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TENSILE TESTS OF TYPE 305 STAINLESS STEEL MINE SWEEPING WIRE ROPE

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**Sponsored by
Naval Coastal Systems Center
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1. INTRODUCTION

The tensile tests described in this report were performed by the Metallurgy Division of the National Institute of Standards and Technology (NIST) at the request of the Naval Coastal Systems Center, Panama City, Florida.

The Naval Coastal Systems Center submitted to NIST approximately 360 feet of each of two different AISI 305 stainless steel wire ropes for testing. Both wire ropes were nominally 5/8 inch in diameter. One was stated as having a 6 x 19 configuration and the other a 7 x 7 configuration. The first number in such a designation indicates the number of strands in the wire rope and the second number indicates how many wires there are per strand¹. For example, the wire rope with a 6 x 19 configuration consists of six strands of 19 wires each. As shown later, the wire rope stated to have a 7 x 7 configuration actually had a 6 x 7 configuration with an independent wire rope core (IWRC)². The core is one of the three basic parts of a wire rope. The other two are the wires and the strands. The core is the foundation upon which the wire rope is constructed. It must provide adequate support for the strands when the wire rope is in service. The core may be comprised of steel or fiber. In the case of both of the submitted wire rope samples, the core consisted of an independent wire rope.

2. PURPOSE

It was requested by the Naval Coastal Systems Center that NIST determine the tensile strength of each of the two wire rope samples.

3. CHARACTERIZATION OF THE WIRE ROPE SAMPLES

Prior to determining the tensile strength of the wire rope samples, some preliminary characterization was performed in order to verify that the wire ropes were as stated.

3.1 Metallographic Examination

A cross section from each of the two wire rope samples was prepared in a metallographic mount and examined to confirm the configuration. Photomicrographs of the wire ropes stated to have a 7 x 7 configuration and a 6 x 19 configuration are shown in figures 1 and 2, respectively. Both wire ropes have an independent wire rope core as stated above. The 6 x 19 wire rope is configured as stated. The wire rope stated to have a 7 x 7 configuration actually has a 6 x 7 configuration with an independent wire rope core. The independent wire rope core can be seen in figure 2.

Representative etched fields of individual wires from each of the two wire rope types are shown in figures 3 and 4 for the 6 x 7 and the 6 x 19 configurations, respectively. The microstructures appear to be normal for cold worked AISI 305 stainless steel³. The center wire of the independent wire rope core of the 6 x 7 wire rope exhibited a somewhat finer grain size

than the other wires. Microstructure representative of the center wire of the independent wire rope core is shown in figure 5.

A longitudinal specimen from each of the two wire rope configurations was examined metallographically. Several apparent lap seams were detected in the section of the 6 x 19 wire rope. They are similar in appearance to cracks. Two examples from wires from different strands are shown in figures 6 and 7. In the plane of the specimen, the apparent lap seams measure 0.005 and 0.006 inch in figures 6 and 7, respectively. These lengths represent about 11 and 13 percent, respectively, of the diameter of the wire. No lap seams were found in the section of the 6 x 7 wire rope.

3.2 Brooming

Because of the apparent misnaming of the 6 x 7 wire rope, a small length of this sample was broomed⁴ to determine the twist direction of each strand of wires and to confirm that there was indeed an independent wire rope core. Brooming consists of spreading the strands apart at the end of a length of wire rope. A photograph of the broomed end is shown in figure 8. The straight, untwisted independent wire rope core can be seen in the center.

3.3 Hardness Measurements

Knoop microhardness measurements at a load of 1000 grams force were made on representative wire from the cross sections of both wire rope samples that are shown in figures 1 and 2. Three measurements were made on each of four wires from the 6 x 7 specimen. Two measurements were made on each six wires from the 6 x 19 specimen. The average results of the Knoop hardness measurements and the approximate Rockwell C (HRC) equivalent values for each specimen are given in Table 1.

3.4 Chemical Analysis

It was confirmed by the NIST Center for Analytical Chemistry that the chemical composition of both wire rope samples corresponded to that specified for AISI 305 stainless steel in the 9th edition of the Metals Handbook⁵. The specified composition is as follows: carbon - .12% max, manganese - 2.00% max, silicon - 1.00% max, chromium - 17.0-19.0%, nickel - 10.5-13.0%, phosphorus - 0.045 % max, and sulfur - 0.03% max.

4. TENSILE TESTING

4.1 Specimen Preparation

Four specimens of each the 6 x 7 and the 6 x 19 wire ropes were prepared for testing to determine breaking strengths. Terminals with closed epoxy resin filled type sockets were placed on each end of each cable sample by a commercial cable company in accordance with NIST instructions. The Wire Rope User's Manual, Second Edition (1981), published by the American Iron and Steel Institute, requires a minimum length of 36 inches between sockets for tensile specimens for wire rope with diameters of from 1/8 through 3 inches⁶. There were 36 inches of unconstrained wire rope between the sockets. This length

was the minimum allowed by the Wire Rope User's Manual. A photograph of one of the terminals is shown in figure 9.

4.2 Tensile Tests

Each of the specimens was tested in tension with a Satec Systems vertical tensile testing machine having a capacity of 25000 kg (55000 lb). Even though the shortest allowable specimens were used, the maximum opening between the upper and lower cross heads of the testing machine was insufficient to accommodate the wire rope specimens. Therefore, a fixture was designed and built to effectively increase the working distance between cross heads. The specimens were attached to the machine for testing with a clevis/pin arrangement at both top and bottom. A typical specimen setup is shown in figure 10. Tests were run at a constant cross head speed of 0.2 inch per minute. Time vs cross head displacement data were recorded with a computer controlled data acquisition system at the rate of one data point every 2 seconds.

Three specimens of each wire rope configuration were tested until total separation of all the wires between the terminals had occurred. The fourth specimen of each configuration was tested until the fracture at maximum load had occurred. The maximum loads sustained by the specimens during testing are presented in the table 2. Load/displacement plots for all eight specimens are presented in figures 11 through 18. Photographs of the tested specimens are shown in figures 19 through 26.

Failure of the 6 x 19 wire rope samples generally initiated with one or a few individual wires fracturing. These fractures were audible and they produced small jogs in the load/displacement curves (figures 15 through 18). For instance, for specimen 6 x 19 - 1 (figure 15), the first two evident wire fractures occurred at loads of approximately 10000 and 18500 pounds. Essentially simultaneous fracture of several strands occurred at the maximum load sustained by the cable. At this point, the sustained load dropped to nearly zero, although the cross heads continued to move apart. Displacement from the point of the first application of load to first strand fracture ranged from 1.7 to 1.8 inches. After further cross head displacement of 0.1 to 0.2 inches, the remaining strands of cable began to sustain load again. The apparent reason for the load having dropped so drastically when the first strands fractured was that with the fractured strands no longer constraining them, the remaining strands were free to at least partially straighten, thereby becoming effectively longer than they had been. The maximum loads reached subsequently were lower than the initial maximum load because the effective cross sectional area of the wire rope had been reduced. Total displacement from the point of initial application of load to final fracture of the last strand for specimens 6 x 19 - 1 through 6 x 19 - 3 ranged from 4.7 to about 5 inches.

In the testing of the 6 x 7 specimens, there was no indication that failure initiated by the fracture of individual wires or a few wires (figures 11 through 14). The first indication of failure was the fracture of several strands. As in the 6 x 19 cable specimens, after initial failure, the load dropped to nearly zero before again increasing as the cross heads continued to separate. Displacement from the point of the first application of load to

the point of the first application of load to initial strand fracture ranged from about 1.9 to 1.95 inches for the 6 x 7 specimens. Total displacement from the point of the first application of load to final fracture of the last strand for specimens 6 x 7 - 1 through 6 x 7 - 3 ranged from 4.05 to 4.40 inches.

5. DISCUSSION AND CONCLUSIONS

Both wire rope samples were verified to be composed of AISI 305 stainless steel as stated. The configurations of the two wire ropes are 6 x 7 and 6 x 19, both having an independent wire rope core. The stated configurations of the samples when received at NIST were 7 x 7 and 6 x 19.

The average maximum tensile load supported by the 6 x 19 configured wire rope specimens before fracture was 33600 pounds, whereas the average maximum load supported by the 6 x 7 wire rope was 33150 pounds, or 450 pounds less. Military Specification MIL-W-18242B(SH)⁷ calls for a minimum breaking strength of 32000 pounds for 5/8 inch diameter AISI 305 stainless steel 6 x 19 and 7 x 7 cable with an independent wire rope core. Even though the wire rope listed as being 7 x 7 appears to be 6 x 7, both wire ropes satisfy the tensile requirements of Mil-Spec MIL-W-18242.

The flaws detected in the 6 x 19 cable sample consisting of apparent lap seams are not uncommon in wire rope. Regardless of these flaws, the material had more than adequate tensile properties. Both hardness and microstructures are typical for cold worked AISI 305 stainless steel.

REFERENCES

1. Wire Rope Users Manual, Second Edition, American Iron and Steel Institute, Washington, DC, 1981, chapter 3.
2. Ref. 1, chapter 2.
3. Atlas of Microstructures of Industrial Alloys, Volume 7, Metals Handbook, 8th Edition, American Society for Metals, Metals Park, OH, 1972, pp. 133-136.
4. Ref. 1, p. 112.
5. Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals, Volume 3, Metals Handbook, 9th Edition, American Society for Metals, Metals Park, OH, 1980, p. 5.
6. Ref. 1, p. 77.
7. Wire Rope and Wire Rope Assemblies; Single Leg-Corrosion Resisting Steel, Minesweeping, Military Specification MIL-W-18242B(SH), 13 October 1987, p. 4.

Table 1. Results of Hardness Measurements on Wire Rope Specimens.

<u>Specimen</u>	<u>Location</u>	<u>Average HK₁₀₀₀^a</u>	<u>HRC Equivalent^b</u>
6 x 7	Center wire, IWRC	421	43
6 x 7	Outer wire, IWRC	398	40
6 x 7	Center wire, outer strand	400	41
6 x 7	Outer wire, outer strand	385	39
6 x 19	Center wire, center strand, IWRC	437	44
6 x 19	Outer wire, center strand, IWRC	460	46
6 x 19	Center wire, outer strand, IWRC	454	46
6 x 19	Outer wire, outer strand, IWRC	415	42
6 x 19	Outer wire, outer strand	420	43
6 x 19	Intermediate wire, outer strand	439	44

^a HK₁₀₀₀ = Knoop hardness at a load of 1000 grams force

^b HRC = Rockwell hardness, C scale

Table 2. Results of Tensile Tests of Wire Rope Specimens.

<u>Specimen Number</u>	<u>Maximum Load Sustained, lbs^a</u>
6 x 7 - 1	33200
6 x 7 - 2	33200
6 x 7 - 3	33100
6 x 7 - 4	33100
Average 6 x 7	33150
6 x 19 - 1	33800
6 x 19 - 2	33500
6 x 19 - 3	33800
6 x 19 - 4	33300
Average 6 x 19	33600

^a Values rounded to the nearest 100 pounds.

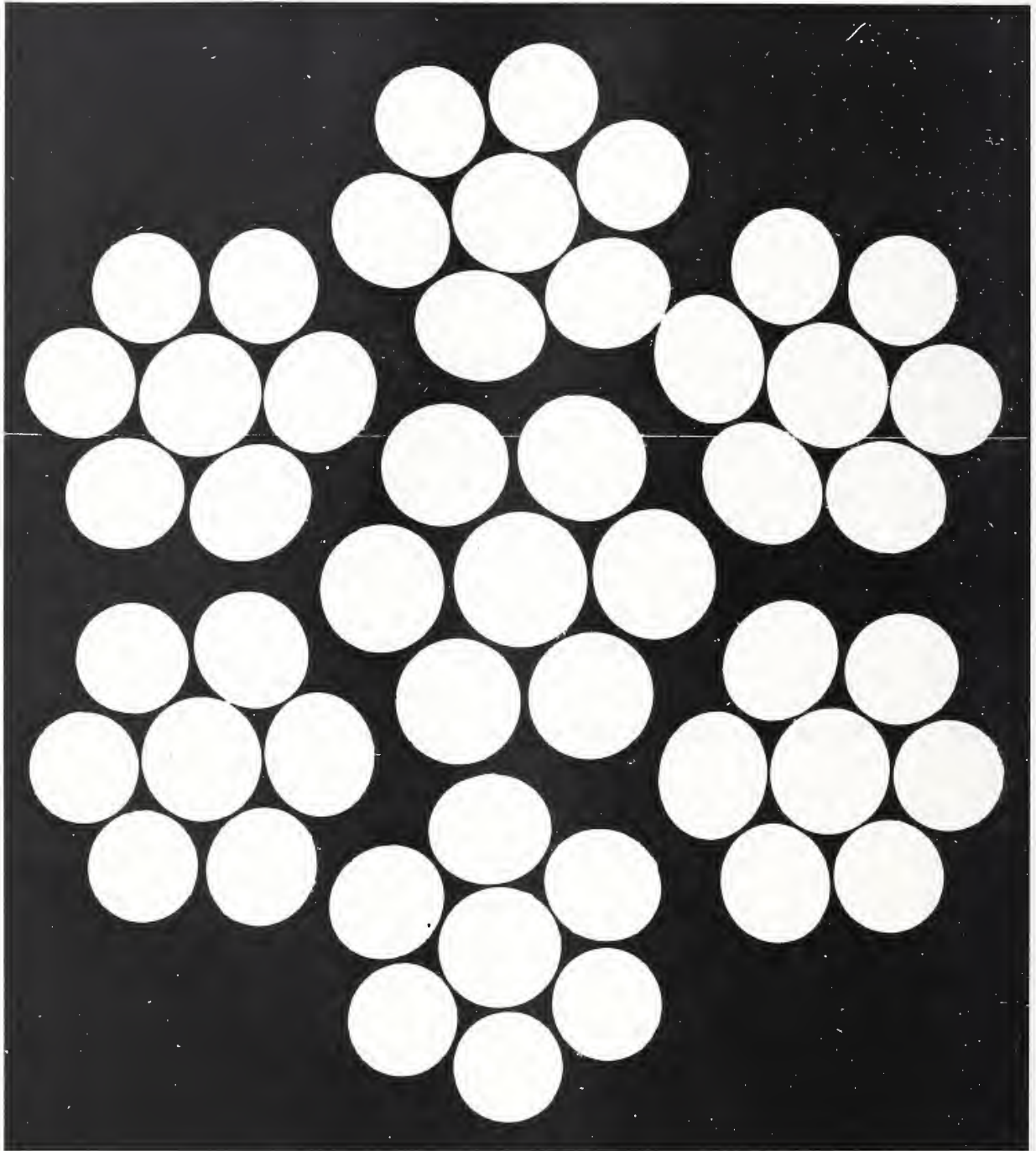


Figure 1. Polished cross section through the 6 x 7 wire rope.
X 10

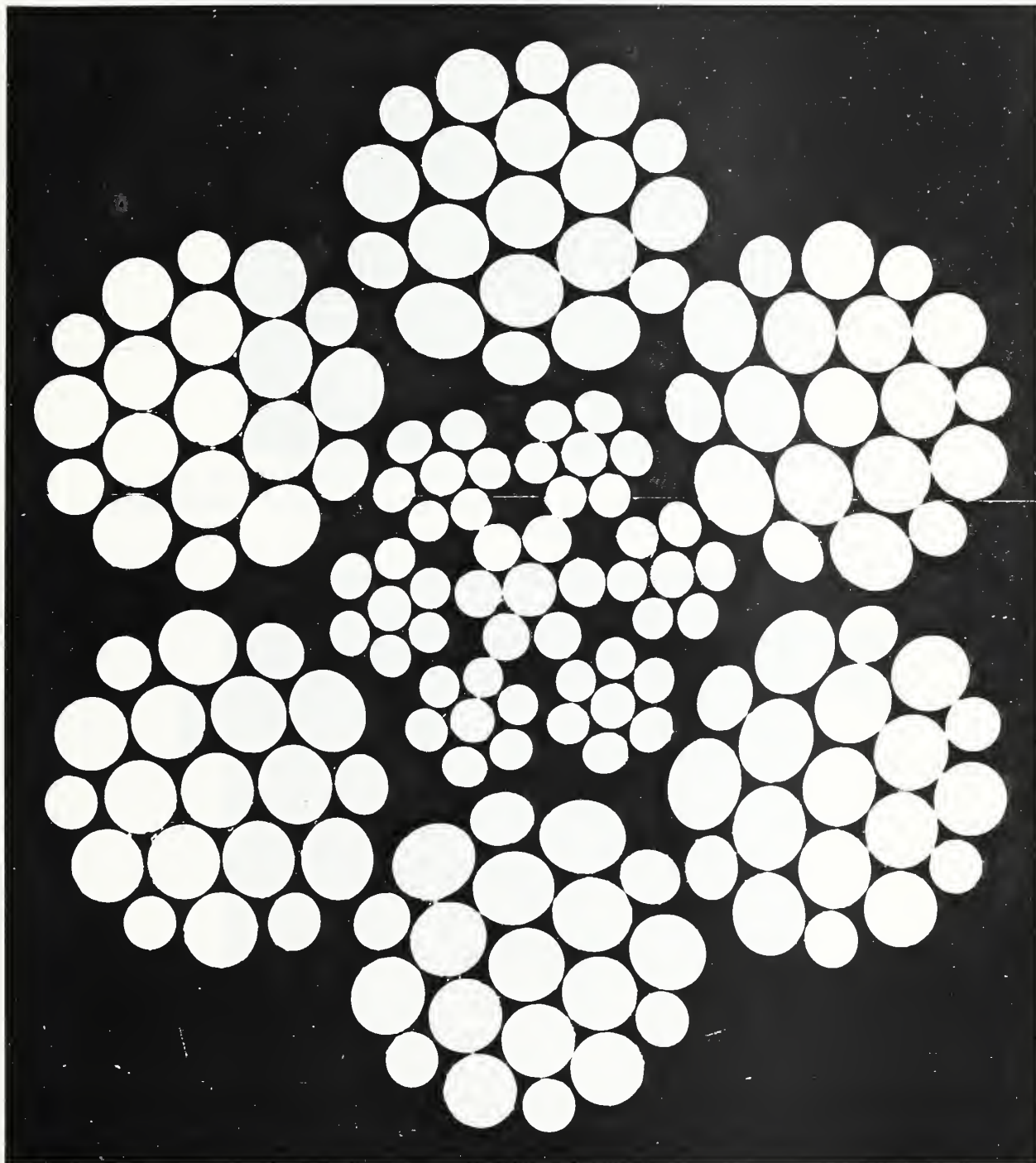


Figure 2. Polished cross section through the 6 x 19 wire rope.
X 10



Figure 3. Representative microstructure of a wire from one of the outside strands of the 6 x 7 wire rope sample. Etchant: Glyceregia X 250

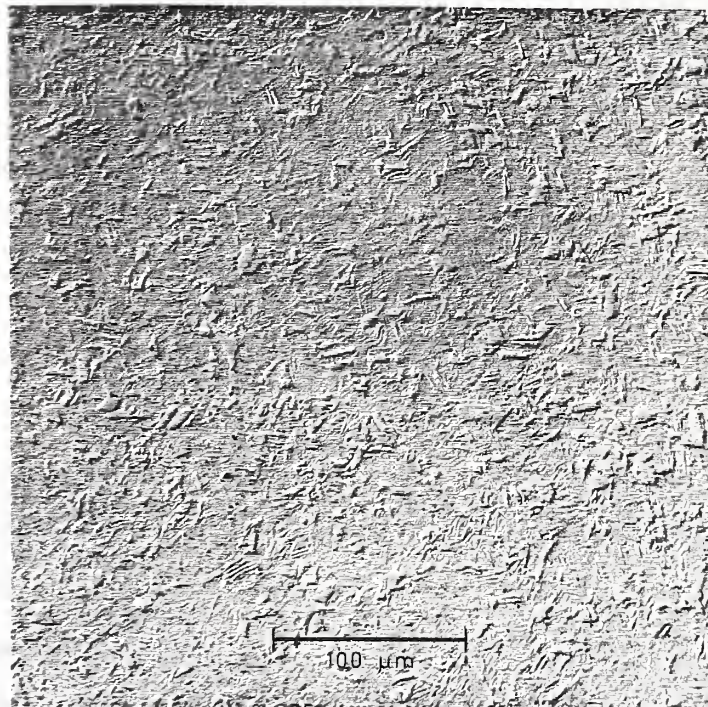


Figure 4. Representative microstructure of a wire from the 6 x 19 wire rope sample. Etchant: Glyceregia X 250

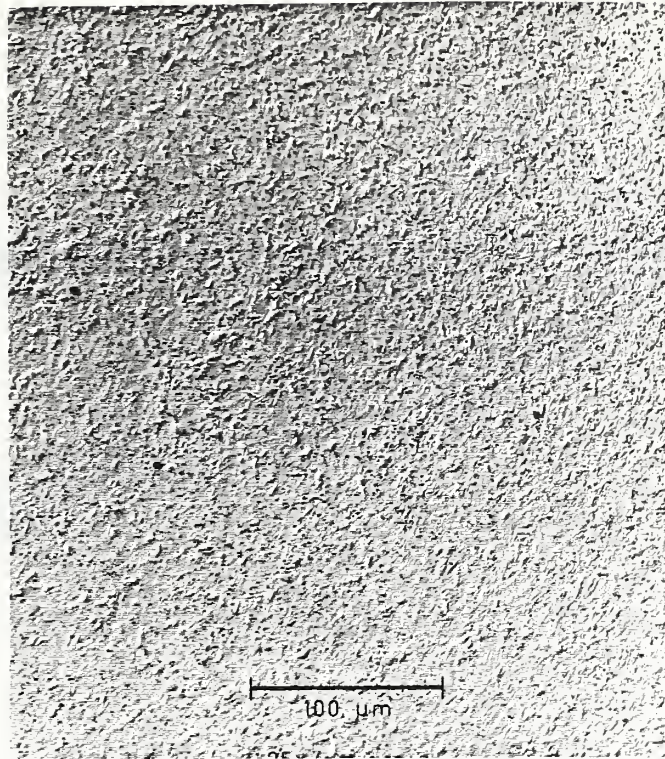


Figure 5. Representative microstructure of the center wire of the independent wire rope center of the 6 x 7 wire rope.
Etchant: Glyceregia X 250

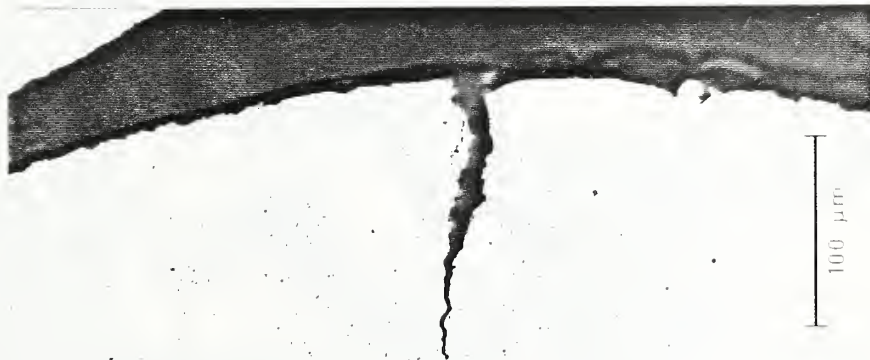


Figure 6. Longitudinal section through a wire from the 6 x 19 wire rope showing apparent lap seam.
Etchant: Glyceregia X 250

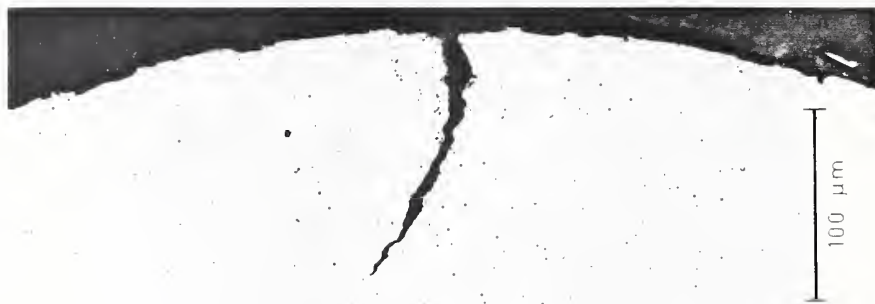


Figure 7. Longitudinal specimen through a wire from a strand of the 6 x 19 wire rope different from the strand containing the wire shown in figure 6.
Etchant: Glyceregia X 250



Figure 8. Broomed end of a specimen of the 6 x 7 wire rope.



Figure 9. Terminal configuration for tensile tests (scale in inches).

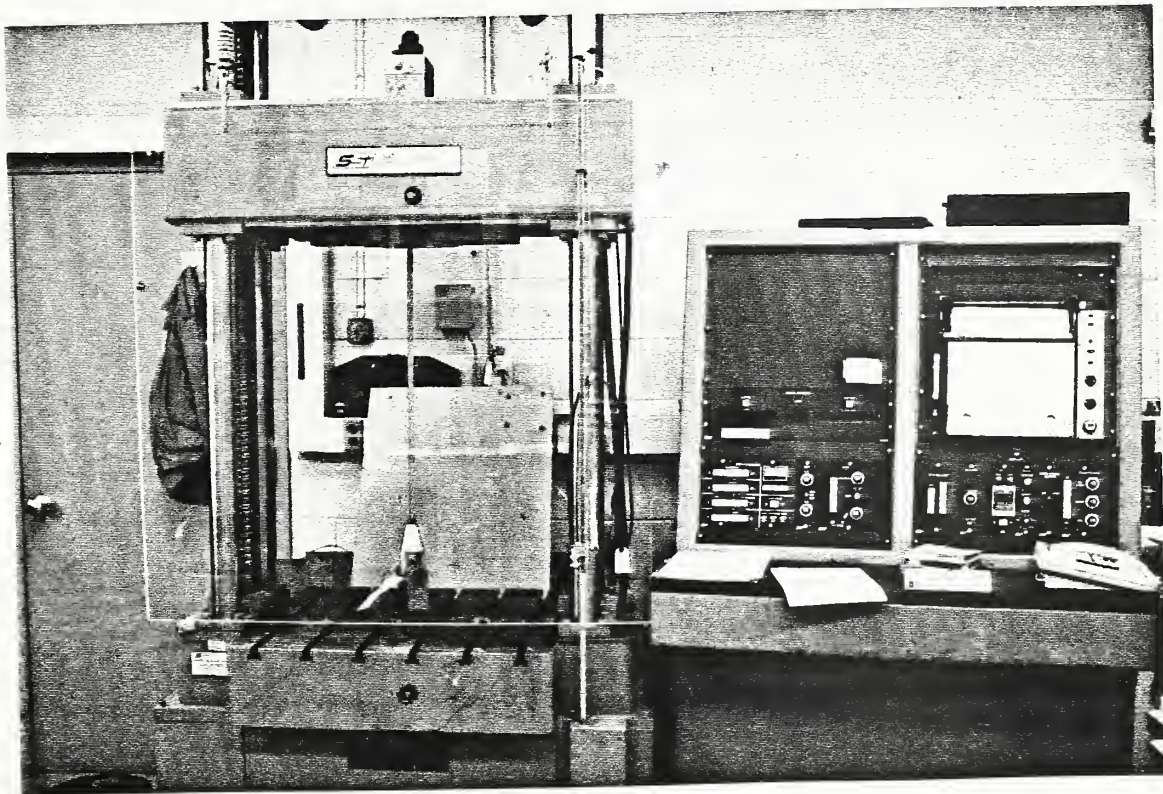


Figure 10. Specimen set up for testing in tensile testing machine.

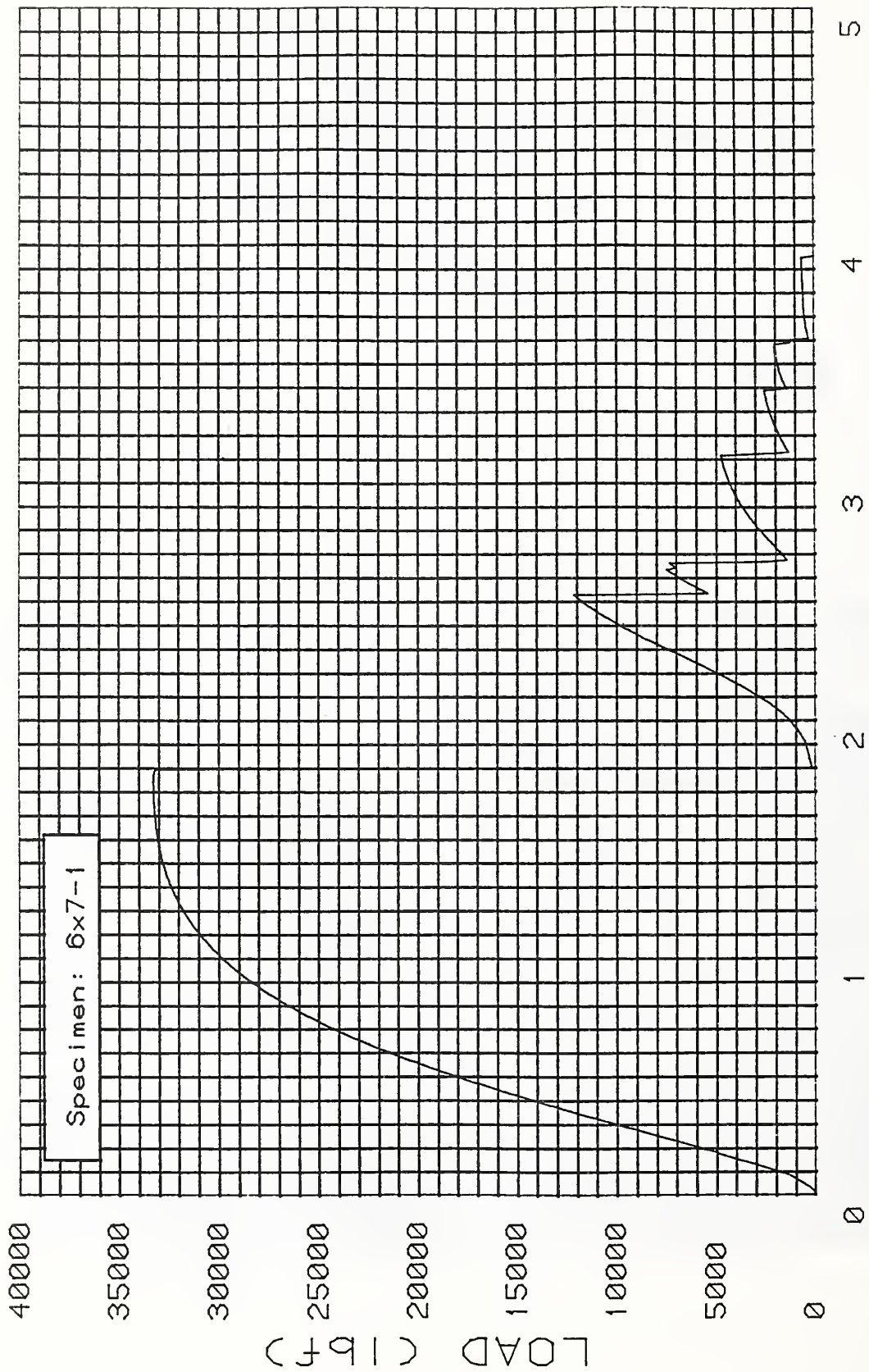


Figure 11. Load/displacement curve for specimen 6 x 7 - 1.

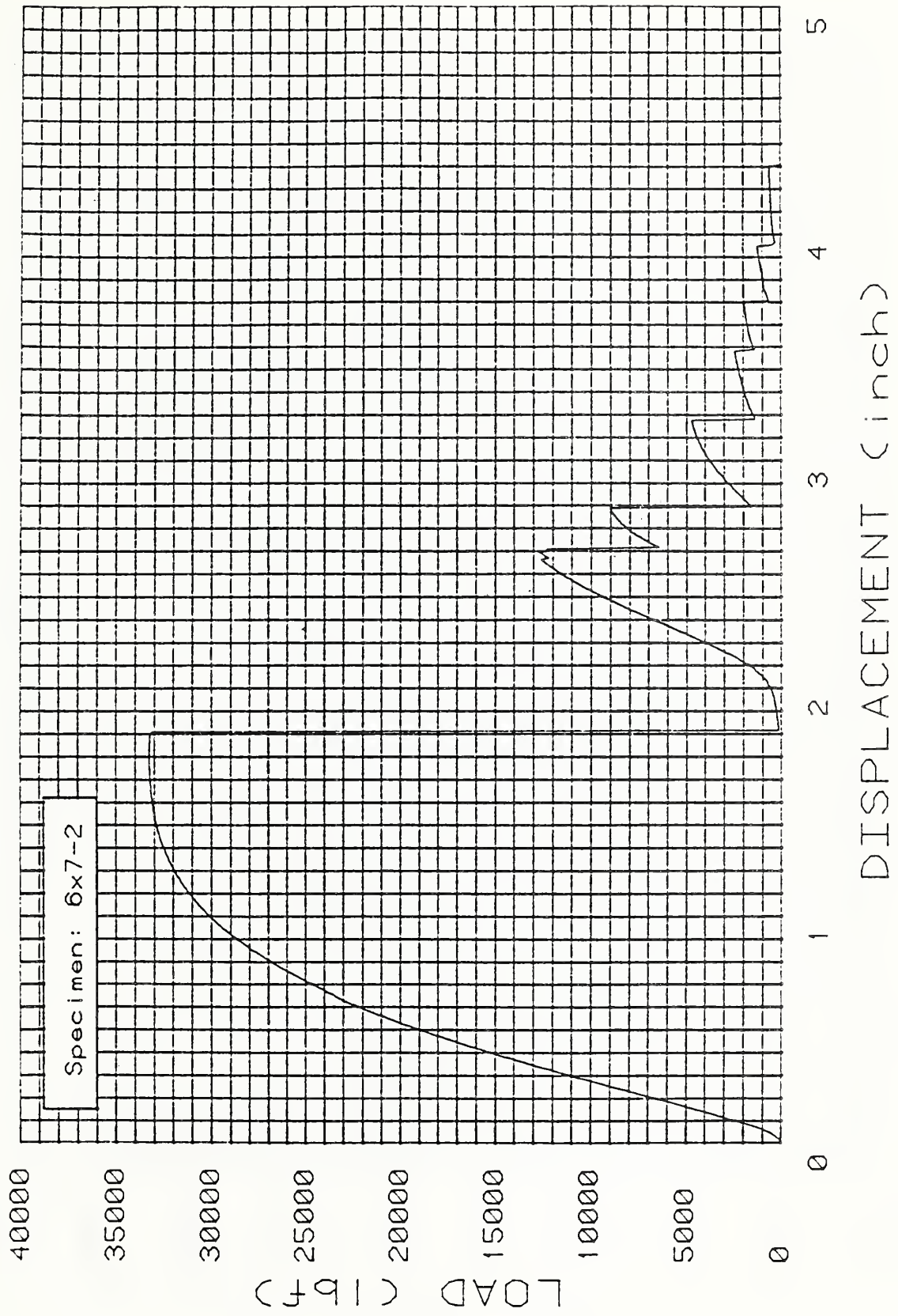
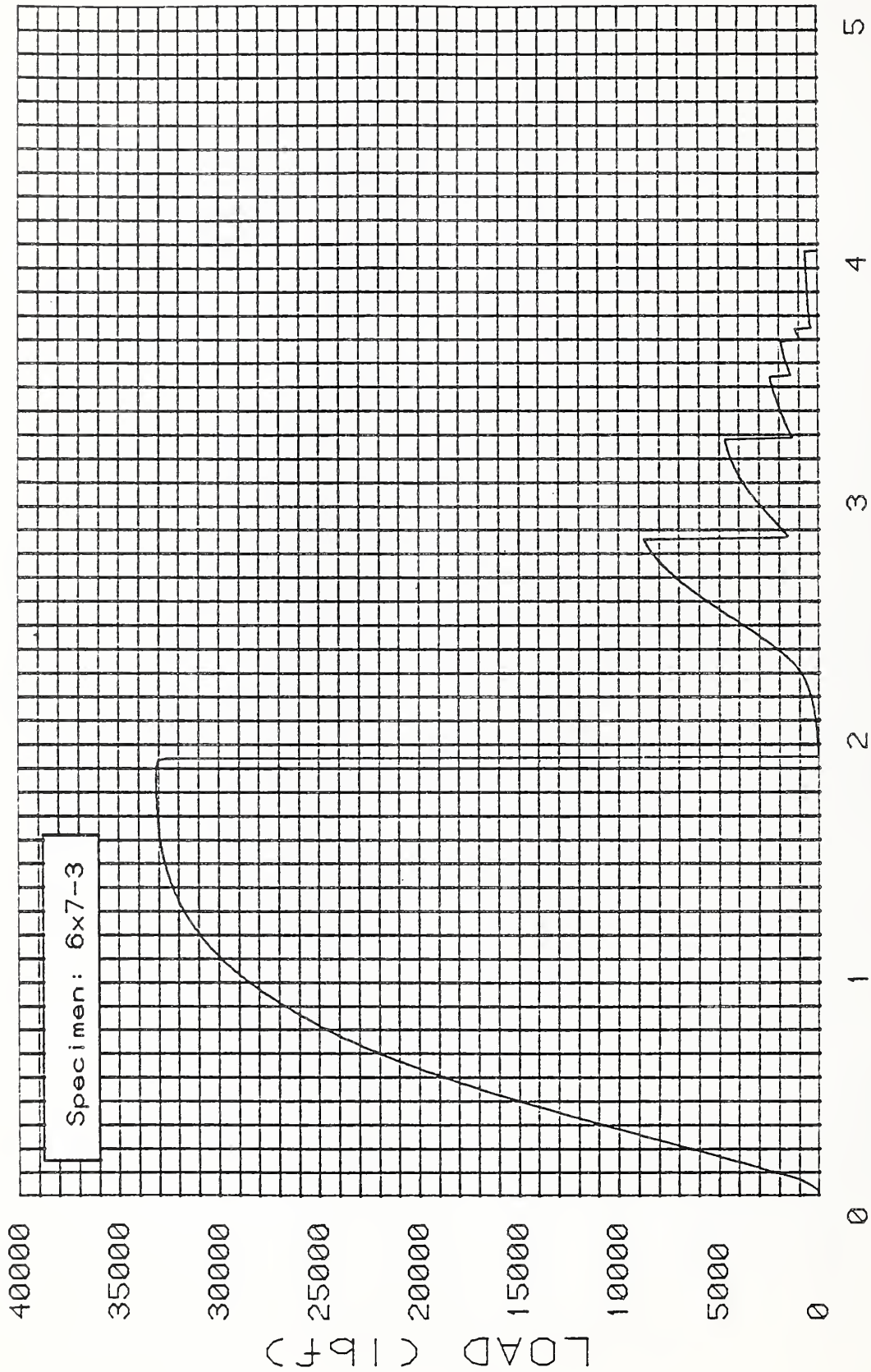


Figure 12. Load/displacement curve for specimen 6 x 7 - 2.



DISPLACEMENT (inch)

Figure 13. Load/displacement curve for specimen 6 x 7 - 3.

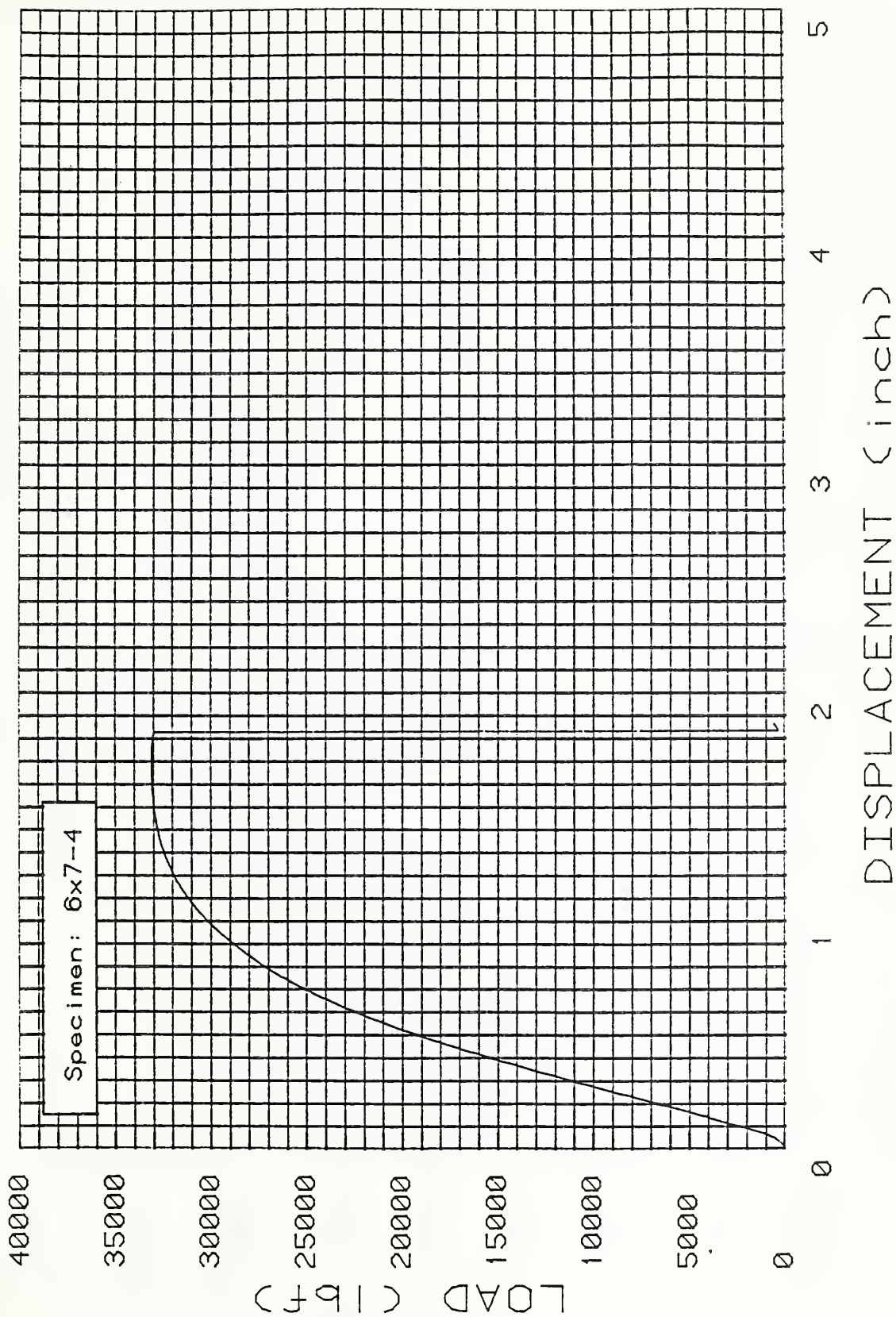
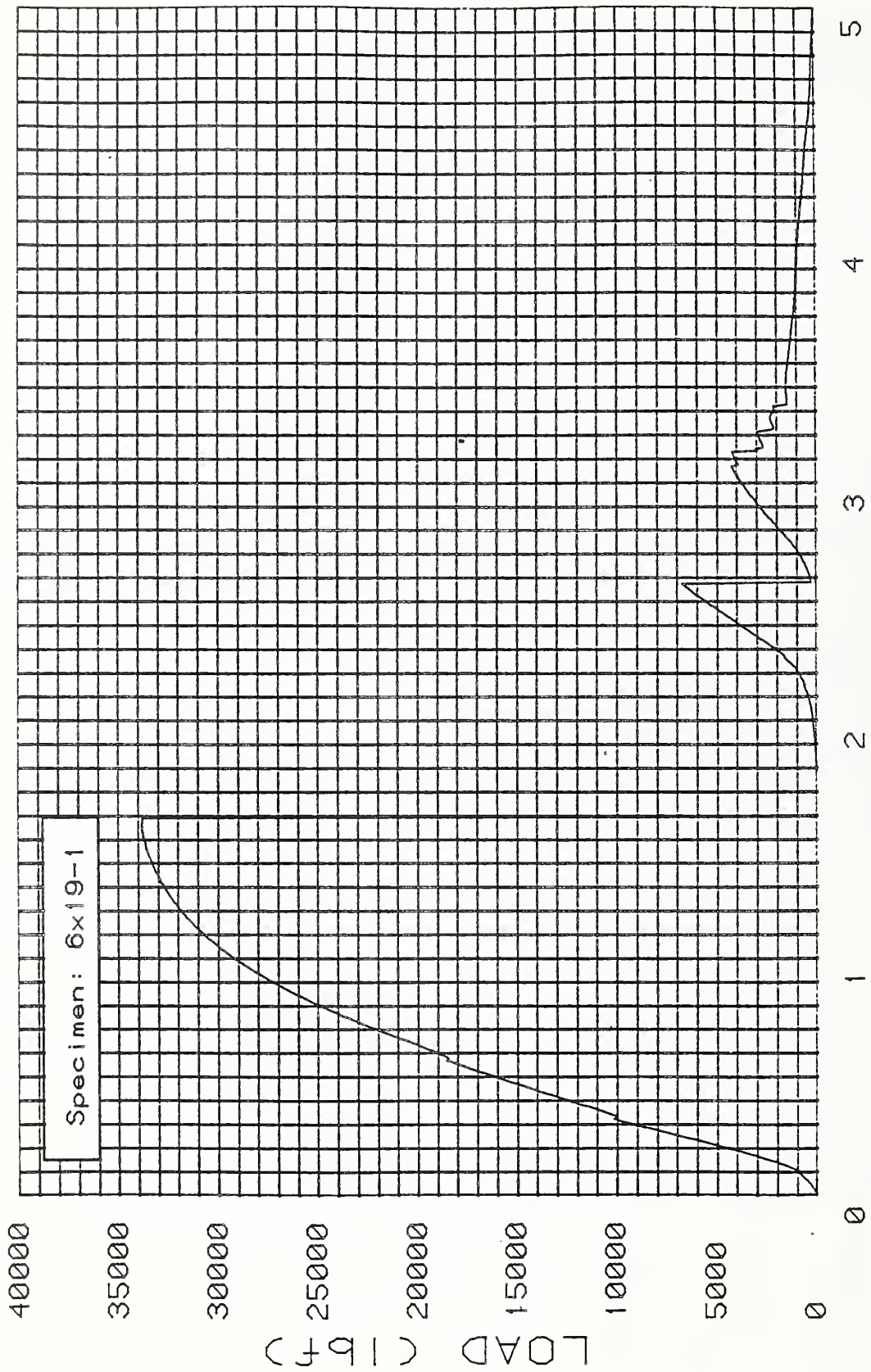
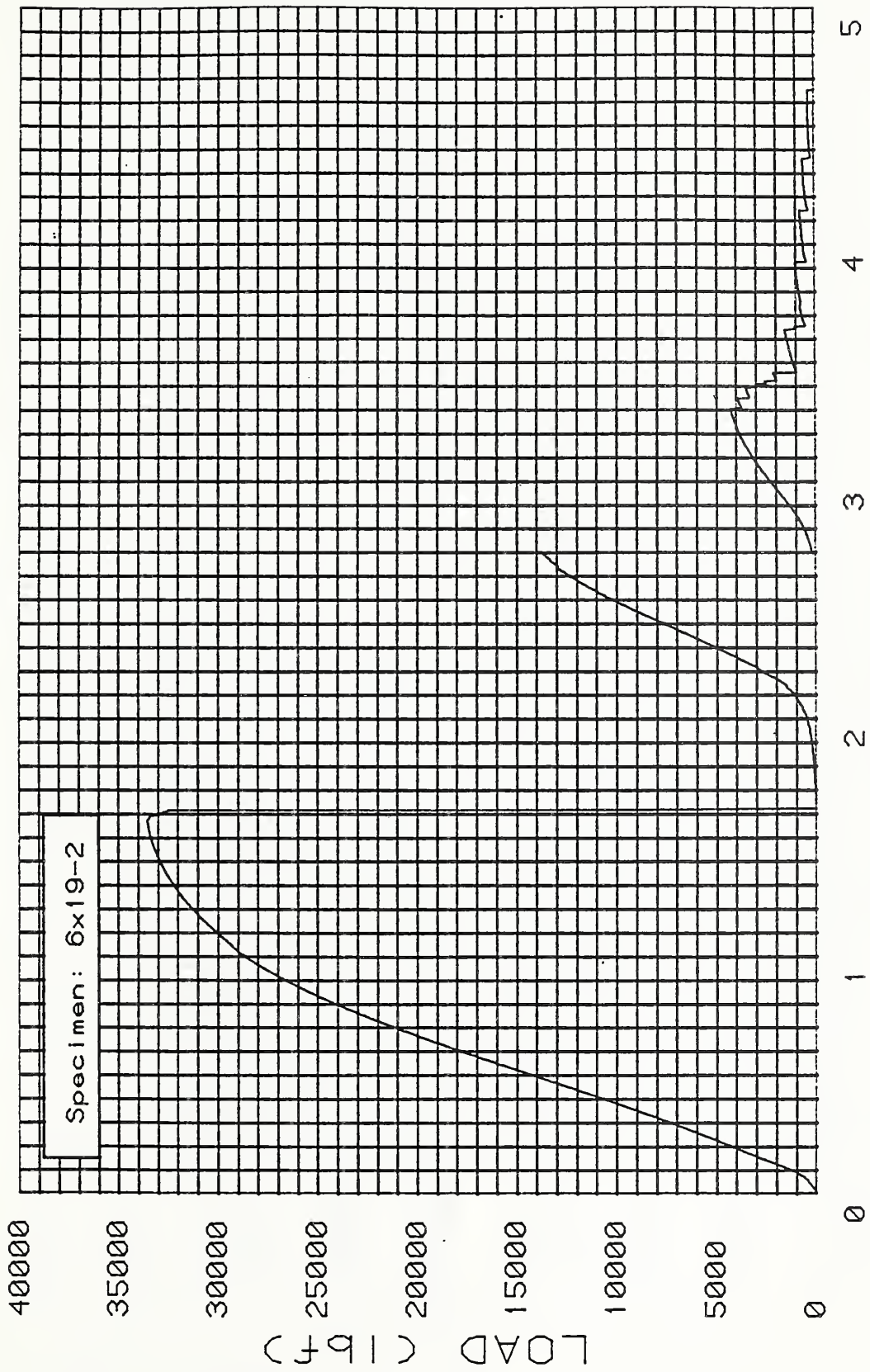


Figure 14. Load/displacement curve for specimen 6 x 7 - 4.



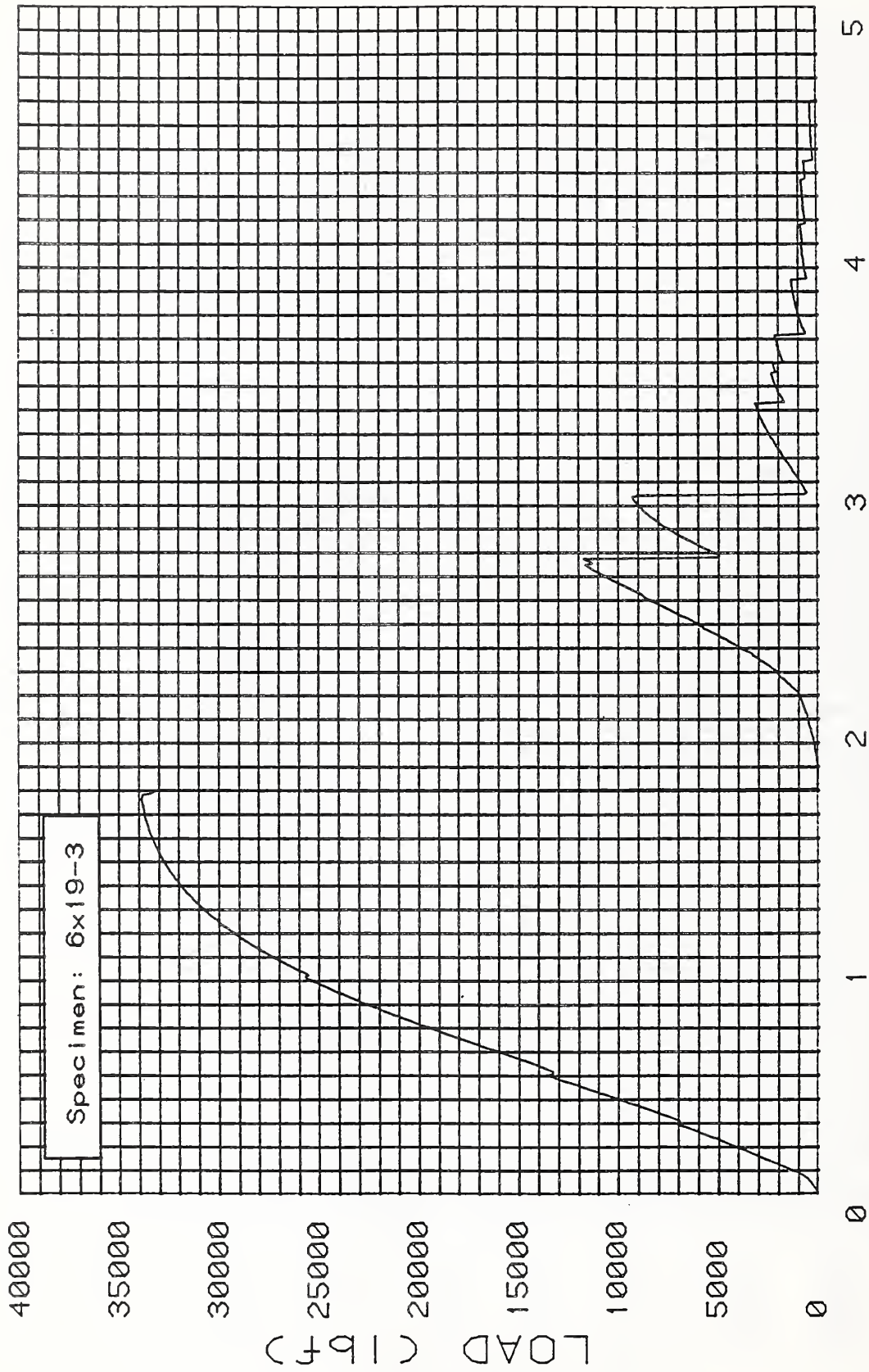
DISPLACEMENT (inch)

Figure 15. Load/displacement curve for specimen 6 x 19 - 1.



DISPLACEMENT (inch)

Figure 16. Load/displacement curve for specimen 6 x 19 - 2.



DISPLACEMENT (inch)

Figure 17. Load/displacement curve for specimen 6 x 19 - 3.

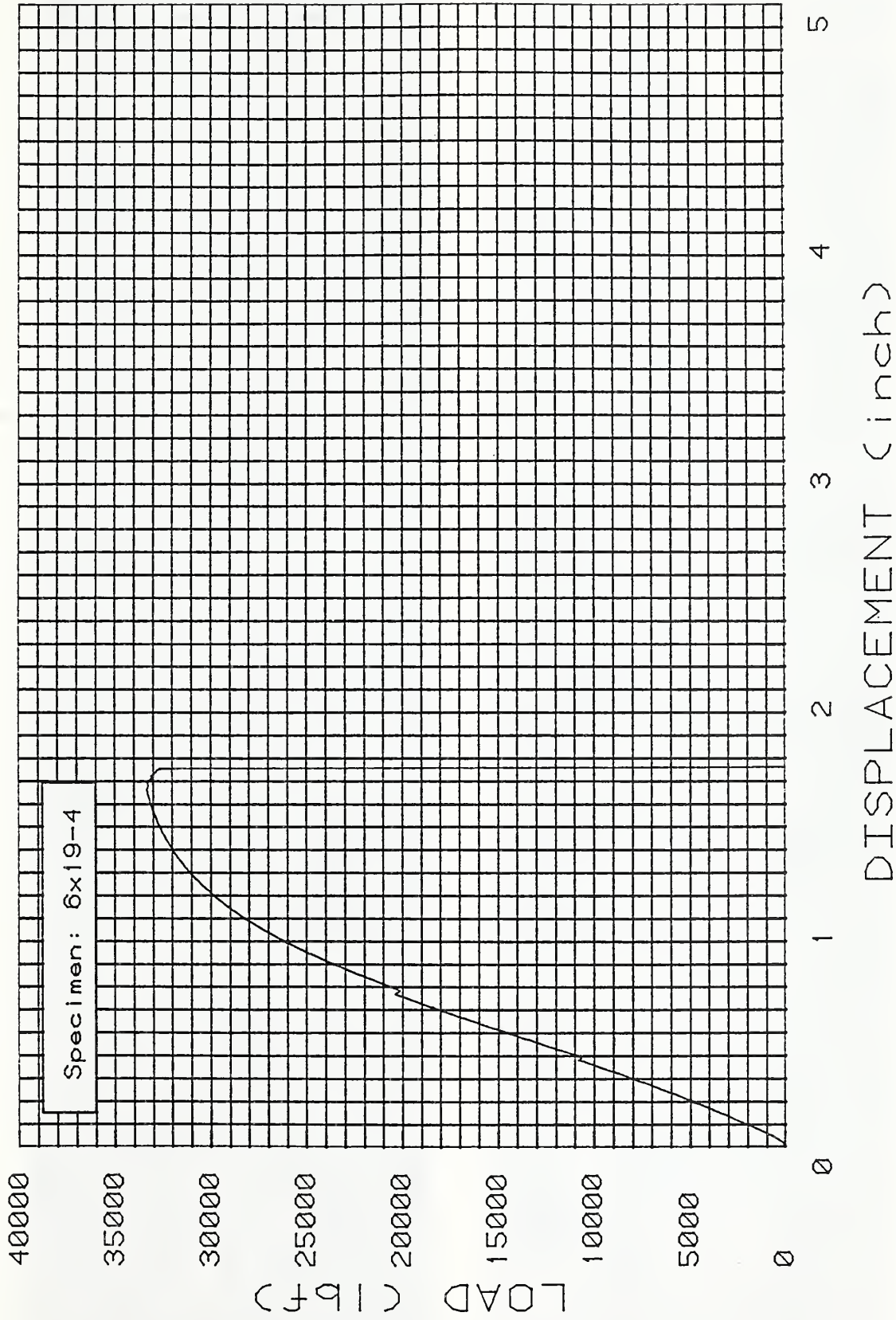


Figure 18. Load/displacement curve for specimen 6 x 19 - 4.

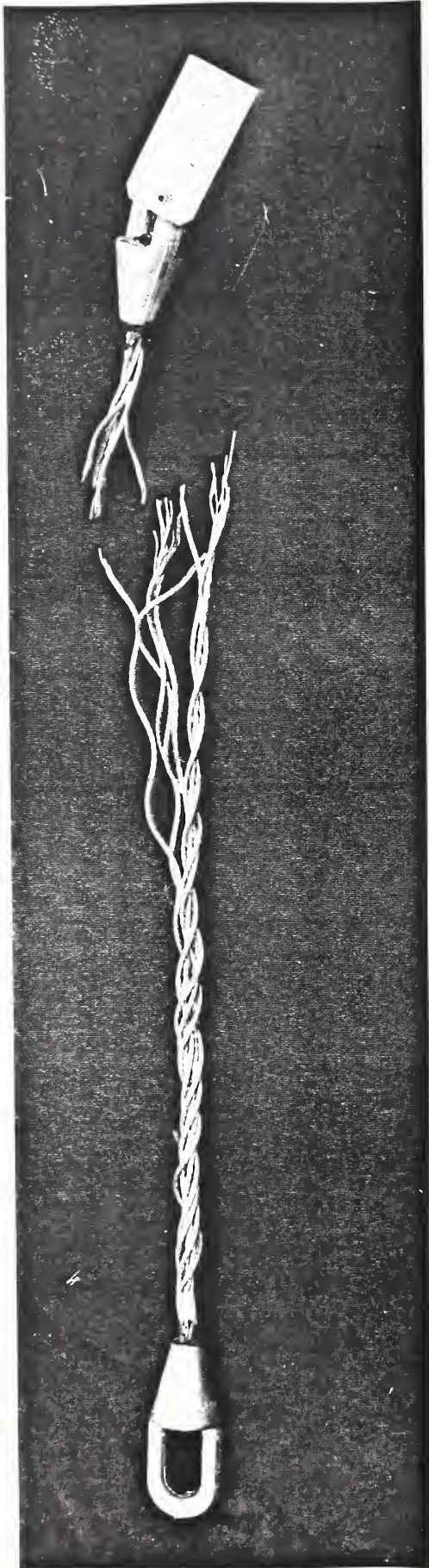


Figure 19. Specimen 6 x 7 - 1 after testing.

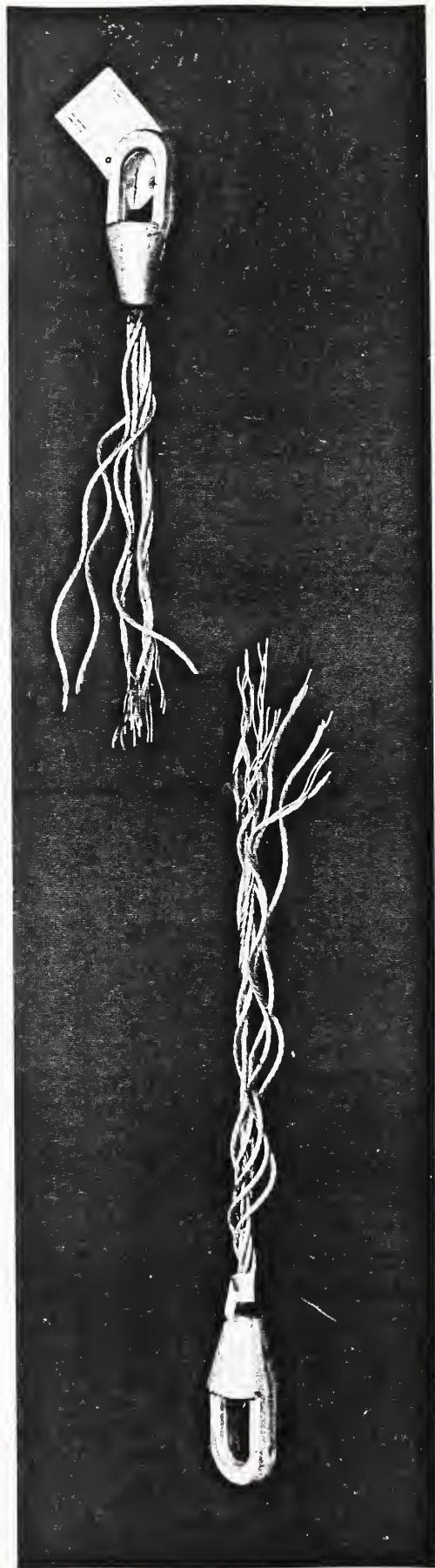


Figure 20. Specimen 6 x 7 - 2 after testing.

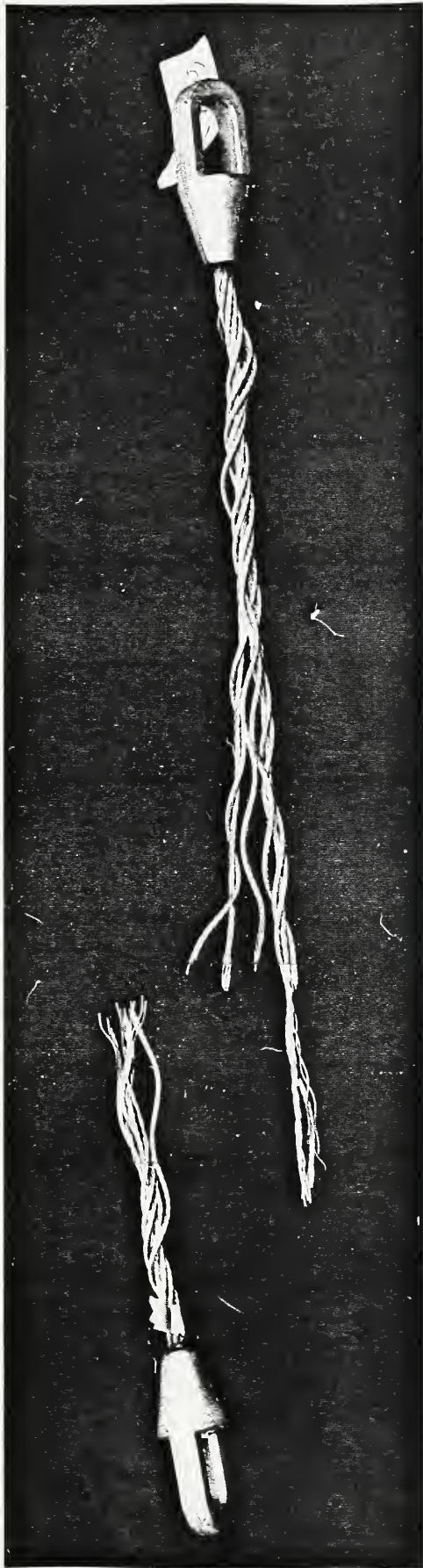


Figure 21. Specimen 6 x 7 - 3 after testing.

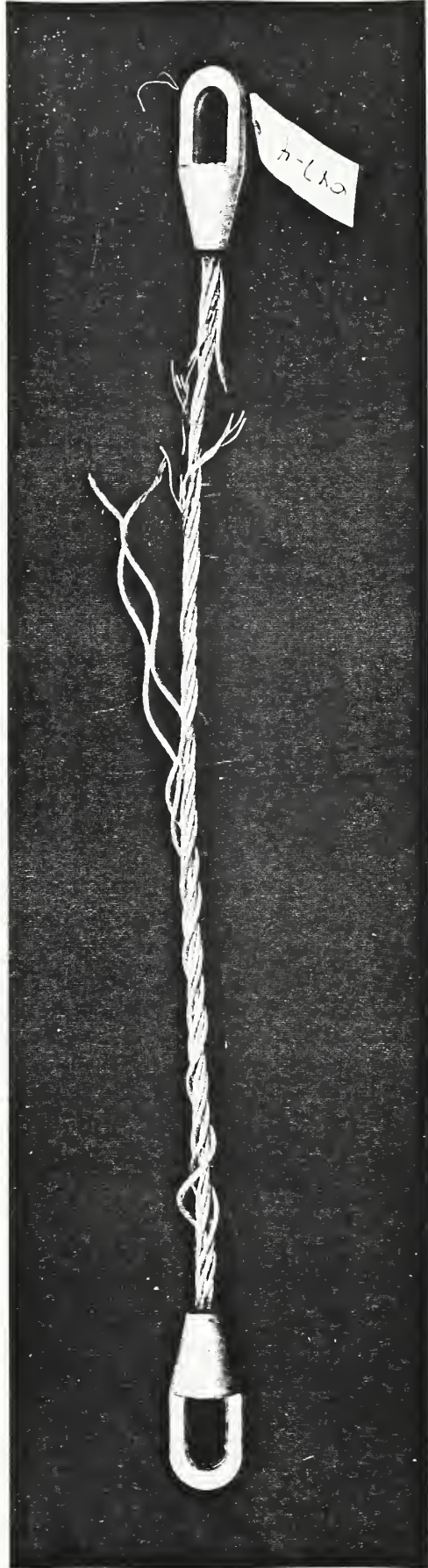


Figure 22. Specimen 6 x 7 - 4 after testing.

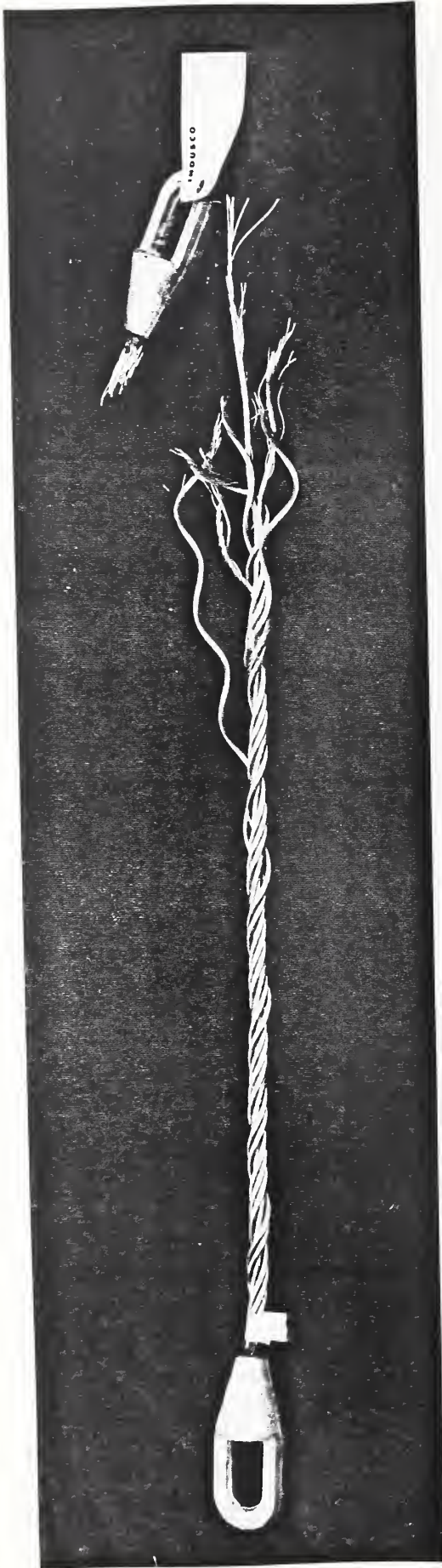


Figure 23. Specimen 6 x 19 - 1 after testing.

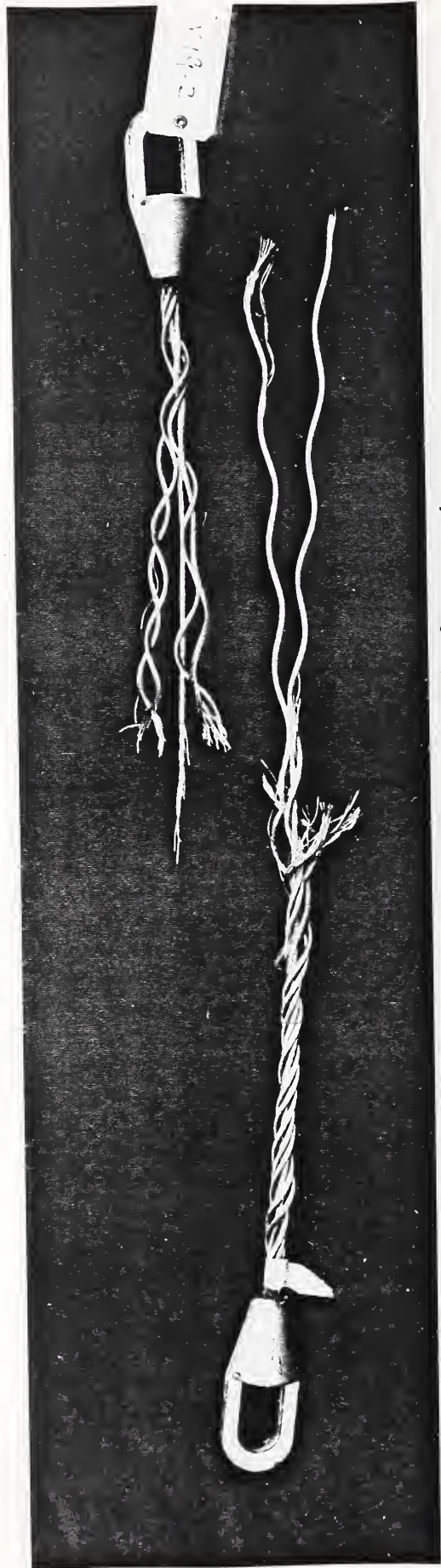


Figure 24. Specimen 6 x 19 - 2 after testing.

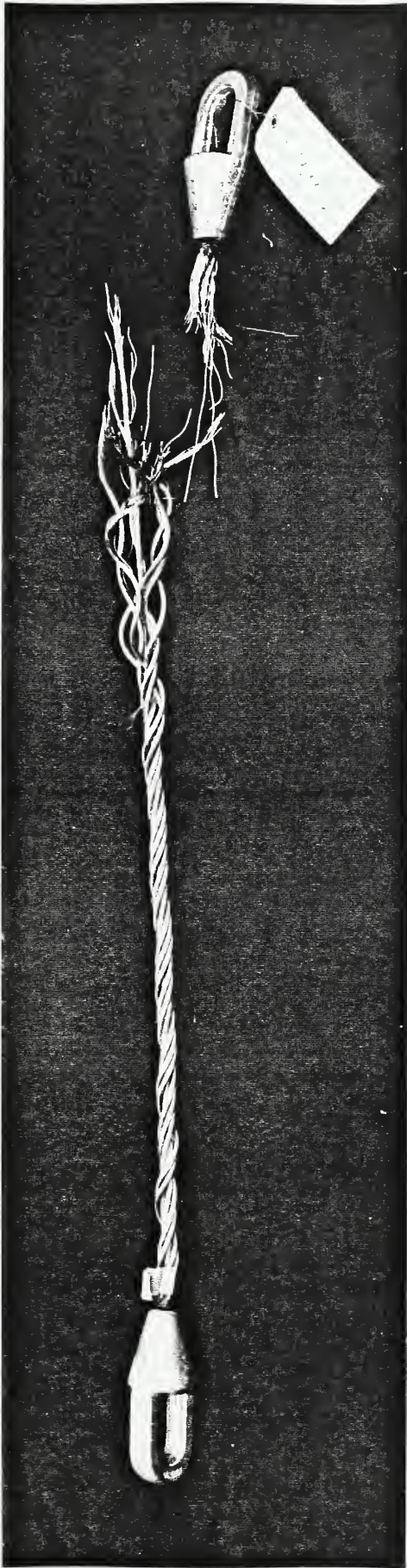


Figure 25. Specimen 6 x 19 - 3 after testing.

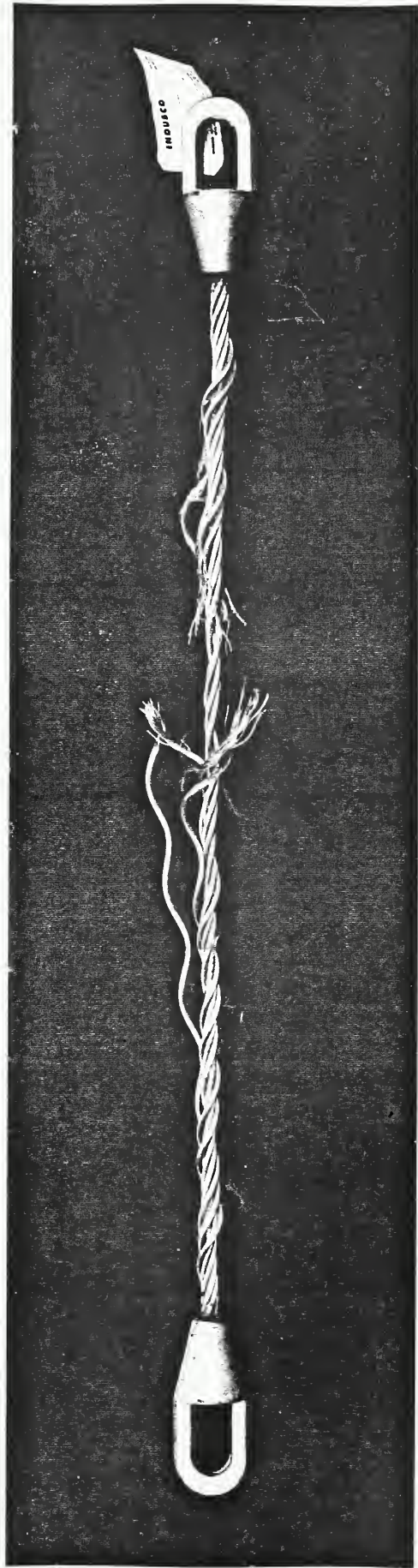


Figure 26. Specimen 6 x 19 - 4 after testing.

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11. ABSTRACT <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> <p>The tensile tests described in this report were performed by the Metallurgy Division of the National Institute of Standards and Technology (NIST) at the request of the Naval Coastal Systems Center, Panama City, Florida.</p> <p>The Naval Coastal Systems Center submitted to NIST approximately 360 feet of each of two different AISI 305 stainless steel wire ropes for testing. Both wire ropes were nominally 5/8 inch in diameter. One was stated as having a 6 x 19 configuration and the other a 7 x 7 configuration. The first number in such a designation indicates the number of strands in the wire rope and the second number indicates how many wires there are per strand. For example, the wire rope with a 6 x 19 configuration consists of six strands of 19 wires each. As shown later, the wire rope stated to have a 7 x 7 configuration actually had a 6 x 7 configuration with an independent wire rope core (IWRC). The core is one of the three basic parts of a wire rope. The other two are the wires and the strands. The core may be comprised of steel or fiber. In the case of both of the submitted wire rope samples, the core consisted of an independent wire rope.</p>			
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