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EVALUATION OF THE COMPRESSIVE PROPERTIES OF A SPECIAL 3DQP.(U)

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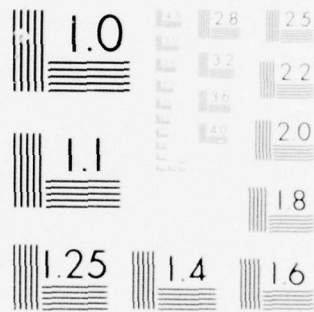
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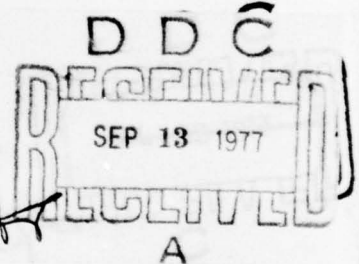
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EVALUATION OF THE COMPRESSIVE PROPERTIES OF A SPECIAL 3DQP

INTRODUCTION

The intent of this program was the evaluation of the hoop and axial compressive properties of two cylinders of three dimensional quartz phenolic. Both cylinders were manufactured by the C process/slat technique and both had an A_r/A_t of roughly 0.7. Cylinder 6.1.4 was seven inches in diameter and cylinder 4.1.18 was approximately 14 inches in diameter.

Two basic specimen configurations were utilized. One was the curved coupon as originally designed by Southern Research Institute (SoRI) in the conduction of the Composite Response Study (CRS). The other was a somewhat shorter and thinner specimen with straight edges and no reduced gage section. These will be referred to as the SoRI design, and the rectangular design, respectively, throughout this report. The resulting data enabled a direct comparison of specimen types, as well as the associated test techniques, to be made. This program was conducted under DNA Contract DNA001-75-C-0037.

TEST MATRIX

SoRI received 2 in. x 2 in. arcs from cylinder 6.1.4 from which hoop and axial specimens of the two design types were machined. In addition specimens of the rectangular design were premachined and sent to SoRI. The test matrix indicating the type and quantity of specimens is shown in Table 1.

CUTTING PLAN

The cutting plan for excising the specimen blanks from cylinder 6.1.4 is shown in Figure 1. From this cylinder SoRI received the twelve arcs labeled SoRI 1 through 12. Arcs 1, 3, 6, 7, 9, and 11 were labeled for use in making

circumferential specimens and arcs 2, 4, 5, 8, 10 and 12 were labeled for making axial specimens.

After NDC of the arcs, these were machined by SoRI into specimens per the following table.

	<u>Side One</u>	<u>Side Two</u>
C-1	1 SoRI ¹ Circ	2 Rectangular Circs ²
A-2	1 SoRI Axial	-
C-3	1 SoRI Circ	2 Rectangular Circs ²
A-4	1 SoRI Axial	-
A-5	1 SoRI Axial	1 Rectangular Axial ³
C-6	-	1 SoRI Circ
C-7	1 SoRI Circ	1 SoRI Circ
A-8	1 SoRI Axial	1 Rectangular Axial ³
C-9	-	1 SoRI Circ
A-10	1 SoRI Axial	-
C-11	1 SoRI Circ	1 SoRI Circ
A-12	1 SoRI Axial	

¹Refers to specimen design - see Test Technique section

²Consisted of four pieces - two from inside and two from outside (labeled In and Out)

³Labeled 5-AC-Rect* and 8-AC-Rect*

In addition, SoRI received six axial specimens of the rectangular design pre-machined by the sponsor from the segments directly below arcs 2, 4, 5, 8, 10 and 12, which were labeled 2-AC-Rect, 4-AC-Rect, etc. The remainder of the material was retained for further use by the sponsor.

The cutting plan used by the sponsor for cylinder 4.1.18 is shown in Figure 2. Of the specimens indicated, SoRI received axial specimens A4, A13, A19, A30, and A39,

and hoop specimens H7, H16, H24, H32, and H33. In addition, axial specimens A43, A46, A48 and A50 were machined from the portion indicated as spare and sent to SoRI.

NONDESTRUCTIVE TEST TECHNIQUES

Radiography

Radiography was performed using state-of-the-art X-ray techniques for low absorptive materials. The radiography unit is a Radiflour 360 manufactured by Torr X-Ray Corporation, rated for operation from 0 to 120KV at either 3 or 5 MA. A beryllium window and small focal spot size (0.35mm) are two characteristics which enable it to examine low absorptive materials with high resolution and sensitivity. Radiographic sensitivity using extra-fine grain film is less than two percent.

The twelve arcs from cylinder 6.1.4 were radiographed simultaneously using a turntable technique before machining into finished specimens. After machining, the SoRI design, the rectangular design, and the premachined specimens were radiographed in groups of varying size. All arcs and specimens were positioned with the axial fibers parallel to the source to enable variations in the circumferential fibers to be viewed. In addition the SoRI design axial specimens were also X-rayed in the circumferential direction.

Gravimetric Bulk Density

Bulk density was determined from direct measurements of weight and dimensions. Weight measurements were made on an analytical balance having a sensitivity of +0.0001 gram. Dimensional measurements were made to the nearest 0.0005 inch using micrometers.

The densities of the twelve arcs were determined before final machining, while those of the additional specimens received by SORI were calculated for each individual specimen.

Ultrasonic Velocity

Acoustic velocity was measured using the through-transmission, elapsed-time technique. In this method, an electrical pulse originated in a pulse generator and was applied to a ceramic piezo-electric crystal (SFZ). The pulse generated by this crystal was transmitted through a short delay line and inserted into the specimen. The time of insertion of the leading edge of this sound beam was the reference point on the time base of the oscilloscope, which was used as a high speed stop watch. When the leading edge of this pulse of energy reached the other end of the specimen, it was displayed on the oscilloscope. The difference between the entrance and exit times was used with the specimen length in calculating ultrasonic velocity. Appendix B should be consulted for a more extensive explanation of the ultrasonic velocity technique.

For Arcs 1, 3, 6, 7, 9, 11, those from which hoop specimens were to be machined, velocity was determined in both the radial and circumferential directions. The remaining arcs, designated for axial specimens, had velocity calculated in the axial direction only.

COUPON COMPRESSION TEST TECHNIQUE

The basic compressive test apparatus had three structural components: a sleeve, a lower grip, and an upper grip as shown in Figures 3 and 4. The lower grip rested on the fixed platform of a conventional loading

frame, while the upper grip was located between the specimen and the moving crosshead. A Tinius Olsen screw-driven compression machine, with a maximum capacity of 30,000 pounds was used in this program. The applied load was monitored directly from the built-in load cell in the platform of the machine. Perpendicular alignment of the load was ensured by the guiding action of the sleeve which fits (within 0.001 in.) around the upper and lower grips. The specimen was held firmly in place in precision inserts which were bolted into the grips. A separate set of inserts was designed to exactly match each of the four specimen configurations used.

SoRI Axial Specimen Configuration

The axial compressive test was used to determine the axial compressive modulus and axial ultimate compressive strength. The axial specimen designed at SoRI having an overall length of 2 in. with a 0.5 in. x 0.6 in. x 0.7 in. gage section is shown in Figure 5. The inside and outside radii of the specimen were approximately the same as the original cylinder which allowed the circumferential fibers to remain intact across the gage section of the specimen.

Axial strain was measured by two independent systems. Clip-ons and surface strain gages were mounted on both edges of the specimens (see Figure 6). Each set of gages was wired in series and the signals from each were monitored on individual x-y recorders. This provided an immediate indication of the relative accuracy of the two strain measuring techniques.

SoRI Circumferential Specimen Configuration

The SoRI circumferential specimen (Figure 7) was designed to enable the determination of circumferential

compressive modulus and ultimate strength. Ideally, inside and outside radii would have been carefully machined in order to provide a uniform distribution of circumferential fibers. However, due to time constraints, the specimens were machined to accommodate the 4.5 in. radius hardware developed for the CRS program. This change from the optimal design allowed approximately one-half ply to "run out" over the length of the gage.

The loading apparatus was the same as used in the axial compressive test with the addition of a lateral support arm. As compressive loads were applied to the grips, the gage section of the specimen experienced both bending and axial compressive loads. However, the support arm, which was inserted through a cutout in the sleeve, was applied in a manner which negated the bending effect. Clip-on gages on the inner and outer faces continuously monitored the displacements there. By adjusting the support arm both displacements were maintained equal and the stress in the gage section was considered nominally uniform. The modulus and ultimate strength were determined as though the loading were simple uniaxial.

Again, both clip-ons and strain gages were mounted on the edges of the specimen. Figure 8 shows a schematic view of the overall instrumentation including a total of four clip-ons and two surface strain gages per specimen.

Rectangular Axial Specimen Configuration

The rectangular axial compressive specimen is shown in Figure 9. It was tested in the same apparatus as described above with a similar arrangement of clip-ons and strain gages as described previously. Except for a miniaturized set of clip-on arms designed to fit the smaller specimen size, the instrumentation (Figure 10) and recording procedures were identical to those used for the SoRI designed axial specimen.

Rectangular Circumferential Specimen Configuration

The rectangular designed circumferential specimen consisted of two separate 1.00 in. x 0.300 in. x 0.150 in.

pieces cut from a circumferential chord of a cylinder. They were mounted face to face in the inserts, with the circumferential fibers from each "half-specimen" bowing towards the center (see Figure 11). This eliminated most bending moment as the two halves tended to apply lateral support to one another during compression. This specimen is often referred to as the "belly to belly" configuration.

The instrumentation was again similar to that described before with a few minor changes. The clip-ons were mounted on opposing sides of the specimen rather than on the edges. Furthermore, a surface strain gage was located on each edge of each "half-specimen" resulting in a total of four gages per specimen (Figure 12). The four gages were monitored two at a time until it was determined that negligible discrepancies occurred between the signals. In subsequent testing all four gages were wired together in series, producing one recorded signal.

NONDESTRUCTIVE CHARACTERIZATION OF 3DQP ARCS AND SPECIMENS

The twelve arcs received were examined using ultrasonic velocity, visuals and X-rays. The gravimetric density of each arc was also determined. For the ultrasonic data three points were measured in both the axial and circumferential directions at $0.25L$, $0.5L$ and $0.75L$ along the surface. In the radial direction five points were measured, one at the center and one each at the center of four quadrants. These data are shown in Table 2 which reports only the average of the velocity data for each arc. Table 3 shows the density values for each of the specimens from 4.1.18 and Table 4 shows the densities of the six pre-machined specimens from 6.1.4. The average

data for the density of the arcs from 6.1.4 was 1.685 gm/cm^3 and for the specimens from 4.1.18, 1.625 gm/cm^3 . The difference in the densities between the cylinders probably was not as great as this would indicate since the specimens from 4.1.18 came from near the inside of the arc. Similar specimens taken adjacent to the arcs in 6.1.4 had an average density of 1.662 gm/cm^3 . The average velocities of the 6.1.4 arcs were 0.1798, 0.1809, and 0.1937 in./ μsec in the axial, circumferential and radial directions, respectively.

Prints of the X-rays of both the specimens and the arcs are included as Figures 13 through 16. Notice the nature of the circumferential yarns, especially towards the center on the arcs from 6.1.4. This bending and waving of the circumferential yarns was evident in the visual examinations and is documented in a 20X photomicrograph in Figure 17. The montage was taken through the center of the arc viewing in the axial direction.

COMPRESSIVE TEST RESULTS

The results of the compressive tests are reported in tabular form in terms of three parameters - tangent modulus, ultimate stress, and ultimate strain. The modulus for each specimen was determined by calculating the slope of a tangent to the linear portion of the stress-strain curve. In many cases a slight nonlinear portion of the curve at low stress levels was ignored in the calculations. Since two independent strain measuring systems were utilized, moduli values as determined from both clip-ons and surface strain gages are reported. The strain-to-failure data are reported from clip-ons only, since strain gages typically give ambiguous results near the end of the run. The ultimate strain reported is the strain value corresponding to the ultimate stress.

The results of the six axial compressive tests using the SoRI design are summarized in Table 5. The average modulus was 2.06×10^6 psi (clip-ons) and 2.15×10^6 psi (strain gages), the average strength 55,733 psi and the average strain-to-failure 35 mils/in. The composite stress-strain curves from these six runs are shown in Figures 18 and 19 (clip-on and strain gage data, respectively). Repeatability is demonstrated by the narrow range within which all curves lie. Individual raw data curves are provided in Appendix A.

The results from the rectangular design axial compressive tests from cylinder 6.1.4 are shown in Table 6. The average modulus for these eight runs was 2.17×10^6 psi (both methods). The average strength was 52,338 psi and the average ultimate strain 28 mils/in. These data include results from two specimens which were machined at SoRI from arcs 5 and 8. Only limited significance may be attributed to the slightly higher values from these runs due to the small sample size. The composite stress-strain curves from these eight runs are shown in Figures 20 and 21.

The results from the rectangular design axial compressive tests on material from cylinder 4.1.18 are shown in Table 7. The average moduli from these nine tests was softer than that for the 6.1.4 material, 1.93×10^6 psi (clip-ons) and 1.86×10^6 psi (strain gages). The average strength was less than that from 6.1.4, 43,656 psi and the ultimate strain was lower, 24.3 mils/in. The composite plots for these runs are shown in Figures 22 and 23. Again, a very tight envelope may be constructed around the stress-strain curves.

The circumferential compressive test data using the

SoRI design specimen for material from cylinder 6.1.4 is given in Table 8. The average modulus, as calculated from the clip-on data was 3.54×10^6 psi and 3.78×10^6 psi per strain gages. The ultimate strength was 75,050 psi and ultimate strain 23.7 mils/in. The composite plot of the stress-strain curves is shown in Figures 24 and 25.

The rectangular design circumferential data on material from cylinder 6.1.4 is given in Table 9. These were machined by SoRI from Arcs 1 and 3. One inner and one outer specimen was obtained from each arc. The average modulus using both inners and outers was 3.77×10^6 psi (clip-ons), average strength, 59,050 and average ultimate strain 17.3 mils/in. In this case the clip-ons were attached to the faces rather than the edges of the specimens. The average strain gage modulus measured was 3.61×10^6 psi. The distinction between the inner and outer specimens is evident, the inners being stronger (average strength, 61,600 psi) than the outers (56,500 psi) and, perhaps, stiffer (per clip-ons). Notice that the same trend exists for these data points as for the SoRI design specimens, arc 1 was stronger but less stiff than arc 3 (arc 3 was denser). These comparisons will be discussed further later. The composite plot of the stress-strain curves are shown in Figures 26 and 27.

The circumferential compressive data (rectangular design specimen) from cylinder 4.1.18 are given in Table 10. The moduli data from the clip-on gages vary widely due, apparently, to bending in some of the specimens. Again, the clip-ons were mounted on the faces while the strain gages were on the edges. The average modulus per the clip-ons was 4.00×10^6 psi and per the strain gages was 3.53×10^6 psi. The average strength was 63,420 psi

and ultimate strain, 17.3 mils/in. The composite stress-strain curves are shown in Figures 28 and 29. Evidence of relatively severe bending is obvious at low stress levels for specimen H32-CC-Rect. The apparent negative strain was verified by visual observation of the specimen during the test. As the load was initially applied, slight gaps, which were observed visually, opened between the two "half-specimens". This indicated that they were actually bending away from each other instead of applying mutual lateral support, as intended. The modulus as calculated from the subsequent linear portion of the curve (4.25×10^6 psi), still falls within the range of values from the other specimens in this group.

Prior Data and Materials

A summary of some prior experience with this class of materials is provided in Tables 11 (Axial) and 12(Hoop). As is evident, material differences make the comparison difficult. A large segment of the prior data was conducted on Process A materials. The best comparisons came from the CRS program. This program was conducted on Process C material (pineapple) on which optimal test techniques were developed. Examples of the data generated are given in Figures 30 (Axial) and 31 (Hoop). The 6.1.4 material is less stiff but stronger than the CRS material.

Clip-on Gages versus Strain Gages

As was mentioned earlier, both clip-on gages and surface mounted strain gages were used to monitor strain for each run. In general, good agreement has been achieved between the two techniques. This is shown graphically in Figures 32 through 37 in which the moduli calculated from both techniques are displayed for the various specimen types. Excellent agreement can be seen for specimens from the

axial direction (both designs) where, in many cases, data points from the two methods fall directly on top of one another (Figures 32 through 34). Slightly more variation is evident in the data from the circumferential direction specimens (Figures 35 through 37) with differences typically ranging up to approximately 10 percent. The fact that specimens H32 and H33 (Figure 37) vary by more than this amount can be attributed to bending in the specimens. Since the specimen halves tended to bow toward the clip-ons, the apparent strain for a given stress level was less than that recorded by surface strain gages mounted on perpendicular sides. This produced an uncharacteristically high modulus in these cases.

For composite materials of this type, clip-on data is considered to be more representative of the true material response than surface strain gages. This data does have the question of effective gage length since the clip-on flags span 0.1 inch of the gage section. However, from previous experience with composite materials, this difference has been found to be negligible. Clip-ons enable local effects, if any, to be avoided by measuring strain over a longer gage length than surface strain gages. Nevertheless, strain gages do provide valid data for comparison purposes if the cell size is sufficiently small in relation to the gage length. Proper application and alignment promotes repeatability and a degree of confidence in the data.

For specimens of both designs from the axial direction either method is suitable as was demonstrated previously, while the clip-on method is desired for the SoRI design circumferential specimen. For the case of the rectangular design circumferential specimen, the strain gage data are

preferable since the clip-on data were more adversely affected by bending in the specimen.

Inside versus Outside

The CRS program showed the distinction to be very small between the material near the ID and material near the OD. It appears to be somewhat stronger in the case of cylinder 6.1.4 but the data gathered are insufficient for a strong conclusion. A summary of pertinent data are shown in Table 13. Further study would be required to develop a correlation.

Effect of Specimen Design

The moduli of specimens from cylinder 6.1.4, as calculated from both the clip-on gages and the strain gages agree very well between the SoRI specimen design and test technique and the rectangular specimen design and test technique. A comparison is shown in Figures 38 (clip-on) and 39 (strain gage) and in Table 14. The ultimate stresses and strains do not correlate well, the SoRI technique showing the material to be stronger with a higher strain ultimate. A comparison of this data is shown in Figures 40 and 41.

Seven Inch (6.1.4) versus Fourteen Inch (4.1.18) Cylinder Data

The comparison between cylinders 6.1.4 and 4.1.18 can be made using data generated on the rectangular design specimens. These data are summarized in Table 15. The larger cylinder appears to be slightly softer and weaker than the 7 inch cylinder. However, the circumferential strength of the 4.1.18 cylinder is actually higher. This may not actually be true based on the comparison of rectangular and SoRI test techniques. The difference in the ultimate

strengths measured between the two techniques is less for the axial specimens than for the circumferential specimens. Taking this a step further, the fourteen inch cylinder with less curvature may be showing less degradation of its true strength vis a vis the 6.1.4 specimens. These data are plotted by specimens in Figures 42 through 46.

CONCLUSIONS

Several general conclusions may be drawn from the test data which has been reported and analyzed in this report. Material from cylinder 6.1.4 can be compared to that from cylinder 4.1.18 by considering results from the rectangular design specimens. Cylinder 6.1.4 is definitely stiffer and stronger in the axial direction. In the circumferential direction the moduli values are more nearly equivalent while the ultimate strength of cylinder 4.1.18 is slightly higher. Further testing of material from cylinder 4.1.18 using the SoRI design specimen would be necessary to validate the legitimacy of the circumferential strength.

The results from cylinder 6.1.4 may be compared with previous SoRI data from the CRS program since identical specimen configurations were used. The 6.1.4 material is less stiff but stronger in both directions than the CRS materials. Also the 6.1.4 material showed extreme "waviness" of the circumferential yarns, especially near the center of the original arcs. This is considered atypical when compared to the CRS material. The processing differences between the materials obviously contributed to the data variability.

Clip-on extensometers and surface mounted strain gages are both viable methods of measuring deformation in the

type of materials considered here. Results from the two techniques vary minimally except in the case of circumferential specimens. These discrepancies were able to be traced directly to specimen design. Except where other factors are involved, the clip-on data are considered to give slightly more representative results.

The SoRI and rectangular design specimens showed similar moduli values in both directions, when measured by either strain device. However, the ultimate strength values from the SoRI specimen are much higher especially in the circumferential direction, where the SoRI type produced a maximum stress approximately 27 percent higher than the rectangular specimen. Apparently, the utilization of lateral support during the test enabled an accurate assessment of the material's resistance to uniaxial compressive loads without the introduction of unknown bending stresses. The curved coupon and its associated test technique must be considered more valid than the smaller rectangular specimen test technique.

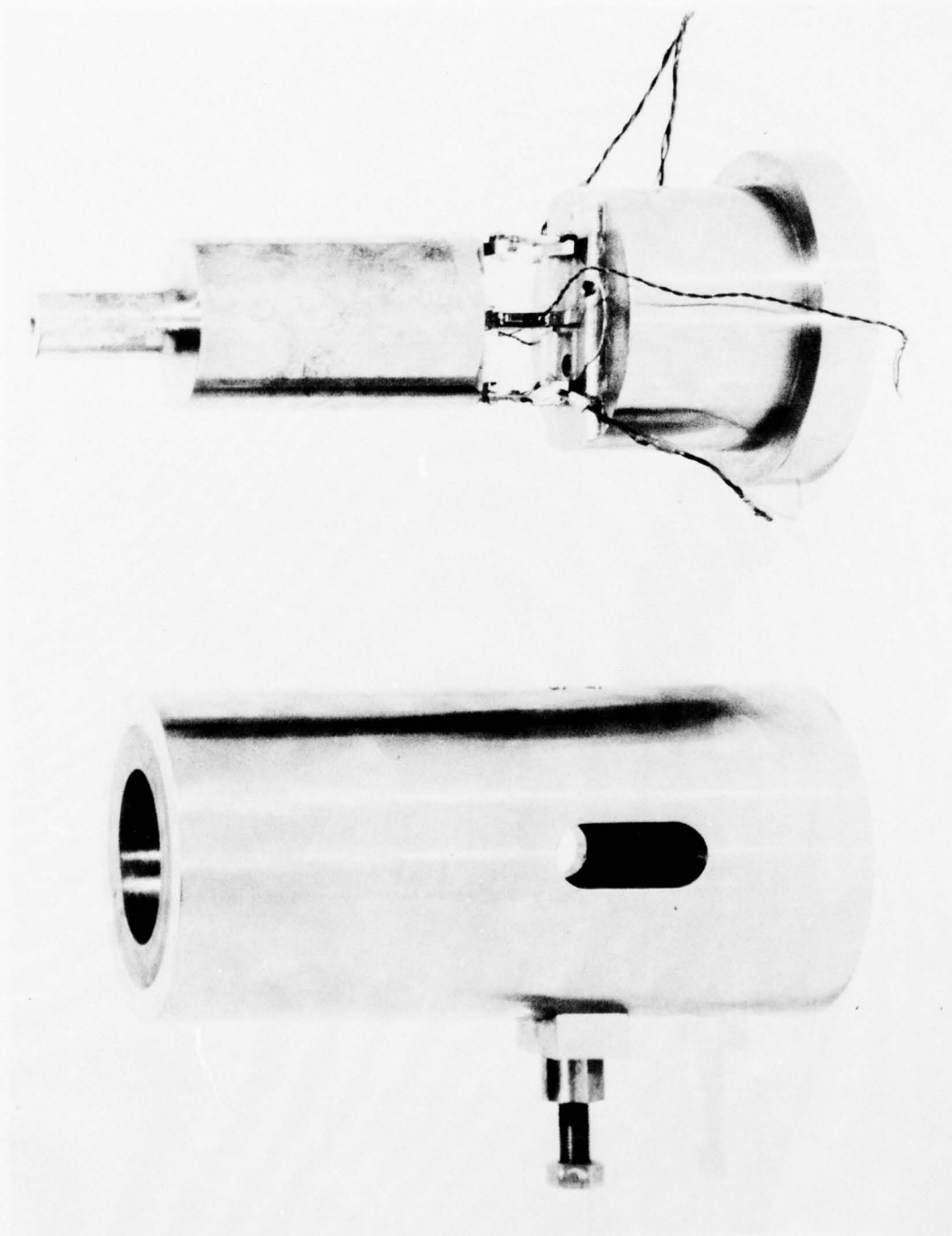


Figure 3. Compressive Test Apparatus for Curved, Circumferential and Axial Coupons

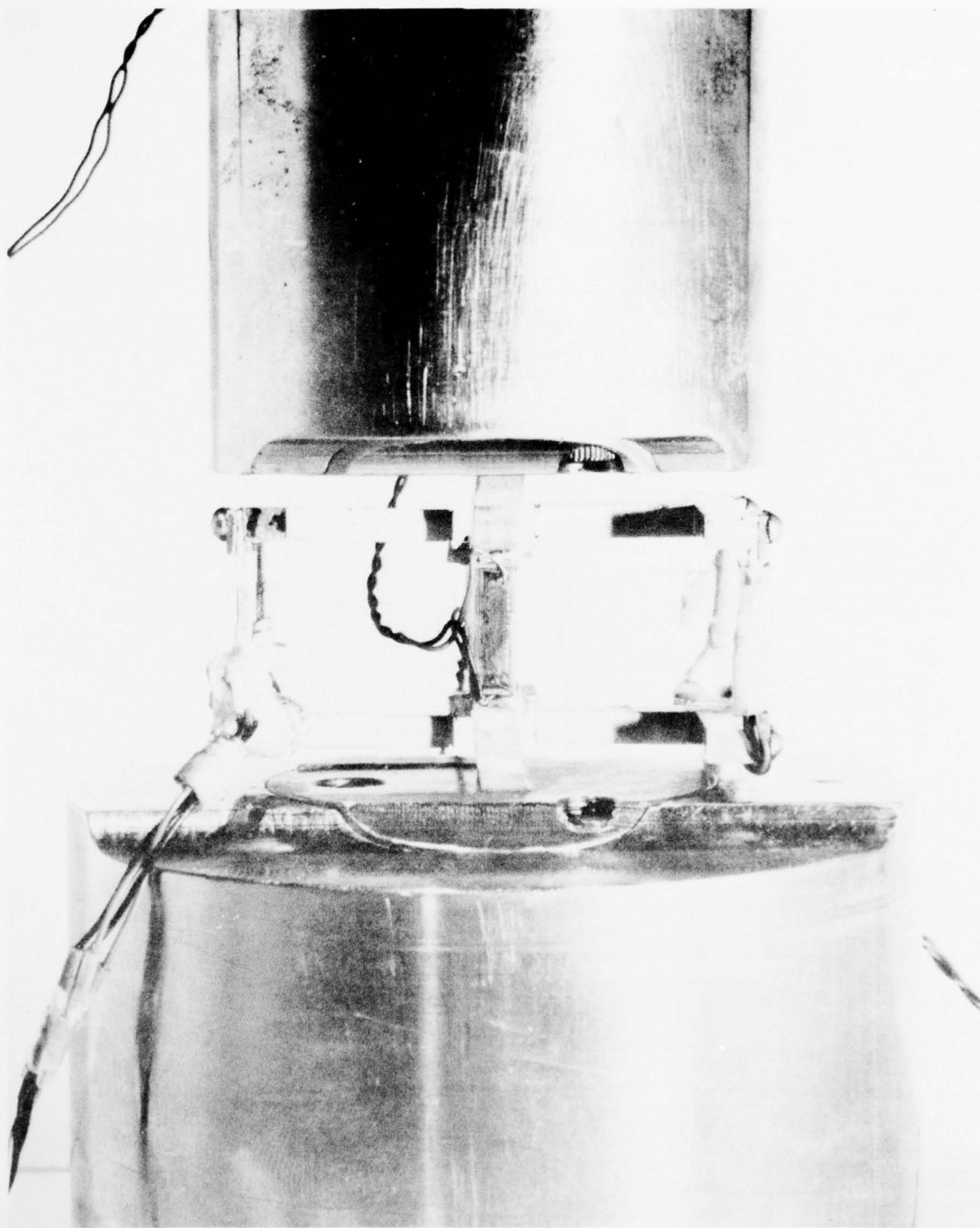


Figure 4. Details of the Curved Circumferential, Compressive Test (Additional Clip-On Gages Were Mounted on the Edges [not shown in photo])

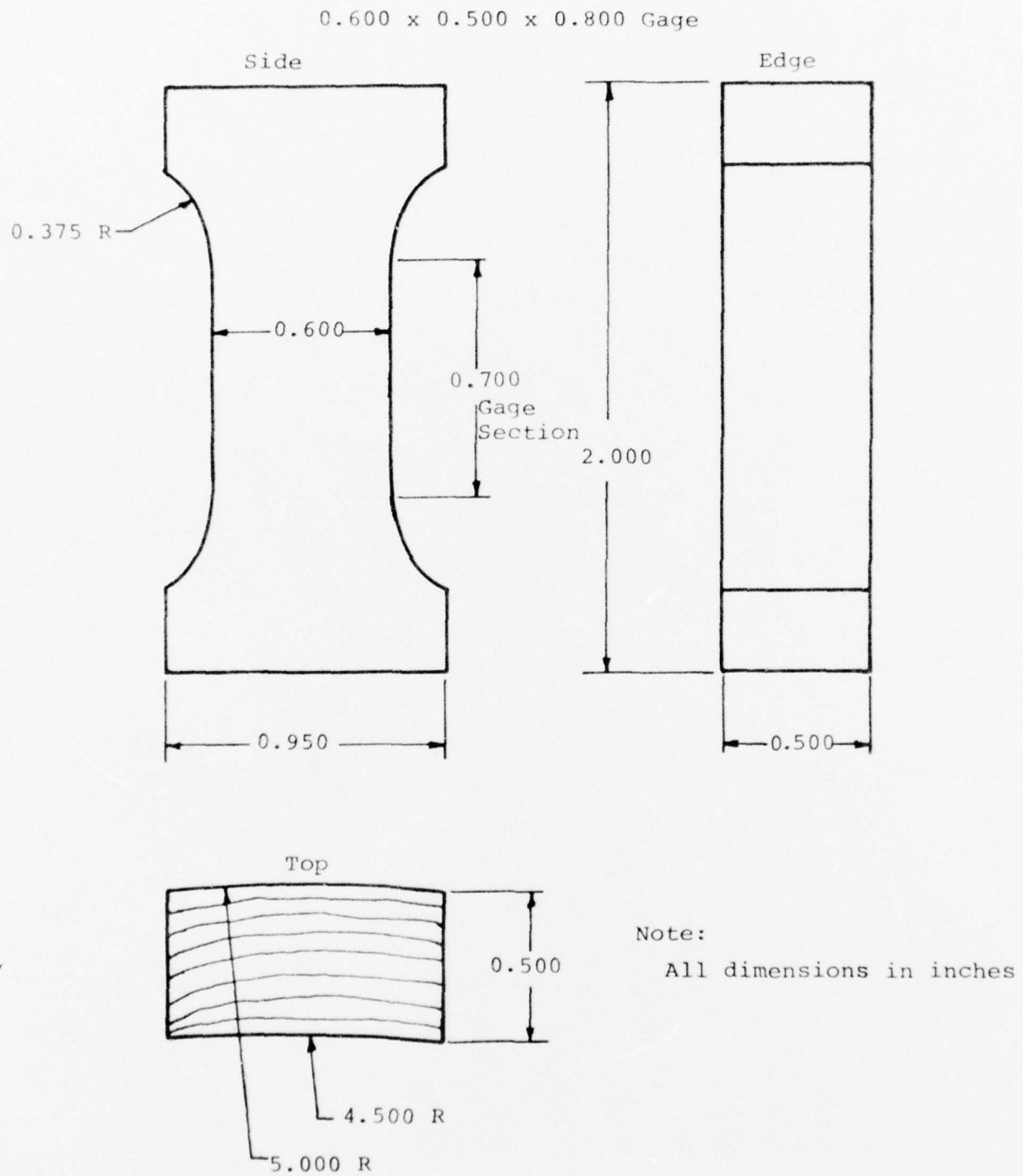


Figure 5. SORI Design Axial Specimen

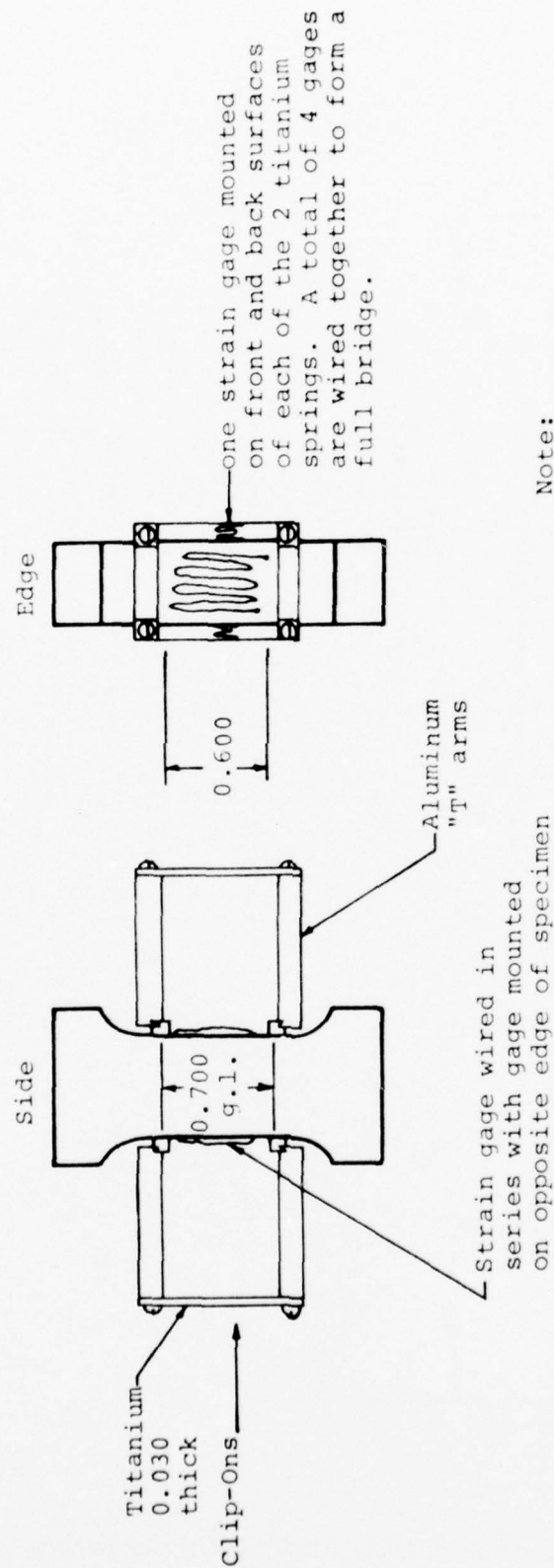


Figure 6. SoRI Design Axial Specimen - Clip-On and Strain Gage Configuration

0.600 x 0.500 x 0.800 Gage

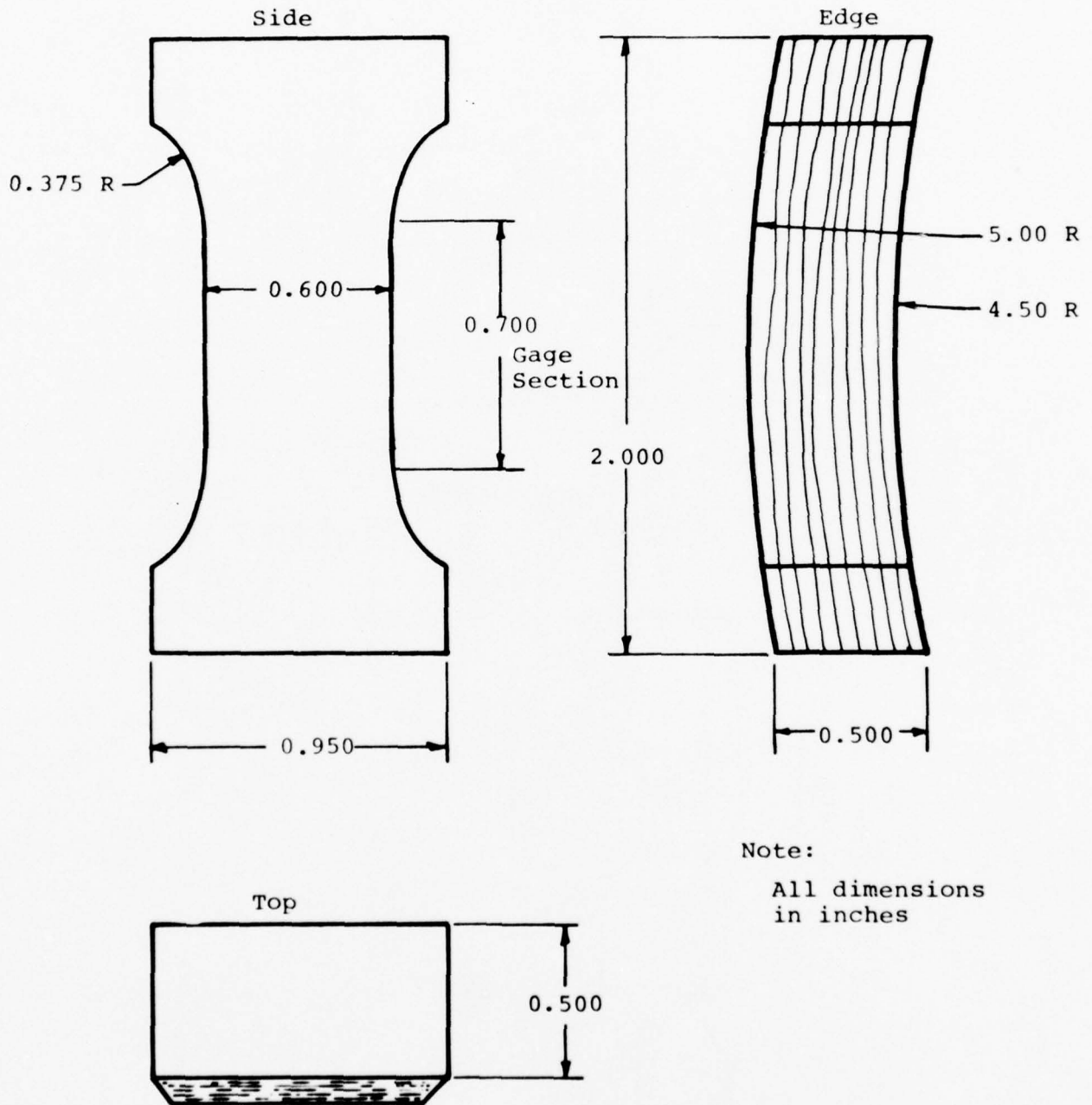


Figure 7. SoRI Design Circumferential (Hoop) Specimen

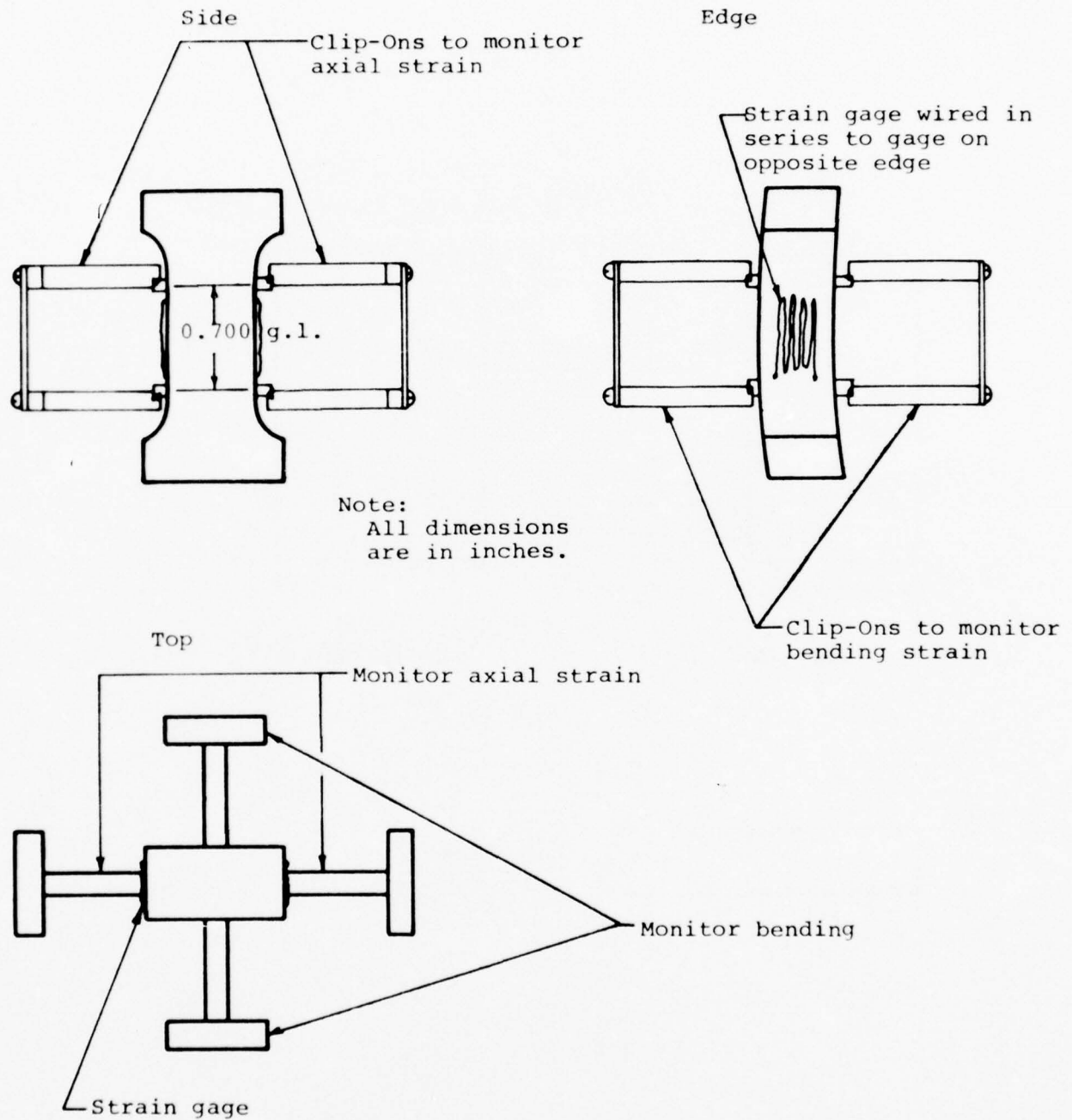
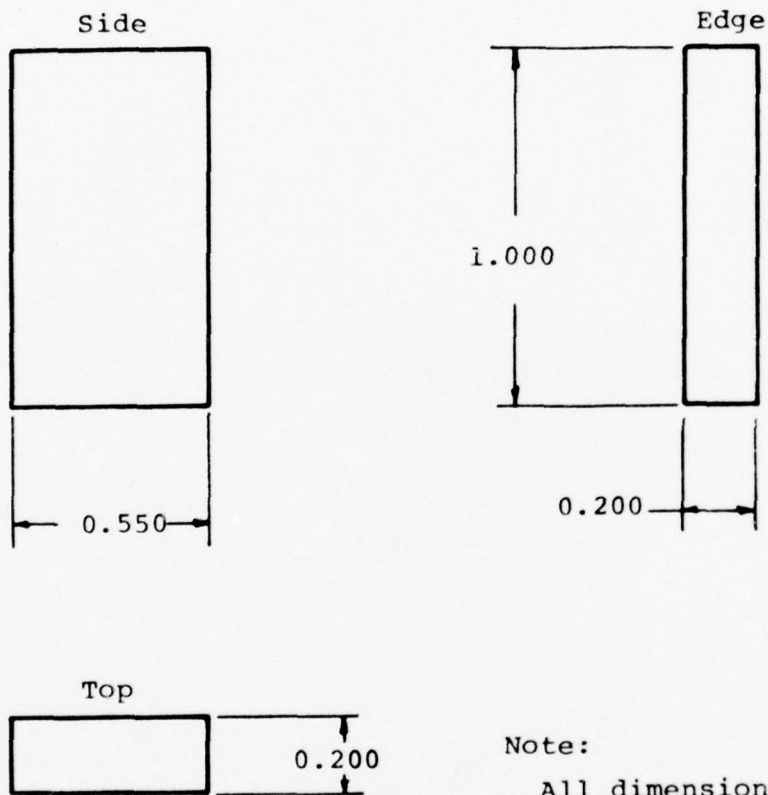


Figure 8. SoRI Design Circumferential Specimen - Clip-On and Strain Gage Configuration



Note:

All dimensions in inches

Figure 9. Rectangular Design Axial Specimen 1.000 x 0.550 x 0.200

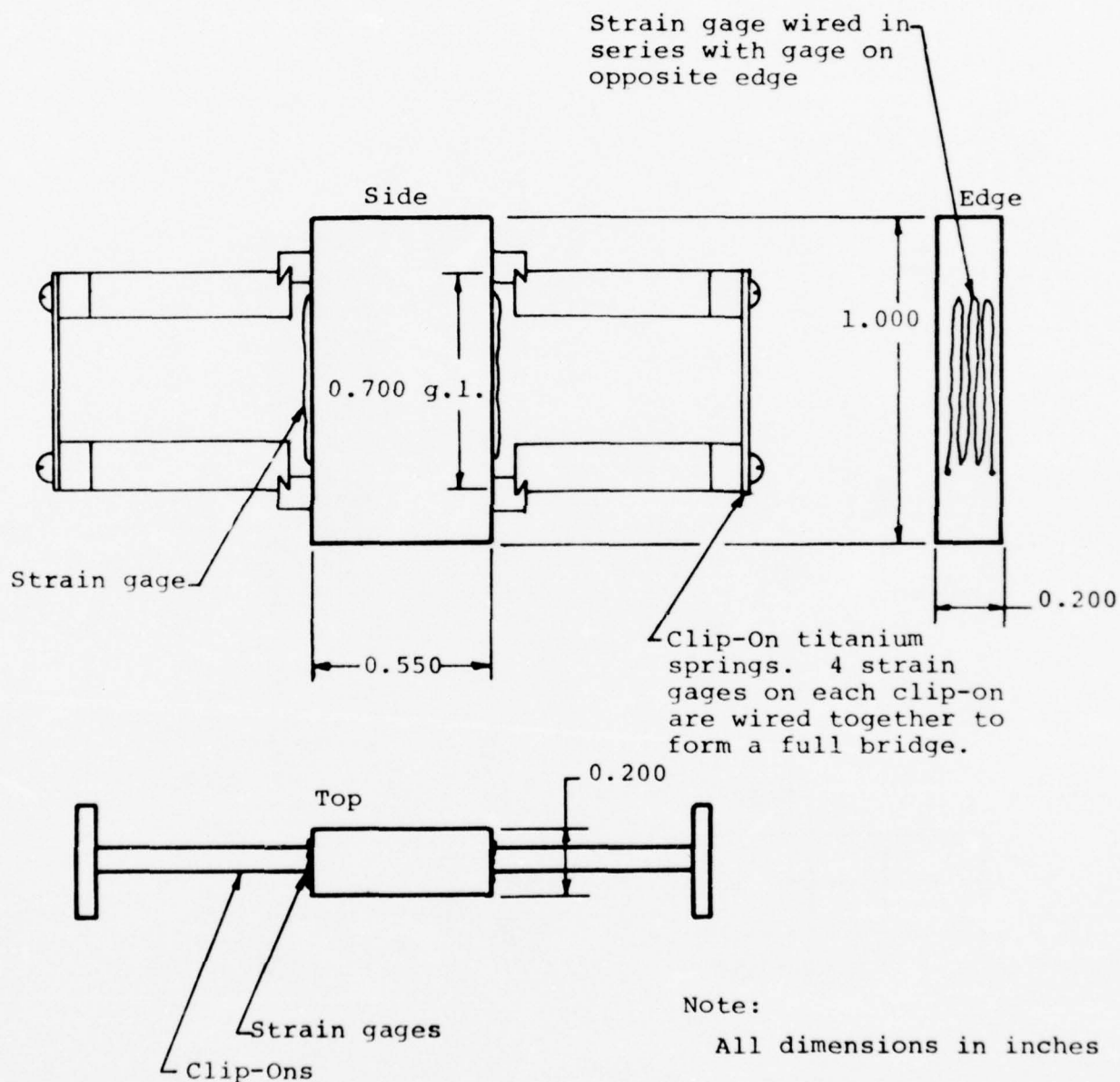


Figure 10. Rectangular Design Axial Specimen - Clip-On and Strain Gage Configuration (1.000 x 0.550 x 0.200)

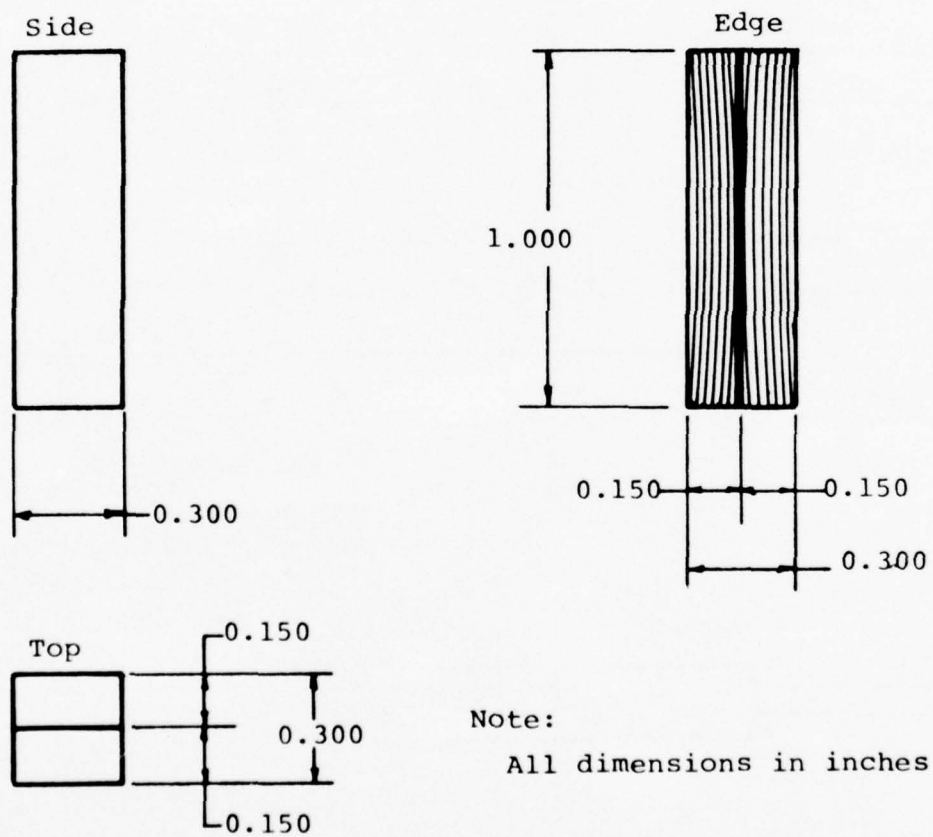


Figure 11. Rectangular Design Circumferential (Hoop) Specimens (1.000 x 0.300 x 0.300)

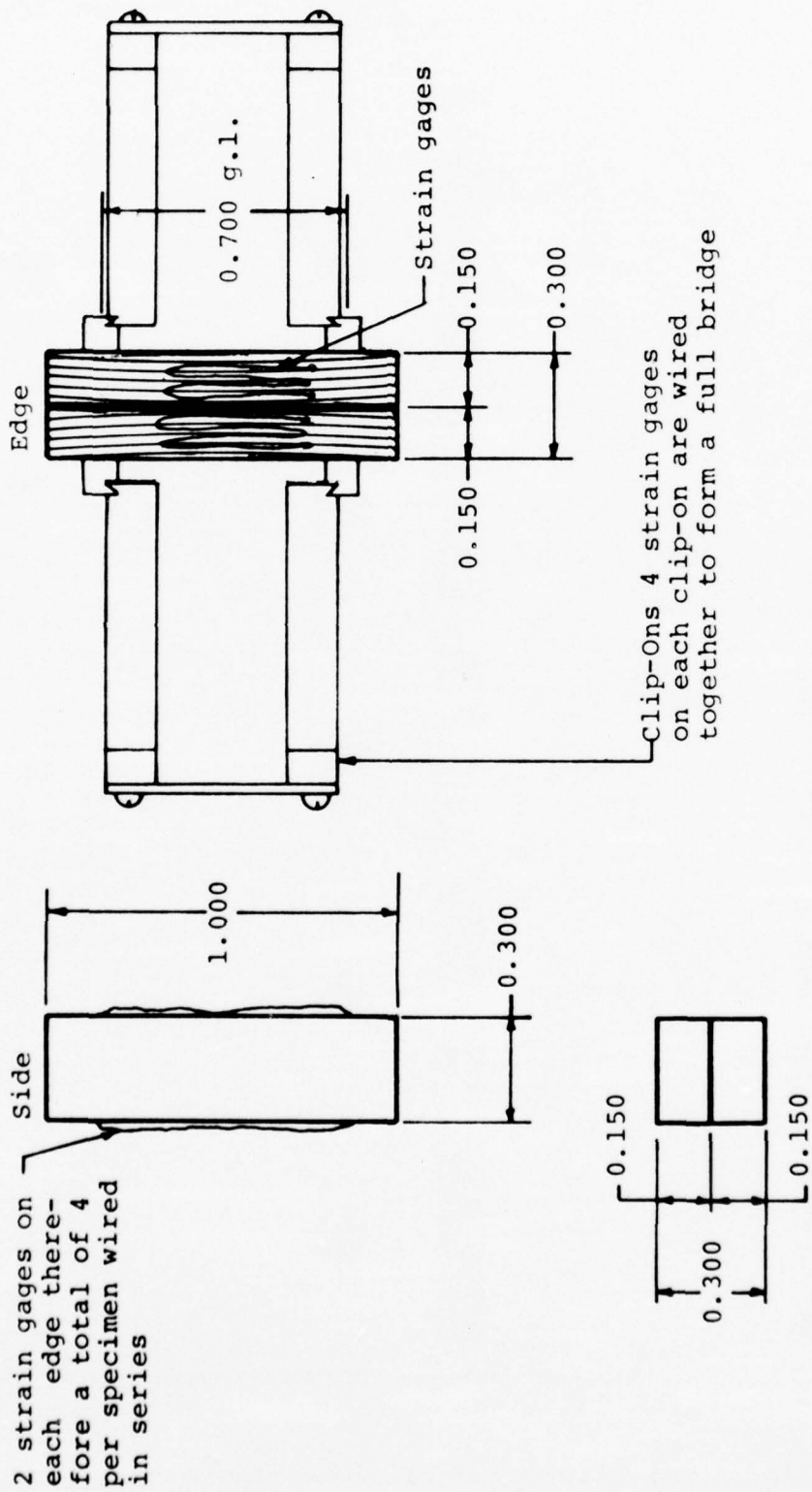
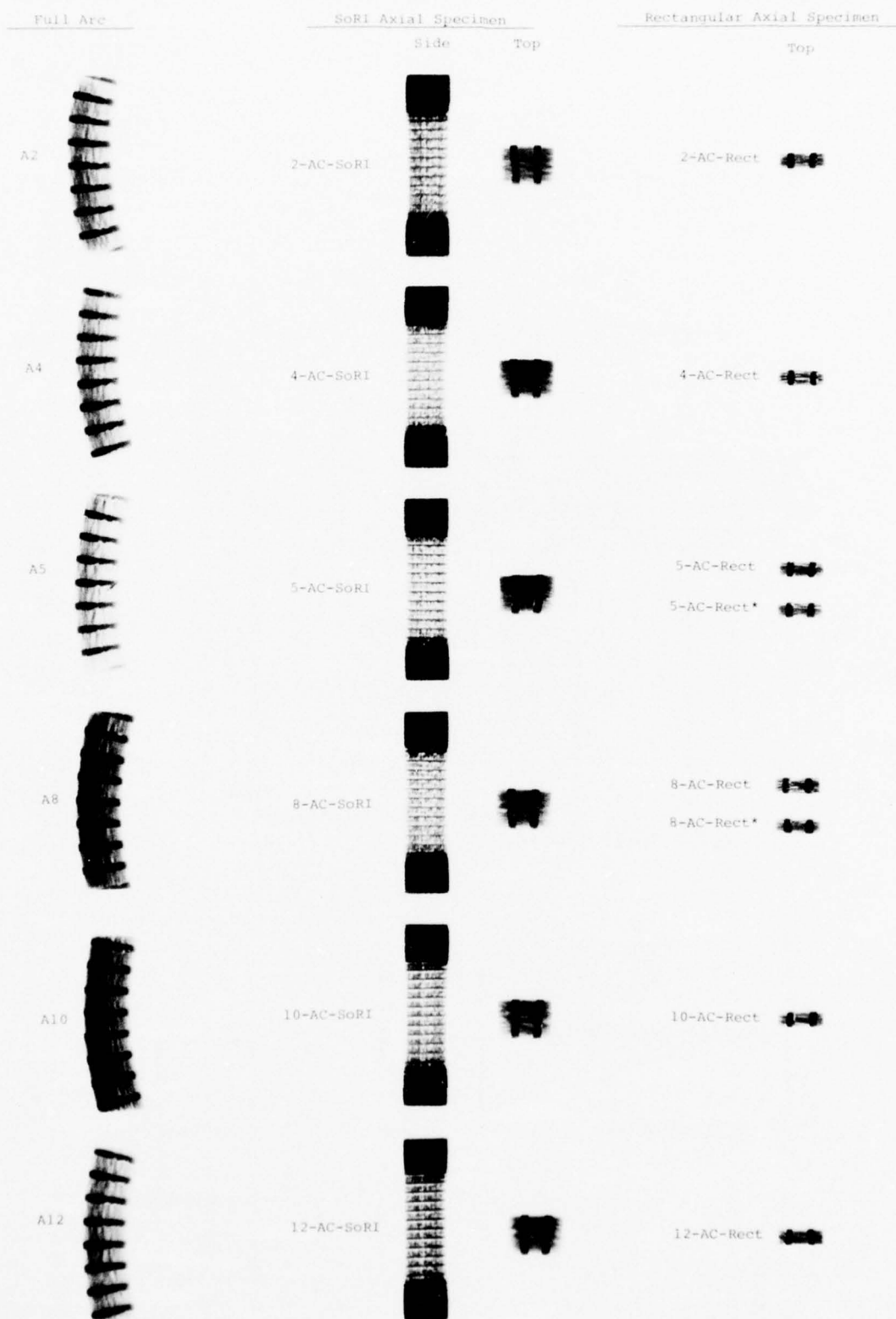


Figure 12. Rectangular Design Circumferential (Hoop) Specimens - Clip-On and Strain Gage Configuration (1.000 x 0.300 x 0.300)



*Machined at SoRI from arc. All other rectangular specimens pre-machined from material adjacent to the respective arc.

Figure 13. X-ray Print of Axial Specimens from Cylinder 6.1.4

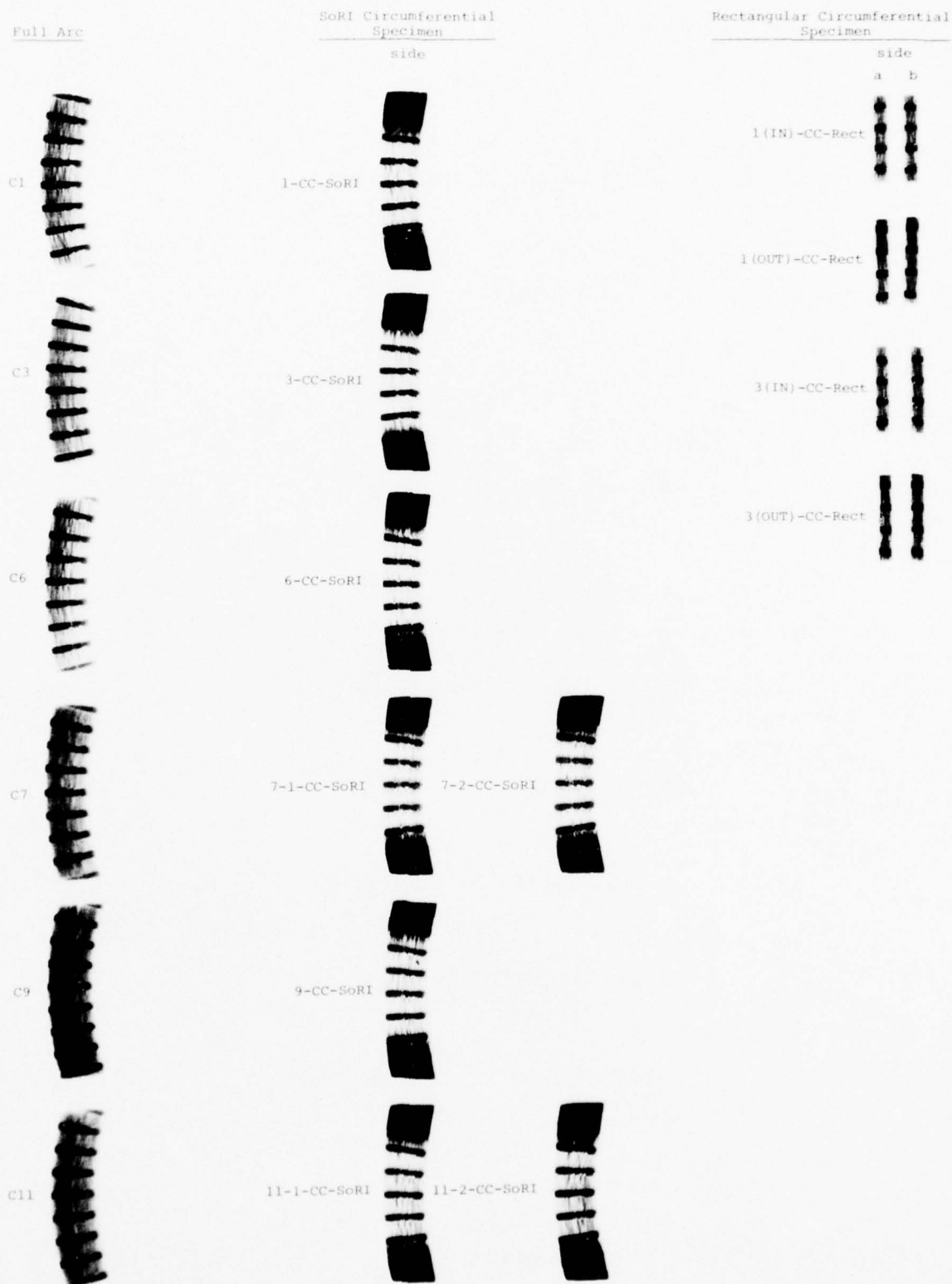


Figure 14. X-ray Print of Circumferential Specimens from Cylinder 6.1.4

Rectangular Axial Specimens

Top View

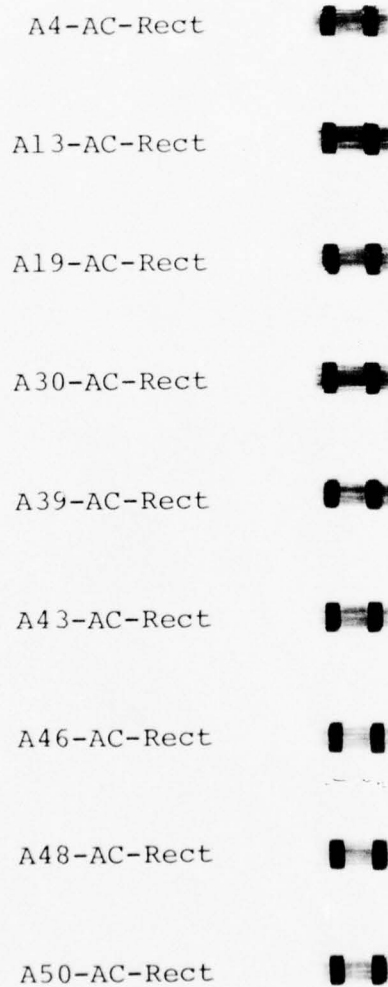


Figure 15. X-ray Print of Axial Specimens from Cylinder 4.1.18

Rectangular Circumferential Specimens

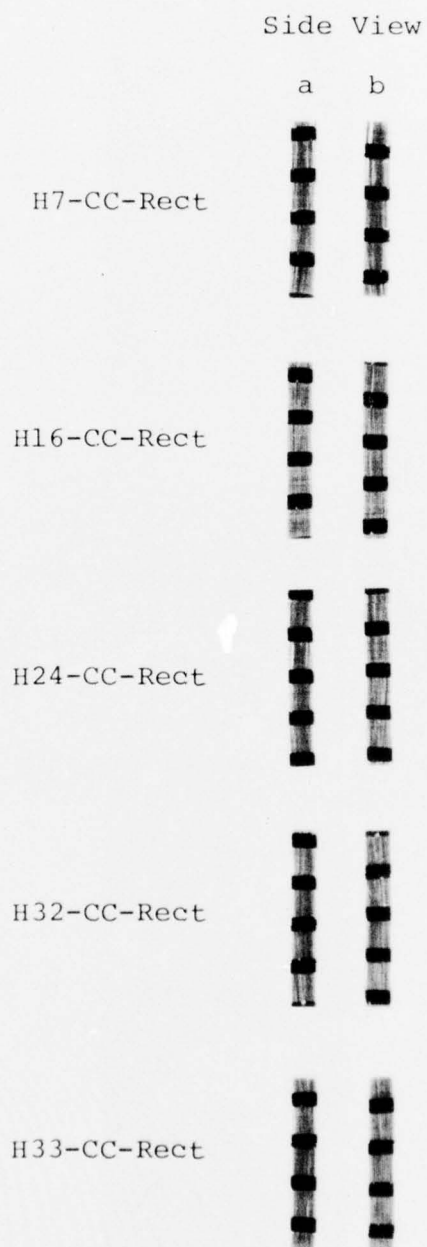


Figure 16. X-ray Print of Circumferential Specimens
from Cylinder 4.1.18



Figure 17. 20X Photomicrograph Showing Circumferential "Waviness" in Arc 6

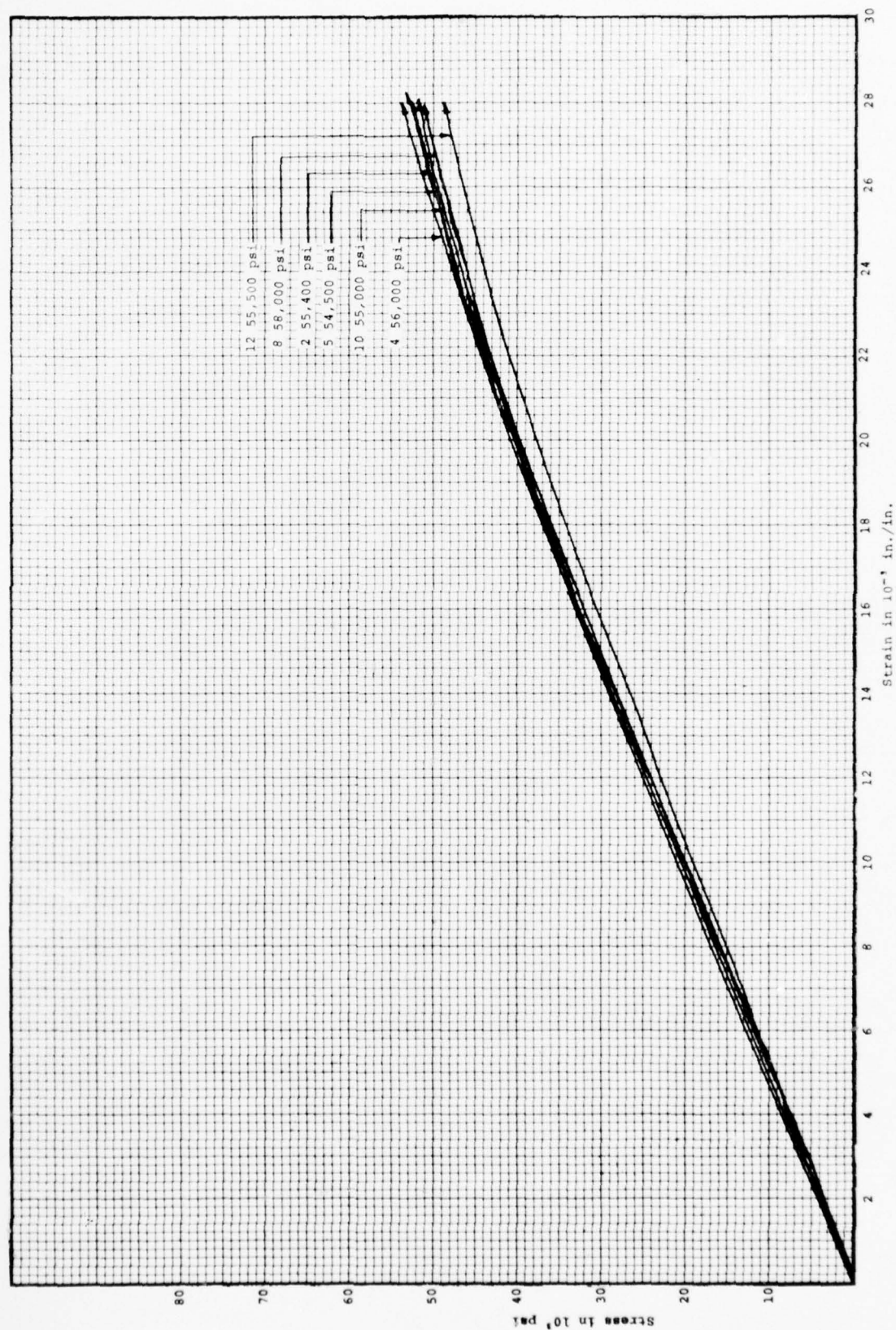


Figure 18. Composite Plot Axial Compression SORI Specimen Configuration 3DQP - 6.1.14 (Clip-On Data)

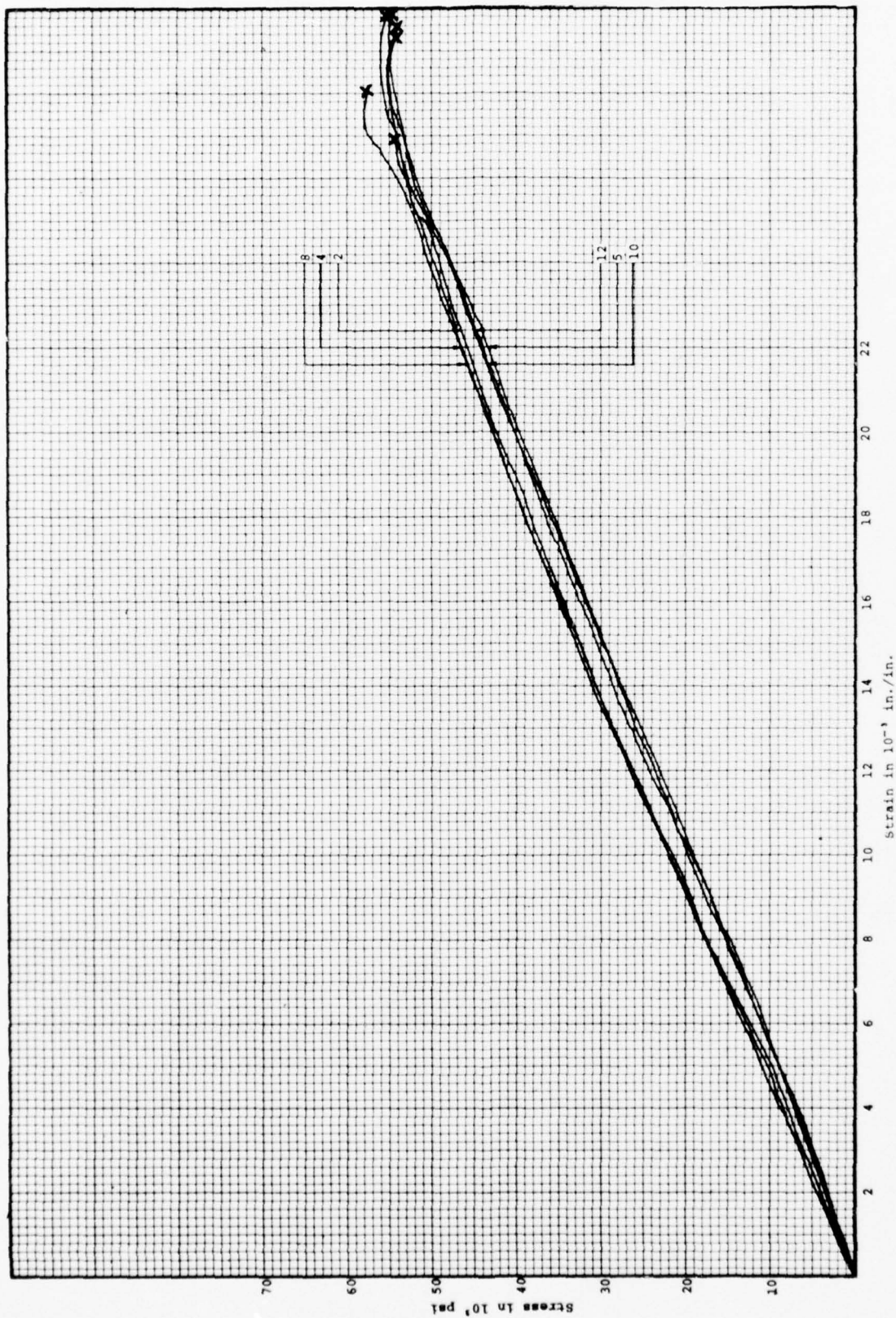


Figure 19. Composite Plot Axial Compression SOR Specimen Configuration 3DOP - 6.1.4 (Strain Gage Data)

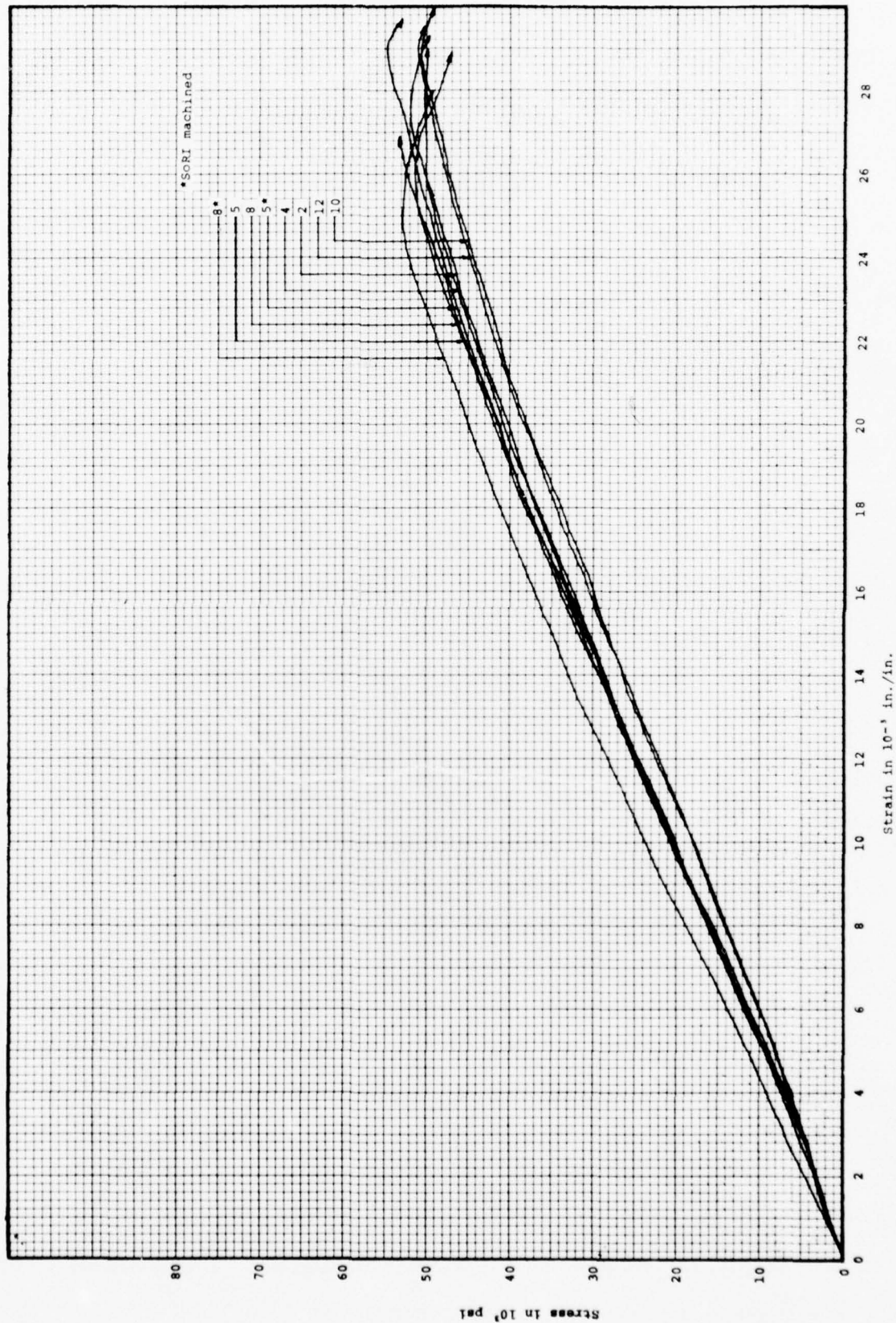


Figure 20. Composite Plot Axial Compression-Rectangular Specimen Configuration 3DQP-6.1.4 (Clip-on Data)

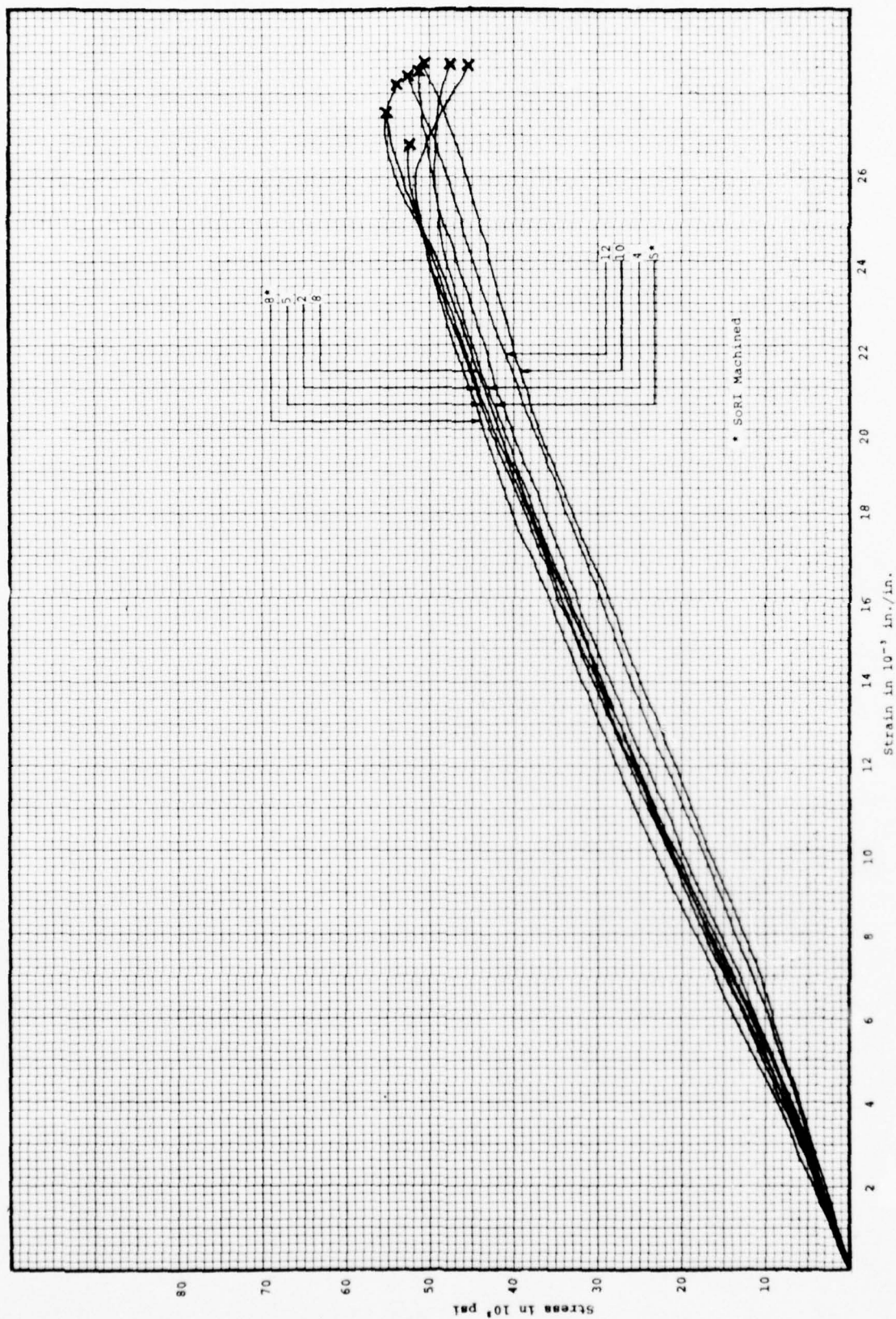


Figure 21. Composite Plot Axial Compression-Rectangular Specimen Configuration 3DQP-6.1.4 (Strain Gage Data)

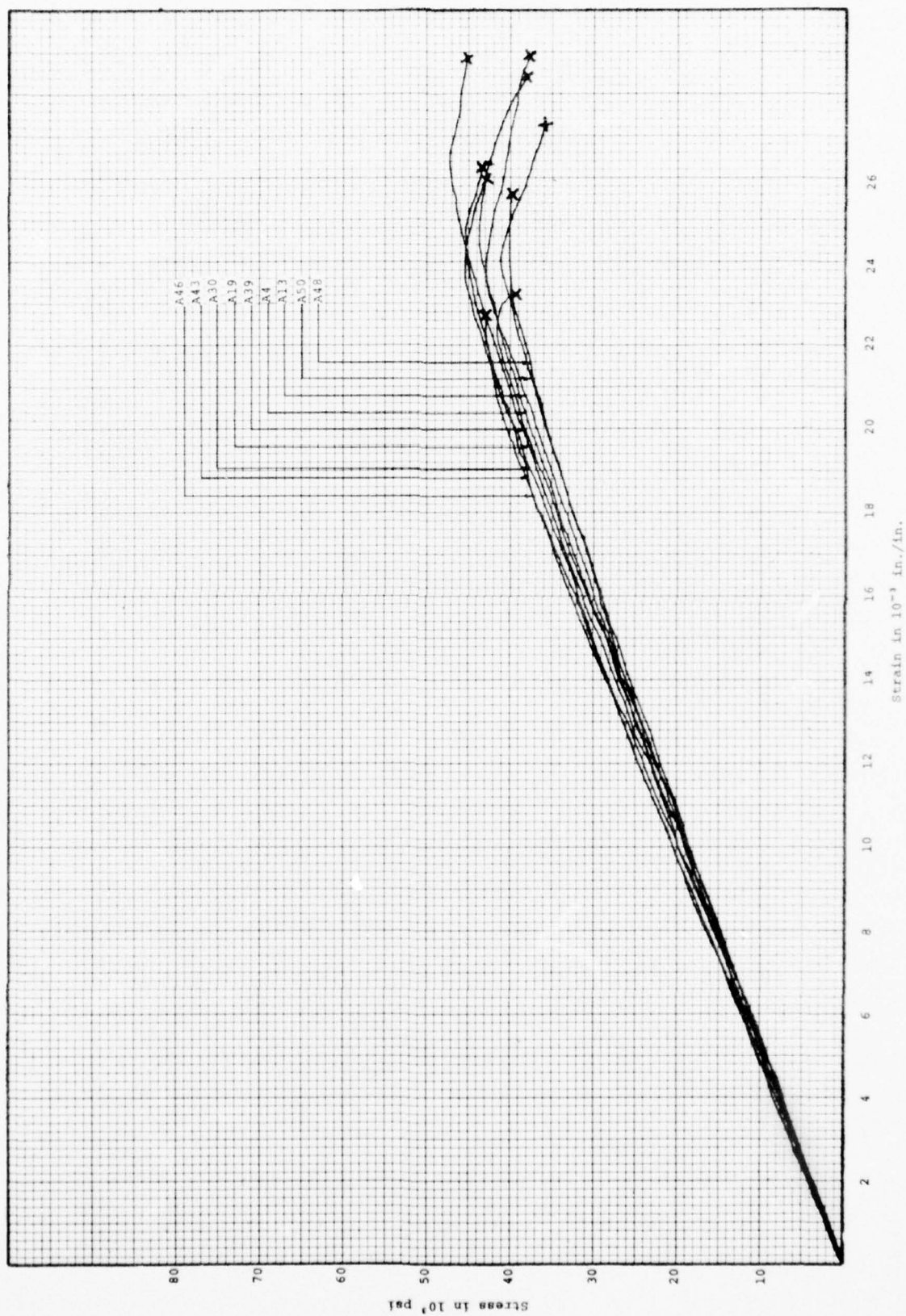


Figure 22. Composite Plot Axial Compression-Rectangular Specimen Configuration IQP-4.1.18 (Clip-on Data)

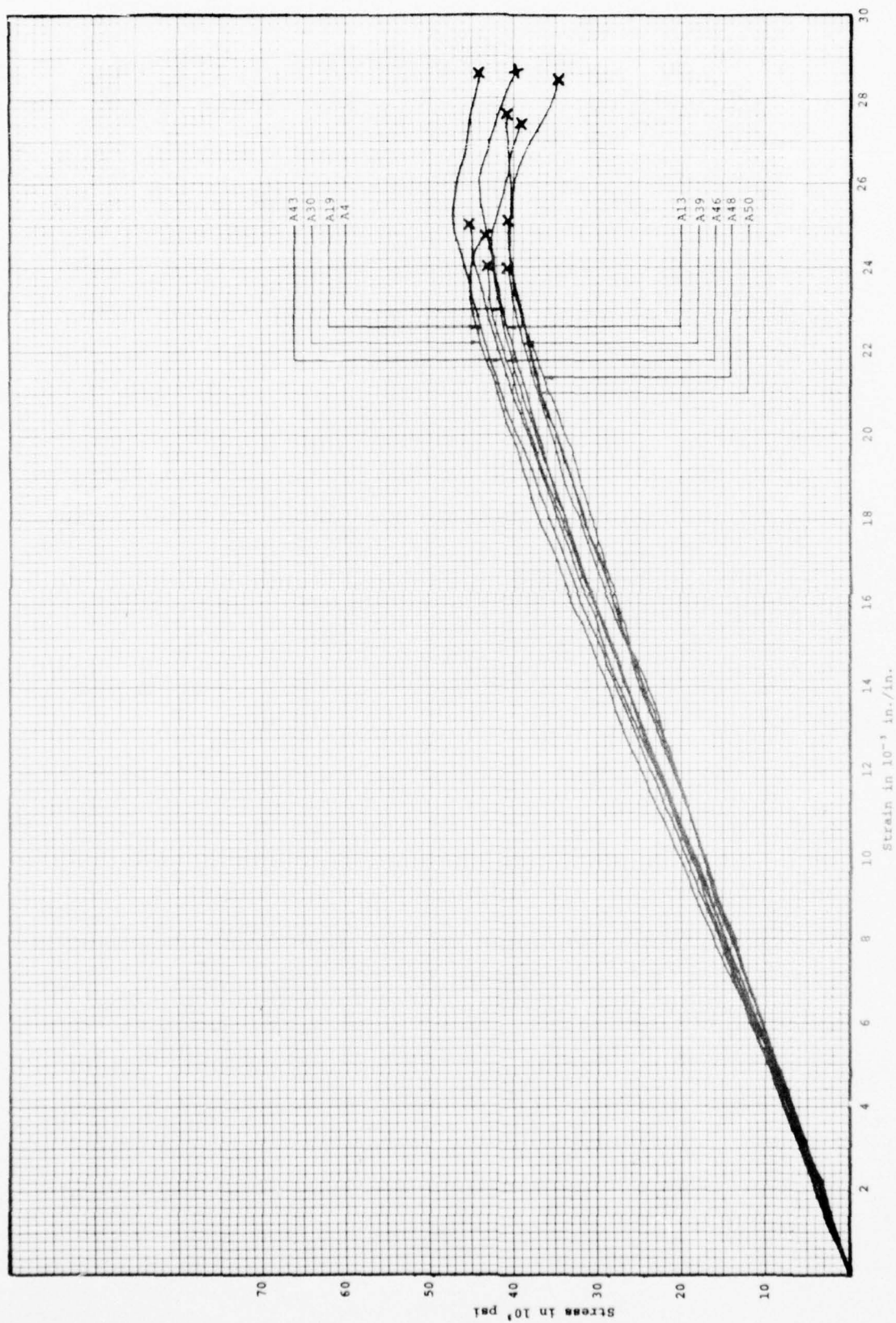


Figure 23. Composite Plot Axial Compression-Rectangular Specimen Configuration 3DQP-4.1.18 (Strain Gage Data)

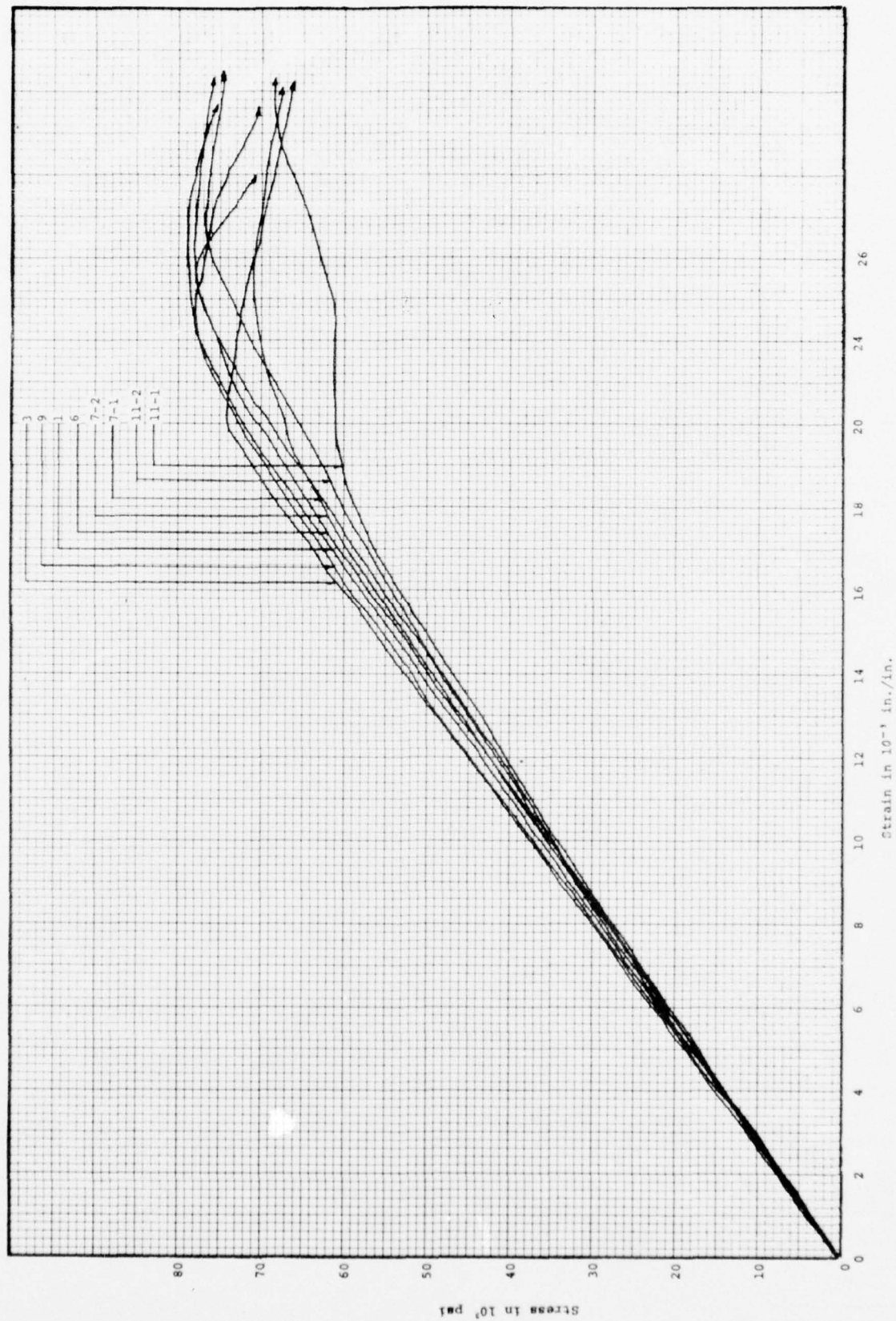


Figure 24. Composite Plot Circumferential Compression-SORI Specimen Configuration 3DCP-6.1.4 (Clip-on Data)

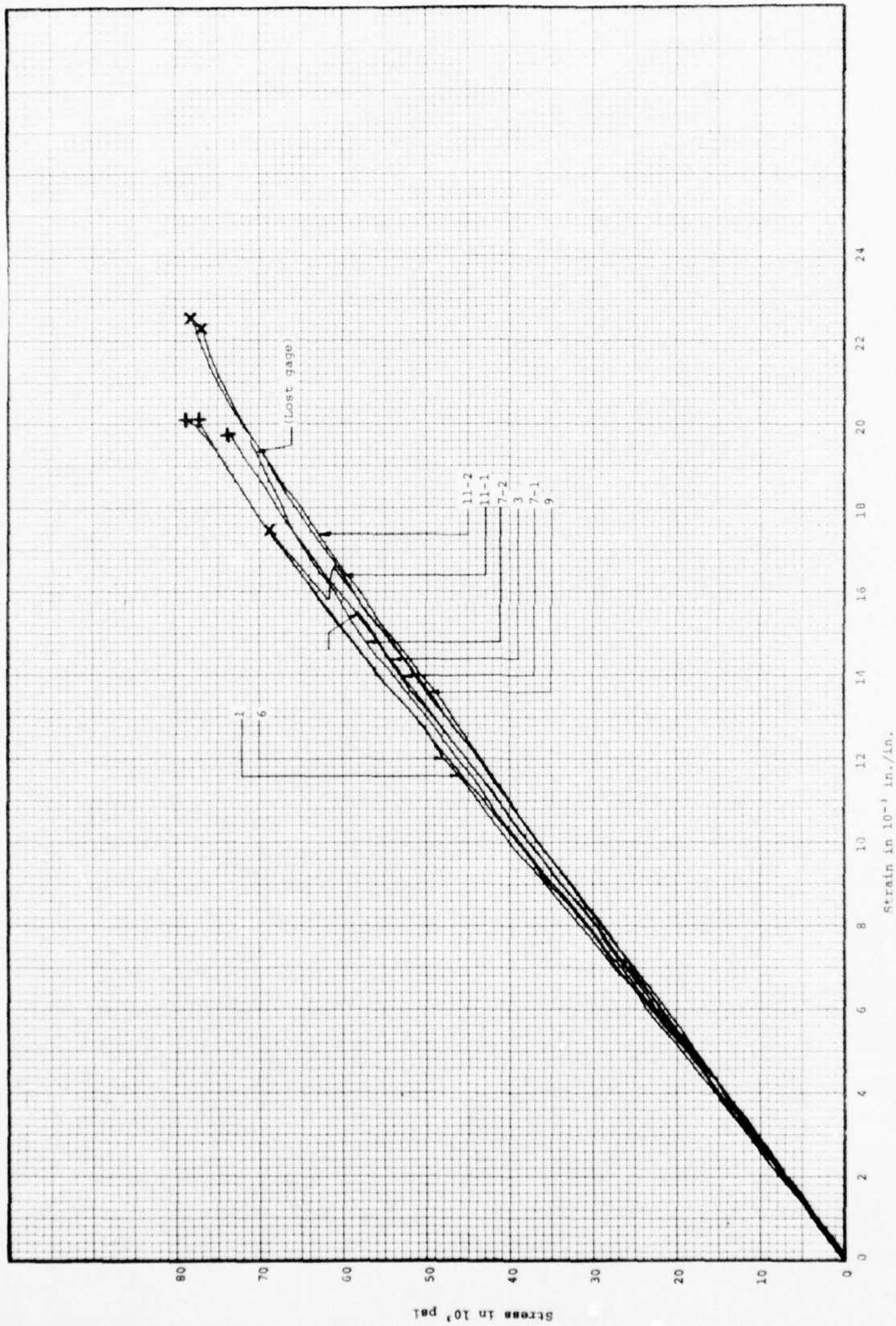


Figure 25. Composite Plot Circumferential Compression-SoRI Specimen Configuration 3DQP-6.1.4 (Strain Gage Data)

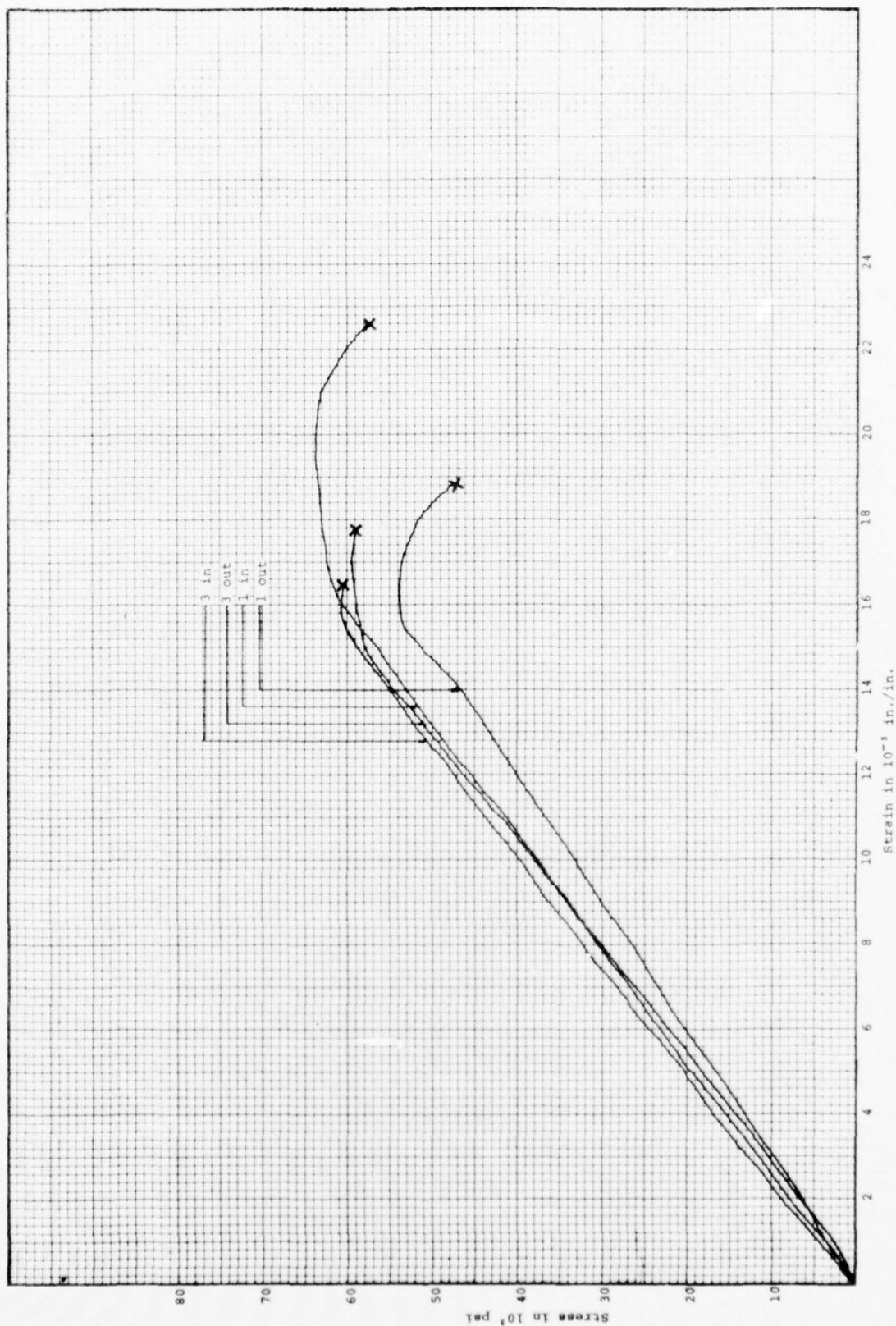


Figure 26. Composite Plot Circumferential Compression-Rectangular Specimen Configuration 3QPF-6.1.4 (Clip-on Data)

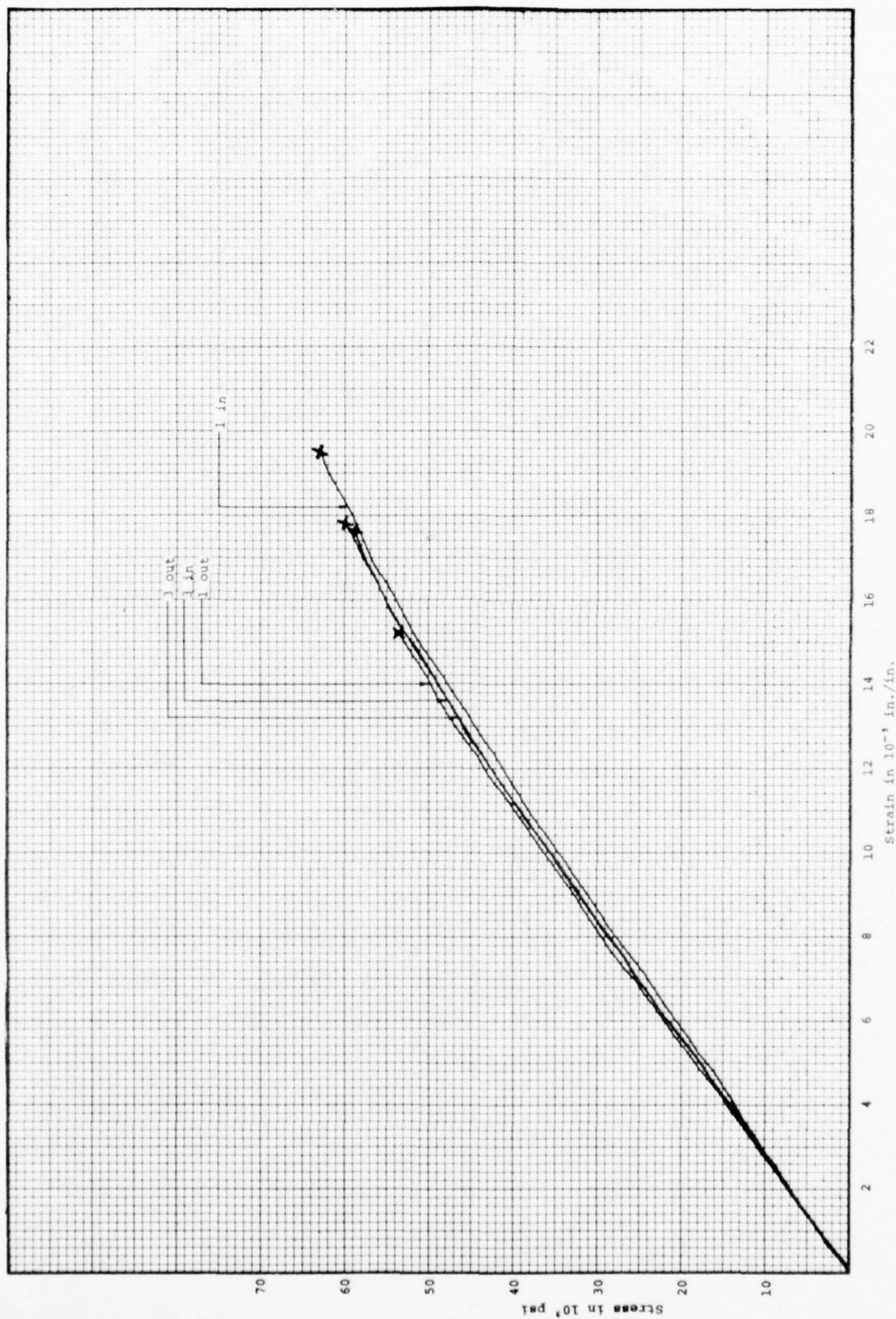


Figure 27. Composite Plot Circumferential Compression-Rectangular Specimen Configuration 35QP-6.1.4 Strain Gage Data

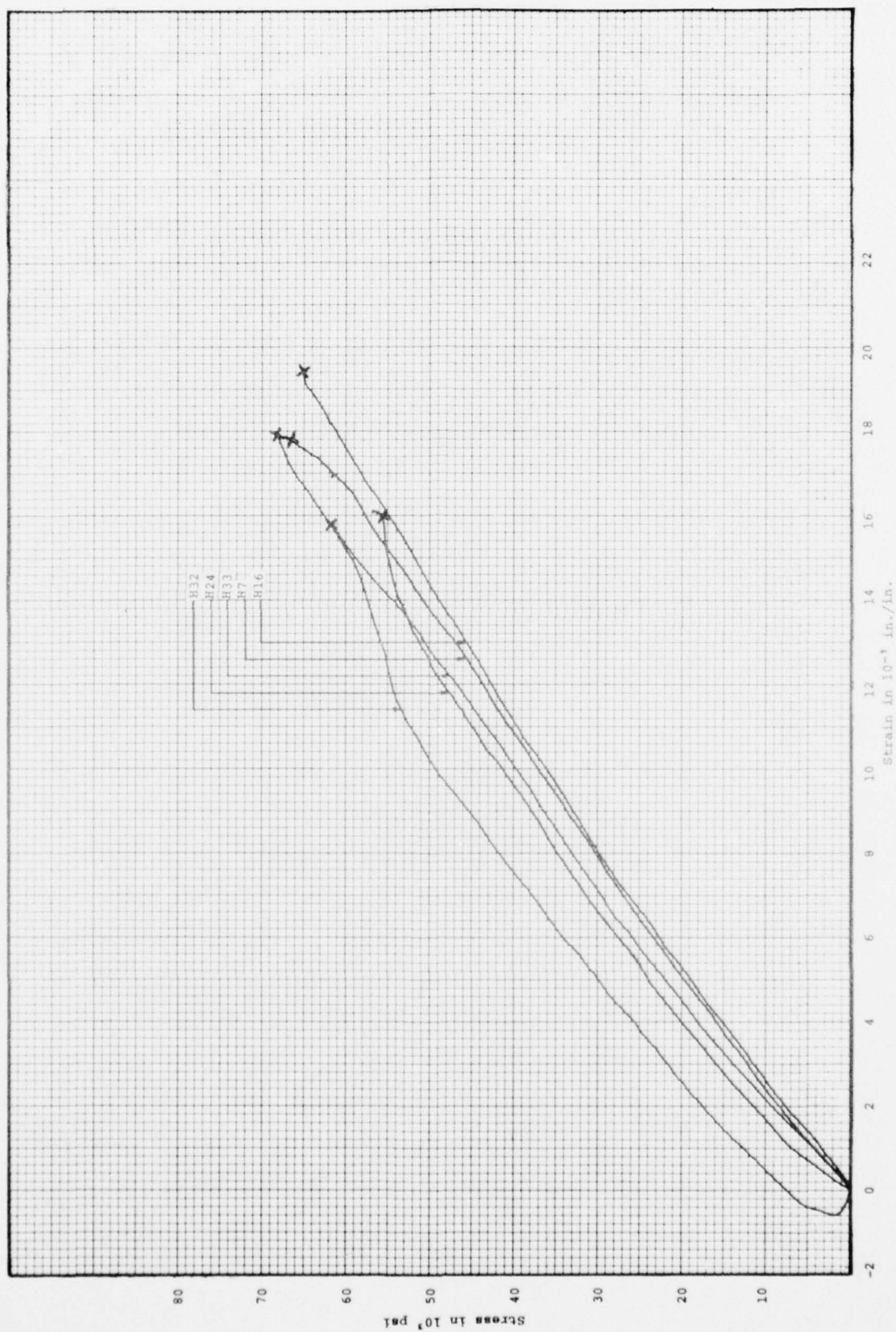


Figure 28. Composite Plot Circumferential Compression-Rectangular Specimen Configuration 3DQP-4.1.18 (Clip-on Data)

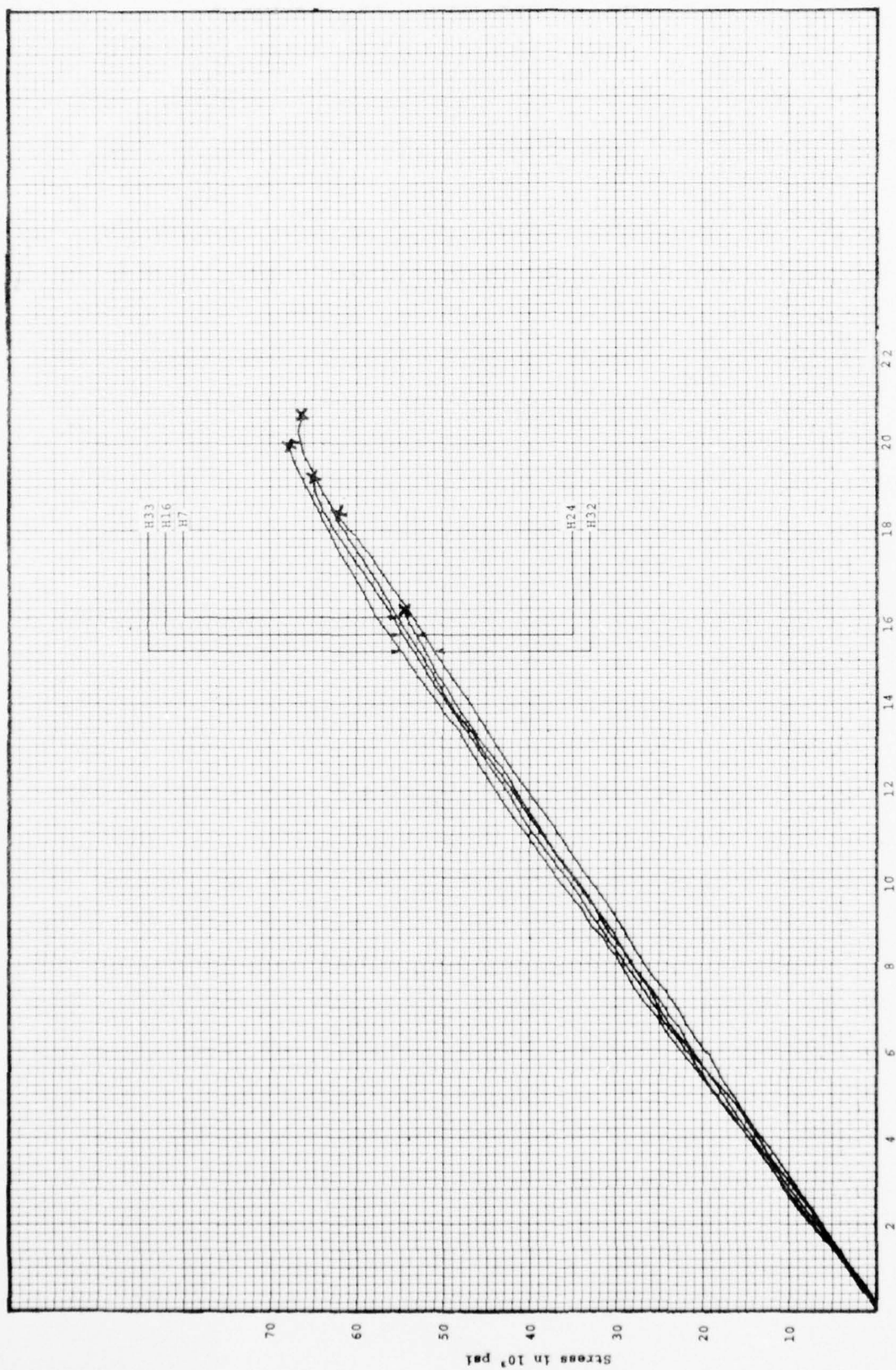


Figure 29. Composite Plot Circumferential Direction-Rectangular Specimen Configuration 3DQP-4.1.18 (Strain Gage Data)

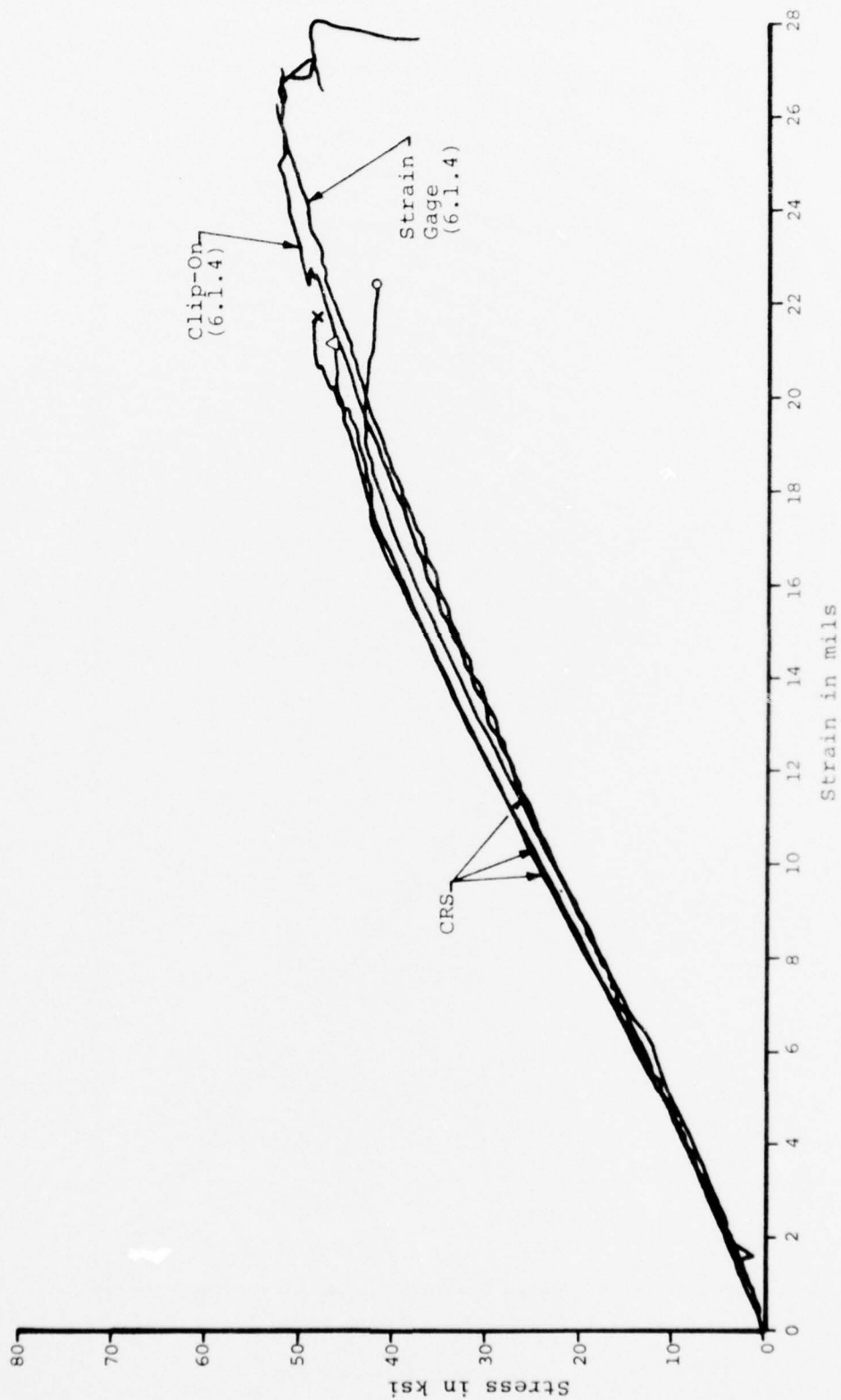


Figure 30. Typical Axial Compression Data from CRS (with one run from 6.1.4)

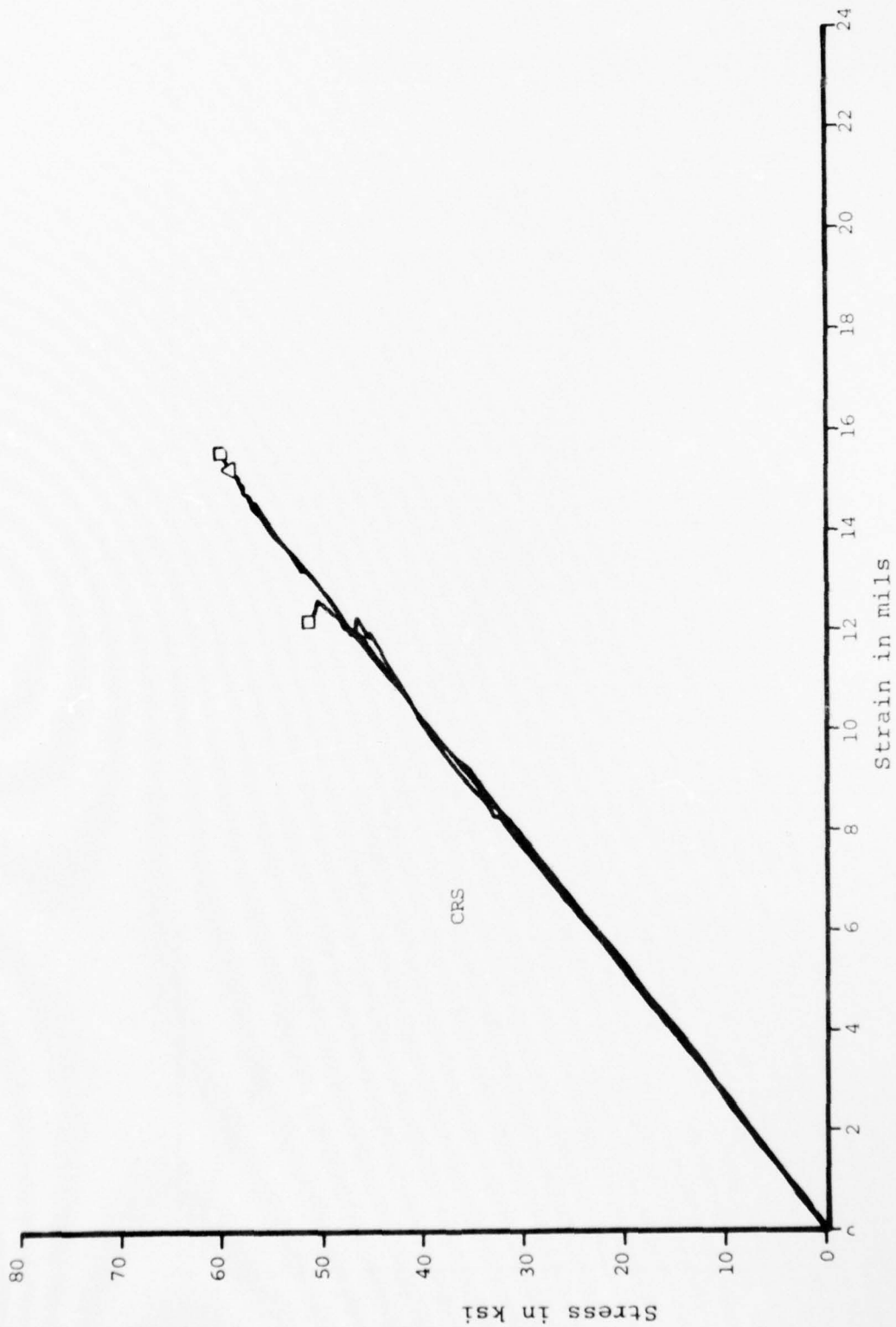


Figure 31. Typical Circumferential Compression Data from CRS

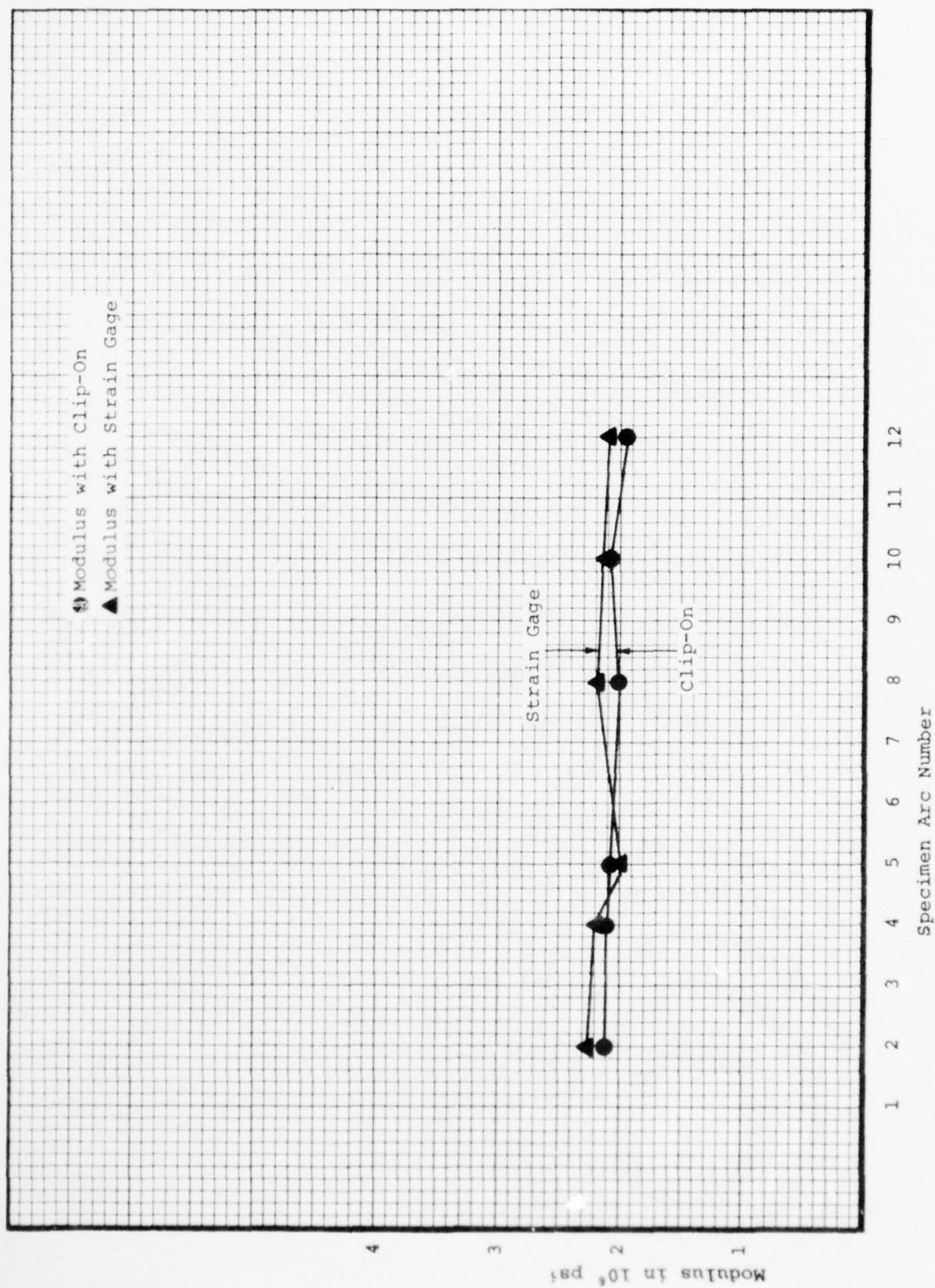


Figure 32. Comparison of SoRI Axial Clip-On versus Strain Gage Data 6-1-4

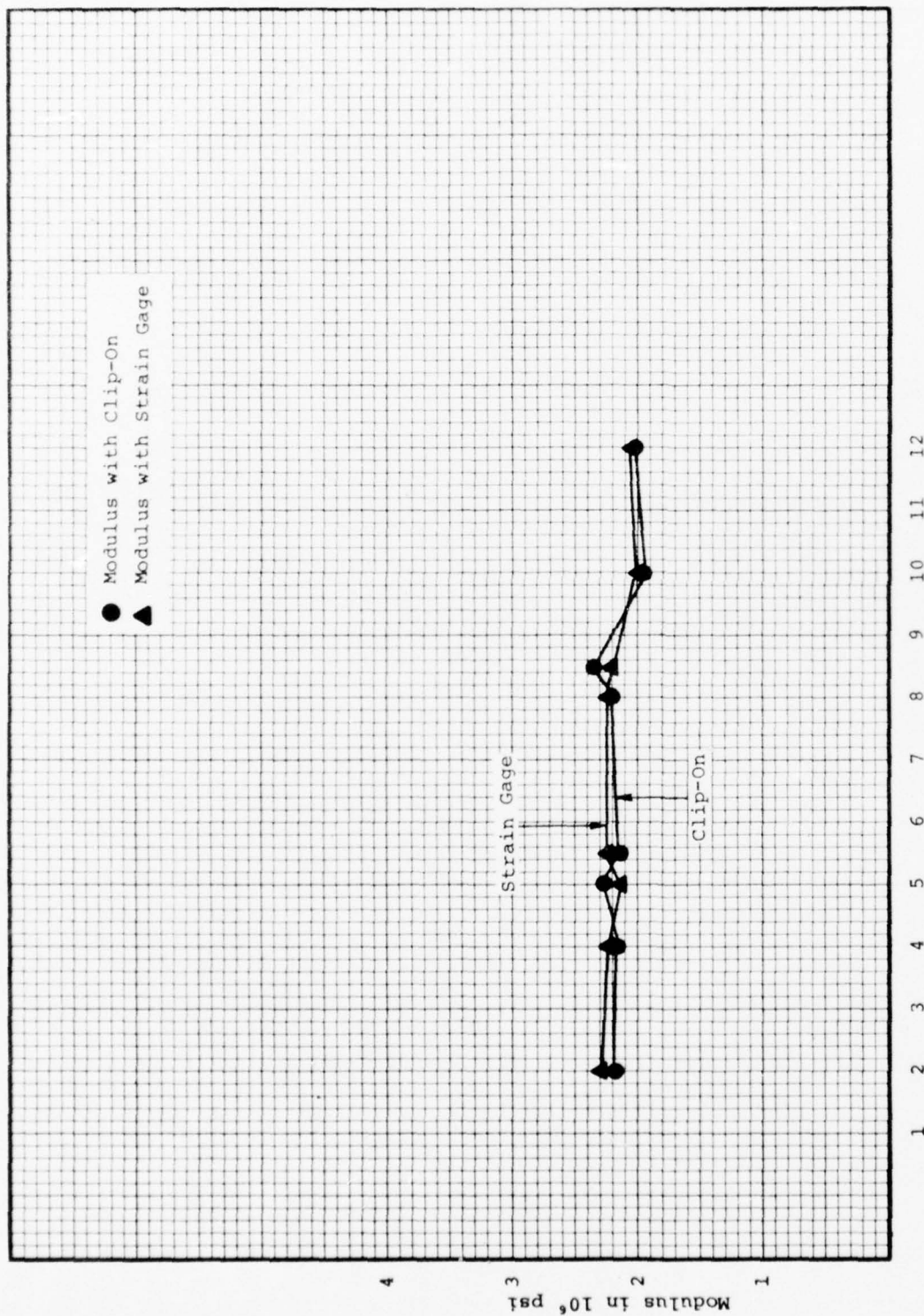


Figure 33. Comparison of Rectangular Axial Clip-on versus Strain Gage Data 6.1.4

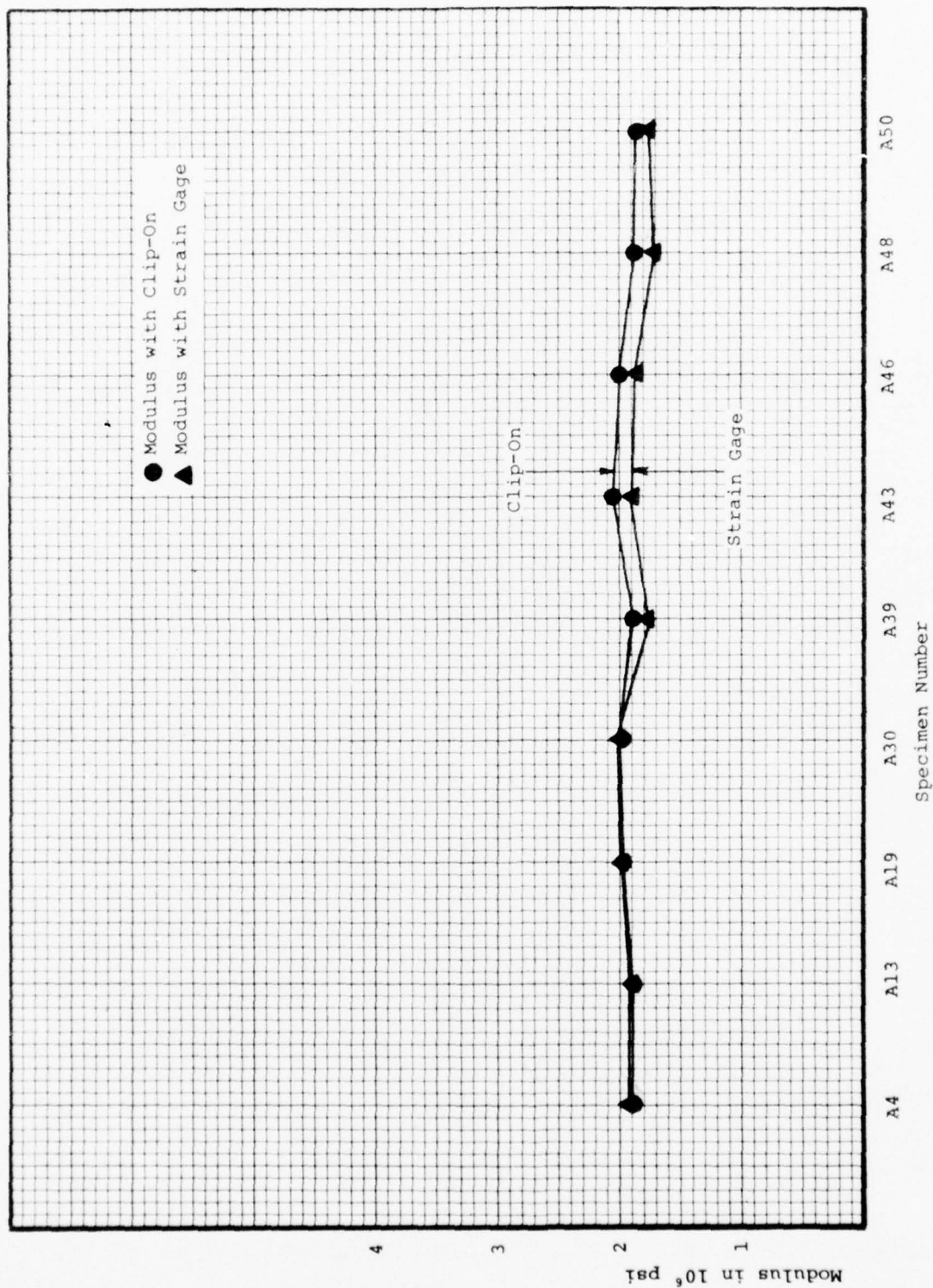


Figure 34. Comparison of Rectangular Axial Clip-On versus Strain Gage Data 4.1.18

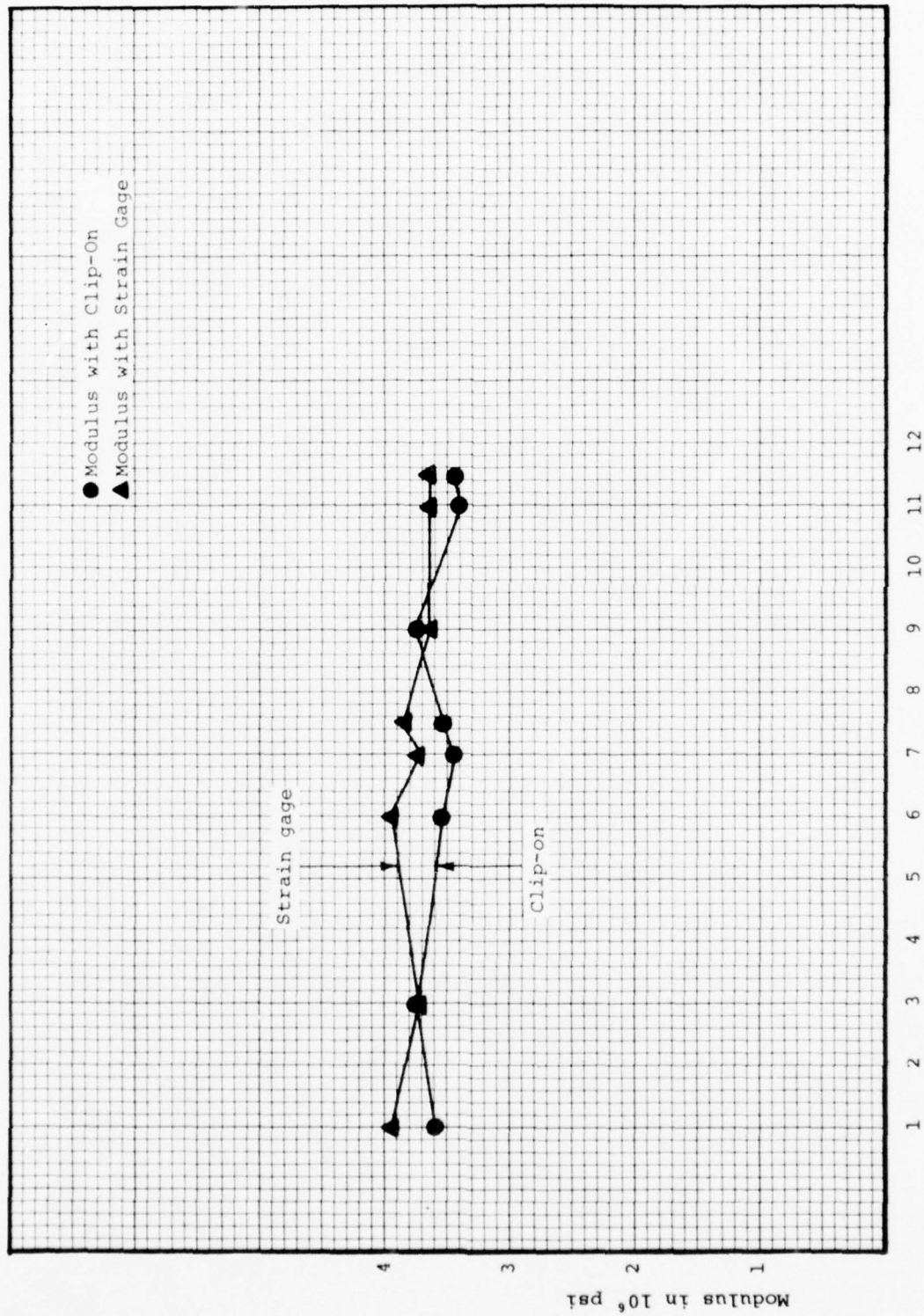


Figure 35. Comparison of SoRI Circumferential Clip-On versus Strain Gage Data 6.1.4

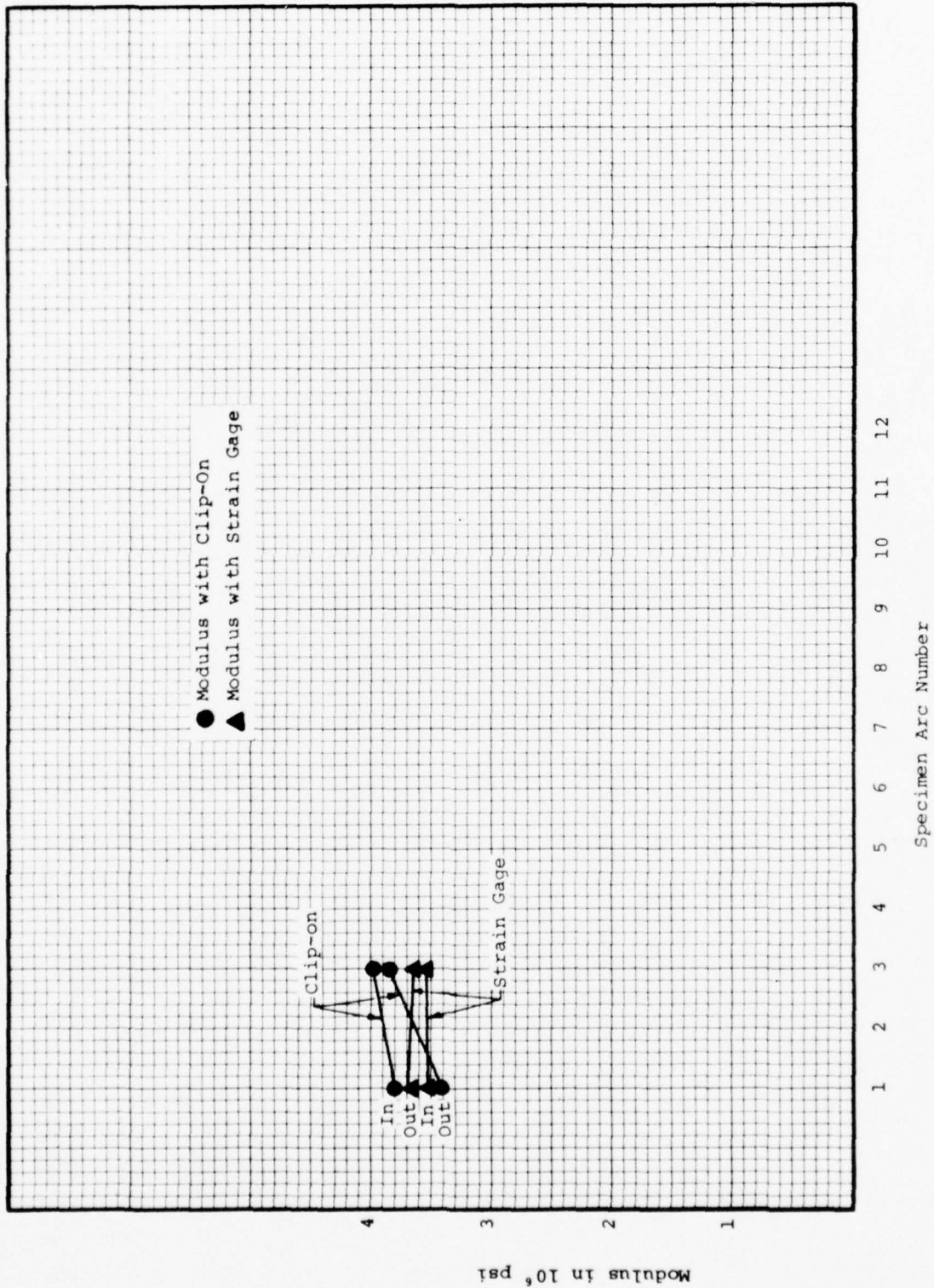


Figure 36. Comparison of Rectangular Circumferential Clip-on versus Strain Gage Data 6.1.4

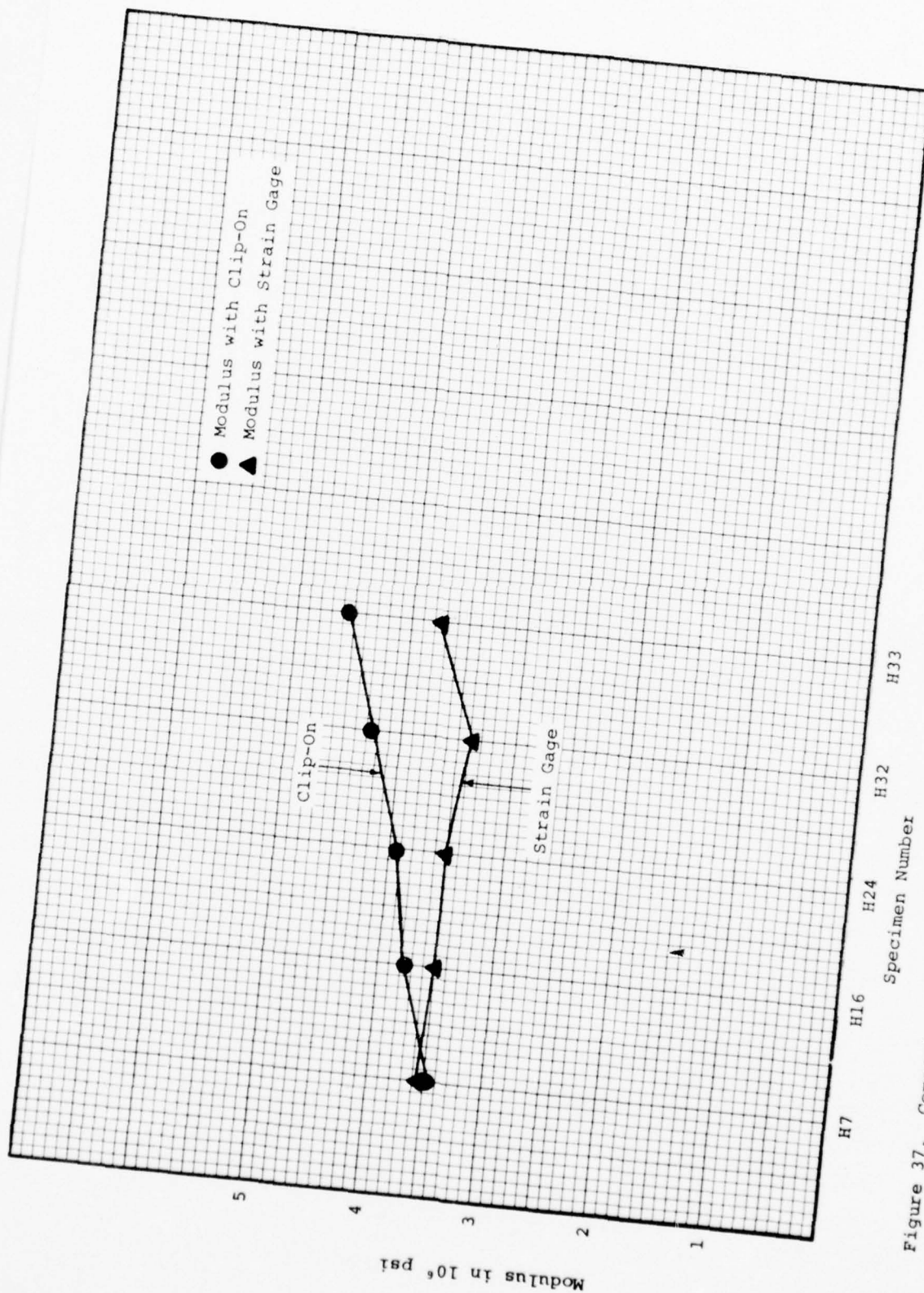


Figure 37. Comparison of Rectangular Circumferential Clip-On versus Strain Gage Data 4.1.18

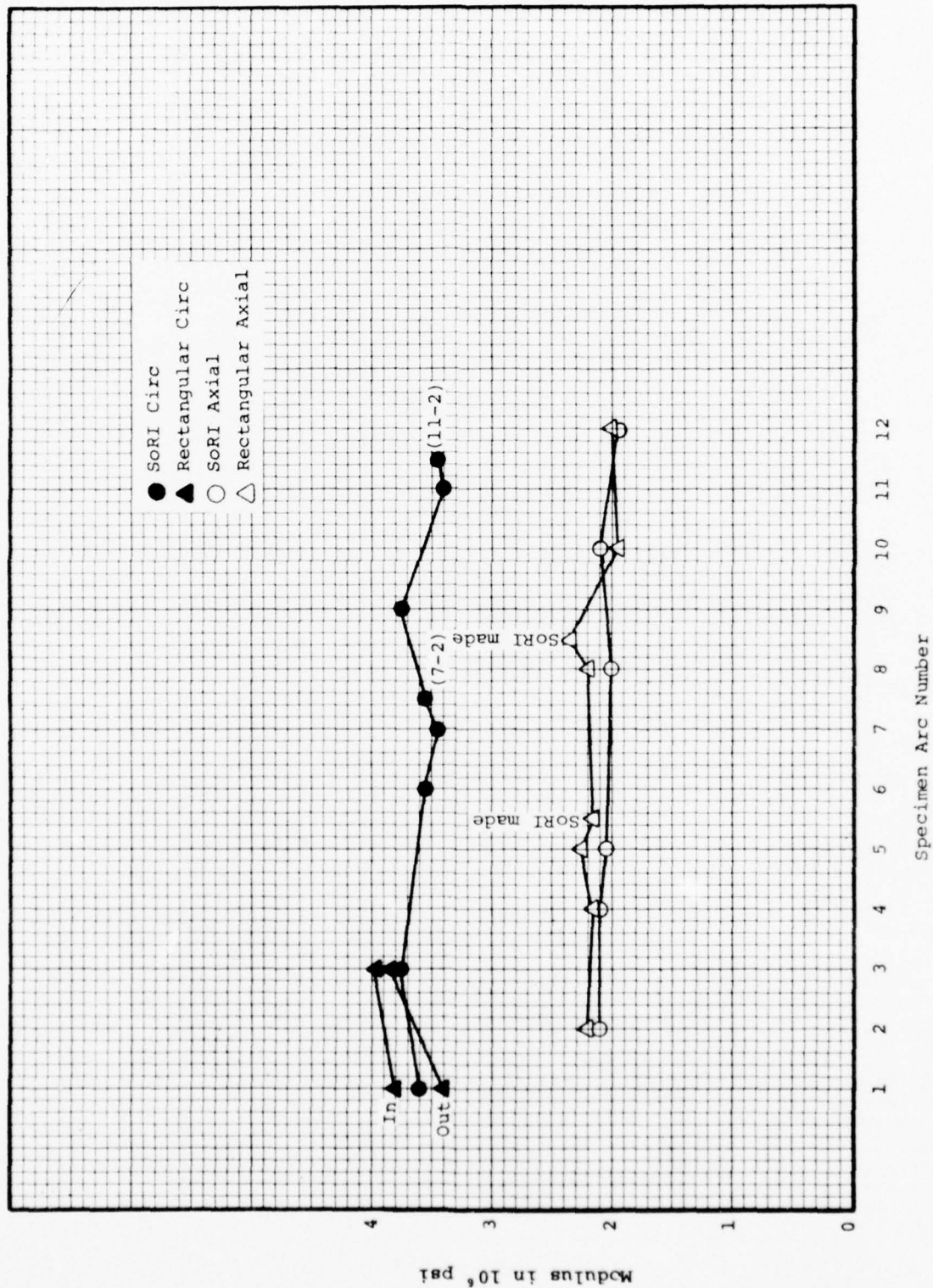


Figure 38. Rectangular versus SoRI Design Specimens Modulus Calculated From Clip-on

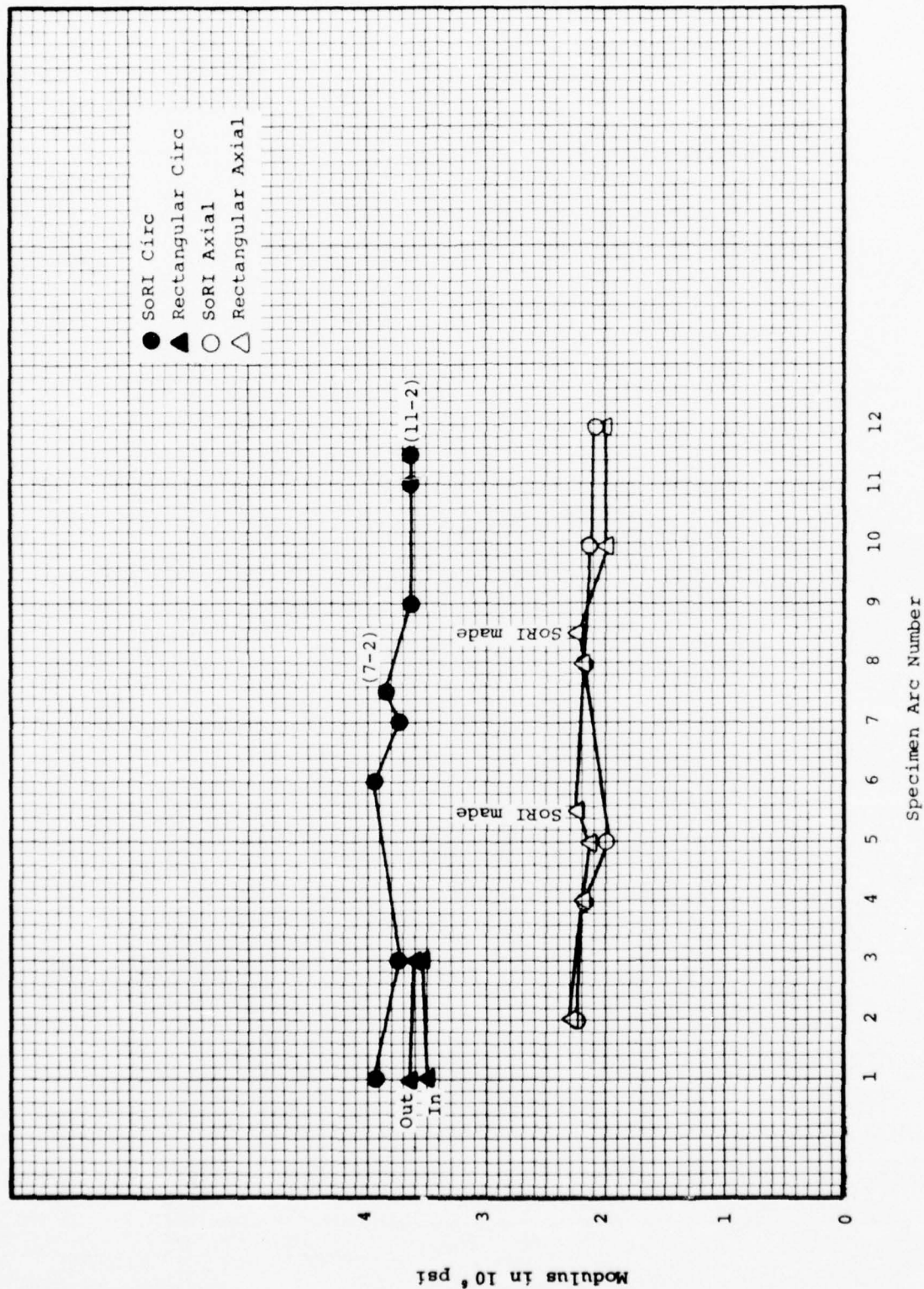


Figure 39. Rectangular versus SoRI Design Specimens Modulus Calculated From Strain Gage

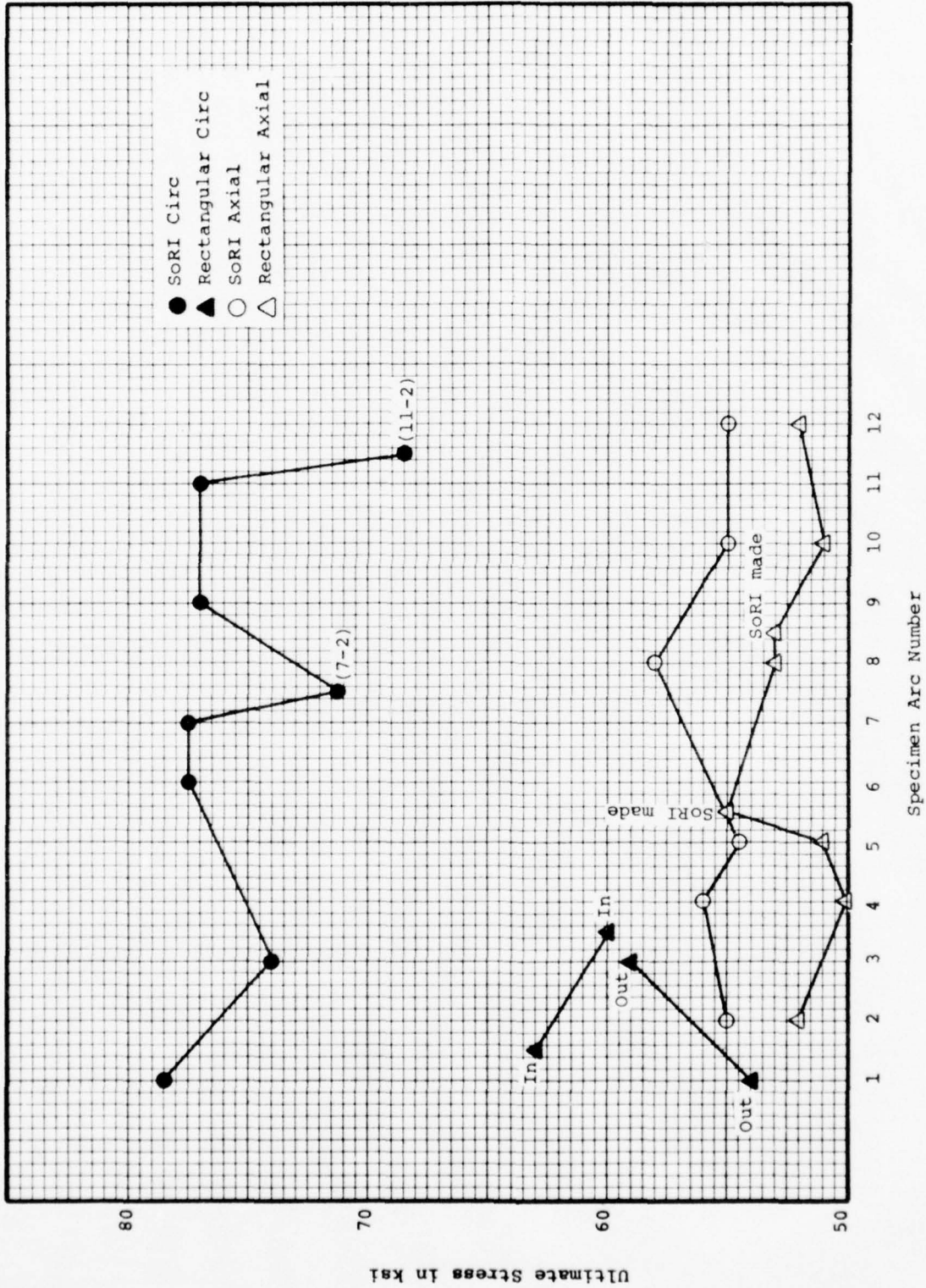


Figure 40. Rectangular versus SoRI Design Specimens Ultimate Stress

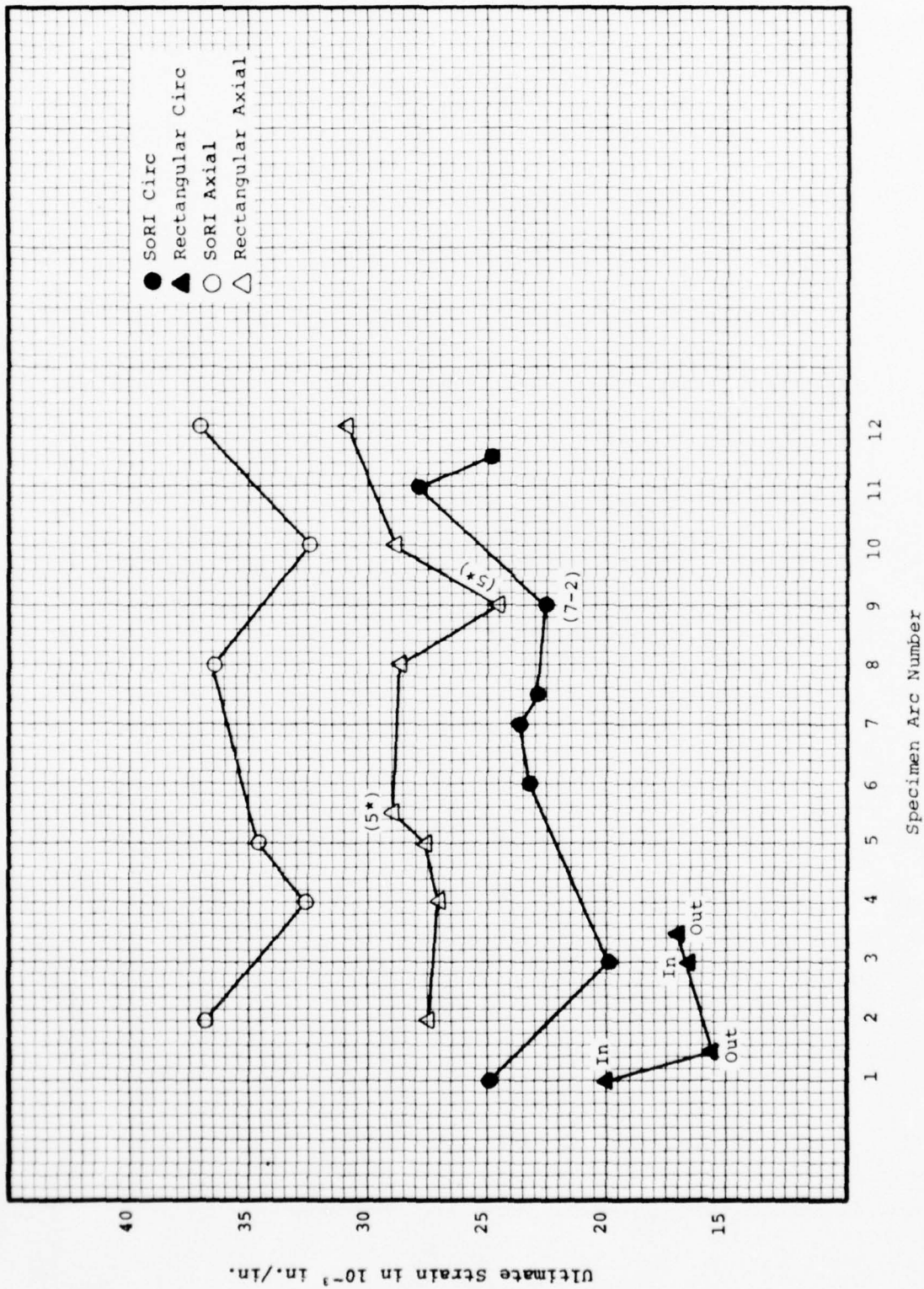


Figure 41. Comparison of Rectangular versus SoRI Design Specimens Ultimate Strain from Clip-ons

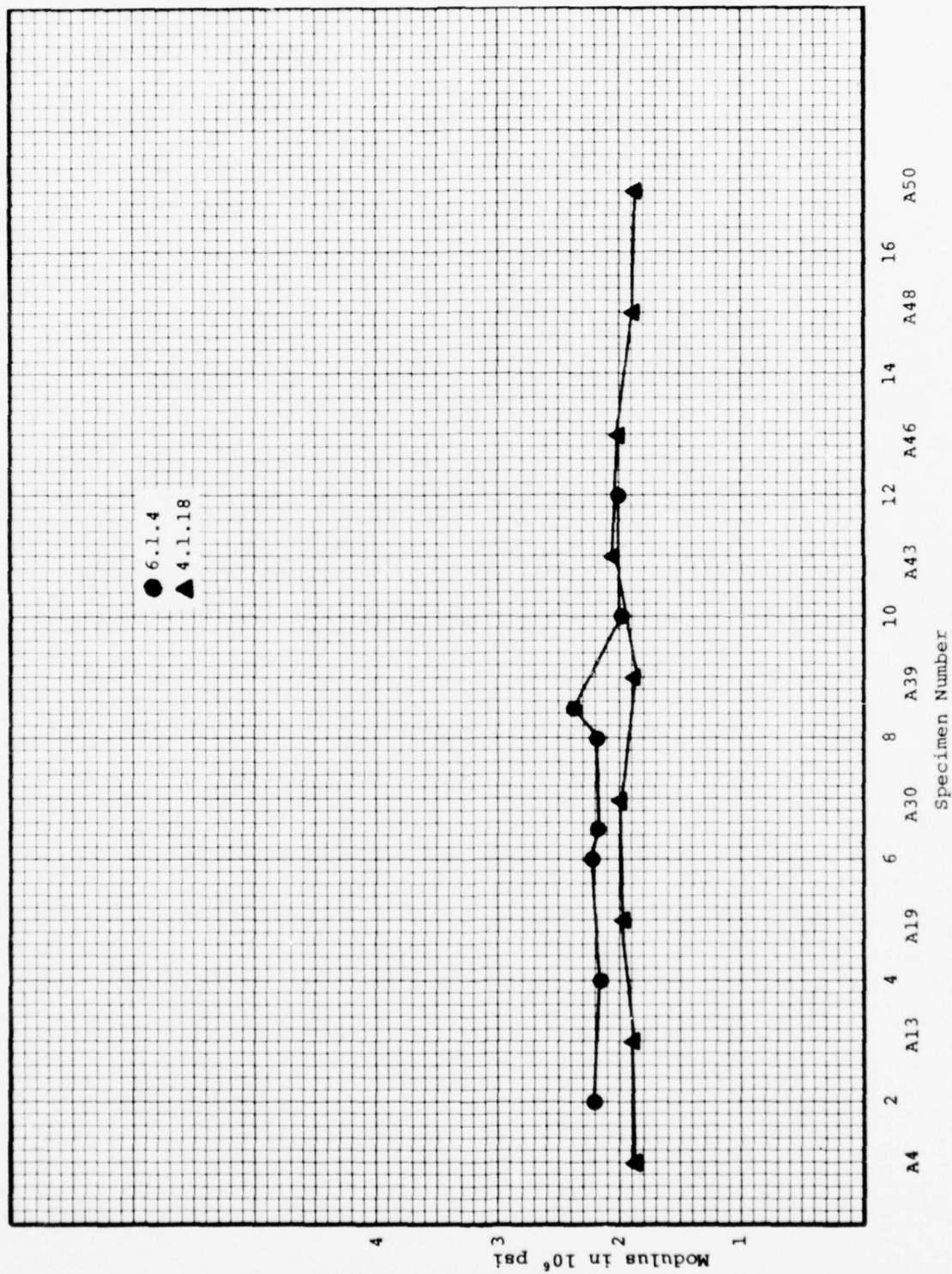


Figure 42. Rectangular Axial Specimens 6.1.4 versus 4.1.18 Modulus (Clip-on)

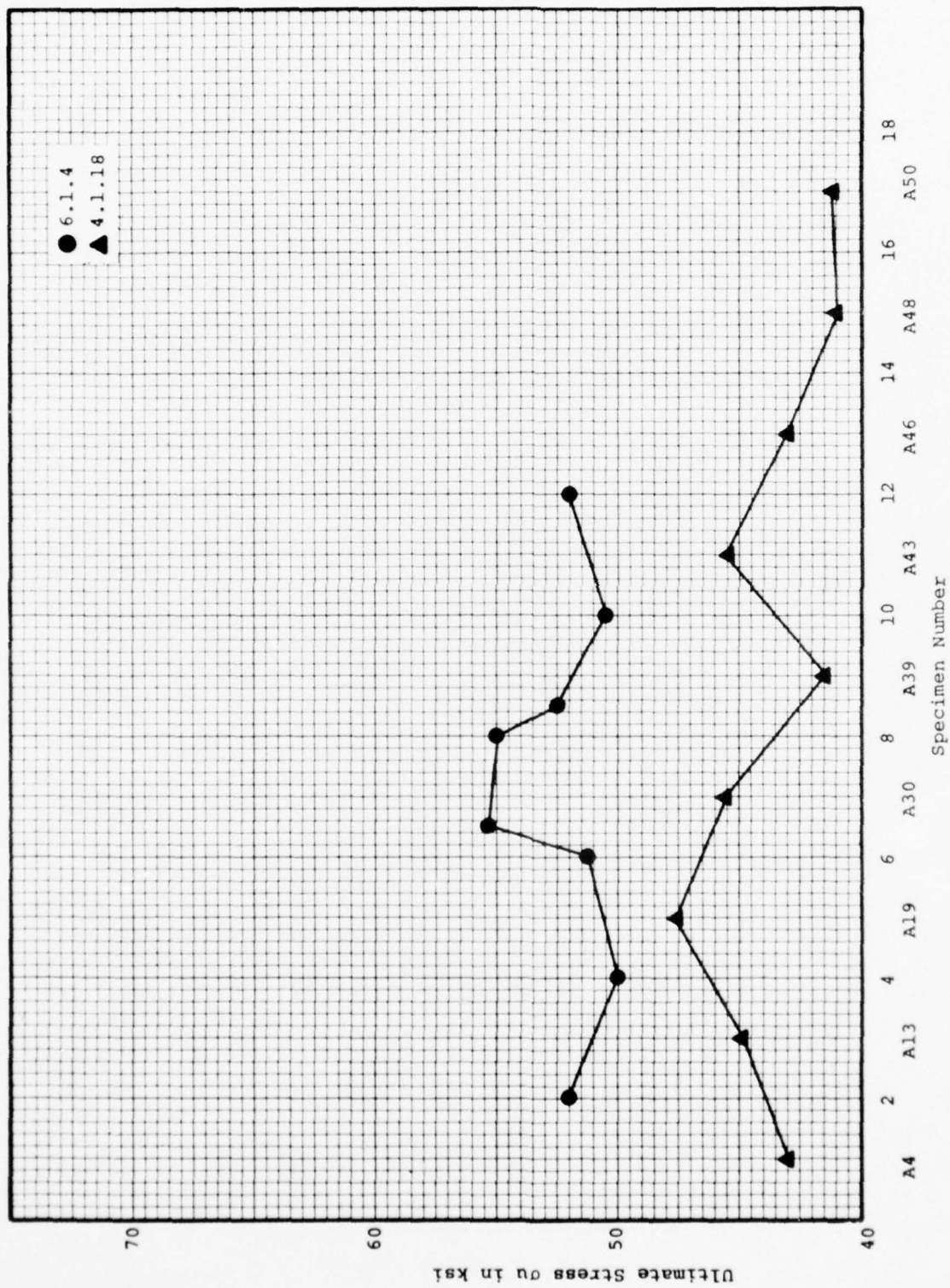


Figure 43. Rectangular Axial Specimens 6.1.4 versus 4.1.18

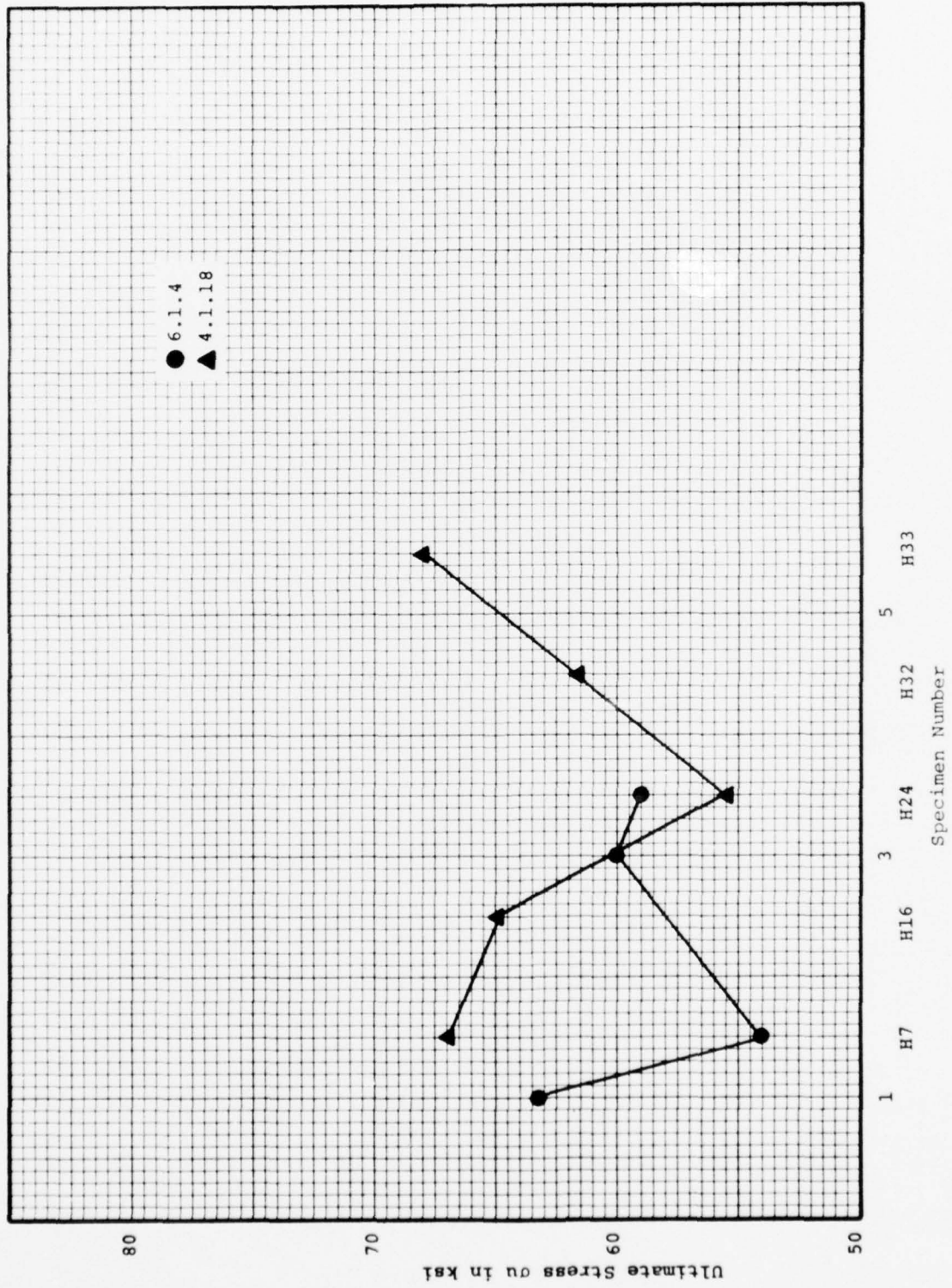


Figure 44. Rectangular Circumferential Specimens 6.1.1.4 versus 4.1.1.18

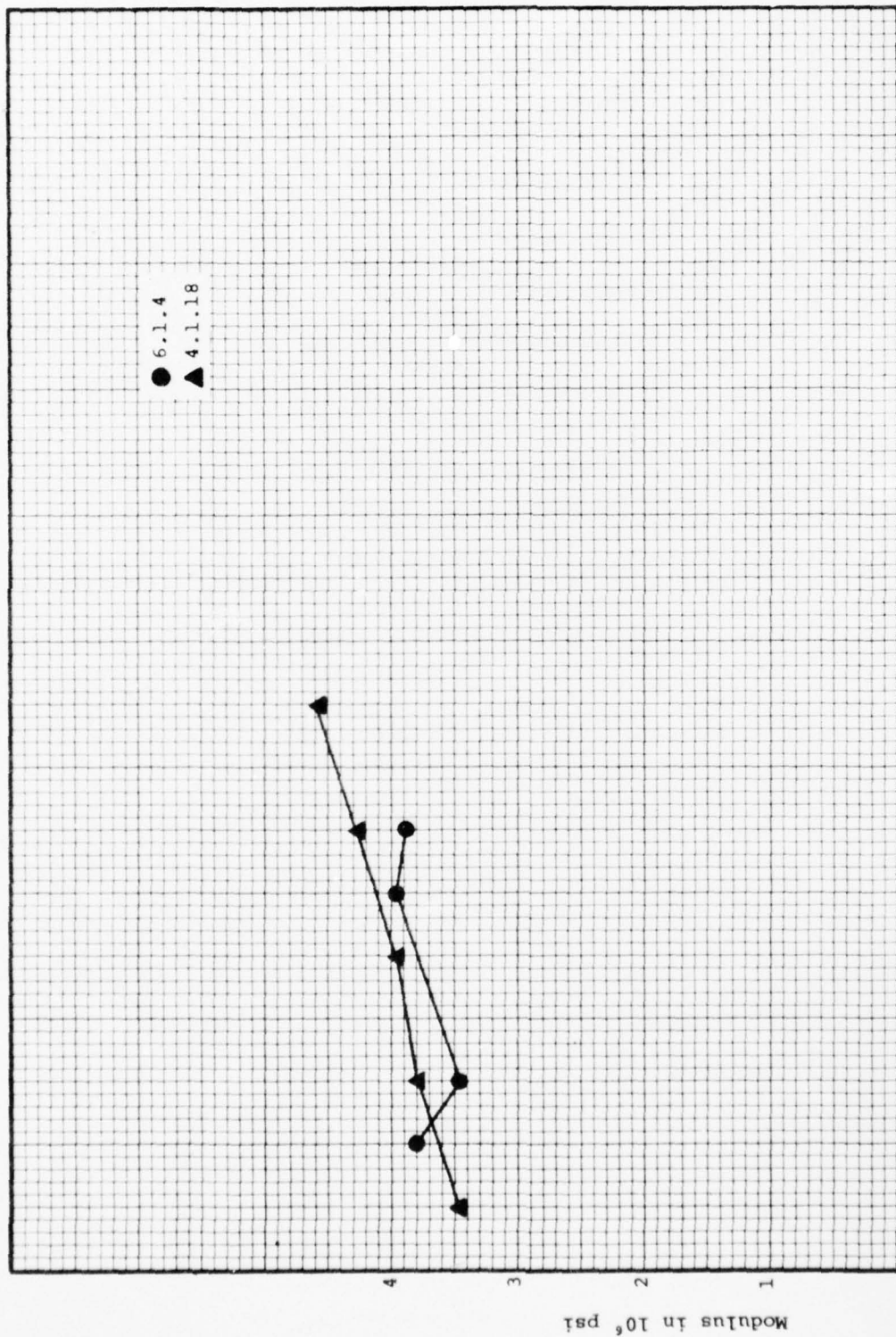


Figure 45. Rectangular Circumferential Specimens 6.1.4 versus 4.1.18 Modulus (Clip-on)

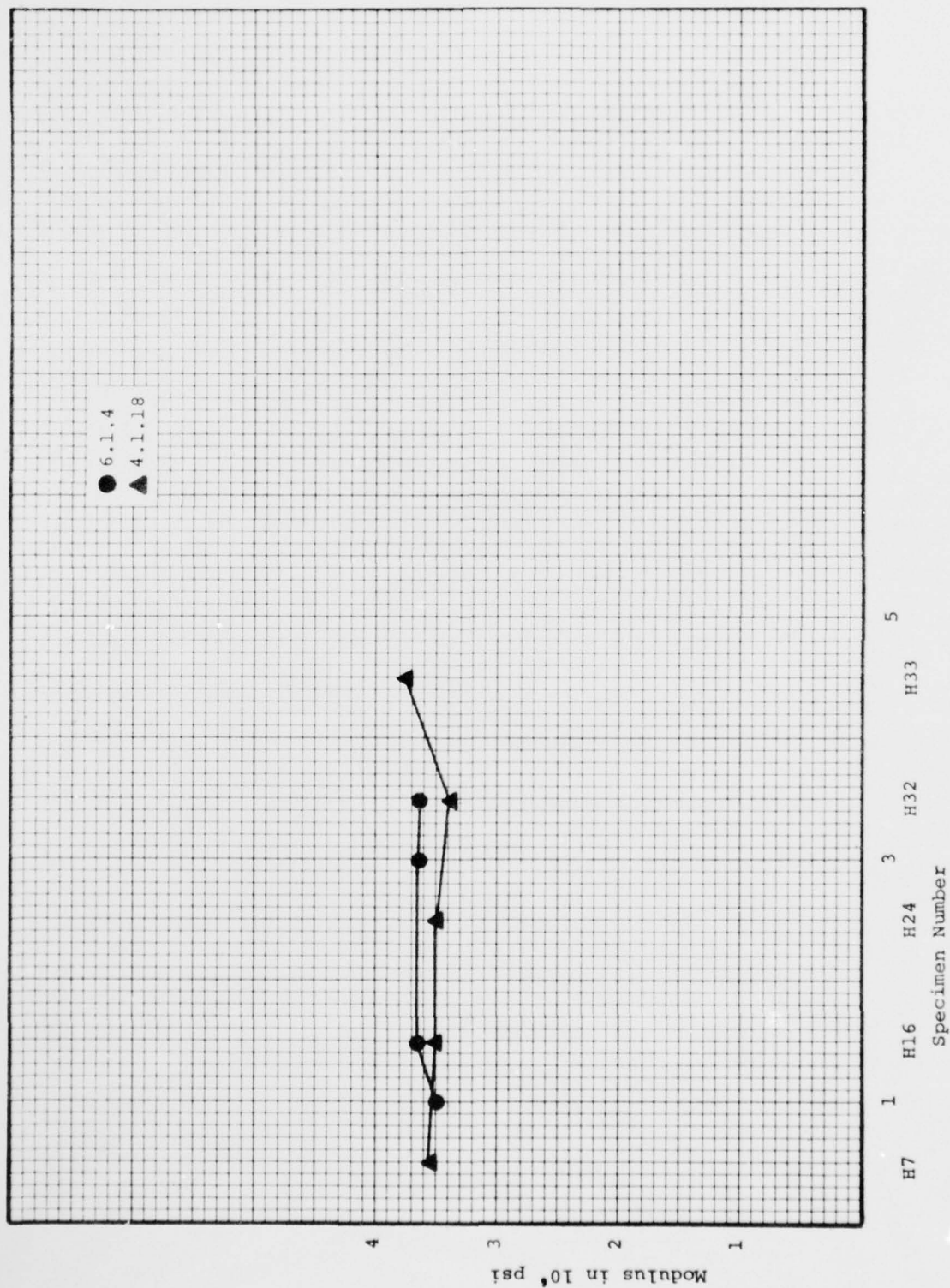


Figure 46. Rectangular Circumferential Specimens 6.1.4 versus 4.1.18 Modulus (Strain Gage)

Table 1
TEST MATRIX

	SoRI Design SoRI Machined	Rectangular Design Pre-Machined	Rectangular Design SoRI Machined
6.1.4	Hoop	--	4
	Axial	6	2
4.1.18	Hoop	5	--
	Axial	9*	--

*only 0.5 inch wide

Table 2
NONDESTRUCTIVE CHARACTERIZATION RESULTS ON TWELVE ARCS
FROM CYLINDER 6.1.4

Arc	Circs/in.	Density gm/cm ³	Axial Velocity in./μsec	Circ Velocity in./μsec	Radial Velocity in./μsec
C1	96	1.680		0.1807	0.1913
A2	96	1.688	0.1790		
C3	96	1.687		0.1804	0.1917
A4	96	1.679	0.1797		
A5	92	1.685	0.1803		
C6	96	1.685		0.1821	0.1990
C7	92	1.676		0.1798	0.1932
A8	100	1.695	0.1802		
C9	96	1.683		0.1812	0.1918
A10	96	1.685	0.1792		
C11	96	1.689		0.1801	0.1951
A12	92	1.688	0.1801		
	Average	1.685	0.1798	0.1809	0.1937
	SD	0.005	0.0008	0.0012	0.0036

Table 3

DENSITIES OF HOOP AND AXIAL SPECIMENS
FROM CYLINDER 4.1.18

Specimen		Density gm/cm ³
H7-CC-Rect	a	1.614
	b	1.611
H16-CC-Rect	a	1.621
	b	1.634
H24-CC-Rect	a	1.633
	b	1.634
H32-CC-Rect	a	1.631
	b	1.638
H33-CC-Rect	a	1.623
	b	1.623
Average		<u>1.626</u>
A4-AC-Rect		1.628
A13-AC-Rect		1.620
A19-AC-Rect		1.623
A30-AC-Rect		1.624
A39-AC-Rect		1.626
A43-AC-Rect		1.625
A46-AC-Rect		1.625
A48-AC-Rect		1.623
A50-AC-Rect		1.621
Average		<u>1.624</u>

Table 4

DENSITIES OF FIVE SPECIMENS MACHINED
FROM THE INSIDE SURFACE ADJACENT TO
RESPECTIVE ARCS IN CYLINDER 6.1.4

Specimen	Density gm/cm ³
2-AC-Rect	1.660
4-AC-Rect	1.660
5-AC-Rect	1.665
8-AC-Rect	1.663
10-AC-Rect	1.661
12-AC-Rect	1.660
Average	<u>1.662</u>

Table 5

AXIAL COMPRESSIVE TESTS
SoRI SPECIMEN CONFIGURATION 3DQP 6.1.4

Specimen Number	Tangent Modulus E ($\times 10^6$ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u ($\times 10^{-3}$ in./in.)
	Clip-on	S.G.		
2-AC-SoRI	2.10	2.24	55,400	36.8
4-AC-SoRI	2.10	2.20	56,000	32.6
5-AC-SoRI	2.07	2.00	54,500	34.6
8-AC-SoRI	2.05	2.20	58,000	36.4
10-AC-SoRI	2.09	2.15	55,000	32.4
12-AC-SoRI	1.92	2.10	55,500	37.0
$\bar{X}$	2.06	2.15	55,733	35.0
S	0.07	0.09	1,219	2.1

Table 6
AXIAL COMPRESSIVE TESTS
RECTANGULAR SPECIMEN CONFIGURATION 3DQP 6.1.4

Specimen Number	Tangent Modulus E (x 10 ⁶ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u (x 10 ⁻³ in./in.)
	Clip-on	S.G.		
2-AC-Rect	2.20	2.26	52,000	27.4
4-AC-Rect	2.16	2.20	50,000	27.0
5-AC-Rect*	2.18	2.25	55,400	28.9
5-AC-Rect	2.23	2.13	51,200	27.6
8-AC-Rect*	2.38	2.28	52,500	24.5
8-AC-Rect	2.19	2.20	55,000	28.7
10-AC-Rect	1.98	2.00	50,600	28.8
12-AC-Rect	2.00	2.02	52,000	30.8
$\bar{X}$	2.17	2.17	52,338	28.0
S	0.13	0.11	1,946	1.8

*Specimen from same arc number machined at SoRI

Table 7

AXIAL COMPRESSIVE TESTS
RECTANGULAR SPECIMEN CONFIGURATION 3DQP 4.1.18

Specimen Number	Tangent Modulus E ($\times 10^6$ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u ($\times 10^{-3}$ in./in.)	
	Clip-on	S.G.		Clip-on	
A4-AC-Rect	1.88	1.89	43,000	23.6	
A13-AC-Rect	1.88	1.91	44,800	25.0	
A19-AC-Rect	1.96	1.98	47,600	26.4	
A30-AC-Rect	1.99	2.00	45,500	24.1	
A39-AC-Rect	1.88	1.77	41,400	22.8	
A43-AC-Rect	2.05	1.90	45,500	24.4	
A46-AC-Rect	2.00	1.86	43,000	22.9	
A48-AC-Rect	1.88	1.71	41,000	25.6	
A50-AC-Rect	1.86	1.76	41,100	24.3	
$\bar{X}$	1.93	1.86	43,656	24.3	
S	0.07	0.10	2,324	1.2	

Table 8

CIRCUMFERENTIAL COMPRESSIVE TESTS
SoRI SPECIMEN CONFIGURATION 3DQP 6.1.4

Specimen Number	Tangent Modulus E ($\times 10^6$ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u ($\times 10^{-3}$ in./in.)	
	Clip-on	S.G.		Clip-on	
1-CC-SoRI	3.60	3.91	78,500	24.9	
3-CC-SoRI	3.73	3.78	73,800	19.9	
6-CC-SoRI	3.55	3.96	77,400	23.2	
7-1-CC-SoRI	3.45	3.76	77,600	23.7	
7-2-CC-SoRI	3.54	3.85	70,800	22.9	
9-CC-SoRI	3.70	3.65	77,000	22.6	
11-1-CC-SoRI	3.40	3.66	68,500	27.8	
11-2-CC-SoRI	3.35	3.63	76,800	24.8	
$\bar{X}$	3.54	3.78	75,050	23.7	
S	0.14	0.12	3,651	2.3	

Table 9
CIRCUMFERENTIAL COMPRESSIVE TESTS
RECTANGULAR SPECIMEN CONFIGURATION 3DQP 6.1.4

Specimen Number	Tangent Modulus E ($\times 10^6$ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u ($\times 10^{-3}$ in./in.)
	Clip-on	S.G.		
1 (In)-CC-Rect	3.80	3.50	63,200	19.9
1 (Out)-CC-Rect	3.45	3.65	54,000	15.6
3 (In)-CC-Rect	3.95	3.63	60,000	16.6
3 (Out)-CC-Rect	3.88	3.64	59,000	17.0
$\bar{X}$	3.77	3.61	59,050	17.3
S	0.22	0.07	3,814	1.9

Table 10

CIRCUMFERENTIAL COMPRESSIVE TESTS

RECTANGULAR SPECIMEN CONFIGURATION 3DQP 4.1.18

Specimen Number	Tangent Modulus E (x 10 ⁶ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u (x 10 ⁻³ in./in.)
	Clip-on	S.G.		
H7-CC-Rect	3.47	3.53	67,000	17.7
H16-CC-Rect	3.78	3.50	65,000	19.3
H24-CC-Rect	3.94	3.50	55,400	16.0
H32-CC-Rect*	4.25	3.37	61,700	15.8
H33-CC-Rect	4.55	3.75	68,000	17.8
$\bar{X}$	4.00	3.53	63,420	17.3
S	0.42	0.14	5,088	1.4

*Apparent bending in specimen

Table 11
70°F AXIAL COMPRESSIVE DATA COMPARISON

Program	AHP	CRS	6.1.4	6.1.4
Material				
Process	A	C	C	C
A_r/A_t	0.48	0.607	0.700	0.700
S/P	P	P	S	S
Density	1.67	(1.64)*	1.685	1.685
Velocity				
Radial	(0.197)	(0.173)	(0.194)	(0.194)
Axial	0.1732 (0.1840)	(0.171)	0.180	0.180
Circ	0.1894	-	(0.179)	(0.179)
Type Test	Coupon	Coupon (Inners & Full)	SoRI Design	Rectangular Design
Specimen Gage (in.)	4 cells/0.5/ 1.2	(0.6 x 0.5 x 0.8) (0.6 x 0.2 x 0.8)	(0.6 x 0.5 x 0.8)	3 cells x 0.2 x 1.0
No. of Tests	3	9	6	8
$\bar{E}$ in 10^6 psi	2.23	2.60	2.06	2.17
$\bar{\sigma}_u$ in 10^6 psi	32.2	45.0	55.7	52.3
$\bar{\epsilon}_u$ in $10^{-3} \frac{\text{in.}}{\text{in.}}$	28.0	21.0	35.0	28.0

*Data not from these particular specimens in parenthesis

Table 12
70°F HOOP COMPRESSIVE DATA COMPARISON

Program	Coated Disc	Coated Disc	AHP	CRS	CRS	CRS/Spades	6.1.4	6.1.4
Material Process A _r /A _t S/P	A 0.40 P	A 0.40 P	A 0.48 P	C 0.607 P	C 0.607 P	C 0.45 S	C S	C S
Density	1.61	1.61	1.66 (1.67)	(1.64)	(1.64)	-	1.685	1.685
Velocity Radial Axial Circ	0.1988 - -	0.1988 - -	(0.1971)* (0.1840) 0.1780 (0.1894)	(0.173) (0.171) - -	(0.173) (0.171) - -	0.166 0.166 - -	0.194 (0.180) 0.179 0.179	0.194 (0.180) 0.179 0.179
Type Test	Inner/100% CCC	Outer/100% CCC	Full/0% CCC	I, O, & Full/ 100% CCC	Hydrostatic	Hydrostatic	SoRI Design	Rectangular Design
Specimen Gage (in.)	0.2 x 0.4 x 0.6	0.2 x 0.4 x 0.6	0.4 x 0.4 x 0.625 and 0.4 x 0.2 x 0.625	0.6 x 0.5 x 0.8 0.6 x 0.2 x 0.8	2.0 x 0.5 x 1.0	2.0 x 0.5 x 1.0	0.6 x 0.5 x 0.8	2 (0.3 x 0.15 x 1.0)
No. of Tests	4	3	3	9	12	2	8	4
E in 10 ⁶ psi	3.07	3.02	2.42	3.81	3.53	3.66	3.54	3.61
σ _u in 10 ³	39.3	37.6	31.2	58.6	-	-	75.1	59.1
ε _u in 10 ⁻³ in. in.	16.5	16.1	20.0	14.3	-	-	23.7	17.3

*Data not from these particular specimens in parenthesis

Table 13

OUTSIDE/INSIDE COMPARISON

Property	ID	OD	Full
Density on full Arcs compared to ID Specimen (Axials) (Adjacent)	1.662	-	1.685
Clip-on Modulus on Circ Specimens (2)	3.87	3.66	(3.54)
S.G. Modulus on Circ Specimens (2)	3.57	3.65	(3.78)
Ultimate Stress on Circ Specimens (2)	61,600	57,000	(75,050)
Ultimate Strain on Circ Specimens (2)	18.2	16.3	(23.7)

Note: Data in parenthesis not truly comparable due to specimen design

Table 14
COMPARISON OF RECTANGULAR AND SORI SPECIMEN CONFIGURATIONS 6.1.4

	Configuration	Tangent Modulus E (x 10 ⁶ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u (x 10 ⁻³ in./in.)
		Clip-on	S.G.		
Axial	SORI	2.06	2.15	55,733	35.0
	Rectangular	2.17	2.17	52,338	28.0
Circ	SORI	3.54	3.78	75,050	23.7
	Rectangular*	3.77	3.61	59,050	17.3

*Inside and outside specimens

Table 15

COMPARISON OF 6.1.4 VERSUS 4.1.18 RECTANGULAR SPECIMEN CONFIGURATION 3DQP

	Cylinder Number	Tangent Modulus E (x 10 ⁶ psi)		Ultimate Stress σ_u (psi)	Ultimate Strain ϵ_u (x 10 ⁻³ in./in.)	
		Clip-on	S.G.		Clip-on	
Axial	6.1.4	2.17	2.17	52,338	28.0	
	4.1.18	1.93	1.86	43,656	24.3	
Circ	6.1.4*	3.88	3.57	61,600	18.3	
	4.1.18	4.00	3.53	63,420	17.3	

*Specimens from inside surface of cylinder only

APPENDIX A

Raw Data

A1

Axial Compressive Tests
SoRI Specimen Configuration

6.1.4

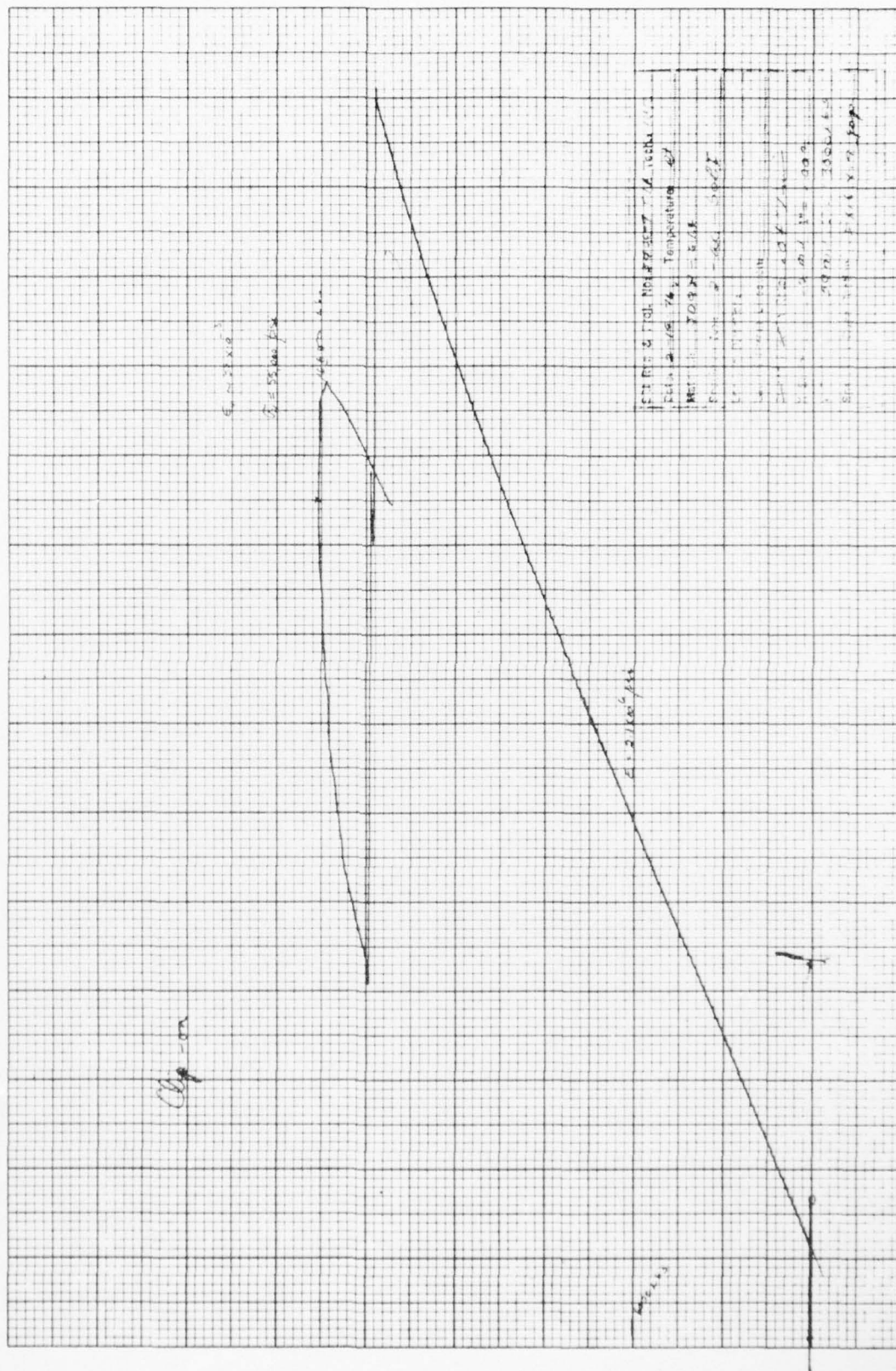


Figure A1 - Test results for Specimen 3 AC Sub 1

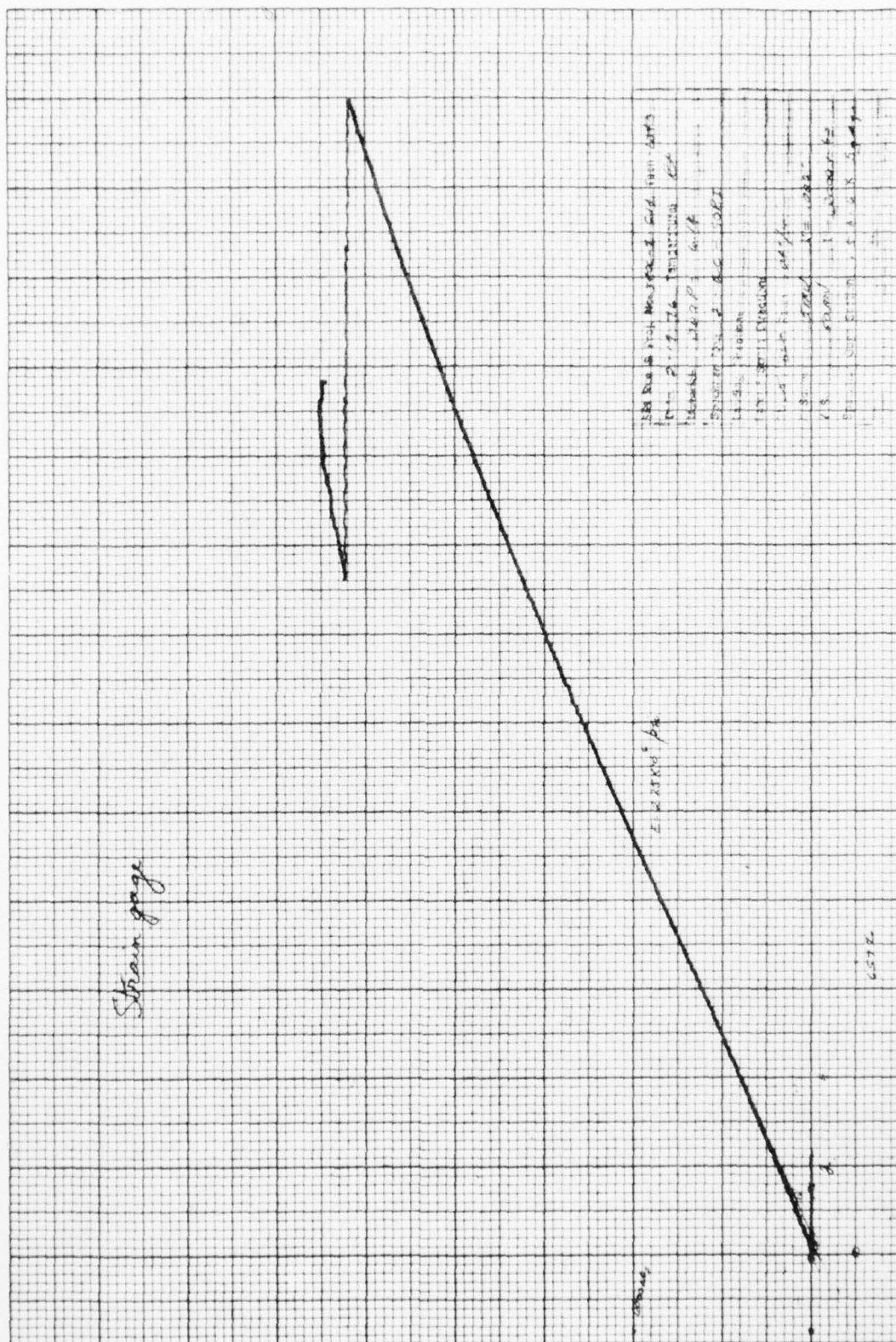


Figure 12 - Test Results for Specimen 2-BC-S-8

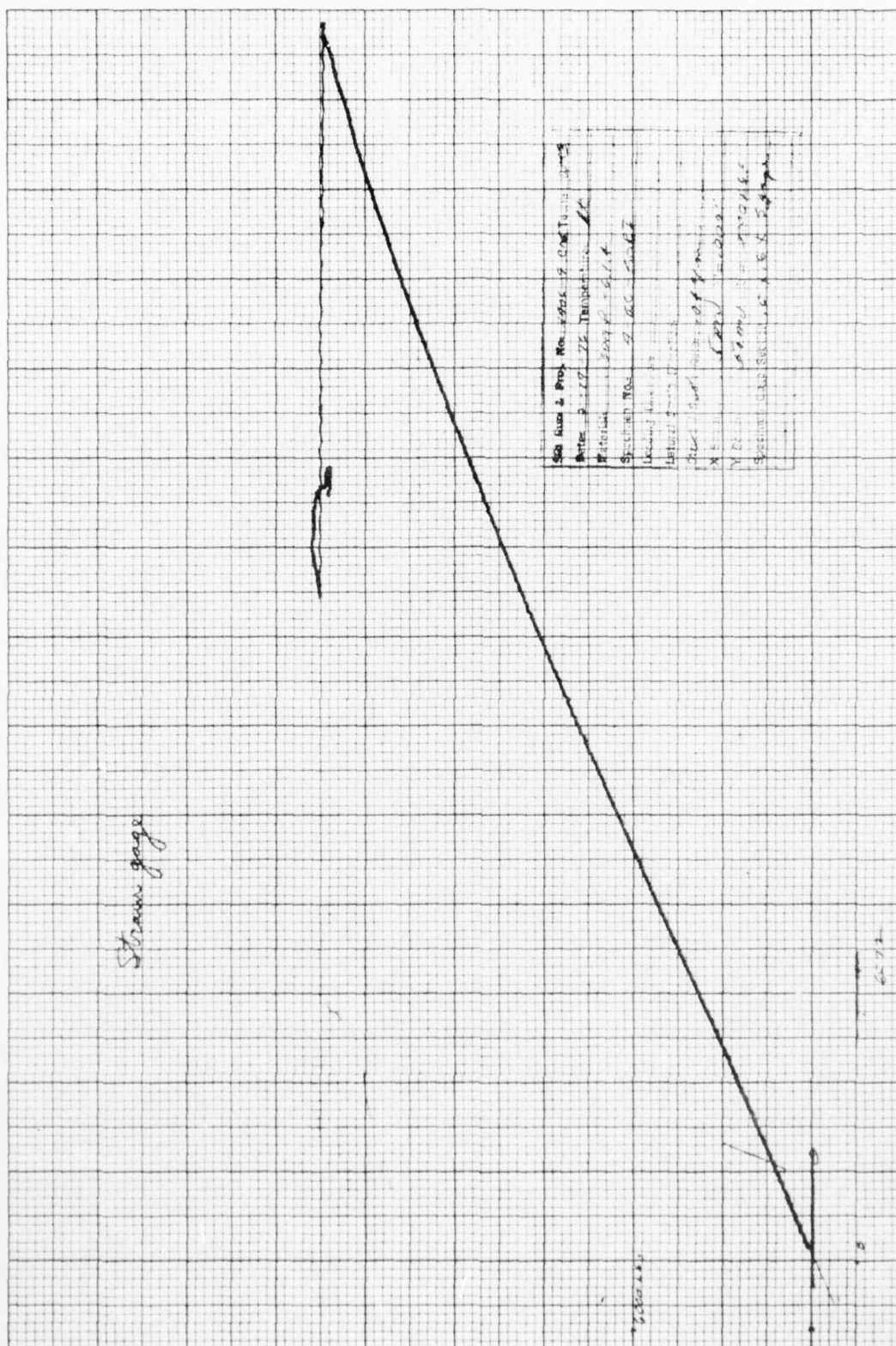


Figure 14. Test Results for Specimen 4-HC-SaB1

Strain gauge

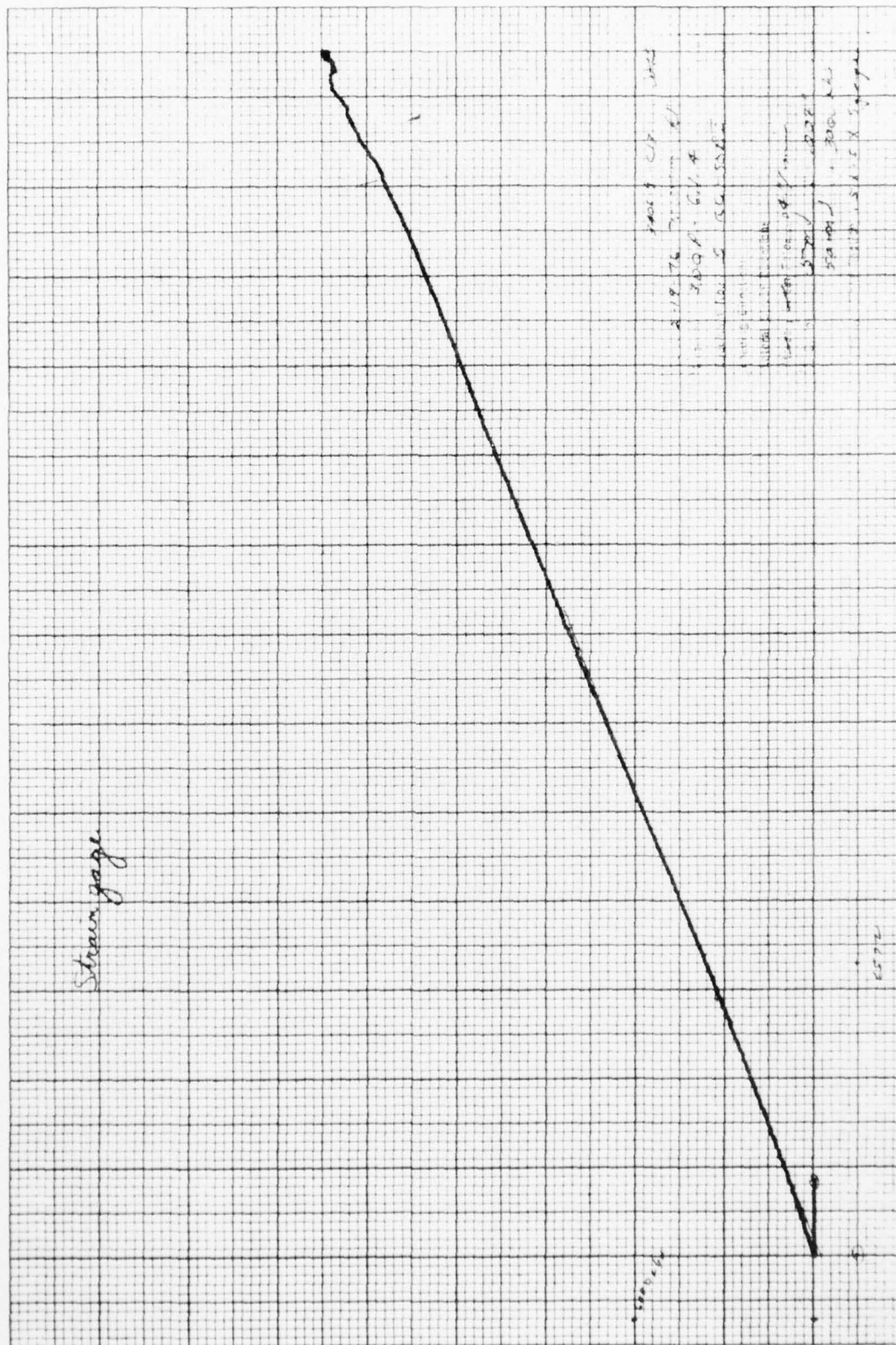


Figure A5 - Test Results for Spectra 5 = AS - 50R

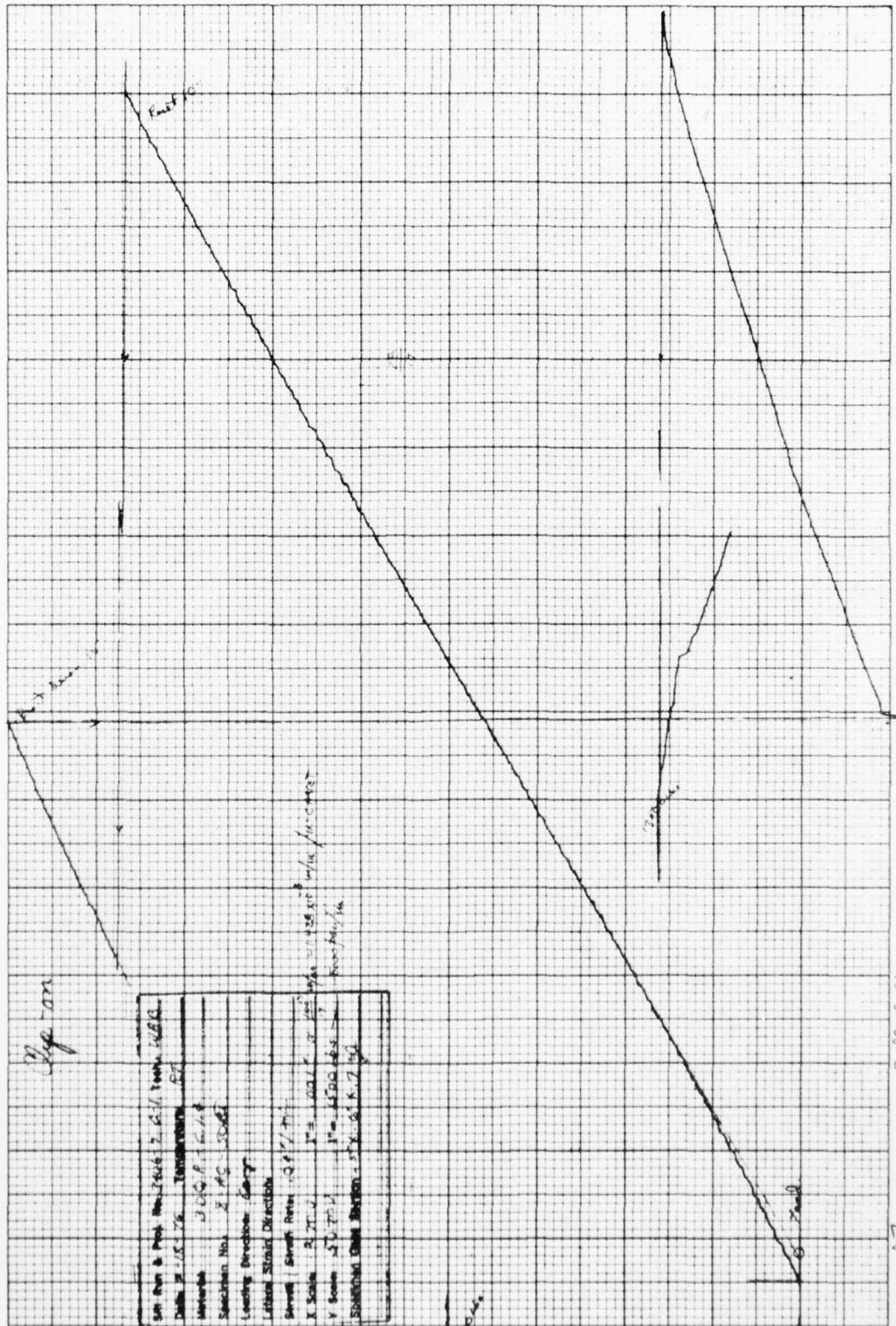
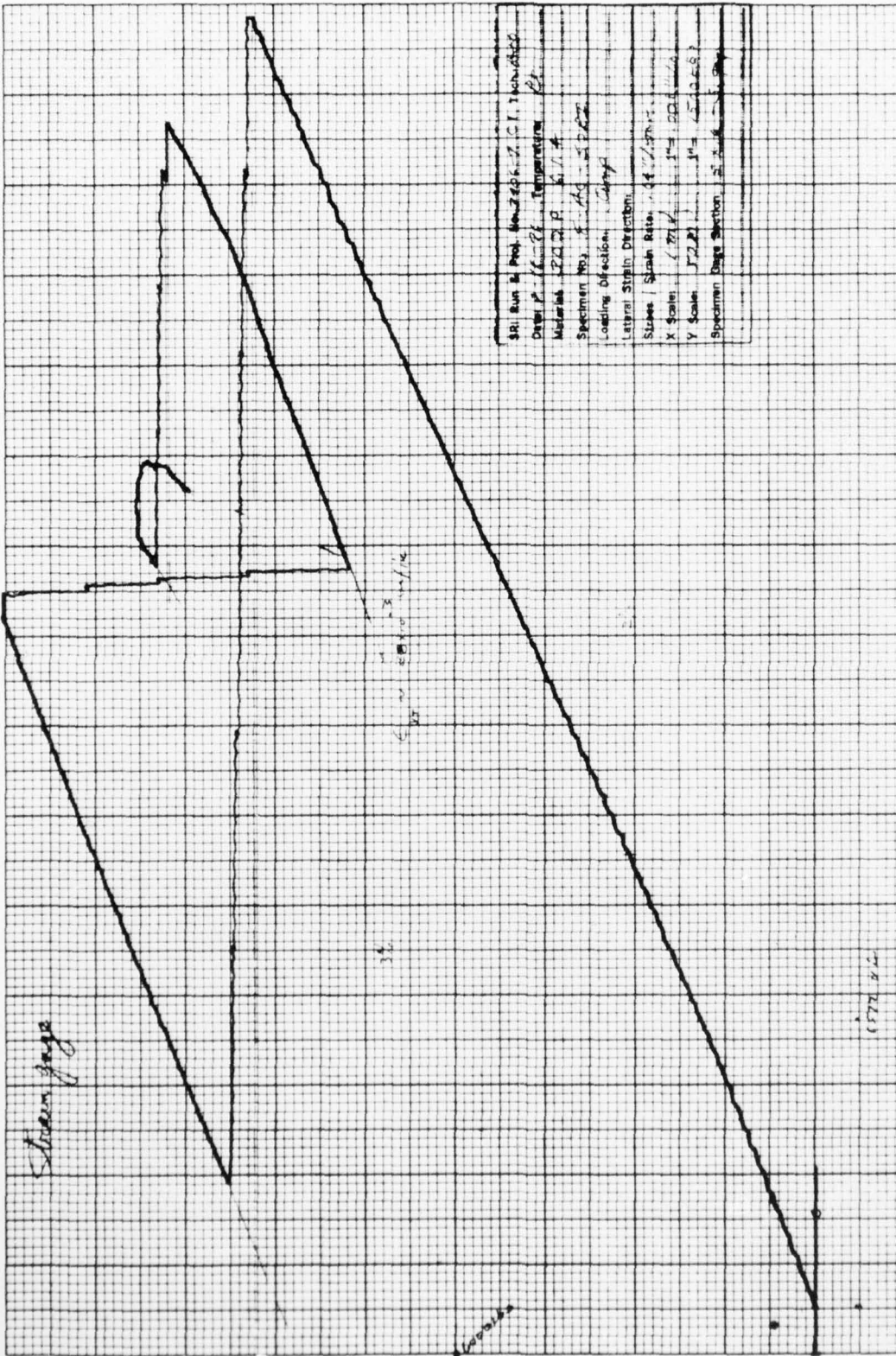
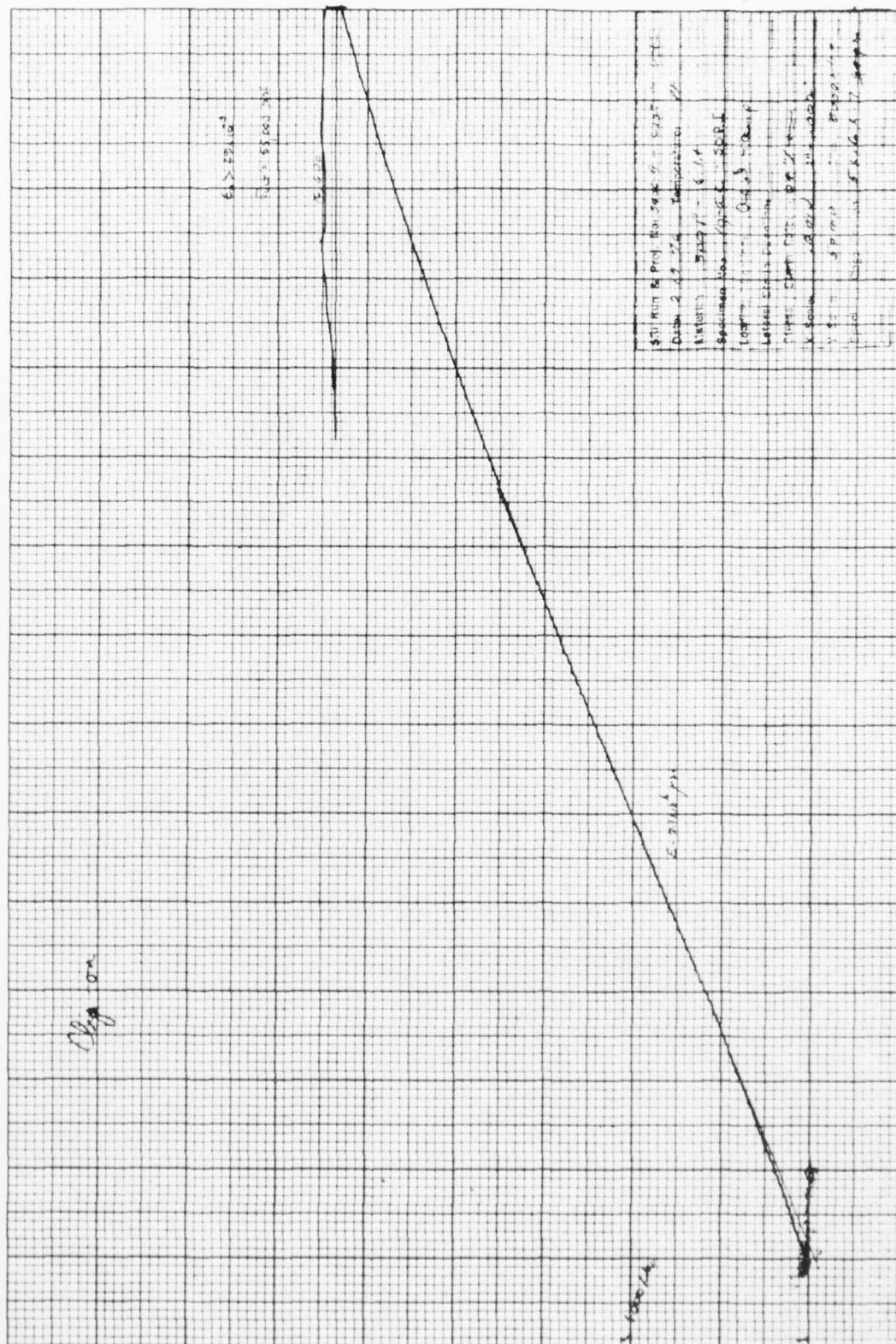


Figure A7 - Test Results for Specimen 8-AQ-500



SA: Run 4	Prod. No. 3486-2	C.I. 1000-0000
Date: 1-16-71	Temperature: 72	
Material: 2222 P	6.14	
Specimen No.: 5	149	5722
Loading Direction: 100%		
Letter: Strain Direction		
Stress / Strain Ratio: 1.5	1.5	1.5
X Scale: 1.5	1.5	1.5
Y Scale: 1.5	1.5	1.5
Specimen Edge Section: 2	2	2

Figure A8 Test Results for Specimen 8-A-C-SaR1



[illegible][illegible]

AD-A044 031

SOUTHERN RESEARCH INST BIRMINGHAM ALA

F/G 11/9

EVALUATION OF THE COMPRESSIVE PROPERTIES OF A SPECIAL 3DQP.(U)

SEP 76 J R KOENIG, G F FORNARO

DNA001-75-C-0037

UNCLASSIFIED

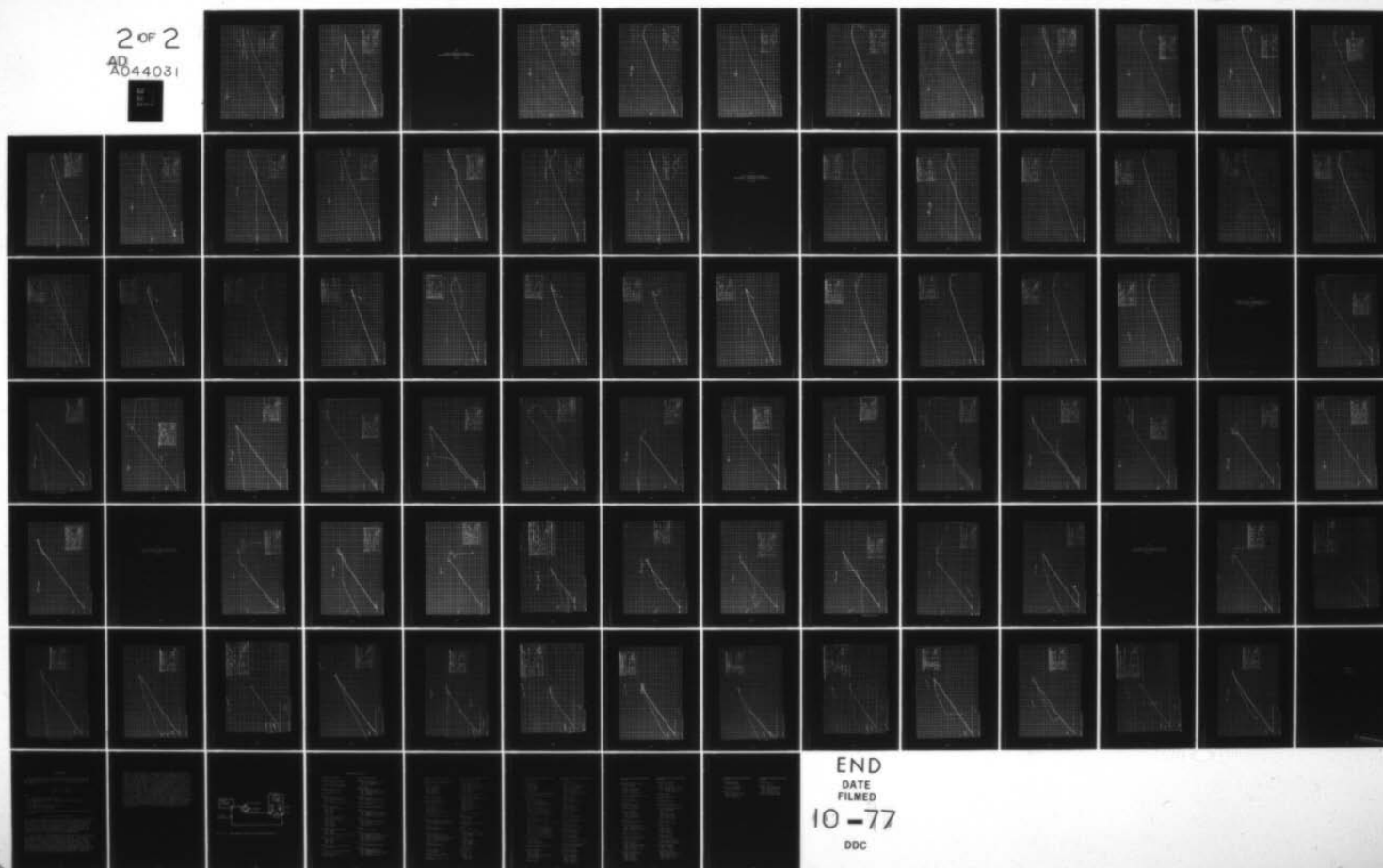
SORI-76-483-3406-9-I-F

DNA-4174F

NL

2 OF 2

AD
A044031



END
DATE
FILMED

10-77

DDC

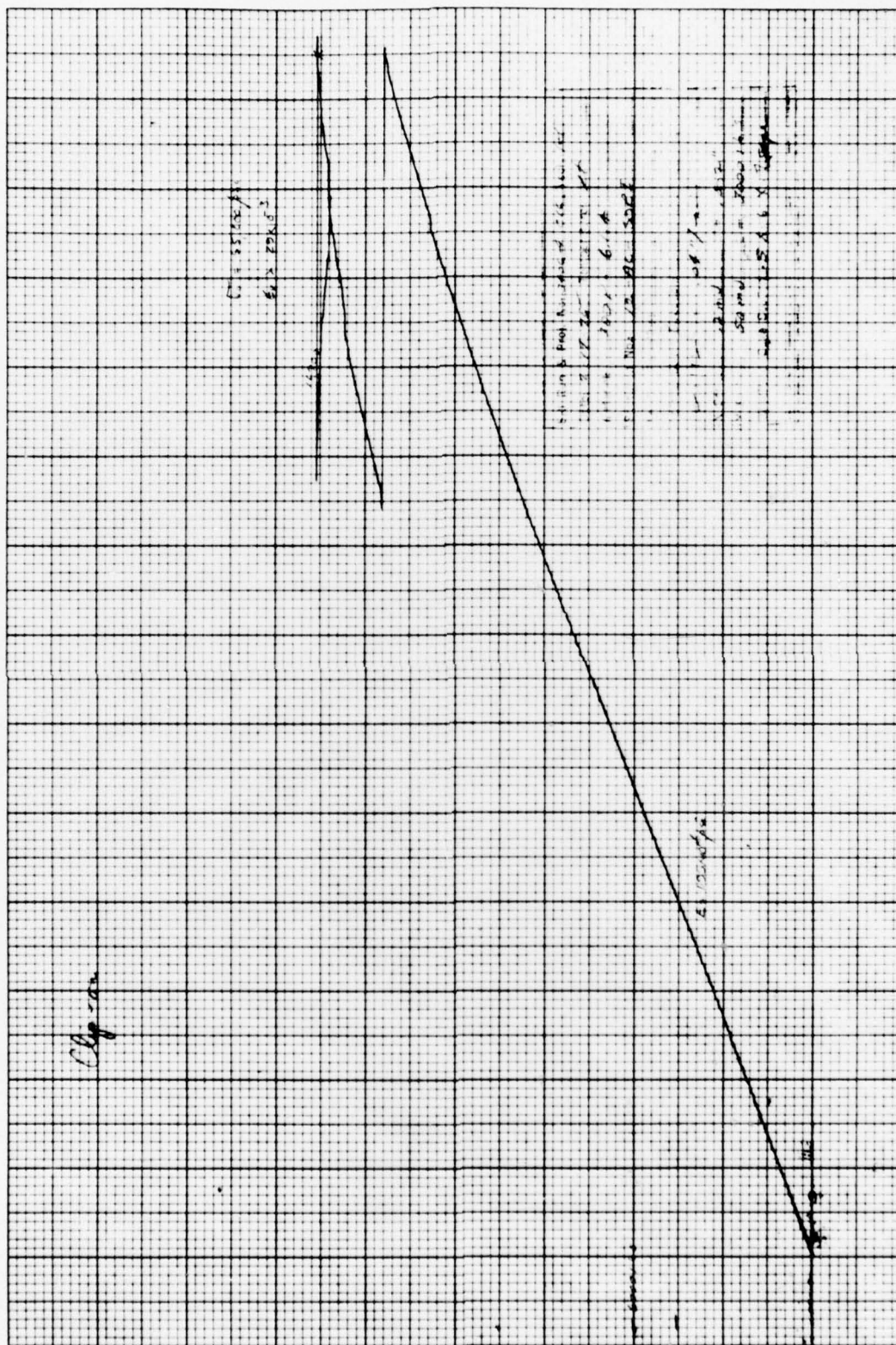
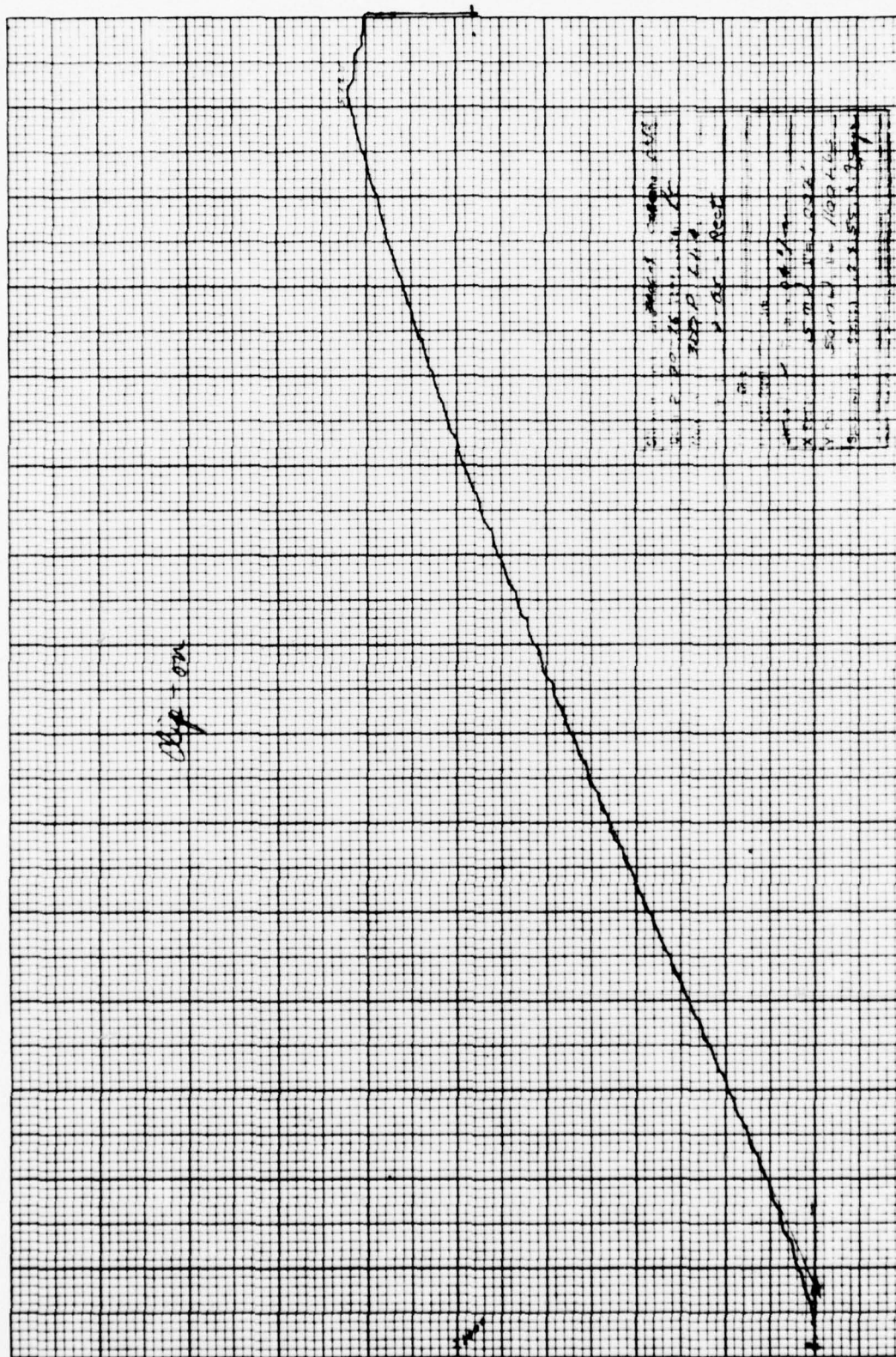


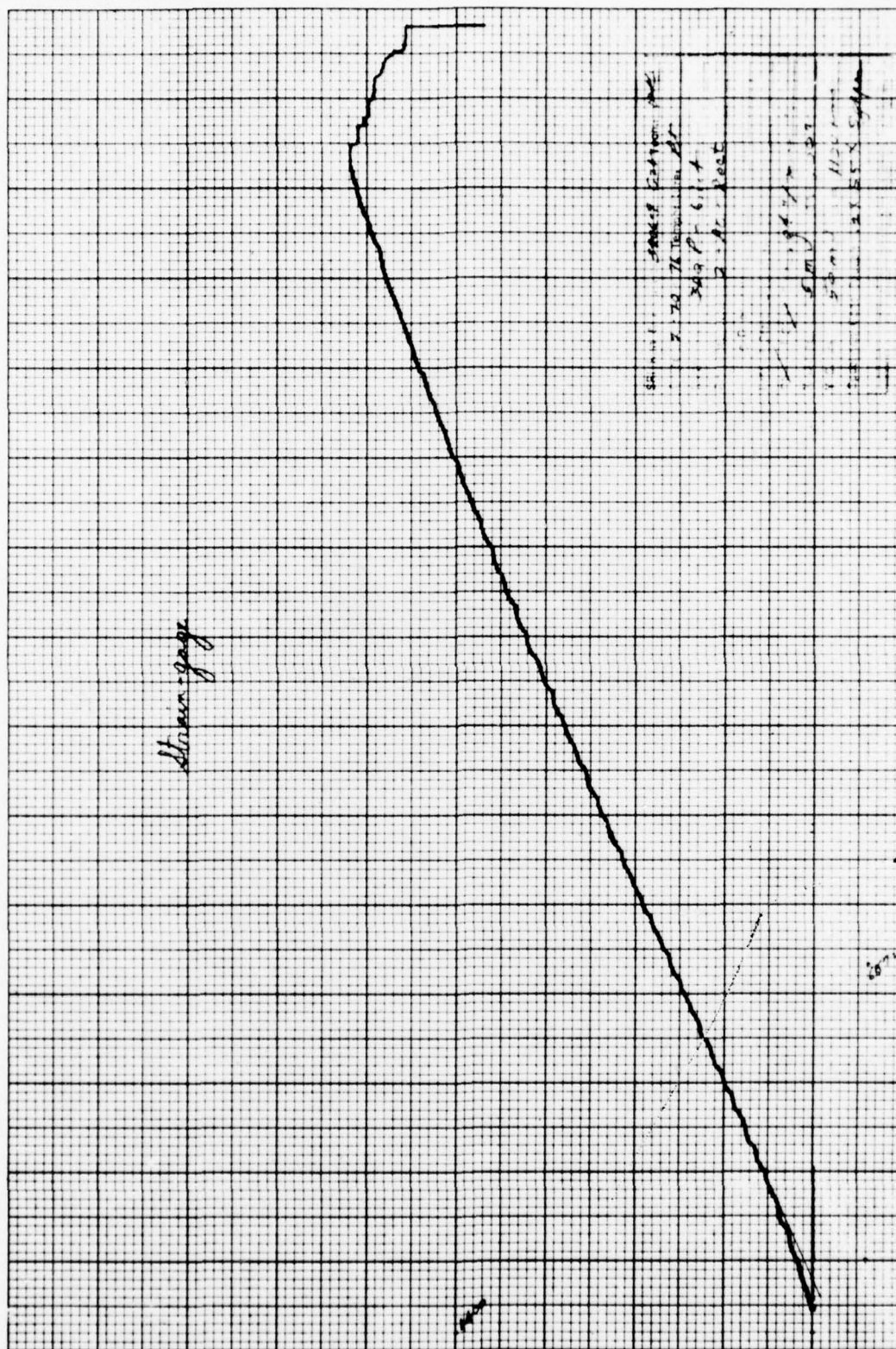
Figure A.11. Test Results for Specimen 12-AC-3081

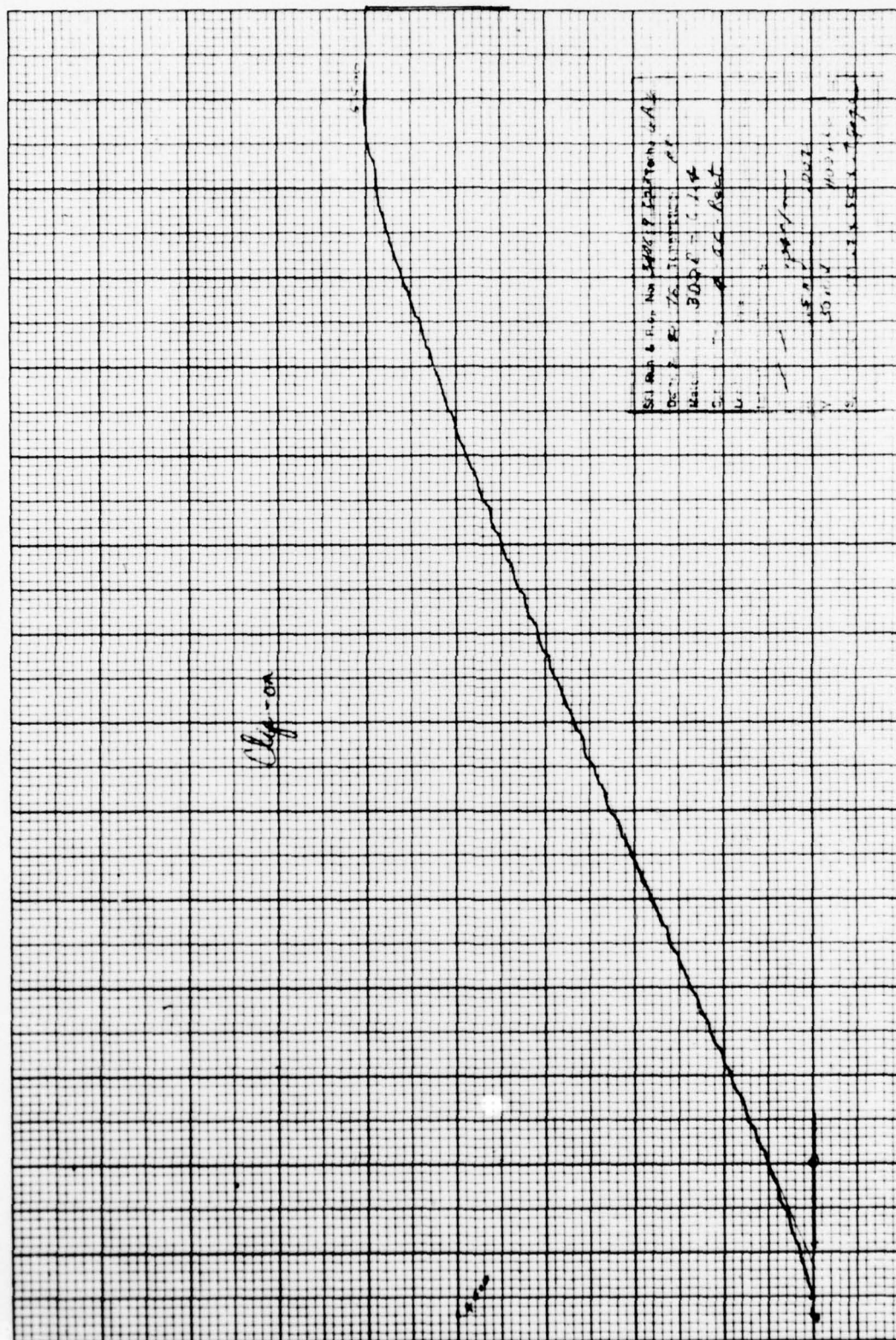
A2

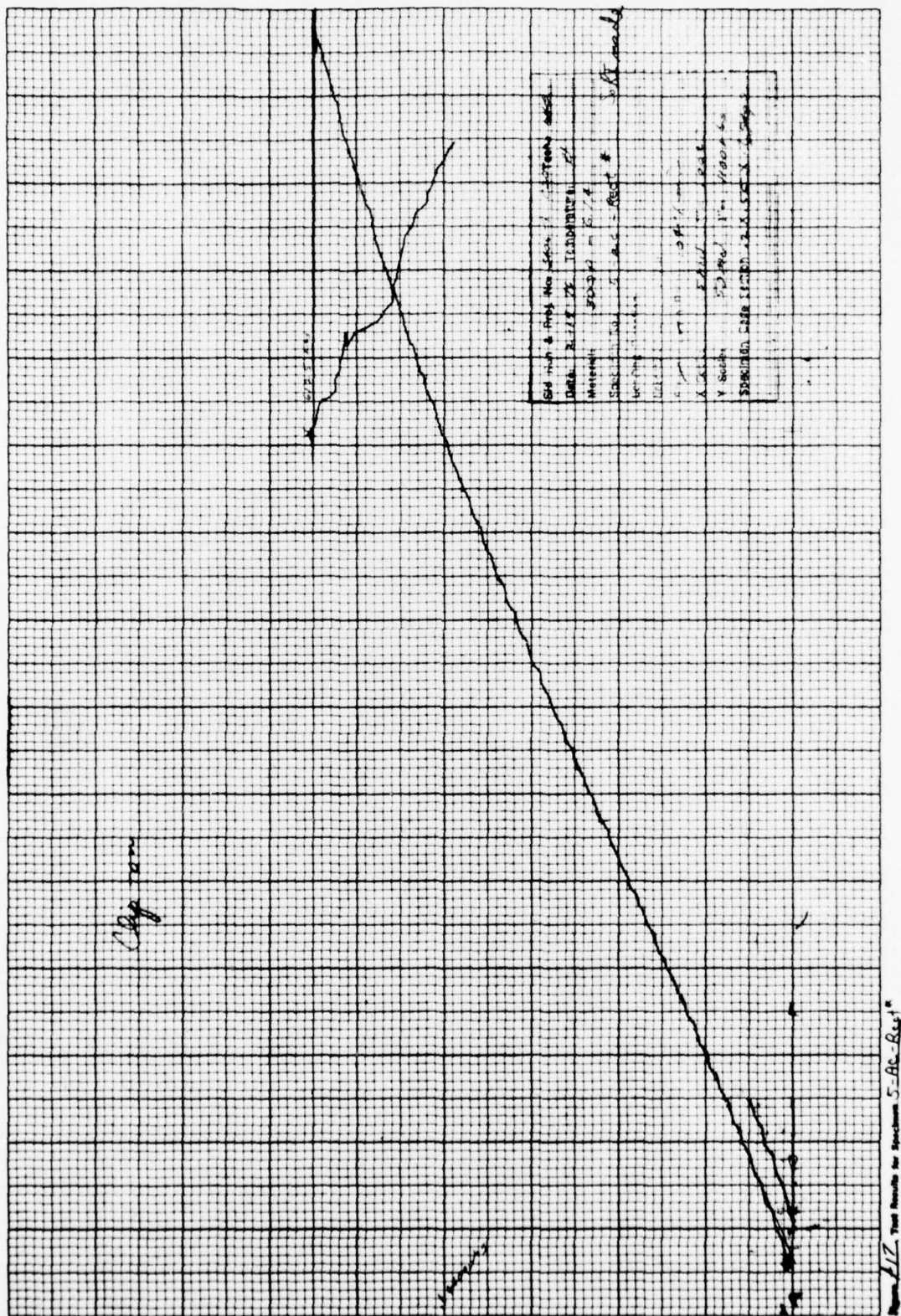
Axial Compressive Tests
Rectangular Specimen Configuration

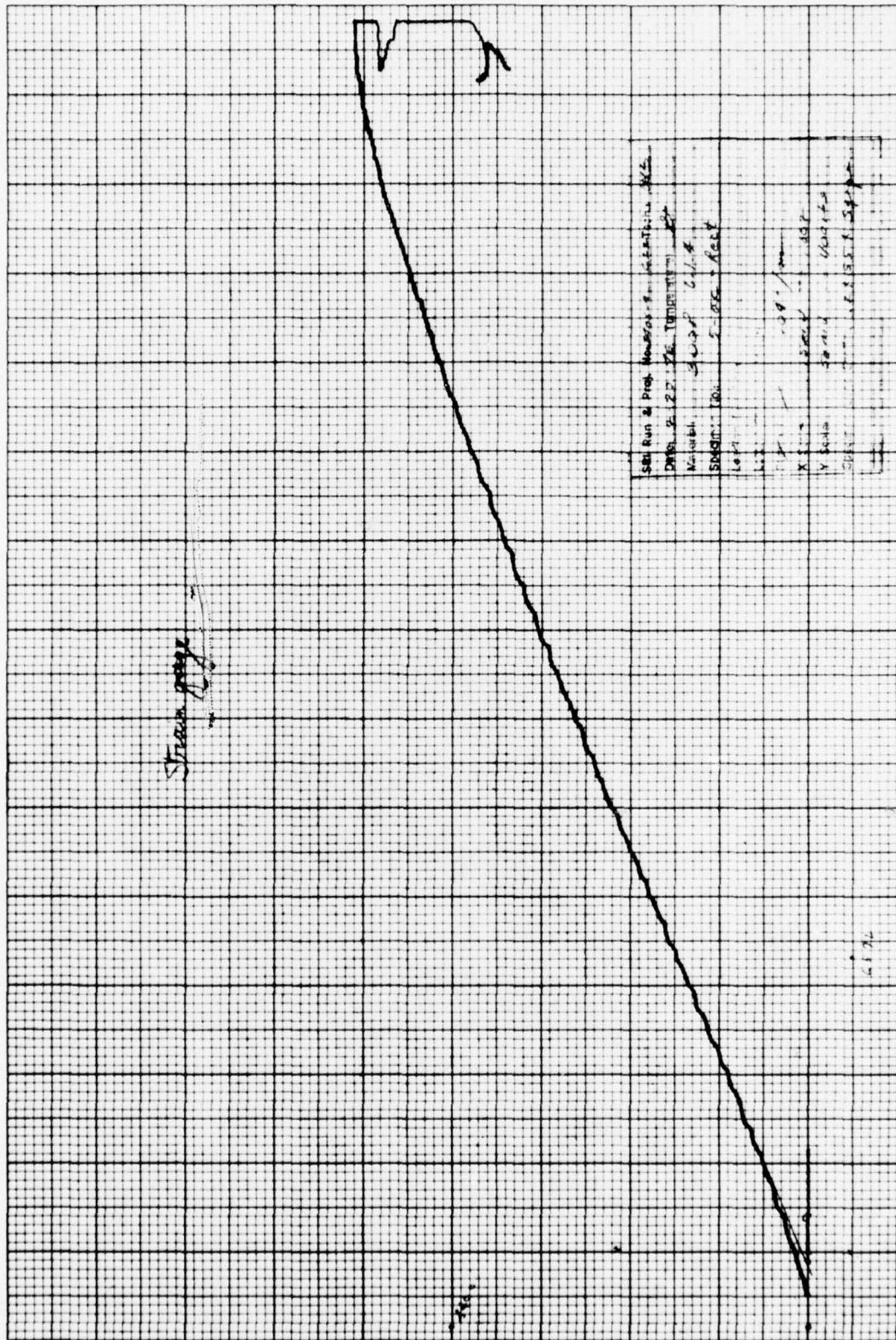
6.1.4

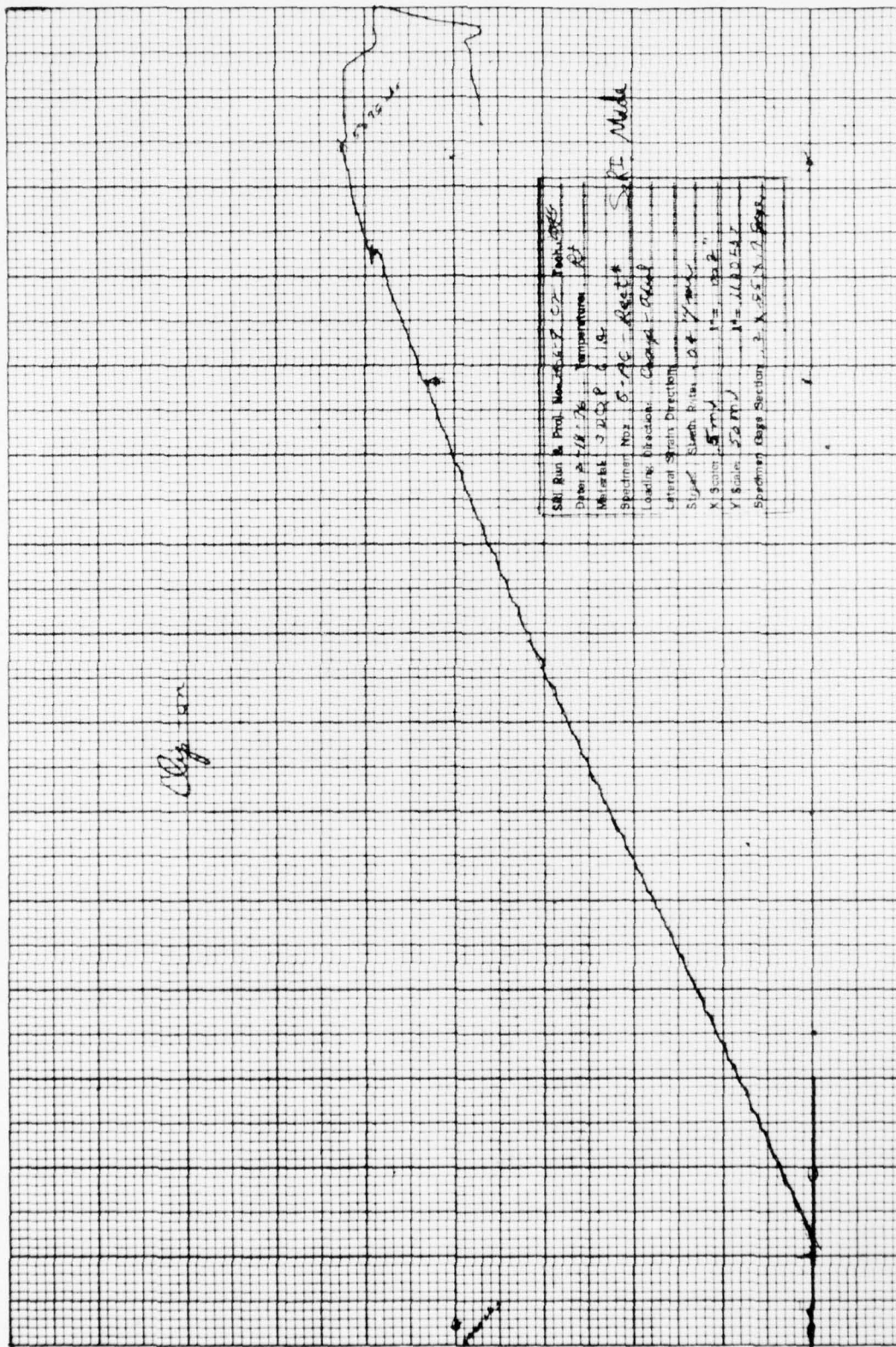




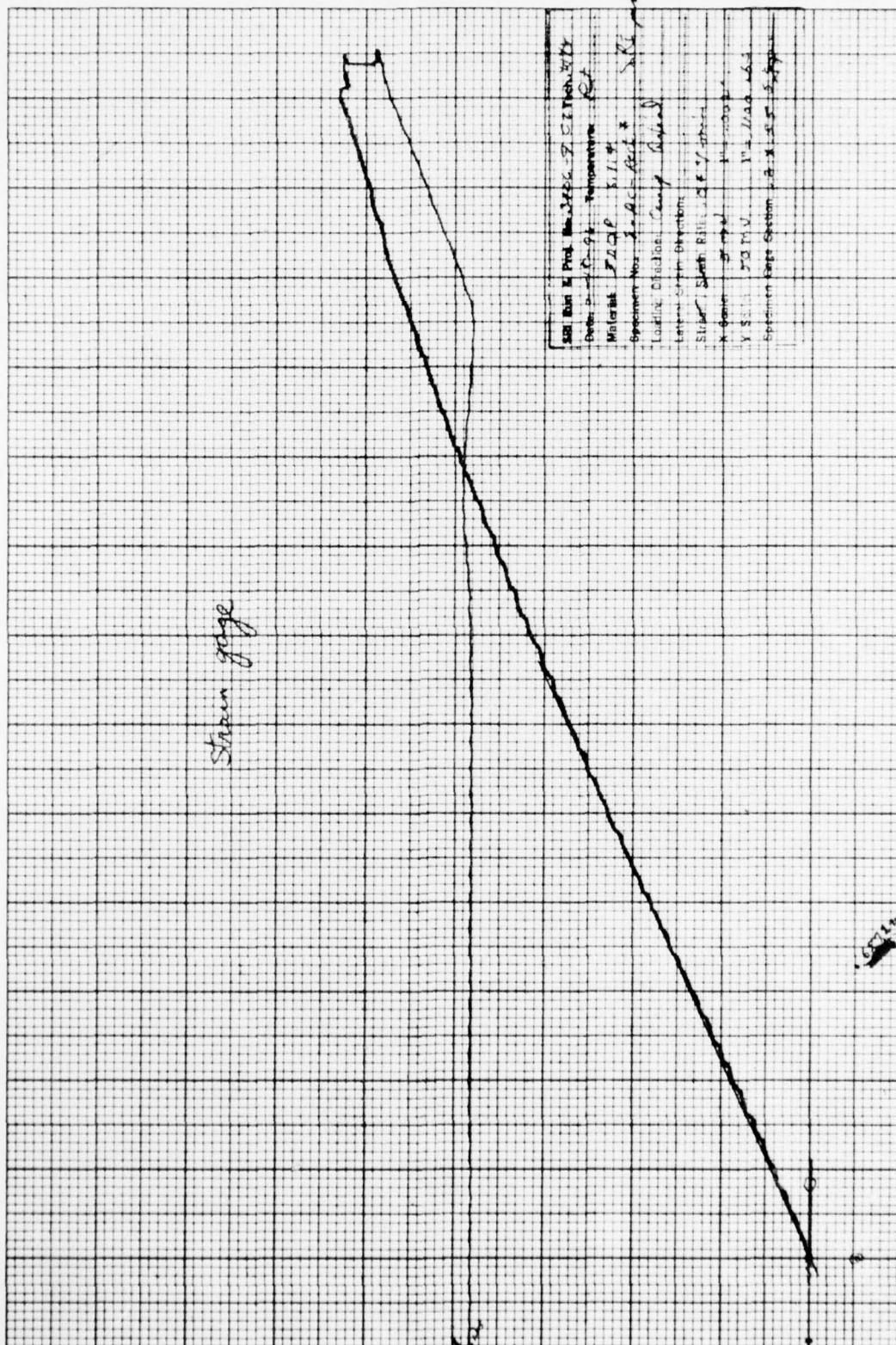






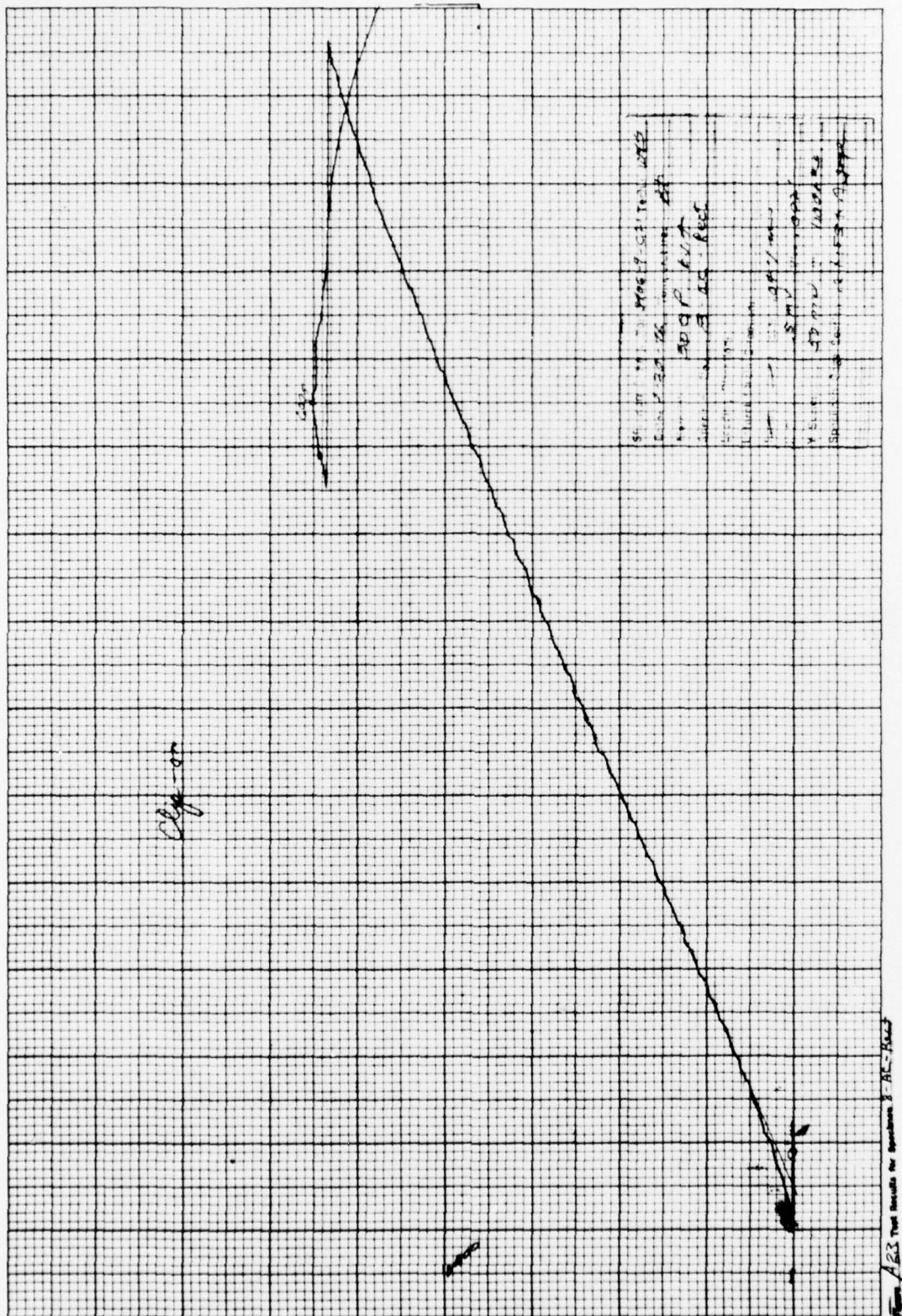


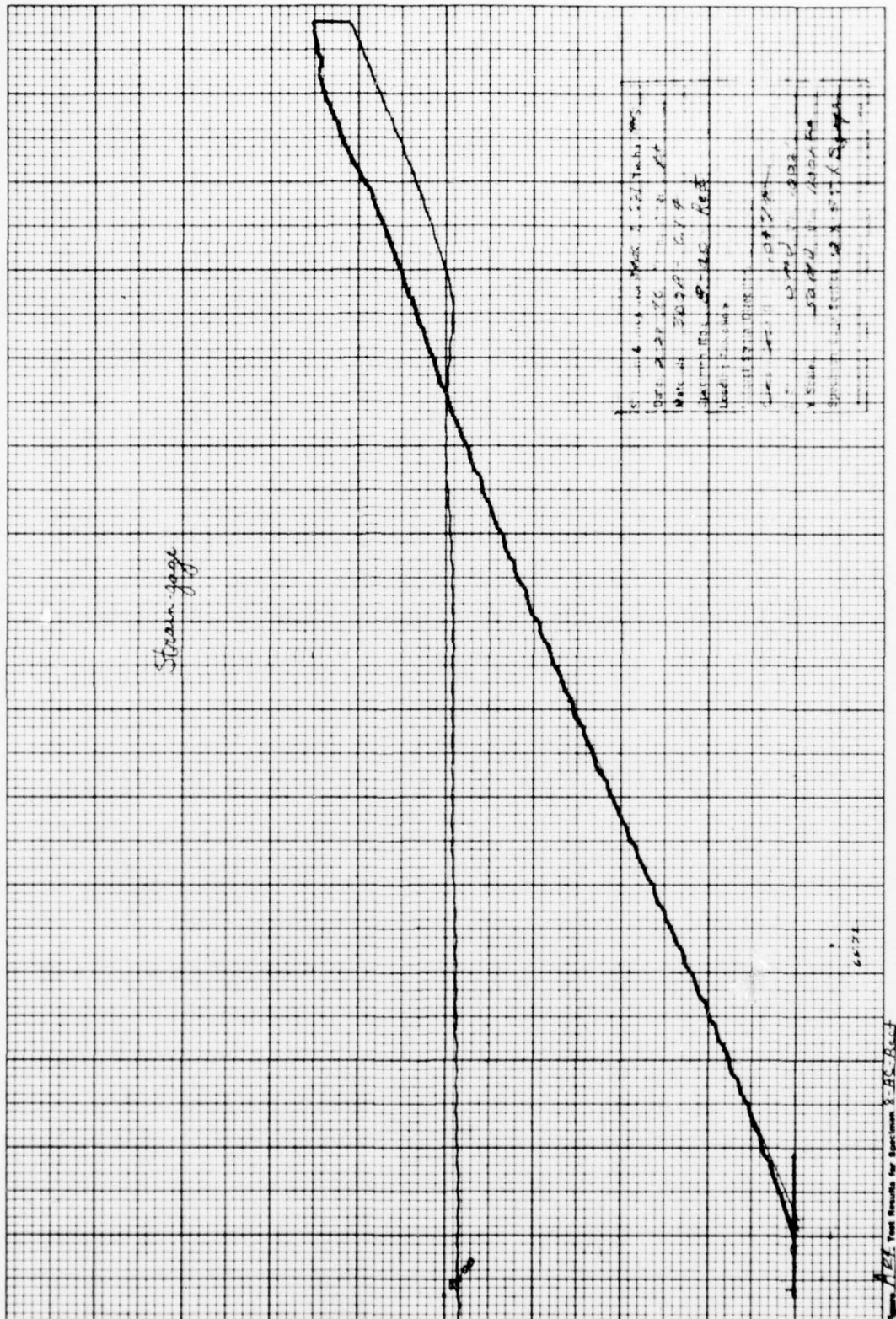
ABE. Test results for specimens 8-AC-86a-f



Soil Run # 100, Run 244, 7 11 1968, 100
 Date 7-11-68, Temperature 80
 Material 244P, 11.9
 Specimen No. 244P-100, 11.9
 Loading Condition, Comp. Direct
 Failure, Strain, Displacement
 Strain, Displacement, 11.9, 11.9
 X-axis, 11.9, 11.9
 Y-axis, 11.9, 11.9
 Specimen Test Section, 11.9, 11.9

Figure 1.23 Test Results for Specimen 244P-100

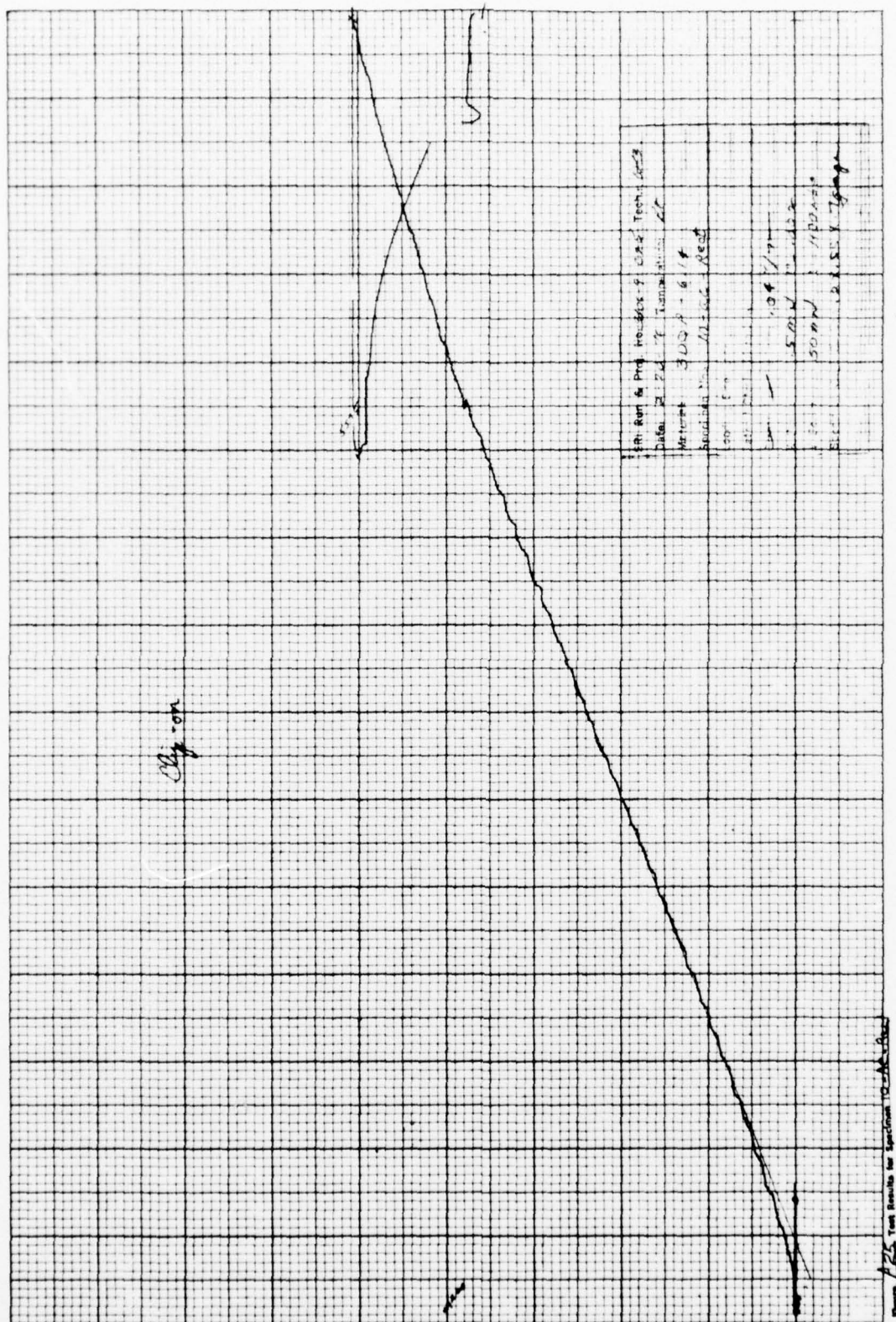


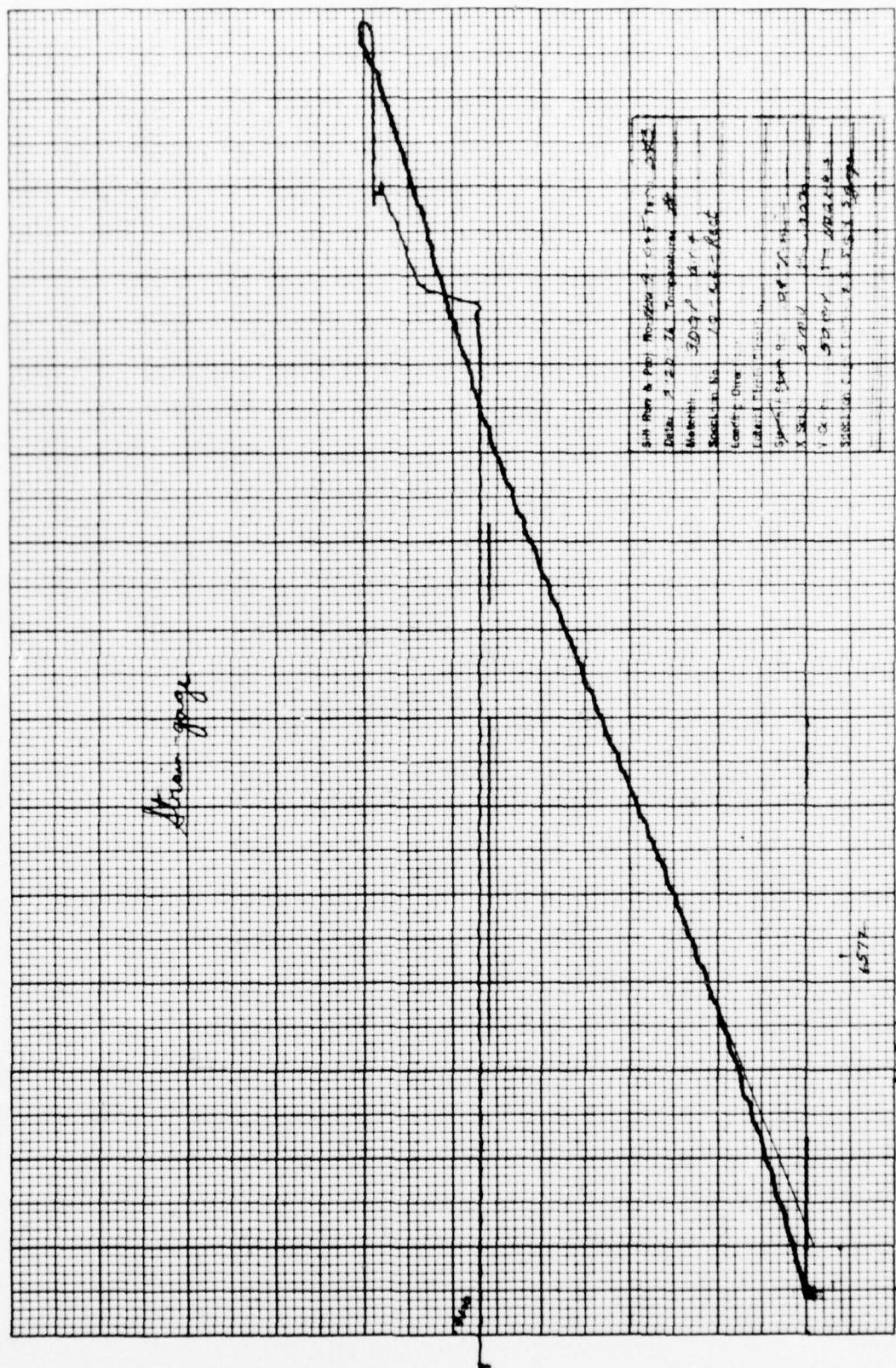


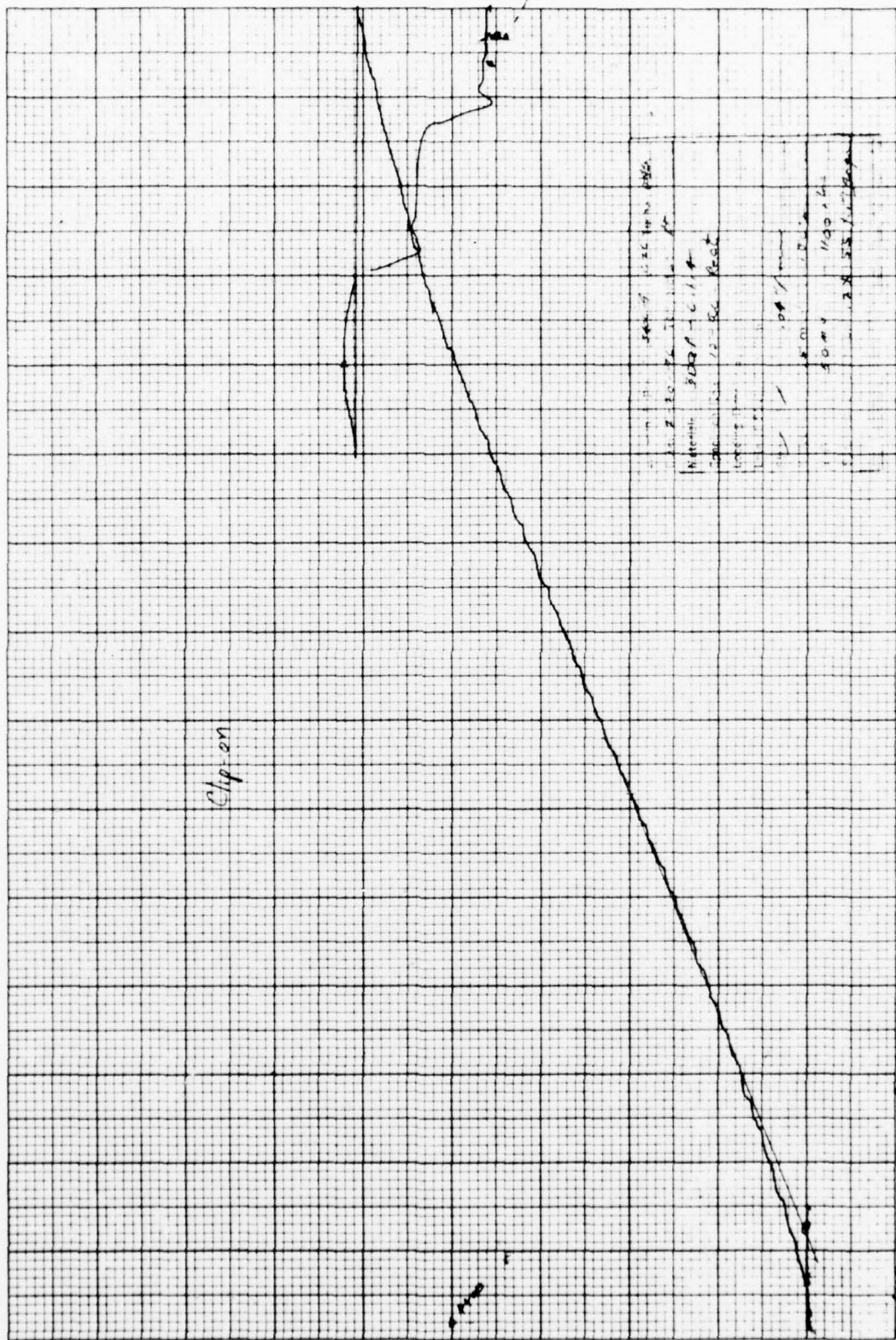
Stream flow

DATE	6-10-68	TIME	10:00 AM
LOCATION	STATION 10+00		
WATER	10.00		
WIND	10.00		
TEMP	10.00		
REL. HUM.	10.00		
WIND DIR.	10.00		
WIND S.P.	10.00		
WIND V.	10.00		
WIND D.	10.00		
WIND F.	10.00		
WIND G.	10.00		
WIND H.	10.00		
WIND I.	10.00		
WIND J.	10.00		
WIND K.	10.00		
WIND L.	10.00		
WIND M.	10.00		
WIND N.	10.00		
WIND O.	10.00		
WIND P.	10.00		
WIND Q.	10.00		
WIND R.	10.00		
WIND S.	10.00		
WIND T.	10.00		
WIND U.	10.00		
WIND V.	10.00		
WIND W.	10.00		
WIND X.	10.00		
WIND Y.	10.00		
WIND Z.	10.00		

Figure 1. Test Results for Specimen 8-10-68

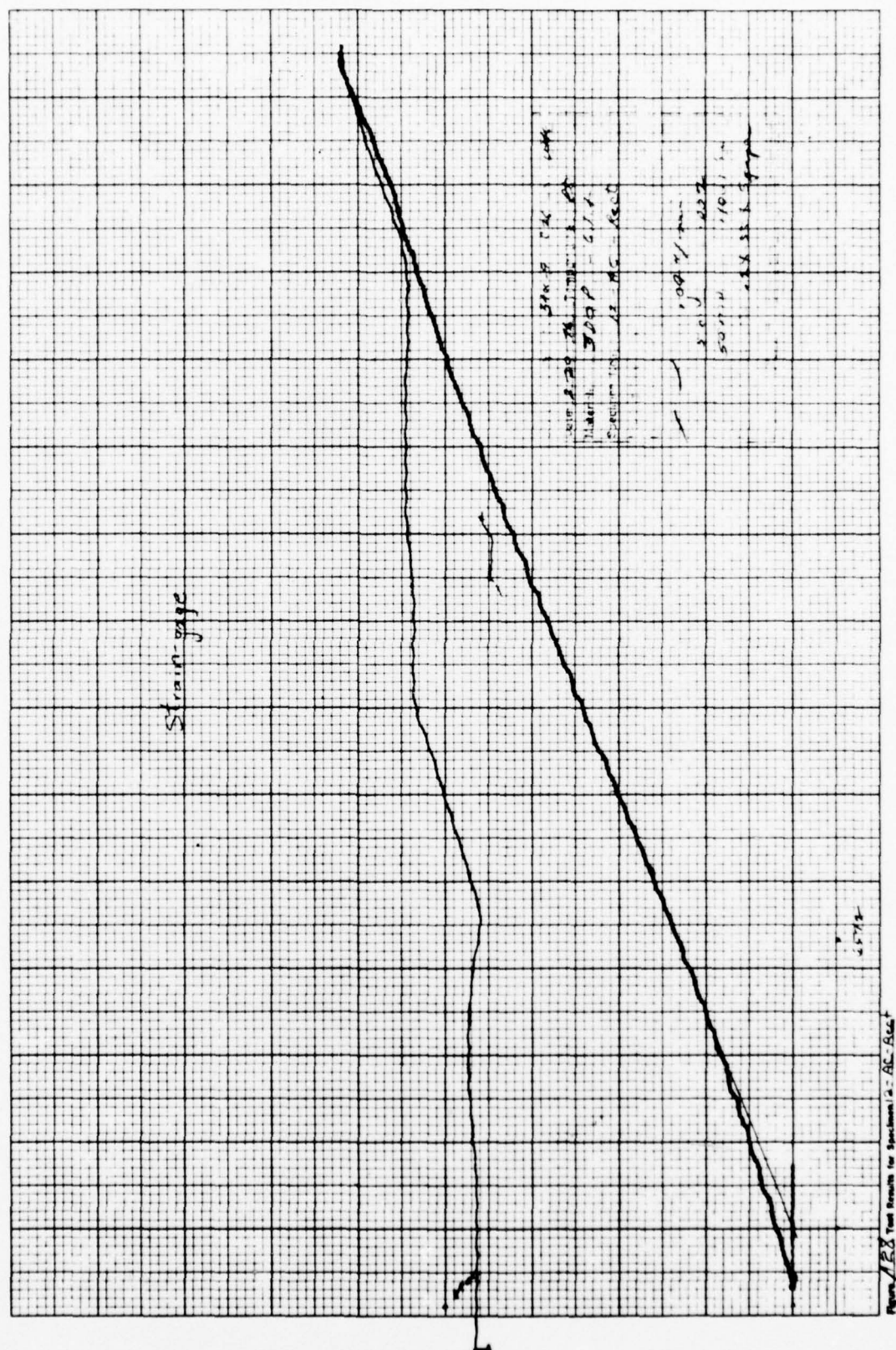






Clip on

From 12.1. That curve for distance 12. AR-Beet



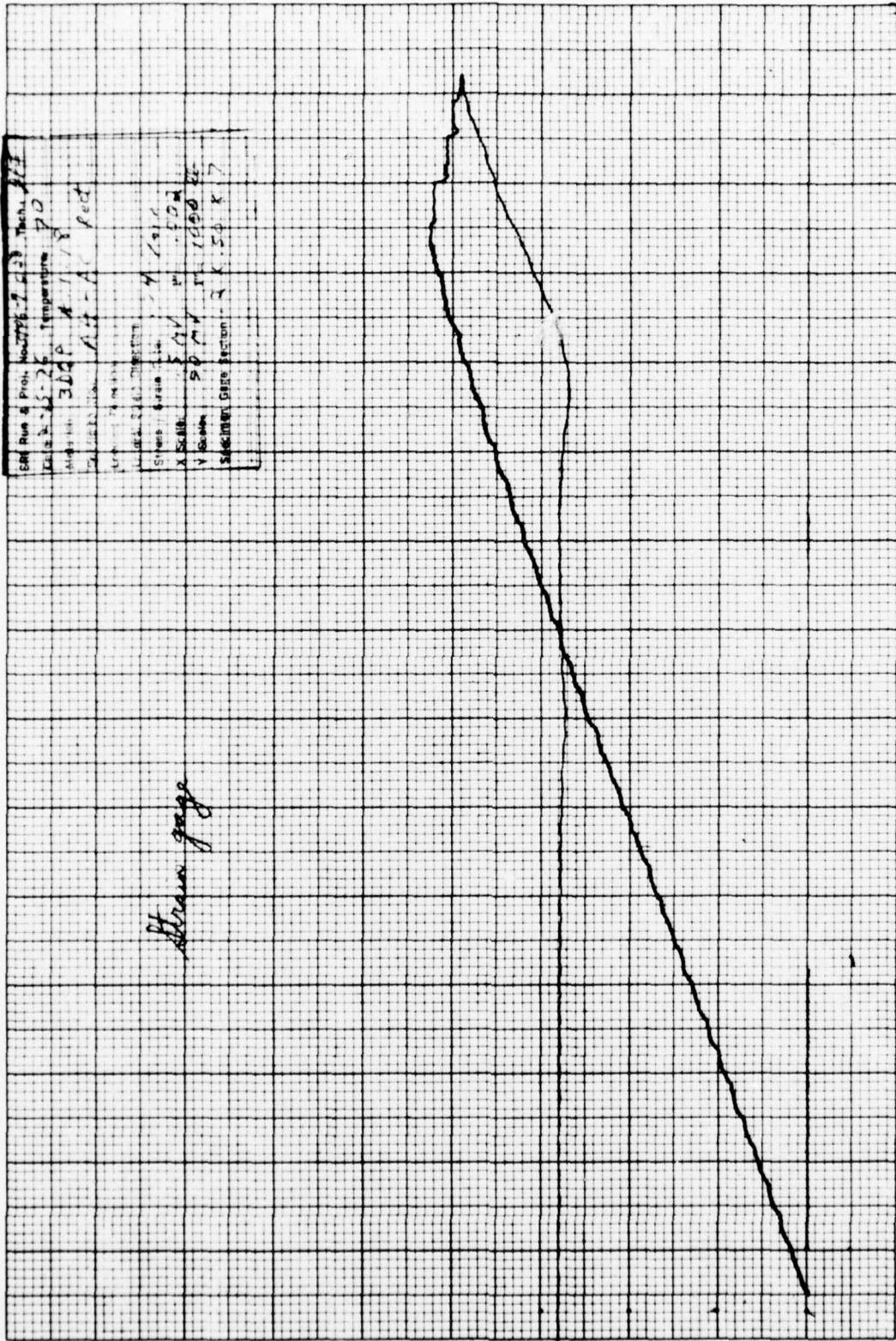
A3

Axial Compressive Tests
Rectangular Specimen Configuration

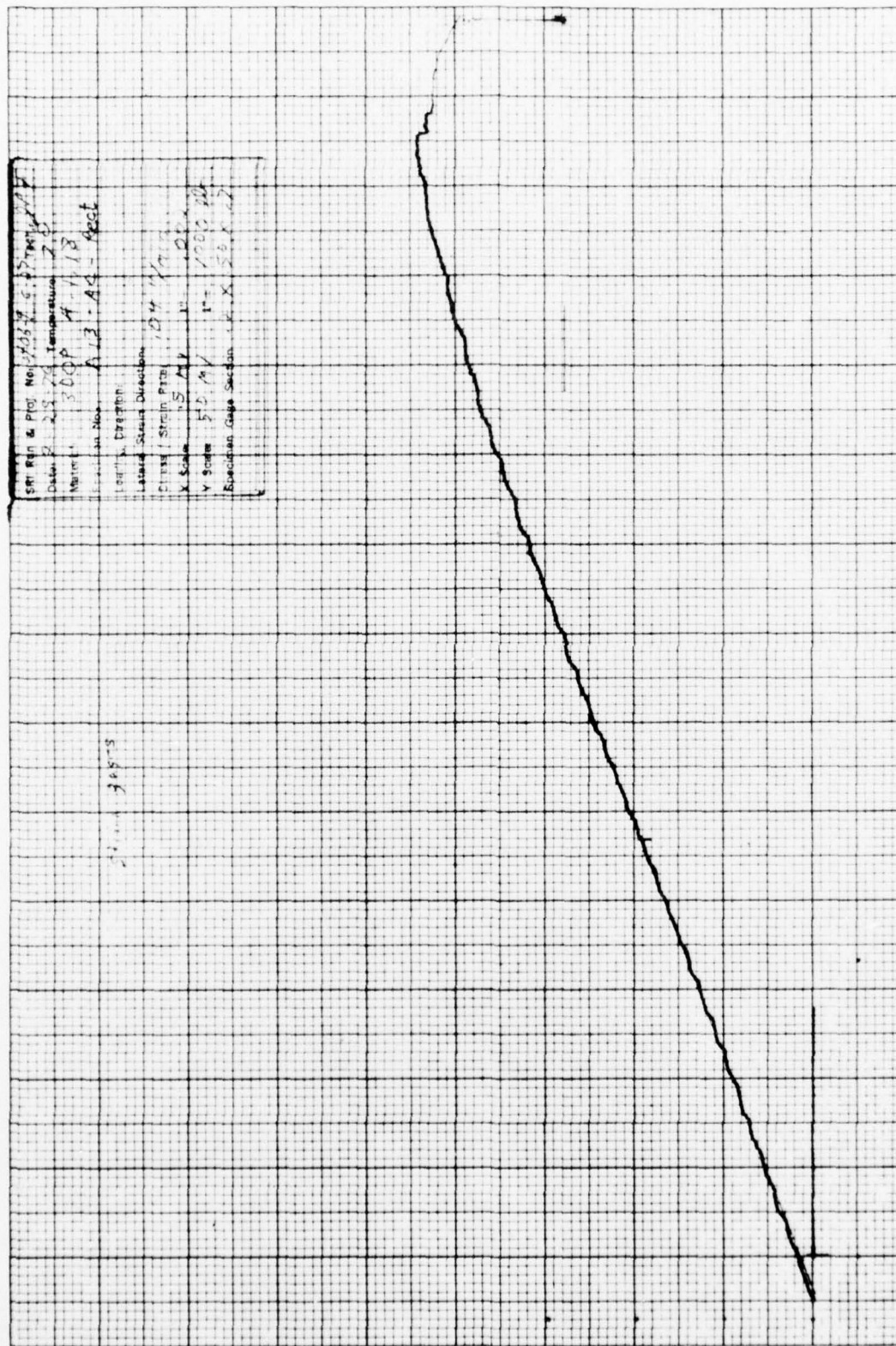
4.1.18

ESR Run & Print Number	2523	Tech.	413
Lot #	25-26	Temperature	70
Analysis	300P	41/18	
Section	11-1	11-1	11-1
Specimen	11-1	11-1	11-1
Specimen Date	11-1	11-1	11-1
Specimen Date Section	11-1	11-1	11-1

Strain gauge



ASD Test Results for Specimen A4-AQ-Bect



SPT Pen & Plot No. 2406
 Date 2-13-74
 Name 300P
 Location A.32-Rect
 Log No. 104
 Latent Sound Direction
 First / Strain Pile 104
 X Scale 5.0
 Y Scale 5.0
 Residual Gauge Section 104

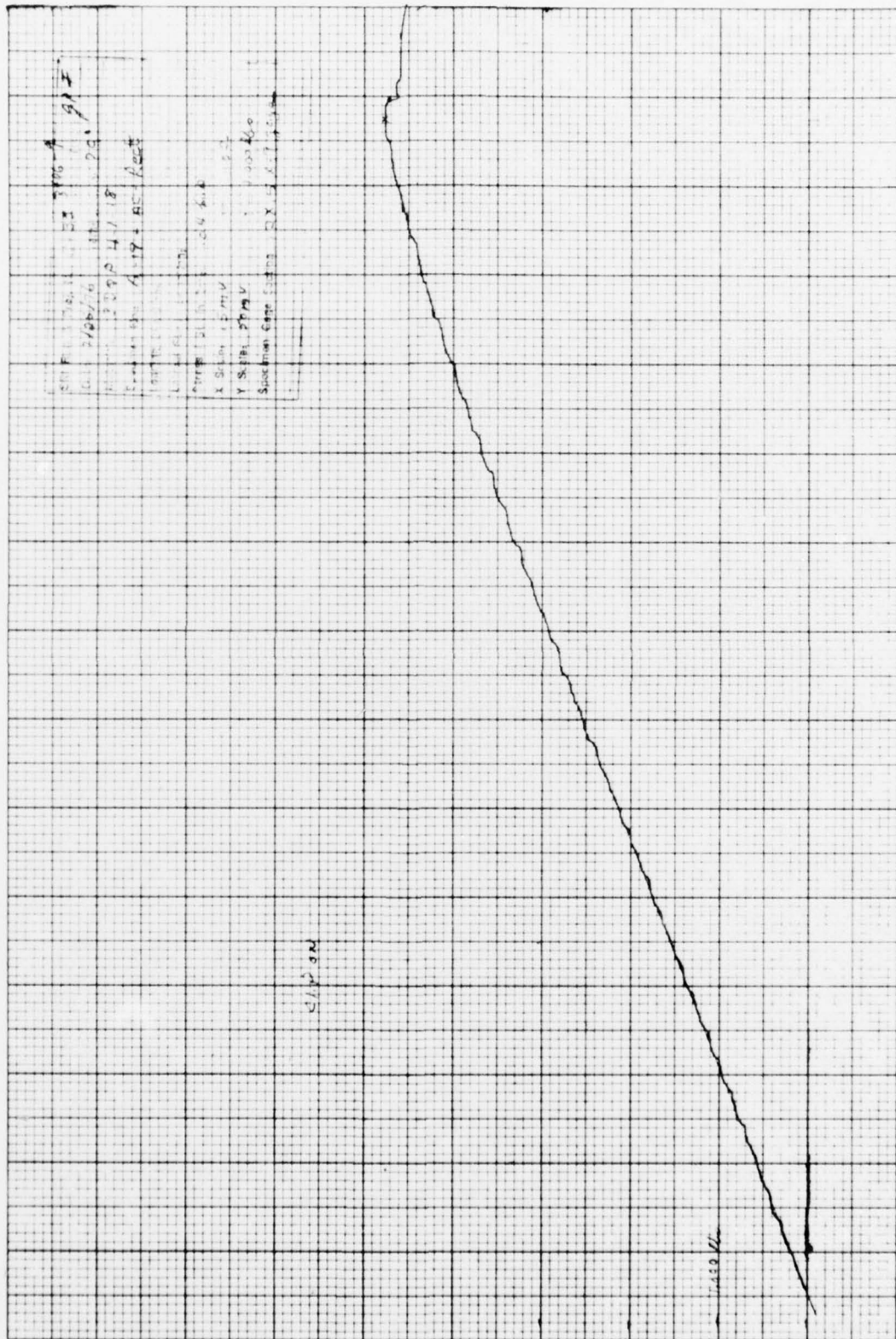
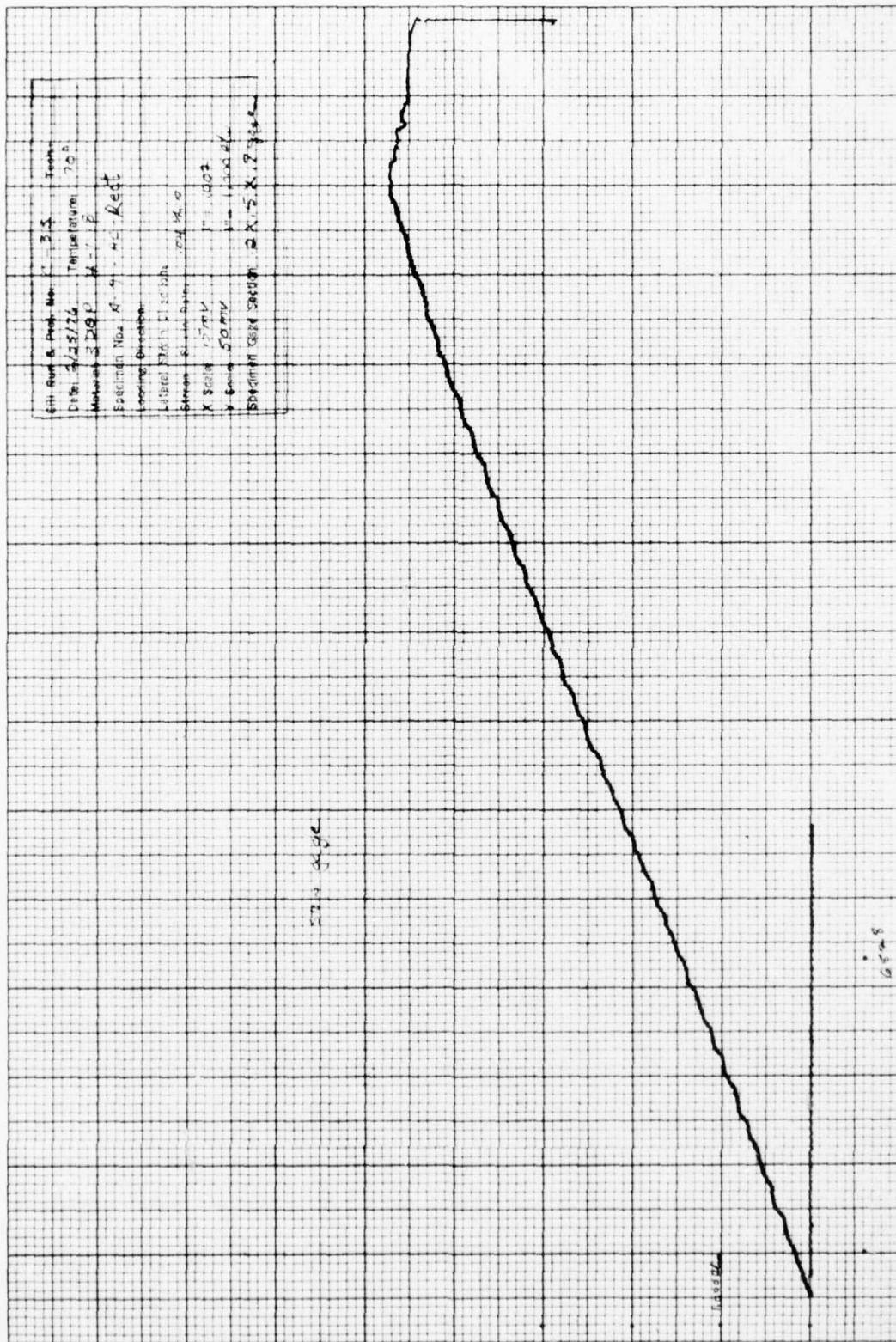
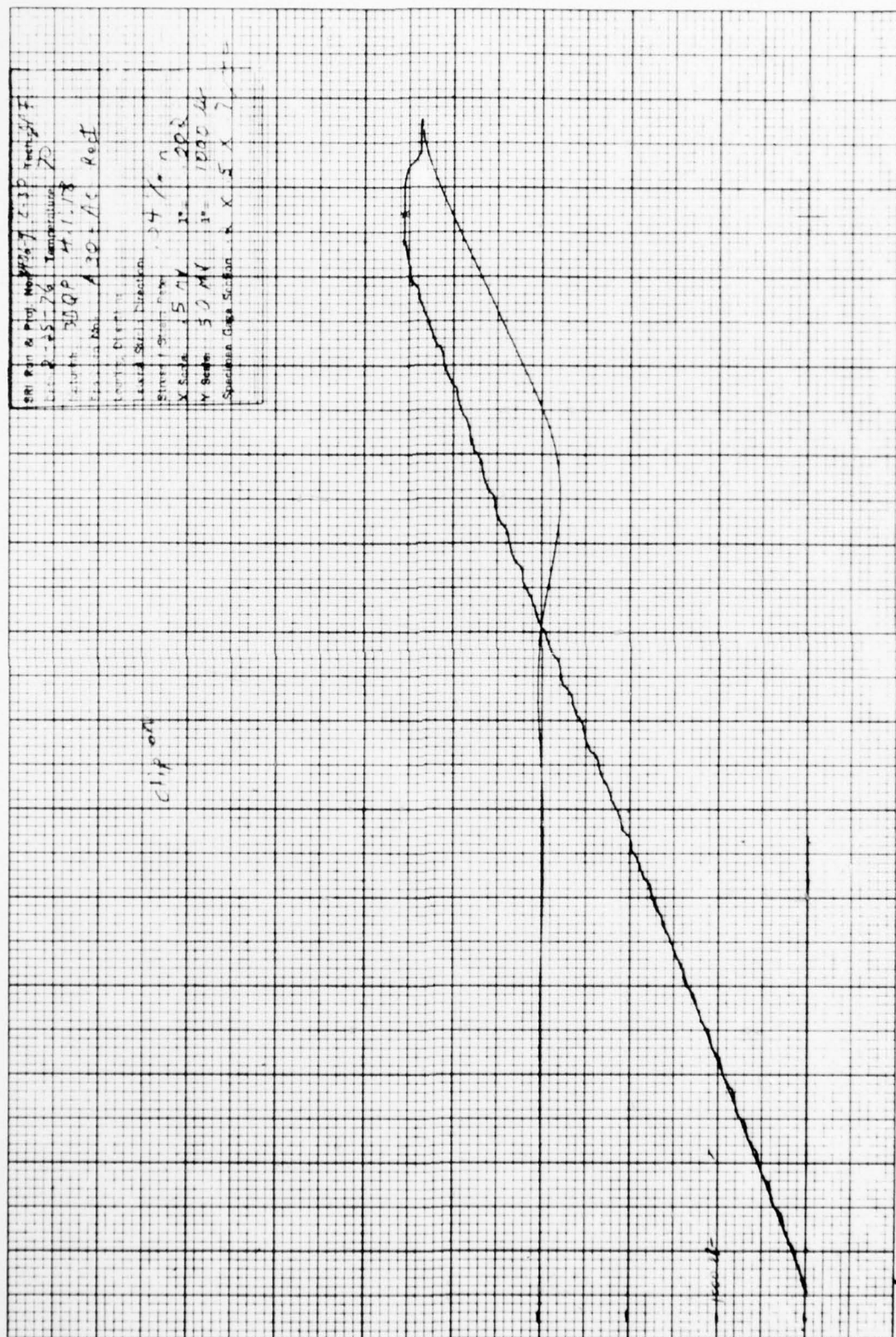


Figure A-33 Test Results for Specimen A-19-A-C-Rect





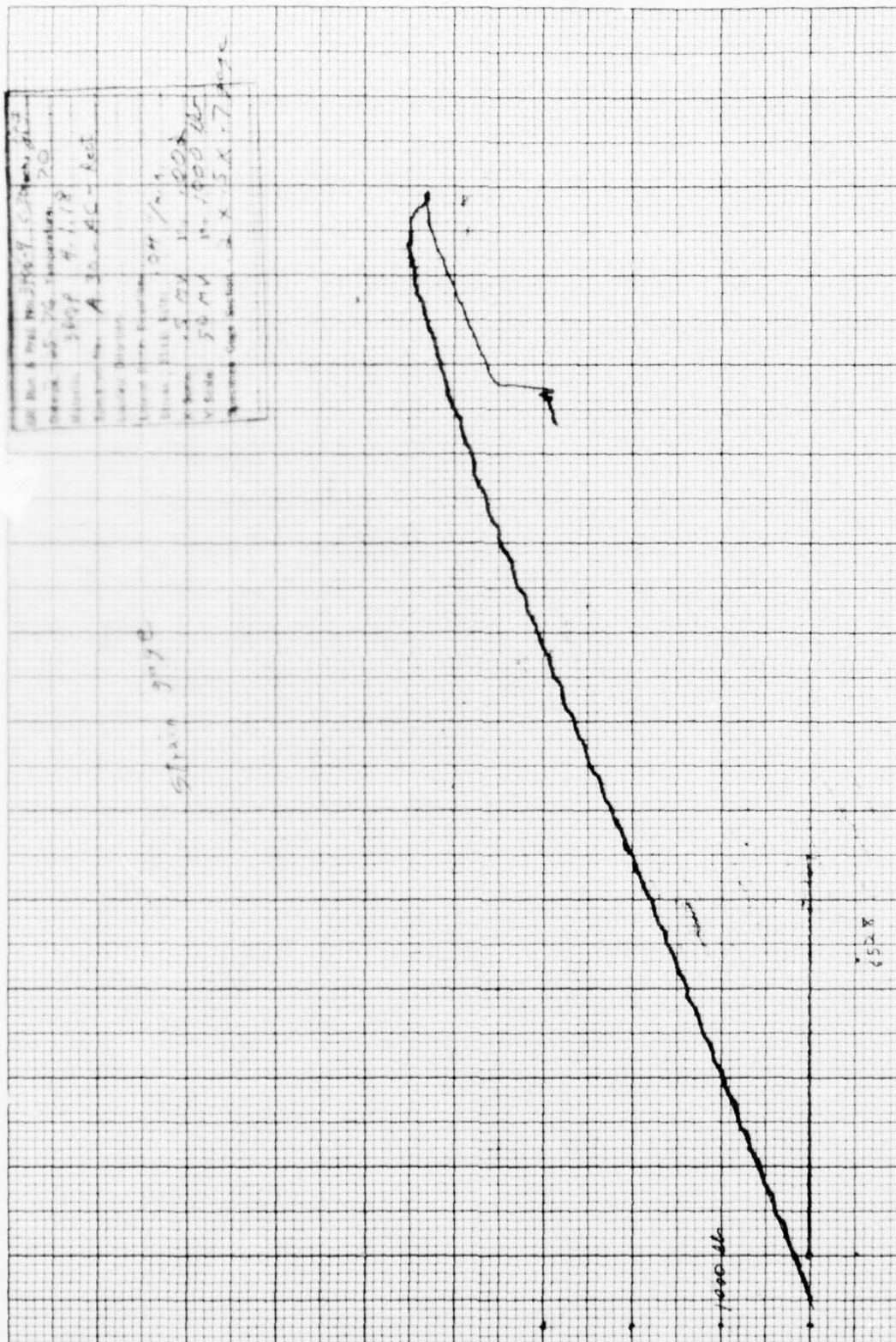
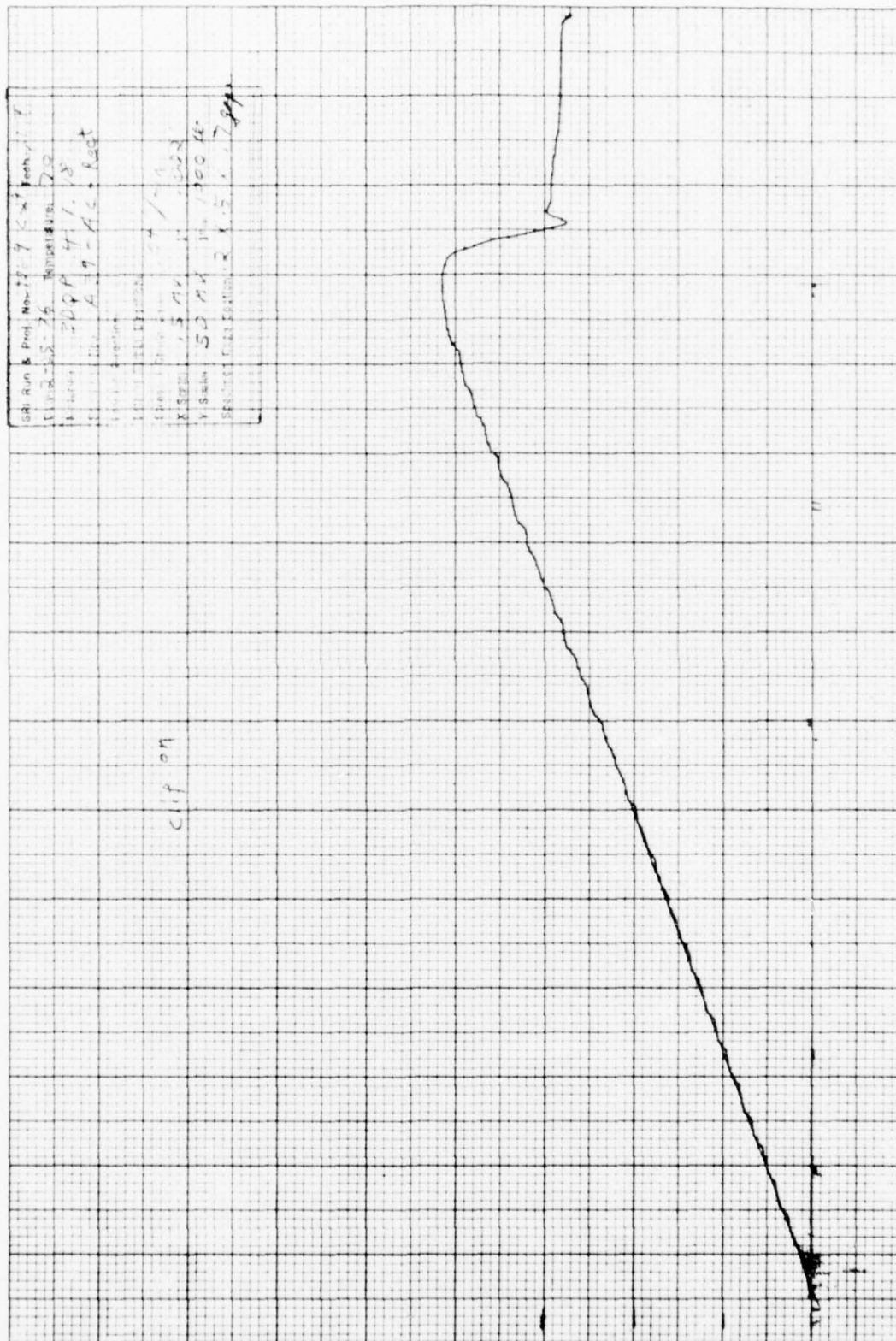


Figure 1. Test Results for Specimen A30-AC-Rect



Run A37 Plot Results for Specimen A39-AC-Rect

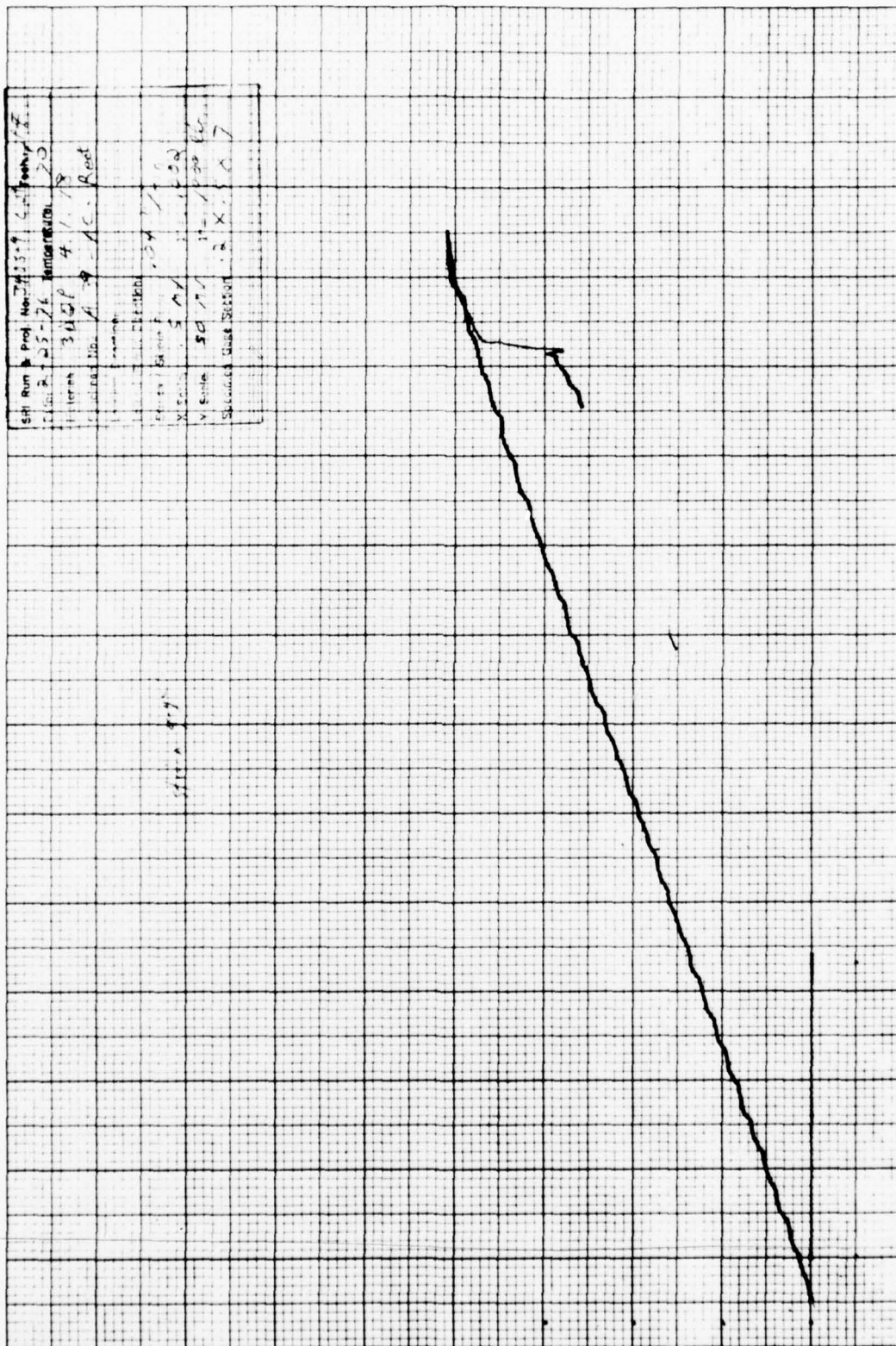
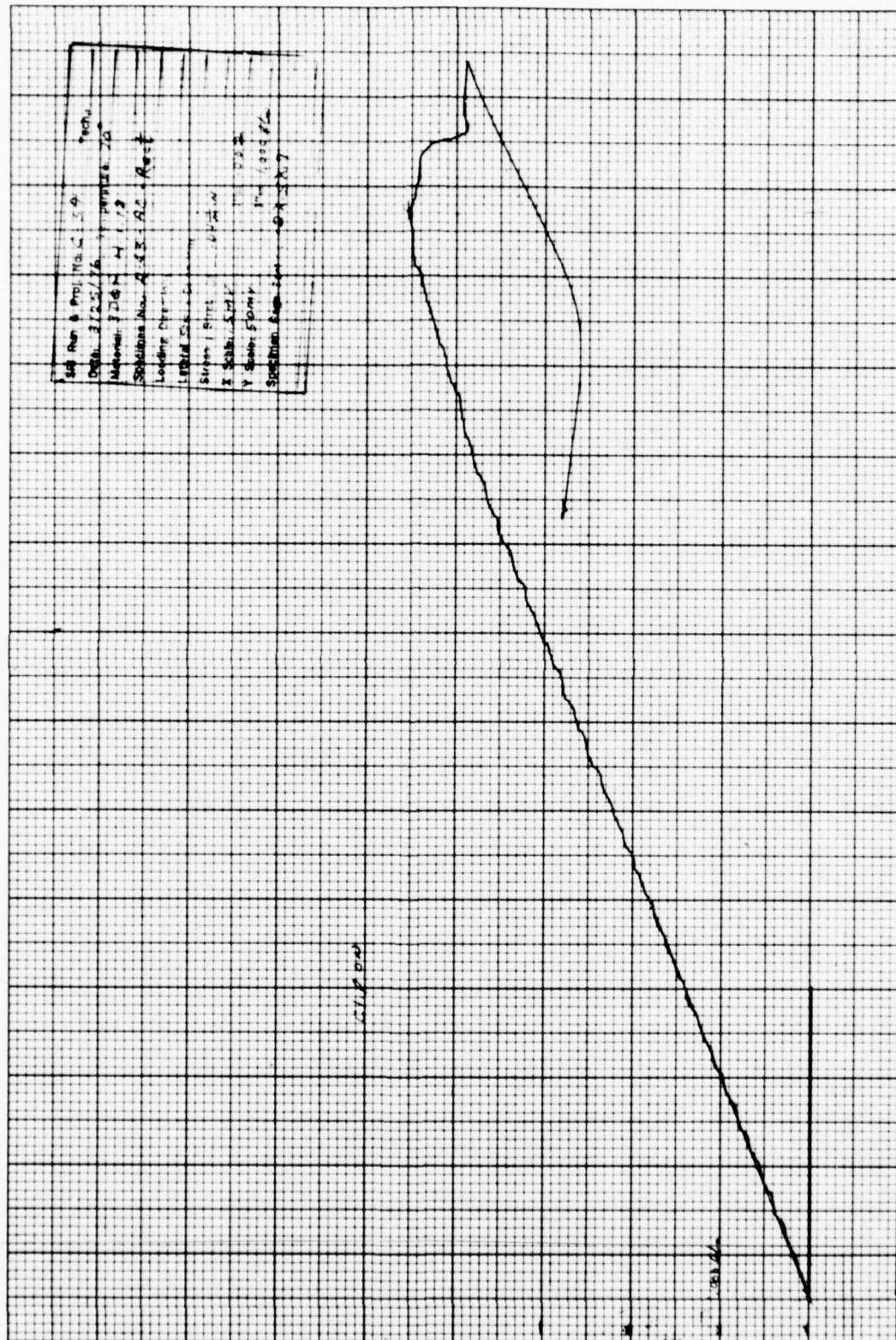
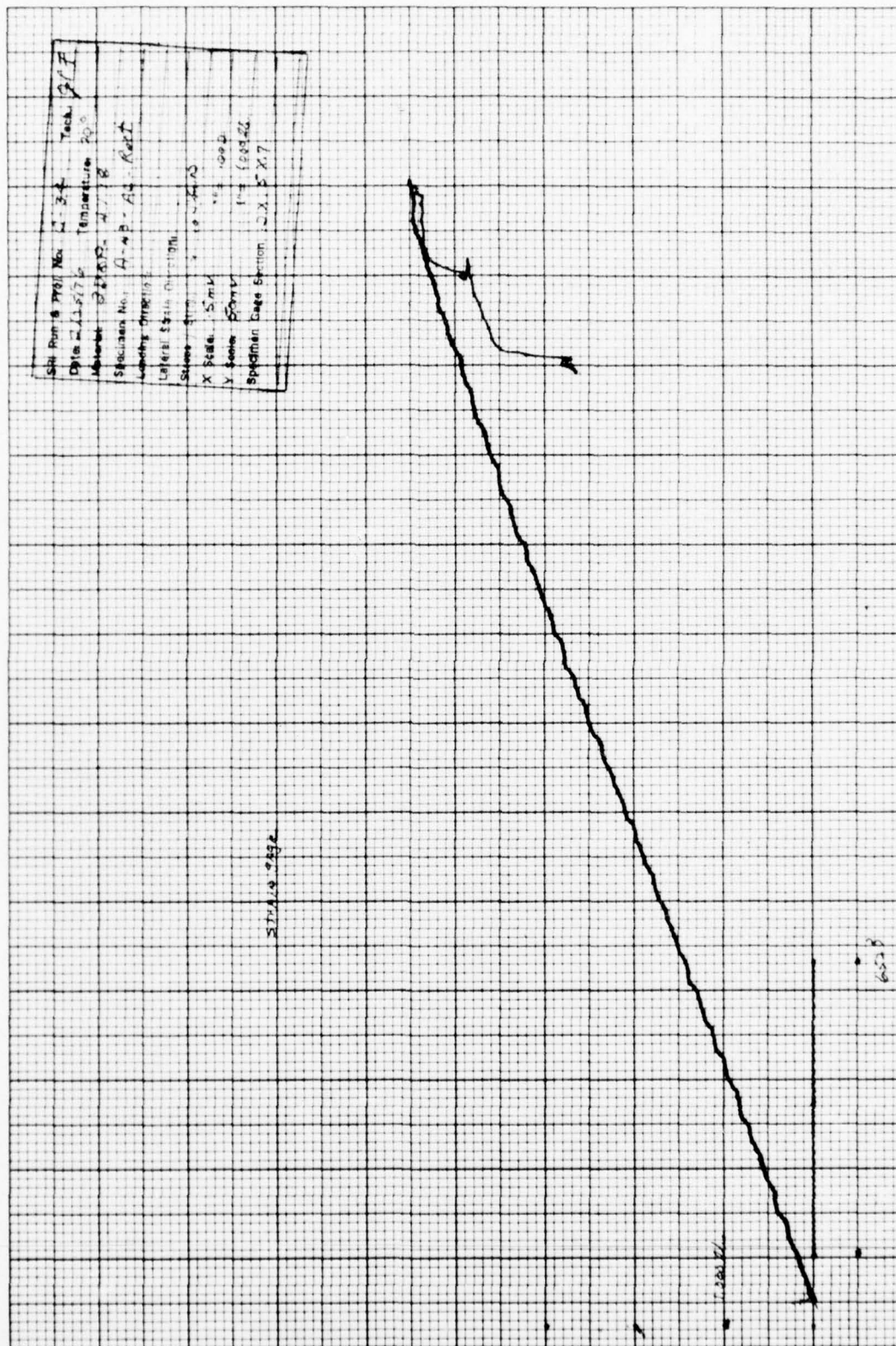


Figure 15.8. Test Results for Specimen AS9-AC-Aect



CLIP 000



Soil Profile No. 1-3-4
 Date 11/17/66
 Location 28855-1-18
 Station No. A-43-AC-Act
 Lateral Station Direction
 X Scale 5m
 Y Scale 5m
 Spodman Base Section 1-1-100-26
 1-1-100-26
 1-1-100-26

A-43-AC-Act
 1-1-100-26

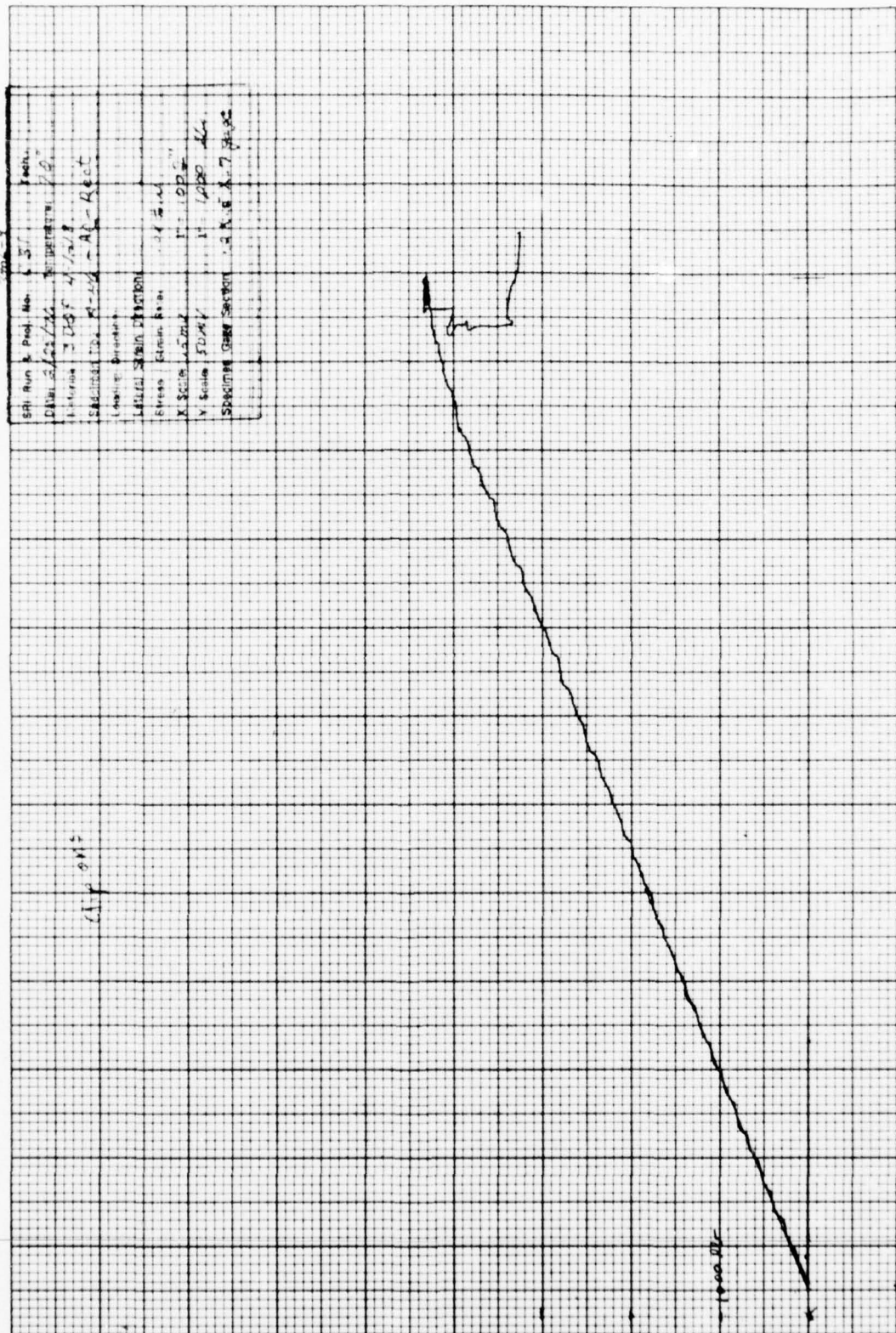
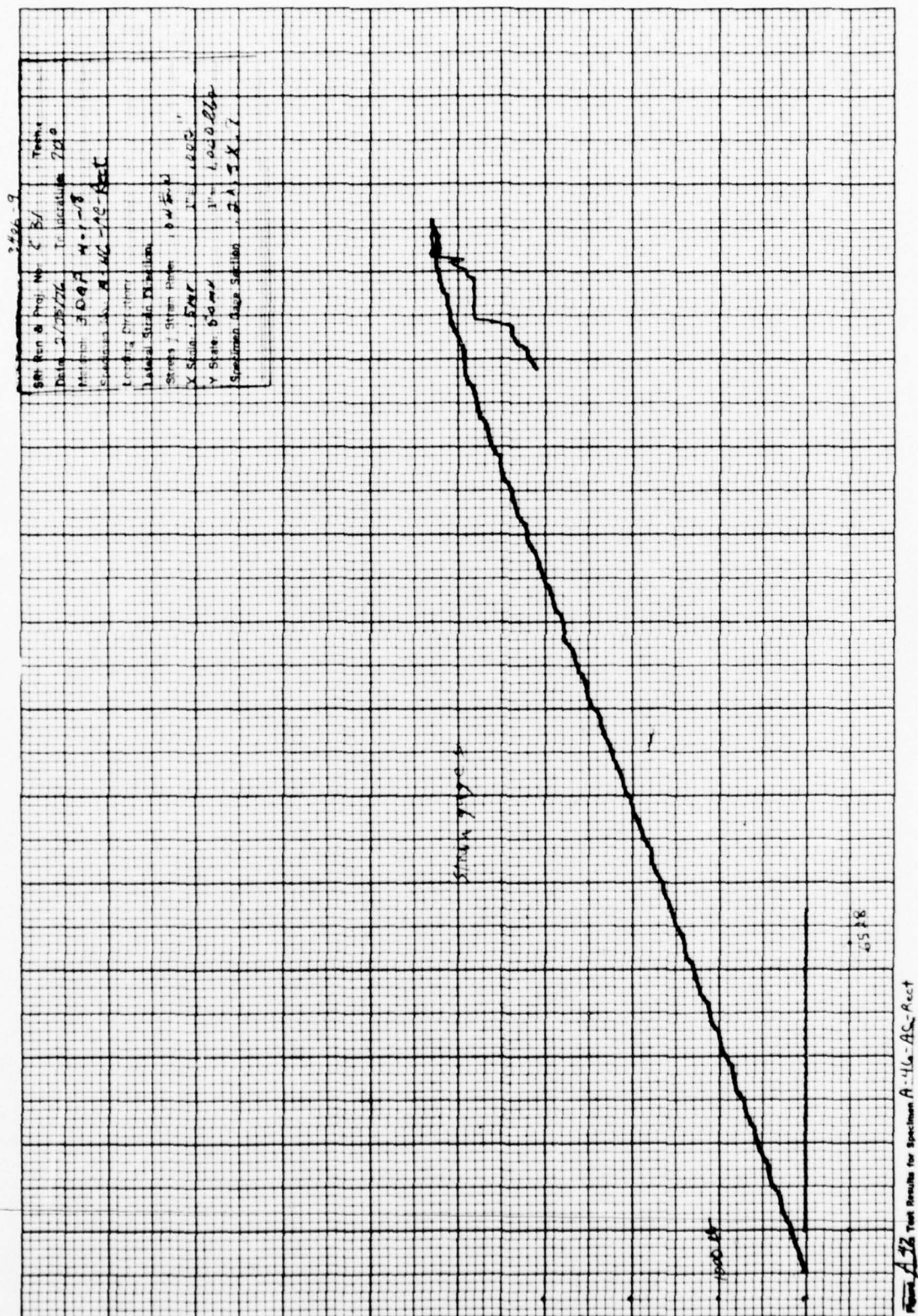
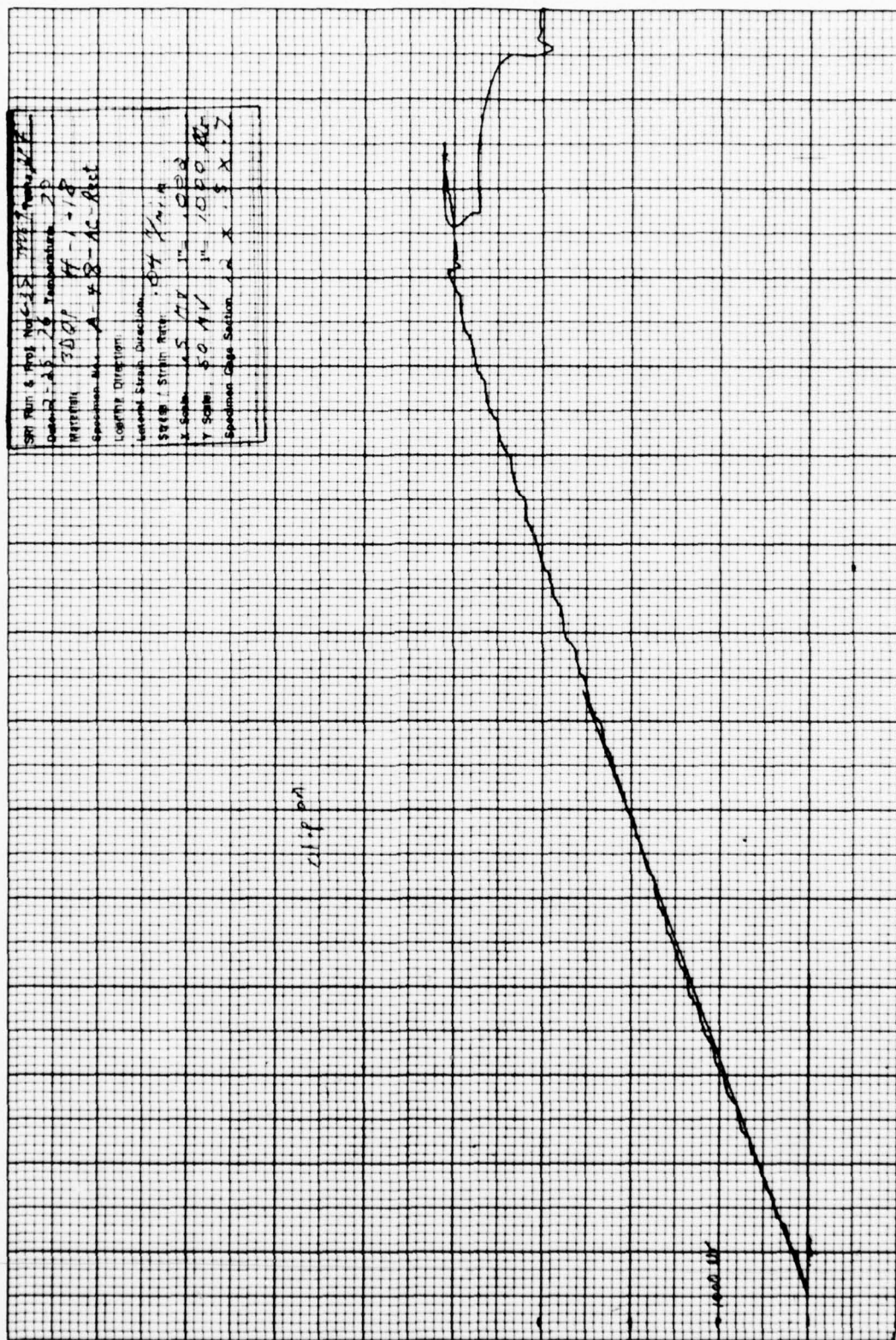
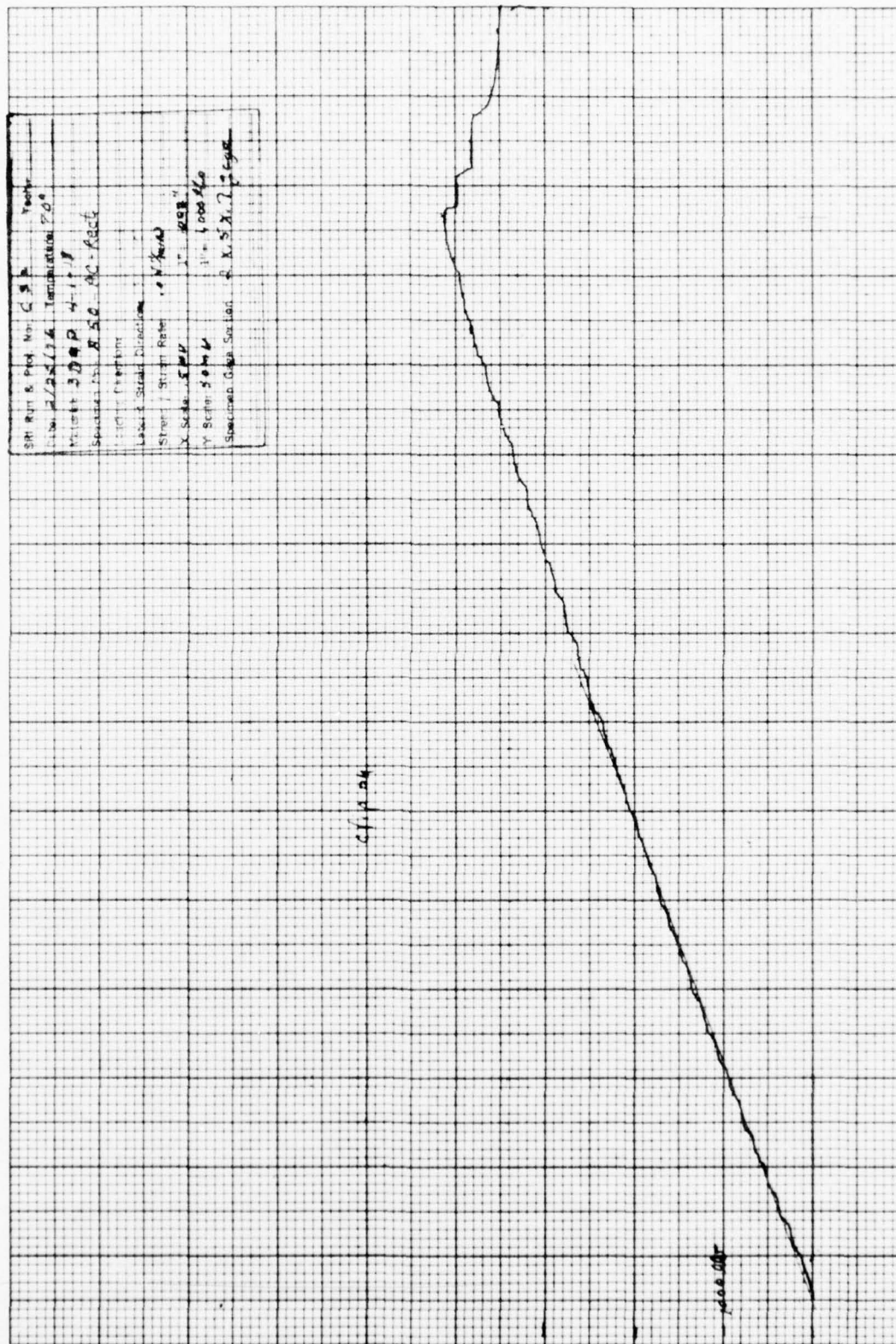


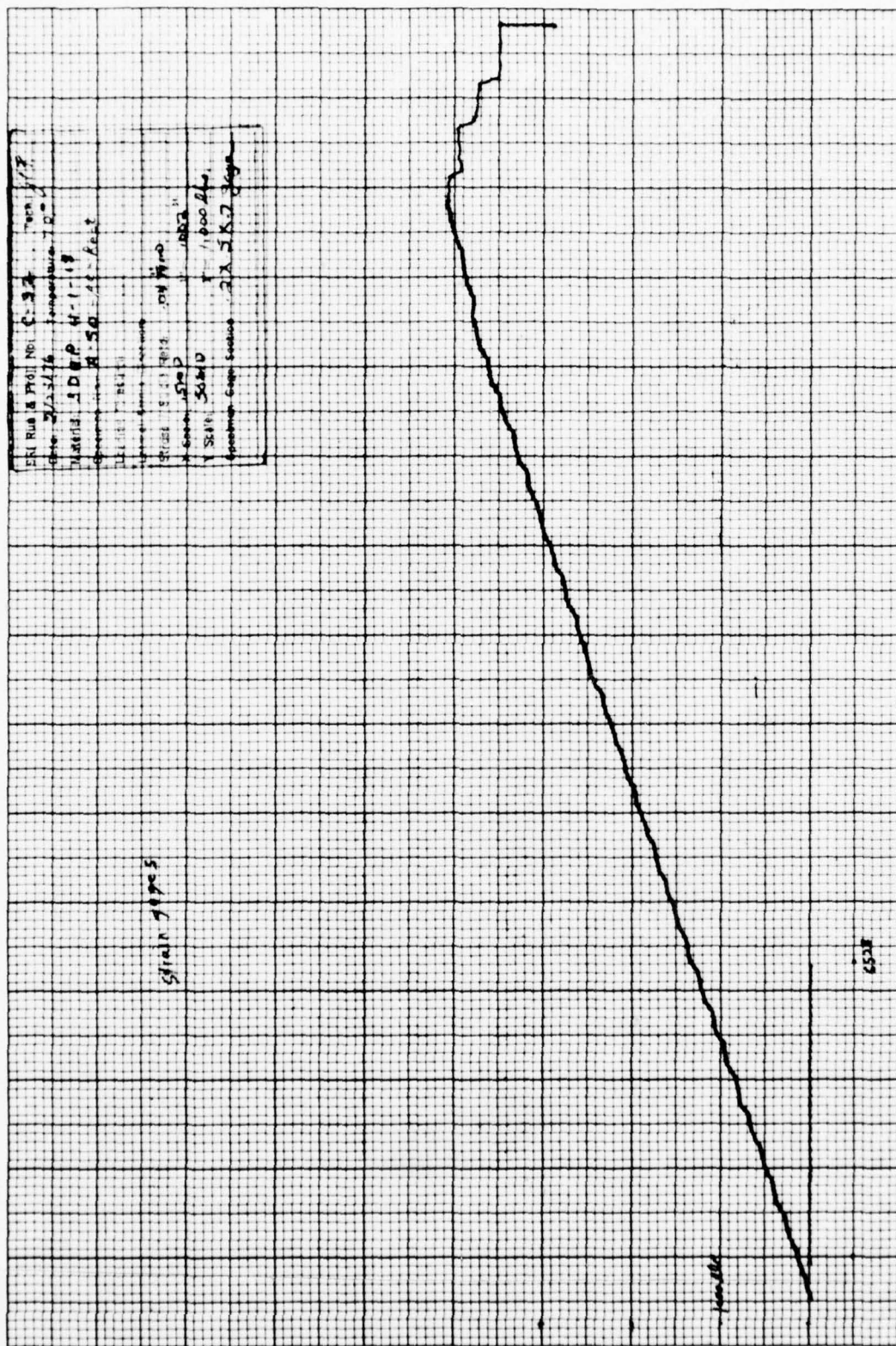
Figure 1. Test Results for Specimen A-46 AC-Rect







Page 195 Test Results for Specimen A50-Ac-Acct



A4

Circumferential Compressive Tests
SoRI Specimen Configuration

6.1.4

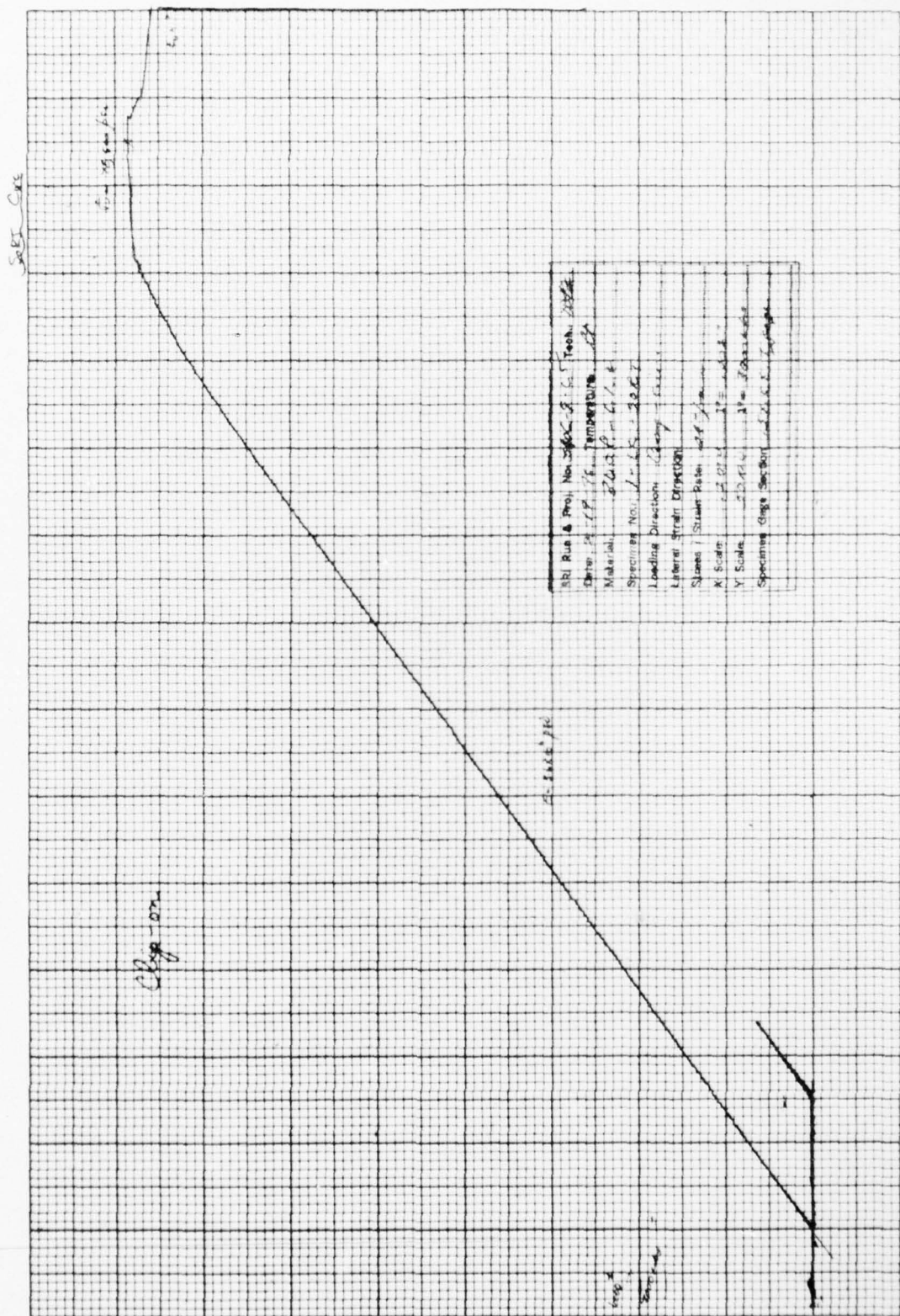
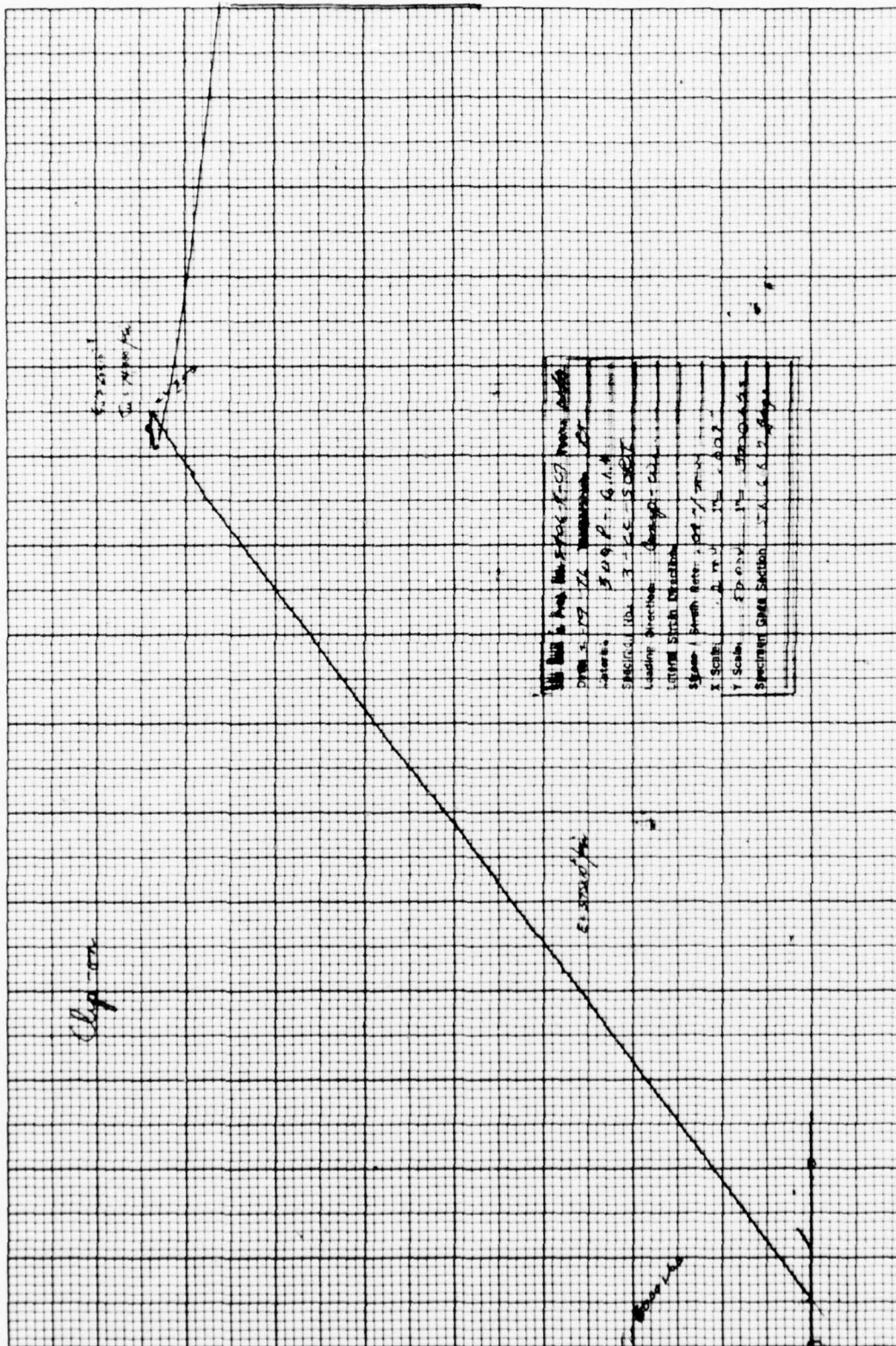
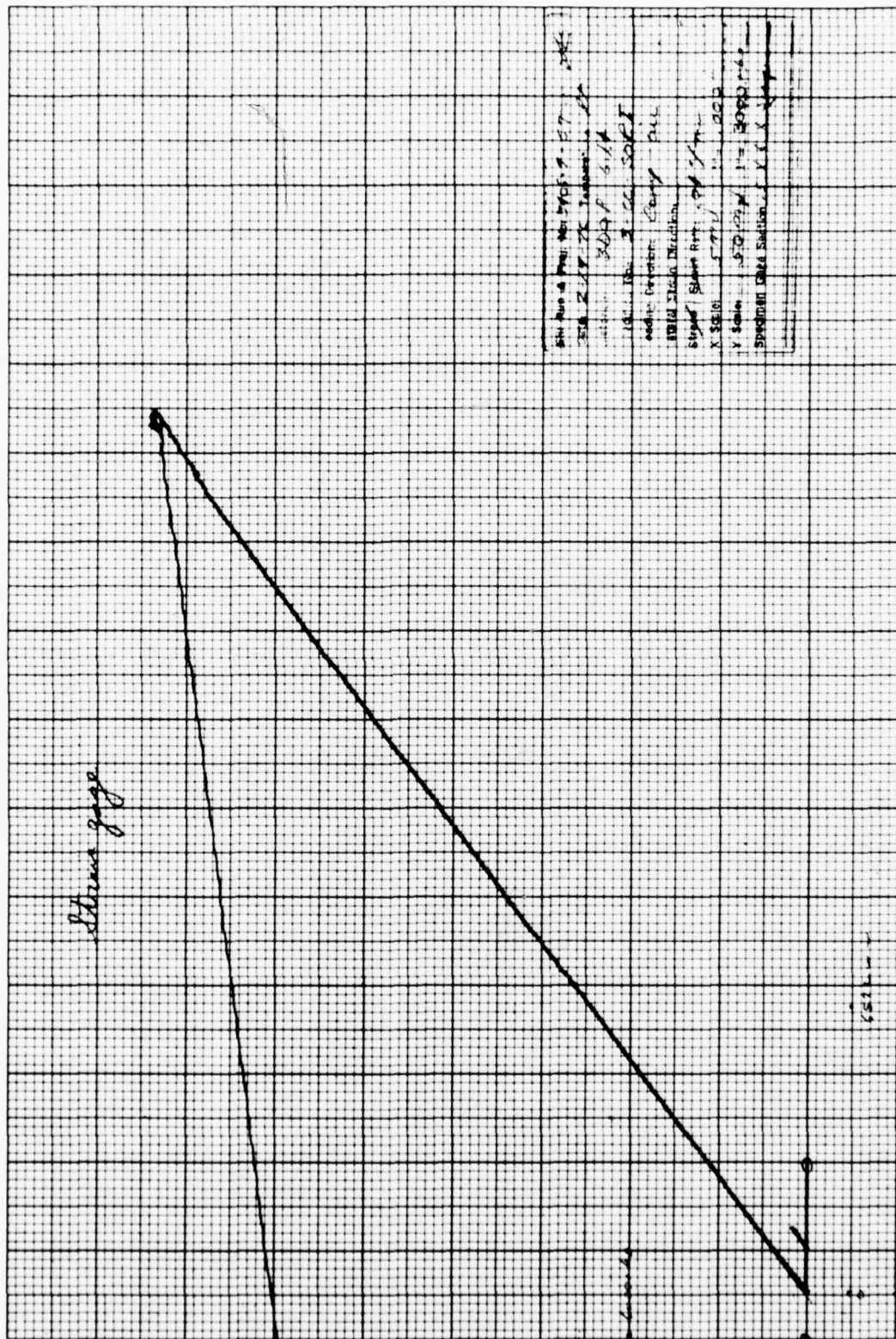


Figure 47. Test Results for Specimen 1-15-1000



Test No.	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1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Soil Name: *Red Clay*
 Test No: *3027*
 Date: *3/1/64*
 Location: *3.00 SOFT*
 Moisture Content: *60%*
 Liquid Limit: *60%*
 Plastic Limit: *20%*
 Shrinkage: *15%*
 Specimen Size: *1.5 x 1.5 x 1.5*

Figure ASD Test Results for Specimen 3.00-3.00

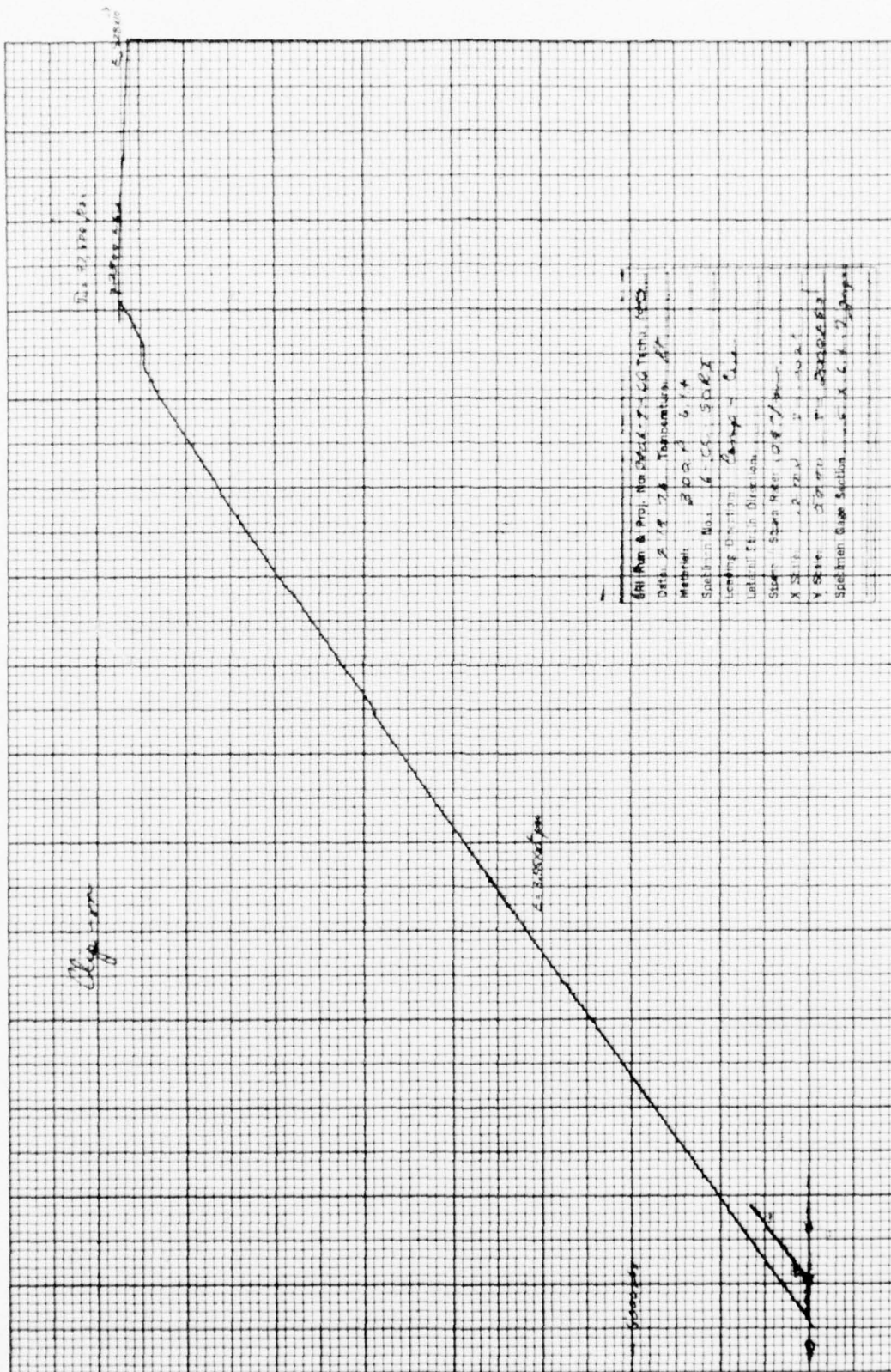


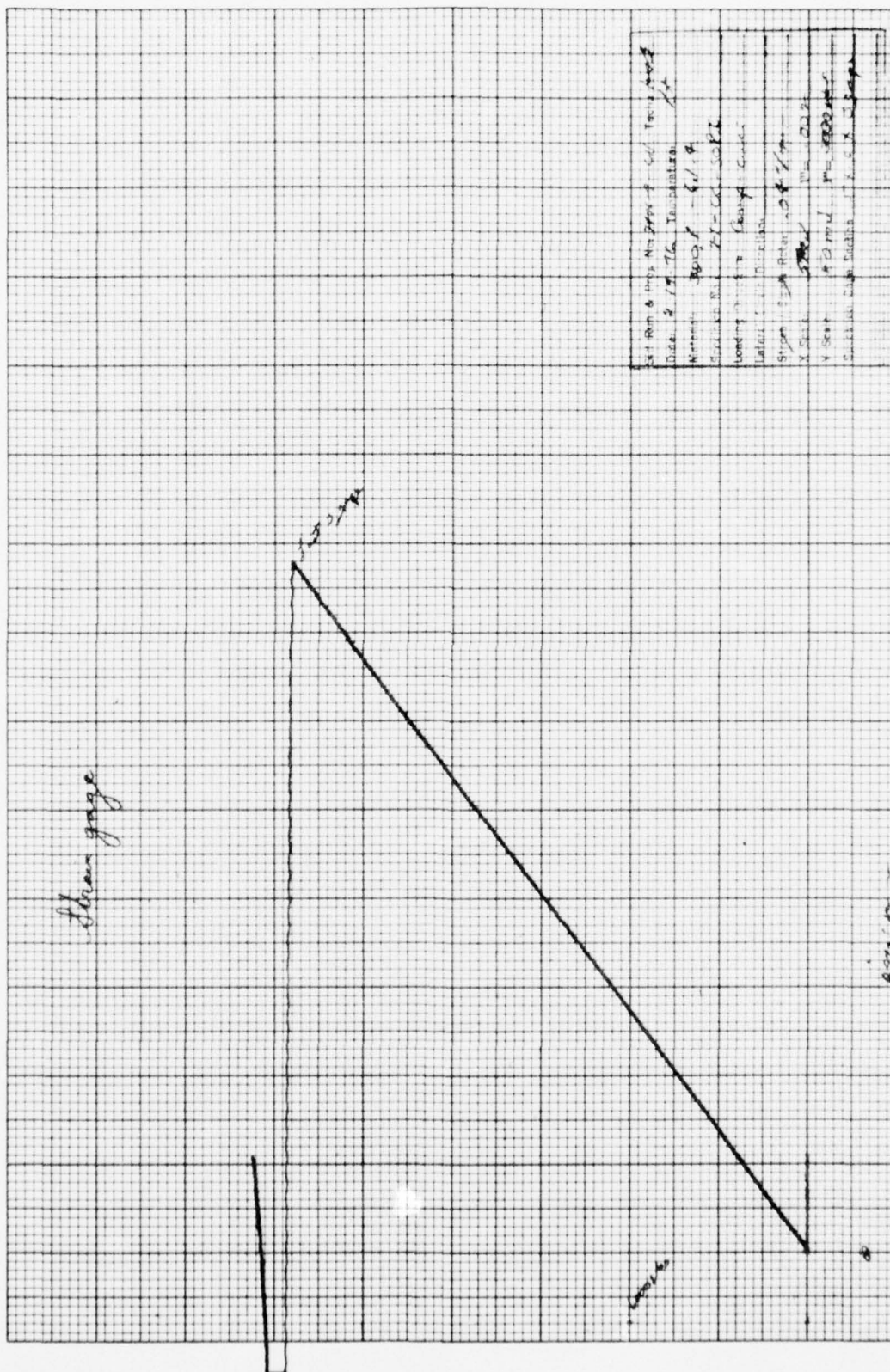
Figure 2.51. Test Results for Specimen G-CC-50R1

Stress vs. Strain



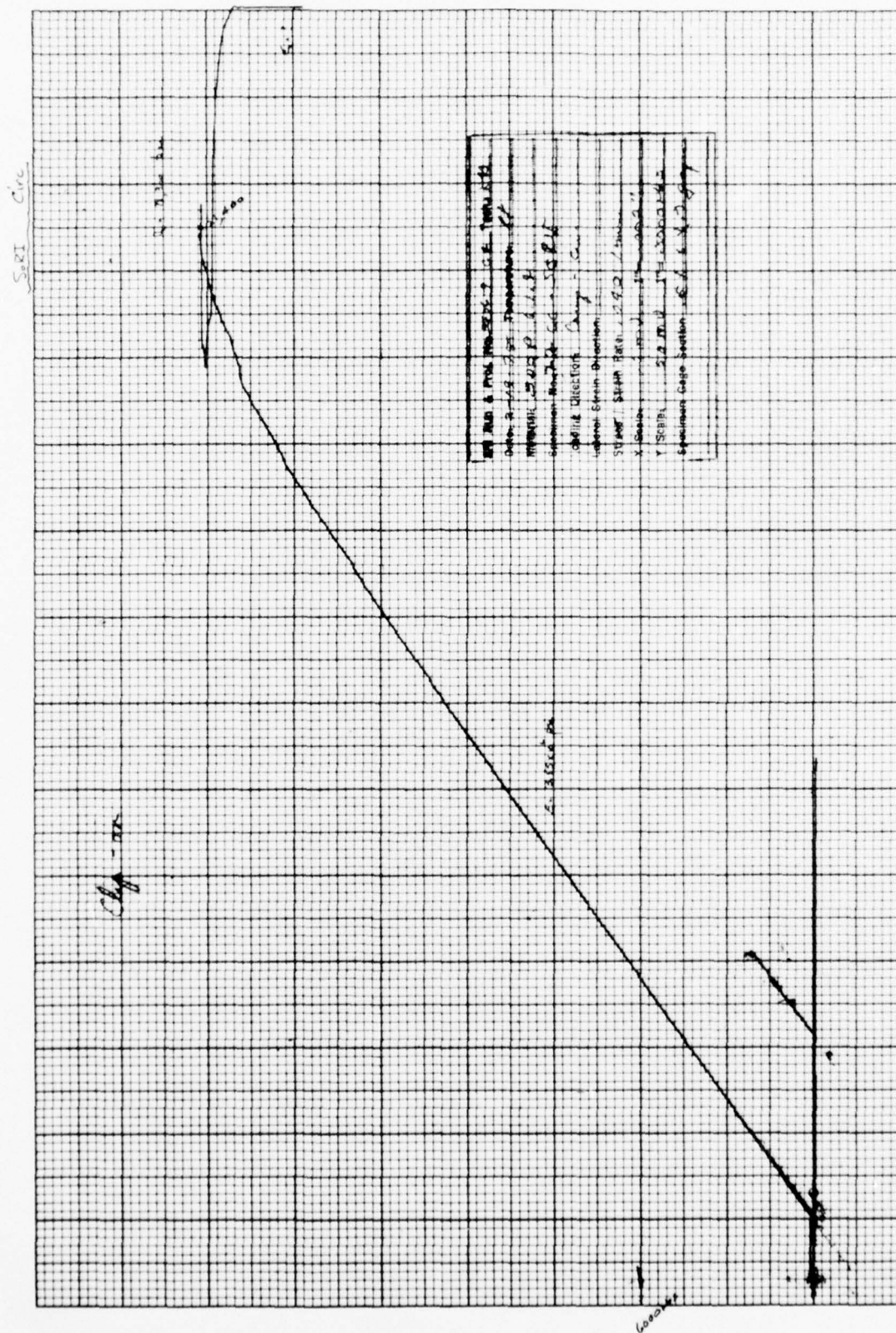
Specimen No.	1000
Material	Steel
Yield Point	1000
Ultimate Tensile Strength	1000
Modulus of Elasticity	1000
Reduction of Area	1000
Specimen Dimensions	1000
Test Date	1000
Test Location	1000
Test Operator	1000
Test Supervisor	1000
Test Results	1000
Test Comments	1000

Figure 1.3.2 Test Results for Specimen L-100-S-10



Set Run 6 mps. No. 1000-9-60. Tens. 1000
 Date: 2/18/76. Tens. 1000
 Name: 1000-9-60
 Size: 1000-9-60
 Location: 1000-9-60
 Notes: 1000-9-60
 X: 1000-9-60
 Y: 1000-9-60
 Z: 1000-9-60
 W: 1000-9-60
 V: 1000-9-60
 U: 1000-9-60
 T: 1000-9-60
 S: 1000-9-60
 R: 1000-9-60
 Q: 1000-9-60
 P: 1000-9-60
 O: 1000-9-60
 N: 1000-9-60
 M: 1000-9-60
 L: 1000-9-60
 K: 1000-9-60
 J: 1000-9-60
 I: 1000-9-60
 H: 1000-9-60
 G: 1000-9-60
 F: 1000-9-60
 E: 1000-9-60
 D: 1000-9-60
 C: 1000-9-60
 B: 1000-9-60
 A: 1000-9-60

Figure A.5. Strain Results for Experiment 7-1-CL-30-R1



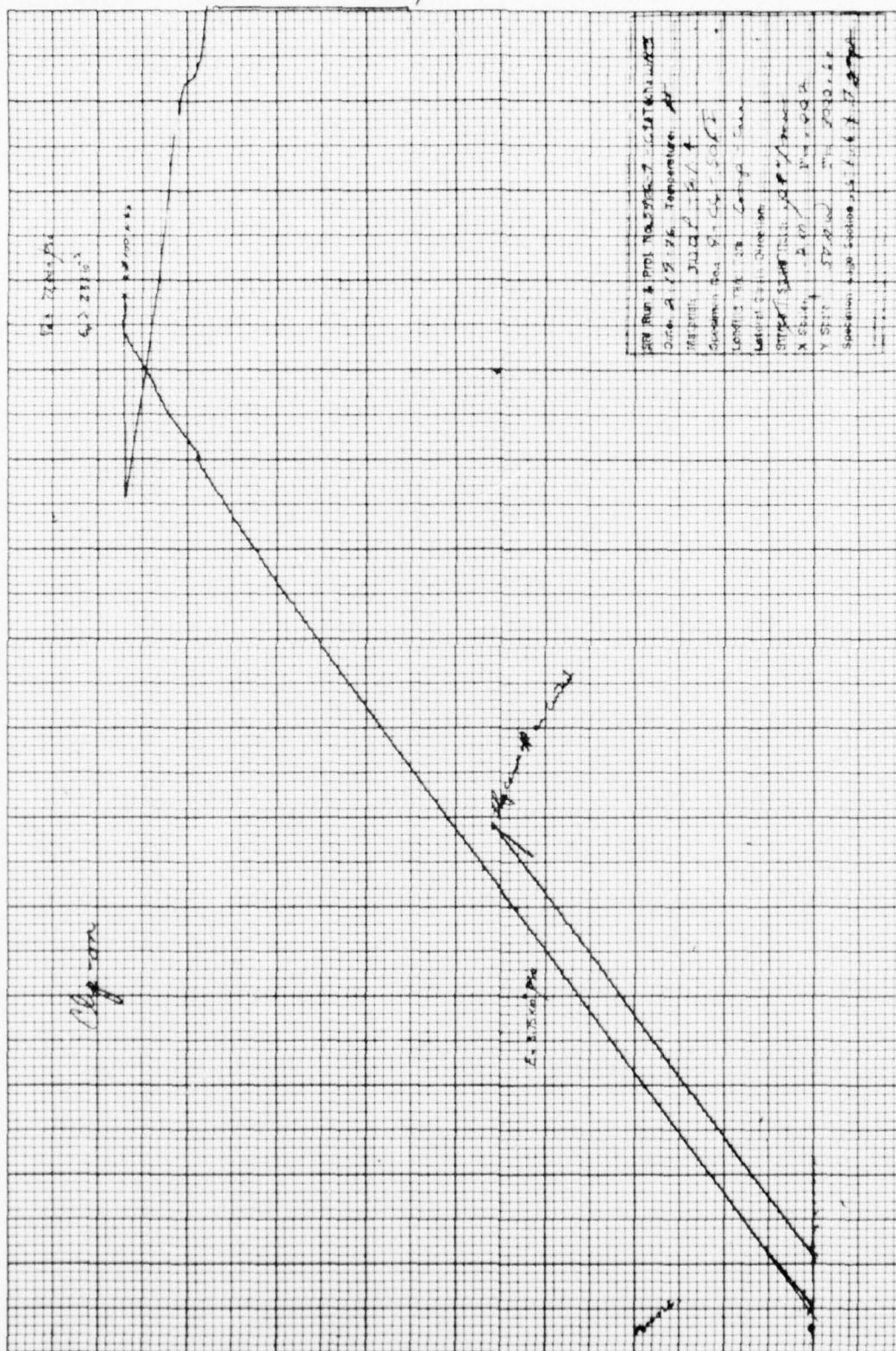
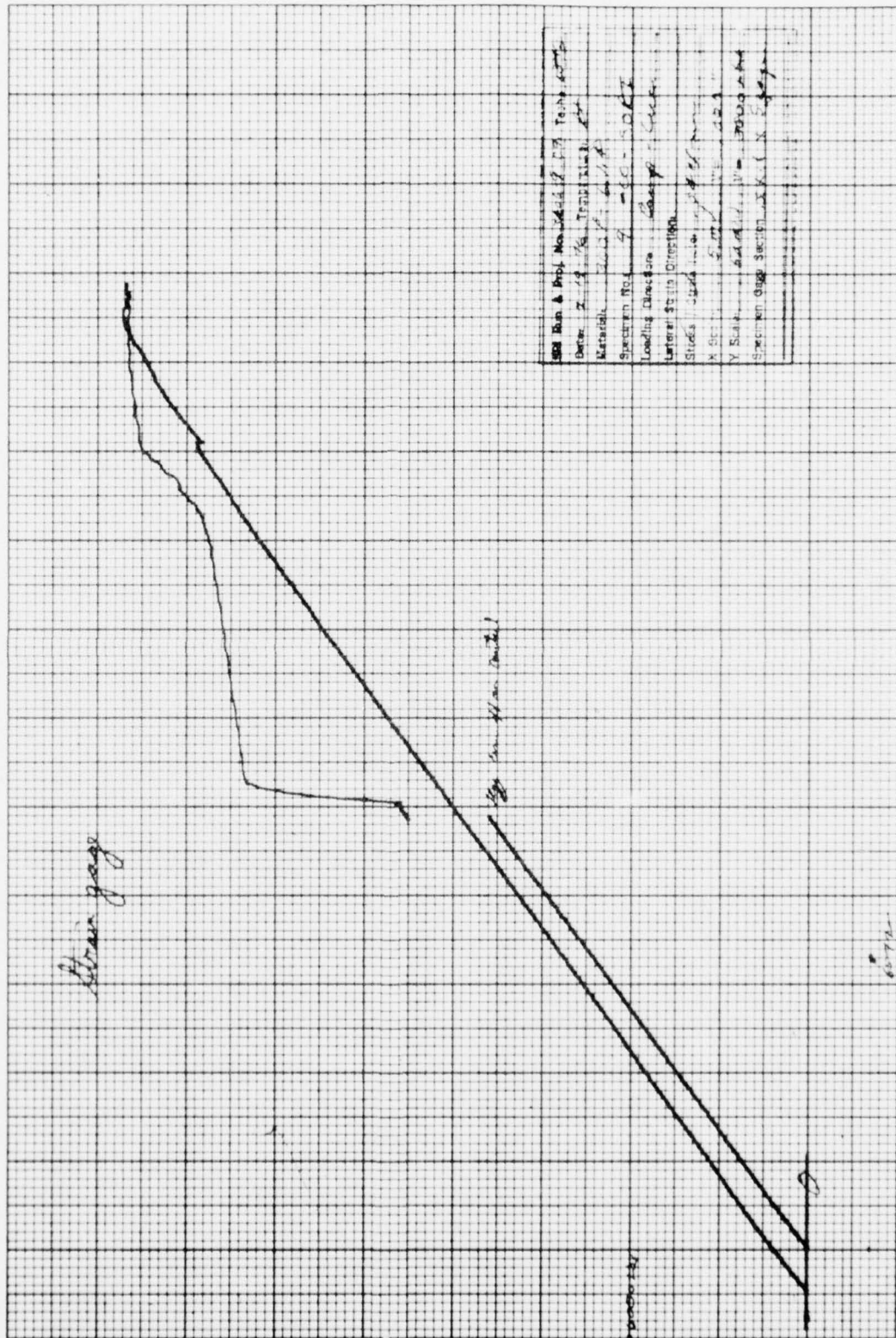
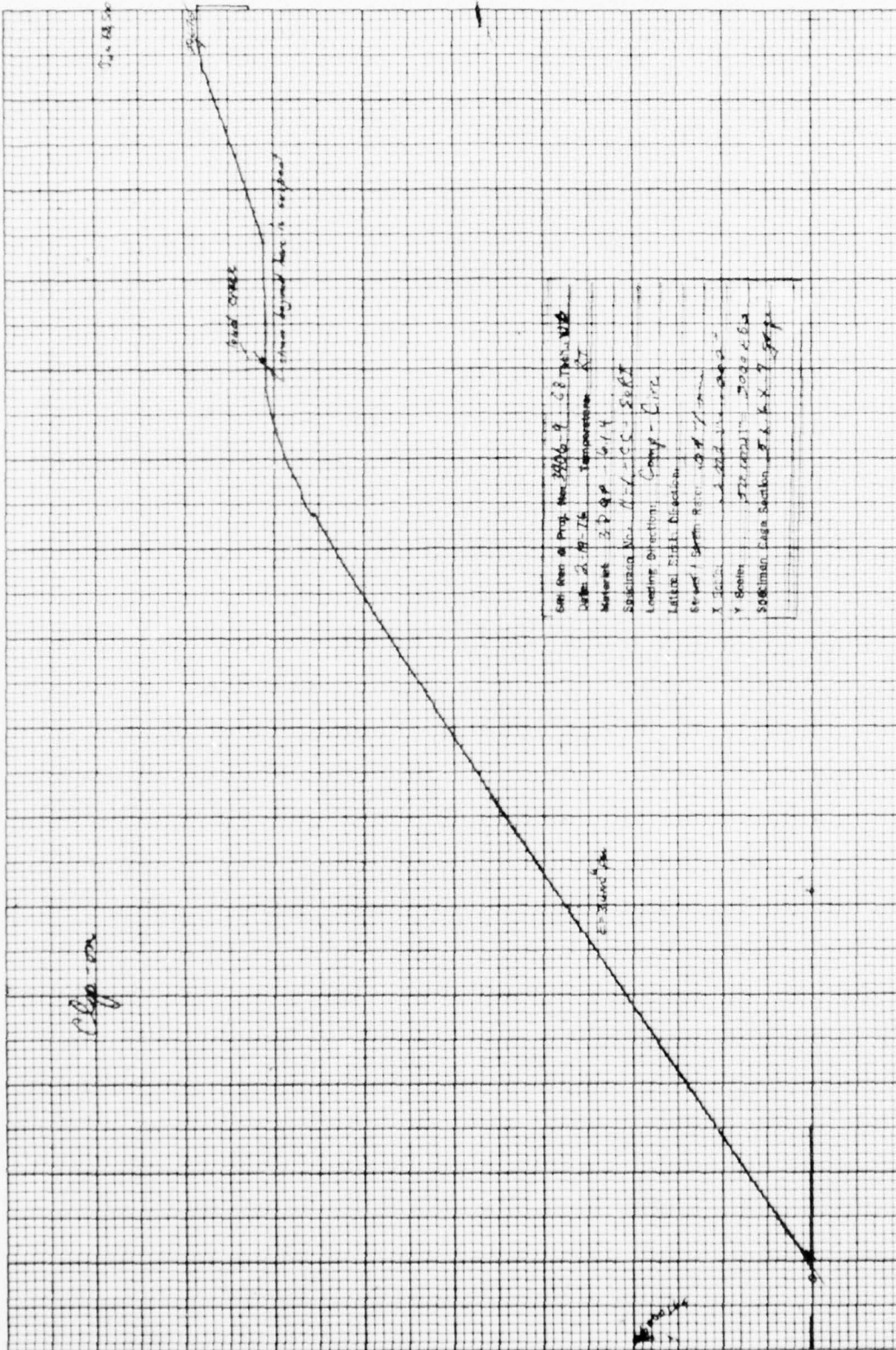


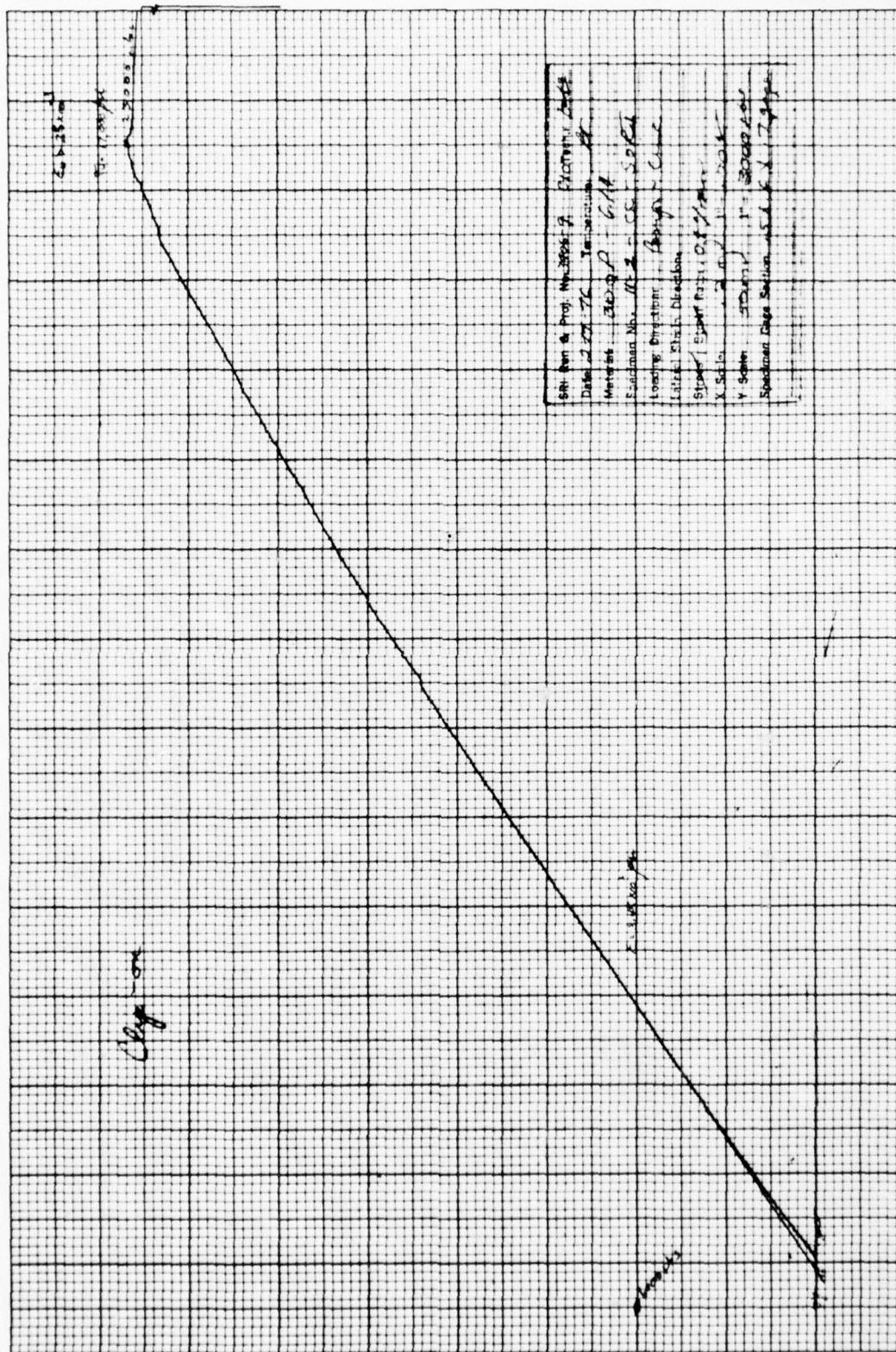
Figure 1.57 Test Results for Specimen 9-CC-SaR1



Specimen No. 9 - 50-50-50
 Loading Direction: Tension
 Initial Stress: 0
 Final Stress: 50
 Y Stress: 50
 Specimen Gage Section: 1/2 x 1/2 x 1/2

Figure A-58 Test Results for Specimen 9-50-50-50





Site No. & Proj. No.	20001-2	20001-2
Date of Test	7-1	7-1
Method	20001-2	20001-2
Equipment No.	10001-2	10001-2
Location	10001-2	10001-2
Initial	10001-2	10001-2
Final	10001-2	10001-2
Notes	10001-2	10001-2
Remarks	10001-2	10001-2

Figure 1. Absolute values for Equations 11-2, 12-2, 13-2, 14-2, 15-2, 16-2, 17-2, 18-2, 19-2, 20-2, 21-2, 22-2, 23-2, 24-2, 25-2, 26-2, 27-2, 28-2, 29-2, 30-2, 31-2, 32-2, 33-2, 34-2, 35-2, 36-2, 37-2, 38-2, 39-2, 40-2, 41-2, 42-2, 43-2, 44-2, 45-2, 46-2, 47-2, 48-2, 49-2, 50-2, 51-2, 52-2, 53-2, 54-2, 55-2, 56-2, 57-2, 58-2, 59-2, 60-2, 61-2, 62-2, 63-2, 64-2, 65-2, 66-2, 67-2, 68-2, 69-2, 70-2, 71-2, 72-2, 73-2, 74-2, 75-2, 76-2, 77-2, 78-2, 79-2, 80-2, 81-2, 82-2, 83-2, 84-2, 85-2, 86-2, 87-2, 88-2, 89-2, 90-2, 91-2, 92-2, 93-2, 94-2, 95-2, 96-2, 97-2, 98-2, 99-2, 100-2

strain gage

SEA Run & Proj No.	2004-2	Stretch	100%
Date	1/17/74	Temperature	80°
Method	3-D-2	1/1/74	
Section No.	11-2	1/1/74	
Leading Direction	East		
Lateral Strain Direction			
Strain / Speed Rate	2.5 / 1		
X Scale	500		
Y Scale	500		
Section No.	11-2		

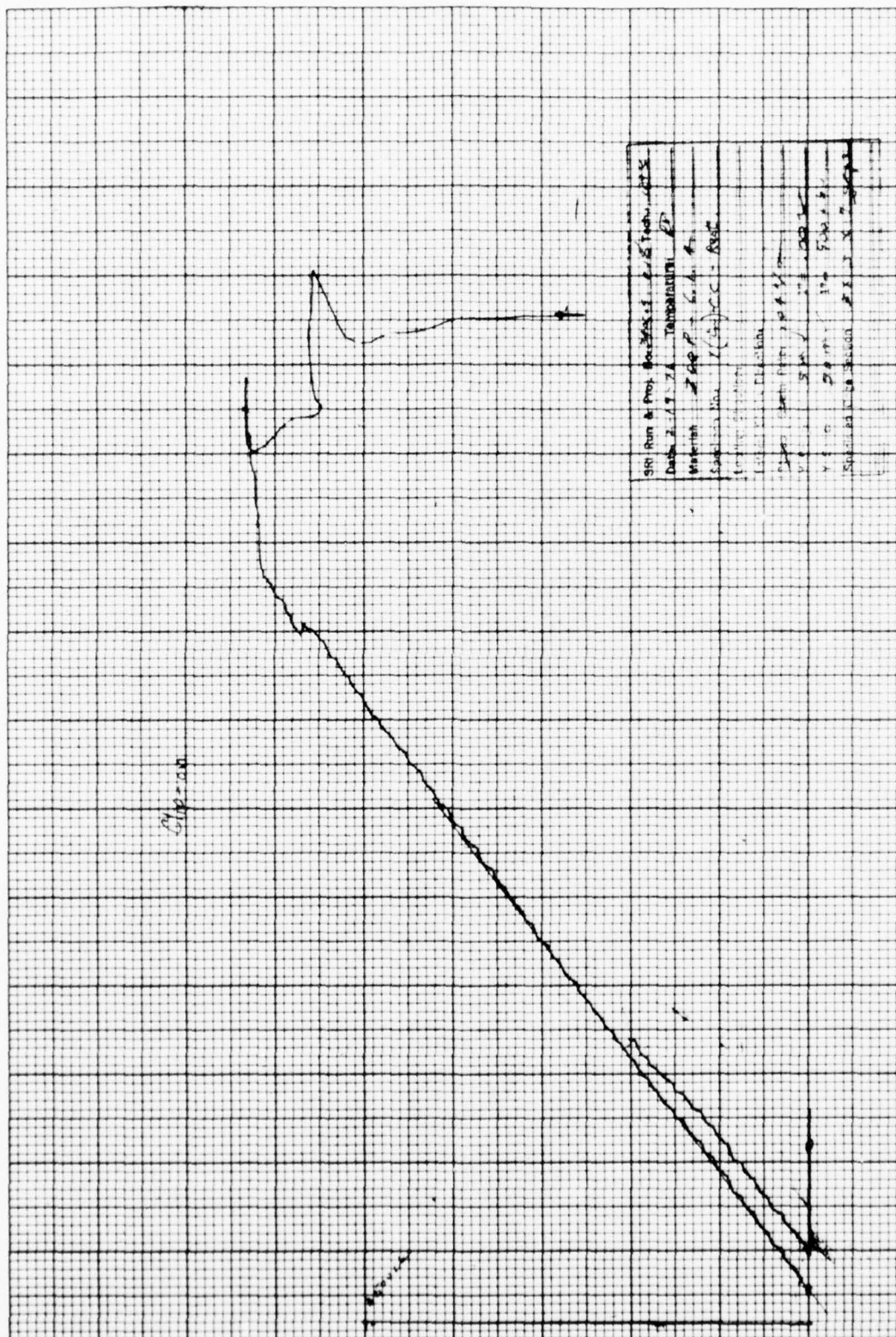
SEA 74

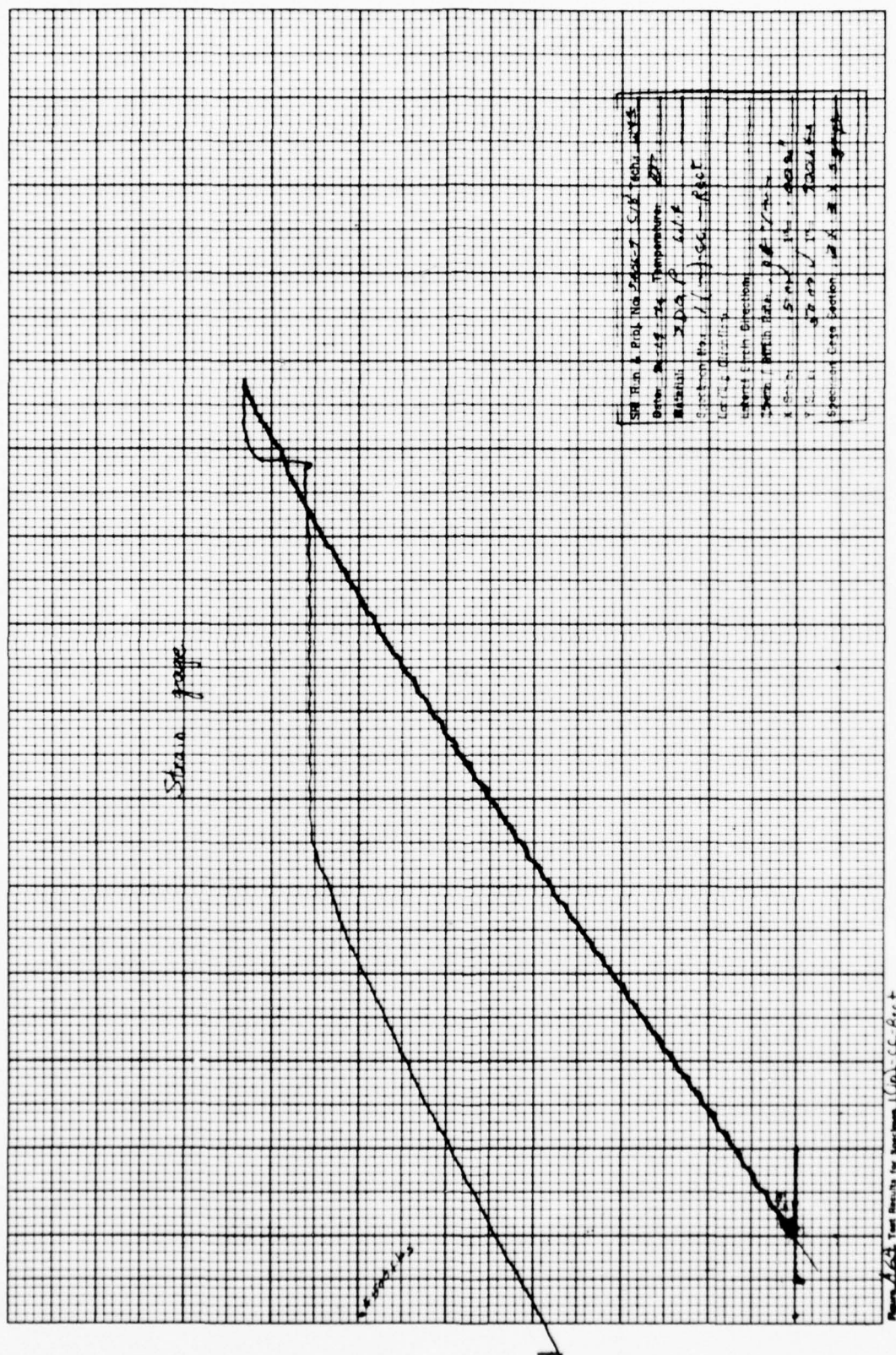
Fig. 2. Test Results for Specimen 11-2-CC-S. R. I

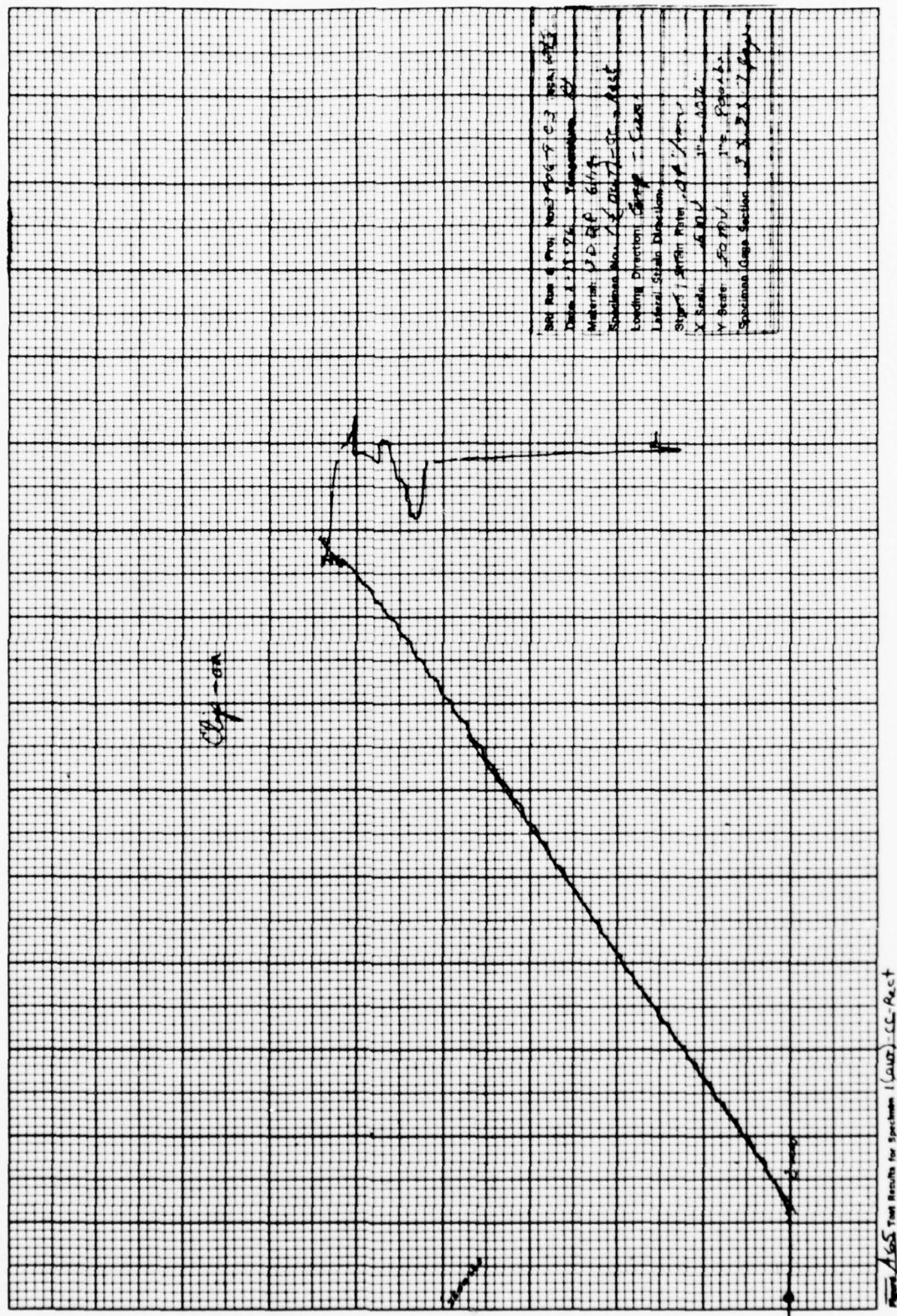
A5

Circumferential Compressive Tests
Rectangular Specimen Configuration

6.1.4







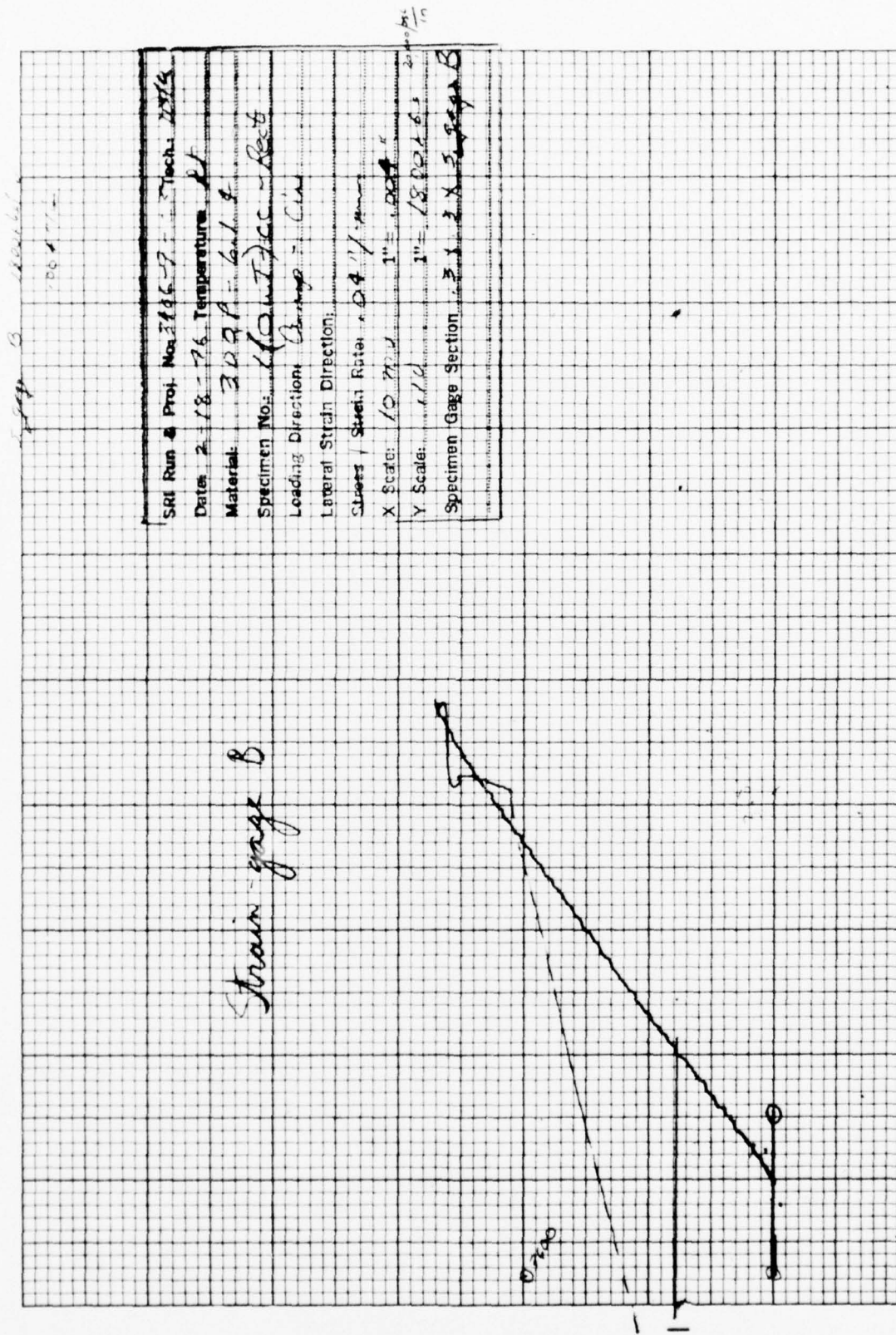


Figure A-6a Test Results for Specimen 1(CUT)-CS-Rect

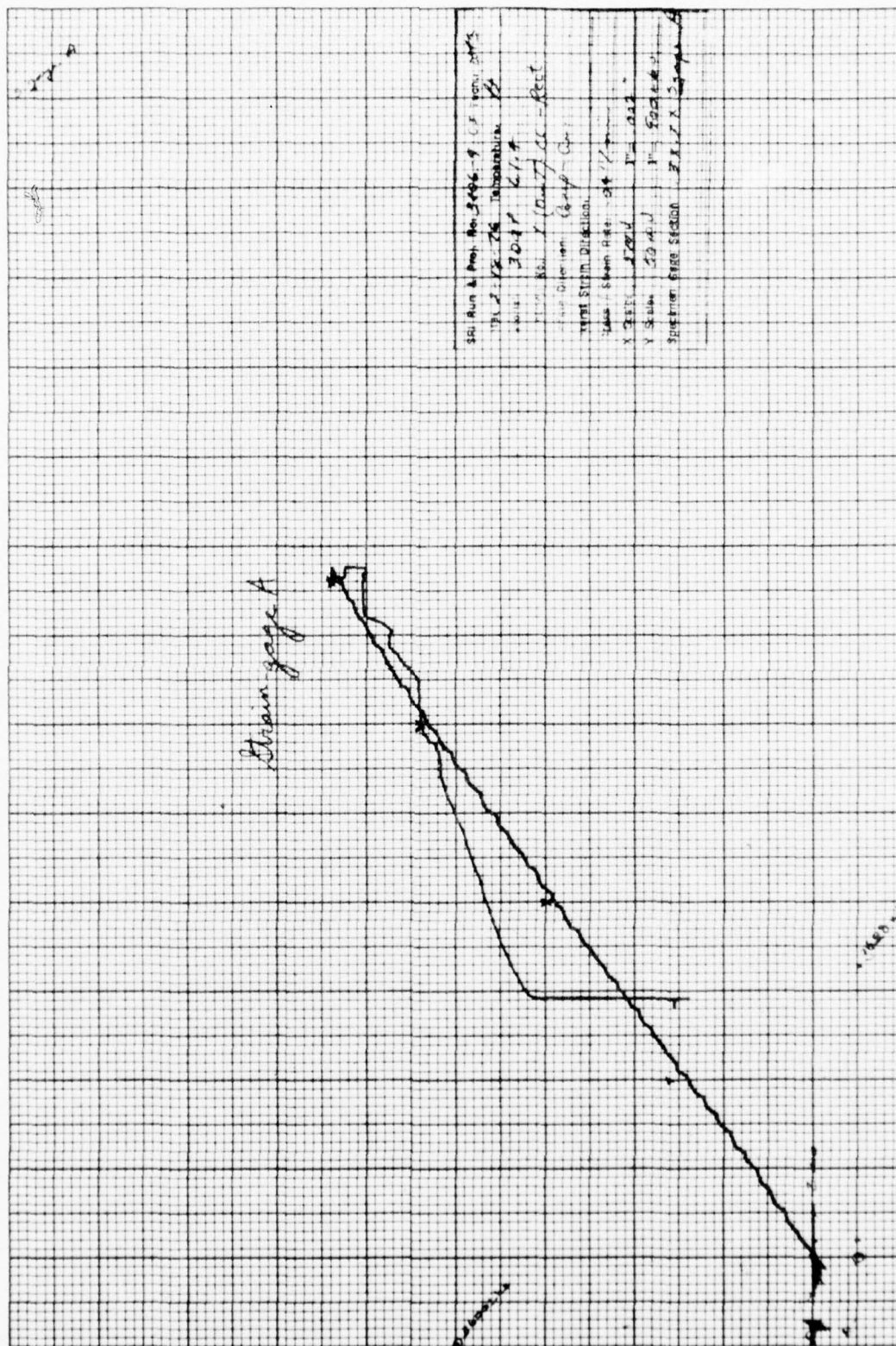


Figure A 67 Test Results for Specimens (QVT)-SC-Aect

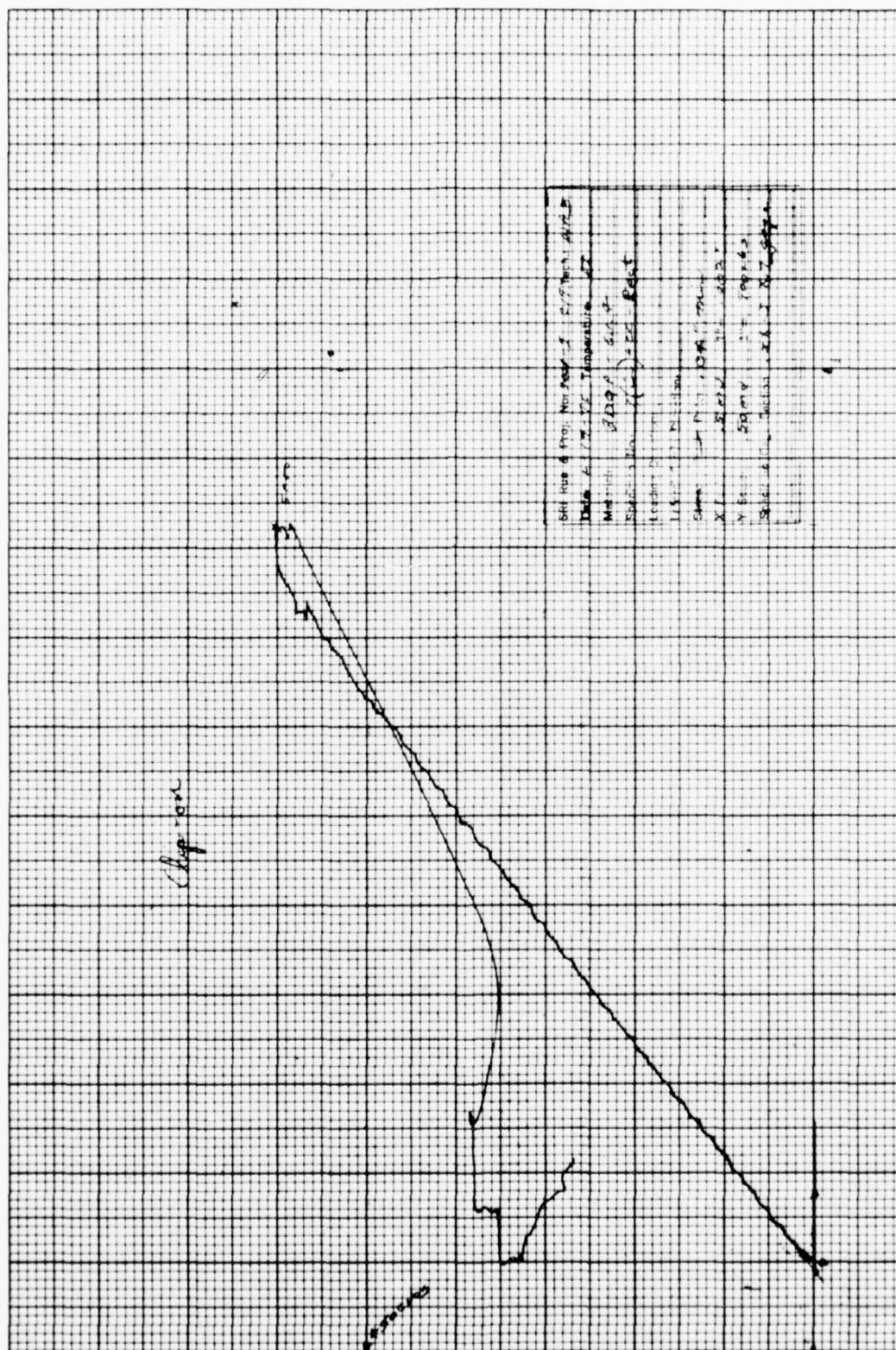
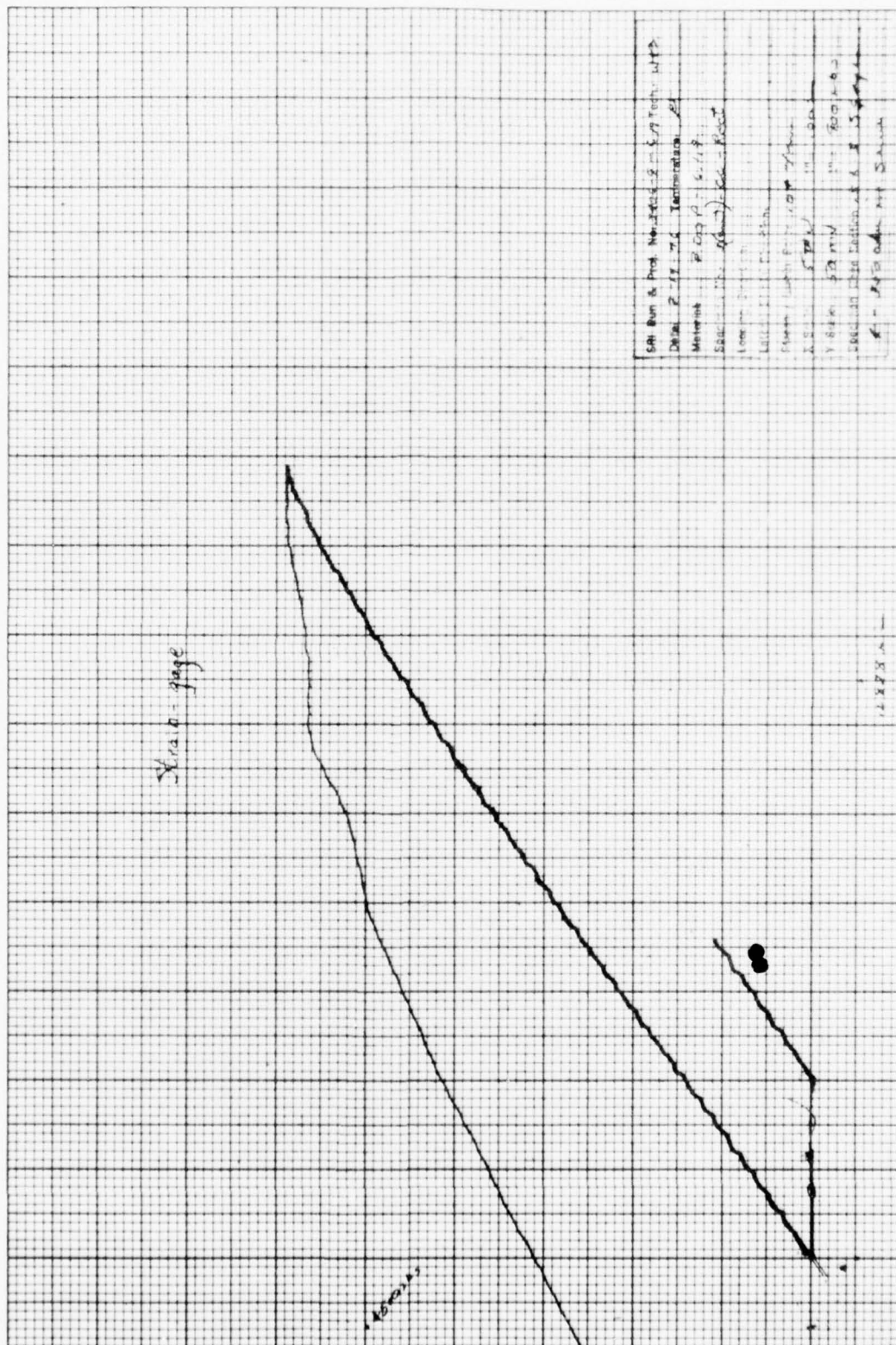


Figure A 6.8 Test Results for Specimen 3 (in) - SS-Rect

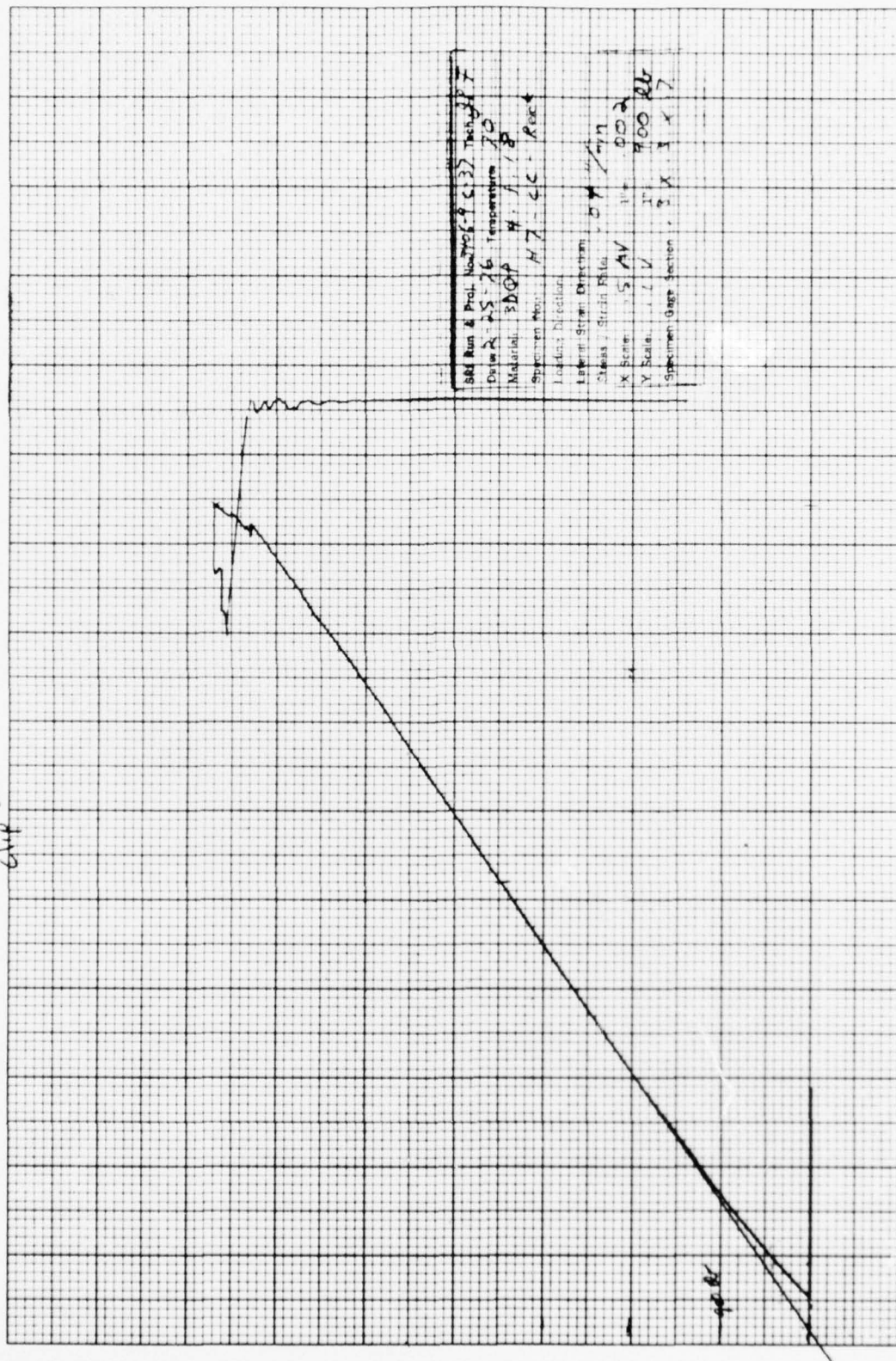


A6

Circumferential Compressive Tests
Rectangular Specimen Configuration

4.1.18

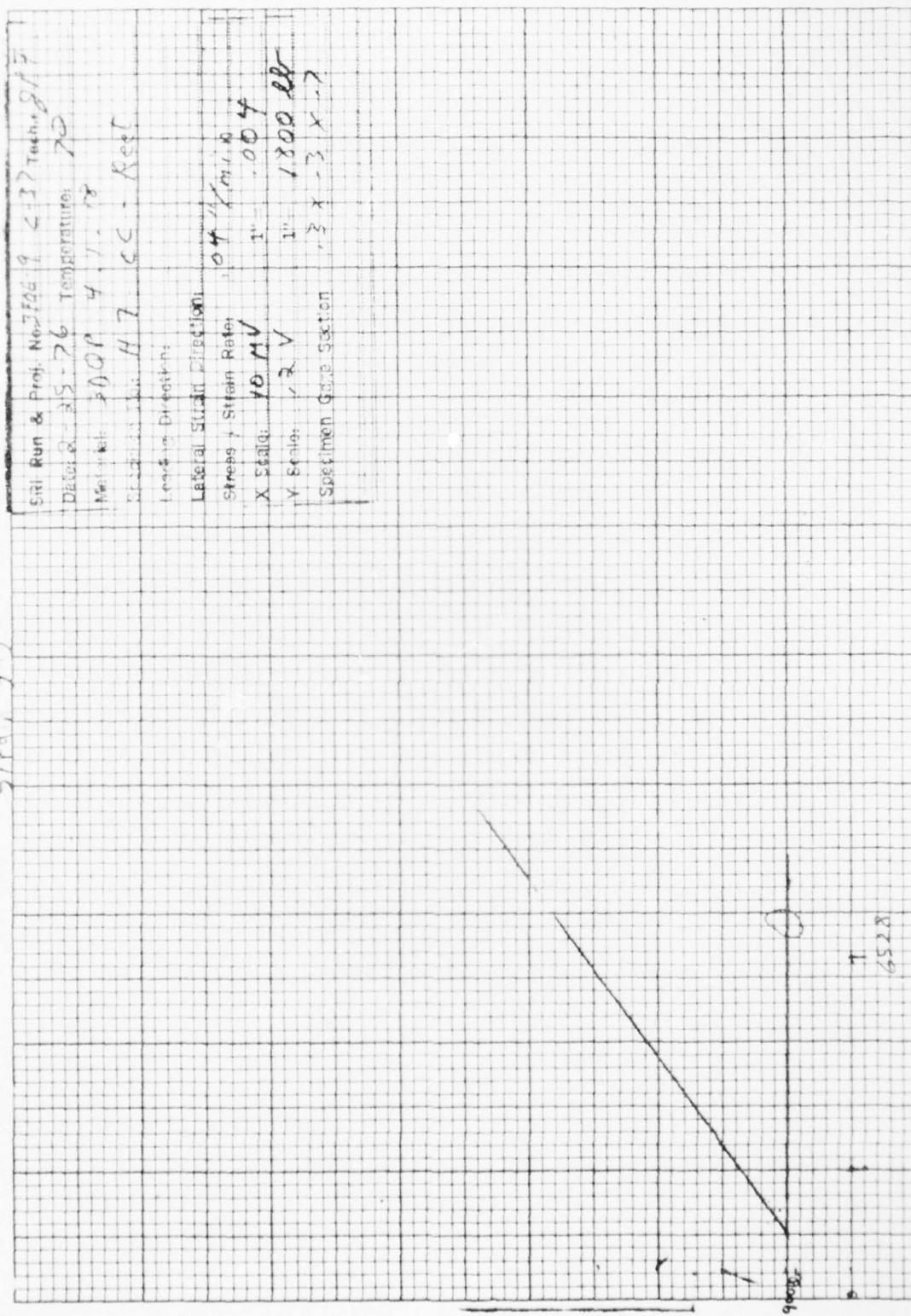
clips on



S&S Run & Prod. No. 206-9 C-37 Tech. 17
 Date 2-25-76 Temperature 70
 Material 300P H-1-18
 Specimen No. H7-CC-Rec-4
 Loading Direction
 Loading Strain Direction
 Stress / Strain Ratio 5000
 X Scale 5 MV 1000
 Y Scale 10 V 1000
 Specimen Gauge Section 3 X 1 X 7

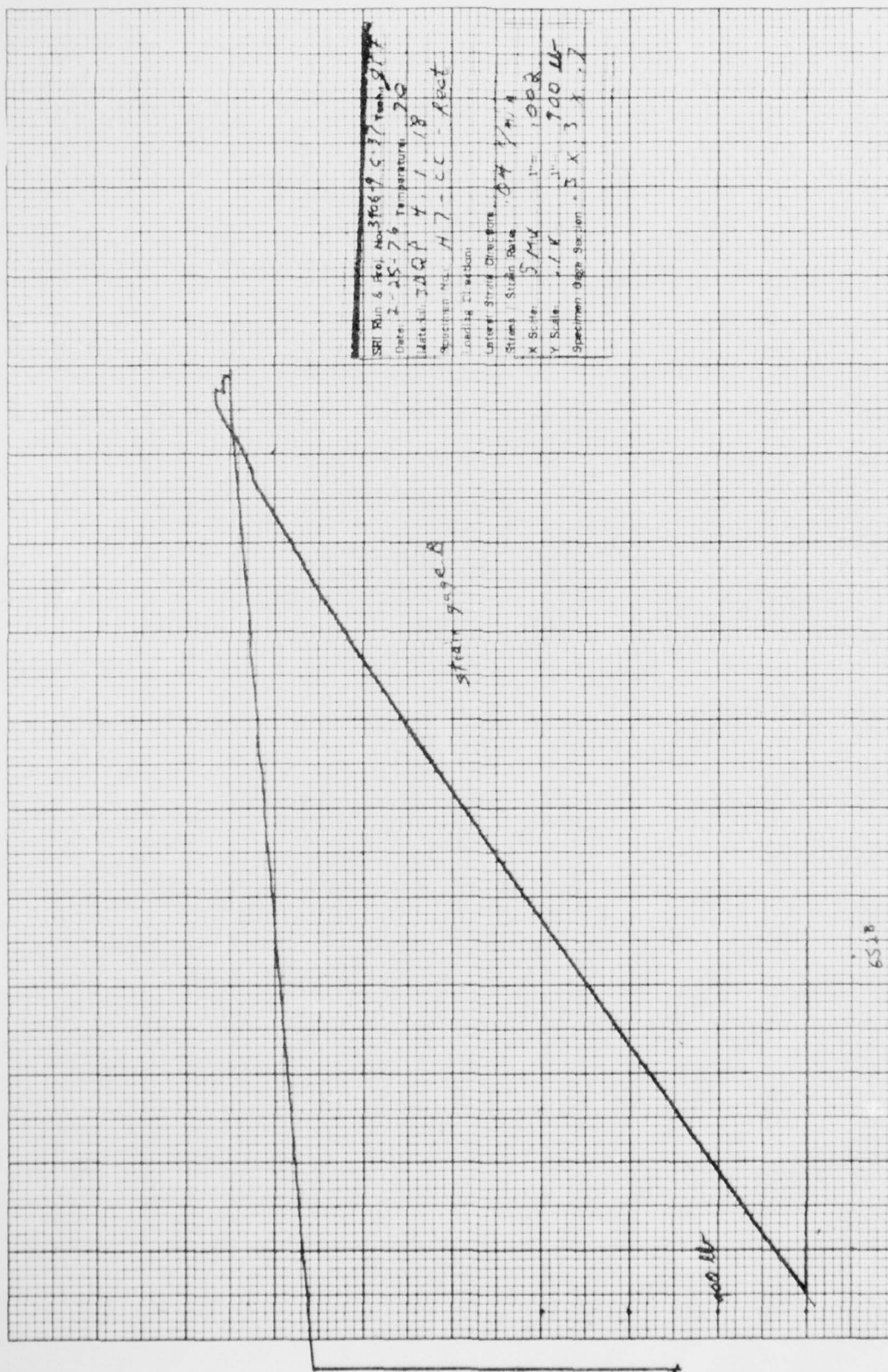
Figure A7a Test results for Specimen H7-CC-Rec-4

Strain gauge



Soil Run & Proj. No: 7269 < 37 Tech. 817
 Date: 2-25-76 Temperature: 70
 No. of: 300P 4 1-18
 Specimen: H7 CC - Keel
 Lateral Strain Direction: 04' 1' m, 0
 Strips & Strain Rate: 1" .004
 X Scale: 10 MV
 Y Scale: 12 V
 Specimen Gauge Section: 3 X 3 X .7

Figure 6.73. Test Results for Specimen H7-CC-Beet



SRI Run & No. A037069 C-37 10/1/51
 Date 2-25-76 Temperature 72
 Data to 1000 4.1.18
 Specimen No. H7-CC-Rect
 Loading Condition
 Uniaxial Stress Direction
 Stress Strain Rate 0.4 1/min
 X Scale 5 M 1" = 1000
 Y Scale 1 K 1" = 700 lb
 Specimen Gage Section 3 X 3 X 1/2

Figure A74 Test Results for Specimen H7-CC-Rect

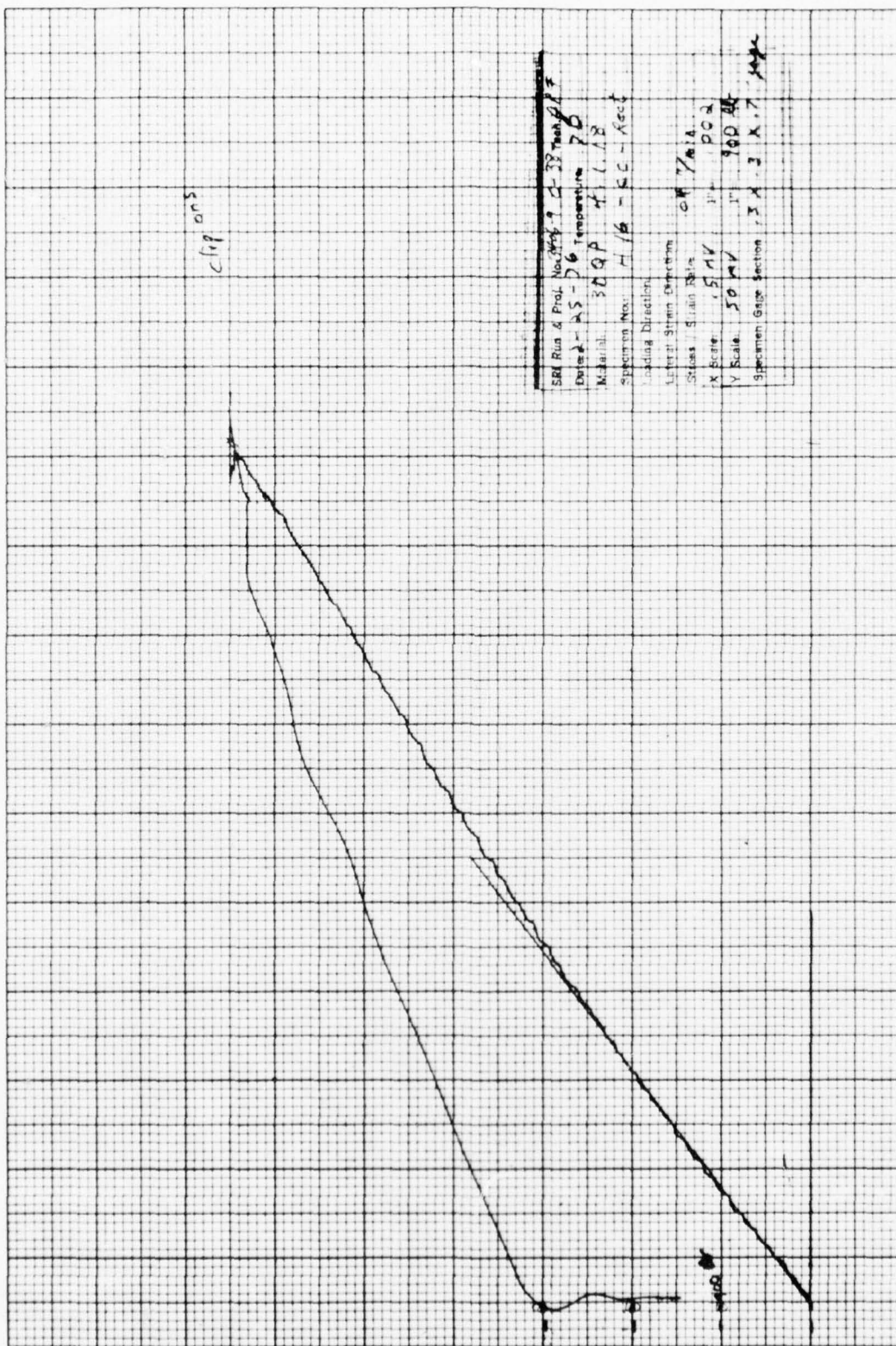


Figure A75 Test Results for Specimen H16-CSC Rect

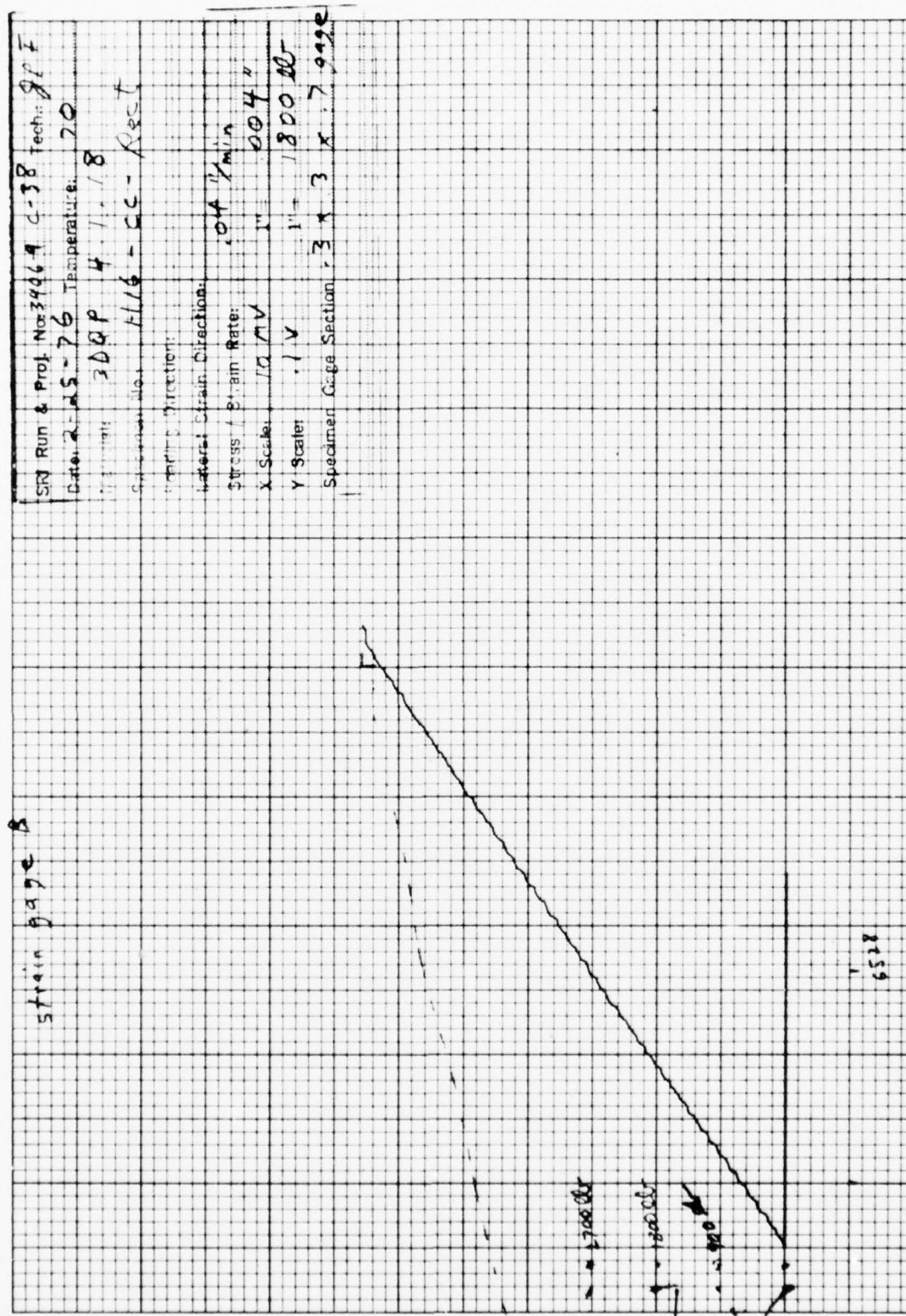
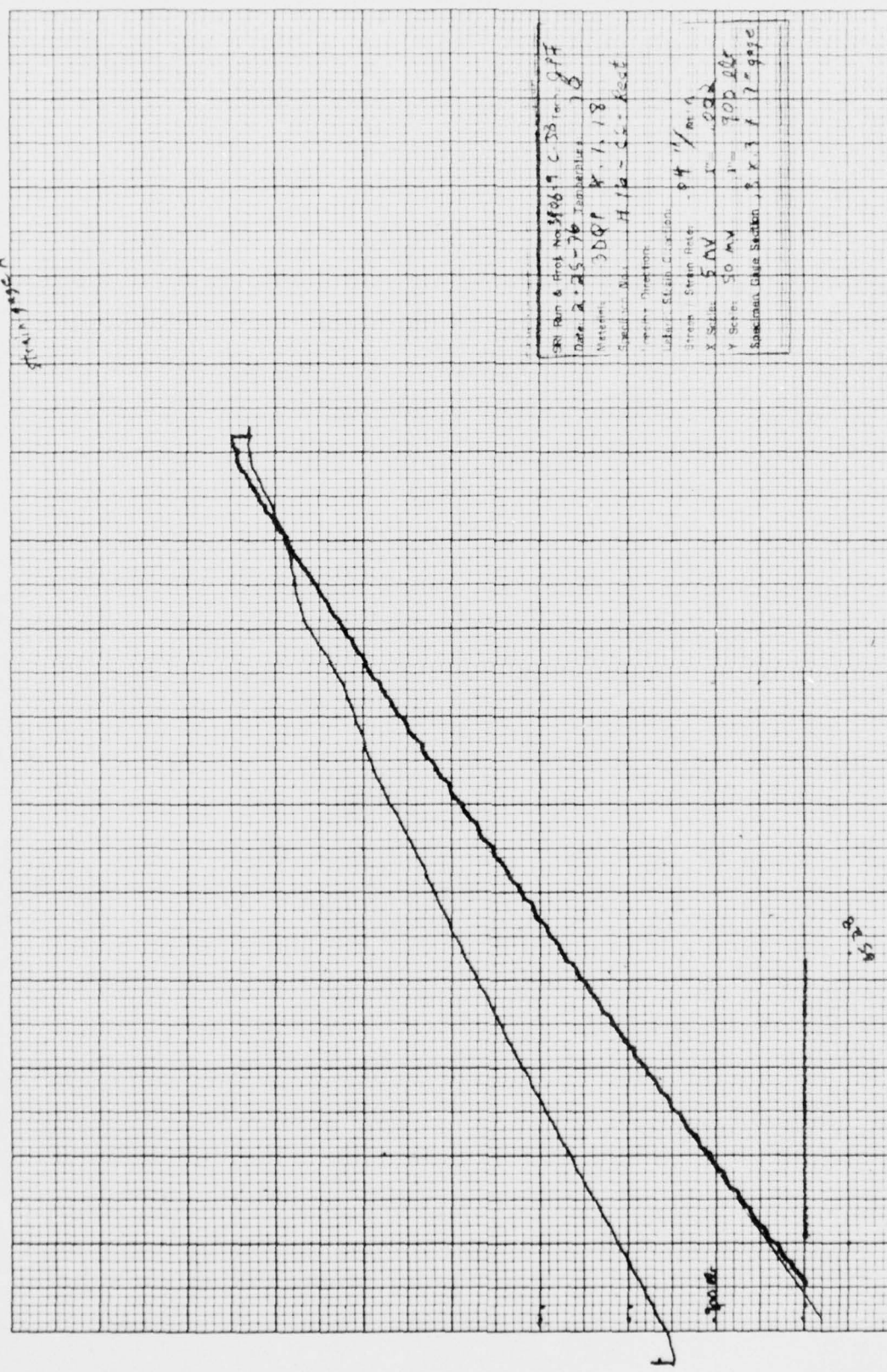


Figure A76 Test Machine for Specimen H16-CC-REST

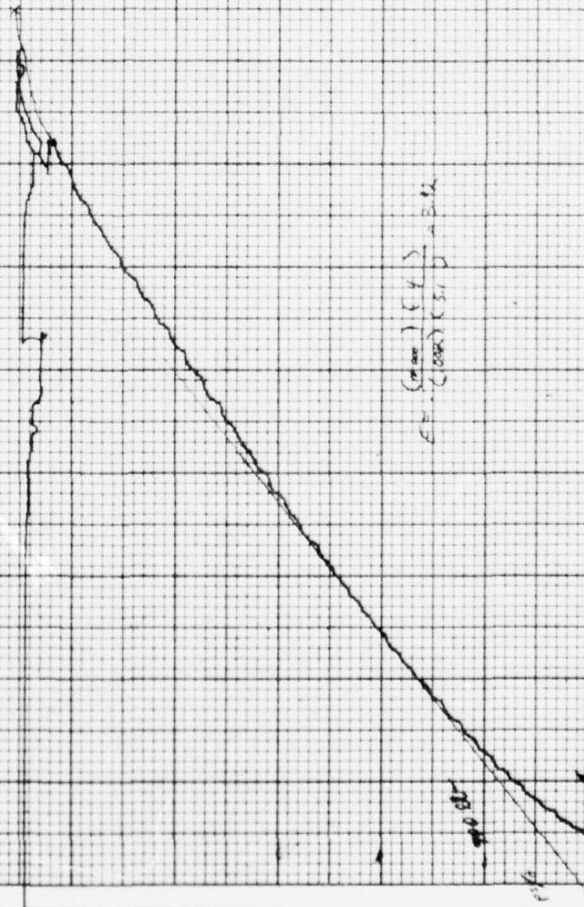
strain gauge A



FBI Lab & Prof. No. 58619 C-38 100 8.4
 Date: 2-25-76 Jambler 18
 Method: 300P W. 1. 18
 Sample No.: H. 16 - 55 - Rec 6
 Machine: Direction
 Machine: Strain Gauge
 Strain: Strain Rate: 0.4 1/100
 X Scale: 5.0V 100
 Y Scale: 50 mV 100
 Specimen Data Section: 8.3258 17.999

Figure A77 Test Results for Specimen H16-55-Rec 6

Clip-on



$$E = \frac{(80 - 10)}{(80 - 10)} \times 10^6 = 10^6 \text{ psi}$$

1000 psi

SERIAL	Run	Prod. No.	3006	C. 10	Test	273
Date	2	5	78	Temperature	20	
Material	300A	4	1	1	8	
Specimen No.	H	2	4	5	4	Recd
Load	Direction					
Support	Strain	Direction				
Stress	Strain	Rate				
X Scale	5	MM				002
Y Scale	50	MM				001
Specimen	Gage	Section	1	3	A	2

Figure 78. Test Results for Specimen H24-SC-Rect

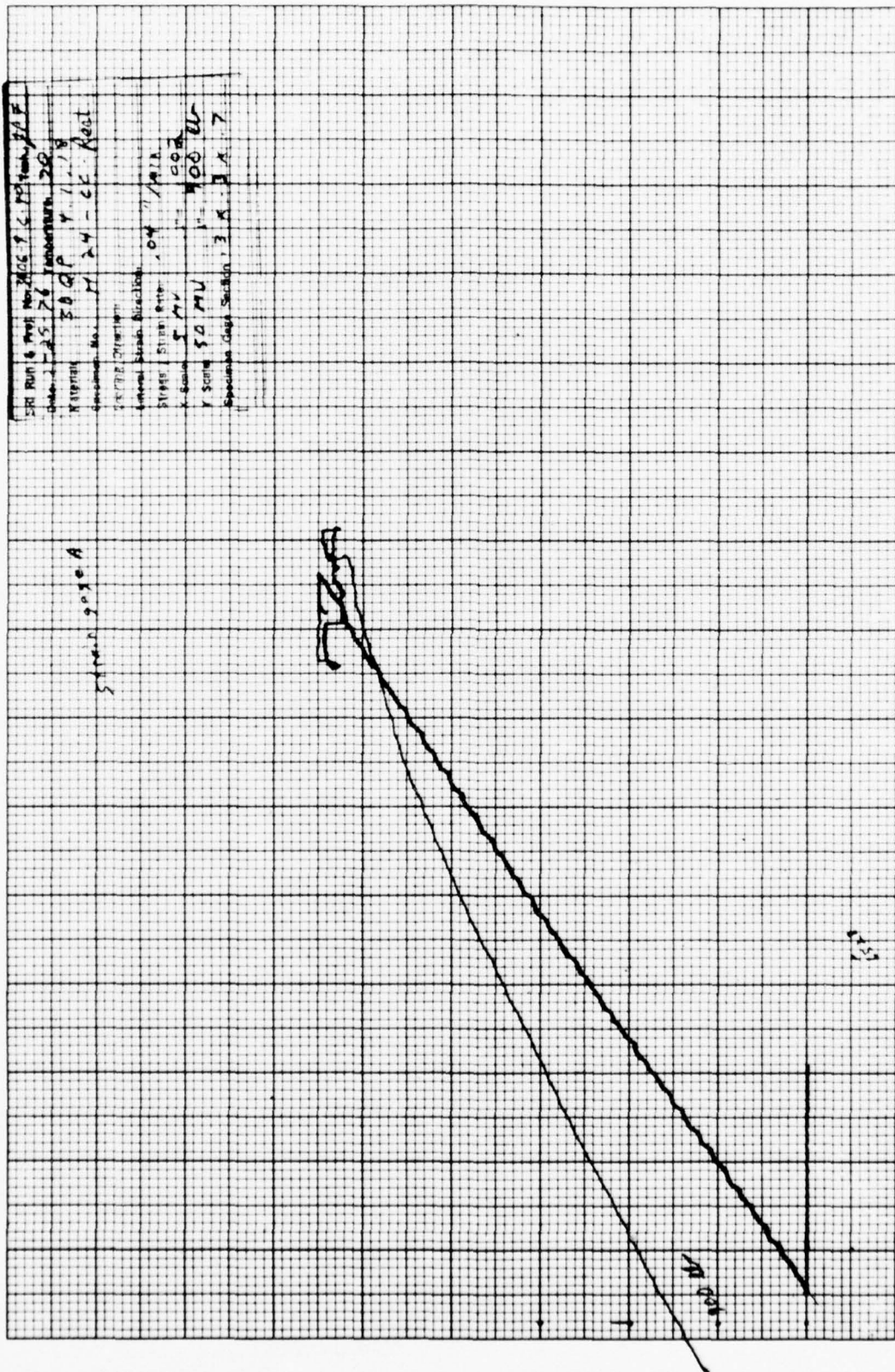
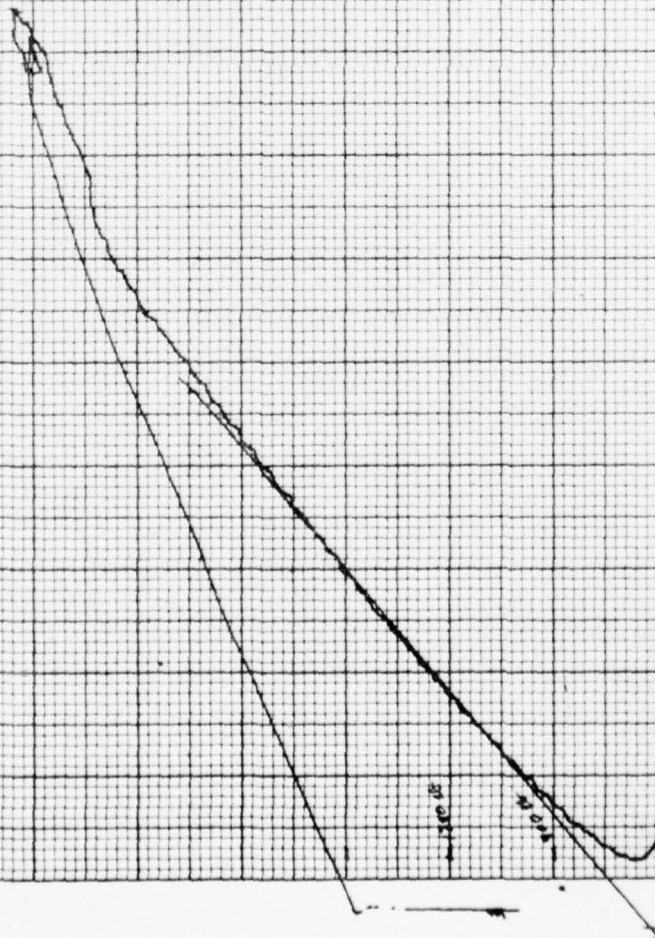


Figure A-80 Test Results for Carbon H₂O-CC-Rect

2.1.2



APR 1, That Records for Suburban H32-CL-Rec +

[illegible]

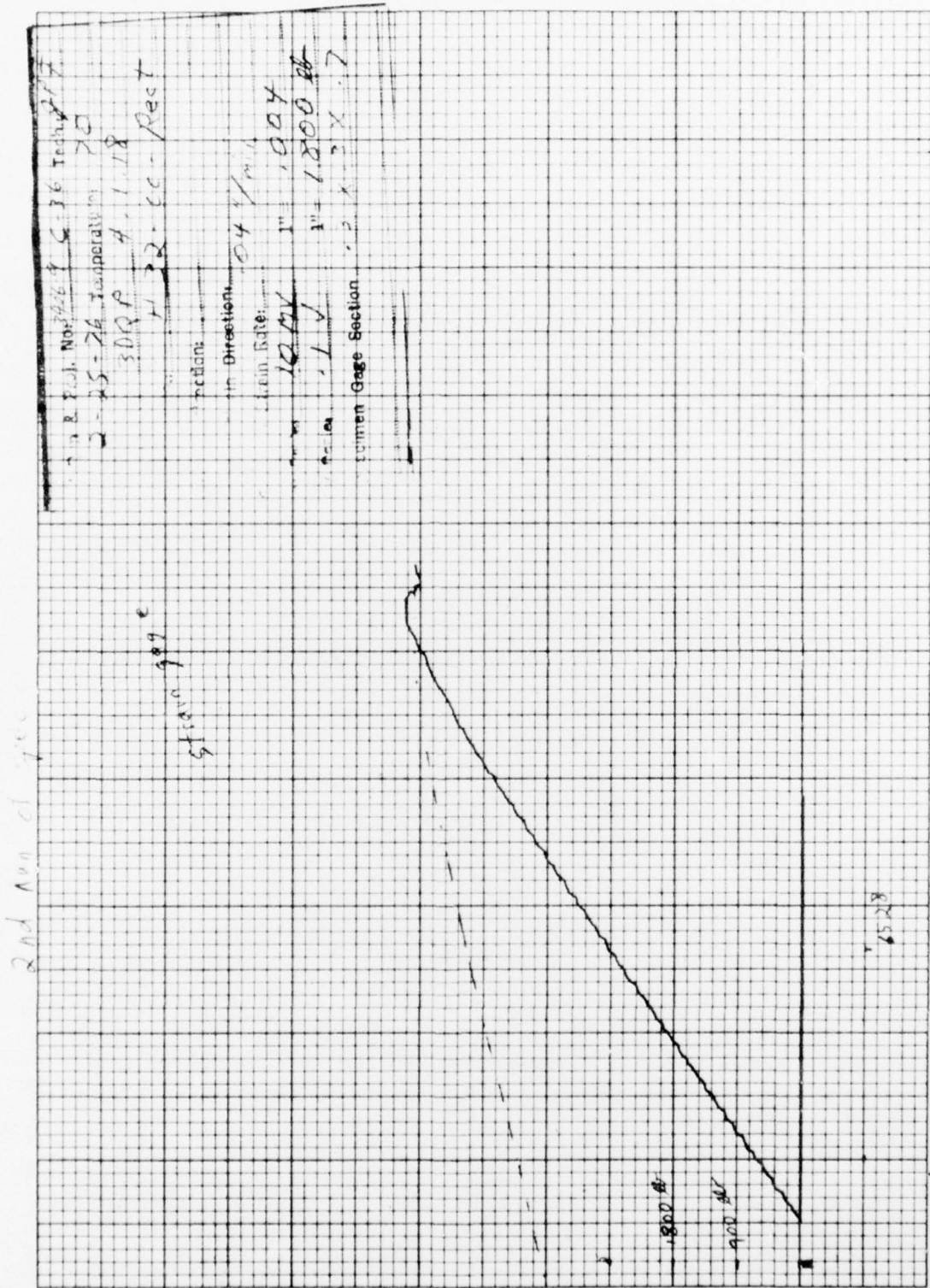
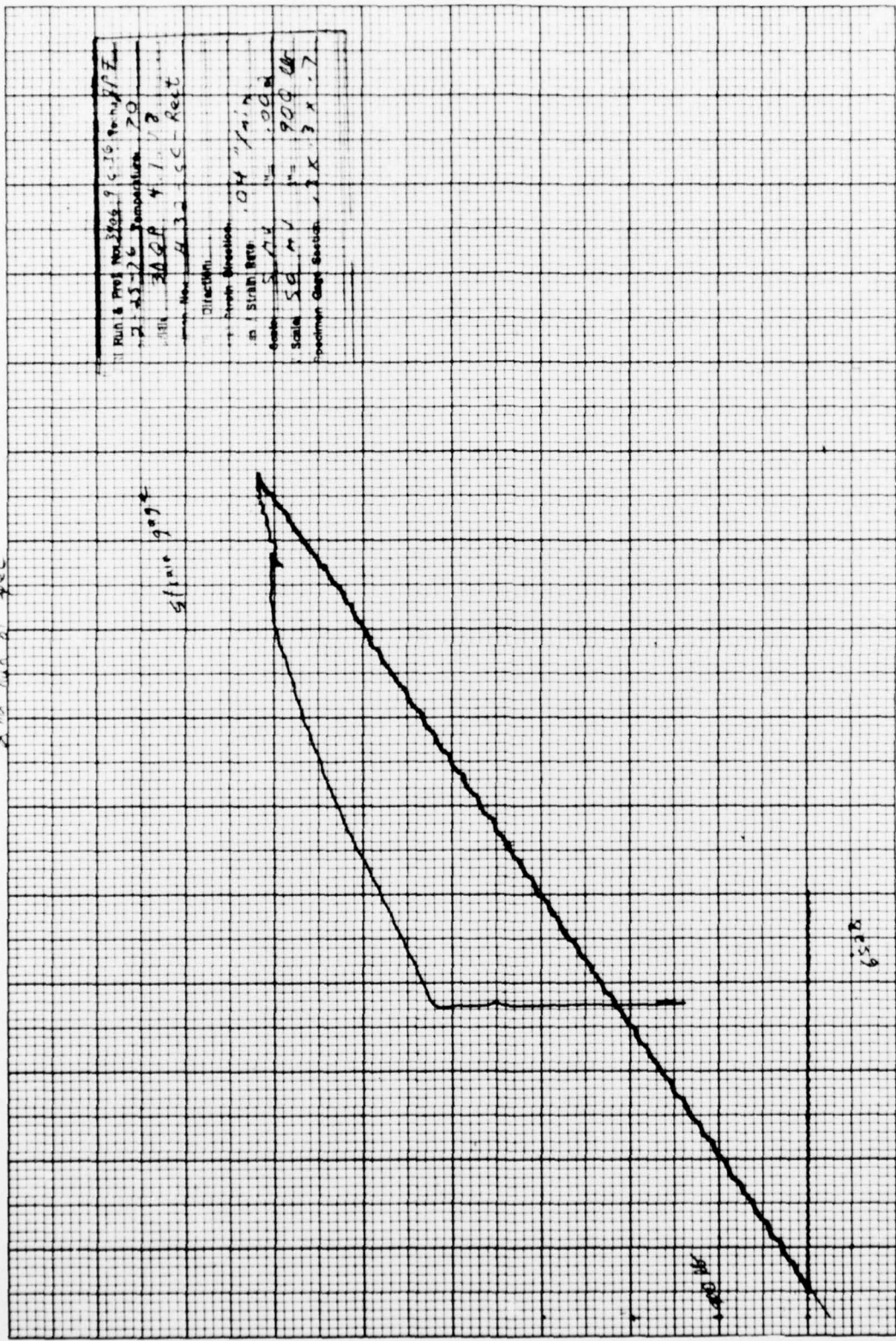


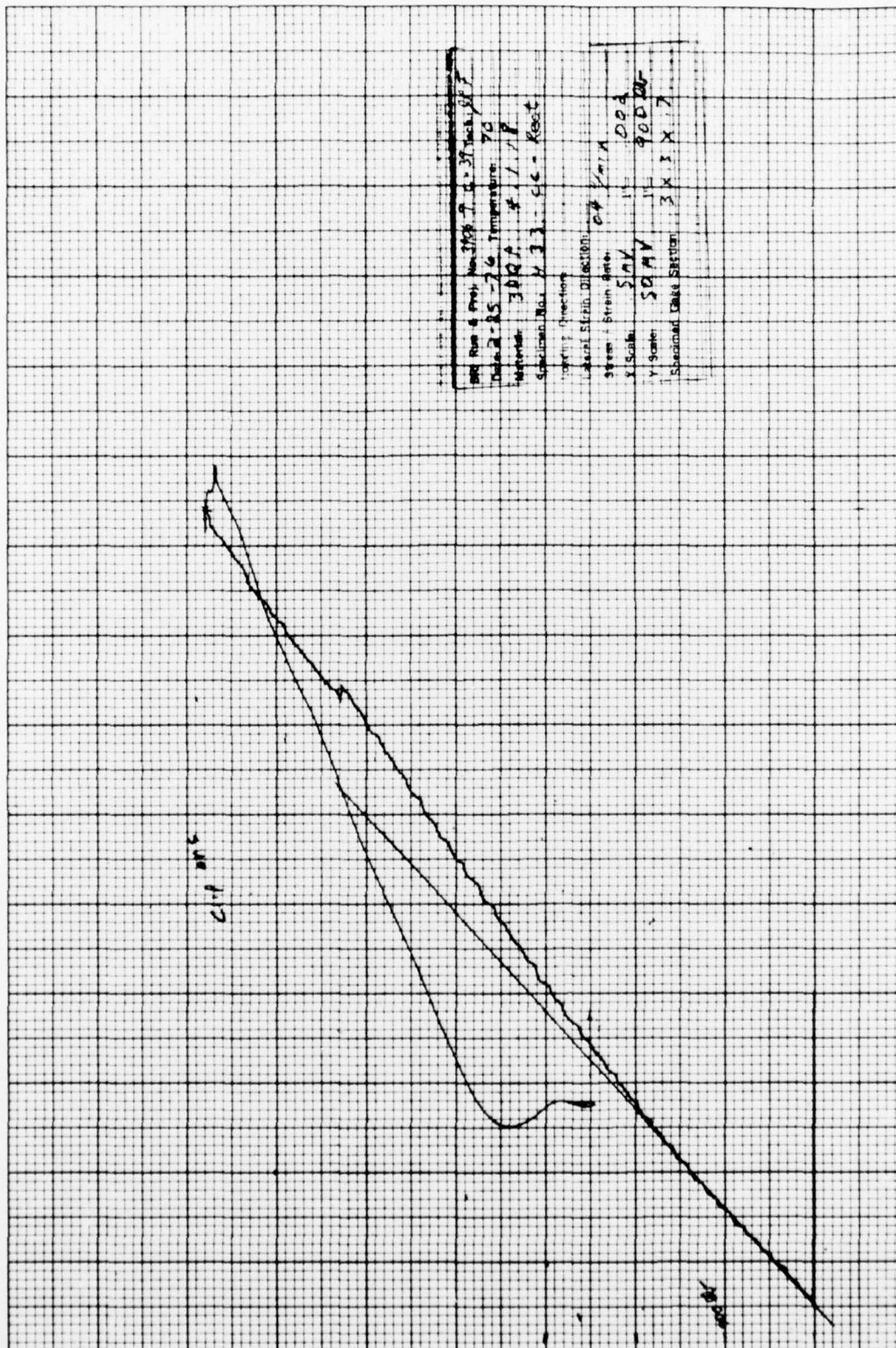
Figure A82 Test Results for Specimen H32-CC-Rect

2nd Run of Spec



Run & Prod No. 200-9 6-16 9-16-72
 2-15-72 Temperature 70
 3000 4 1 1 2
 No. H 32 SC-Rect
 Direction
 in 1 Start Bed 104 1/2 in
 Scale 50 m V 1 900 00
 Depthm Gage Scale 2 X 3 X 7

Fig. A83 Test Results for Specimen H 32-SC-Rect



Test Run # 306
 Date 2-25-76
 Temperature 70
 Specimen 306
 Specimen Size 1/2" x 1/2" x 1/2"
 Specimen Orientation 0°
 Specimen Strain Rate 0.01 in/in
 Specimen X Scale 50X
 Specimen Y Scale 50X
 Specimen Z Scale 50X
 Specimen Load Section 3 X 3 X 7

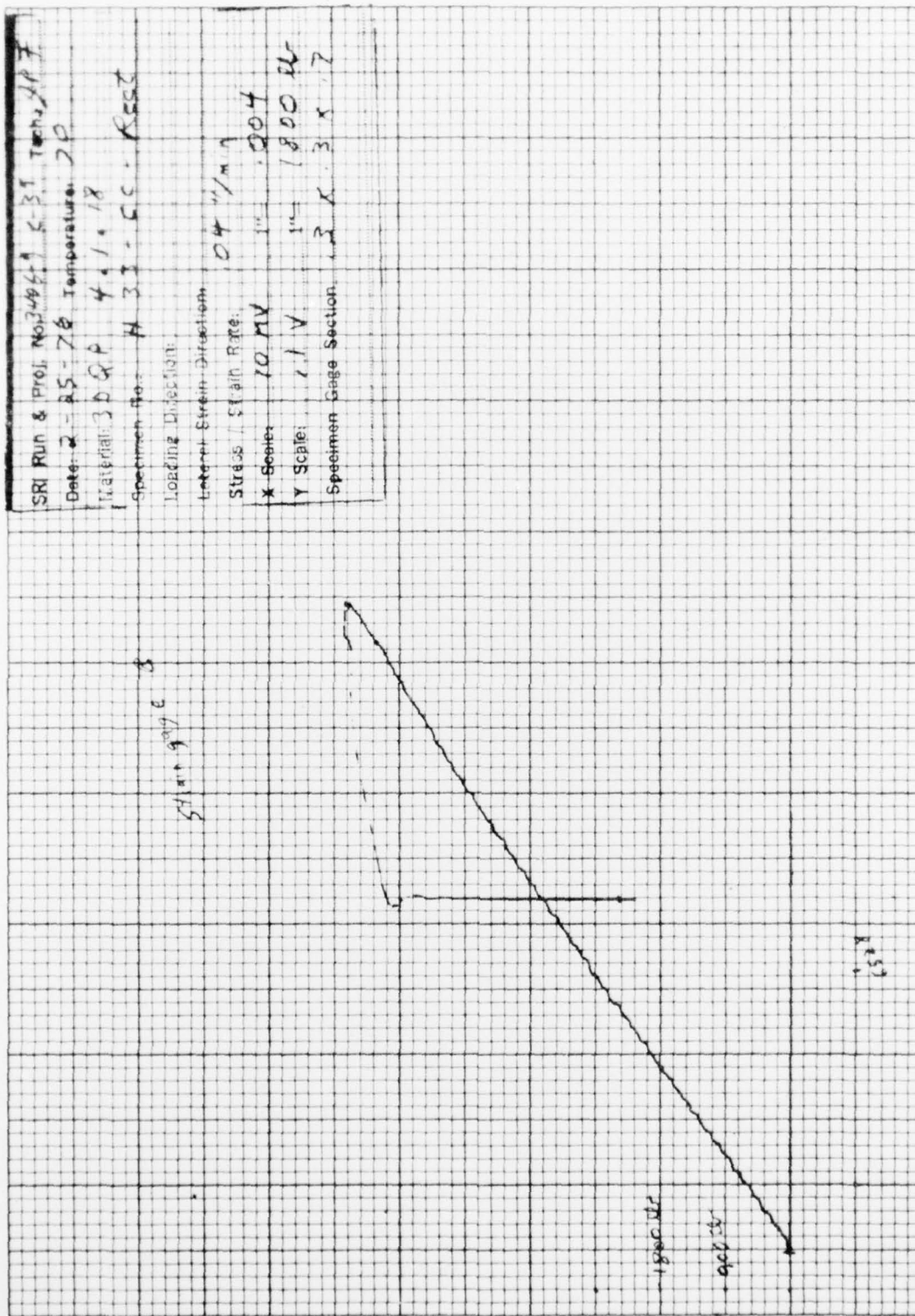
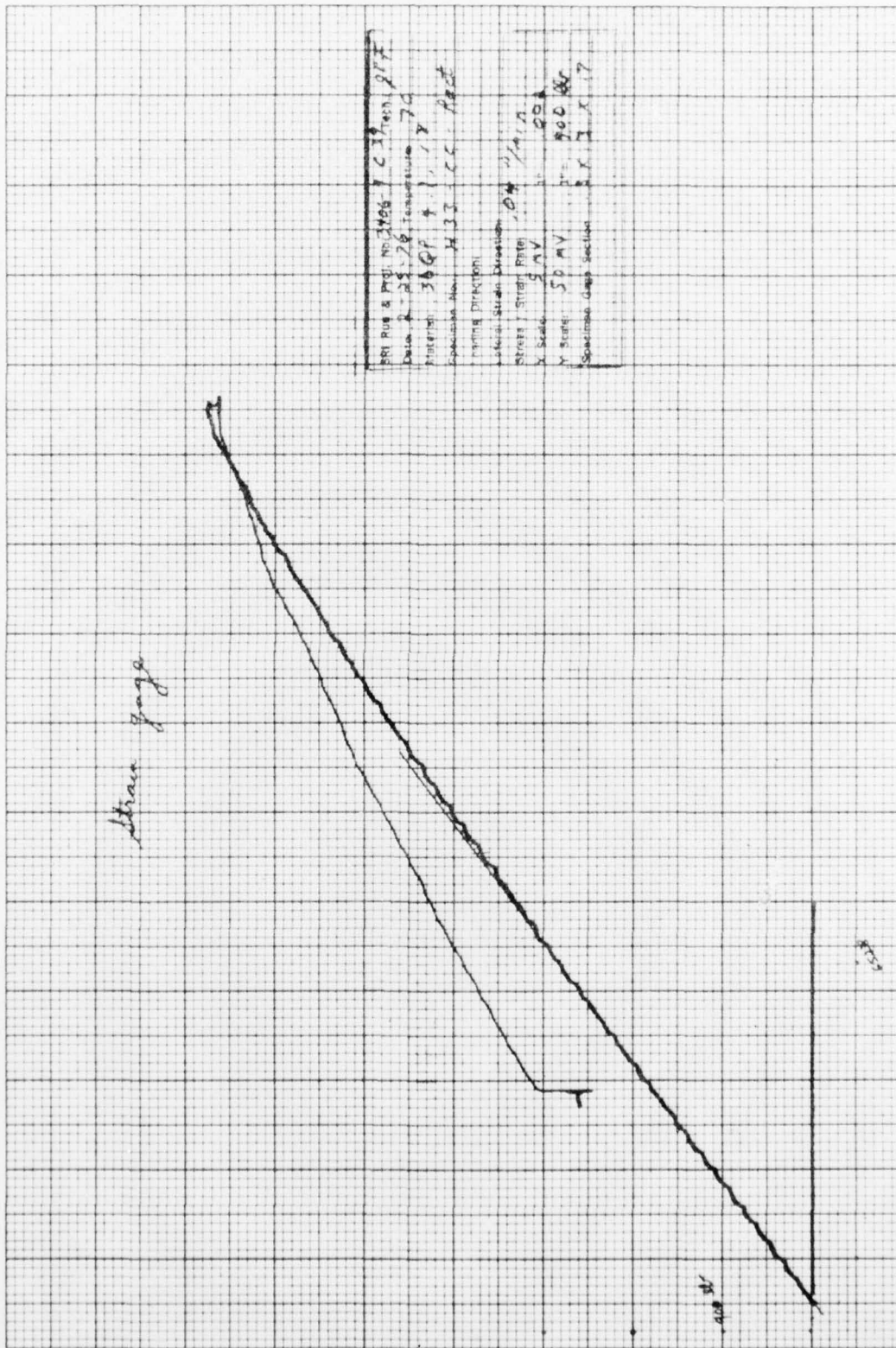


Figure A85 Test Results for Specimen H 33-CC-Rect



BPI Pub & Prod No 3406 C 39 Rev 877
 Date: 2-28-78 Temperature: 70
 Pressure: 36 QP + 1.18
 Specimen No: H 33 CC Rect
 Loading Direction: 0° 1/4 in
 Strain / Strain Rate: 5 MV 20
 X Scale: 50 MV 100 AC
 Y Scale: 50 MV 1.7 in
 Specimen Gage Section: 1.7 in 1.7

Name: A 6000 Results for Specimen H 33 - CC - Rect

APPENDIX B

Ultrasonics

ULTRASONICS

The classical theory of the propagation of waves in elastic solid media describes the longitudinal motion of an element between two adjacent cross sections in a long prismatical bar by the equation

$$\frac{\partial^2 u}{\partial t^2} = V_0^2 \frac{\partial^2 u}{\partial x^2}$$

where

u = longitudinal displacement
 x = distance along the longitudinal axis of the bar
 t = time
 $V_0 = (E/\rho)^{1/2}$
 E = modulus of elasticity, and
 ρ = mass per unit volume

The general solution to the equation of motion can be written in the form

$$u = f(x + V_0 t) + g(x - V_0 t)$$

and is seen to represent two waves traveling in opposite directions along the longitudinal axis of the bar with constant velocity V_0 . Thus V_0 is the velocity of wave propagation and depends only on the modulus of elasticity and the density. It must be kept in mind, of course, that the assumption of a long prismatical bar infers that the transverse dimensions of the bar are small when compared to the length, and it is also assumed that the cross sections of the bar remain plane during deformation.

Sound transmission measurements for flaw detection and velocity are made utilizing a Sperry UM721 reflectoscope. The pulsed echo, reflection technique is used for detecting flaws. At 1 MHz, propagation is limited to a distance of approximately 12 inches -- or to state it another way -- a discontinuity at a depth below 6 inches of the surface is out of range. Sound velocity is determined by the through-transmission, elapsed-time method using the Sperry UM721 as a pulser unit and a Tektronix 564 oscilloscope complete with a 3B3 time base unit (time base precision of 1%) and a 3A3 vertical amplifier as measuring devices. Using this

method, a short pulse of longitudinal mode sound is transmitted through the specimen. An electrical pulse originates in a pulse generator and is applied to a ceramic piezoelectric crystal (SFZ). The pulse generated by this crystal is transmitted through a short delay line and inserted into the specimen. The time of insertion of the leading edge of this sound beam is the reference point on the time base of the oscilloscope which is used as a "high-speed stop watch". When the leading edge of this pulse of energy reaches the other end of the specimen, it is displayed on the oscilloscope. The difference between the entrance and exit times is used with the specimen length in calculating ultrasonic velocity. A short lucite delay line is used to allow time isolation of the sound wave from electrostatic coupling and to facilitate clear presentation of the leading edge of the entrant wave resulting in a more accurate "zero" in time. Reading time to initial rise portion of the sound wave gives some freedom from frequency distortion. This ultrasonic test system utilizes a longitudinal wave motion at frequencies near 1 MHz for graphites. A block diagram of the ultrasonic velocity measuring apparatus is shown in Figure B-1.

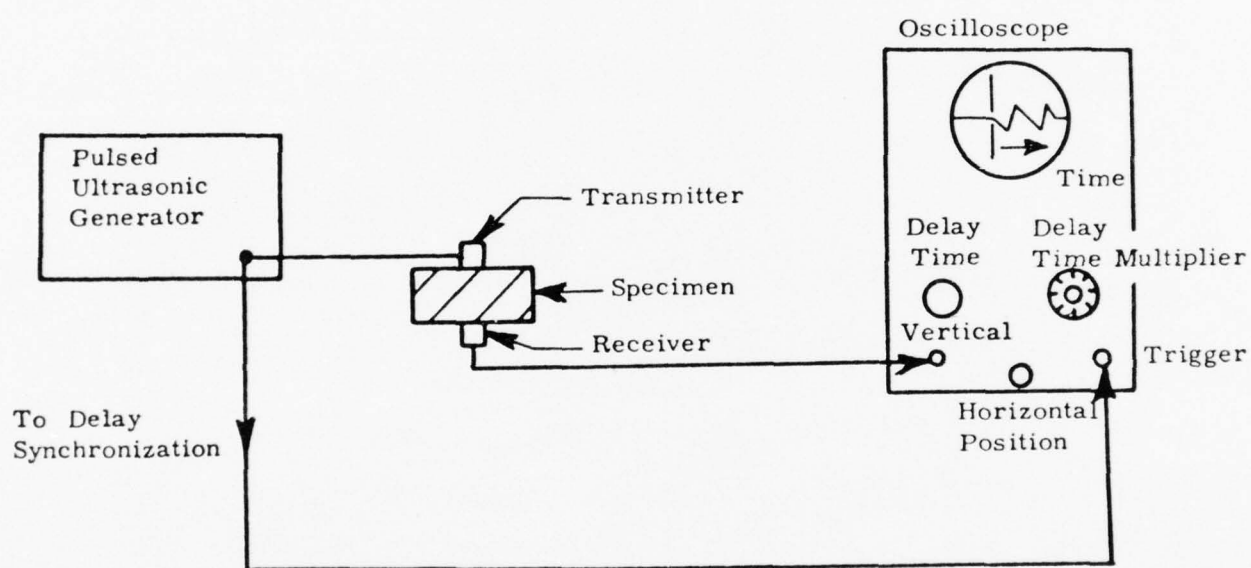


Figure B-1. Block Diagram of Ultrasonic Velocity Measuring Apparatus

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