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PRELIMINARY TESTS ON TUBULAR COLUMNS

by

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ABSTRACT

In order to predict the buckling strength of fabricated tubular columns, some initial measurements and data are required. Reported herein are the results of the tensile specimen tests required for basic material properties and stub column tests, conducted to predict the buckling strength of long columns.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

The prediction of the buckling load of a long tubular column can be made from a number of different bases without an extensive theoretical investigation. For the design of fabricated tubular steel columns, it is usual to use CRC design curve A [1] but even this needs an assumed value of material tensile yield stress.

Apart from this design curve, it is also possible to derive column buckling curves (i.e., curves of critical buckling stress, σ_{cr}, versus effective column slenderness ratio, kL/r) from stub column tests. In this method, it is necessary to derive a static stress-strain curve for the material and then to determine the tangent modulus of elasticity, E_t at various stress levels. The column critical buckling stress is then given by

$$\sigma_{cr} = \frac{\pi^2 E_t}{\left(\frac{KL}{r}\right)^2} \tag{1}$$

This report discusses the stub column tests and tensile specimen tests conducted. From the results of these basic tests, Eq. (1) may be used to derive column buckling curves.

2. Stub Column Tests

2.1 Introduction

When the tubular columns were manufactured, four short specimens were set aside for stub column tests. There were two 15 in. diameter specimens about 3 ft. long, and two 22 in. diameter specimens about 4 ft. long. Since two heat lots were used in the manufacture of the specimens, this meant one specimen of each size was manufactured in each heat lot. However, it was decided to divert one 22 in. diameter specimen to an experimental investigation of residual stresses, the results of which are reported in Ref. 2. Thus, three stub column specimens were tested. The experimental method is outlined briefly below, but for the procedure and a discussion of the application and significance of the results, the reader is referred to Refs. 3 and 4.

It is appropriate here to note that a stub column may be defined as a column long enough to retain the original magnitude of residual stress in the section and short enough to prevent any premature failure occurring before the yield load of the section is reached [3]. A stub column test is performed in order to obtain an average stress-strain curve for the complete cross section which takes into account the effects of residual stresses. As such, its use is a significant improvement on predictions made directly from tensile specimen tests. For tubular sections, the minimum length, L, to diameter, D, ratio of a stub column is usually taken to be about 2 to 2.5 [1]. The length to diameter ratio for the specimens tested varied from 2.10 to 2.38. This is probably not too critical as Ref. 7 recommends only that L/D be greater than 0.75.

2.2 Test Method

The stub columns were all tested in a 5,000,000 lb. universal testing machine at Lehigh University. Figures 1 and 2 indicate the positions of the measuring apparatus in a typical setup. Basically, five electric resistance strain gages were mounted on each specimen at midheight.

One of these was directly opposite (180°) the weld and the other four were spaced at 45°, 135°, 225° and 315° from weld. Other instrumentation included two 10-in. Whittemore gages used to measure strains at midheight (one on the weld and one 180° from the weld), and four dial gages measuring the relative movement between the machine heads (total overall movement).

Of critical importance in stub column tests is the alignment of the heads of the machine in order to provide a uniform load over the column cross section. The ends of each specimen were machined flat but this did not necessarily ensure that they were parallel. Therefore, the fixed heads of the machine had to be rotated so that the loading resulted in a uniform stress. This was done by a trial-and-error basis using the strain gages until the strain readings were all within 10% of each other. In order to protect the machine heads, a thin piece of copper was placed between each head and the specimen being tested. This also overcame the effects of slight machining imperfections.

The rate at which a specimen is tested determines the particular stress strain curve derived. A static stress strain curve is required for prediction purposes but it is impractical to conduct a test at zero strain rate. Thus, it is usual to conduct a test at an appropriate strain rate and, from it, to construct a static stress strain curve. For a report on the comparison of tests conducted dynamically and statically, the reader is referred to Ref. 6. References 1 (Appendix), 5 and 6 give a detailed resume of test procedure.

2.3 Test Results and Discussion

A qualitative series of results is shown in the photographs and diagrams of Figs. 3 through 7. It is interesting to note that each specimen failed in a somewhat different manner although each specimen gave substantially the same test results.

Figure 3 shows specimen 1 (15 in. diameter x 35½ in. long) during testing, i.e., after the first yield had occurred. The diagonal yielding pattern is clearly visible and this was the first form of yielding noted. It is significant that this diagonal diamond-shaped yielding pattern occurred only close to the weld, while 180° from the weld, more general yielding is noted. Even here, however, it is obvious that there is some yield banding along the length, i.e., some areas which have yielded and some which have not. Figure 4 shows the specimen after completion of the tests. It is noted that primary failure was by a buckle forming with 2 to 3 in. of the base of the specimen. However, a series of smaller buckles could also be seen extending along the length of the specimen. Up to seven distinct buckles could be detected, spaced approximately evenly along the specimen.

Figure 5 shows specimen 2 (15 in. diameter x 35-3/4 in. long) upon completion of the test sequence. The initial diagonal yielding near the weld and the final buckle near the base of the specimen are again clearly visible. However, for this specimen, there appeared to be a much-reduced tendency to have secondary buckles forming along the length of the cylinder. Some general yielding of most of the cylinder length is noted but only one failure buckle was noted.

The progress of the yielding and failure of specimen 3 (22 in. diameter x 46-1/8 in. long) can be observed in Figs. 6 and 7. It is visible that the diagonal yielding pattern again was the first visible evidence of yielding but this time it was more localized along the length of the specimen, i.e., it was concentrated in a band about 4 in. wide starting about 6 in. from the base of the specimen. The photographs show that the initially-yielded band developed into the primary yield buckle with relatively little other yielding of the specimen. This failure mode is especially interesting for it was the only specimen tested for which the buckle occurred at a substantial distance from an end of the specimen, i.e., it was the only specimen for which end effects apparently played no role in failure. It also noted that this failure buckle did not remain in a horizontal plane around the entire circumference of the tube. Rather, there was a slight upturn in the buckle at the position of the weld.

Quantitative results of the three stub column tests are shown in Figs. 8 through 10 in the form of stress-strain curves for each specimen. Apart from showing the test results obtained, these figures also show the "static" stress-strain curves from which the column buckling predictions were made.

It was shown that, once initial conditions have been stabilized, all three methods of measurement give similar results for the slope of the elastic portion of the curve, i.e., the modulus of elasticity. (There was a slight trend for the head-to-head dial gages to give a slightly lower value of elastic modulus but this was not considered to be significant.) However, the head-to-head dial gages gave the most reliable results in the inelastic portion of the curve. Generally, the electric resistance strain gages gave poor results in the inelastic range of testing because their applicability or accuracy depended on whether or not the small element of steel surface underneath the gage had yielded or not. As might be expected, the Whittemore gages gave better results for some distance into the inelastic range of specimen behavior because they are avoiding some of the problems of local yielding by considering a larger gage length.

3. Tensile Specimen Tests

3.1 Introduction

Since there were two heat lots used in construction of the test specimens, at least two tensile specimen tests are required. However, the specimens were supplied in conjunction with three flat plates, two from one heat lot and one from the other. Three test specimens were cut from each plate supplied and tested to provide the stress-strain curves presented.

3.2 Test Method

It is not proposed here to recount the detailed procedure by which the tensile specimens were tested. The method conformed to ASTM Specifications. Due to an oversight, only eight specimens have results recorded herein but the results of all were consistent. A diagram is shown in Fig. 11 of the dimensions of the specimens as fabricated and Fig. 12 shows a typical specimen with measuring apparatus attached. The dial gage mounted on the specimen was part of a Whittemore gage by which extension of an overall gage length of eight in. could be measured. The extensometer, on the other hand, had the purpose of allowing recording of the load-deflection curve on a graph. It also recorded extension over a finite gage length. Both extensometer and dial gage were strapped to the specimen with flexible straps and were removed prior to fracture of the specimen.

3.3 Test Results and Discussion

Table 1 gives the material specifications as contained in the mill report accompanying the specimens. From the tensile specimens tested, many properties of the steel used were derived. In Fig. 13 is a sketch of a typical stress-strain curve and many of the terms used are shown on it. Table 2 presents the relevant results as determined from the tests and Figs. 14 through 16 show the stress-strain curves obtained for curves A3, B3 and C3, respectively.

Good correlation was found between the results obtained from the autographic recorder and those of the hand-plotted dial gage output. Because of the similarity of the results (as witnessed by Table 2), it was thought necessary only to present the three stress-strain curves shown as being representative of all tensile coupon test results.

As explained in the introduction, column buckling curves can be produced from stess-strain curves by use of Eq. (1). Figure 17 presents these curves from results of stub column tests. These column curves will be discussed together with test results in a future report.

4. Acknowledgments

This work was undertaken in Fritz Engineering Laboratory, Lehigh University, of which Dr. L. S. Beedle is Director. Dr. W. F. Chen is the Project Director and the research is part of a project on "The Strength of Tubular Columns". Mr. L. A. Boston was Chairman of the Task Committee and Mr. C. Miller is Chairman of the present Task Committee.

The assistance of Mr. J. E. McGraw in preparing diagrams is gratefully acknowledged. Acknowledgment is also due Dr. L. Tall who reviewed the final manuscript of this report.

5. References

1. Johnston, B. G., "Guide to Design Criteria for Metal Compression Members," Third Edition, John Wiley & Sons, New York, 1976.

2. Ross, D. A. and Chen, W. F., "Residual Stress Measurement in Fabricated Tubular Steel Columns," Fritz Engineering Laboratory Report No. 393.4, Lehigh University, July 1975.

3. Tall, L., "Stub Column Test Procedure," Document C-282-61, Class C Document, International Institute of Welding, Oslo, June 1962; also, CRC Technical Memorandum No. 3, 'Column Research Council Guide', Third Edition (B. G. Johnston, Editor), John Wiley, 1976.

4. Yu, C. K. and Tall, L., "Significance and Application of Stub Column Test Results," Journal of the Structural Division, ASCE, Vol. 97, No. ST7, July 1971, pp. 1841-1861.

5. Tebedge, N. and Tall, L., "Procedure for Testing Centrally-Loaded Columns," Fritz Engineering Laboratory Report No. 351.6, Lehigh University, December 1971.

6. Tebedge, N., Marek, P. and Tall, L., "Comparison of Testing Methods for Heavy Columns," Fritz Engineering Laboratory Report No. 351.2, Lehigh University, October 1959.

7. Von Karman, T., Dunn, L. G. and Tsien, H. S., "The Influence of Curvature on the Buckling Characteristics of Structures," Journal of Aeronautical Sciences, Vol. 7, May 1940, pp. 283.

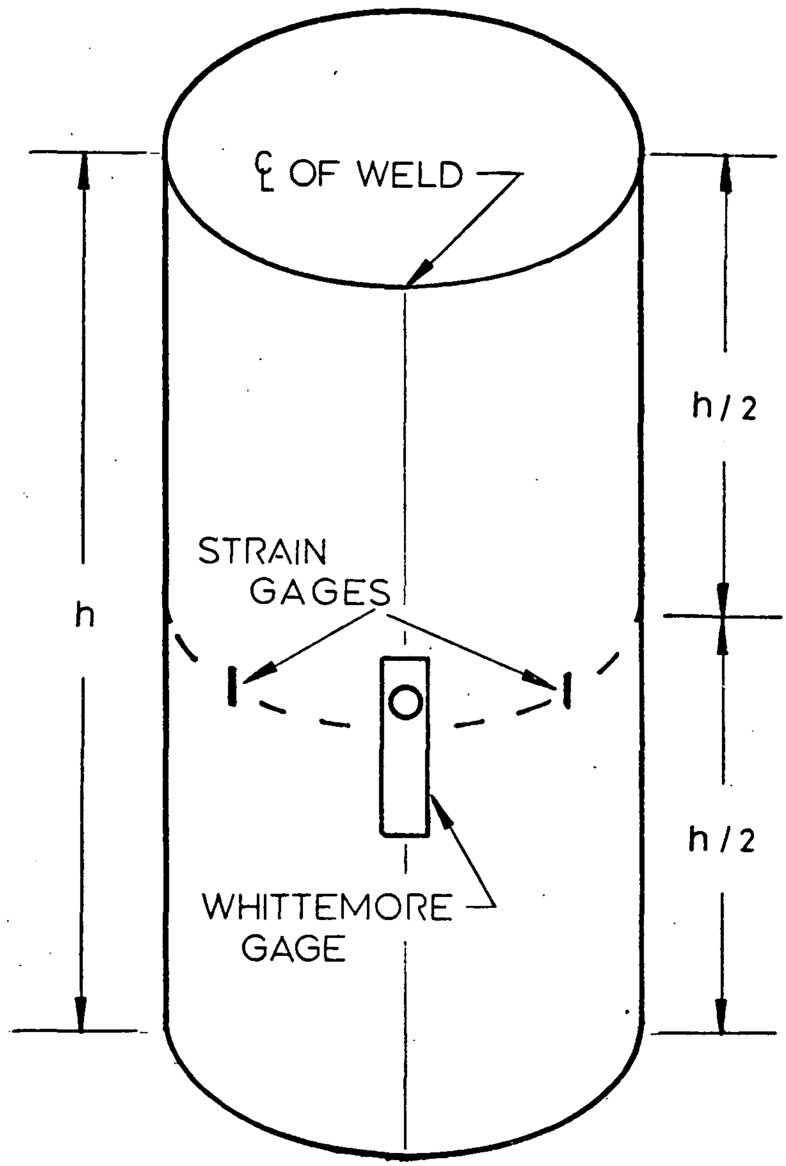


Fig. 1 Stub Column Instrumentation Diagram - Elevation

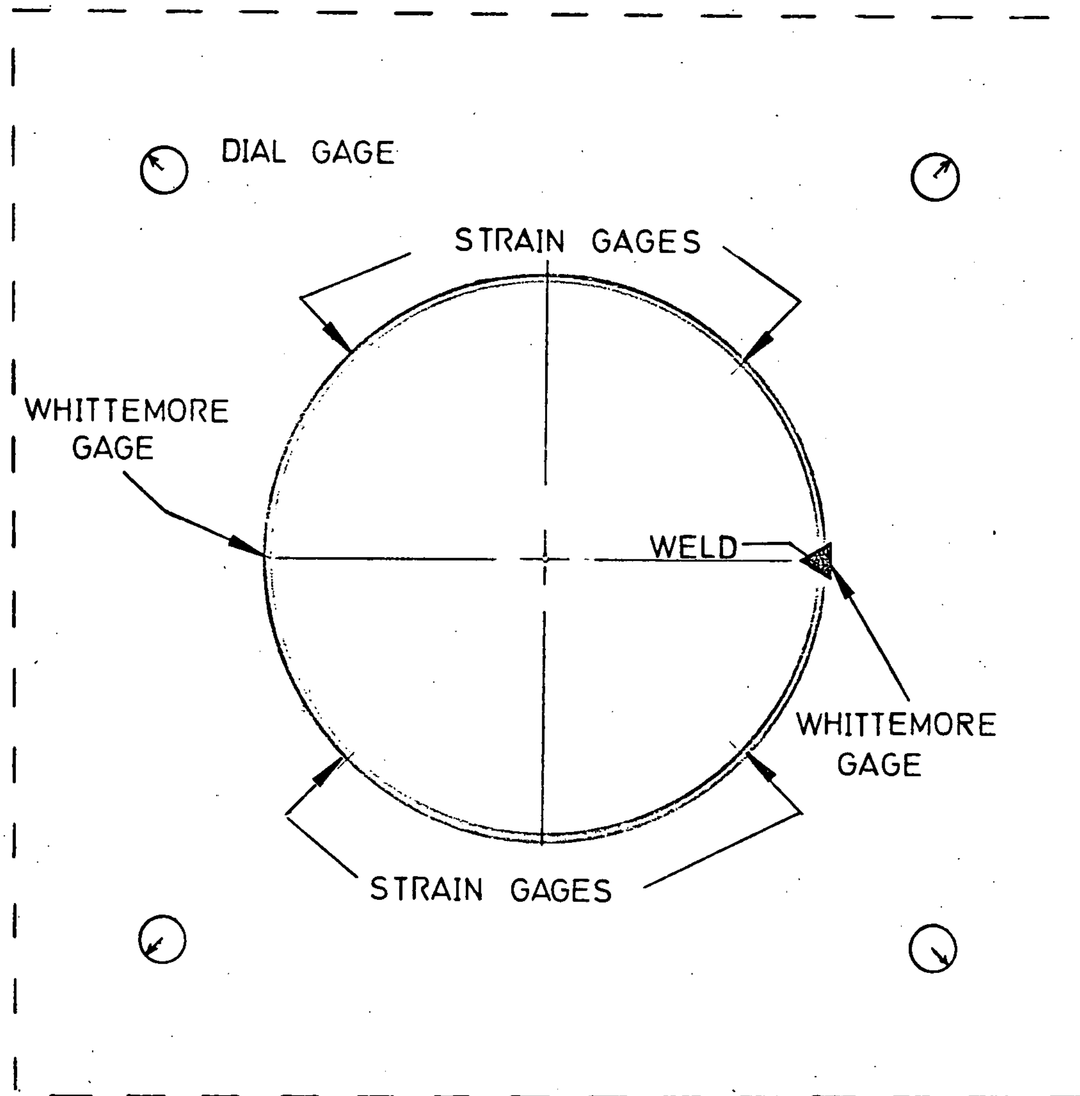
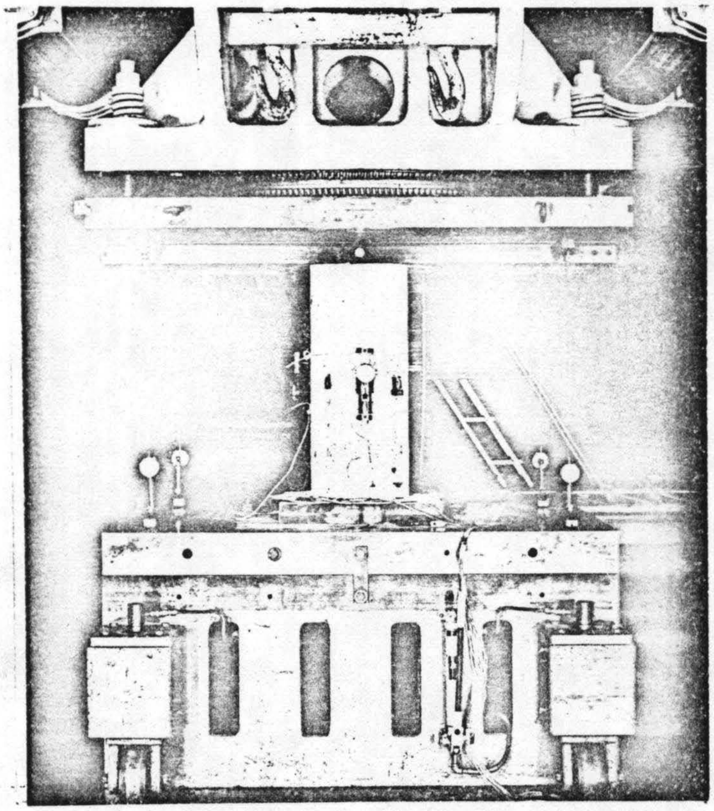
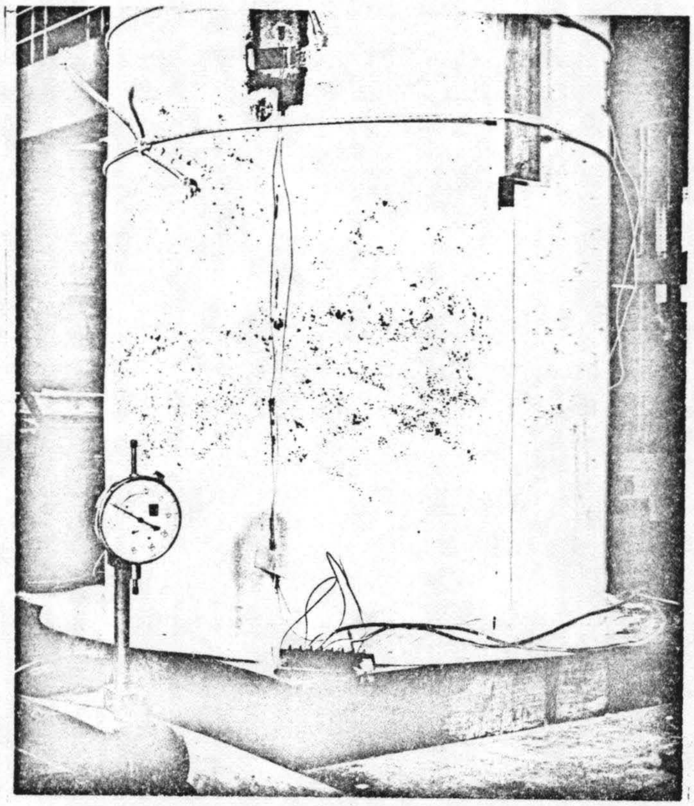


Fig. 2 Stub Column Instrumentation Diagram - Plan

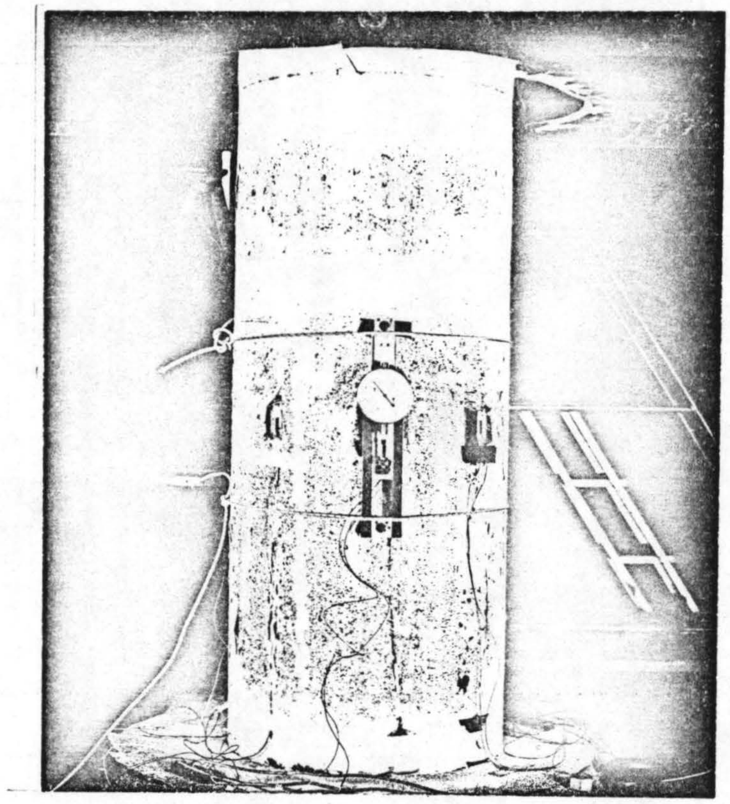


a) Overall in Testing Machine

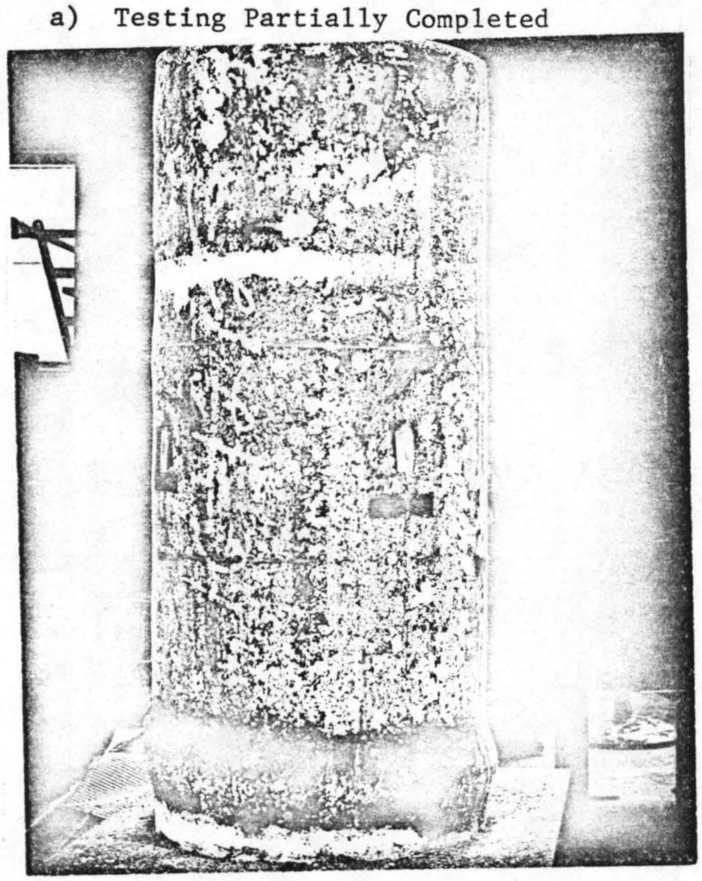


b) Detailed Instrumentation

Fig. 3 Typical Stub Column Testing Technique



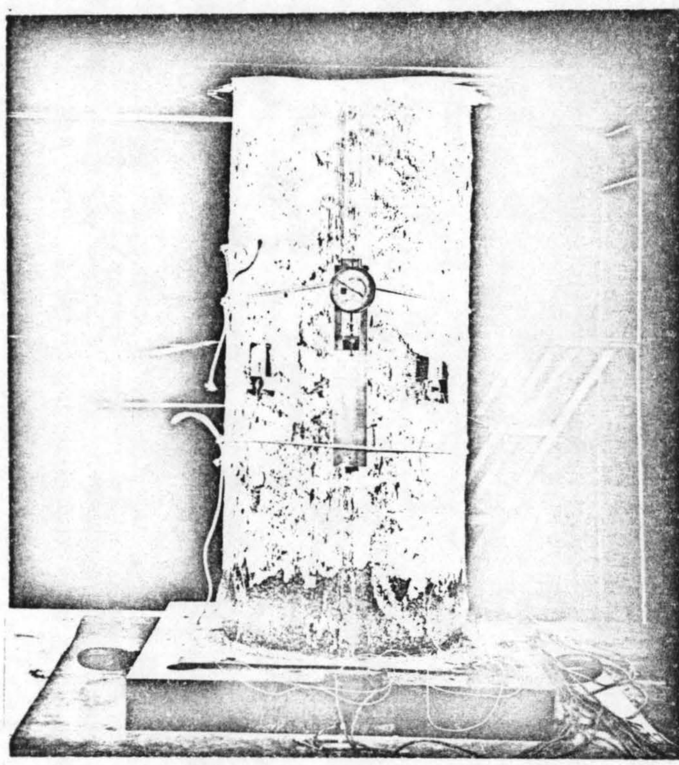
a) Testing Partially Completed



b) After Completion of Testing

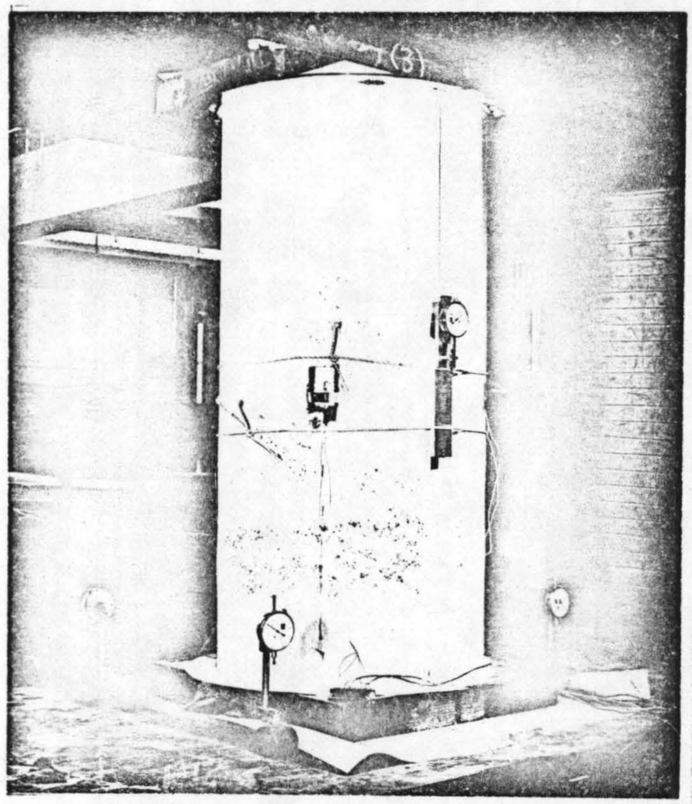
Fig. 4 Stub Column No. 1 - Testing Photograph

a) Testing Complete - Opposite to Weld

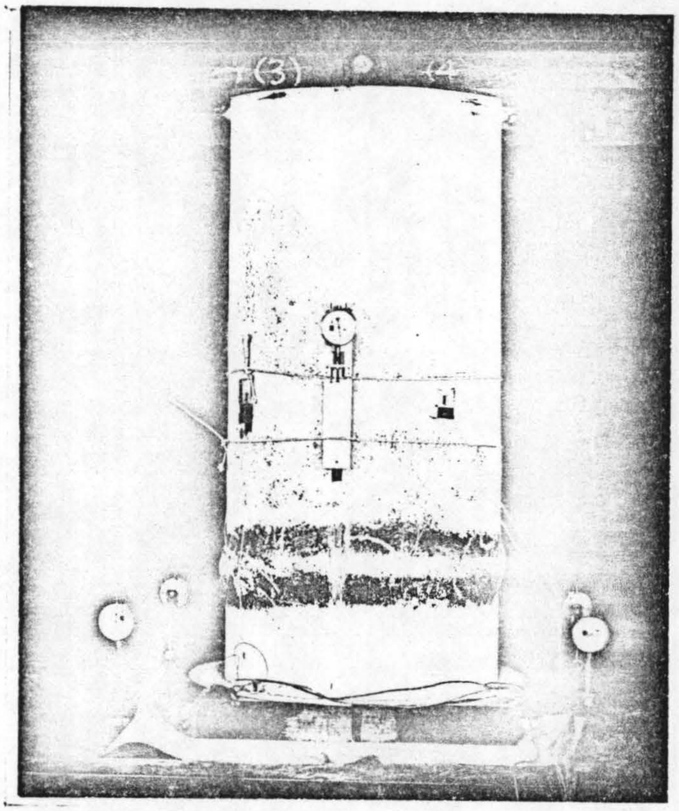


b) Testing Complete - Weld Side of Specimen

Fig. 5 Stub Column No. 2 - Testing Photograph

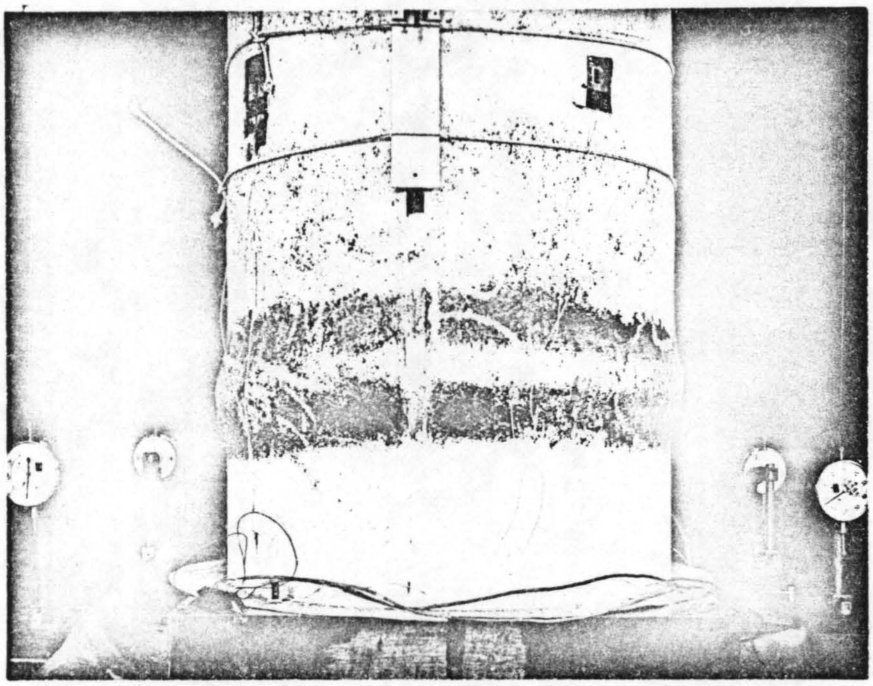


a) Onset of Yield

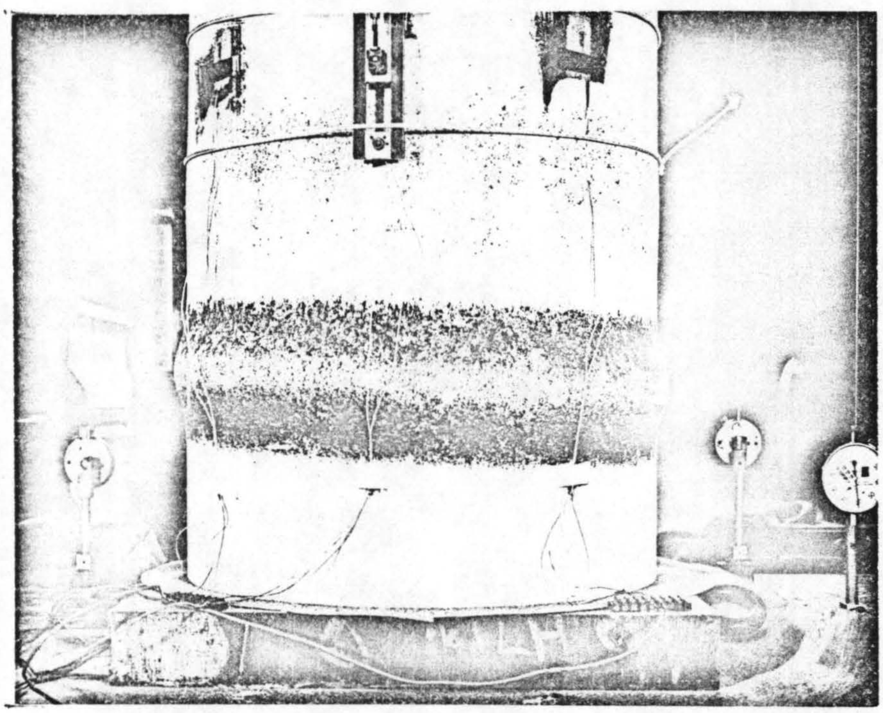


b) Testing Completed

Fig. 6 Stub Column No. 3 - Testing Photograph



a) Weld Side of Specimen



b) Opposite to Weld

Fig. 7 Details of Specimen No. 3 Failure

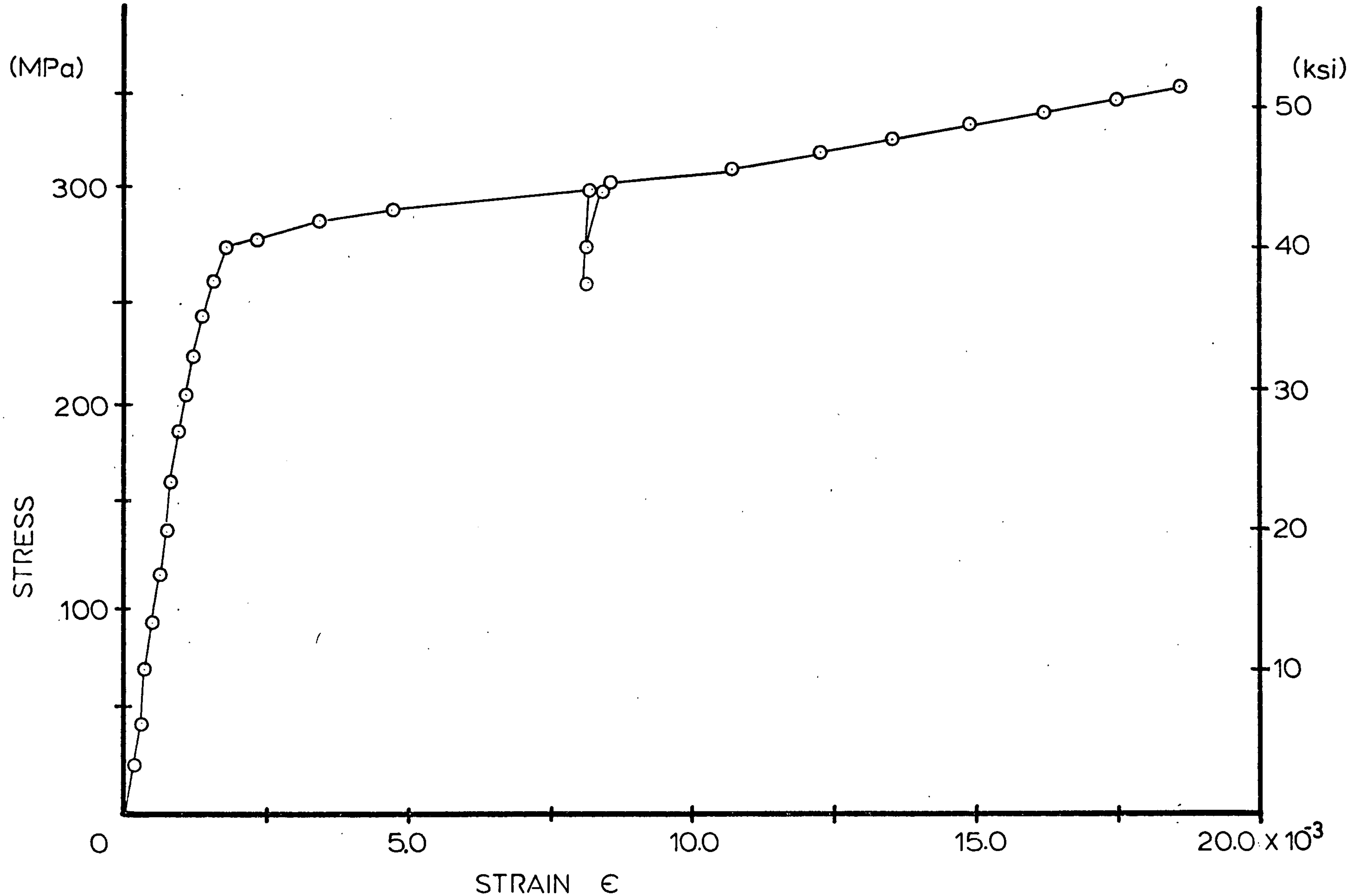


Fig. 8 Stress-Strain Curve for Stub Column 1 (Heat Lot II)

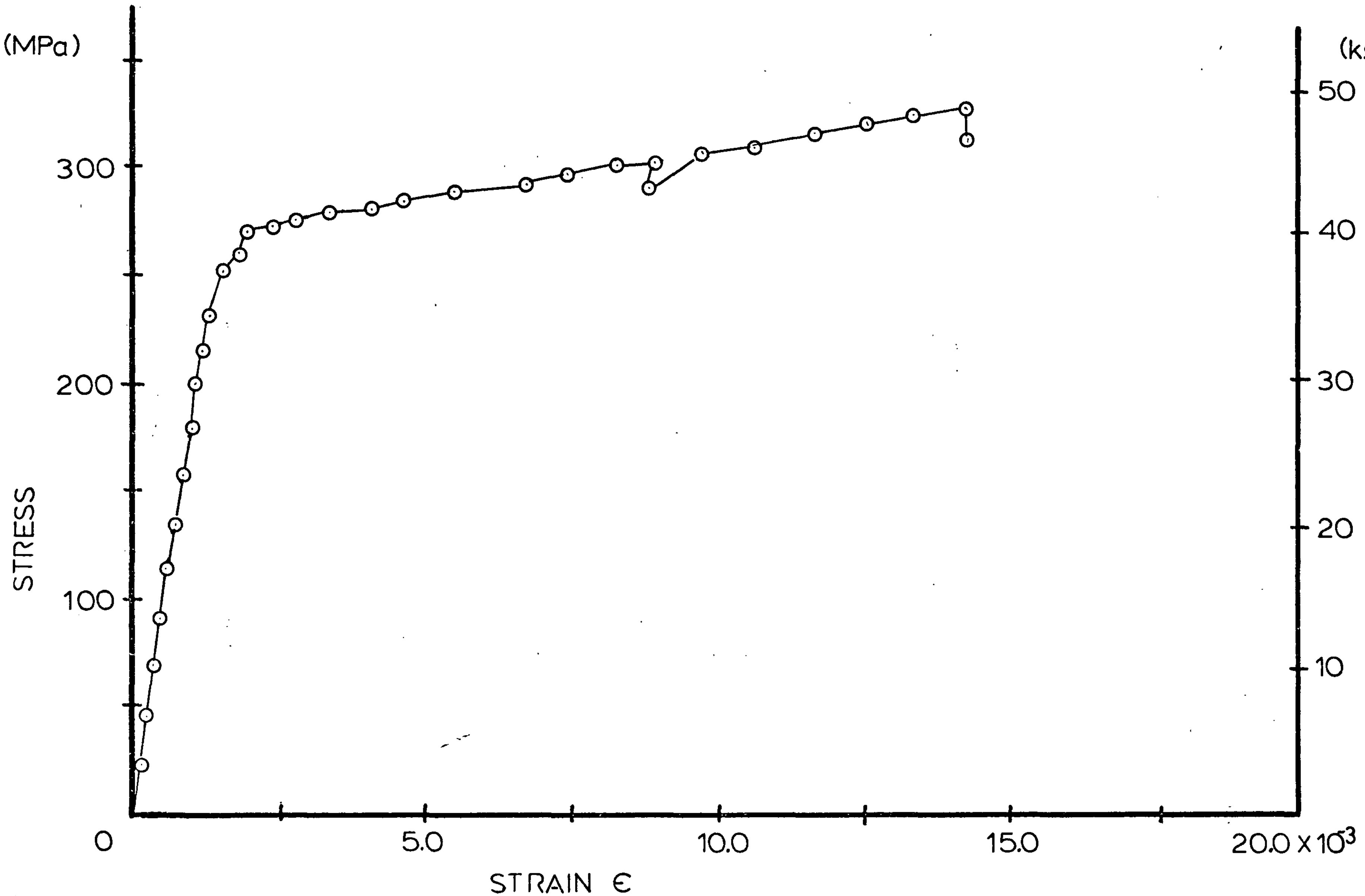


Fig. 9 Stress-Strain Curve for Stub Column 2 (Heat Lot I)

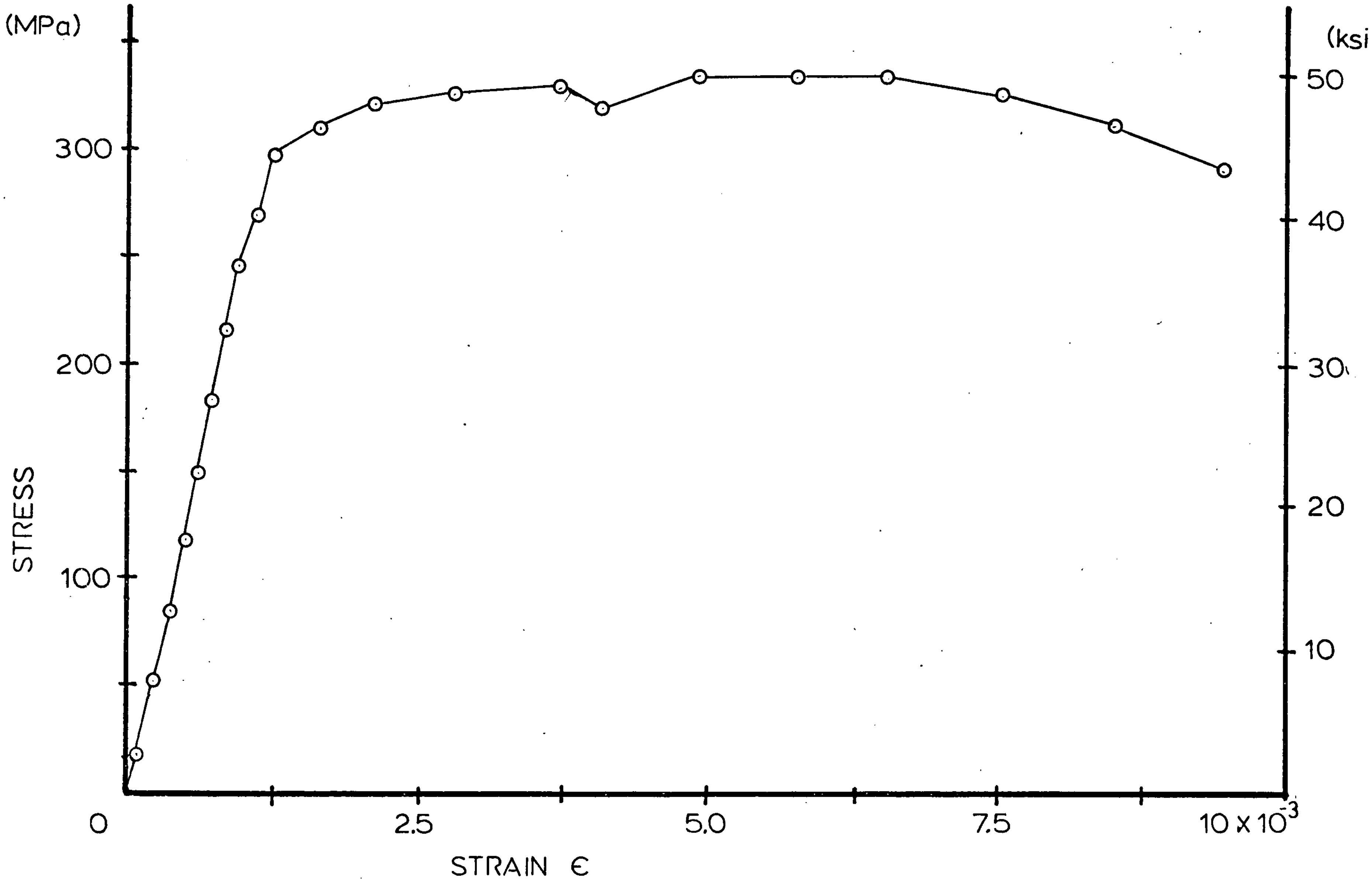


Fig. 10 Stress-Strain Curve for Stub Column 3 (Heat Lot II)

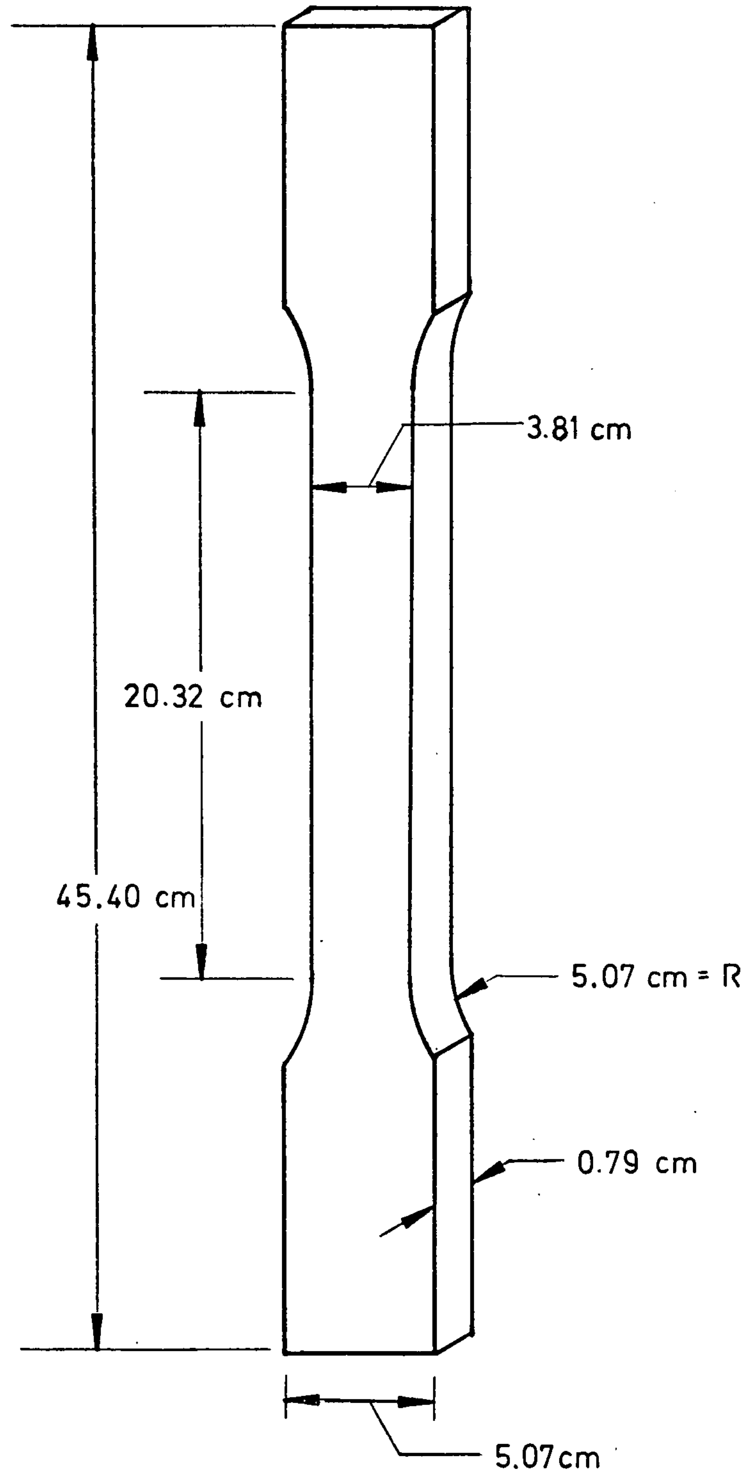


Fig. 11(a) Typical Tensile Specimen Dimensions - SI Units

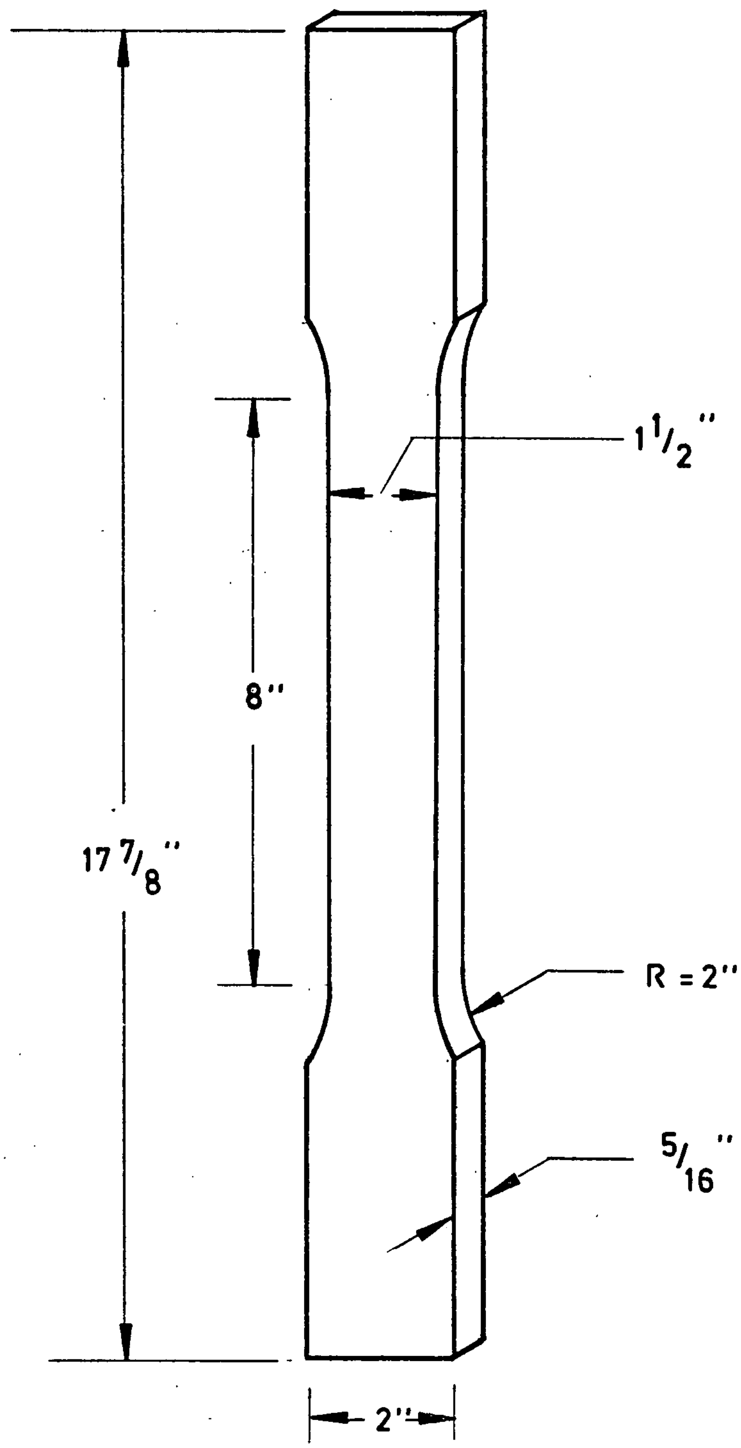


Fig. 11(b) Typical Tensile Specimen Dimensions - Imperial Units

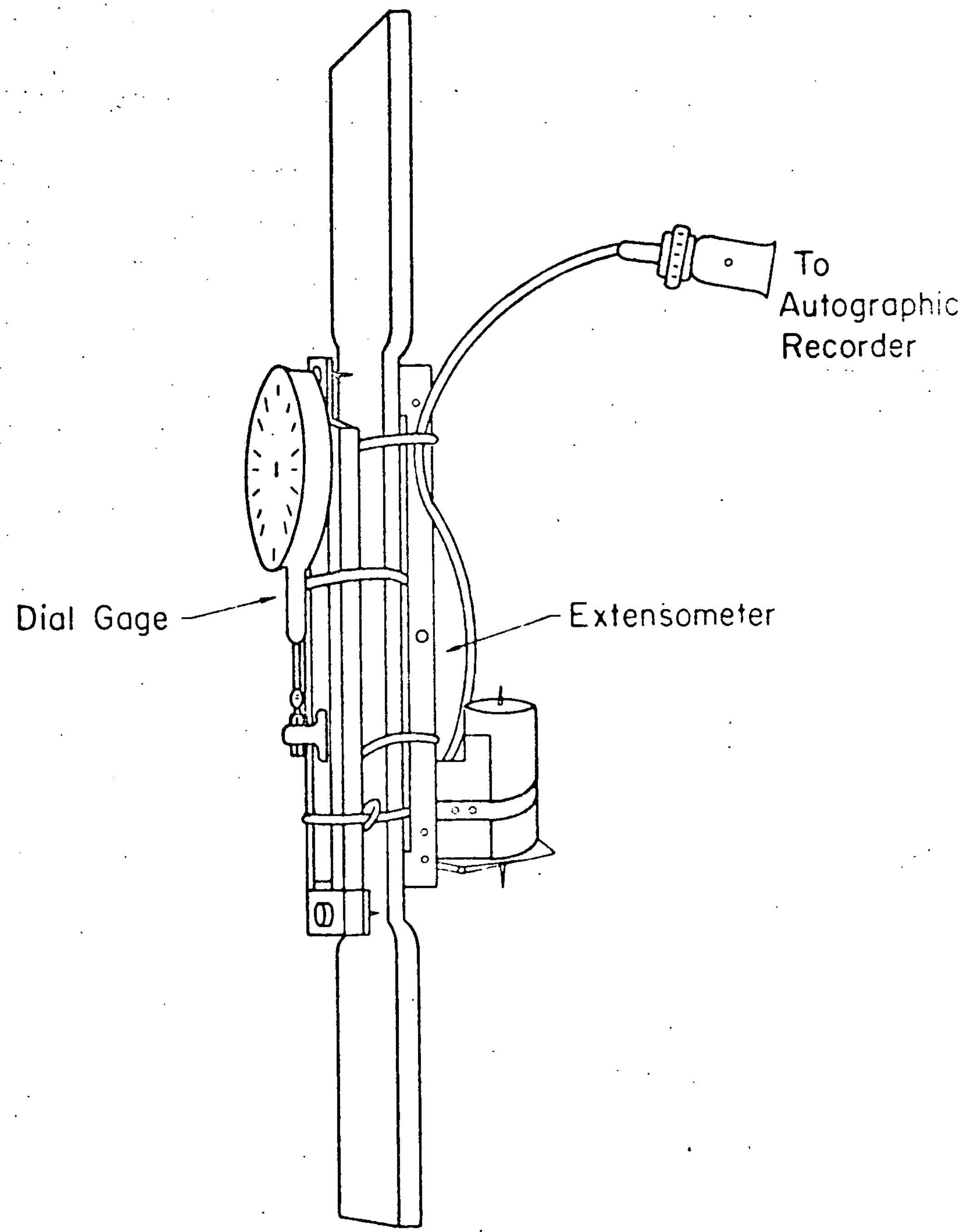


Fig. 12 Tensile Specimen Instrumentation Diagram

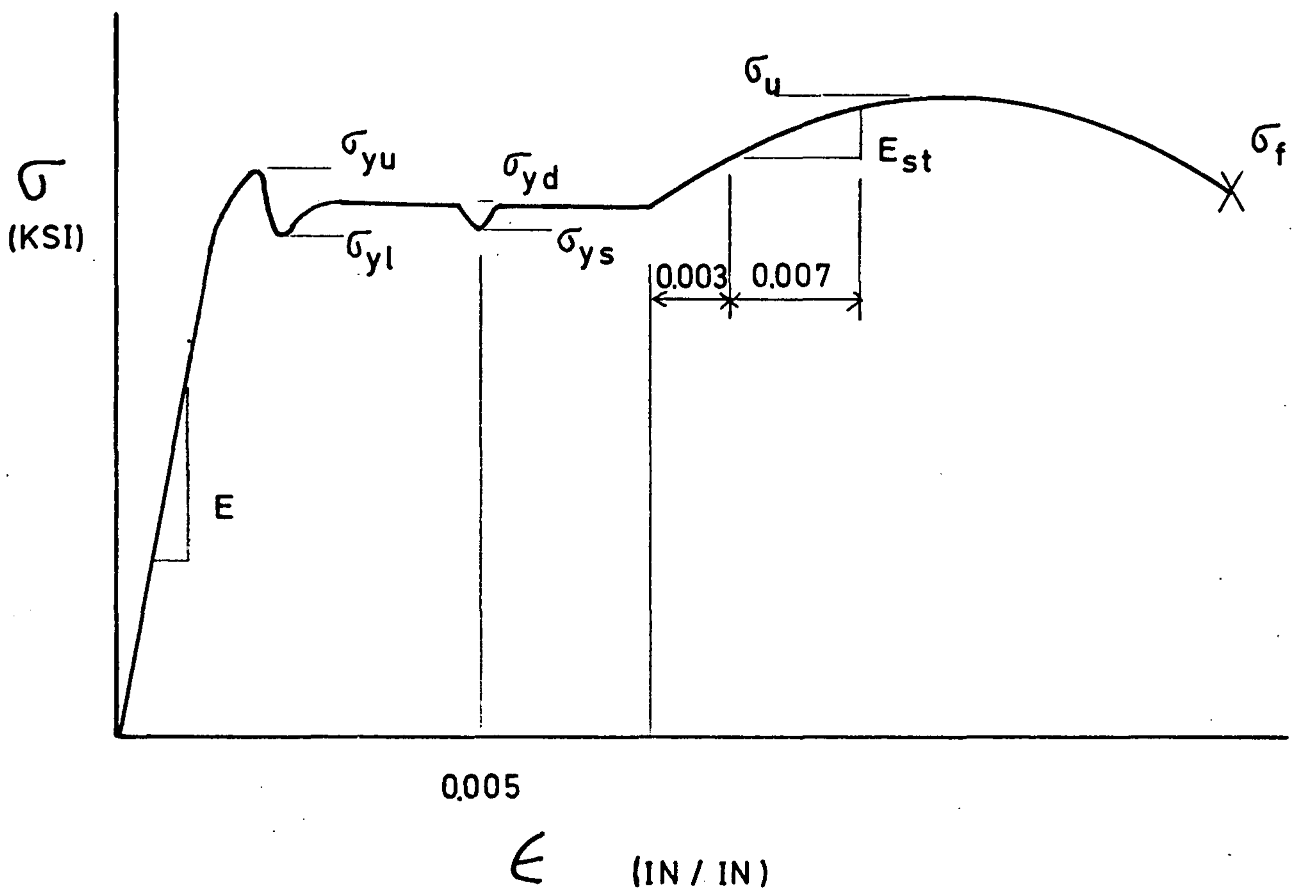


Fig. 13 Typical Stress-Strain Curve for Steel

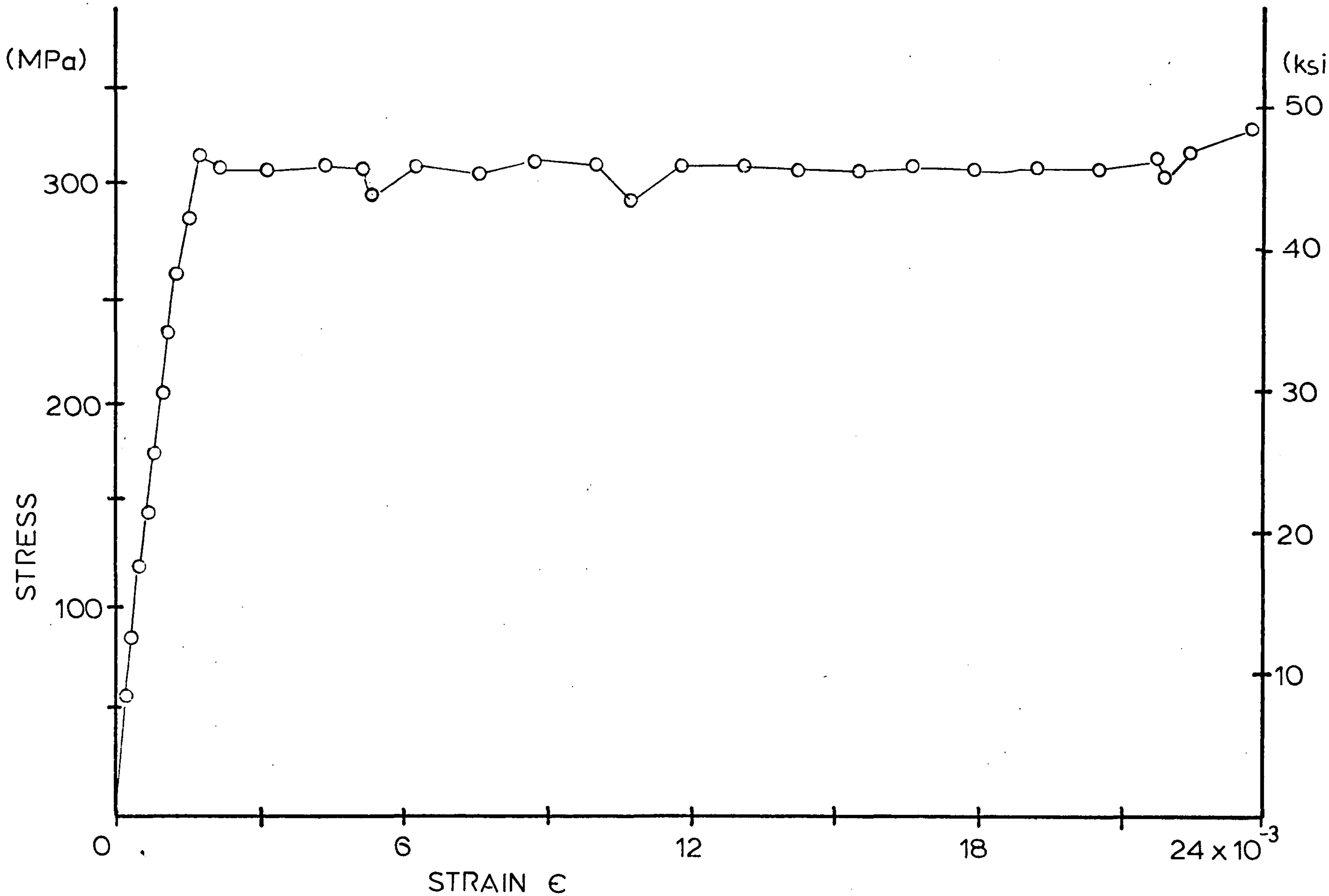


Fig. 14 Stress-Strain Curve for Tensile Specimen A-3

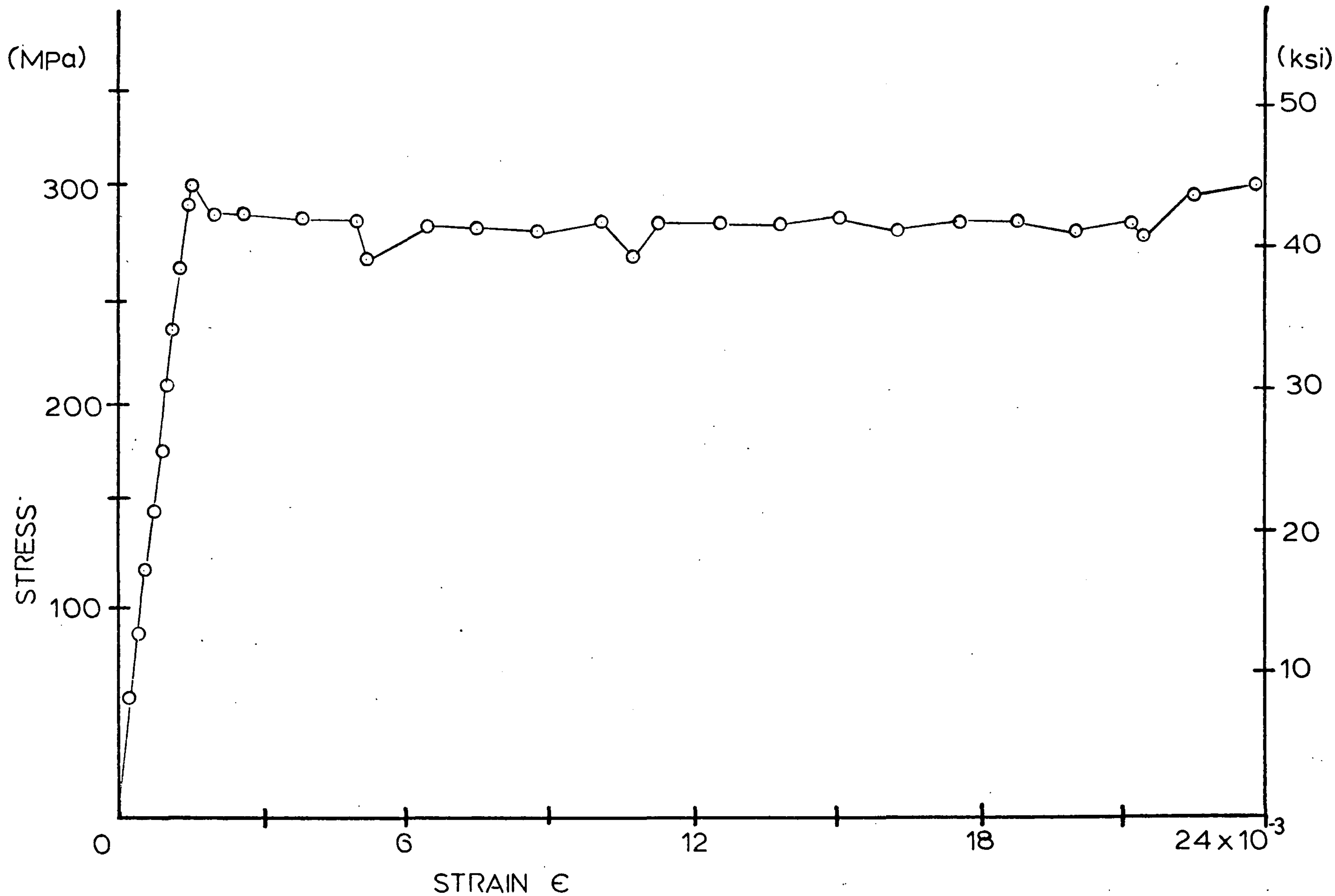


Fig. 15 Stress-Strain Curve for Tensile Specimen B-3

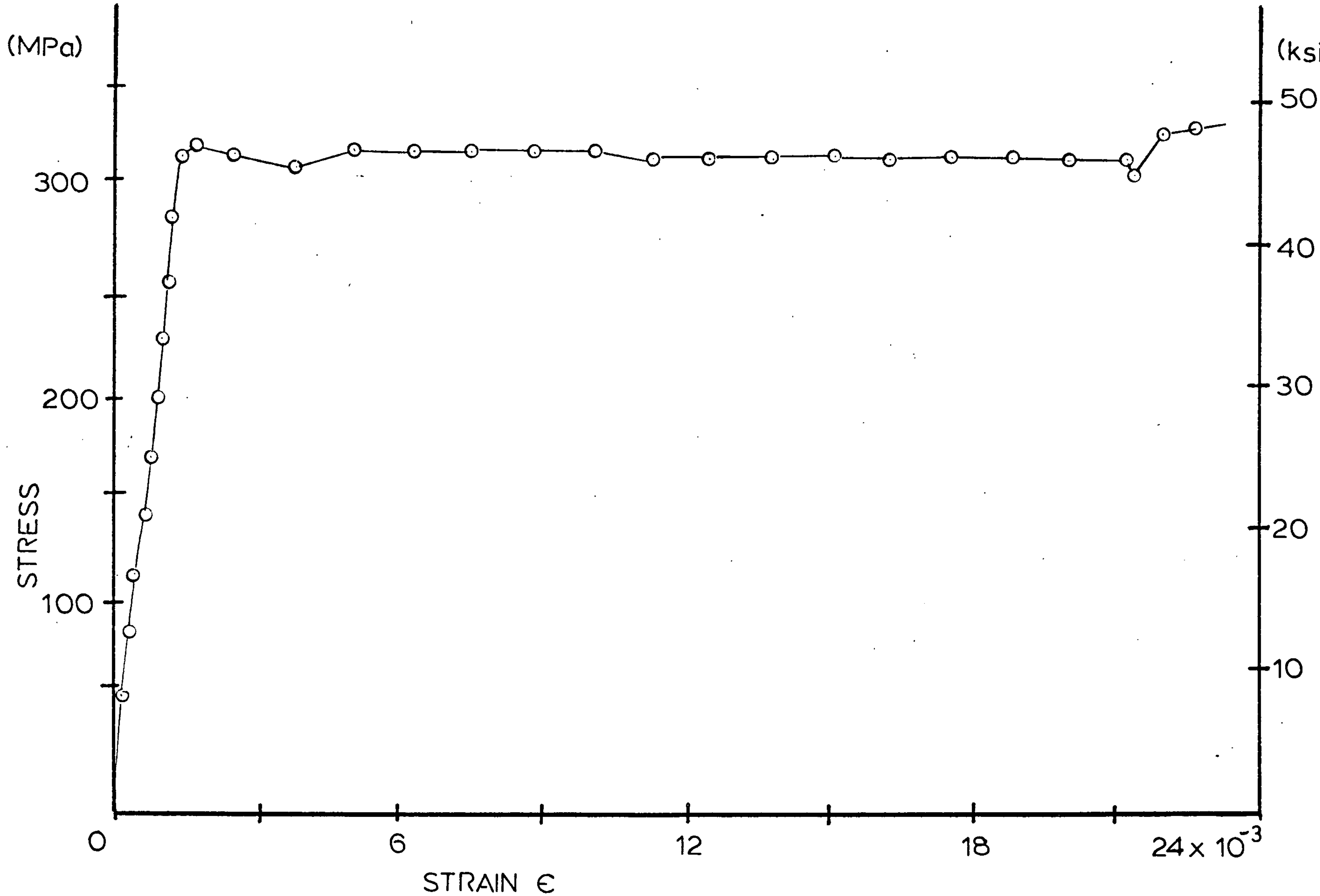


Fig. 16 Stress-Strain Curve for Tensile Specimen C-3

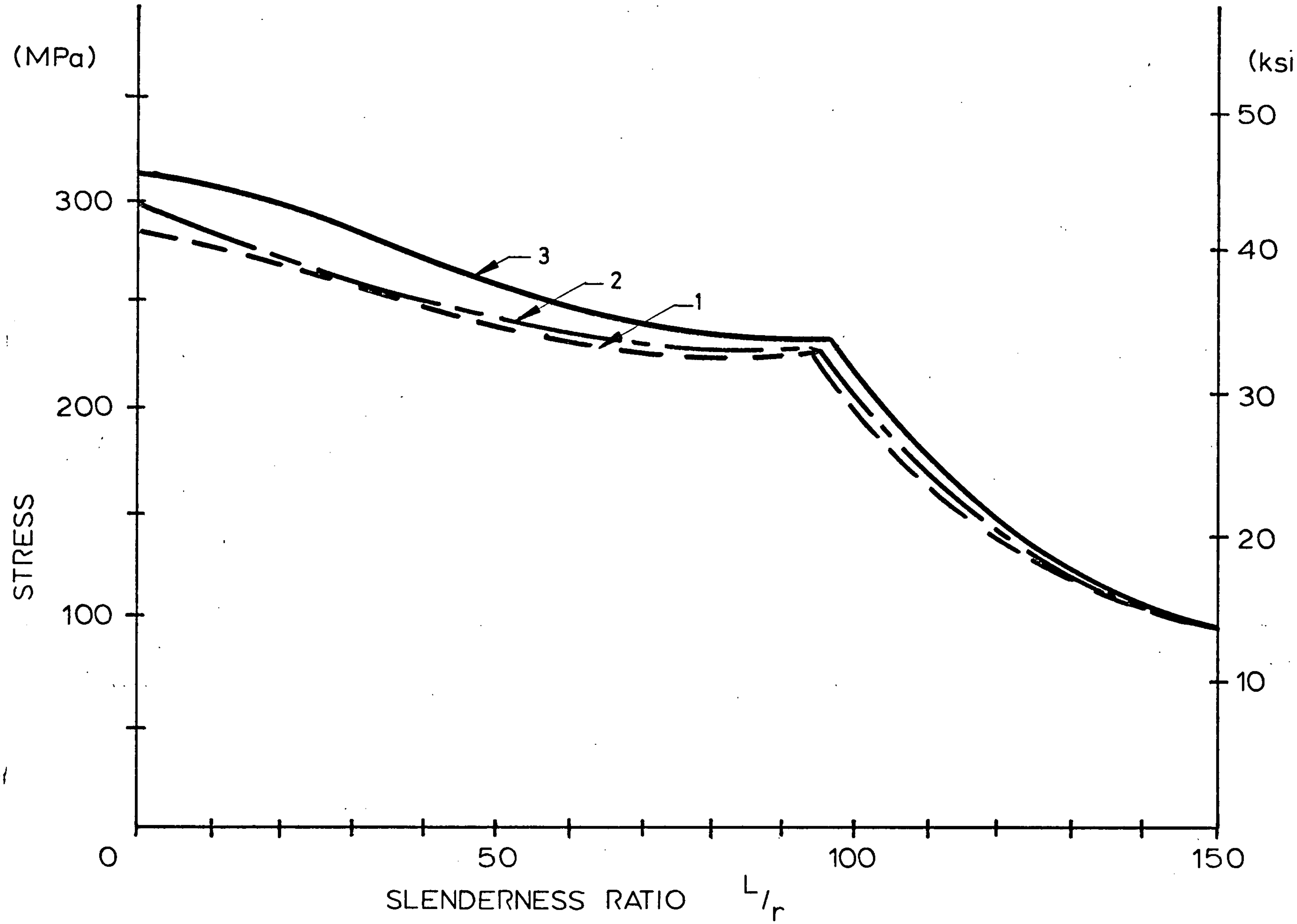


Fig. 17 Column Buckling Curves Predicted from Stub Column Tests

Table 1 Mill Report Material Properties

Heat Lot	Yield Point (ksi)	Tensile Strength (ksi)	% Elongation (8 m)
I(161295)	46.1	65.7	26.7
II(1G1341)	46.9	66.4	25.0
	50.1	71.2	26.0

Table 2(a) Tensile Specimen Material Properties - SI Units

Heat Lot	No.	Upper Yield Stress (MPa)	Dynamic Yield Stress (MPa)	Static Yield Stress (MPa)	Ultimate Stress (MPa)	Fracture Stress (MPa)	E (GPa)	E_{st} (GPa)	Percent Elongation	% Reduction of Area
II(1G1341)	A1	327	319	304	476	364	216	3.3	25.03%	40.04%
	A2	335	322	304	473	408	208	2.9	26.65%	42.40%
	A3	323	317	304	473	413	210	3.2	26.73%	39.53%
	C2	330	324	313	474	386	211	2.8	26.46%	47.83%
	C3	323	323	308	476	381	214	2.9	26.55%	47.71%
I(1G1295)	B1	288	286	270	445	377	209	2.8	27.32%	46.15%
	B2	309	290	273	443	369	213	3.0	27.90%	47.75%
	B3	307	288	272	445	367	211	2.9	28.73%	44.73%

Table 2(b) Tensile Specimen Material Properties - Imperial Units

Heat Lot	No.	Upper Yield Stress (ksi)	Dynamic Yield Stress (ksi)	Static Yield Stress (ksi)	Ultimate Stress (ksi)	Fracture Stress (ksi)	E (ksi)	E_{st} (ksi)	Percent Elongation	Percent Reduction of Area
II(1G1341)	A1	47.32	46.25	44.11	68.95	53.53	31,263	481	25.03%	40.04%
	A2	48.61	46.68	44.11	68.52	59.10	30,135	417	26.65%	42.40%
	A3	46.79	45.94	44.02	68.60	59.83	30,389	465	26.73%	39.53%
	C2	47.83	46.99	45.34	68.74	55.90	30,612	412	26.46%	47.83%
	C3	46.87	46.87	44.58	68.96	55.21	31,016	420	26.55%	47.71%
I(1G1295)	B1	41.67	41.45	39.10	64.32	54.70	30,354	406	27.32%	46.15%
	B2	44.75	41.97	39.61	64.24	53.53	30,835	433	27.90%	47.75%
	B3	44.52	41.72	39.35	64.52	53.12	30,512	424	28.73%	44.73%

Table 3 Stub Column Failure Data

Specimen	Diameter m (in.)	Length m (in.)	Dynamic Ultimate Load kN (kips)	Static Ultimate Load kN (kips)
1	.381 (15)	.907 (35.7)	3596 (808)	3444 (774)
2	.381 (15)	.907 (35.7)	3373 (758)	3222 (724)
3	.559 (22)	1.17 (46.1)	4584 (1030)	4459 (1002)