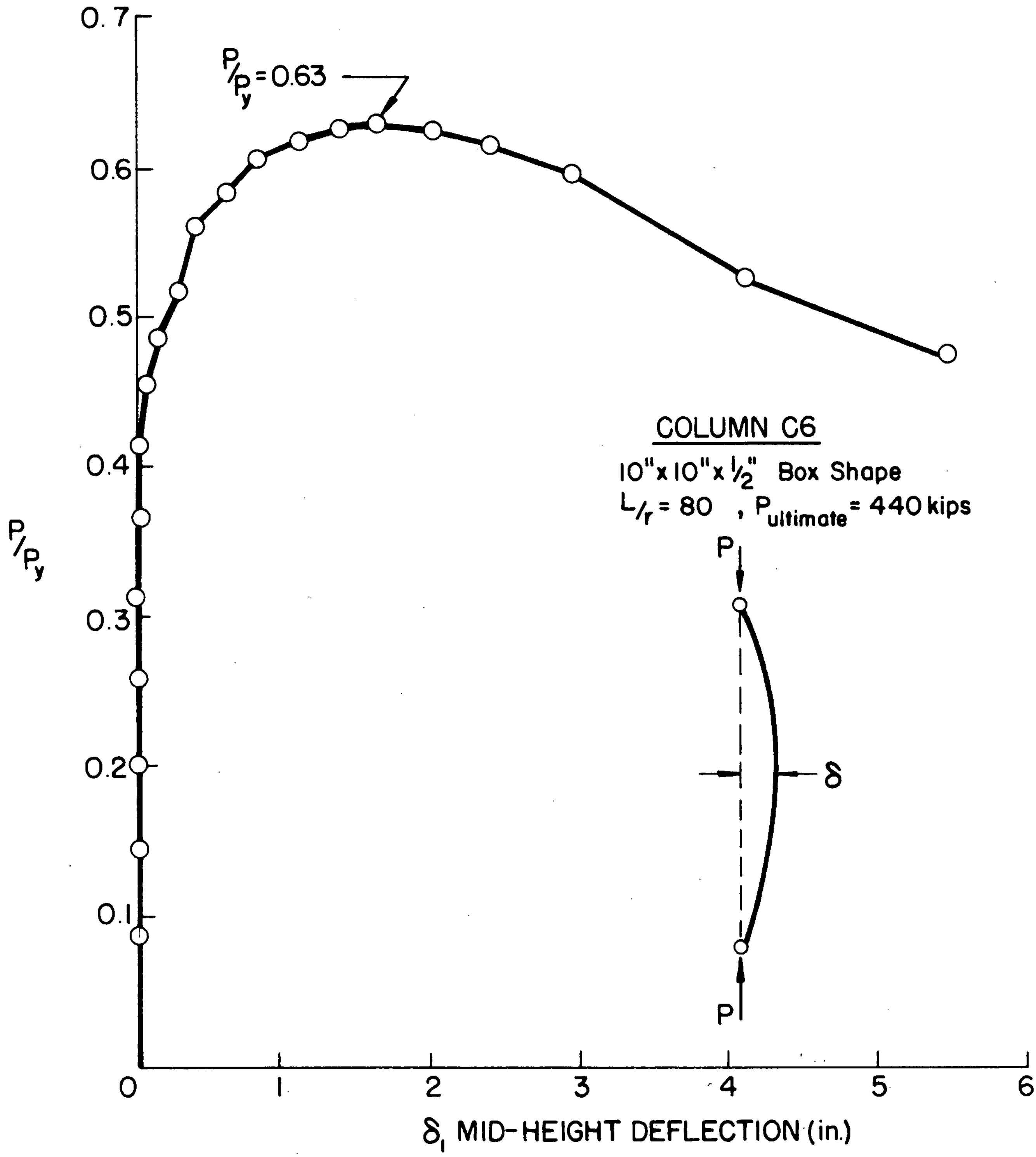

FIG. 11 LPAD VS. DEFLECTION CURVE

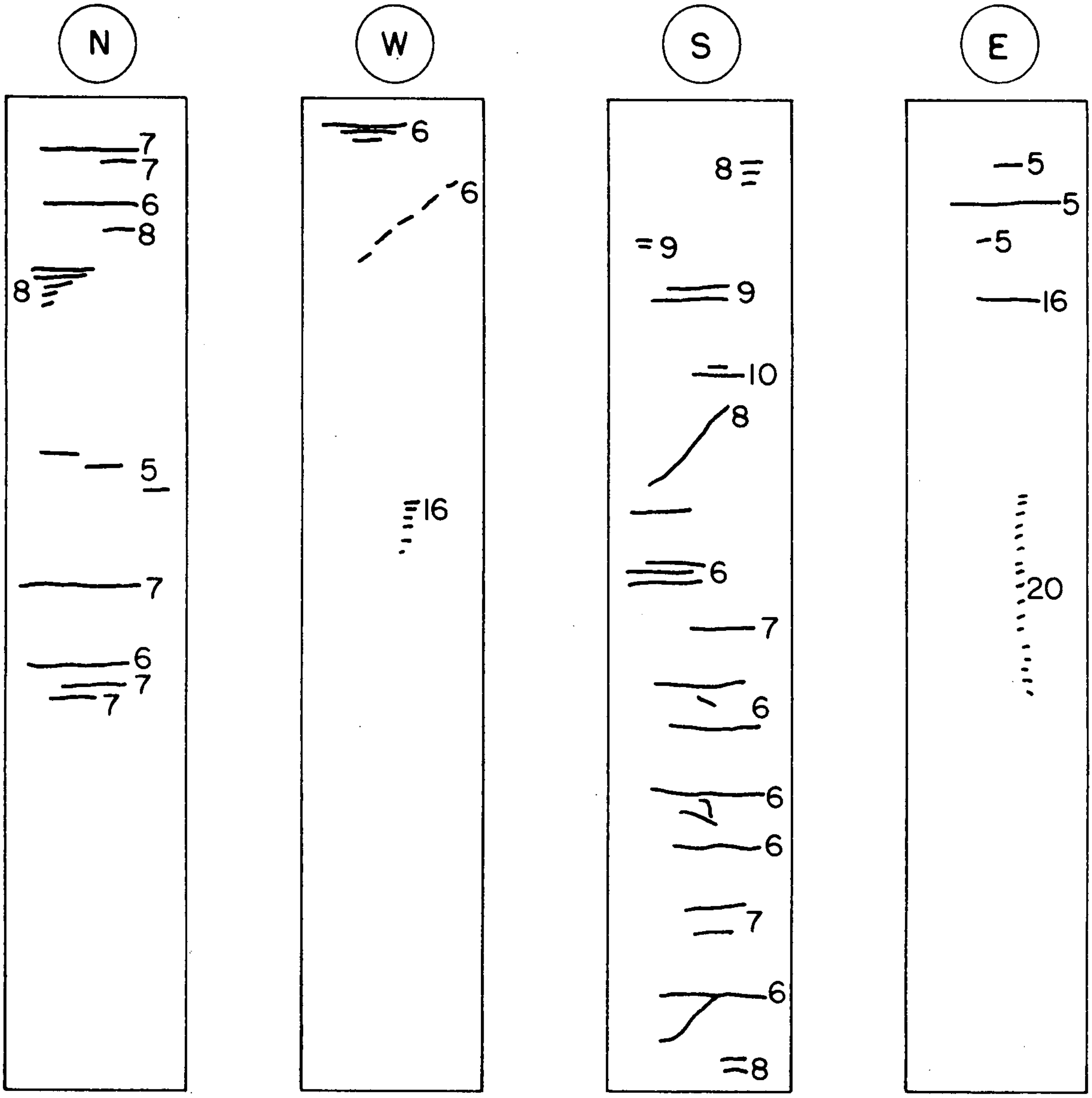

FIG. 12 WHITEWASH CRACKING PATTERN

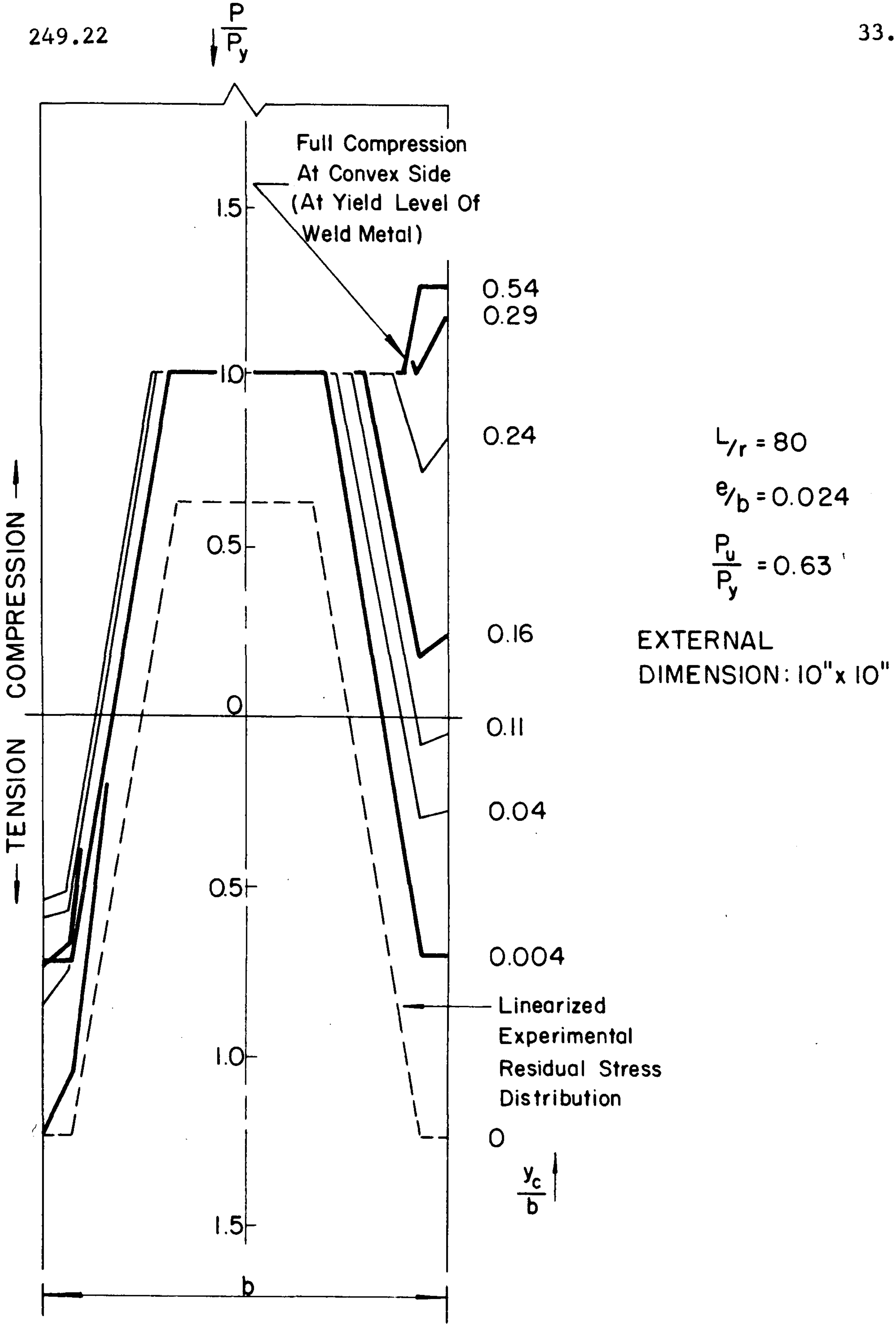

FIG. 13 STRESS DISTRIBUTION AT DIFFERENT LOAD LEVELS

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