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Commission X

Proposal for

STUB COLUMN TEST PROCEDURE

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Submitted by:

Working Group for
Effect of Residual Stresses
on Stability of Compression
Members.

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THE STUB COLUMN TEST

Definition:

A stub column is a column whose length is sufficiently small to prevent failure as a column, but long enough to contain the same residual stress pattern that exists in the column itself.

Application:

Column strength may be expressed as a function of the tangent modulus determined from the stress-strain relationship of the stub column test*. Hence, a stub column test is an important tool in the investigation of the strength of columns.

The difference between the Young's modulus and the tangent modulus at any load level, determined from a compression test on the complete cross section, essentially reflects the effect of residual stresses. This may be realized when one considers that the cross section, hitherto completely elastic under load, becomes elastic-plastic at the proportional limit. The presence of residual stresses in the cross section implies that some fibers are in a state of residual tension while others are in a state of residual compression. The fibers in a state of residual compression are the first to reach the yield point under load.

The difference between the behavior of a column free of residual

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* Column strength is not a direct function of the tangent modulus. For example, for an H-shape bent about the strong axis the function is approximately direct, whereas about the weak axis, the strength is a function, approximately, of the cube of the tangent modulus. Further, the tangent modulus theory will give a conservative estimate of column strength.

stresses and one containing residual stresses lies in the fact that both the tangent modulus and the effective moment of inertia are greater for the column free of residual stresses. On the other hand, the behavior of a stub column reflects only the effect of residual stresses on the tangent modulus*; the reduction of the moment of inertia due to plastification has no effect on the behavior. Under load some parts of the cross section will yield before others leading to a decrease of the effective moment of inertia and hence in the strength of the column since those portions of the cross section which have yielded play no further role in strength consideration, provided the effect of strain hardening is neglected.

Therefore it may be seen that the residual stress distribution in the cross section, through its influence on the effective moment of inertia, supplies the connecting link between the strength of a column and the tangent modulus of the stress-strain relationship of the stub column.

References:

Extensive literature exists to show that residual stress are, indeed, the major factor contributing to the strength of axially loaded, initially straight, columns, and that a conservative value for this strength may be specified in terms of the tangent modulus determined from the results of a stub column test. The papers presented at the IIW Commission X Colloquium in Liege in 1960 contained these references. Further references are in a summary paper in preparation by the working group.

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* When the cross section is free of residual stresses, the tangent modulus coincides with Young's modulus.

Proposal:

The importance of residual stresses on the stability of columns has been recognized, and programs of testing are underway in many countries. At this early stage it would be most desirable if all stub column tests could be completely correlated for comparison purposes.

STUB COLUMN TEST PROCEDURE

1. Object: to determine the average stress-strain relationship of the complete cross section by means of the stub column.

2. <u>Preparation</u>

a. the stub column length must be free of cold-bending yield lines, and should be cut a distance at least equal to the section depth away from flame-cut sections.

b. the length of the stub column should be

$2d + 10''$ [2d + 25cm] (or 3d) minimum

$20\ r_y$ (or 5d) maximum

where d = depth of section

r_y = radius of gyration about weak axis

c. the ends of the stub column are to be milled flat and perpendicular to the longitudinal axis of the column.*

d. the thickness of flanges, webs, length and area of the stub column should be measured.

3. <u>Gaging</u>

Mechanical dial gages or electrical resistance gages should be used, although the use of dial gages over a comparatively large gage length is to be preferred since they provide a better average for the cross section.

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* The alignment is greatly simplified when the tolerance across the milled surface is ± 0.001 inch (± 0.02 mm).

The dial gages should read to 1/10,000 inch when read over a 10" gage length, or to 1/1000 inch when used between base plates over the complete length of the stub column.* Where it can be demonstrated that electrical resistance gages give the same results, they may be used instead of dial gages.

The gage length should be placed symmetrically about the mid-height of the stub column. At least two gages in opposite positions should be used and the average of the readings taken. Corner gages over the complete column length are used for alignment; mid-height gages are used for the measurement of stress-strain relationship. When four mid-height gages instead of two are used, the corner gages may be dispensed with. (This is possible with the flange-tips of an H-shape.)

Figure 1 gives typical gage arrangements for a structural shape.

For uniformity, the following gaging procedure for H-shapes is advised:

a) four, 1/1000 inch dial gages over the complete length of stub column, at the four corners; tc be used for alignment.

b) two, 1/10,000 inch dial gages on opposite sides over a 10" gage length at the mid-height; to be used in the determination of the stress-strain relationship. The points of attachment for the gage length are to be at the junction of the flange and web, to afford freedom from local flange crippling. When early local flange crippling will not occur, four, 1/10,000 inch dial gages over 10" gage length at mid-height may be clamped to each flange tip; alignment corner gages are not then needed.

c) the specimens are whitewashed before testing. Flaking of the mill scale during testing gives a general idea of the progress of yielding.

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* A length of 25 cm. would correspond to the 10" gage length. Dial gages used on a 25 cm. base should read to a precision between limits of 1/10,000 cm. and 1/4,000 cm.

4. Set-Up

The specimen should be set up in the testing machine so that it rests between flat bearing plates. These plates should be thick enough to ensure a uniform distribution of load through the specimen.

Alignment is achieved preferably by the use of special beveled bearing plates, or else by the use of sperical bearing blocks which are fixed by wedges after alignment to prevent rotation.

The test set-up is shown in Fig. 2.

5. Alignment

The alignment should be carried out at loads up to but less than the proportional limit. For rolled H-shapes of mild structural steel this limit is about 1/2 of the predicted yield load; for welded shapes, the limit may be as low as 1/4 of the yield load.

The alignment is carried out by noting the variation of strain at the four corners of the specimen. The variation of individual strains at the four corners should be less than 5% from their average at the maximum alignment load. Alignment at very low loads is unsatisfactory. The alignment should consist of about ten increments up to the maximum alignment load.

To check that the load is below the proportional limit, the stress-strain relationship may be plotted during the test and linearity observed. It is inadvisable to exercise this control by observing for yielding of the mill scale on the whitewash, indeed this method is unsatisfactory since it indicates yielding at a load value in excess of the actual proportional limit as indicated by the plotted stress-strain relationship.

6. Testing

The stress-strain curve should be constructed from as many experimental data points as possible. To this end, the load increment in the elastic region should be at about 1/30 of the expected yield load. After the proportional limit the load increments should be reduced so that there are sufficient data points to delineate the "knee" of the stress-strain curve.

The proportion limit* will be marked by the beginning of the deviation of the stress-strain relationship from the linear behavior, and the development of yield lines (made clearly visible by whitewash) will indicate the progress of yielding. This is further covered in Item 10.

After the onset of yielding, readings should be recorded when both load and strain have stabilized. The criteria used to specify when data may be recorded depend on the type of machine used for testing. This is explained further below in Item 7.

To ensure correct evaluation of the yield level and other compressive properties, the test should be continued until one of the following conditions is satisfied:

a) For an immediate drop in load due to buckling, the test should be continued until the load has dropped to about 50% of the load at the predicted yield level.

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* It is assumed that the residual stresses are symmetrical and constant in the longitudinal direction, so that the proportional limit does not indicate localized yielding.

b) For a specimen that exhibits a plastic region of considerable extent, the test should be continued until the load has dropped to about 80% of the load at the predicted yield level.

c) For a specimen that strain hardens without apparent buckling, or which strain hardens without a plastic range, the test should be continued until the load is about 25% above that at the predicted yield level, for mild steel.

The load and strain at all critical levels should be recorded. This is further outlined in Item 9.

It may become necessary to remove some of the mechanical gages before the completion of the test to prevent damage due to local buckling.

7. Criteria for Stabilization of Load

Standard criteria should be followed for the recording of test data when the load is greater than the proportional limit. The choice of the criterion will depend upon the type of testing machine, either hydraulic or mechanical. That is

a) with a mechanical testing machine, the criterion is for no further decrease of load, and

b) with a hydraulic testing machine, the criterion is for no further movement of the sensitive cross head, with the loading valve closed, provided the machine does not 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 of 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. See Fig. 3.

The test data is recorded when

a) the asymtotic load is approached, with the load criterion, or

b) the asymptotic cross-head movement is approached, with the cross-head movement criterion.

Readings should not be recorded until the asymptote is definite. Experience will indicate the time intervals required, but three minute intervals are usually satisfactory. The cross-head movement should be measured by a 1/10,000 inch mechanical dial gage.

8. Evaluation of Data

The following methods may be used for the evaluation of the test data:

1. plot the test data during the test to detect any inconsistencies.
2. translate the test data to those of stress versus strain (from a knowledge of the exact cross-sectional area), and plot to an enlarged scale for the stress-strain relationship.
3. determine the tangent modulus curve from the stress-strain relationship. This is best determined by use of a strip of mirror; the mirror is held normal to the curve and a line drawn along the mirror. The normal is determined from the continuity of the stress-strain relationship and its mirror image at the tangent point considered.

9. Data to Report

The following information should be obtained from the stress-strain relationship given by a stub column compression test:

a) Young's modulus of elasticity
b) Proportional limit
c) Yield strength
d) Yield stress level

e) Elastic range
f) Elastic-plastic range
g) Plastic range
h) Onset of strain hardening
i) Strain hardening range
j) Strain hardening modulus

The occurrence of local buckling, and any other phenomena during the test, should be recorded.

The stress-strain diagram is shown in Fig. 4.

10. Definition of Terms

The above terms should be defined and measured as follows:

a) Young's Modulus, E, is the ratio of stress to strain in the elastic range. (The method of measuring is defined by ASTM Standard E 111-58T (1958), "Determination of Young's Modulus at Room Temperature".)

b) Proportional Limit, σ_p, is the load corresponding to the strain above which the stress is no longer proportional to strain. It is best measured by the use of an offset of 10 micro in./in.

c) Yield Strength is "the stress, corresponding to the load which produces in a material, under the specified conditions of the test, a specified limiting plastic strain." This is the definition of ASTM Standard A370-54T (1958), and an offset of 0.2% is suggested. (The yield strength criterion is normally used when there is yielding without constant stress.) (For stub column stress-strain curves, the Yield Stress Level is mainly used, as it is a more representative value; it is an average value in the plastic range.)

d) Yield Stress Level, σ_y, is the stress corresponding to a strain of 0.5%. This stress will usually correspond to the constant stress under yield when the stress-strain relationship is such as shown in Fig. 4.

e) Elastic Range may be defined as the increment of strain between zero strain and the strain at the point A in Fig. 4.

f) Elastic-Plastic Range is the increment of strain corresponding to the increment of stress between the proportional limit and the first value of stress equal to the yield stress level.

g) Plastic Range may be defined as the increment of strain between the elastic range and the onset of strain hardening.

h) Onset of Strain Hardening may be defined as the strain corresponding to the intersection on the stress-strain curve of the yield stress level in the plastic range with the tangent to the curve in the strain-hardening range. This tangent is drawn as the average value in an increment of 0.002 in./in. after the apparent onset of strain hardening.

i) Strain Hardening Range is the range of strain after the plastic range where the cross section no longer strains at a constant or near constant stress.

j) Strain Hardening Modulus is the ratio of stress to strain in the strain-hardening range. It is measured as the average value in an increment of 0.005 in./in. strain after the onset of strain hardening.

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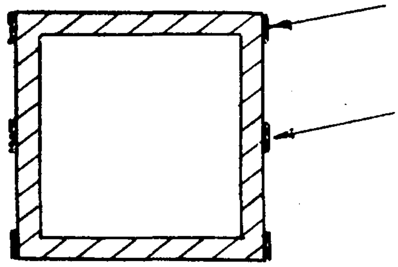
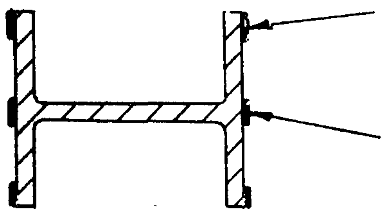
Figure 1: POSITION OF GAGES FOR ALIGNMENT AND TESTING

(a) Electric Resistance Gages



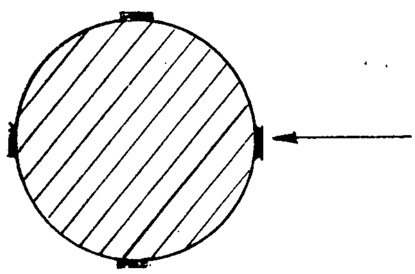
Gages for alignment and/or stress-strain relationship

Gages for determination of stress-strain relationship



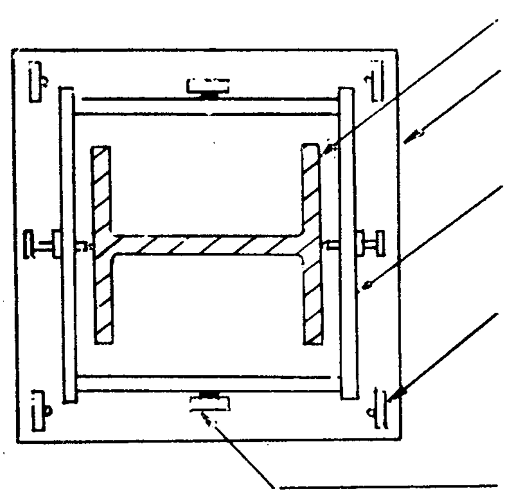
Gages for alignment

Gages for determination of stress-strain relationship

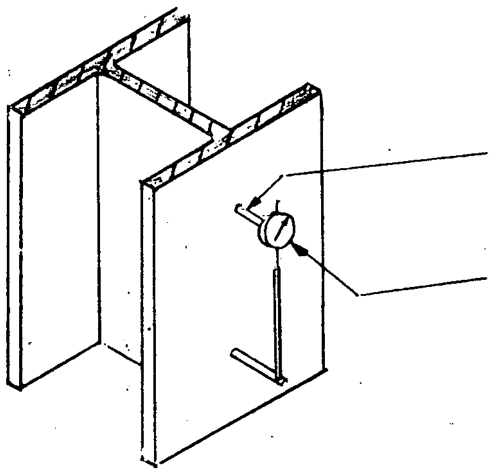


Gages for determination of stress-strain relationship and for alignment

(b) Dial Gages with Gage Frame



(c) Dial Gages with Tack-Welded Dowels



(d) Dial Gages Clamped to Flange Tips of H-shape

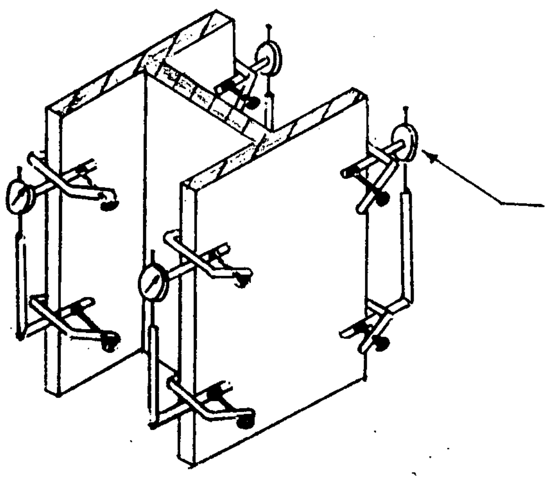


Figure 2

STUB COLUMN SET UP FOR TESTING

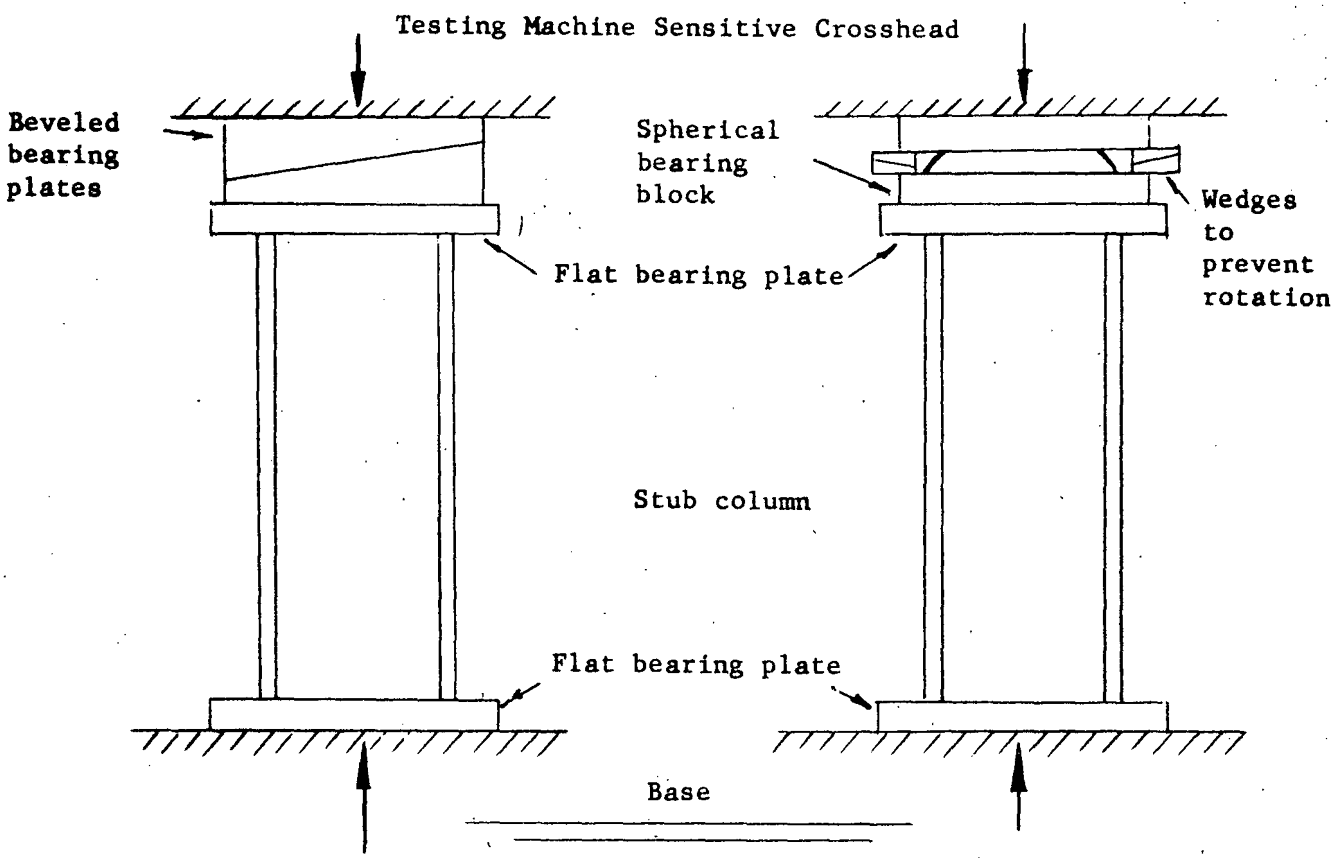
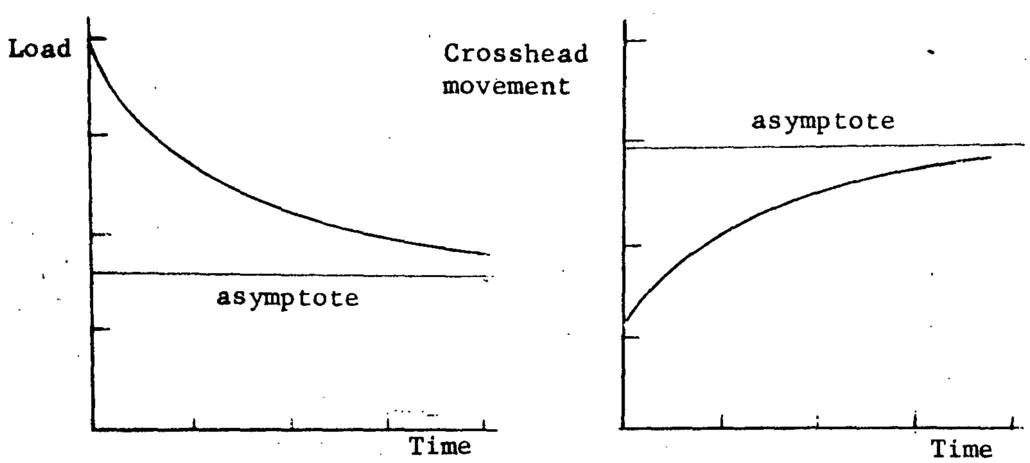


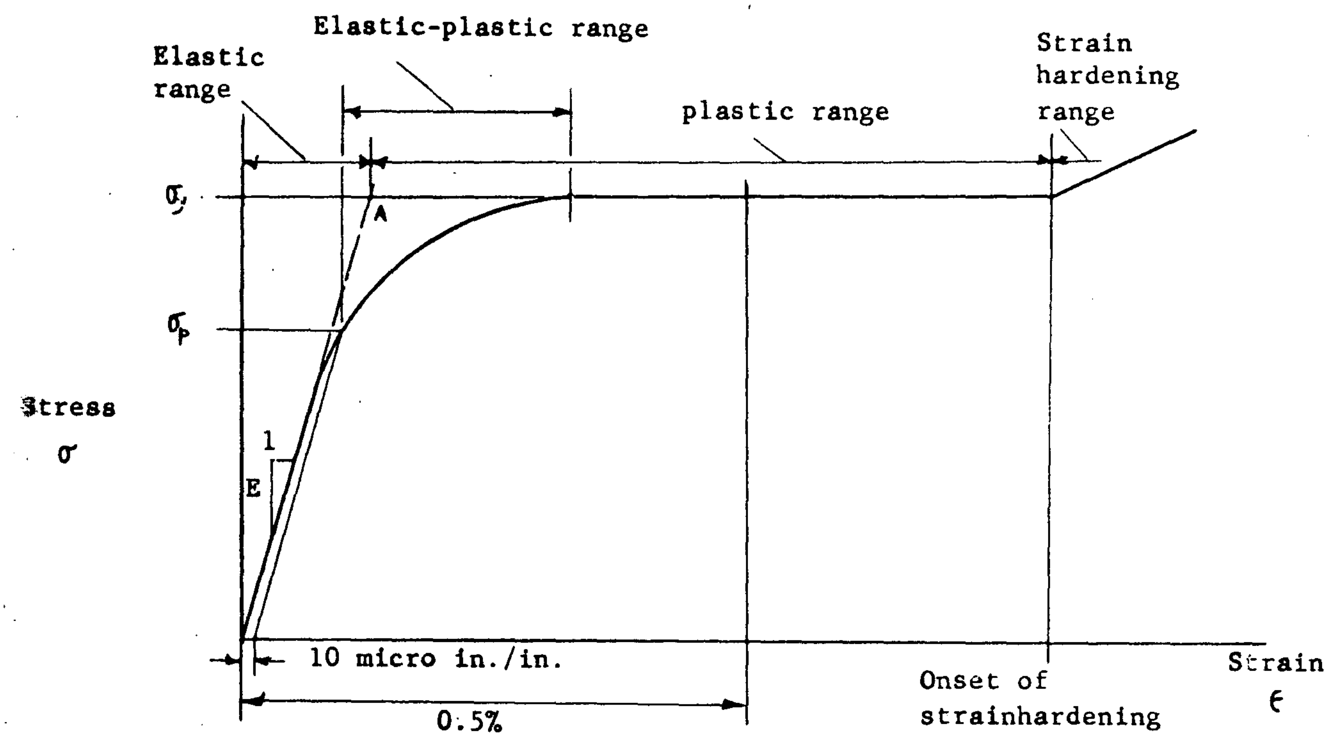
Figure 3

YIELD CRITERIA



(a) Load Criterion (b) Crosshead Movement Criterion

(a) Yielding under constant stress



(b) Yielding without constant stress

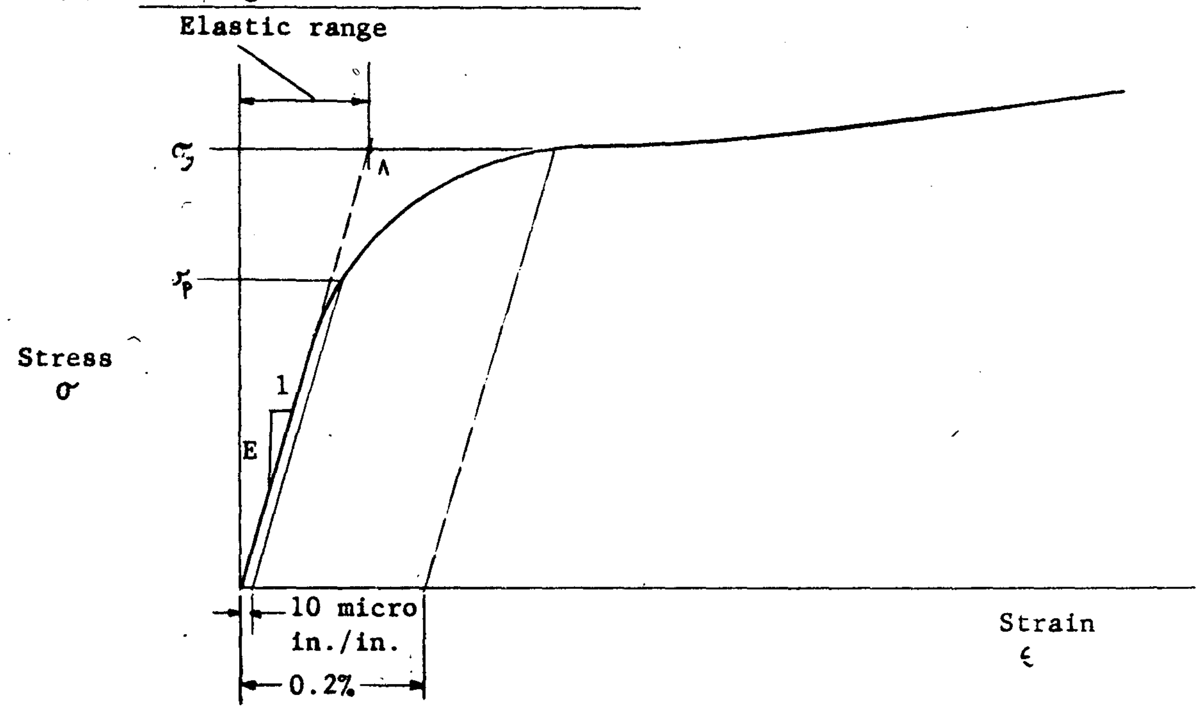


Figure 4

THE STRESS STRAIN DIAGRAM