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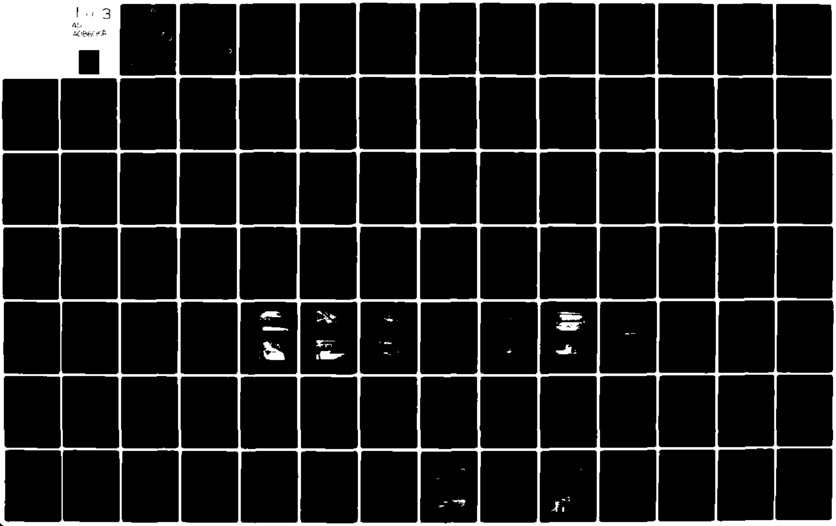

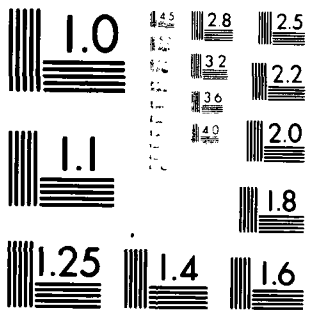

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MILITARY ADAPTATION OF KEVLAR FOR PORTABLE BRIDGE REINFORCEMENT CABLES

Tension Member Technology
15161 Golden West Circle
Westminster, California 92683

18 June 1980

Final Report for Period 5 January 1978 - 15 May 1979

Approved for public release;
distribution unlimited

Prepared for

U. S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

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Report DAAK70-78-C-0024

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Harold D. Wolfe and Philip T. Gibson

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This report prepared by Tension Member Technology, presents the findings of adapting existing small and large Kevlar Ropes to Military Bridging. The data obtained during the program was used to construct large diameter cables for reinforcement on a rapidly emplaced, portable military bridge.

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SUMMARY

The purpose of this program was to investigate the potential application of Kevlar rope as reinforcement cables for the Army's bridges. A series of tension and fatigue tests was conducted on candidate Kevalr ropes and appropriate terminations to identify the optimum combination for this application. Included in these studies were ropes having a minimum breaking strength of 150,000 pounds and also larger ropes having approximately four square inches of Kevlar fiber area. Emphasis was placed on cable assemblies which displayed light weight and minimum elongation as well as adequate environmental protection and fatigue performance. Once the most desirable ropes and terminations were identified, 10 cable assemblies were fabricated, proof loaded, and delivered to the Army for use on a prototype bridge.

PREFACE

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INTRODUCTION

Portable bridges in use or under development by the Army have typically made use of either steel bars or steel wire ropes as reinforcement members. Increasing spans and the desire to reduce the manpower and time required for bridge deployment have made it desirable to explore other reinforcement members which offer lighter weight and greater ease of handling. The recent development of Kevlar aramid fiber by du Pont has given rise to a new family of strength members which offer a potential solution to this overall objective. The purpose of this program was to explore commercially available Kevlar strength members and termination techniques to determine which, if any, were viable candidates for bridge reinforcement cables.

The approximate physical properties of natural Kevlar fiber are summarized in Table 1. This material offers a combination of high strength, low weight (specific gravity = 1.45), flexibility, and ease of fabrication which is unmatched by other natural and man made fibers. The goal of this program was to determine how this material could be used most effectively for the portable bridge application. Because of its higher elastic modulus, only the Kevlar 49 material was considered.

Two different groups of Kevlar ropes were tested during this program to determine their potential usefulness for two different portable bridge configurations. These bridge configurations are shown schematically in Figures 1 and 2. In both cases, the segmented bridges achieve their load carrying capability by means of reinforcement cables which are positioned below the bridge deck. The main difference between the two bridge configurations is the method used for establishing a pretension in these reinforcement cables. In either case, segmented cables are required to accommodate bridges of various spans.

For the bridge configuration shown in Figure 1, each reinforcement cable passes over two sets of centrally located sheaves which can be displaced by mechanical or hydraulic means to achieve a cable pretension. Due to space and weight limitations, the individual sheaves are of necessity restricted in overall diameter. Thus, in order to preserve acceptable sheave-to-rope diameter ratios, it is necessary that the individual bridge cables also be limited in size. For this application, the Army specified a minimum rope breaking strength of 150,000 pounds. The test program called for each of the small rope assemblies to be subjected to cyclic-straight-tension and cyclic-tension-over-sheave fatigue testing for a maximum of 30,000 cycles, at tensions of up to 75,000 pounds, and with sheave-to-rope diameter ratios of 10 and 14. Those rope assemblies which survived the fatigue tests were then pulled to failure to determine their remaining breaking strength. The ropes tested for this particular bridge application are referred to in this report as the "small" rope assemblies.

For the portable bridge configuration shown in Figure 2, the reinforcement cables are pretensioned by means of a centrally located king post which is mechanically forced downward against the midspan of the cable. For this application, the Army specified a maximum operating tension of 150,000 pounds and an elastic characteristic which provided a minimum value of $AE = 30 \times 10^6$ pounds. The test program called for subjecting candidate ropes to a minimum of 90,000 tension cycles with the rope tension varying between 15,000 and 150,000 pounds, followed by a proof load to 260,000 pounds. In this report, these ropes are referred to as the "large" rope assemblies.

Overall program objectives which were common to both the small and large rope assemblies were minimum weight for the rope and terminations, minimum stretch, ease of assembly in incremental lengths, adequate environmental protection against external abrasion and water and dirt contamination, and, of course, adequate fatigue performance. An additional requirement placed upon the small rope assemblies was that they operate properly over relatively small diameter sheaves. Similarly, the large rope assemblies were required to function satisfactorily while in contact with the king post.

The results of extensive laboratory testing of various candidate rope and termination designs led to the final selection of a 30-part grommet assembly of 5/8-inch diameter Kevlar 49 Miniline for the reinforcement cables which were ultimately delivered to the Army. Ten of these seven-meter long assemblies, together with appropriate high-strength connecting links and pins, were fabricated and proof loaded to 260,000-pounds tension prior to shipment to the U. S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia.

SELECTION OF CANDIDATE ROPE MATERIALS AND DESIGNS

The initial phase of this program was directed at determining the availability and physical characteristics of various types of Kevlar strength members. Visits were made to six manufacturers of ropes and webbing who had experience with the fabrication of these products using Kevlar fiber. The companies visited included Buffalo Weaving and Belting Company, Columbian Rope Company, Cortland Line Company, Murdock Webbing Company, Wall Rope Company, and Philadelphia Resins Corporation. In addition, telephone contact was made with Samson Cordage Works and a great deal of technical literature on their products was obtained by mail.

Quite early in the program it became apparent that commercially available ropes could potentially be obtained with breaking strengths of 150,000 pounds to meet the requirements for the small rope assemblies. However, no product existed which would provide the required stretch characteristics (AE = 30 x 10^6 pounds) for the large rope assemblies. Thus, for the large ropes emphasis was placed on the evaluation of assemblies which could be fabricated by Tension Member Technology using multiple parts of smaller commercially available Kevlar ropes. This design concept was also used for two of the candidate small rope assemblies tested during this program.

The initial evaluation of potential termination techniques for both the small and large rope assemblies indicated that multiple part grommet-type rope configurations would allow the use of much smaller, lighter weight, and more efficient termination hardware.

Because of these considerations, each manufacturer of Kevlar strength members was approached for quotations on two different types of products. The first item of interest was a rope which, as delivered, would provide a 150,000-pound minimum breaking strength and could be used with relatively small diameter sheaves. The second item of interest was a small rope, having a breaking strength of approximately 25,000 to 30,000 pounds which could be used by TMT to fabricate grommet assemblies of various configurations.

In addition to exploring these two basic types of strength members, one of the program objectives was to evaluate the relative performance of impregnated versus nonimpregnated Kevlar fiber. Existing test data indicated that for some fatigue applications, polyurethane impregnation of the Kevlar fiber greatly prolongs the useful life of the rope by preventing interfiber abrasion. Furthermore, the polyurethane impregnation allows the use of epoxy sockets, a termination technique not likely to succeed with nonimpregnated fiber. However, because of the increased cost of the impregnated fiber, it was also important that nonimpregnated fiber be evaluated in the interest of minimizing the future overall costs of the bridge reinforcement cables.

Kevlar Webbing

At Buffalo Weaving and Belting Company in Buffalo, New York, discussions were held with Charles Johnson, President, and Edward F. Selleck, Sales Manager. Discussions revolved around the possibility of manufacturing a large belt-type tension member similar to webbing which had been previously manufactured in 3- and 4-inch widths using Kevlar-29 fiber. These webbings were approximately 3/16-inch thick, were rated at 20,000 pounds ultimate tensile strength per inch of width, and had a polyester cover to resist abrasion and contamination. They were of the stuffer weave construction with all load bearing fibers being essentially straight and parallel. Webbings of adequate width and thickness to meet the requirements of this program were within the capabilities of existing manufacturing equipment.

In addition to the conventional polyester cover, a plastic or rubber material can be applied as either a thin coating or as a pressure vulcanized jacket which deeply penetrates all fiber interstices. Such coatings or jackets provide additional environmental protection to the strength members.

The methods typically used to terminate webbings and belts were also explored. One type was a loop termination in which a loop is made in the webbing with the end stitched back on itself as shown in Figure 3. This method had been shown to yield approximately 80 to 85 percent loop strength efficiency with nylon or polyester webbing. However, the efficiency for large Kevlar webbing was unknown. Grommet assemblies using the webbing material were also discussed. Such an assembly would consist of a loop of the webbing material with the ends attached to each other by a sewing technique as shown in Figure 4.

It was felt that either of these webbing configurations would require a considerable length for the sewn joint. The result was a doubling of the required load bearing fiber over the length of the joint and, thus, a significant weight and cost penalty.

Discussions at Murdock Webbing Company were primarily with Mr. John DeAngelis. It was learned that Murdock had built several Kevlar webbings of the stuffer weave construction with measured breaking strengths up to 139,000 pounds. This largest webbing was 6-1/8-inches wide by 1/4-inch thick and had a theoretical breaking strength of 165,000 pounds. Webbing up to 12-inches wide was within Murdock's manufacturing capabilities. Possible facing materials and termination techniques were also discussed. While Murdock did not routinely fabricate complete terminated assemblies on a production basis, they were willing to provide some loop terminations for a limited number of test samples.

The webbing type of tension member was ultimately rejected for this program because it was not a proven strength member in the required sizes. Furthermore, the termination problem appeared to be formidable and the relative cost of the webbing was quite high.

Kevlar Rope

Discussions with Mr. Richard Clapp, Technical Director of Columbian Rope Company, yielded information regarding two constructions of Kevlar rope which were within existing manufacturing capabilities. The "Nolaro" construction consisted of parallel bundles of twisted Kevlar fiber and an outer extruded plastic jacket. This rope could be made in sizes up to 1.25 inch diameter as limited by the size of the extruder head. An eye splice termination was recommended for achieving the highest strength efficiency for this rope construction.

A second construction offered by Columbian Rope Company was the eight-part plaited "HBL" construction. Each strand of this rope consisted of parallel bundles of twisted Kevlar fiber with a braided polyester jacket. This construction was considerably more flexible than the Nolaro, and unlike Nolaro was thought to be suitable for limited operation over sheaves. However, the elongation of the eight-part plaited construction was significantly greater. The HBL rope was available in sizes up to three-inch diameter and with a breaking strength up to 460,000 pounds.

The Nolaro construction was rejected for the small rope assemblies because of its inability to be used over sheaves, the required length of the spliced terminations, and the relatively high cost. Similar considerations eliminated this rope as a candidate component for the large rope assemblies. The HBL construction was also ultimately rejected because of its relatively large constructional stretch and relatively high cost.

At Cortland Line Company discussions were held with Dr. E. Scala. Cortland Line had been involved in making several Kevlar grommet assemblies with a maximum breaking strength of 60,000 pounds for an Army helicopter sling leg application. They were willing to attempt the fabrication of the much larger grommet assemblies required for this program using the techniques which had been developed during previous efforts. They also had the capability to overbraid assembled grommets up to six inches in diameter for abrasion and contamination protection.

Cortland Line also offered smaller braided rope configurations which were potentially useable for producing multiple part grommet assemblies fabricated by TMT. However, in the final analysis, neither the large grommet assemblies nor the small rope constructions were selected for evaluation because of their extremely high costs and, in the case of the preassembled grommets, the developmental nature of the effort and the uncertainty regarding the potential for achieving the strength and the elongation goals.

Samson Cordage Works offered a double braid rope construction with braided Kevlar fiber strength members covered by a braided polyester jacket. However, the experience of this company with this construction was quite limited, and the quoted price was found to be prohibitive. Thus, this rope was rejected as a viable candidate for the bridge reinforcement cables.

Discussions with Alexander Hood and Gavin Hood of Wall Rope Company were directed primarily toward using their Kevlar "Miniline" as a component strength member for fabricating grommet assemblies. Miniline is manufactured in sizes from 1/4- to 5/8-inch diameter as measured over its polyester braided jacket. The 1/2-inch size has a catalog breaking strength of 20,000 pounds. The Miniline construction is composed of braided Kevlar using very long pick lengths (low braid angles) to reduce the internal compression and, therefore, abrasion, and to increase the effective elastic modulus. Miniline is very flexible and has been shown to perform well in tension fatigue testing at tension loads of 50 percent of rated breaking strength.

At Philadelphia Resins Corporation, discussions were held with Mr. A. Simeon Whitehill. Many candidate rope constructions were discussed including several which were currently in stock and could be used for immediate testing. All of Philadelphia Resins' rope products are manufactured from polyurethane impregnated Kevlar fiber which provides improved resistance to interfiber wear and allows the use of a variety of termination techniques. Candidates included a variety of constructions of ropes or grommets which could be built up from component strands which were in stock, or unique designs manufactured to order from impregnated Kevlar fiber.

Philadelphia Resins Corporation offered a 1.9-inch diameter, 6 x 7 rope construction with a rated breaking strength of 180,000 pounds. The particular design of this rope, together with the polyurethane impregnation, promised to provide good performance during the required cyclic-tension-over sheave fatigue tests. Furthermore, the rope could be readily terminated with epoxy sockets as well as with standard eye-splicing techniques. Because of these technical considerations, and in view of the modest cost of this rope, this product was included in the test program.

Cost and delivery quotations were also received from five manufacturers for small ropes which could be fabricated into grommets. These manufacturers included Columbian Rope Company, Cortland Line Company, Philadelphia Resins Corporation, Samson Cordage Works, and Wall Rope Company.

Three rope companies including Cortland Line, Samson Cordage, and Wall Rope, bid on a rope composed of braided Kevlar fibers and covered with a braided polyester jacket. These three companies responded with greatly differing prices for their ropes. This factor, in addition to the status of test data and knowledge about each individual product, led to the selection of the Miniline produced by Wall Rope Company.

A quotation was also received from Philadelphia Resins Corporation for a small rope which could be used for the manufacture of larger rope or grommet assemblies. This rope was a 1 x 37 construction manufactured from impregnated Kevlar fiber and covered with a braided polyester jacket. The breaking strength was approximately 11,500 pounds. Existing fatigue data on similar constructions suggested that this product might perform well for the bridge reinforcement cable application. This factor, combined with modest cost, made this particular rope a good candidate, and it was included in the test program.

Summary of Rope Selection Rationale

The selection of rope constructions for fabrication of the "small" rope assemblies was influenced primarily by the need for these ropes to survive large numbers of cyclic tension load cycles while wrapped around sheaves of relatively small diameters. Thus, various stranded and braided constructions were considered as opposed to parallel fiber constructions which are unable to accommodate small radius bending.

The small rope constructions ultimately selected included both natural Kevlar fiber and Kevlar fiber which was impregnated with polyurethane resin. The natural Kevlar rope was fabricated as a grommet assembly to minimize the weight of the rope terminations. The two rope constructions which were fabricated with polyurethane impregnated Kevlar fibers were tested with epoxy type terminations.

The only other potentially viable termination type for the small rope assemblies was a conventional eye splice. While it was likely that this type of termination would have provided acceptable strength efficiency and cyclic-tension fatigue life, it was not included in the test program because the anticipated length of each splice would have made it unsuitable for short reinforcement cables. The effective doubling of the required load bearing fiber over the length of each splice would have imposed a significant weight and cost penalty.

The selection of rope constructions for fabrication of the "large" bridge cable assemblies was influenced primarily by the need for low cable stretch and small, light weight end terminations. Since no commercially available Kevlar rope was available with sufficient fiber content to provide the required cable stretch characteristics, it became necessary to fabricate these large assemblies from multiple parts of smaller rope or strands. In the interest of minimizing total cable stretch for a given amount of Kevlar fiber, it was necessary that the smaller ropes or strands have a very high elastic modulus. This consideration eliminated from contention those candidate ropes which had a complex, multiple strand or cabled construction, since such ropes typically have a relatively low elastic modulus.

An obvious candidate for this application was a parallel fiber strand such as Uniline produced by Wall Rope Company or Nolaro produced by Columbian Rope Company. These ropes typically display a very high elastic modulus. Although certain constructions of webbing or flat belts also have essentially parallel load bearing fibers, this type of strength member was rejected as a viable candidate because of uncertainties regarding the manufacture of a suitable webbing of the required size and the development of suitable end terminations.

The major problem associated with the use of parallel fiber ropes or strands was, again, the development of a satisfactory termination technique. Epoxy type sockets seemed to be a possibility if such ropes were manufactured from polyurethane impregnated Kevlar fiber. However, a termination of this type posed a size and weight penalty, and it was anticipated that great difficulty would be encountered in achieving uniform fiber load sharing for a bridge cable assembly composed of a large number of parallel fiber bundles. Of course, any unequal load sharing would contribute to a reduction in the effective elastic modulus and breaking strength. Furthermore, existing test data on epoxy socketed Kevlar ropes suggested that achieving good termination strength efficiency and fatigue performance is increasingly difficult with larger rope sizes. In fact, no attempts had yet been made to install epoxy sockets on a Kevlar rope having the quantity of fiber required for the bridge cable assemblies.

The one type of termination which had been used successfully with parallel fiber rope constructions was an eye splice. For this type of termination, the entire rope or its subunits are passed around a large spool or thimble and are then spliced back into the load carrying portion of the rope. While such terminations had been demonstrated to be effective for small diameter parallel fiber ropes, their application to the large bridge cable assemblies presented a number of special problems. Because of the low elastic stretch of the Kevlar fiber, it was necessary that the termination thimbles or spools be quite large in diameter. Small bending radii were known to produce unequal fiber load sharing and, therefore, poor rope modulus and termination strength efficiency. Furthermore, the eye splice type of termination for parallel fiber rope is inherently quite long. Thus, spliced type terminations were rejected for the parallel fiber ropes because of their large size and because such terminations would have greatly increased the quantity of Kevlar required in each assembly due to the length of each eye splice.

Preliminary tensile tests of 1/2-inch and 5/8-inch diameter Kevlar-49 Miniline produced by Wall Rope Company demonstrated that this braided construction provided an effective elastic modulus nearly the same as that of the parallel fiber rope. The very shallow helix angle of the fibers in the braid minimized the constructional elongation displayed by stranded or cabled Kevlar ropes at low values of the applied tension. Although the tension/elongation curve for the Miniline rope displayed some nonlinearity, the experimental data suggested that if such a rope were used with an adequate pretension, its effective elastic modulus would be quite high. Furthermore, because the load bearing fibers follow a helical path within the braided construction, the Miniline could be used effectively over quite small diameter termination spools or thimbles, an advantage not present with the parallel fiber ropes.

Because of these considerations, the rope construction selected for the large bridge cables was a grommet assembly made up of 5/8-inch diameter Miniline which passed over small diameter spools at each termination. A very compact and light weight termination was thereby achieved. However, the suitability of this bridge cable design was dependent upon establishing a significant preload in each cable in order to avoid the lower relative elastic modulus exhibited at low tension loads. The 20,000-pound cable pretension specified for the bridge system was adequate to achieve the desired cable stretch characteristics.

Of course, uniform load sharing among all members of such a multiple-part grommet is essential to achieving good strength efficiency and high overall elastic modulus. As described later in this report, a rope assembly technique was developed which provided good load sharing.

PRELIMINARY TESTS OF INDIVIDUAL CABLE COMPONENTS

Prior to the fabrication of grommet assemblies using both the Kevlar-49 Miniline and the Phillystran PS49-1x37x.322 strand, tensile tests of short samples of these materials were conducted to determine the strength efficiency of various end termination techniques and also the strength efficiency of the strands themselves when pulled to failure while wrapped around spools of various diameters. Additional tensile tests were then conducted to determine the elastic characteristics of these materials.

Termination Strength Efficiencies

The first series of tests was conducted using the apparatus shown schematically in Figure 5. Each test specimen was wrapped around a grooved spool which simulated the termination hardware planned for the grommet assemblies. Both ends of the specimen were attached to a load equalizing plate. Tension was applied by means of a hydraulic ram and was monitored by means of a strain gage load cell with calibration traceable to the National Bureau of Standards.

The test spools had tread diameters (as measured at the bottom of the groove) of 1.5, 2.5, and 3.5 inches. In each case, the groove profile was selected to match the diameter of the particular strand being tested. Termination techniques evaluated included epoxy sockets, various types of eye splices, and swaged Nicopress sleeves.

The strand breaking loads measured during these tensile tests are indicated in Figures 6 through 8. For all tests of the 1/2-inch diameter Kevlar-49 Miniline, the strand was first loaded ten times to approximately 12,500 pounds, and on the eleventh cycle it was pulled to failure. The Phillystran PS49-1x37x.332 strand received ten load cycles to approximately 5,500 pounds prior to being pulled to failure. In each case, the selected preload was approximately 50 percent of the breaking strength. In Figures 6 through 8 the first trace for each specimen corresponds to the initial preloading cycles. Subsequent traces indicate the maximum loading achieved prior to rope failure or prior to slipping within the termination which caused a momentary drop in tension.

The first and simpliest effort directed at developing a termination for the Miniline was the use of Nicopress sleeves. A simple loop was formed in the end of the cable specimen, and the soft metal sleeves were compressed onto the rope using the recommended Nicopress swaging tool and dies. A range of one to five sleeves per termination was investigated with very little success. The strands continually pulled out of or broke adjacent to the swaged sleeves. The results of several of these preliminary tests are indicated as Samples 1 through 5 in Figure 6.

Another termination which was tried for the Miniline was the standard eye-splice technique recommended by Wall Rope Company. This technique, which was originally developed for their Uniline product line, is described in Appendix A. A number of modifications of this splicing technique were explored to improve the strength efficiency. These modifications included variations in the lay angles of the individual yarn bundles as they were wrapped to form the eye splice. The results of several of these tensile tests are shown as Samples 6, 7, and 9 in Figure 6 and Samples 10 and 11 in Figure 7. The maximum breaking strength achieved with a modified Uniline splice was 27,000 pounds (Sample 11). For each of Specimens 9, 10, and 11, rope failure occurred at the end of the splice joint and not at the 3-1/2-inch diameter grommet spool used for these tests.

Subsequent tests of the 1/2-inch diameter Kevlar-49 Miniline using this modified splicing technique and smaller diameter grommet spools produced the results shown for Specimens 18 through 22 in Figure 7. For each of these tests, rope failure occurred at the grommet spool.

A summary of these test results showing the relationship between spool diameter and measured breaking load is shown in Figure 9. These results suggest that for static loading conditions, a 3-1/2-inch diameter grommet spool is sufficient to achieve good breaking strength efficiency with the 1/2-inch diameter Kevlar-49 Miniline.

Although the modified Uniline splice produced quite satisfactory tensile test results, it was nevertheless a rather long spliced joint which required extreme care in its assembly in order to achieve the desired strength efficiency. Effort was thus directed at exploring the performance achievable with a hollow braid type of splice. This type of splice is quite short, and it is rather easy to install in the Miniline construction. The results of tensile tests of two specimens prepared with eight-tuck splices are shown in Figure 8. These test results were sufficiently encouraging to warrant the use of this particular splice for the fabrication of all grommet assemblies tested during the remainder of this program.

All tests of the PS49-1x37x.332 strand were conducted using epoxy sockets. Two specimens each were pulled to failure around spools of 1.5, 2.5, and 3.5-inch tread diameter. In all cases, rope failure occurred at the spools in a range of tensions between 9,200 and 10,400 pounds. Spool diameter seemed to have little effect on the strength of this type of rope. These test results are shown as Specimens 12 through 17 in Figure 7. The results suggested that better strength efficiency with smaller, lighter weight spools could be obtained with the Kevlar-49 Miniline.

Details of Hollow Braid Splice

The hollow braid type of splice was ultimately selected for the formation of both eye-splice terminations at the end of a length of Kevlar-49 Miniline and also as an end-to-end splice used to join two lengths of this type of rope. Details of the splicing procedure are shown in Figures 10 through 22 and in TMT Drawing 10200 (this drawing is included later in this report).

Selected sections of the braided polyester jacket were first removed from the Miniline with the aid of a hot soldering iron. Note that soldering iron temperatures are adequate to melt the polyester fiber, but have no adverse effect on the Kevlar fiber. This jacket removal procedure is illustrated in Figures 10 through 13.

To assure that the individual Kevlar strands were spliced in the proper sequence, green and red ink marks were placed on the right and left lay strands, respectively, where they emerged from the cable jacket as shown in Figure 14. The Kevlar strands were then separated into eight groups of two fiber bundles each, and their ends were secured with PVC tape as shown in Figure 15.

An eye was then formed in the Miniline and secured with tape as shown in Figure 16. Note that the jacket has not been removed from that section of rope which forms the eye.

Individual strands were then braided back into the rope body beginning with a green strand and then alternating red and green in order. A partially completed eye-splice is shown in Figures 17 and 18. Figures 19 and 20 show the completed eye splice with the individual strands uniformly tucked and tightened. The splice was then wrapped with PVC tape as shown in Figures 21 and 22. The final installation of shrink tubing over the taped splice then completed the rope termination.

Elongation Characteristics

The design ultimately selected for the deliverable bridge cable assemblies depended heavily upon the elongation characteristics of the individual Kevlar strands. To determine how many of these strands would be required to produce satisfactory reinforcement cables, tensile tests were conducted on a number of samples of the Kevlar-49 Miniline and the Phillystran PS49-1x37x.332 strand.

The results of tensile tests of three samples of 1/2-inch diameter Kevlar-49 Miniline are shown in Figures 23 through 25. The elongation characteristics for the first and tenth load cycles are recorded on these graphs to demonstrate the magnitude of the permanent constructional stretch which can be expected from this rope construction. This material provided an elastic modulus of approximately 14.0×10^6 pounds per square inch over a range of tensions approximating that which was anticipated in actual service.

A quantity of 5/8-inch diameter Kevlar-49 Miniline was then purchased to determine whether this same high modulus of elasticity could be achieved with the larger diameter rope. Initially, there had been some concern that the larger Miniline would have a reduced effective elastic modulus as a result of less uniform fiber load sharing. To offset this common trend, the larger Miniline was manufactured using a relatively greater pitch length for the fiber braid. The tension/elongation characteristics of this larger Miniline are shown in Figure 26 and 27. Note that this larger rope provided a modulus of elasticity of 16.0×10^6 pounds per square inch. As discussed later in the report, these test results prompted the selection of the 5/8-inch diameter Miniline for fabrication of the deliverable bridge cable assemblies.

Similar tensile tests were conducted on samples of the Phillystran PS49-1x37x.332 strand. The results of these tests are shown in Figures 28 through 32. This material yielded an elastic modulus of approximately 15.0×10^6 pounds per square inch.

EVALUATION OF "SMALL" BRIDGE CABLE CONSTRUCTIONS

Three different small bridge cable designs were evaluated for a bridge configuration which requires rope with a 150,000-pound breaking strength and with an ability to operate over sheaves. (See Figure 1.) Two of these rope constructions, designated as S-1 and S-2, were assembled by TMT from smaller commercially available Kevlar strands. One construction, designated as S-3, was purchased as a finished rope. Details of the rope constructions and the test specimen identification codes are included in Table 2.

S-1 Rope Construction

Initially, two experimental specimens of the S-1 rope design were tested to evaluate the effect of individual strand lay lengths on rope strength and elastic modulus. These first two 19-strand specimens were assembled from PS49-1x37x.332D strands in a 1-6-12 configuration. For the first experimental specimen, identified as S-1-A-T1X, the lay lengths of the first and second layer strands were 10 and 21 inches, respectively. For the second specimen, designated as S-1-A-T2X, these lay lengths were 10 and 25 inches. Both layers were a right-hand lay for both ropes. These specimens were terminated with epoxy-type sockets and were tensile tested to determine the elongation and breaking strength characteristics.

These tests were conducted in a horizontal load frame using a hydraulic tensioning cylinder, a calibrated load measuring transducer, and a 40-inch gage length extensometer which attached directly to the rope specimen. Each specimen was subjected to 10 load cycles to 25,000 pounds, 10 load cycles to 50,000 pounds, and 10 load cycles to 75,000 pounds, prior to being pulled to failure.

Figures 33 through 35 show the elongation characteristics of Specimen Number S-1-A-T1X. This specimen displayed a permanent constructional stretch of slightly more than one percent and a breaking strength of 166,000 pounds. Figures 36 through 38 show the elongation characteristics of Specimen S-1-A-T2X. In this case, a problem with the extensometer prohibited an accurate measurement of total constructional stretch; while the tension/elongation curves are accurate with regard to their slope, they are not accurately positioned with respect to zero elongation. The breaking strength of this specimen was 160,000 pounds. During the testing sequence, the measured diameter of this rope ranged from 1.90 inches at 25,000 pounds tension to 1.775 inches at 75,000 pounds tension.

For both of these specimens, final failure occurred adjacent to one of the epoxy sockets. In each case, the core strand failed at a tension load below 150,000 pounds. This premature core failure was the result of the relatively higher tensile stress induced in the core member of the 1x19 construction and is typical of this rope design.

To eliminate this problem of premature core failure, the PS49-1x37x.332D central strand was replaced by a PS29-19x7x.45 strand for all subsequent test specimens. This replacement core strand provided an increased breaking strength because it contained more Kevlar fiber in place of a braided Dacron jacket. It also provided additional elongation, since a 19x7 construction of Kevlar 29 fiber has significantly greater stretch than a 1x37 construction of Kevlar 49 fiber.

Eighteen specimens of this modified 1x19 rope design were then fabricated and socketed for tensile and fatigue tests. Lay lengths of 12 and 25 inches were used for the inner and outer strands, respectively.

Three of these samples were subjected to tensile tests to evaluate their load/elongation characteristics and breaking strength. In each case, the samples were loaded 10 times to 75,000 pounds and were then pulled to failure. The results of these tests are shown in Figures 39 through 41. The tensile strength achieved for these samples ranged from 167,000 to 181,000 pounds. No premature core failures were experienced.

Three cyclic-straight-tension fatigue tests were conducted on the S-1 rope construction with maximum test loads of 25,000, 50,000, and 75,000 pounds. Each of these specimens survived 30,000 fatigue cycles. The remaining breaking strengths were 157,000, 162,000, and 149,000 pounds, respectively. All failures occurred at a socket. The rope elongation measured during the break tests is shown in Figures 42 through 44.

The remaining 12 specimens of the S-1 rope were subjected to cyclic-tension-over-sheave fatigue tests to evaluate their potential performance when used with a reinforcement cable tensioning system such as shown in Figure 1.

These tests were conducted on the apparatus shown schematically in Figure 45. Two specimens were tested simultaneously, one wrapped around each of two test sheaves. One sheave was mounted in a fixed location on the test machine, and the other sheave was attached to a hydraulic tensioning ram. A calibrated strain gauge load cell was used to monitor rope tension.

Six of the S-1 rope specimens were tested with 20-inch tread diameter sheaves which provided a D/d ratio of 10. Pairs of rope specimens were tested with maximum tensions of 25,000, 50,000, and 75,000 pounds. Six additional specimens were subjected to similar tests using 28-inch tread diameter sheaves which provided a D/d ratio of 14.

In the actual portable bridge system, particularly with an asymmetrical bridge configuration, vehicular traffic will produce high tension in the reinforcement cables together with a small amount of rotation of the tensioning sheaves. The amplitude of rotation will be approximately that which results from the elongation of a seven-meter section of the reinforcement cable. To investigate the effects of this combined tension cycling and small-amplitude sheave rotation, a stretch simulator was used during these laboratory tests. This simulator consisted of a hydraulic ram which communicated with a hydraulic/pneumatic accumulator. For each test, the accumulator precharge was adjusted to produce the desired amplitude of motion of the stretch simulator. Photographs of the stretch simulator and the fixed position sheave are shown in Figures 46 and 47.

The test equipment was designed such that when the peak tension was 25,000 pounds, each even numbered specimen (those wrapped around the right-hand sheave) moved on and off its test sheave with a stroke amplitude of approximately one inch. This motion was approximately two inches for a peak tension of 50,000 pounds and approximately three inches for a peak tension of 75,000 pounds. In each case, the amplitude of motion of the odd numbered samples (those wrapped around the left-hand sheave) was exactly one-half of the motion of the even numbered samples. Thus, the fatigue tests provided data not only on the effect of tension amplitude and sheave size, but also on the amplitude of motion of the test specimens relative to the sheaves.

The results of all tensile and fatigue tests of the S-1 rope specimens are summarized in Table 3. The test data indicate that while this rope construction provided excellent breaking strength and good remaining strength after cyclic-straight-tension fatigue tests, its performance in the cyclic-tension-over-sheave fatigue tests was somewhat disappointing. When tested over sheaves which provided a D/d ratio of 10, this rope survived only 13,426 cycles when loaded to a peak tension of 50,000 pounds and only 770 cycles when loaded to a peak tension of 75,000 pounds. When tested over sheaves providing a D/d ratio of 14, this rope survived only 2,480 cycles when loaded to a peak tension of 75,000 pounds.

The test data also reveal a significant difference in the performance of the two rope samples tested simultaneously during the cyclic-tension-over-sheave fatigue tests, but with different amplitudes of motion over the left- and right-hand sheaves. For example, Specimen S-1-A-CTOS-M2 survived a total of 13,426 cycles prior to failure at the peak tension of 50,000 pounds. With the same total number of cycles, but with a smaller amplitude of motion, the mate to this specimen had a remaining breaking strength of 106,000 pounds when pulled to failure in straight tension after the cyclic-tension-over-sheave fatigue tests.

S-2 Rope Construction

The S-2 rope was an eight-part plaited construction made up of 1/2-inch diameter Kevlar-49 Miniline which had a braided Dacron jacket. Each rope specimen was fabricated as a grommet using a single length of Miniline. The testing program for this rope included tension, cyclic-tension, and cyclic-tension-over-sheave fatigue tests. Spools of two different diameters were used in the grommet eyes to evaluate the effect of spool size on rope strength. The specimens designated as S-2-C had 2-1/2-inch tread diameter spools, and the specimens designated as S-2-D had 3-1/2-inch tread diameter spools.

The fabrication procedures used for the S-2 rope specimens are shown in Figures 48 through 69. The spool geometry is shown in Figures 70 and 71.

To begin the fabrication of each S-2 rope specimen, a hollow braid eye splice was placed in one end of a length of 1/2-inch diameter Kevlar-49 Miniline. The Miniline was then wrapped around two 'dummy' spools on an adjustable frame as shown in Figure 48. The Miniline was then adjusted to provide a uniform tension in all components, and reference marks were placed on the strands at one end of the assembly as shown in Figure 49. These reference marks were used throughout the fabrication process to assure that all strands were properly adjusted to assume their fair share of any applied tension load.

The desired lay length crossover positions were then marked along the initial section of Miniline as shown in Figure 50. The first and second strands were then wrapped together as shown in Figure 51.

As rope fabrication continued, each strand was numbered and its lay direction was marked where it wrapped around each grommet spool. The marking of two strands is shown in Figure 52. Figure 53 shows the rope after wrapping of all four left-lay strands.

Fabrication then continued with wrapping of the right-lay strands. Each of these strands was tucked up and down through the previously wrapped left-lay strands to produce the plaited construction as shown in Figures 54 through 61. The individual strands were then adjusted along the length of the rope specimen so that the reference marks originally placed on the individual strands were brought into fairly good alignment as shown in Figure 62.

Completion of the rope assembly required that a hollow-braid splice be placed in the final end of the Miniline. Because of the foreshortening which naturally occurs during the installation of an eye-splice, a 1/2-inch adjustment of the original reference mark was required as shown in Figure 63. After installation of the eye-splice, this new reference mark then came into alignment with the reference marks on the other strands. The eye-splice was installed in the end of the Miniline, and the rope construction was completed as shown in Figures 64 through 68. Figure 69 shows three typical samples of the S-2 rope construction with grommet spools installed in one test specimen.

The test results for all S-2 rope specimens are summarized in Table 4. Note that during the tensile tests, the larger 3-1/2-inch diameter spools in the S-2-D specimens provided a new assembly breaking strength ranging from 163,000 to 174,000 pounds. The smaller 2-1/2-inch diameter spools used in the S-2-C specimens provided a lower strength ranging from 132,000 to 142,000 pounds. In the former case, rope failures occurred in the body of the rope at strand crossover points within the plaited construction. In the latter case, strand failures occurred at the smaller grommet spools. A photograph of one S-2-C specimen installed in the tensile test equipment is shown in Figure 72. Figure 73 shows this specimen after failure of the lower strand at the grommet spool termination.

Testing of the S-2 rope design was begun with the S-2-C specimens which had the smaller grommet spools. The tension/elongation characteristics of the three tensile test specimens are shown in Figures 74 through 76. Three additional specimens were subjected to cyclic-straight-tension fatigue tests with peak tensions of 25,000, 50,000, and 75,000 pounds. The tension/elongation characteristics of these specimens recorded during the final breaking strength tests are shown in Figures 77 through 79.

Tensile tests and cyclic-straight-tension fatigue tests were then conducted on additional specimens of the S-2 rope using the larger grommet spool termination. The tension/elongation characteristics of these test specimens are shown in Figures 80 through 84. (No elongation data were recorded for Specimen S-2-D-CST-L1.)

As shown in Table 4 the test results indicate the superiority of the larger spools for both the tension and cyclic-straight-tension tests. During the breaking strength tests of the specimens with the smaller spools, strand failures occurred at the spools rather than in the rope body. However, for the specimens tested with the larger spools, strand failures occurred in the rope body indicating no strength loss due to this spool diameter.

Because of this superiority of the larger spools, these terminations were chosen for all specimens of S-2 rope which were subjected to cyclic-tension-over-sheave fatigue testing. In no case did failure of the fatigue samples occur at a spool termination.

The cyclic-tension-over-sheave fatigue tests of the S-2 rope specimens utilized the same apparatus and procedures that had been used for the S-1 rope specimens. Table 4 reveals that rope S-2 provided a rather poor performance during these tests. Because of the low fatigue life achieved with a peak test tension of 50,000 pounds, the 75,000-pound tests originally planned were replaced by 37,500-pound tests.

S-3 Rope Construction

Rope S-3 was a preassembled PS49-6x7x1.9D construction manufactured by Philadelphia Resins Corporation. As shown in Table 2, this rope consisted of a PS29-7x19x0.67D core, the components of which were manufactured from polyurethane impregnated Kevlar 29 fibers and had polyester centers. This core was surrounded by six PS49-7x19x0.58D strands, the components of which were manufactured from polyurethane impregnated Kevlar 49 fibers and had Kevlar 29 centers. Each of these seven main rope elements had a braided polyester jacket. The unique combination of polyester, Kevlar 29, and Kevlar 49 fibers used in this rope was selected in an effort to optimize the fiber stress balance and rope breaking strength.

Samples of this rope were subjected to tension, cyclic-straight tension, and cyclic-tension-over-sheave fatigue tests using the same apparatus and procedures previously used for the other "small" rope constructions. The results are summarized in Table 5. Each of the tensile test and the cyclic-straight-tension fatigue test specimens were socketed using an epoxy resin system having a longer cure time than the system used earlier for tests of the S-1 rope construction. The relatively low breaking strengths recorded for these specimens suggests that the original epoxy was superior. The tension/elongation characteristics of these specimens are shown in Figures 85 through 89.

During the cyclic-tension-over-sheave fatigue tests, all rope specimens achieved 30,000 fatigue cycles except those tested at the highest tension of 75,000 pounds. As shown in Table 5, the even numbered specimens, which experienced the greatest amplitude of motion over test sheaves, exhibited the greatest loss in breaking strength due to fatigue cycling.

Summary of Test Results for "Small" Bridge Cables

The comparative performance characteristics of all three "small" rope constructions are summarized in Table 6. Specific details of the performance of each rope design can be found in Tables 3, 4, and 5.

These test results reveal that Ropes S-1 and S-3 provided somewhat similar performance. (It should be noted that if a modified socketing resin had not been used for several samples of Rope S-3, it is likely that the maximum achievable fiber stress would have been similar than that obtained for Rope S-1.) The tension/elongation data for these two rope designs revealed that Rope S-3 had slightly greater stretch. This characteristic is likely attributable to the relatively shorter lay lengths and compound helix angles inherent in the S-3 construction.

Both Ropes S-1 and S-3 provided fairly good fatigue performance in cyclic-tension-over sheave testing. The fatigue data revealed that the attainable fatigue life was greatly influenced by the size of the sheave and by the amplitude of motion of the rope relative to the sheave. In an actual bridge system, regardless of the sheave size selected, it is likely that quite satisfactory fatigue performance can be obtained with the bridge deployed in a symmetrical configuration. However, in an asymmetrical bridge wherein the reinforcement panel is not centrally located, the sheave motion will increase as a result of differential cable elongation on either side of the sheaves; this motion will likely contribute to a reduced cable fatigue life.

Rope S-2 was found to provide a very poor performance during cyclic-tension-over-sheave fatigue tests. However, it is significant to note that this eight-part plaited rope construction provided the highest strength efficiency (maximum fiber stress equal 249,000 pounds per square inch) and a very low elastic stretch, particularly after being subjected to cyclic-tension fatigue loading. These results suggest that this construction is an excellent candidate for applications requiring high strength and low stretch in the absence of operation over sheaves. This rope construction also had the advantage of being torque free.

Another advantage of Rope S-2 is the very light weight of the grommet spool type of termination. While it is conceivable that Rope S-1 might be fabricated as a grommet assembly, the likelihood of success is not great. Thus, both Ropes S-1 and S-3 are potentially useable only with epoxy type terminations. Such terminations are not only larger and heavier, but they also contribute to a reduced rope strength efficiency. (Note that except in tests which produced severe rope damage due to cyclic loading over sheaves, all tensile test specimens of Ropes S-1 and S-3 failed at the epoxy terminations.) Thus, bridge reinforcement cables which must operate over sheaves will likely be somewhat bulkier and heavier than cables which are subjected to tension loading only.

EVALUATION OF "LARGE" BRIDGE CABLE CONSTRUCTIONS

The Army's requirement that the "large" bridge reinforcement cables have very low stretch (AE = 30 x 10^6 pounds) eliminated from contention any rope constructions which had a relatively low elastic modulus due to the stranding or cabling geometry of the Kevlar fibers. The results of preliminary tests for the "small" bridge cable constructions revealed that the 1/2-inch and 5/8-inch diameter Kevlar 49 Miniline provided a very high elastic modulus (see Figures 23 through 27) and provided good strength and fatigue performance when used over spool-type terminations of quite small diameter. These considerations led to the selection of multiple-part grommet assemblies of Kevlar 49 Miniline for the candidate "large" rope test specimens. Assemblies were fabricated from both 1/2-inch and 5/8-inch diameter Kevlar 49 Miniline and were tested to determine their stretch characteristics and fatigue performance.

The termination type selected for the large bridge cable assemblies consisted of grooved spools around which the Miniline was wrapped to form a parallel element grommet assembly. Hollow-braid splices were incorporated at the bitter ends of the Miniline. To provide the most compact termination and bridge cable cross section, pairs of nested spools were used at each end of the assemblies. The result was a grommet within a grommet, with the inner and outer assemblies being fabricated from separate lengths of Miniline.

To minimize the stretch of the final assemblies it was necessary that all of the individual parts of Miniline be equally loaded. To assure that this condition was attained, sets of small individual sheaves with needle bearings were manufactured and used in the eyes of the grommet assemblies during initial preconditioning. After a number of preconditioning load cycles to achieve uniform loading in all parts of the assembly, the small sheaves were removed from the eyes of the grommet and replaced with appropriate spools.

Preliminary Tests

To obtain a preliminary indication of the stretch characteristics that might be achieved from the large bridge cables, a 13-part assembly of the 5/8-inch diameter Miniline was fabricated using 2-1/2-inch diameter sheaves. The assembly had an overall length of 116.5 inches eye-to-eye. The tension/elongation data obtained during the test of this sample are shown in Figure 90. In addition to displaying the basic tension/elongation characteristics of this 13-part assembly, this figure indicates the additional elongation due to creep as a result of maintaining a 130,000-pound tension over periods of 15 minutes and one hour.

If it is assumed that in the actual bridge system a pretension on such an assembly would be 10,000 pounds (20,000 pounds for the double assembly made with nested spools in the grommet eyes) and that the peak cable tension encountered under most severe loading conditions would be 75,000 pounds (150,000 pounds for the nested spool assembly), then the thirteenth-cycle secant modulus displayed in Figure 90 between these two load limits provided an AE value of 14.1 million pounds. This result indicated that a nested cable assembly made up of a total of 26 parts of the 5/8-inch Miniline would have an AE value of approximately 28.2 million pounds.

A second experiment was then conducted using the same section of Miniline, but in this case using 4-1/4-inch diameter spools. The results of this test are shown in Figure 91. The secant modulus of this assembly between loads of 10,000 and 75,000 pounds provided an AE value of 13.1 million pounds.

The results of these initial experiments revealed that the 13-part Miniline assembly had greater stretch than was originally predicted on the basis of tests of the single length of this rope. While some of this additional elongation may have been due to slight nonuniformity of loading in the 13 parts, it was anticipated that some of the elongation may have been due to the seating and compression of the Miniline where it wrapped over the spools in the grommet eyes.

To explore this possibility further, another 13-part assembly of 5/8-inch diameter Miniline was made up with 4-1/4-inch diameter spools and a total length of 272.5 inches eye-to-eye. This longer assembly was repeatedly loaded to approximately 75,000-pounds tension, and the results of various cycles through the 24th load cycle are shown in Figures 92 through 96. The secant modulus between tension loads of 10,000 and 75,000 pounds revealed an AE value of 14.9 million pounds on the 24th cycle.

Tests were then continued on this same rope assembly using 2-1/2-inch rather than 4-1/4-inch diameter spools. The test results are shown in Figures 97 and 98. After twenty additional load cycles to 75,000 pounds, the secant modulus between tension loads of 10,000 and 75,000 pounds revealed an AE value of 14.8 million pounds on the 44th load cycle.

These last tests came very close to providing the minimum required AE value of 15 million pounds. To assure that the deliverable bridge cable assemblies would have the proper stretch characteristics, the decision was made to increase the number of parts of Miniline from 13 to 15 for each set of spools. Thus, the final nested spool assembly contained a total of 30 parts of Miniline to provide a sufficiently high elastic modulus to meet the Army's requirements.

Final Tests

Since attaining the desired elastic characteristics for these ropes required that they have a rather large Kevlar fiber content, the anticipated breaking load exceeded one million pounds. However, in the interest of minimizing the weight of the cable assemblies, it became apparent that the terminations need not be designed to provide such a high breaking strength, but should be designed to withstand 30,000 fatigue cycles under the most severe loading conditions, and then a final proof load to 260,000 pounds. Thus, planned tests for these large bridge cable assemblies included such proof loading in lieu of measurement of the remaining breaking strength after fatigue cycling.

To provide a suitable light weight connecting link and pin assembly, it became apparent that a high strength material would be necessary. A maraging steel identified as Vasco Max 300 VM and produced by 'Teledyne Vasco', Latrobe, Pennsylvania, was selected. The physical properties of this material are included in Appendix B.

Two 15-part grommet assemblies were then prepared using the 5/8-inch diameter Kevlar 49 Miniline. The spools used in the eyes of these grommets were of two sizes, representing the inner and outer spools of the final nested-spool assembly. The design details for these spools and the associated hardware are included in Appendix C. The fabrication history and technique is tabulated in Tables 7 and 8.

Figure 99 shows the tension/elongation characteristics of the portion of Specimen 1 assembled with the larger 'outer' spools. For the anticipated working load range of 10,000 to 75,000 pounds, this sample provided quite acceptable stretch characteristics with AE = 17.1 x 10^6 pounds. Figure 100 shows the tension/elongation characteristics of the portion of Specimen 1 assembled using the smaller 'inner' spools. For this sample, AE = 17.4 x 10^6 pounds. These two samples were then combined to create a single nested-spool assembly, and the final elongation characteristics provided AE = 28.9 x 10^6 pounds over a load range of 20,000 to 150,000 pounds as shown in Figure 101. This value for AE increased to 36.1 million pounds after 30,000 tension fatigue cycles. The tension/elongation curve recorded during proof loading of the assembly after fatigue cycling is shown in Figure 102.

Similar tension/elongation curves for Specimen 2 are shown in Figures 103 through 106. For this specimen, the measured value of AE after fatigue cycling was 34.4 million pounds.

The two bridge cable specimens discussed above were subjected tension fatigue cycling using the apparatus shown schematically in Figure 107. Figure 108 is a photograph of this equipment. One end of the specimen pair was anchored to a fixed position on the load frame, and the other end was attached to a hydraulic ram tensioning mechanism. The tensioning end of the machine appears in Figure 109, and the fixed end appears in Figure 110. At the center of the machine, each specimen passed over a simulated king-post assembly with the same 158 degree wrap angle anticipated in actual service. A close up view of the king post end is shown in Figure 111. Details of the design of the king post end fixture are shown in Figure 112.

Prior to fatigue cycling, each bridge cable specimen was subjected to a proof load of 260,000 pounds. The proof loading was accomplished with the specimen held straight in the machine (without the king post). The pair of specimens was then subjected to 30,000 fatigue cycles with the rope tension varying between approximately 15,000 to 150,000 pounds. At the conclusion of the fatigue cycling, the samples were again proof loaded to 260,000 pounds tension. (The tension/elongation characteristics recorded during these proof loading cycles are those shown in Figures 101, 102, 105, and 106.)

Fatigue cycling of these cable specimens proceeded without incident until the fatigue failure of one connecting link at 19,898 fatigue cycles. A photograph of this failed link is shown in Figure 113. The failure resulted in some minor damage to the corresponding aluminum spools; however, after some rework of these spools, the test was continued with the connecting links removed from the system.

As previously mentioned, the specimens successfully withstood the 260,000 pounds proof load after the first 30,000 tension fatigue cycles. As the test was continued, one of the connecting pins failed at a total of 48,094 cycles. The pin broke in two nearly equal halves and exhibited a classical bending fatigue failure.

The failure of this pin was due in part to excessive bending stresses produced by the method of mounting the specimens in the test machine. The use of supplemental spacers on either end of the spool assemblies caused the effective length of the connecting pin to be approximately one inch greater than will exist in the actual bridge installation. (The resulting high bending stress situation existed after the failure of the connecting link and was due to the method in which the test machine was reconfigured to allow continuation of fatigue cycling.) After the failure of the connecting pin, the machine was modified to reduce the effective pin length. One new set of nested spools and two new pins were then used to continue the test.

Another factor which contributed to the extraordinary bending stresses imposed upon the connecting pin was the load distribution among the 30 parts of 5/8-inch diameter Miniline. As fatigue cycling continued, some adjustment was noted in the splices at the bitter ends of the Miniline. The result was a loosening of those wraps of Miniline adjacent to the ends of the spool assemblies. This looseness caused those strands near the center of the spools to carry a significantly higher load than would have existed if a uniform load distribution had been maintained in all strands. This poor load distribution produced unacceptable bending stresses in the connecting pins.

A second pin failure was then encountered after an additional 25,631 fatigue cycles. Although the pin fatigue life fell short of original expectations, it is significant to note that two of the other connecting pins which had been in the system since the beginning of the tests survived 73,725 fatigue cycles without failure.

Two additional rope specimens were then assembled of 1/2-inch diameter Kevlar-49 Miniline. The spool terminations were designed to accommodate a total of 38 parts of the smaller Miniline. The preliminary test of a 23-part assembly of 1/2-inch Kevlar-49 Miniline on a 12-groove spool (Figure 114) assisted in arriving at the 38-part design. The fabrication history and technique for these specimens is tabulated in Tables 9 and 10. The tests of these specimens provided a comparative evaluation of the 5/8-inch and 1/2-inch diameter Miniline to determine which version of this rope would yield the most desirable bridge cable characteristics, i.e., the highest elastic modulus.

Tension/elongation curves for these 1/2-inch diameter Miniline assemblies prior to fatigue cycling are shown in Figures 115 through 120. Figures 115 and 116 show the elongation characteristics of the inner and outer spool assemblies of Specimen 1, and Figure 117 shows the final elongation characteristics with these components combined to form a complete nested-spool bridge cable assembly. Similar curves for Specimen 2 are shown in Figures 118, 119, and 120.

As shown in Figures 117 and 120, the completed assemblies had an effective value of AE slightly less than the design goal of 30 million pounds. This value could have been increased, of course, by incorporating additional parts of Miniline in the final assemblies. However, these additional parts would have required longer spool and pin assemblies and would have increased the weight and cost of the final product. This would not have been a practical approach in view of the fact that the desired stretch characteristics had been achieved with the 5/8-inch diameter Miniline using the shorter spool assemblies.

The cyclic-tension fatigue tests of the 1/2-inch diameter Miniline assemblies allowed an evaluation of a redesigned connecting link. New connecting links of slightly larger cross section and with a slightly different heat treatment were tested in conjunction with these assemblies. Also, the braid splices used in the ends of the Miniline were modified to preclude slippage so that a uniform load distribution would be maintained in all strands. This final test sequence provided complete fatigue data not only on the rope and spool assemblies, but also on the associated connecting links and pins.

These two specimens were subjected to cyclic-tension fatigue testing with the midspan of each specimen wrapped over a simulated king-post assembly as previously described. Tension/elongation curves for these specimens after certain periods of fatigue cycling are included in Figures 121 through 124. As anticipated, the fatigue cycling increased the effective elastic modulus of these ropes to a value for AE greater than the 30 million pounds minimum desired by the Army.

During initial testing of these 1/2-inch Miniline assemblies, another failure of a connecting link occurred at 20,868 cycles. This failure prompted a redesign of the link to increase its cross sectional area and to provide bushings within the pin holes to minimize stress concentrations. At the same time, the pin diameter was increased from 2-1/4 to 2-1/2 inches. The final design of the links and pins is included in Appendix C.

Prior to continuation of fatigue cycling, the rope assemblies, links, and pins were proof loaded to 260,000-pounds tension. Fatigue cycling between 15,000 and 150,000 pounds rope tension was then continued for a total of 30,000 additional cycles. At this point, each assembly was again proof loaded to 260,000 pounds. Fatigue cycling was then continued for an additional 60,000 cycles, bringing the total number of cycles for the links and pins to 90,000 and for the rope assemblies 110,868 cycles.

During the final proof loading of these two specimens, pin failures occurred in the attachment hardware of the fatigue machine. (These components were not a part of the link and pin assemblies of the test specimens.) After a rework of the test setup, the ropes, links, and pins were successfully proof loaded to 260,000-pounds tension.

DELIVERABLE HARDWARE

The tests of the large bridge cable assemblies revealed outstanding performance for the final design of the grommet spools, connecting links, and pins. Furthermore, these tests revealed the superiority of the 5/8-inch diameter Miniline to the 1/2-inch diameter Miniline. The larger Miniline required not only fewer parts and thus reduced complexity, but gave a higher overall elastic modulus. These factors led to the selection of the 5/8-inch diameter Miniline for use in the manufacture of the deliverable bridge cable assemblies.

Production Procedures

Production procedures established for the final fabrication of the ten deliverable bridge cable assemblies are described in detail in the fabrication and assembly drawings, reduced copies of which are included in Appendix C. During cable production, an attempt was made to fabricate both the inner and outer grommet assemblies from a given supply spool of 5/8-inch diameter Kevlar-49 Miniline. This technique assured the most consistent matching of AE values between the inner and outer rope assemblies and, thus, assured the highest possible composit AE values for the deliverable bridge cables.

This procedure was followed with one exception; one supply spool was found to have an insufficient length of rope for both the inner and outer grommet assemblies. This deficit was overcome by the addition of approximately 60 feet of Miniline which was attached by means of a special 'end splice'. This added length rope was selected from the surplus of another supply spool that had exhibited a similar AE value for its assemblies. This end splice, described in Appendix C, was essentially identical to the eye splices which were incorporated in the ends of all sections of Miniline.

The suitability of the eye splice was verified by a series of cyclic-tension fatigue tests described in Table 11. A test specimen of 5/8-inch diameter Kevlar-49 Miniline which included one end splice was first loaded to 8,670 pounds and was then subjected to 30,000 tension fatigue cycles with the tension varying from 500 to 5,000 pounds. The specimen was again proof loaded to 8,670 pounds and was then subjected to an additional 60,000 tension fatigue cycles. Finally, the specimen was again proof loaded to 8,670 pounds. The sample successfully survived this test series without excessive slippage of the splice joint or breakage of any of the Kevlar fiber. These tests confirmed the suitability of the end splice technique and indicated that the end splice is a viable method for connecting two lengths of Miniline.

Fabrication of the deliverable bridge cable assemblies proceeded as follows (see Appendix C for complete details):

1. An eye splice corresponding to an inner or outer assembly, as required, was first produced at the exposed bitter end of a supply spool.

2. Sixteen bearing sheaves representing the grommet spool groove geometry were located on a fixture (8 at each end) with the centerline distance from end-to-end equal to the deliverable rope length minus approximately 1/2 inch. The rope, starting with the eye splice, was wound around the sheaves ending with a sufficient length of rope to pass at least two turns around a 12-inch diameter drum grip. Care was exercised not to twist the rope during assembly.

3. The spacer plates, end plates, and restraining pins (with dummy spacer ropes for the inner rope assembly only) were inserted and temporarily secured in place.

4. Each assembly was then put in a load frame as shown in Figures 125 and 126. The free end of the rope was then wrapped two turns and secured around the drum grip which was located opposite the initial eye splice end of the assembly. Five thousand pounds tension was applied to the assembly. By cycling the load from 0 to 5,000 pounds and developing equal tensions in all strands by a technique of deflecting each strand near the center of the assembly, proper load sharing was accomplished. The rope was then shortened or extended on the drum grip as necessary to achieve the desired center-to-center distance between the grommet spools.

5. The rope was then marked at the desired location for the final eye splice. The drum grip was removed, and the terminating eye splice was accomplished. The tension load was again applied to the assembly to verify the splice location and the final rope assembly length. Each inner and matching outer assembly was dimensionally matched within 1/32-inch tolerance.

6. Each assembly was clamped in approximately three equal spaces along its length to retain the strand-to-strand orientation during storage until its matching counterpart assembly was completed. Each assembly was appropriately identified and was removed from the load frame, together with the bearing sheaves and other hardware.

7. Both matching inner and outer grommet assemblies were then married with all the production hardware (spools, plates, and pins). The composite assembly was then reinstalled in the load frame and proper load sharing among all strands was accomplished by the deflecting technique at the center of the assembly in conjunction with load cycling from 0 to 10,000 pounds.

8. A constant tension load of 50,000 pounds was then applied to the composite assembly for a period of 16.5 to 20 hours. This conditioning sequence removed the initial stretch and seated the individual strands into the spool grooves to help to establish a reliable and desired AE value for the bridge rope assembly. The assembly lengths before and after this conditioning are shown in Table 12.

9. The ropes were then proof loaded to 260,000 pounds tension, and the rope lengths at 10,000 pounds tension were documented (see Table 12). The load versus elongation curves from which final AE values were established are shown in Figures 127 through 136. All connecting links and pins were also proof loaded, either with the rope assemblies or in a separate test setup for convenience. (See Figure 137.) A list of all laboratory instrumentation used during this acceptance testing is included in Table 13.

10. While still in the load frame, the king post divider was inserted and secured as shown in Figures 138 and 139.

11. The fabric reinforced jacket was put on the rope assembly and secured with the zipper sealer. The rope was then removed from the load frame.

12. The stainless steel protective covers were installed on both ends of the assemblies to complete the bridge cables as shown in Figures 140 and 141.

CONCLUSIONS AND RECOMMENDATIONS

The phase of this program which involved the evaluation of the "small" bridge cable designs revealed that, within certain limitations, a stranded Kevlar rope is a viable reinforcement cable for applications requiring operation over sheaves. However, the amplitude of cable motion relative to the sheaves has a very strong influence on the attainable fatigue life, and this factor must be taken into consideration during bridge design. The test results indicate further that if the bridge does not require the cables to operate over sheaves, then grommet-type assemblies can be produced which have higher strength, lower stretch, and lower overall weight.

Tests of the "large" bridge cables revealed that the nested spool grommet termination provides a rope assembly with low stretch and high strength efficiency. This termination design also offers a potentially lower overall weight than can be achieved with epoxy terminations.

The particular nested spool configuration used during this program required pairs of connecting links and pins for attaching the reinforcement cable assemblies to each other or to the bridge structure. While this configuration offers the fewest number of individual parts, it does not provide the lowest overall assembly weight or cost. The required pin length was such that the pin diameter and material strength had to be relatively high to avoid bending fatigue failures. The large pin, in turn, required relatively large grommet spools and connecting links.

Preliminary calculations suggest that a modification of the termination design to include three connecting links instead of two would allow a significant reduction in assembly weight and would allow the use of less expensive materials for the links and pins. With this approach the nested spool assemblies would be separated into two halves such that connecting links could be used between, as well as on either side of, the nested spools. The reduced bending moment on the pins would then allow the use of smaller, lighter weight pins, spools, and connecting links. It is recommended that the Army explore this approach in the interest of optimizing the Kevlar reinforcement cables.

The proof loading tests revealed that the deliverable bridge cable assemblies will meet the required stretch characteristics ($AE = 30 \times 10^6$ pounds minimum) if they are used with a pretension of 20,000 pounds or greater. Lower values of pretension will result in a lower effective elastic modulus because of the nonlinearity of the tension/elongation characteristics at low values of cable tension.

Although the deliverable bridge cables exhibited relatively low stretch for a Kevlar construction having such a large fiber content, the elastic modulus of each 30-part assembly was, nevertheless, only approximately one-half of that exhibited by the 5/8-inch diameter Miniline of which the assemblies were fabricated. It is likely that this modulus reduction was due in part to some slight variations in load sharing and in part to the transverse rope compression at the termination spools in response to tension loading. Since extreme steps were taken during this program to achieve uniform load sharing throughout each cable assembly, it is not clear that additional efforts in this direction would further improve the overall elastic modulus for bridge cables of this design.

The earlier section of this report entitled "Summary of Rope Selection Rationale" described in some detail the considerations which led to the selection of the multiple part bridge cable design fabricated from 5/8-inch diameter Kevlar Miniline. The need for compact, light weight terminations eliminated the other candidate cable configurations. Thus, it is unlikely that significant improvements in overall cable assembly weight or elasticity could be achieved through additional efforts to adapt commercially available Kevlar ropes to this military application.

However, in the interest of further reducing the weight and stretch of these bridge reinforcement members, it is recommended that the Army explore alternative means of more effectively utilizing the physical properties of Kevlar fiber to achieve this goal. It is likely that rigid bridge reinforcement members fabricated from epoxy impregnated Kevlar fiber using a version of the filament winding technique would produce a final product which has significantly lower stretch and weight. Although this approach was not within the scope of the program reported herein, it is the next logical step in the optimization of the bridge reinforcement system.

TABLE 1. APPROXIMATE PHYSICAL PROPERTIES OF NATURAL KEVLAR FIBER

	Individual Filaments			Twisted Yarn[a]		
Type of Kevlar	Diameter, inch	UTS[b], lb/in.^{2}	Modulus 10^6 lb/in.^{2}	UTS[b], lb/in.^{2}	Modulus, 10^6 lb/in.^{2}	Area, 10^{-4} in.^{2}
K-29	0.000476	525,000	14.0 - 14.5[c]	400,000	12.0 - 13.0[d]	1.78
K-49	0.000465	510,000	18.5 - 19.0	390,000	15.0 - 16.0	1.70

(a) 1500 denier K-29 or 1420 denier K-49 (1000 filaments each).

(b) Ultimate tensile strength.

(c) Elastic modulus on first load cycle = 11-12 x 10^6 lb/in.^{2}
Elastic modulus after many load cycles = 14-14.5 x 10^6 lb/in.^{2}.

(d) Elastic modulus on first load cycle = 9-10 x 10^6 lb/in.^{2}
Elastic modulus after many load cycles = 12-13 x 10^6 lb/in.^{2}.

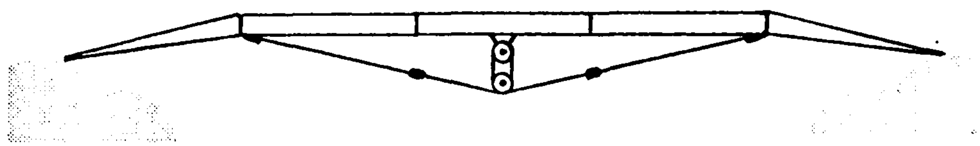


FIGURE 1. DIAGRAM OF PORTABLE BRIDGE CONFIGURATION REQUIRING 'SMALL' ROPE ASSEMBLIES

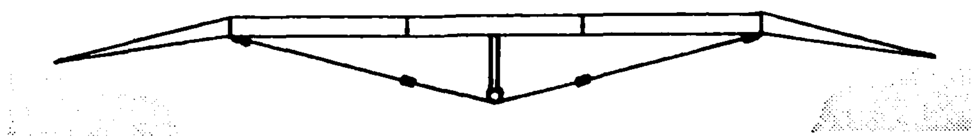


FIGURE 2. DIAGRAM OF PORTABLE BRIDGE CONFIGURATION REQUIRING 'LARGE' ROPE ASSEMBLIES

FIGURE 3. SEWN LOOP TERMINATION FOR WEBBING OR BELTING

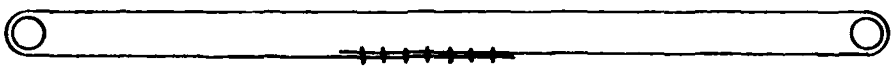


FIGURE 4. SEWN GROMMET CONFIGURATION FOR WEBBING OR BELTING

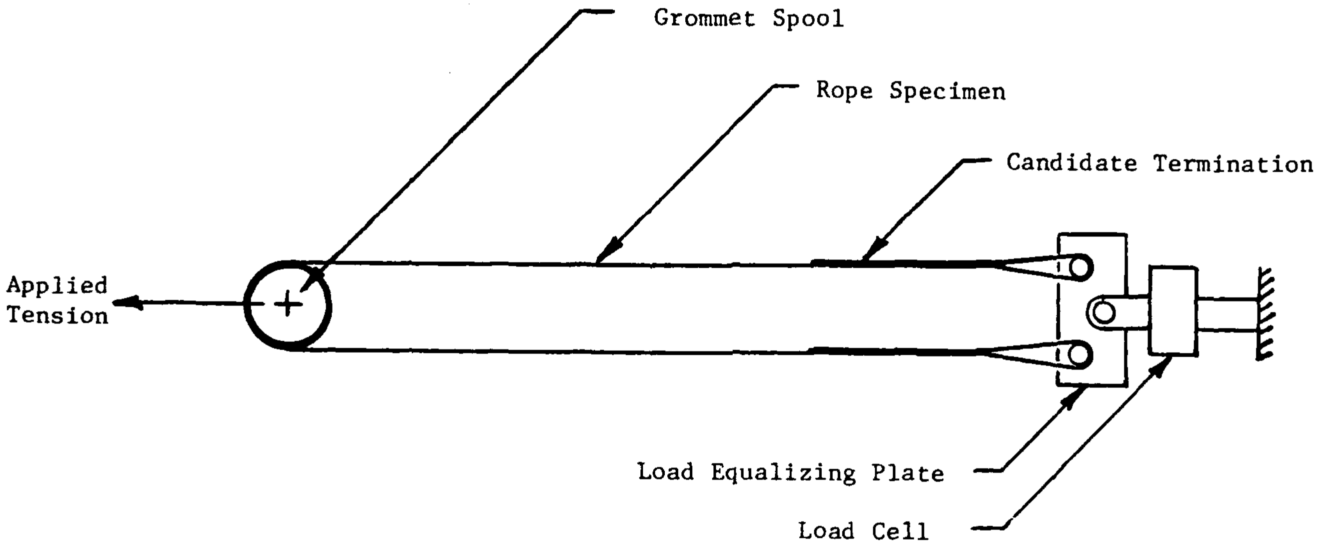
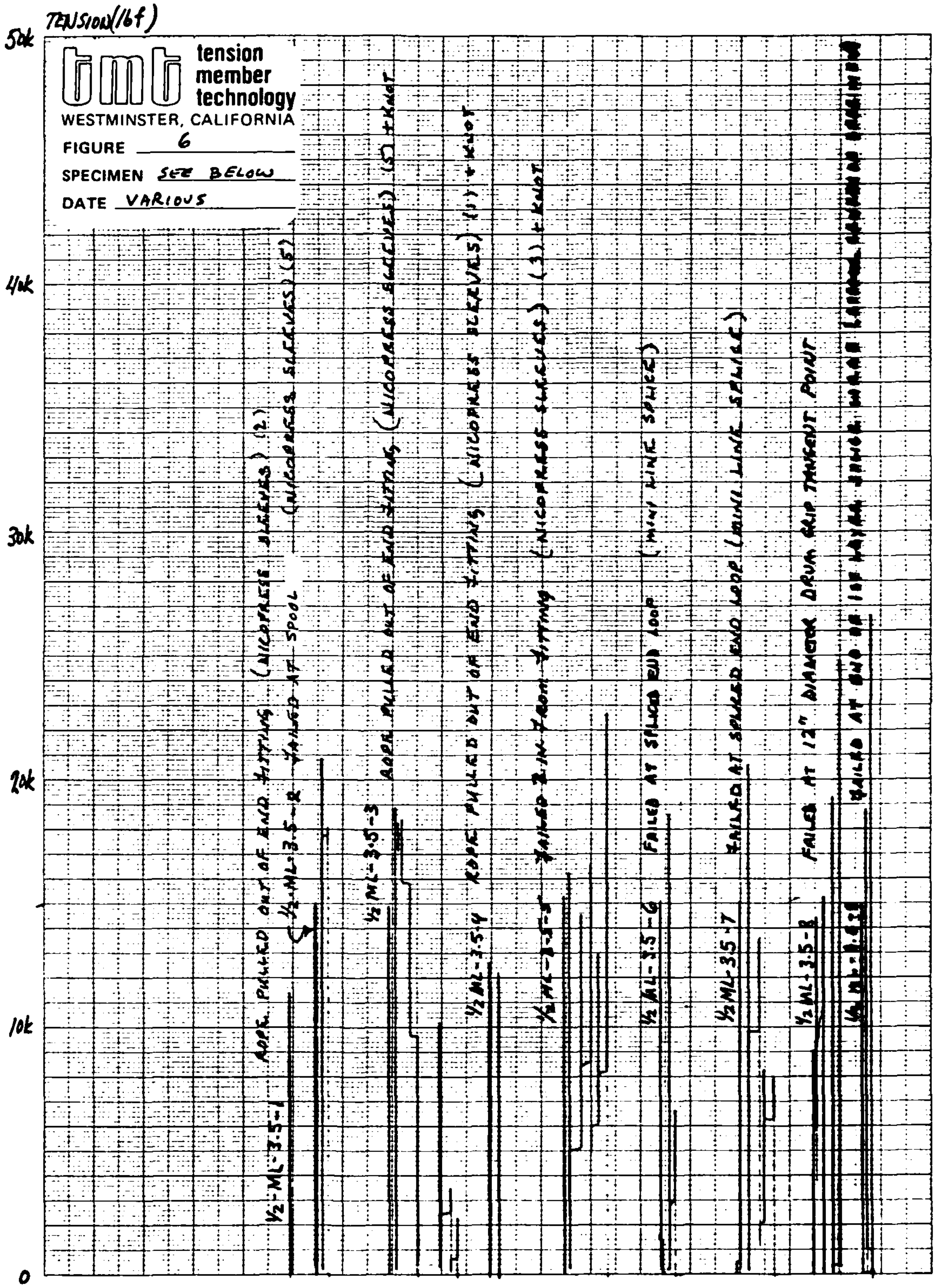
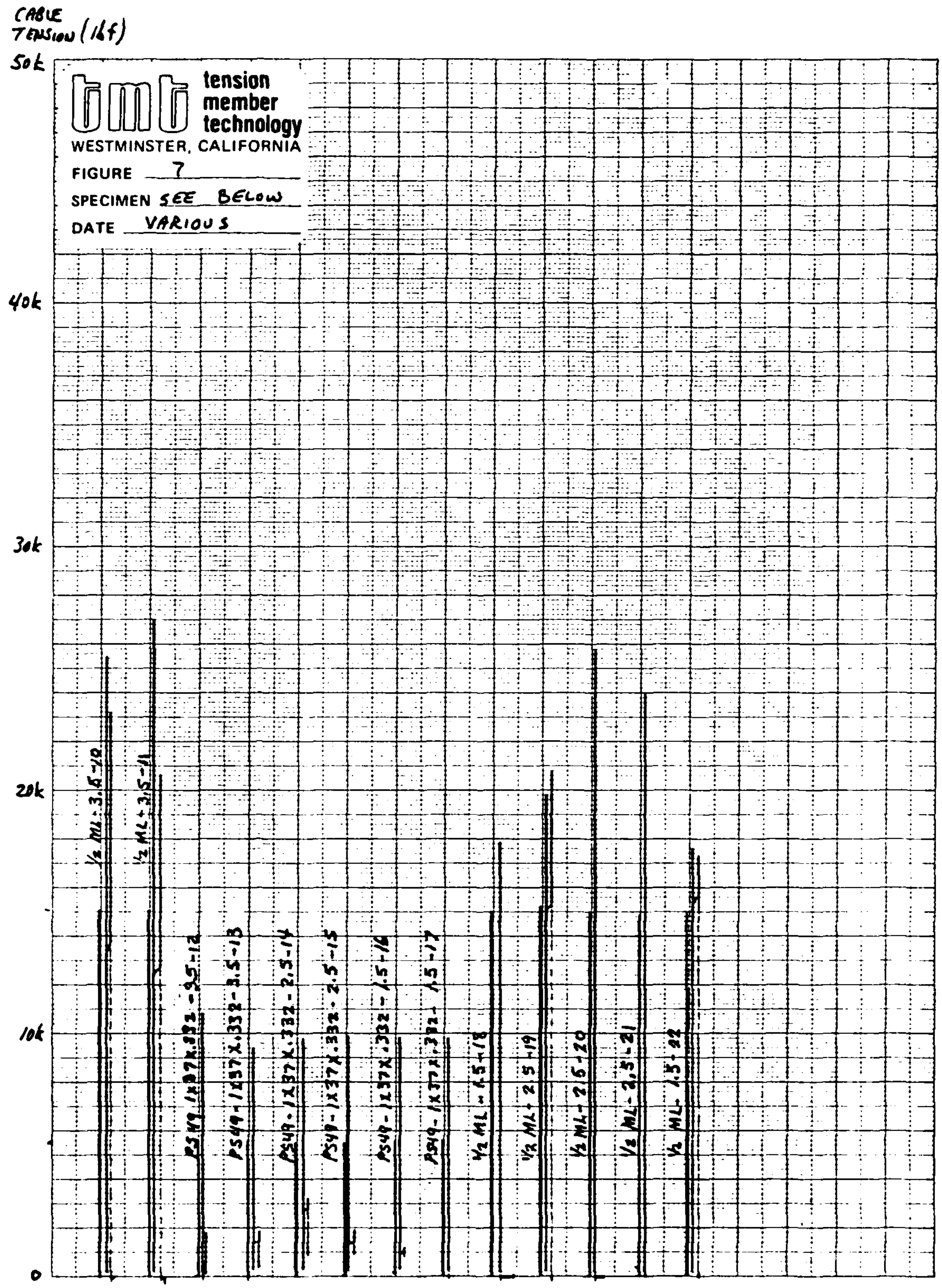
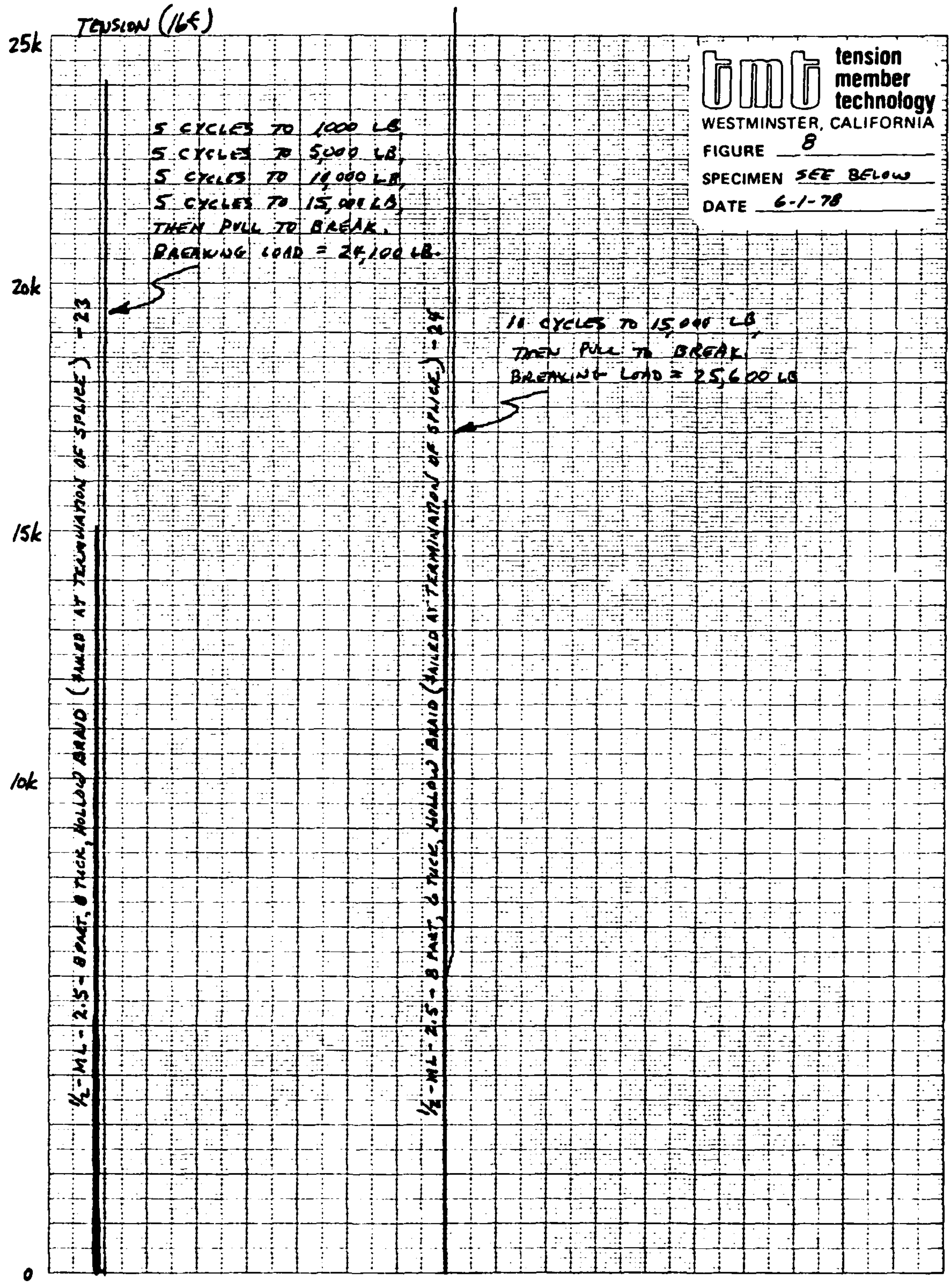


FIGURE 5. DIAGRAM OF APPARATUS USED FOR PRELIMINARY TENSILE TESTS


TENSION (lbf)
50k
40k
30k
20k
10k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 6
SPECIMEN SEE BELOW
DATE VARIOUS
½-ML-3.5-1 ROPE PULLED OUT OF END FITTING (NICOPRESS SLEEVES) (2)
½ ML-3.5-2 FAILED AT SPOOL (NICOPRESS SLEEVES) (5)
½ ML-3.5-3 ROPE PULLED OUT OF END FITTING (NICOPRESS SLEEVES) (5) + KNOT
½ ML-3.5-4 ROPE PULLED OUT OF END FITTING (NICOPRESS SLEEVES) (3) + KNOT
½ ML-3.5-5 FAILED 2 IN FROM FITTING (NICOPRESS SLEEVES) (3) + KNOT
½ ML-3.5-6 FAILED AT SPLICED END LOOP (MINI LINE SPLICE)
½ ML-3.5-7 FAILED AT SPLICED END LOOP (MINI LINE SPLICE)
½ ML-3.5-8 FAILED AT 12" DIAMETER DRUM GRIP TANGENT POINT


CABLE
TENSION (lbf)
50k
40k
30k
20k
10k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 7
SPECIMEN SEE BELOW
DATE VARIOUS
½ ML - 3.5 -10
½ ML - 3.5 -11
PS49 - 1X37X.332 - 3.5 -12
PS49 - 1X37X.332 - 3.5 -13
PS49 - 1X37X.332 - 2.5 -14
PS49 - 1X37X.332 - 2.5 -15
PS49 - 1X37X.332 - 1.5 -16
PS49 - 1X37X.332 - 1.5 -17
½ ML - 1.5 -18
½ ML - 2.5 -19
½ ML - 2.5 -20
½ ML - 2.5 -21
½ ML - 1.5 -22


TENSION (LBS)
25k
20k
15k
10k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 8
SPECIMEN SEE BELOW
DATE 6-1-78
5 CYCLES TO 1000 LB,
5 CYCLES TO 5,000 LB,
5 CYCLES TO 10,000 LB,
5 CYCLES TO 15,000 LB,
THEN PULL TO BREAK.
BREAKING LOAD = 24,100 LB.
10 CYCLES TO 15,000 LB,
THEN PULL TO BREAK.
BREAKING LOAD = 25,600 LB
1/2"-ML-2.5-8 PART, 8 THICK, HOLLOW BRAID (FAILED AT TERMINATION OF SPLICE) -23
1/2"-ML-2.5-8 PART, 6 THICK, HOLLOW BRAID (FAILED AT TERMINATION OF SPLICE) -24

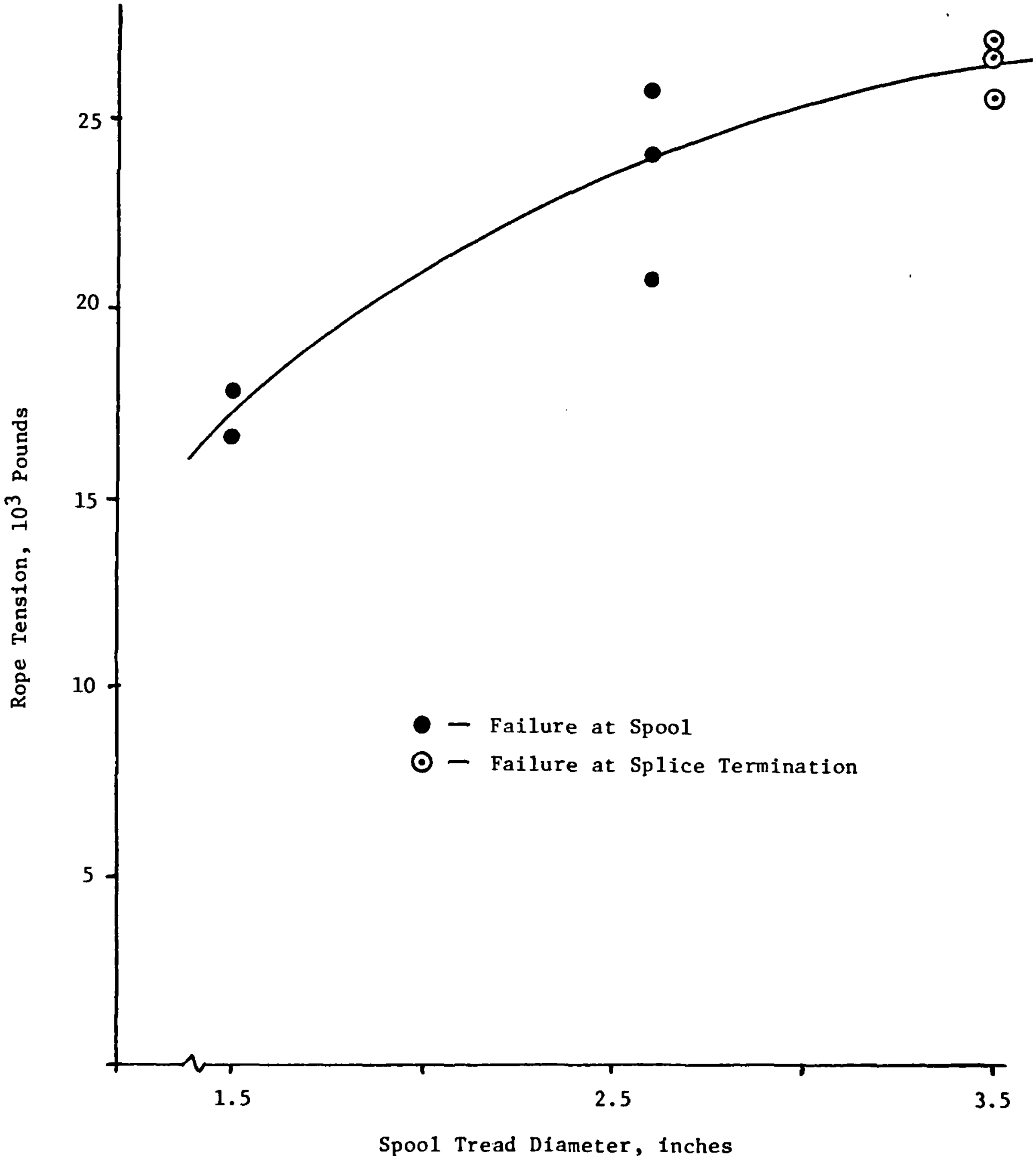


FIGURE 9. EFFECTS OF GROMMET SPOOL DIAMETER ON BREAKING STRENGTH OF 1/2-INCH DIAMETER KEVLAR 49 MINILINE

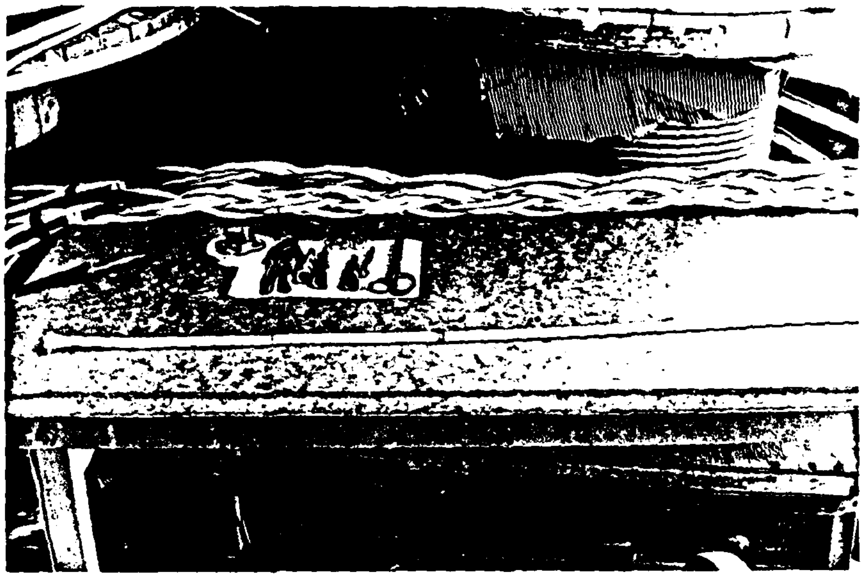


FIGURE 10. TOOLS REQUIRED AND ROPE LAYOUT FOR MINILINE HOLLOW BRAID EYE SPLICE

(Clamp identifies centerline of eye loop.)

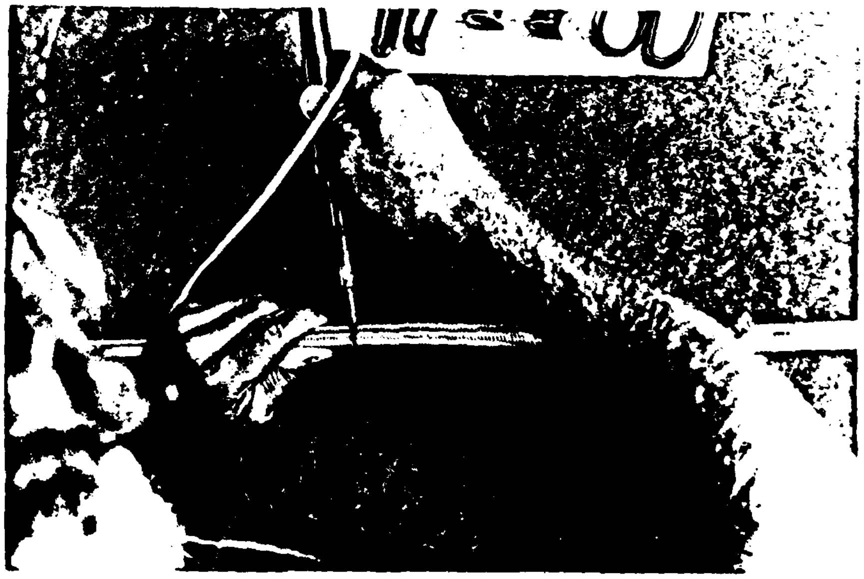


FIGURE 11. REMOVING OUTER JACKET WITH SOLDERING IRON--CIRCUMFERENTIAL SEPARATION

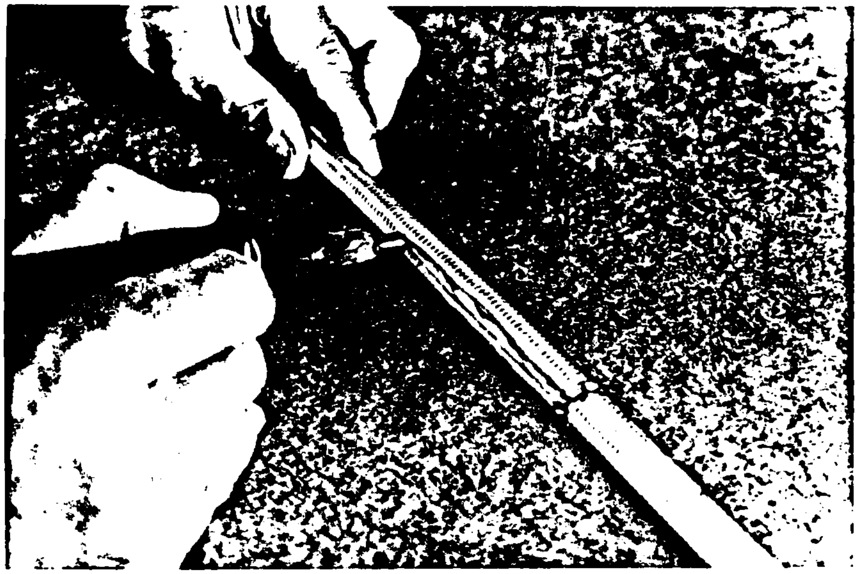


FIGURE 12. REMOVING OUTER JACKET WITH SOLDERING IRON--
LONGITUDINAL SEPARATION

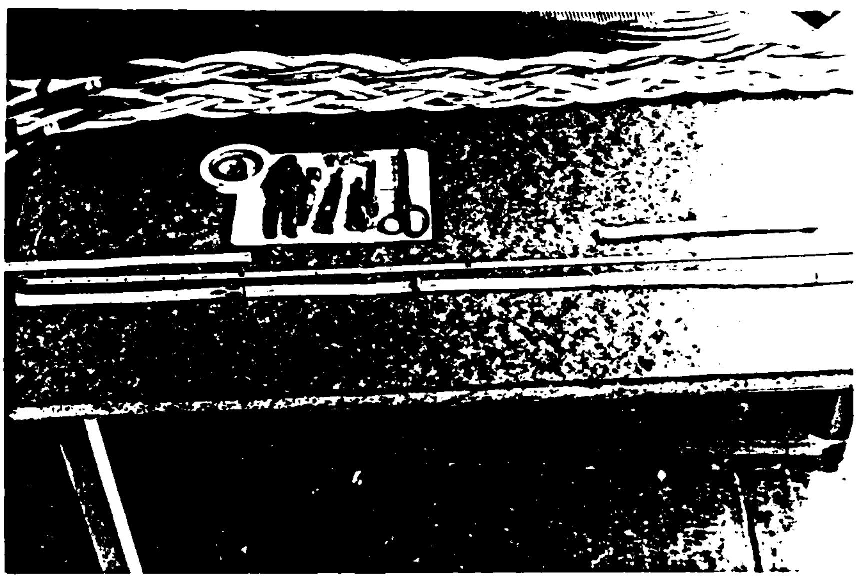


FIGURE 13. OUTER JACKET REMOVED FROM REQUIRED SPLICE AREA

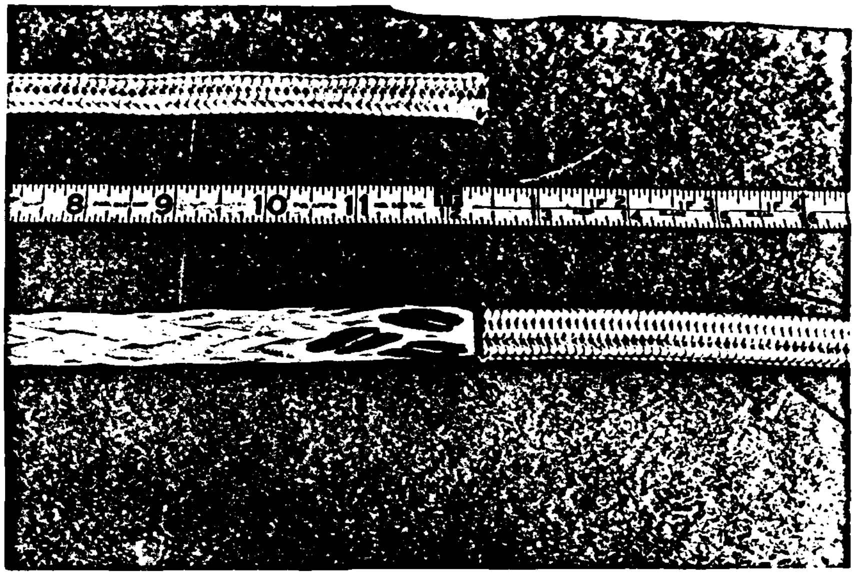


FIGURE 14. RIGHT AND LEFT LAY STRANDS MARKED GREEN
AND RED, RESPECTIVELY

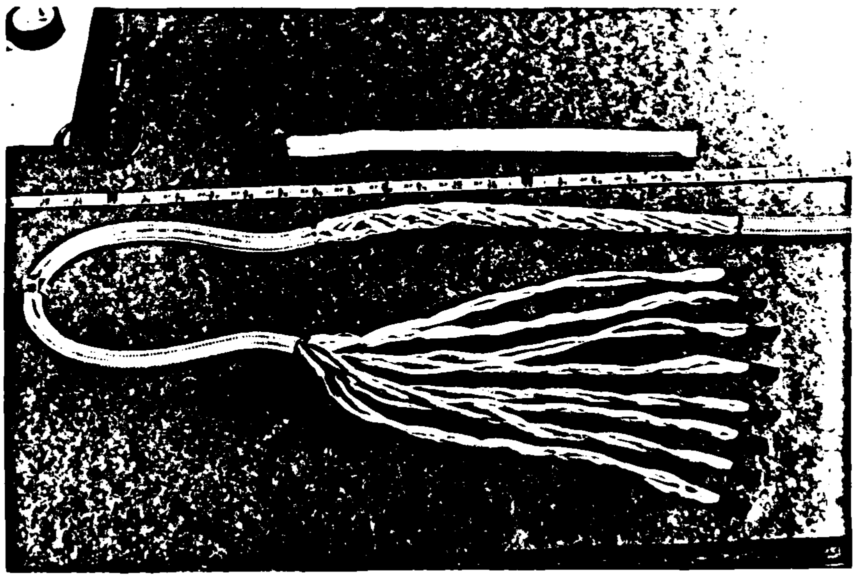


FIGURE 15. KEVLAR STRANDS SEPARATED INTO EIGHT GROUPS
OF TWO EACH

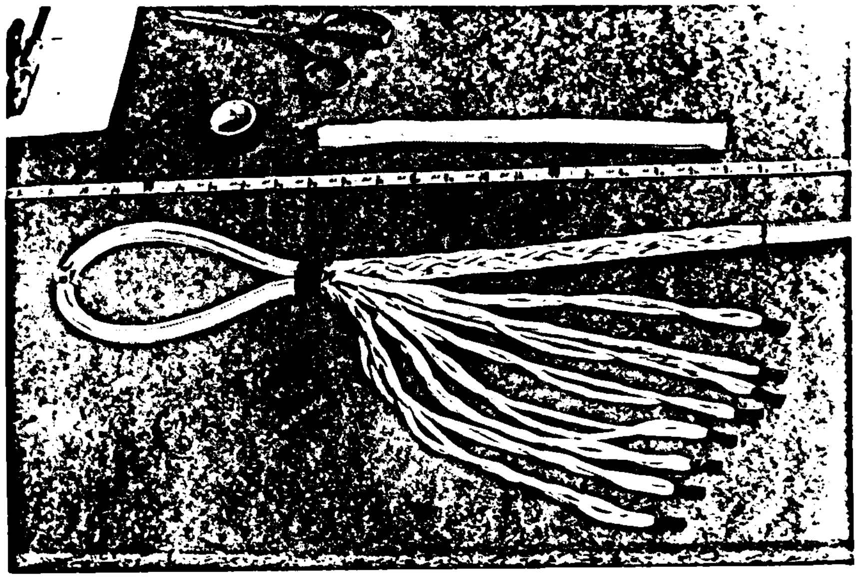


FIGURE 16. EYE SPLICE LOOP FORMED AND TAPED

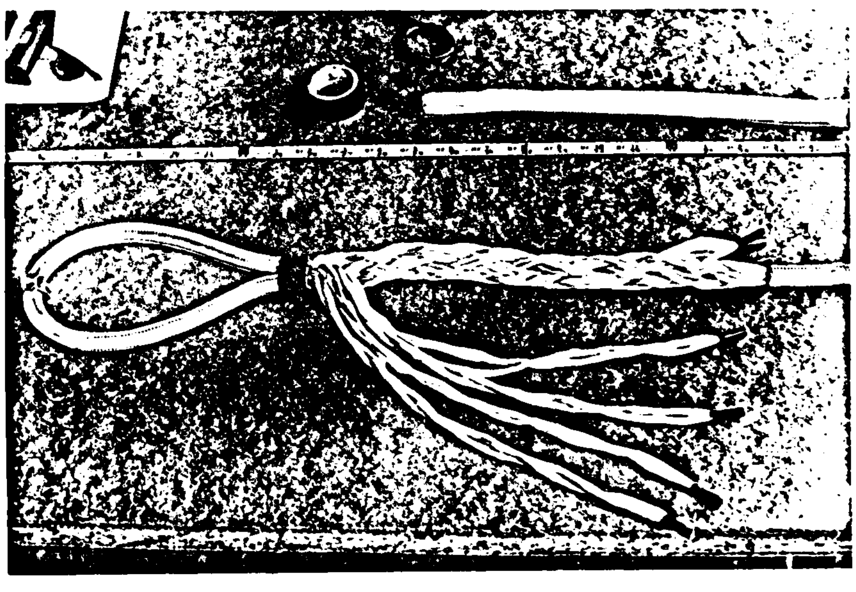


FIGURE 17. TUCKING OF STRANDS, BEGINNING WITH A GREEN STRAND AND ALTERNATING RED AND GREEN STRANDS IN ORDER

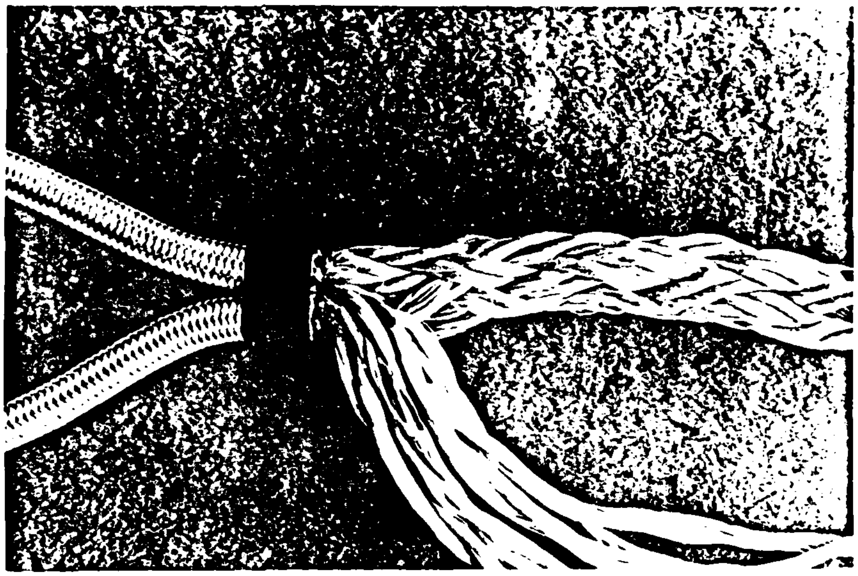


FIGURE 18. PARTIALLY COMPLETED EYE SPLICE

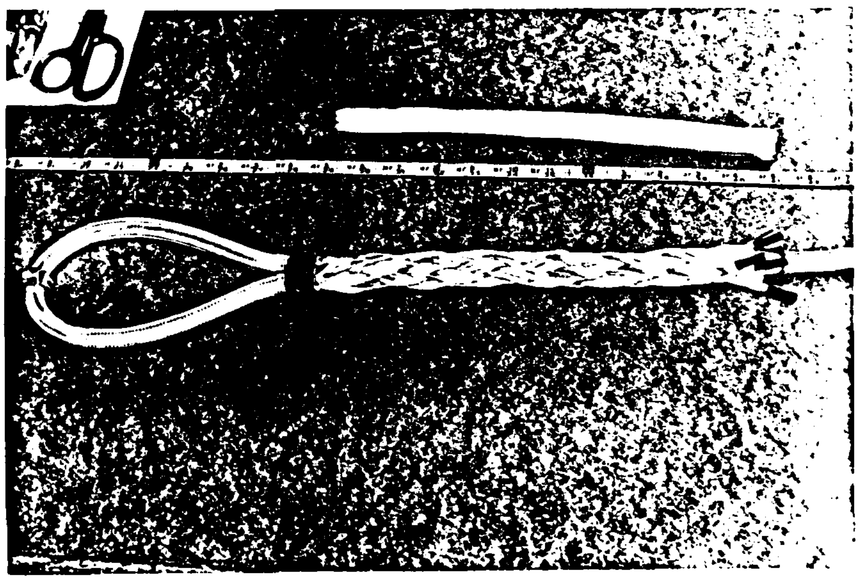


FIGURE 19. TUCKING COMPLETED

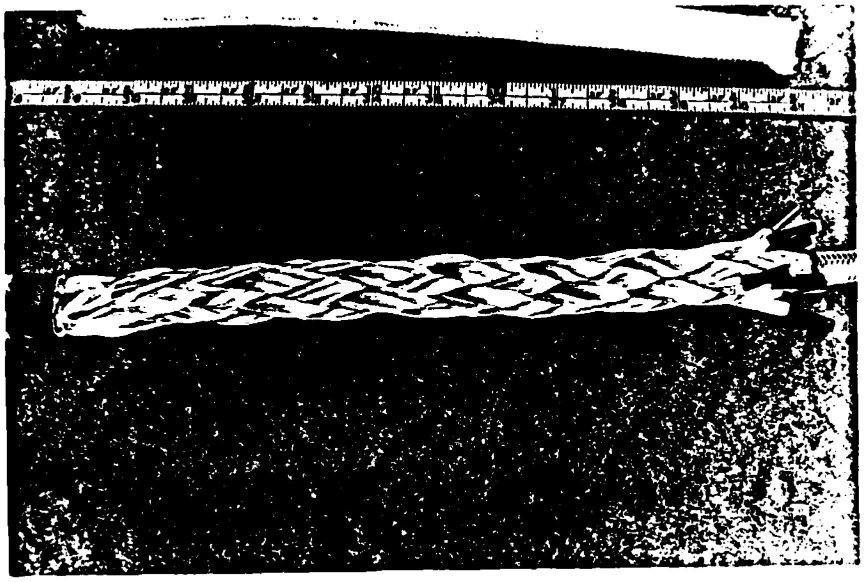


FIGURE 20. STRANDS UNIFORMLY TUCKED AND TIGHTENED

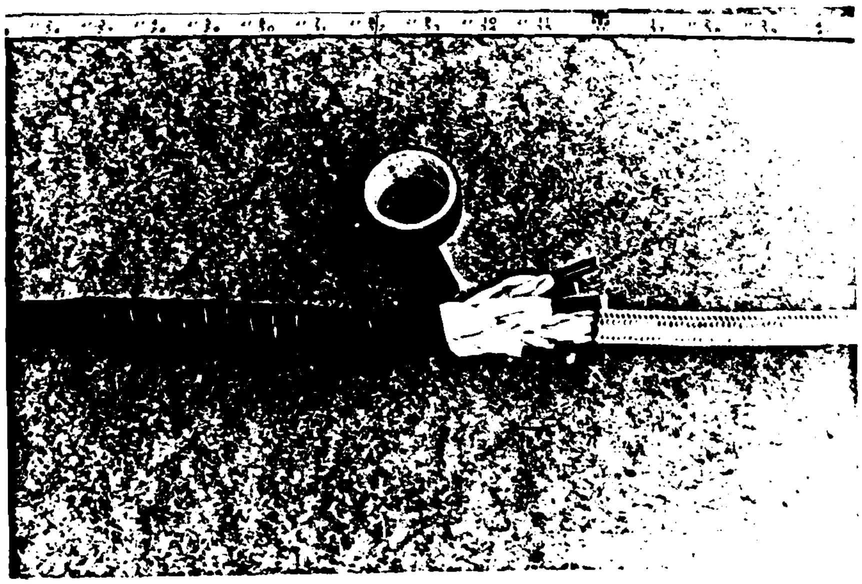


FIGURE 21. WRAPPING SPLICE JOINT WITH PVC ELECTRICAL TAPE

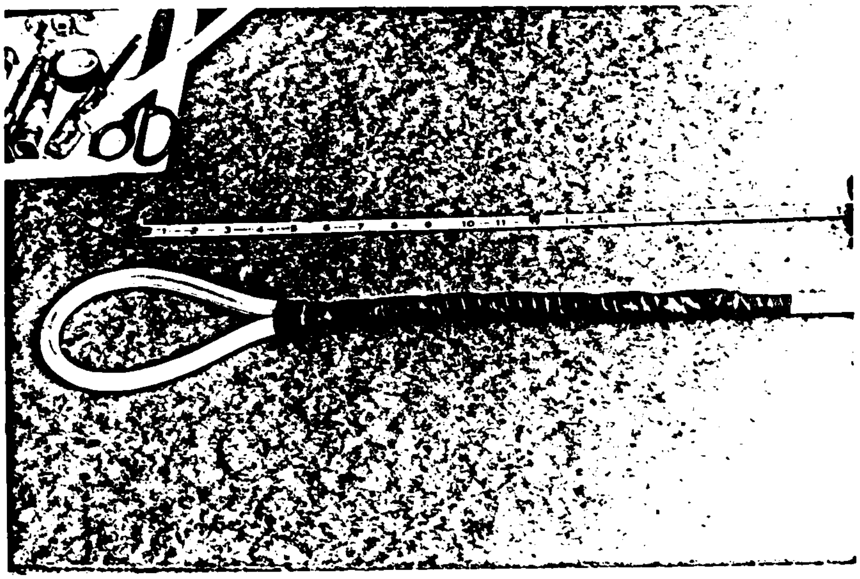
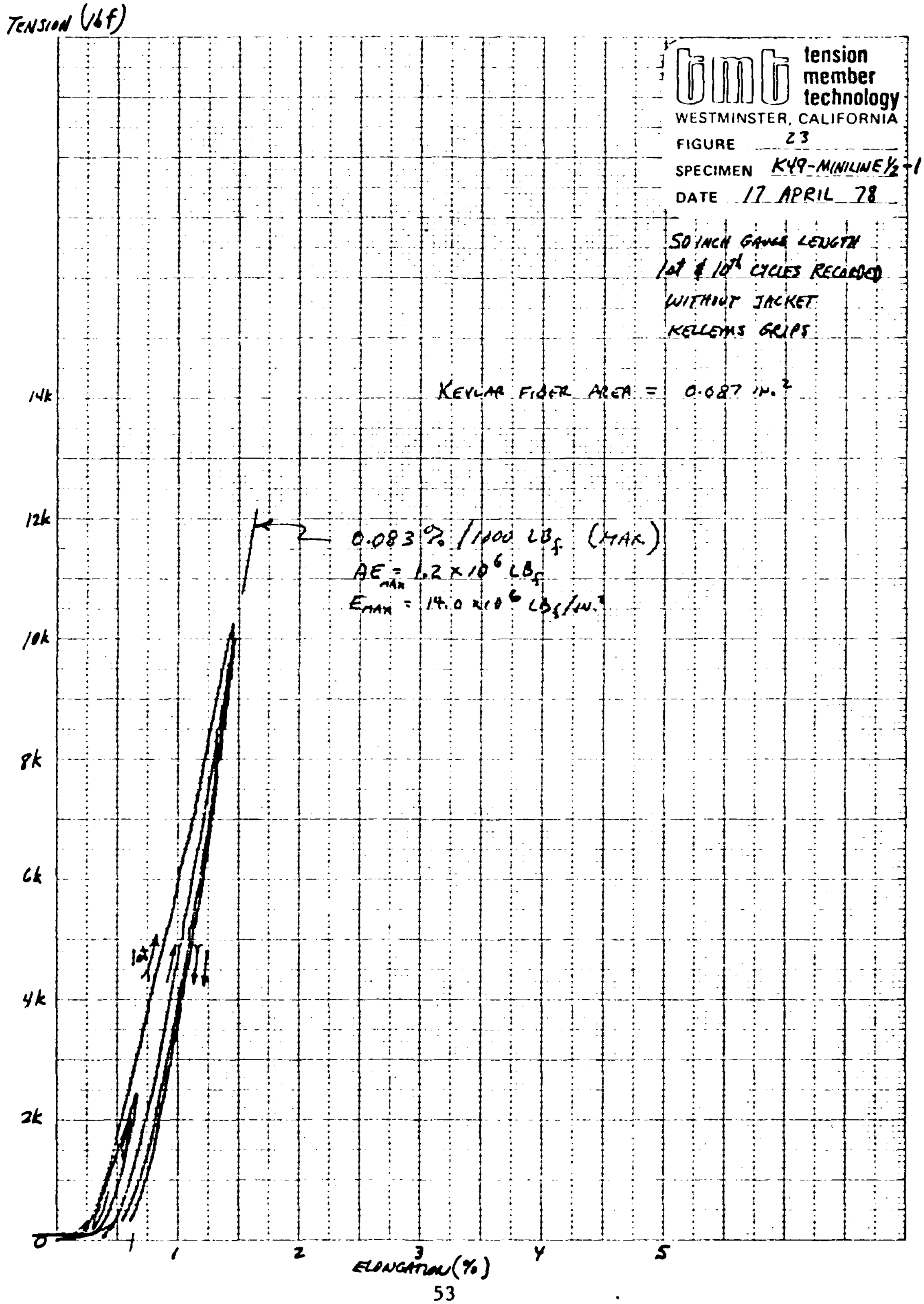
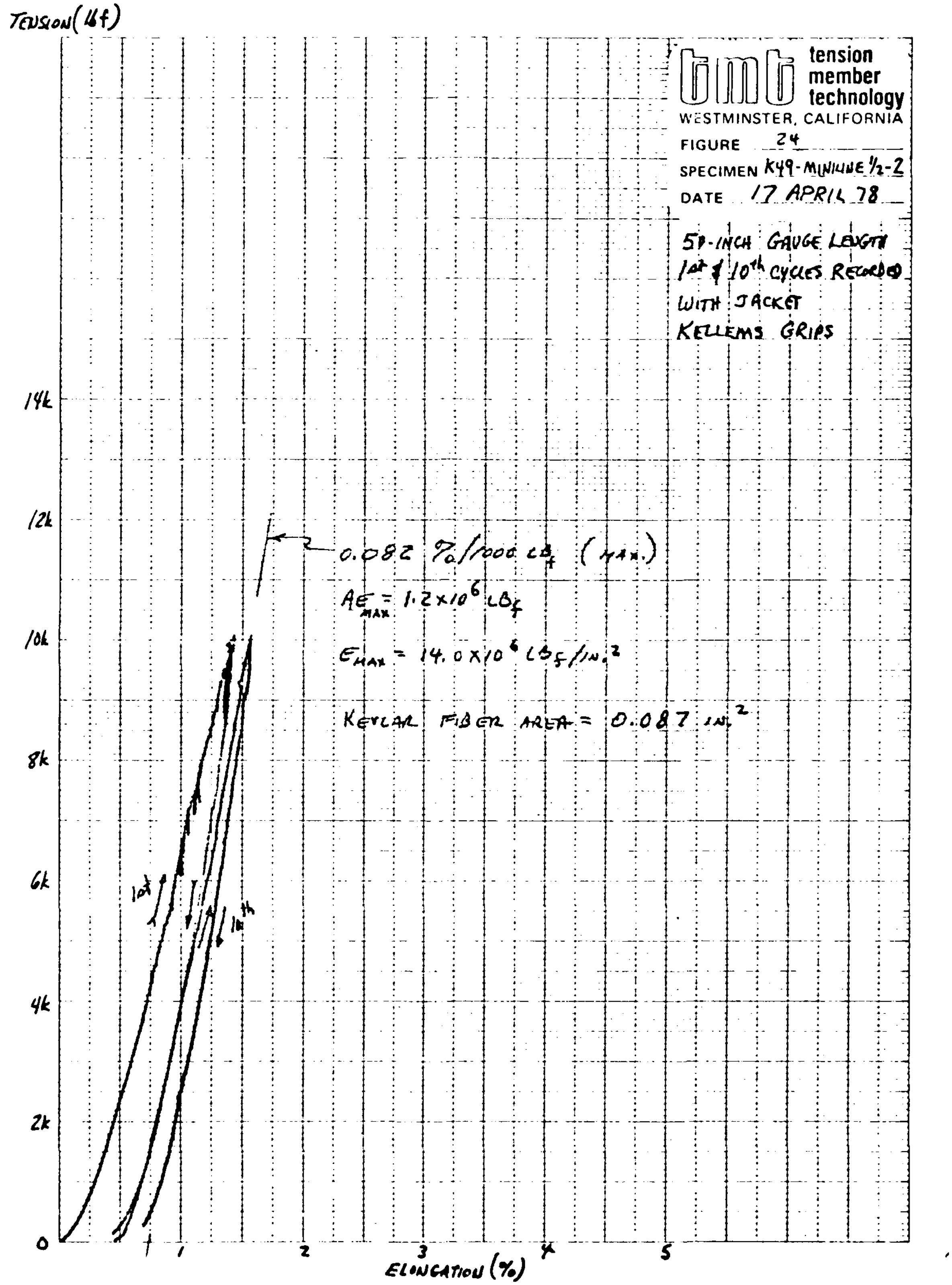
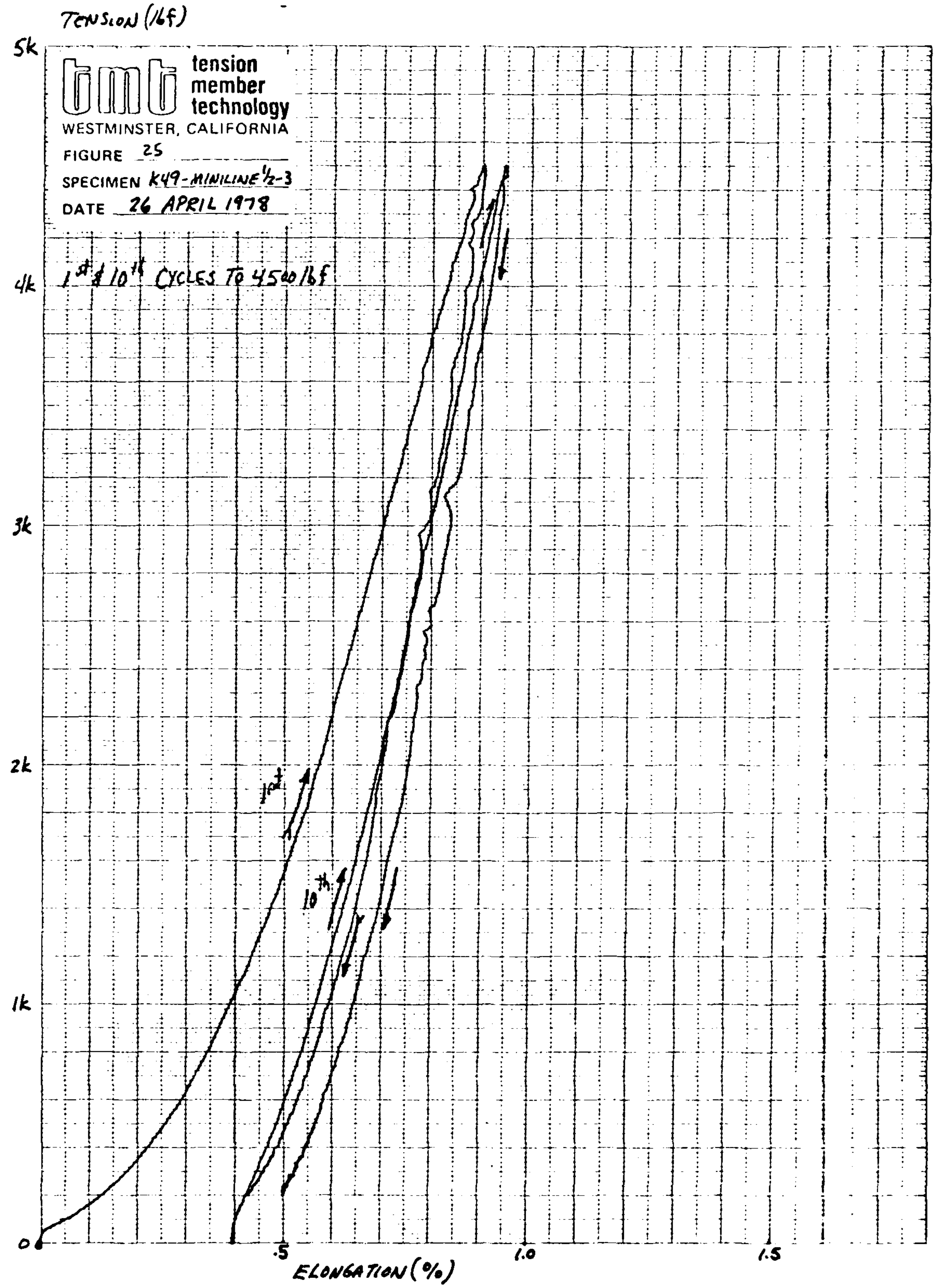


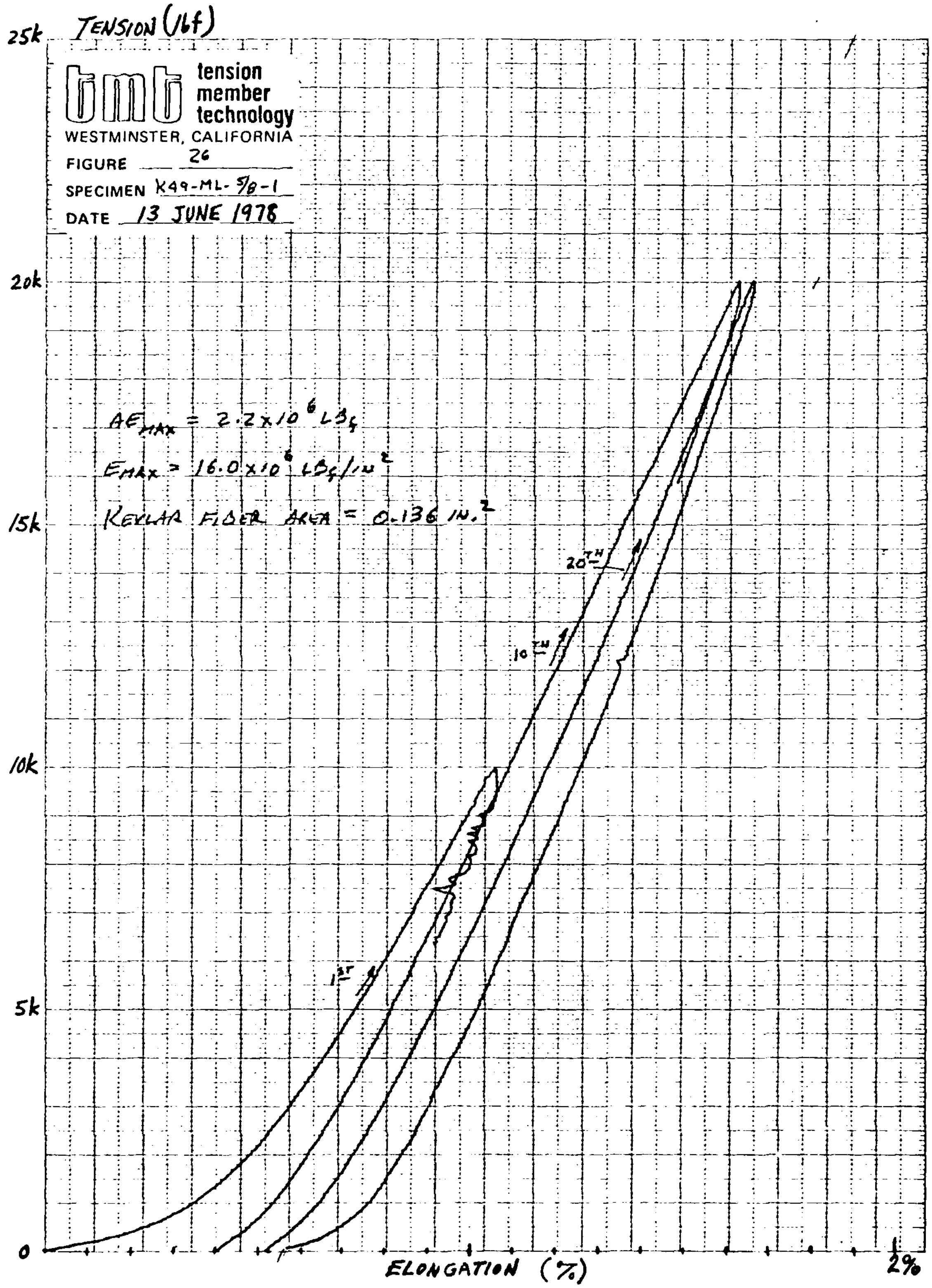
FIGURE 22. COMPLETED EYE SPLICE PRIOR TO INSTALLATION OF SHRINK TUBING

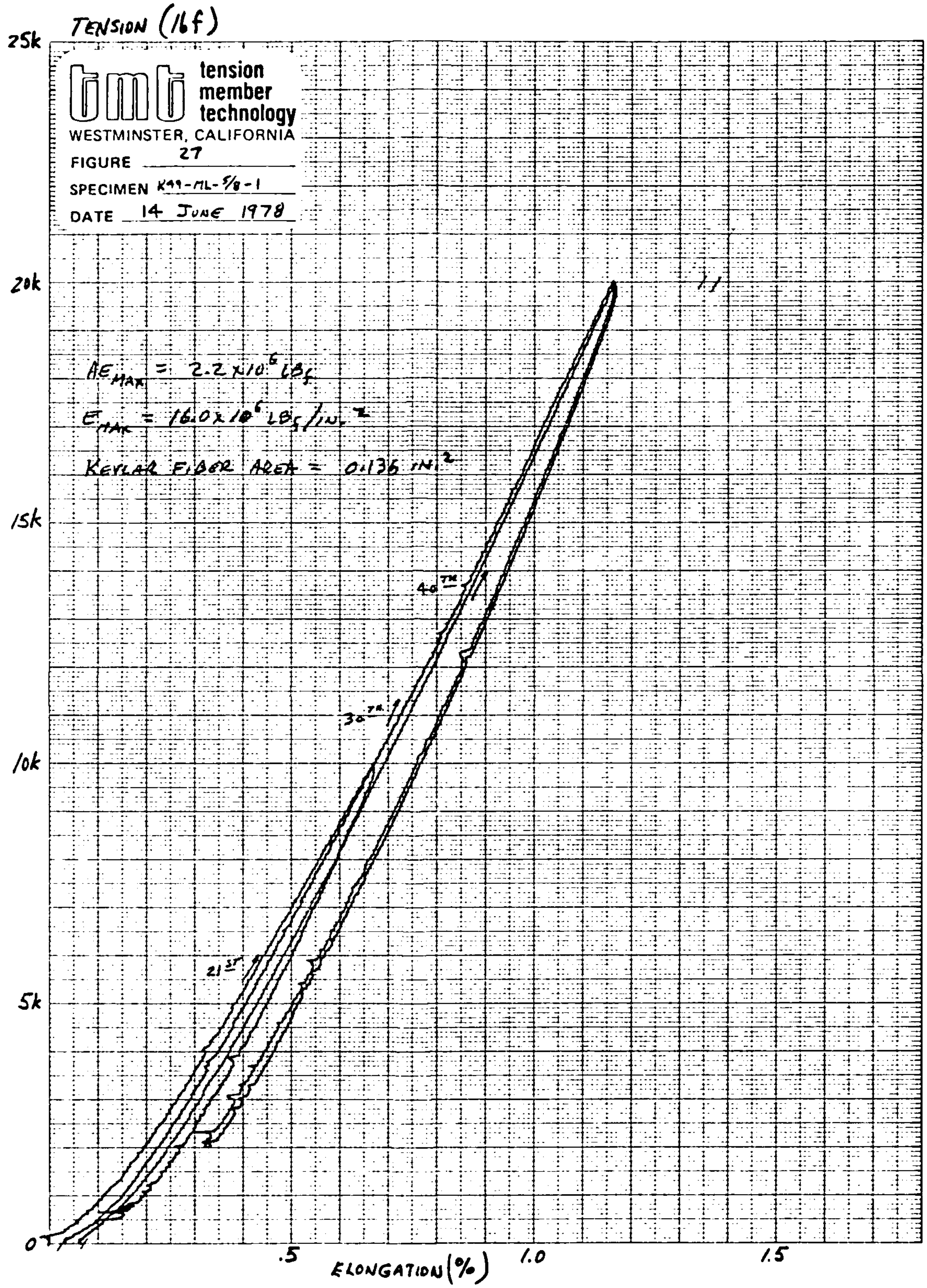

TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 23
SPECIMEN K49-MINILINE 1/2 -1
DATE 17 APRIL 78
50 INCH GAUGE LENGTH
1st & 10th CYCLES RECORDED
WITHOUT JACKET
KELLEMS GRIPS
KEVLAR FIBER AREA = 0.087 IN.²
0.083 % / 1000 LBf (MAX)
AE max = 1.2 x 10⁶ LBf
E max = 14.0 x 10⁶ LBf/IN.²
14k
12k
10k
8k
6k
4k
2k
0
1st
10th
1
2
3
4
5
ELONGATION (%)

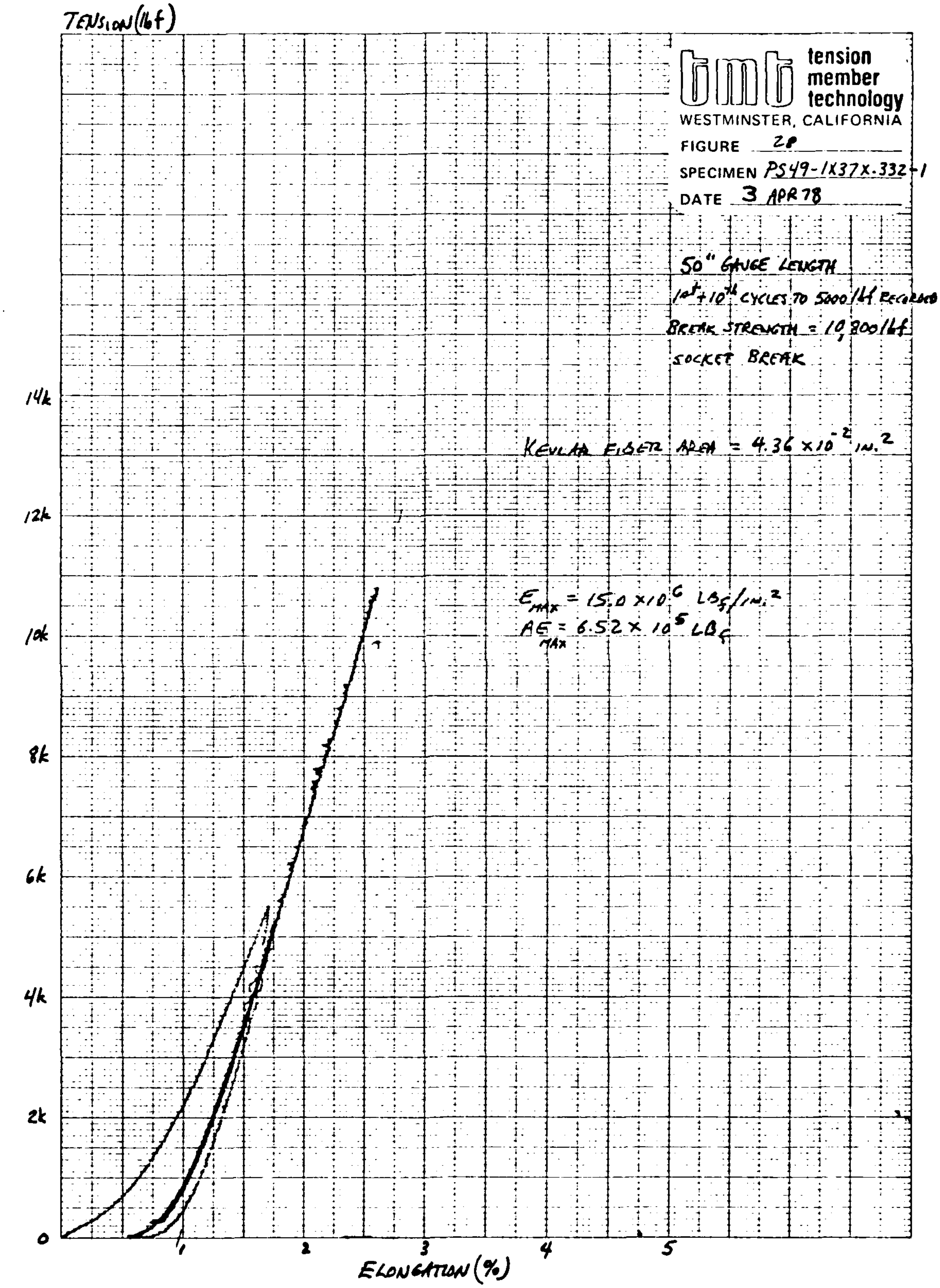


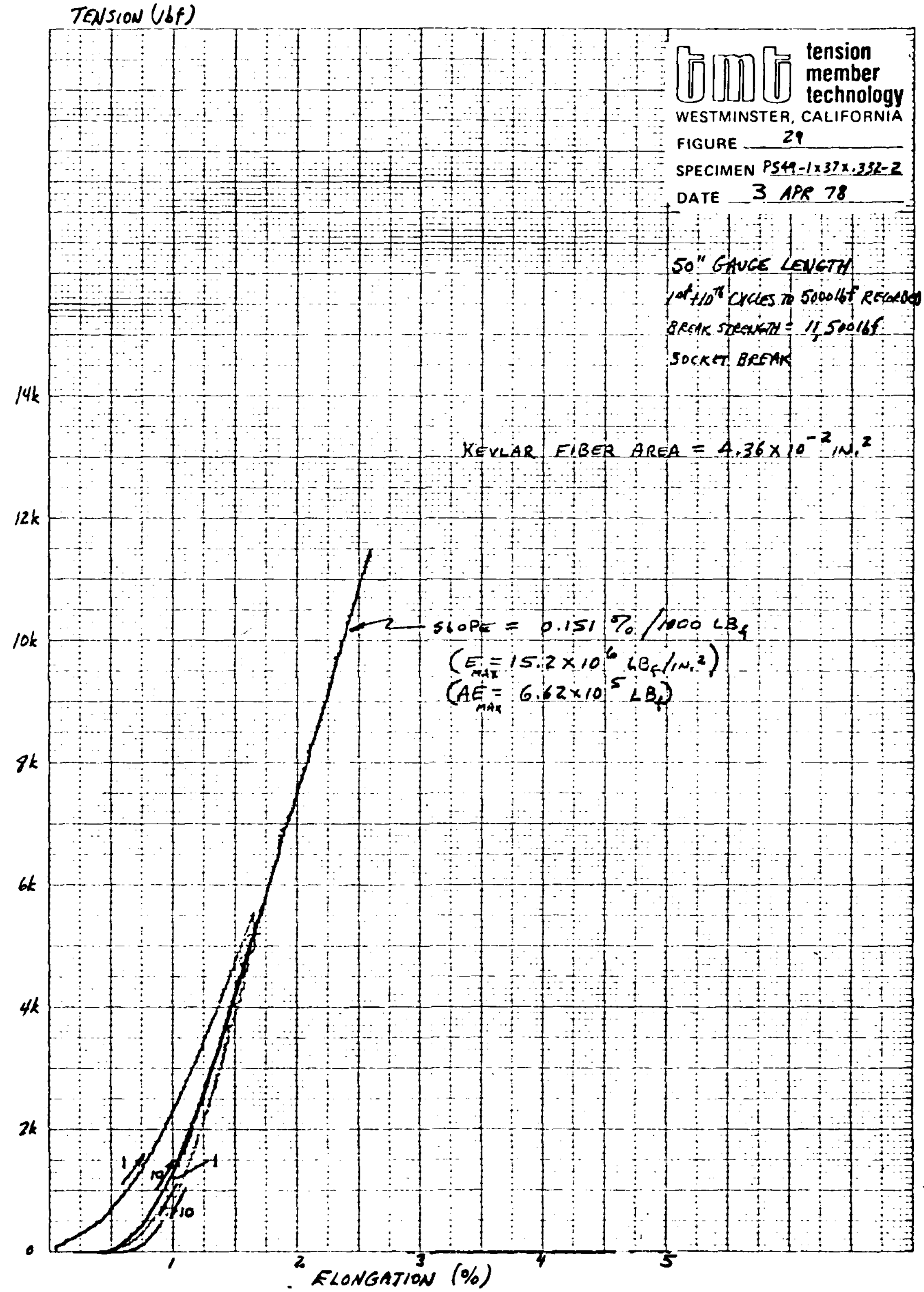
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 24
SPECIMEN K49-MINILINE ½-2
DATE 17 APRIL 78
50-INCH GAUGE LENGTH
1st & 10th CYCLES RECORDED
WITH JACKET
KELLEMS GRIPS
0.082 %/1000 LBf (MAX.)
$AE_{MAX} = 1.2 \times 10^6$ LBf
$E_{MAX} = 14.0 \times 10^6$ LBf/IN.^{2}
KEVLAR FIBER AREA = 0.087 IN.^{2}
1st
10th
14k
12k
10k
8k
6k
4k
2k
0
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
5k
4k
3k
2k
1k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 25
SPECIMEN K49-MINILINE ½-3
DATE 26 APRIL 1978
1st & 10th CYCLES TO 4500 lbf
1st
10th
.5
1.0
1.5
ELONGATION (%)

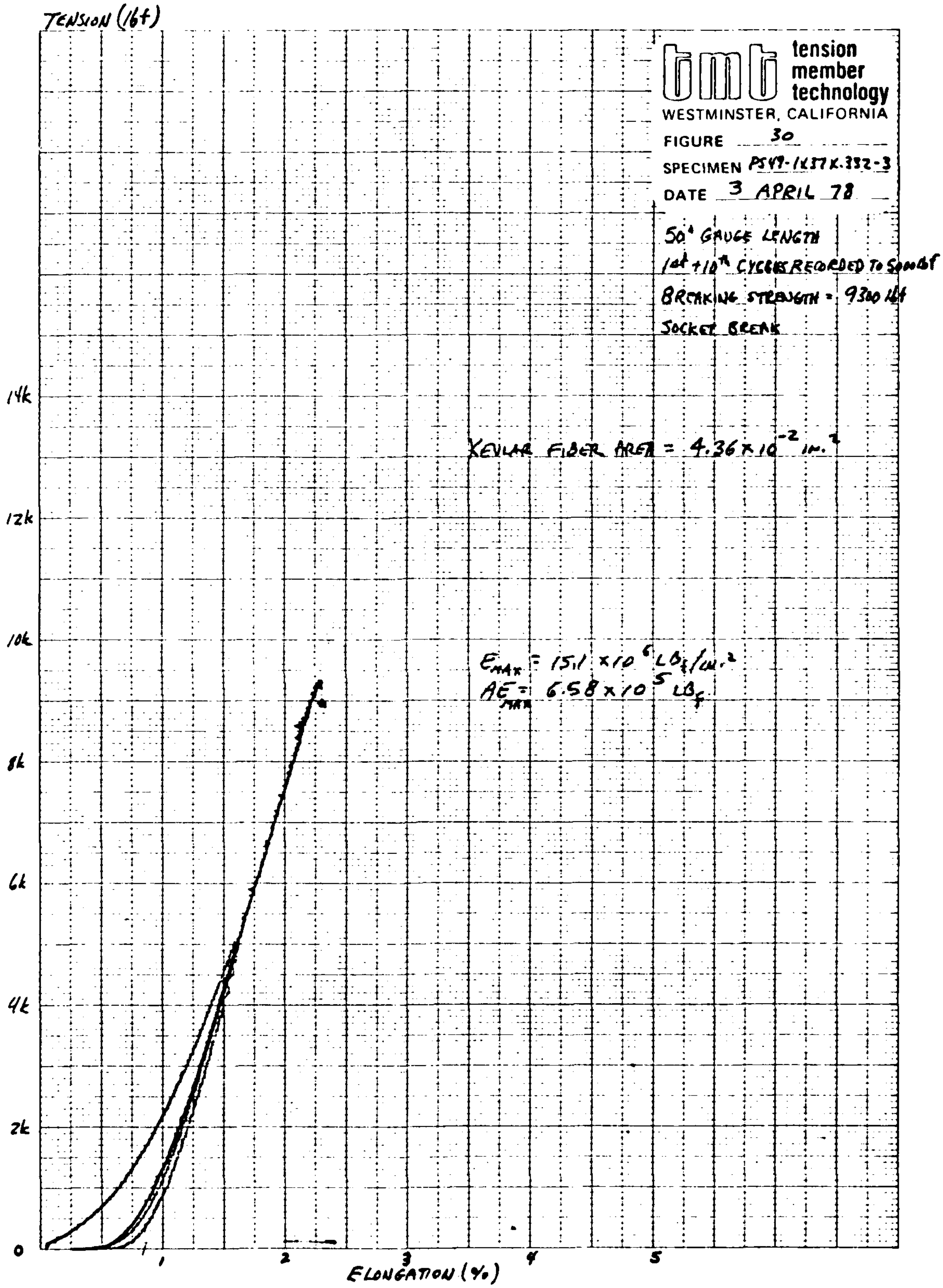

TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 26
SPECIMEN K49-ML-5/8-1
DATE 13 JUNE 1978
25k
20k
15k
10k
5k
0
AE MAX = 2.2 x 10^6 LBf
EMAX = 16.0 x 10^6 LBf/IN^2
KEVLAR FIBER AREA = 0.136 IN.^2
20TH
10TH
1ST
ELONGATION (%)
2%

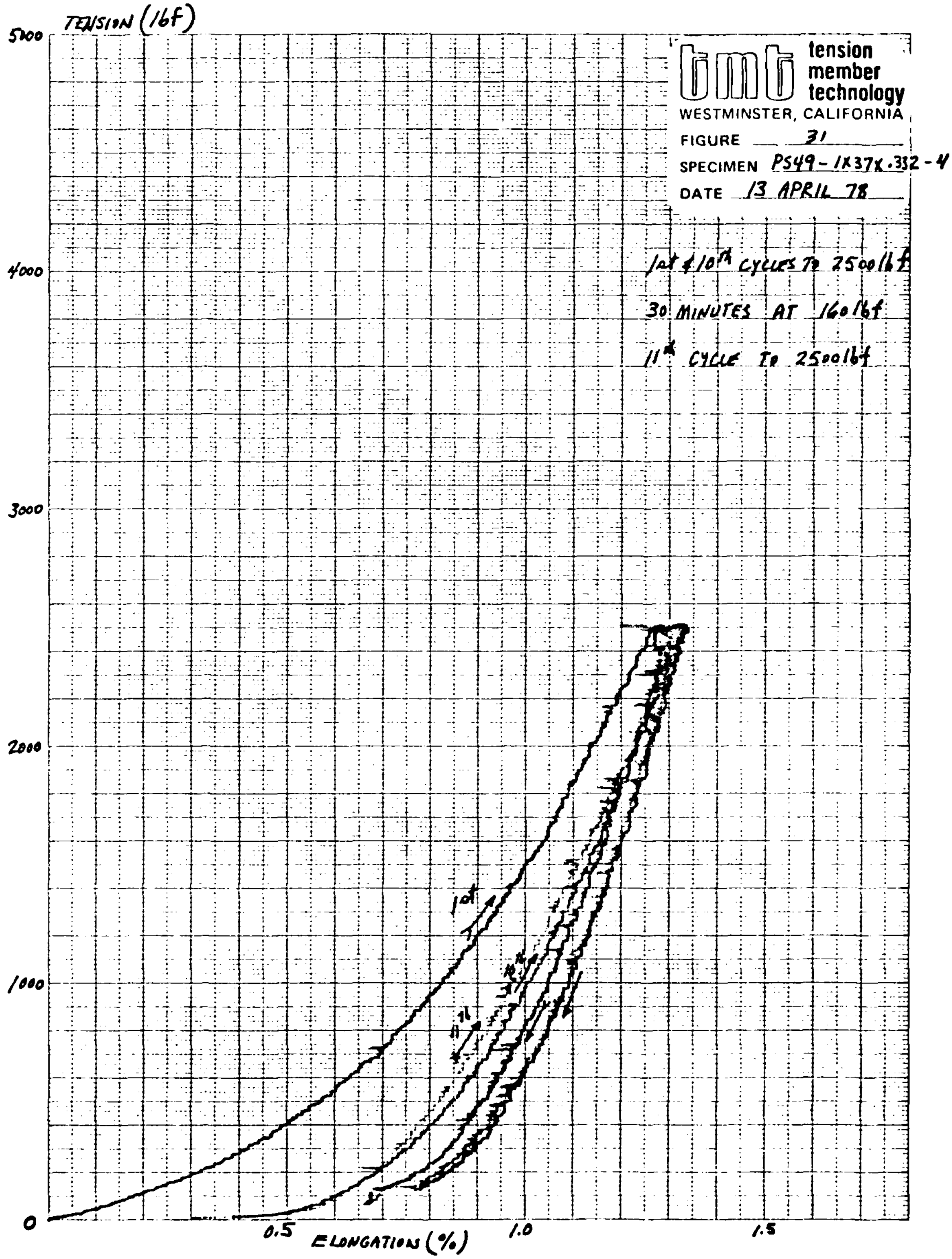

TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 27
SPECIMEN K49-ML-5/8-1
DATE 14 JUNE 1978
25k
20k
15k
10k
5k
0
.5
1.0
1.5
ELONGATION (%)
AE_MAX = 2.2 x 10^6 LBf
E_MAX = 16.0 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.136 IN.^2
40TH
30TH
21ST


TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 28
SPECIMEN PS49-1X37X.332-1
DATE 3 APR 78
50" GAUGE LENGTH
1st + 10th CYCLES TO 5000 lbf RECORDED
BREAK STRENGTH = 10,800 lbf
SOCKET BREAK
KEVLAR FIBER AREA = 4.36 x 10^-2 IN.^2
E MAX = 15.0 x 10^6 LBf/IN.^2
AE MAX = 6.52 x 10^5 LBf
14k
12k
10k
8k
6k
4k
2k
0
1
2
3
4
5
ELONGATION (%)



TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 29
SPECIMEN PS49-1x37x.332-2
DATE 3 APR 78
50" GAUGE LENGTH
1st + 10th CYCLES TO 5000lbf RECORDED
BREAK STRENGTH = 11,500lbf
SOCKET BREAK
KEVLAR FIBER AREA = 4.36 x 10^-2 IN.^2
SLOPE = 0.151 % / 1000 LBf
(E MAX = 15.2 x 10^6 LBf/IN.^2)
(AE MAX = 6.62 x 10^5 LBf)
14k
12k
10k
8k
6k
4k
2k
0
1
10
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 30
SPECIMEN PS49-1X37K.332-3
DATE 3 APRIL 78
50" GAUGE LENGTH
1st + 10th CYCLES RECORDED TO 5000 lbf
BREAKING STRENGTH = 9300 lbf
SOCKET BREAK
KEVLAR FIBER AREA = 4.36 x 10^-2 in.^2
E_MAX = 15.1 x 10^6 LBf/in.^2
AE_MAX = 6.58 x 10^5 LBf
14k
12k
10k
8k
6k
4k
2k
0
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
5000
4000
3000
2000
1000
0
0.5
1.0
1.5
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 31
SPECIMEN PS49-1X37X.332-4
DATE 13 APRIL 78
1st & 10th CYCLES TO 2500 lbf
30 MINUTES AT 160 lbf
11th CYCLE TO 2500 lbf
1st
10th
11th

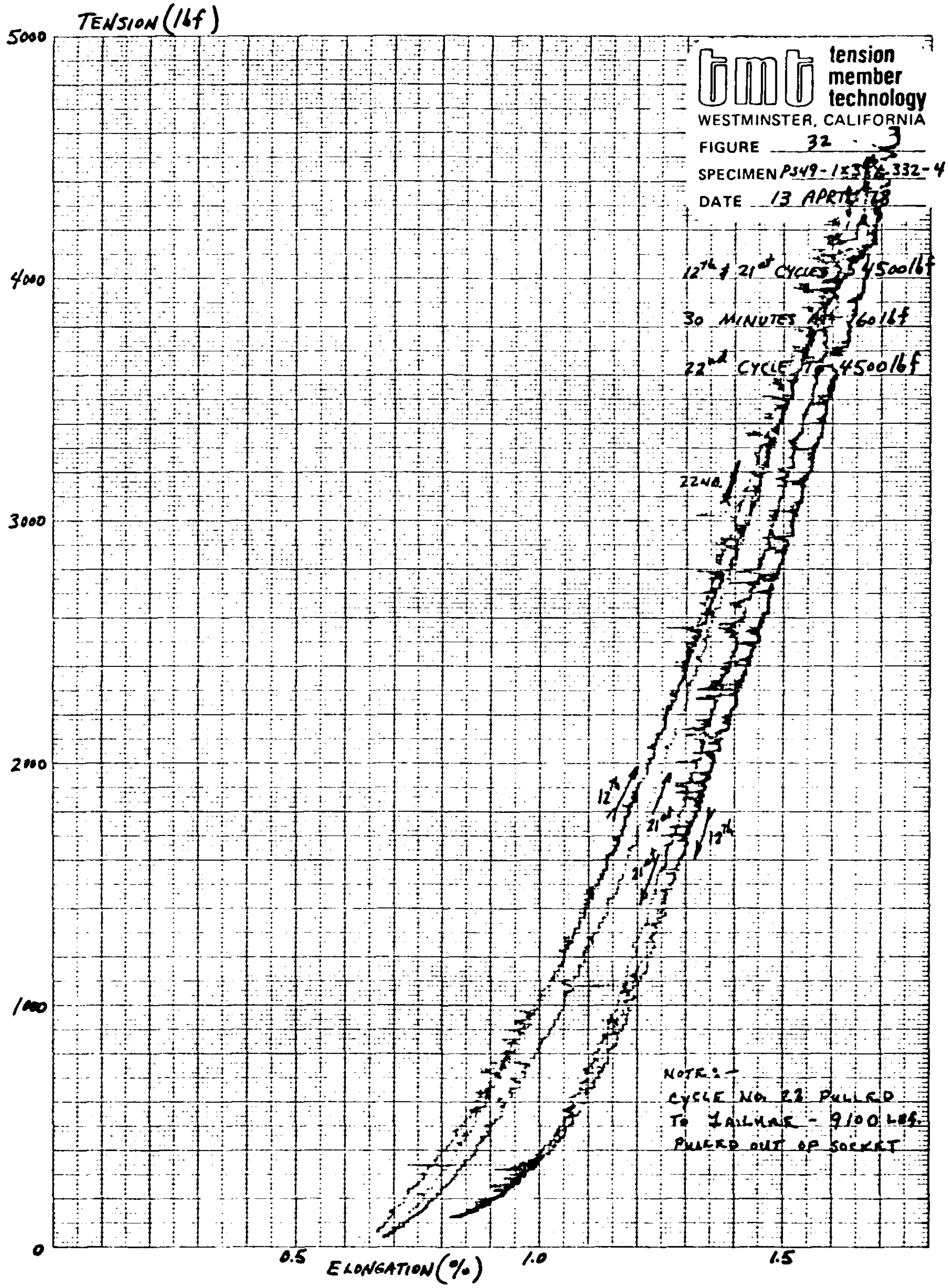

TENSION (lbf)
5000
4000
3000
2000
1000
0
0.5
1.0
1.5
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 32-3
SPECIMEN PS49-1x3 1/2-332-4
DATE 13 APRIL 78
12th & 21st CYCLES TO 4500 lbf
30 MINUTES AT 3760 lbf
22nd CYCLE TO 4500 lbf
22nd.
12th
21st
12th
21st
NOTE:-
CYCLE No. 22 PULLED
TO FAILURE - 9100 LBS.
PULLED OUT OF SOCKET

TABLE 2. SMALL BRIDGE CABLE DESIGN AND TEST PARAMETERS

Rope Constructions

Rope S-1 - 1x19 construction with a PS29-19x7x.45 core and 18 strands of PS49-1x37x.332D

Rope diameter = 2.0 inches

Fiber area = 0.86 square inches.

Rope S-2 - 8 part plaited construction made up of 1/2-inch diameter Kevlar 49 Miniline with a braided Dacron jacket

Rope diameter = 1.9 inches (approximately)

Fiber area = 0.70 square inches.

Rope S-3 - PS49-6x7x1.9 D with a PS29-7x19x0.67 D core and 6 strands of PS49-7x19x0.58 D

Rope diameter = 1.9 inches

Fiber area = 0.81 square inches.

Rope Specimen Identification Code

T - tensile

CST - cyclic-straight tension

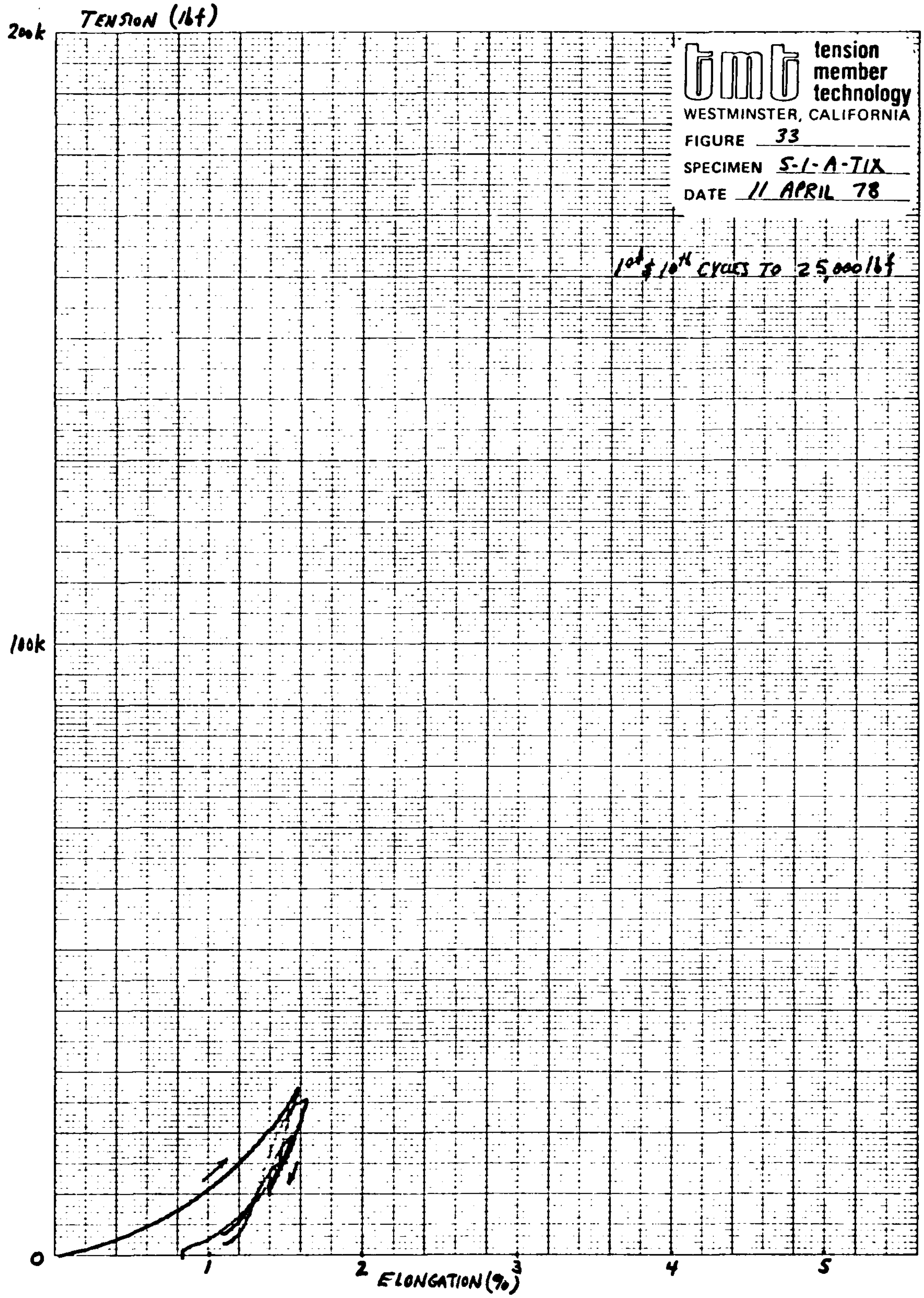
CTOS - cyclic-tension-over sheave.

Termination Types

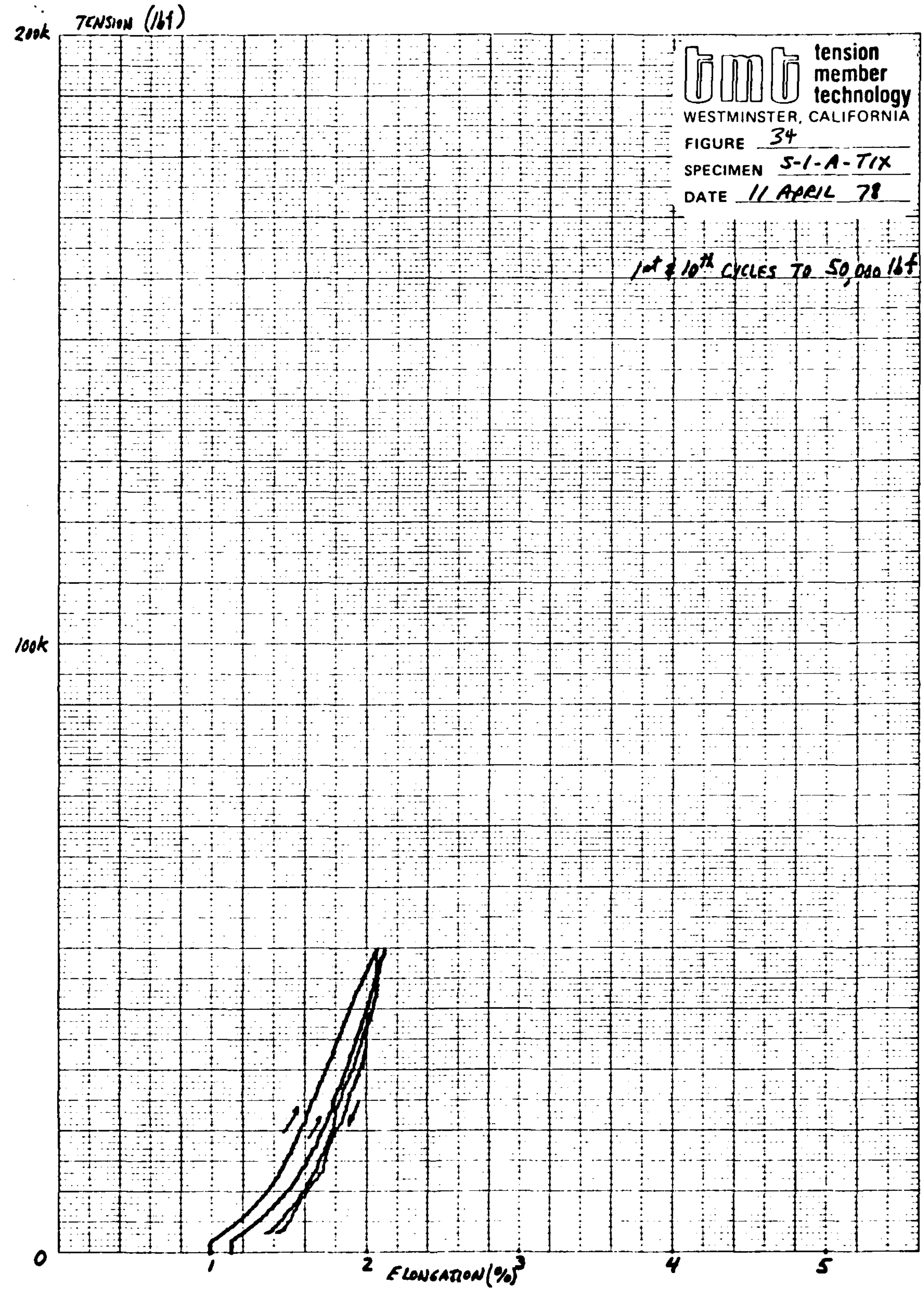
Epoxy sockets - standard Crosby Laughlin open sockets and Philadelphia Resins Corporation A14-C epoxy resin and hardener

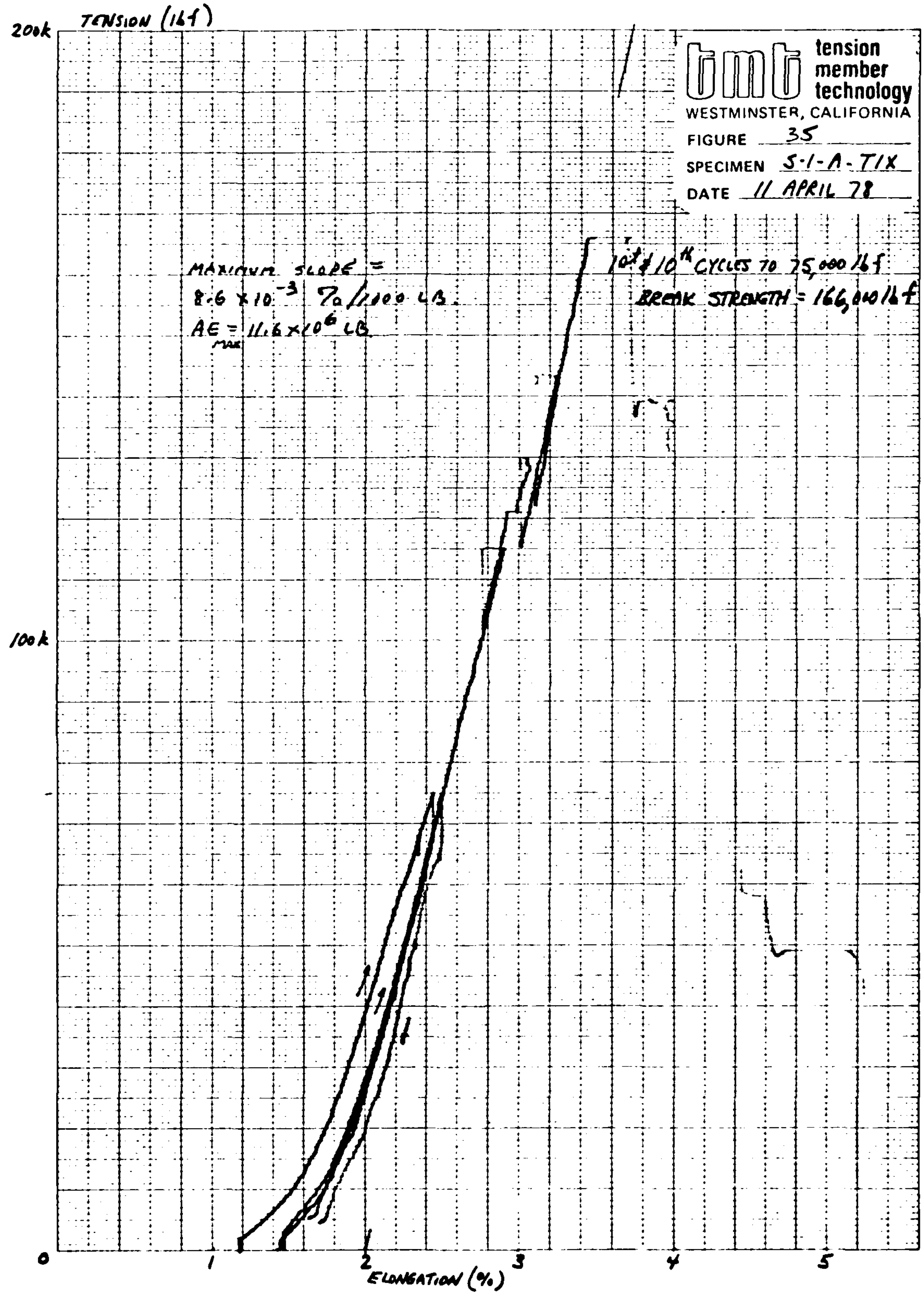
Grommet eyes - C - 2-1/2-inch diameter spools

Grommet eyes - D - 3-1/2-inch diameter spools

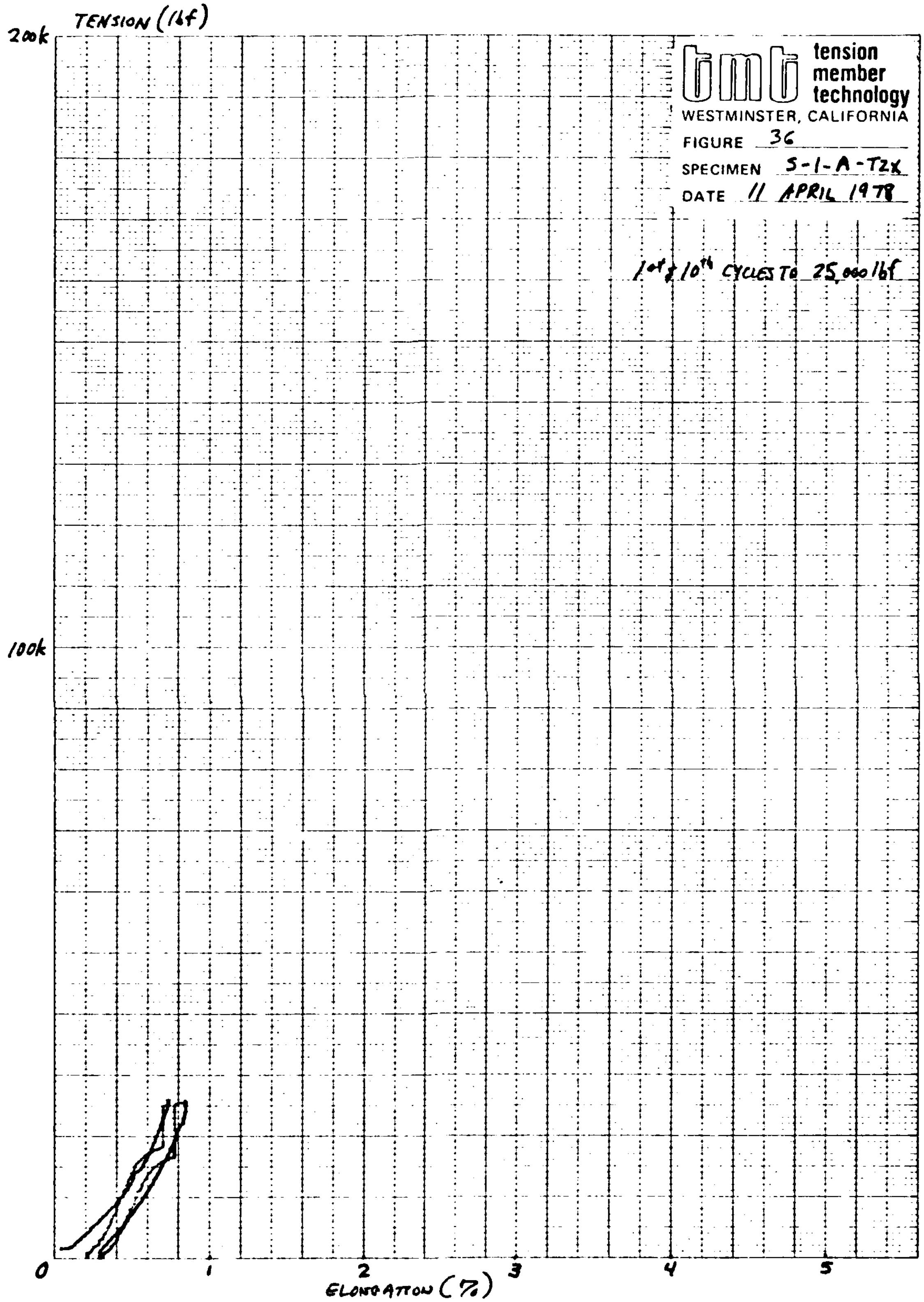


TENSION (lbf)
200k
100k
0
1
2
3
4
5
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 33
SPECIMEN S-1-A-TIX
DATE 11 APRIL 78
1st & 10th CYCLES TO 25,000 lbf

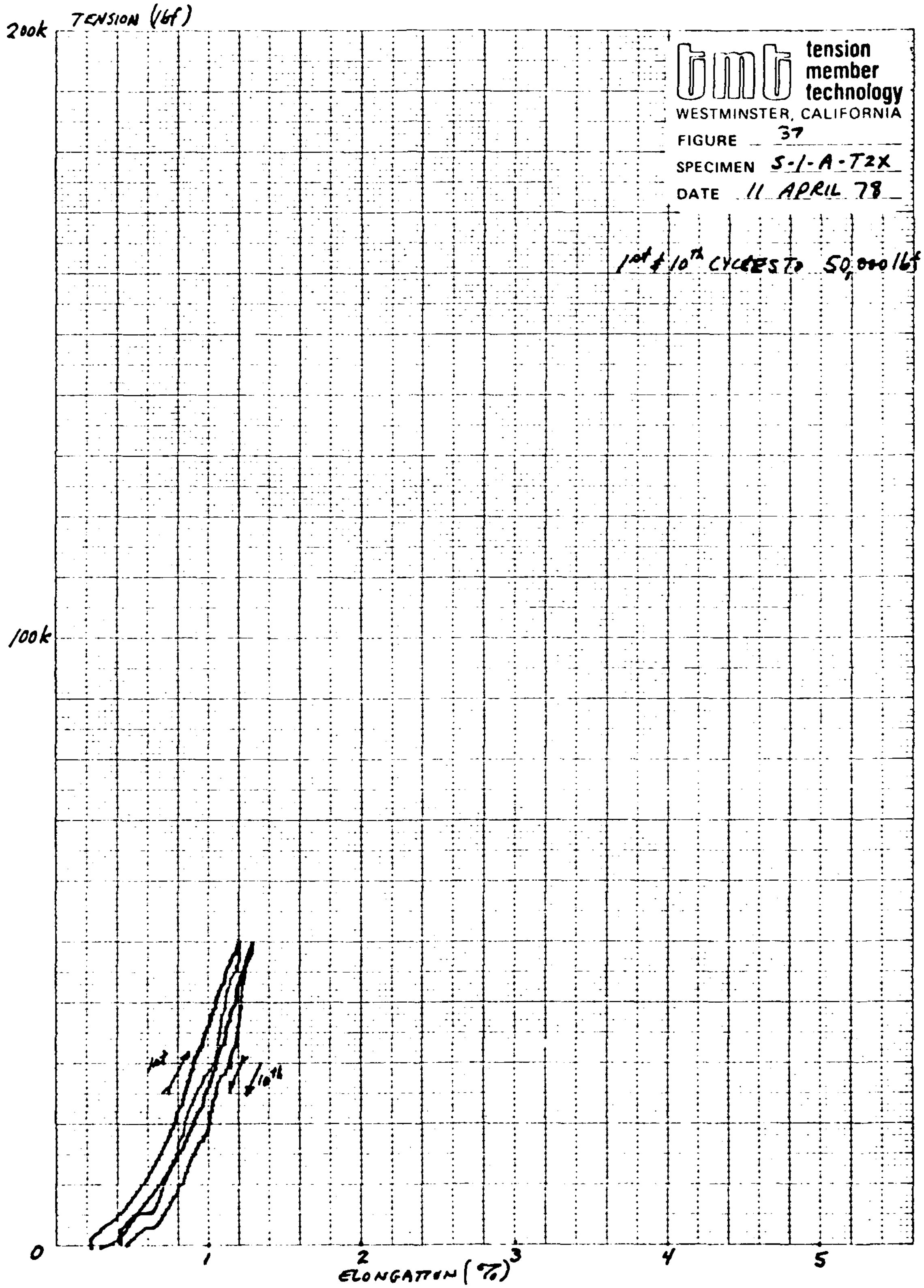

TENSION (lbf)
200k
100k
0
1
2
3
4
5
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 34
SPECIMEN S-1-A-TIX
DATE 11 APRIL 78
1st & 10th CYCLES TO 50,000 lbf



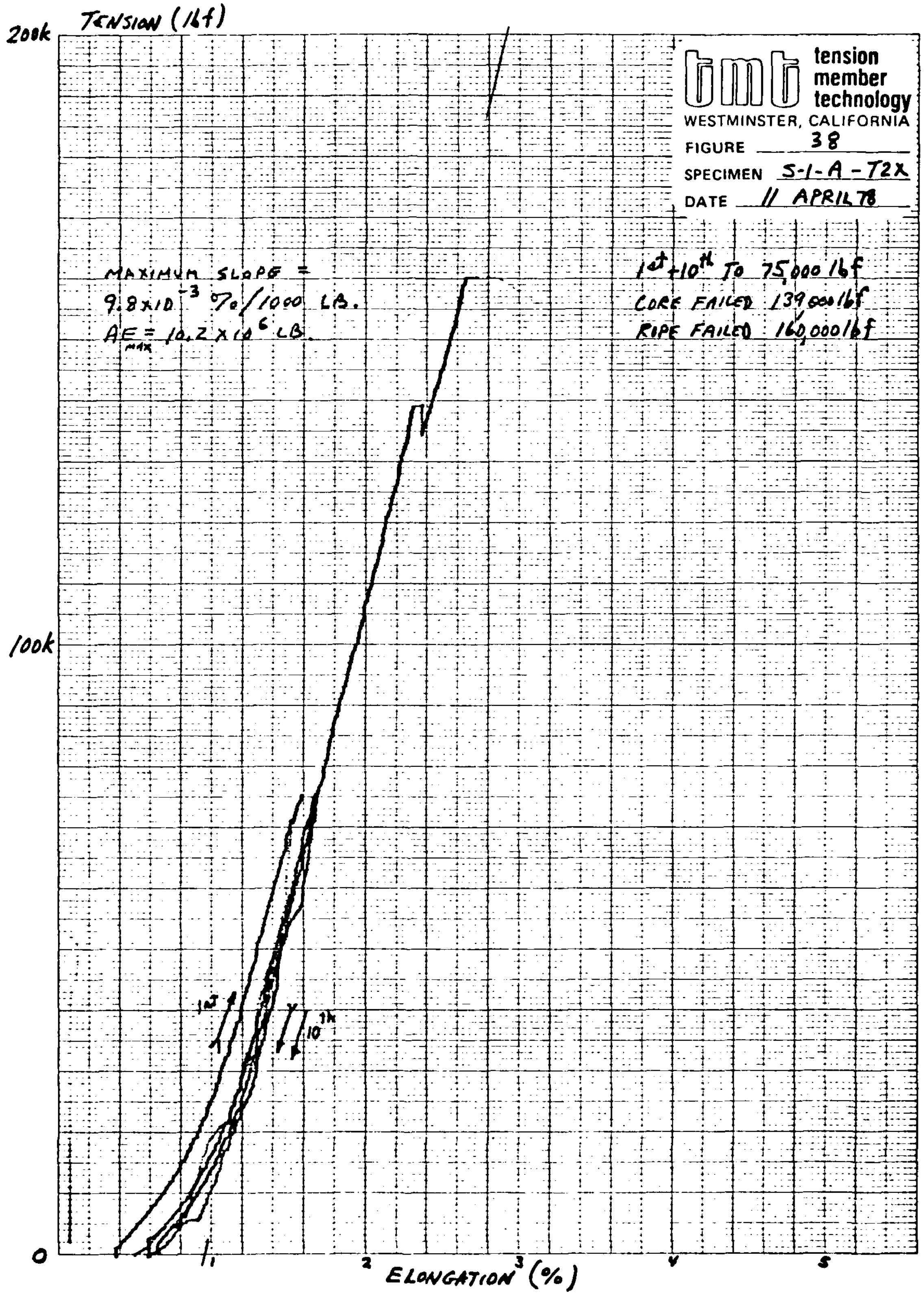
TENSION (lbf)
200k
100k
0
1
2
3
4
5
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 35
SPECIMEN S-1-A-T1X
DATE 11 APRIL 78
MAXIMUM SLOPE =
8.6 × 10⁻³ %/1000 LB.
AE MAX = 11.6 × 10⁶ LB
10³ & 10⁴ CYCLES TO 75,000 lbf
BREAK STRENGTH = 166,000 lbf

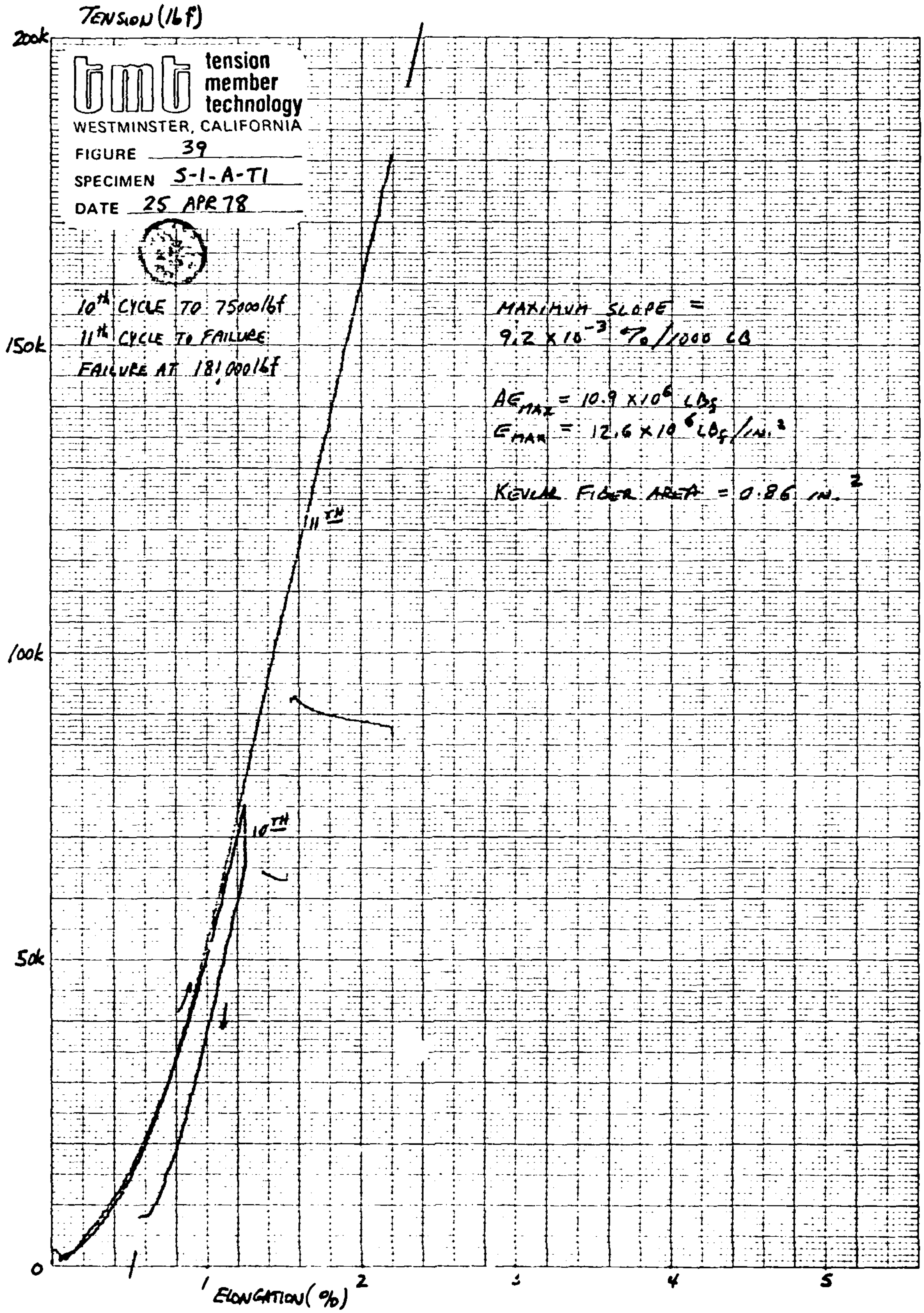


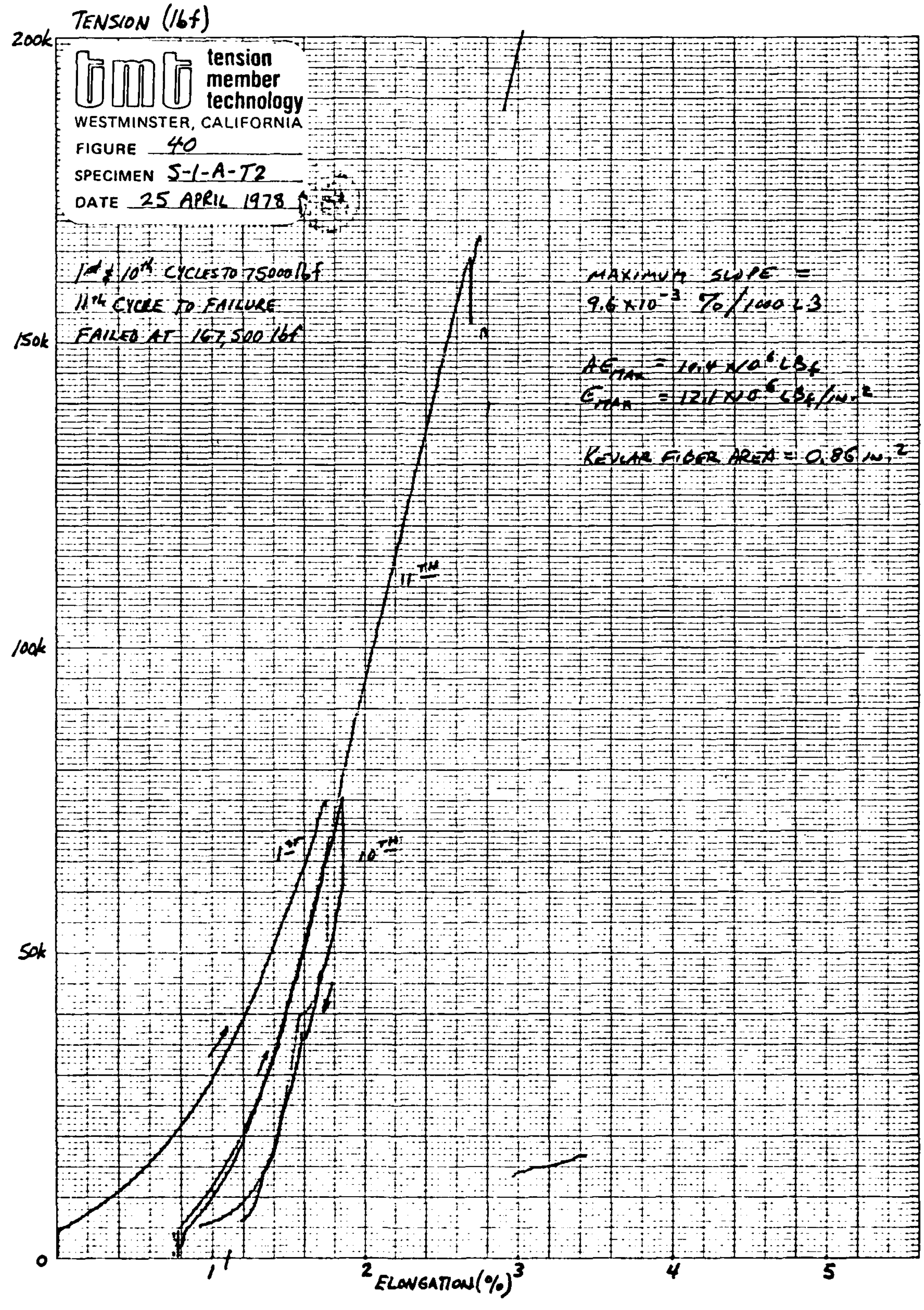
TENSION (lbf)
200k
100k
0
1
2
3
4
5
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 36
SPECIMEN S-1-A-T2X
DATE 11 APRIL 1978
1st & 10th CYCLES TO 25,000 lbf

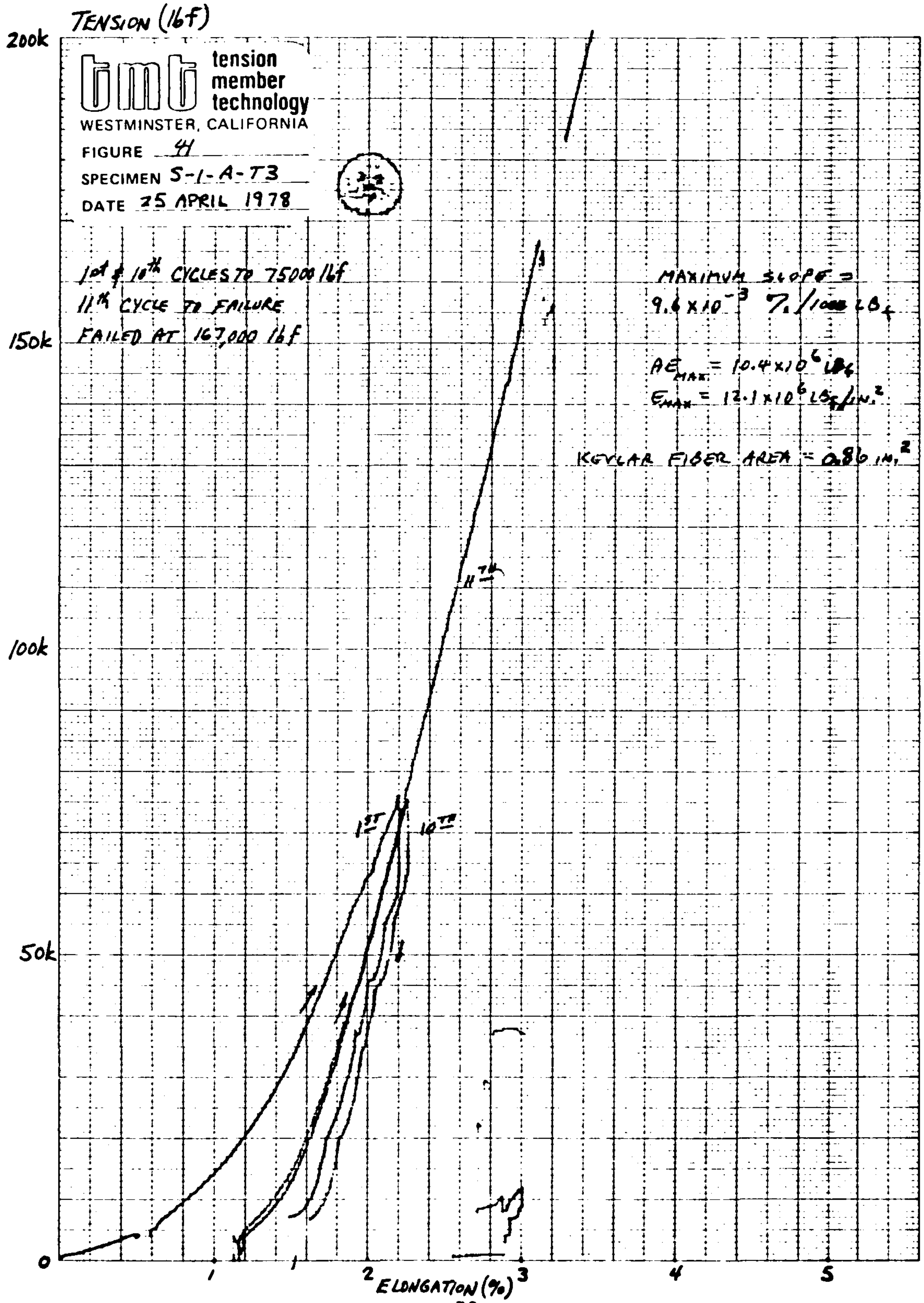


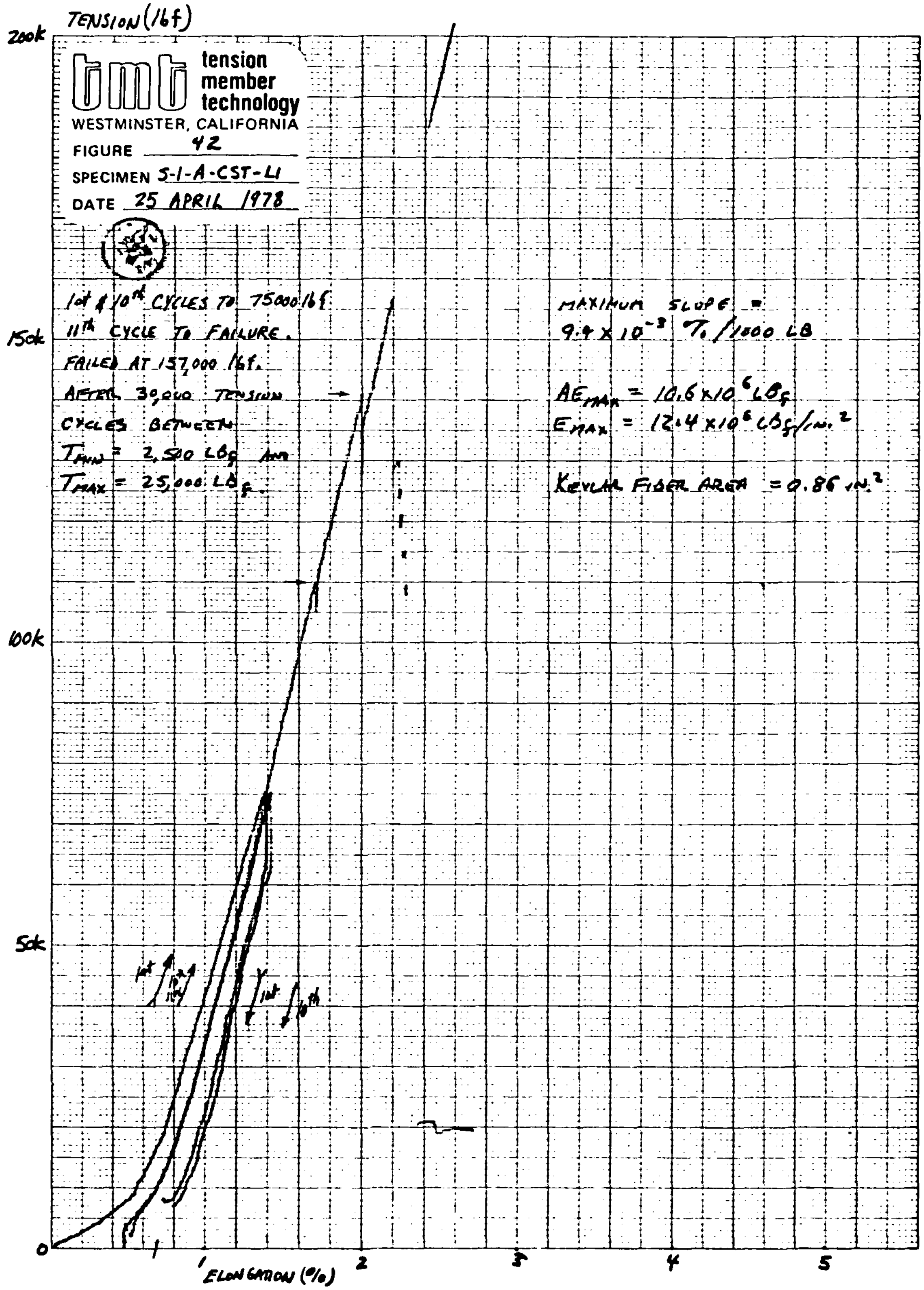
200k
TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 37
SPECIMEN S-1-A-T2X
DATE 11 APRIL 78
1st & 10th CYCLES TO 50,000 lbf
100k
1st
10th
0
1
2
3
4
5
ELONGATION (%)

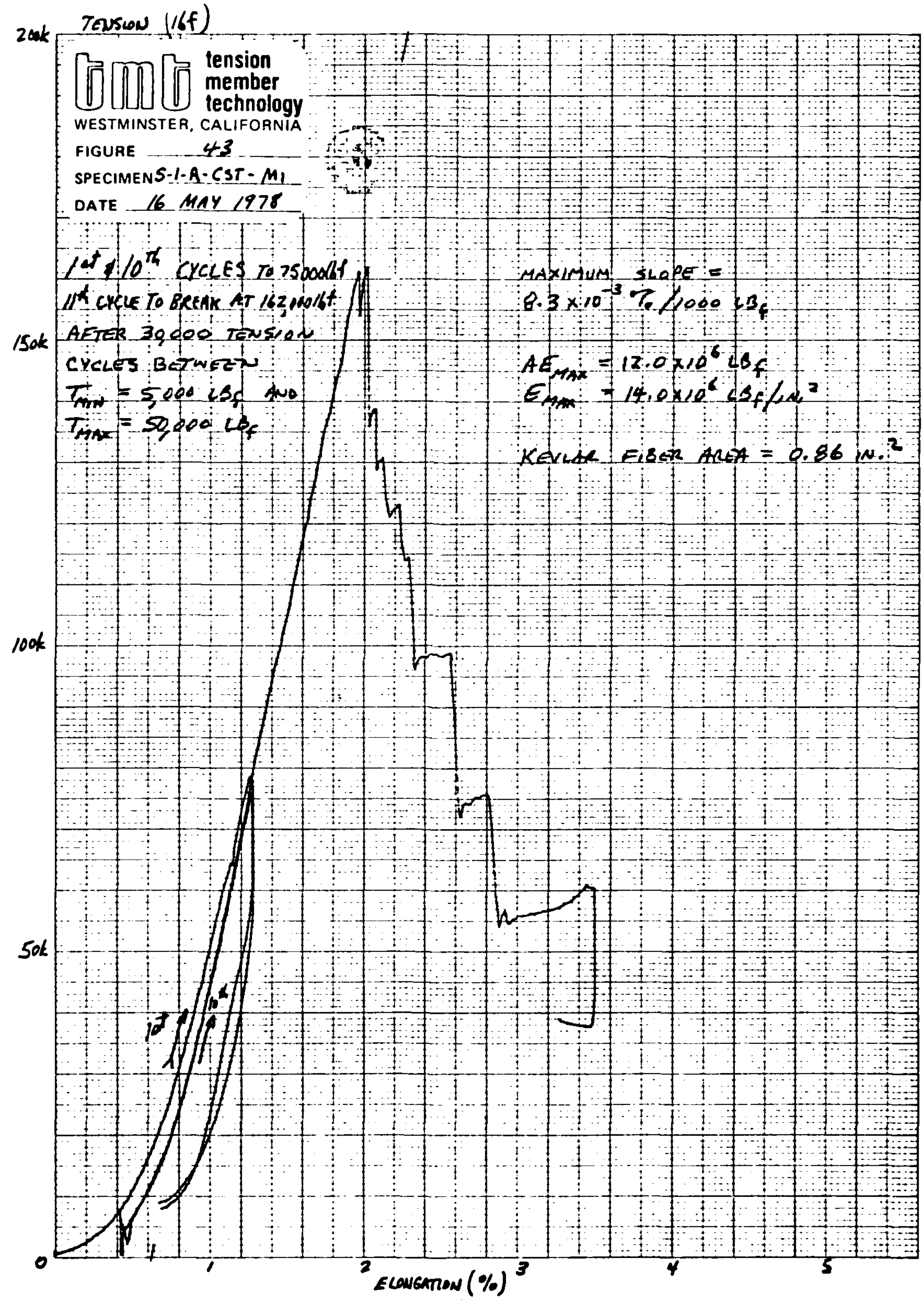

TENSION (lbf)
200k
100k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 38
SPECIMEN S-1-A-T2X
DATE 11 APRIL 78
MAXIMUM SLOPE =
9.8x10^-3 %/1000 LB.
AE max = 10.2 x 10^6 LB.
1st + 10th TO 75,000 lbf
CORE FAILED 139,000 lbf
ROPE FAILED 160,000 lbf
1st
10th
1
2
3
4
5
ELONGATION (%)

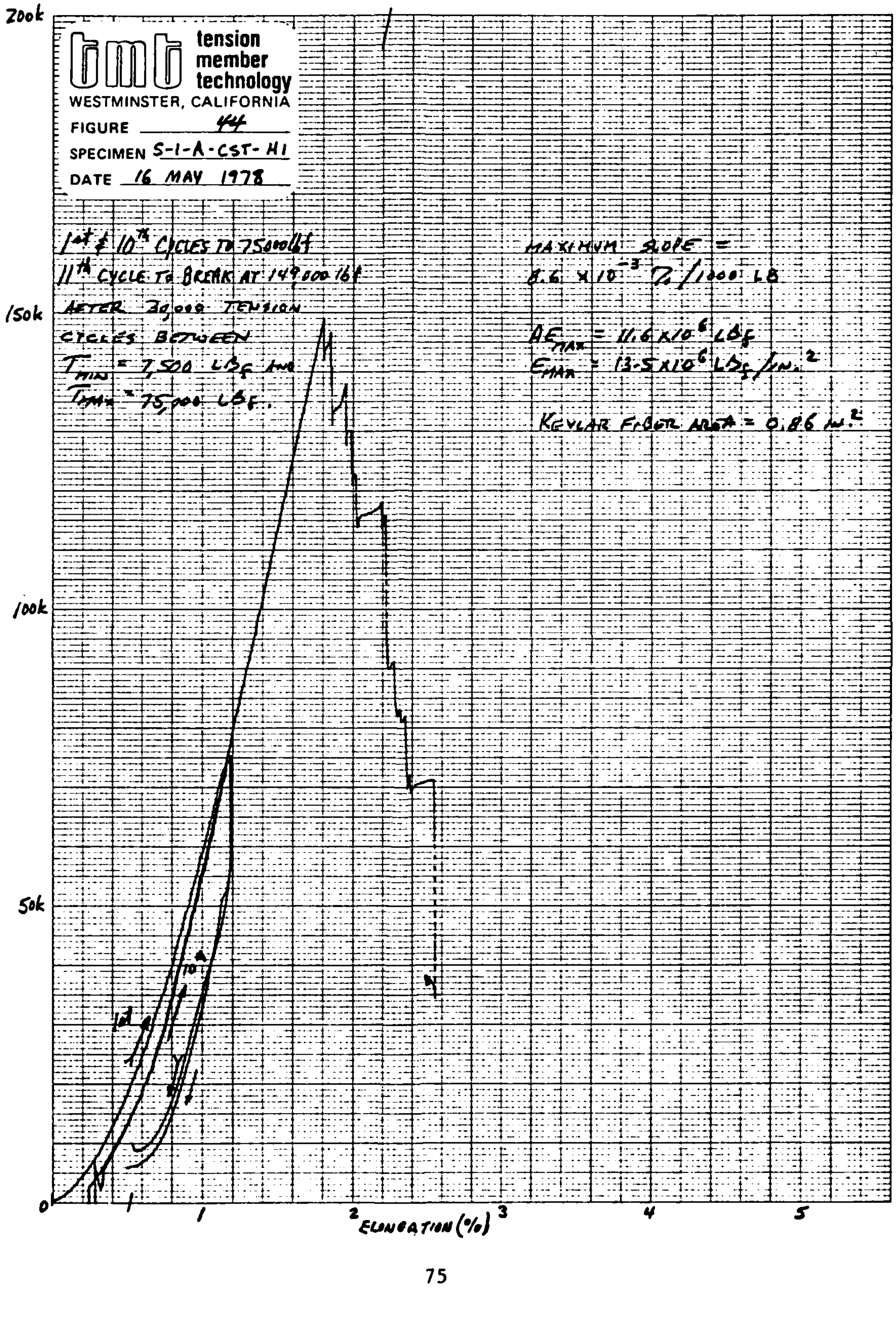

TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 39
SPECIMEN S-1-A-T1
DATE 25 APR 78
10th CYCLE TO 75000 lbf
11th CYCLE TO FAILURE
FAILURE AT 181,000 lbf
MAXIMUM SLOPE =
9.2 x 10^-3 %/1000 LB
AE MAX = 10.9 x 10^6 LBS
E MAX = 12.6 x 10^6 LBS/IN.^2
KEVLAR FIBER AREA = 0.86 IN.^2
11TH
10TH
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 40
SPECIMEN S-1-A-T2
DATE 25 APRIL 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO FAILURE
FAILED AT 167,500 lbf
MAXIMUM SLOPE = 9.6 x 10^-3 %/1000 LB
AE_MAX = 10.4 x 10^6 LBf
E_MAX = 12.1 x 10^6 LBf/in.^2
KEVLAR FIBER AREA = 0.86 in.^2
11TH
1ST
10TH
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 4
SPECIMEN S-1-A-T3
DATE 25 APRIL 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO FAILURE
FAILED AT 167,000 lbf
MAXIMUM SLOPE =
9.6 x 10^-3 %/1000 LBf
AE_MAX = 10.4 x 10^6 LBf
E_MAX = 12.1 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.86 IN.^2
11TH
1ST
10TH
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 42
SPECIMEN S-1-A-CST-L1
DATE 25 APRIL 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO FAILURE.
FAILED AT 157,000 lbf.
AFTER 30,000 TENSION
CYCLES BETWEEN
TMIN = 2,500 LBf AND
TMAX = 25,000 LBf.
MAXIMUM SLOPE =
9.4 X 10^-3 %/1000 LB
AEMAX = 10.6 x 10^6 LBf
EMAX = 12.4 x 10^6 LBf/in.^2
KEVLAR FIBER AREA = 0.86 in.^2
1st
10th
1st
10th
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 43
SPECIMEN S-1-A-CST-M1
DATE 16 MAY 1978
1st & 10th CYCLES TO 75000lbf
11th CYCLE TO BREAK AT 162,000lbf
AFTER 30,000 TENSION
CYCLES BETWEEN
T MIN = 5,000 LBf AND
T MAX = 50,000 LBf
MAXIMUM SLOPE =
8.3 x 10^-3 %/1000 LBf
AE MAX = 12.0 x 10^6 LBf
E MAX = 14.0 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.86 IN.^2
1st
10th
1
2
3
4
5
ELONGATION (%)


tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 44
SPECIMEN S-1-A-CST-H1
DATE 16 MAY 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO BREAK AT 149,000 lbf
AFTER 30,000 TENSION CYCLES BETWEEN
T_MIN = 7,500 LBf AND
T_MAX = 75,000 LBf.
MAXIMUM SLOPE =
8.6 × 10^-3 %/1000 LB
AE_MAX = 11.6 × 10^6 LBf
E_MAX = 13.5 × 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.86 IN.^2
200k
150k
100k
50k
0
1
2
3
4
5
ELONGATION (%)

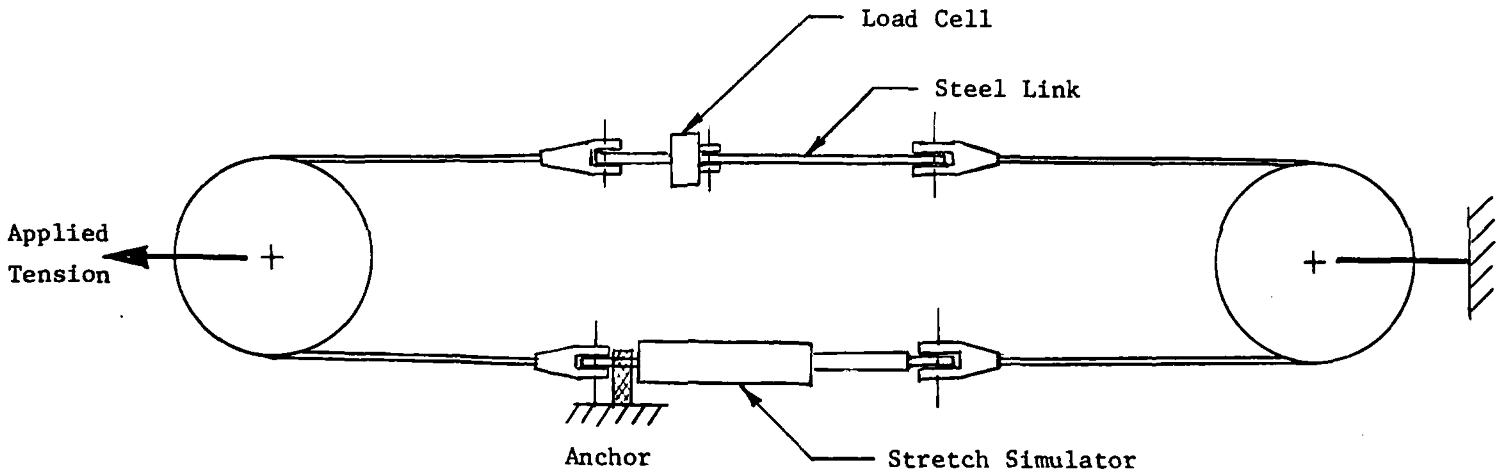


FIGURE 45. DIAGRAM OF APPARATUS USED FOR CYCLIC-TENSION-OVER-SHEAVE FATIGUE TESTS

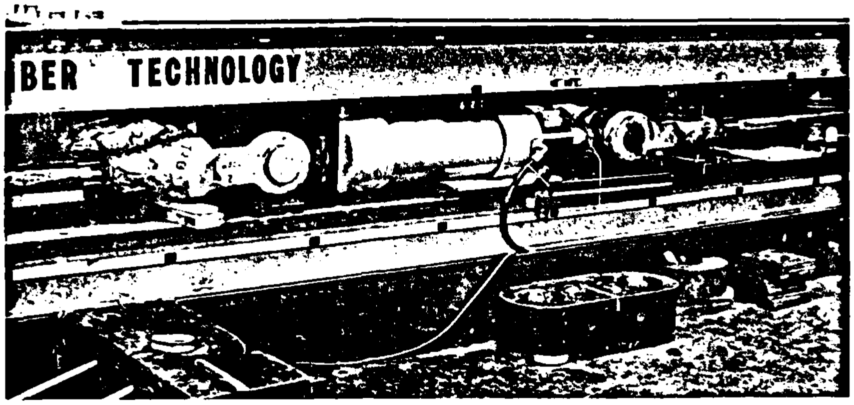


FIGURE 46. FIXED SOCKET, STRETCH SIMULATOR WITH POINTER ATTACHED TO CYLINDER ROD, MOVING SOCKET, AND FIXED-POSITION SHEAVE

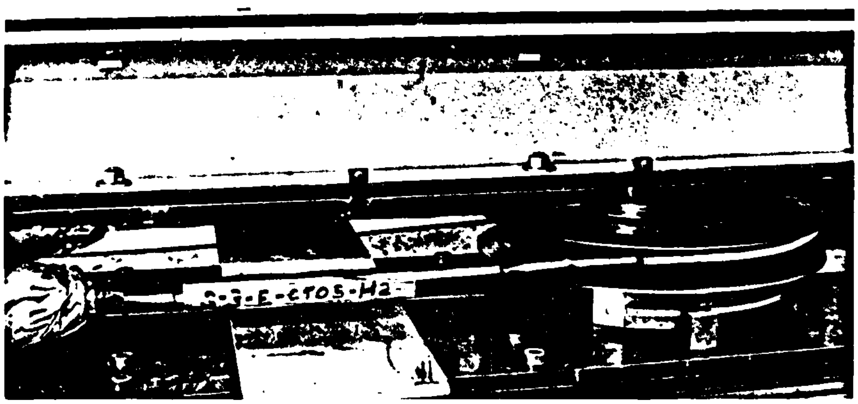


FIGURE 47. FIXED POSITION SHEAVE

TABLE 3. SUMMARY OF TEST RESULTS FOR ROPE S-1

Specimen Number	Termination Type	Fatigue Test Parameters D/d	T_{max}, lb	Cycles	Breaking Load, Lb	Failure Location
T1	Epoxy sockets	—	--	--	181,000	Socket
T2	Ditto	--	--	--	167,500	Ditto
T3	"	--	--	--	167,000	"
CST-L1	"	--	25,000	30,000	157,000	"
CST-M1	"	--	50,000	30,000	162,000	"
CST-H1	"	--	75,000	30,000	149,000	"
CTOS-L1	"	10	25,000	30,000	144,000	"
CTOS-L2	"	10	25,000	30,000	139,000	"
CTOS-M1	"	10	50,000	13,426	106,000	"
CTOS-M2	"	10	50,000	13,426	50,000	Sheave
CTOS-H1	"	10	75,000	770	141,500	Socket
CTOS-H2	"	10	75,000	770	75,000	Sheave
CTOS-L3	"	14	25,000	30,000	156,000	Socket
CTOS-L4	"	14	25,000	30,000	146,000	Socket
CTOS-M3	"	14	50,000	30,000	141,500	Socket
CTOS-M4	"	14	50,000	30,000	135,000	Sheave
CTOS-H3	"	14	75,000	3,480	140,500	Socket
CTOS-H4	"	14	75,000	3,480	75,000	Sheave

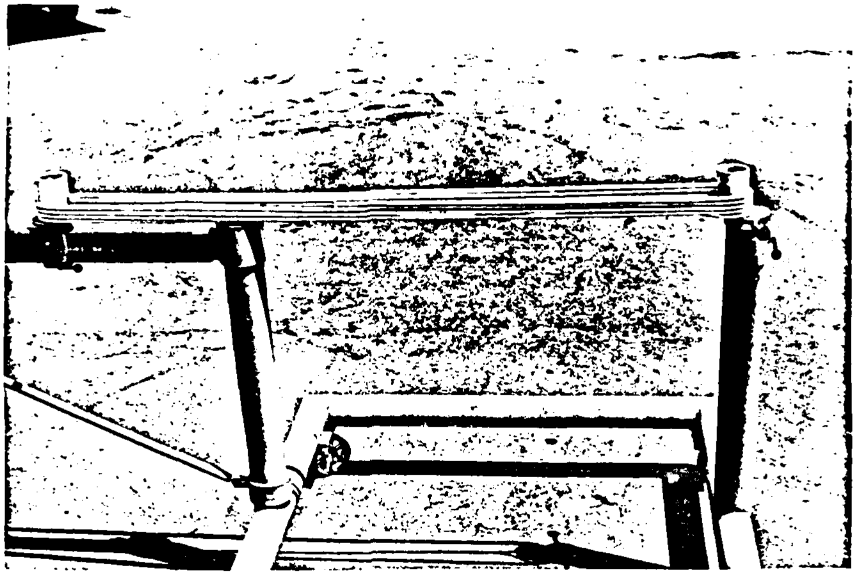


FIGURE 48. ESTABLISHING EQUAL STRAND LENGTHS PRIOR TO PLAITING

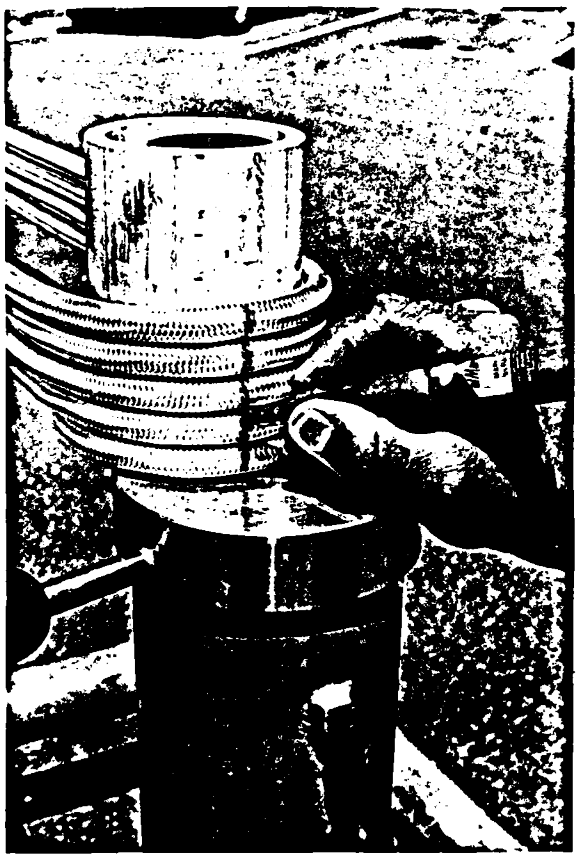


FIGURE 49.

APPLICATION OF REFERENCE MARKS TO MAINTAIN STRAND LENGTHS DURING PLAITING

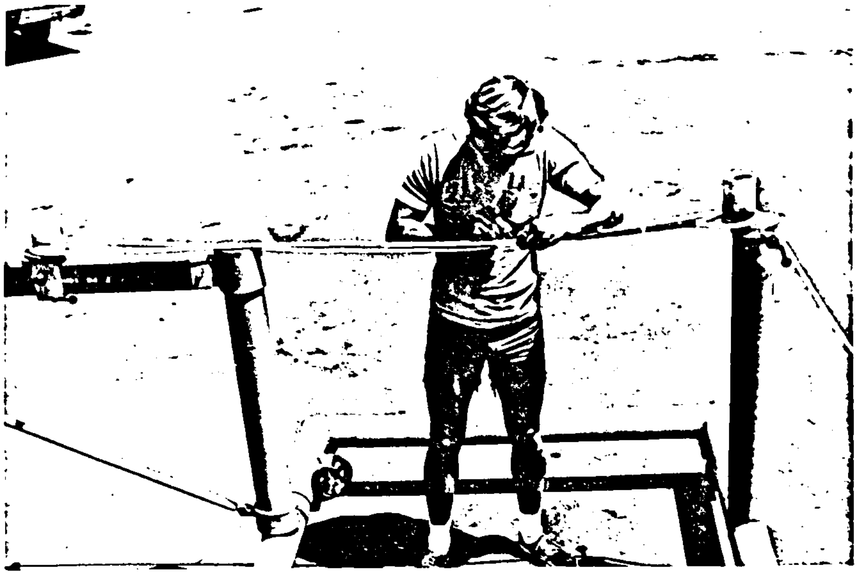


FIGURE 50. MARKING LAY LENGTHS FOR PLAITING

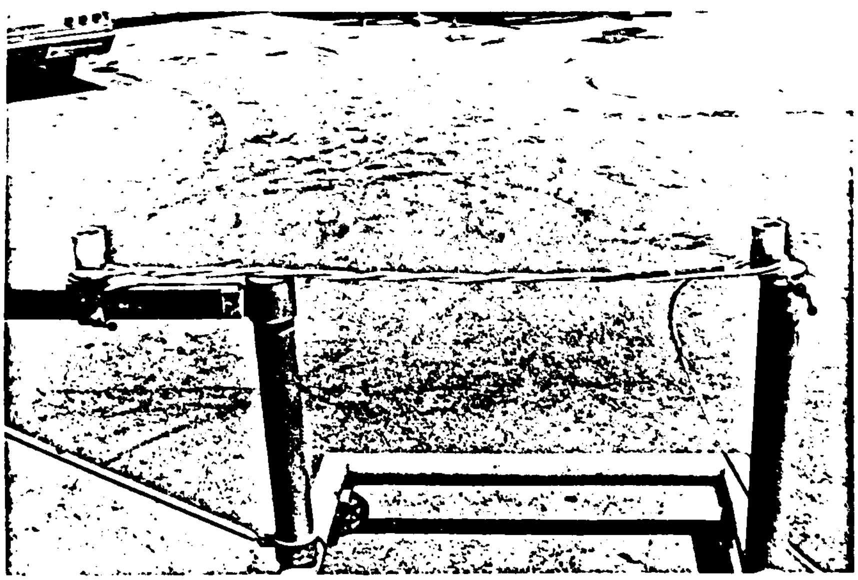


FIGURE 51. PLAITING OF FIRST AND SECOND STRANDS

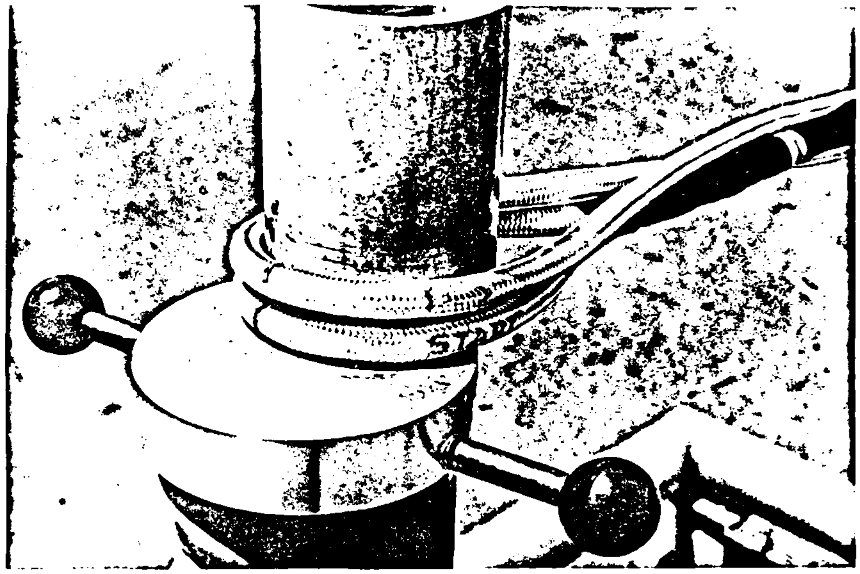


FIGURE 52. MARKING OF DIRECTION AND ORIENTATION DURING PLAITING PROCEDURE

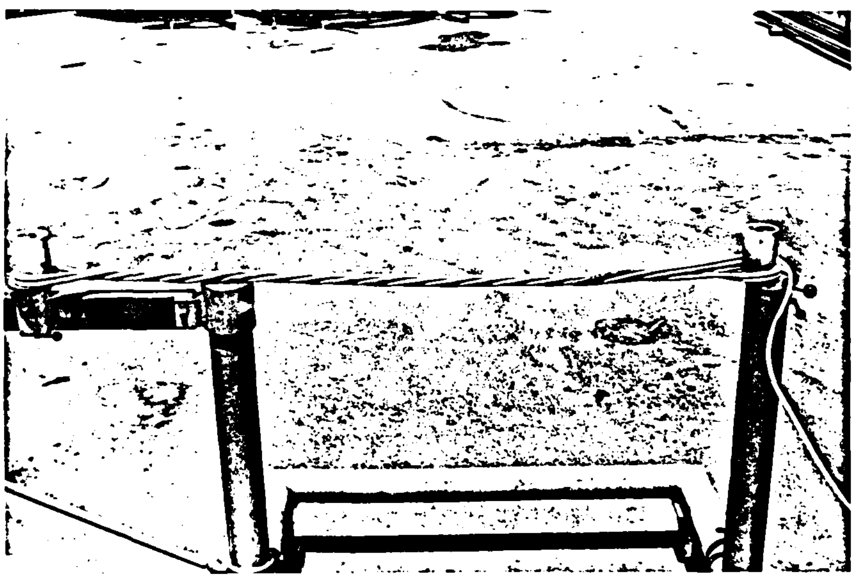


FIGURE 53. CONTINUATION OF PLAITING OF LEFT LAY STRANDS

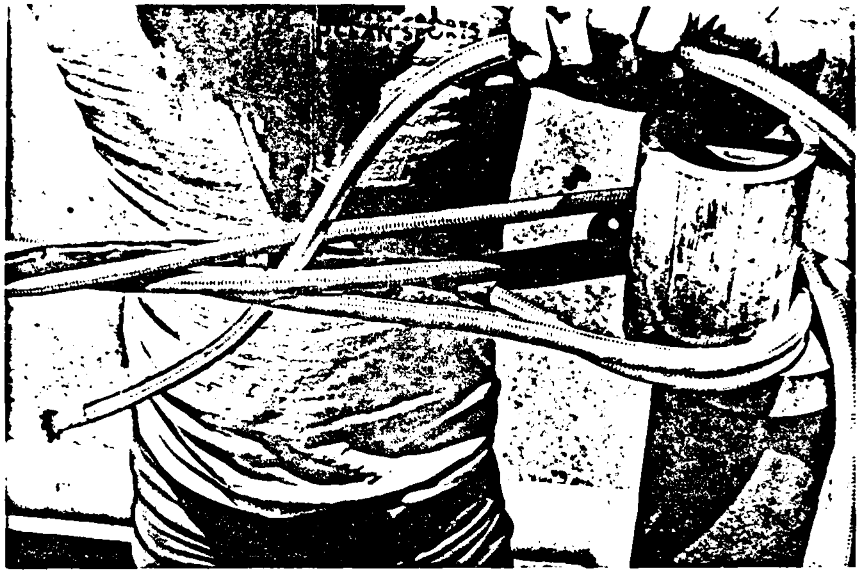


FIGURE 54. INITIATION OF PLAITING OF RIGHT LAY STRANDS

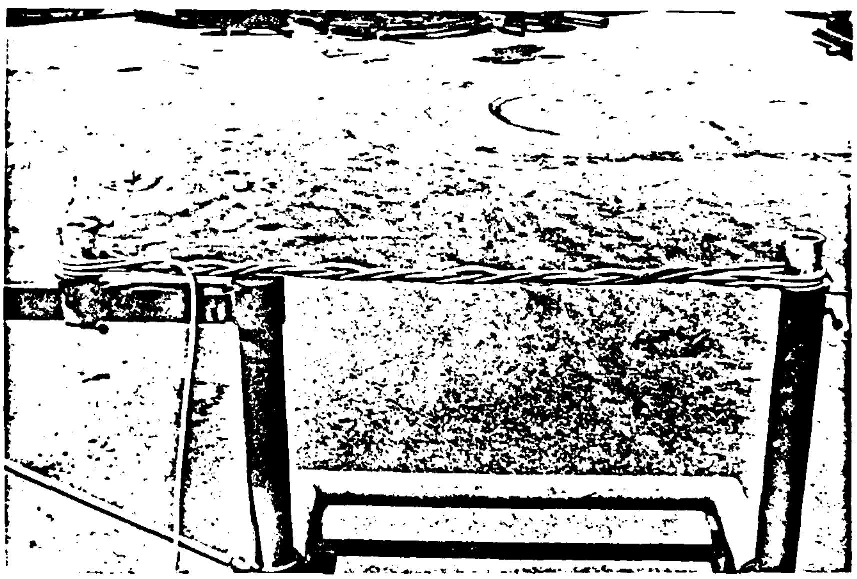


FIGURE 55. COMPLETION OF FIRST RIGHT LAY STRAND
AND START OF SECOND RIGHT LAY STRAND

FIGURE 56.

CONTINUATION AND ILLUSTRATION OF PLAITING TECHNIGUE

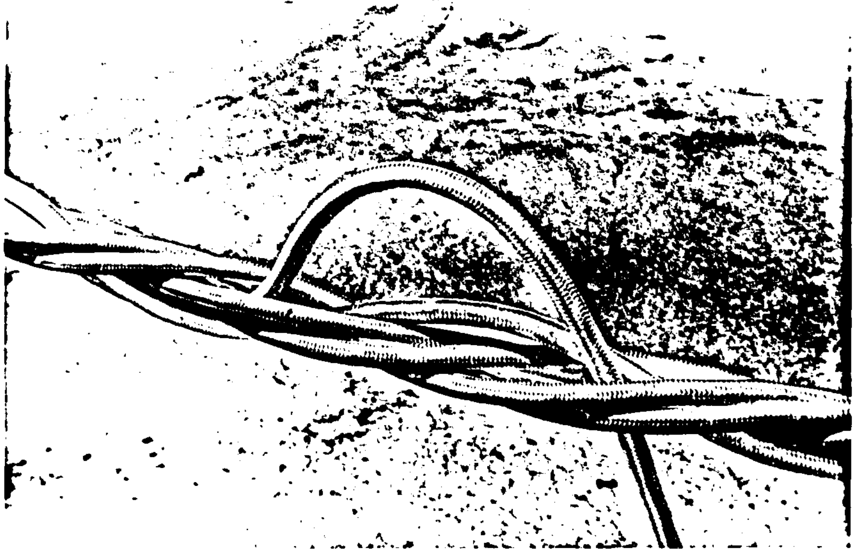
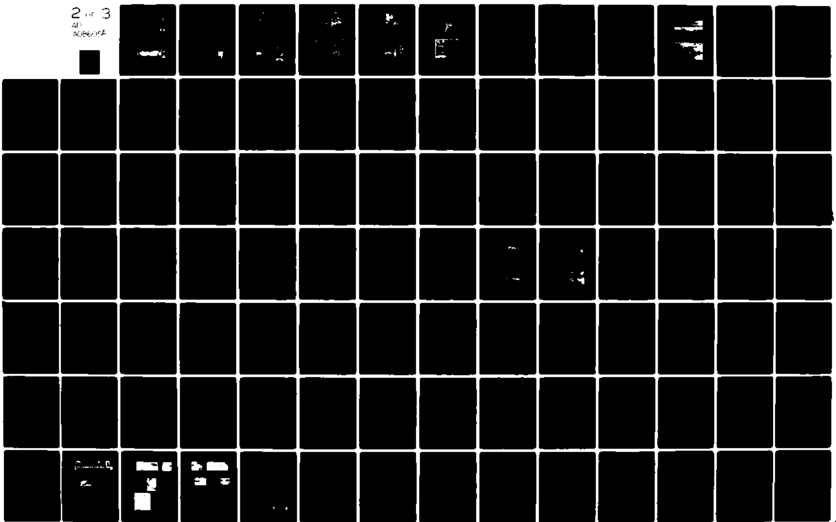


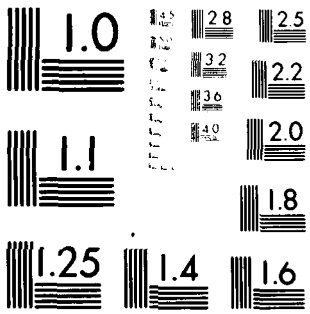
FIGURE 57. CONTINUATION AND ILLUSTRATION OF PLAITING TECHNIQUE

AD-A086 058 TENSION MEMBER TECHNOLOGY WESTMINSTER CA F/6 11/9
MILITARY ADAPTATION OF KEVLAR FOR PORTABLE BRIDGE REINFORCEMENT--ETC(U)
JUN 80 H D WOLFE, P T GIBSON DAAK70-78-C-0024

UNCLASSIFIED NL

2 of 3
AD
A086058





MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

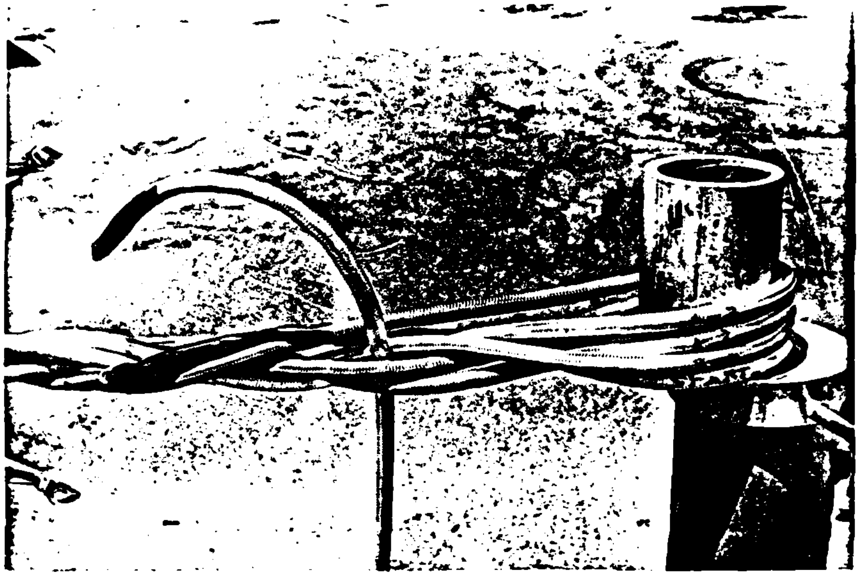


FIGURE 58. START OF THIRD RIGHT LAY STRAND

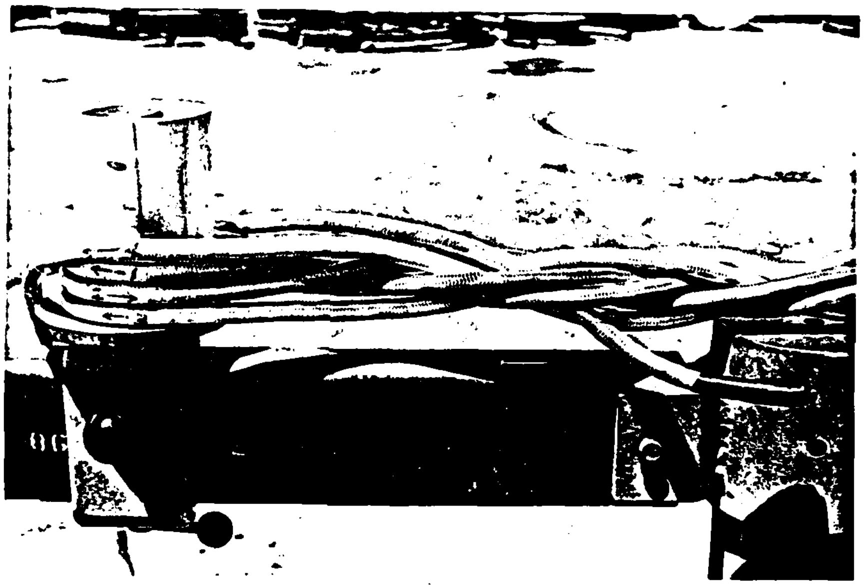


FIGURE 59. COMPLETION OF THIRD RIGHT LAY STRAND
AND START OF FOURTH RIGHT LAY STRAND

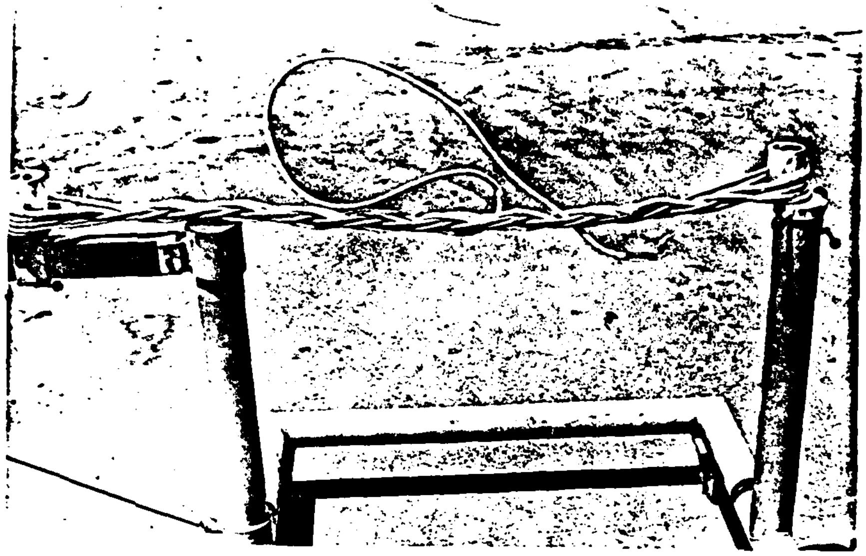


FIGURE 60. CONTINUATION OF FOURTH RIGHT LAY STRAND

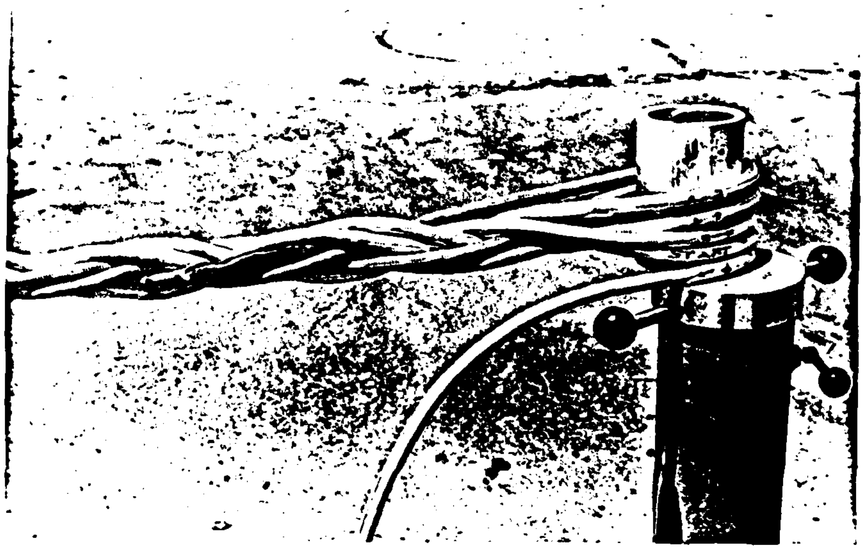


FIGURE 61. FINISH OF LAST STRAND PRIOR TO TERMINATION SPLICE

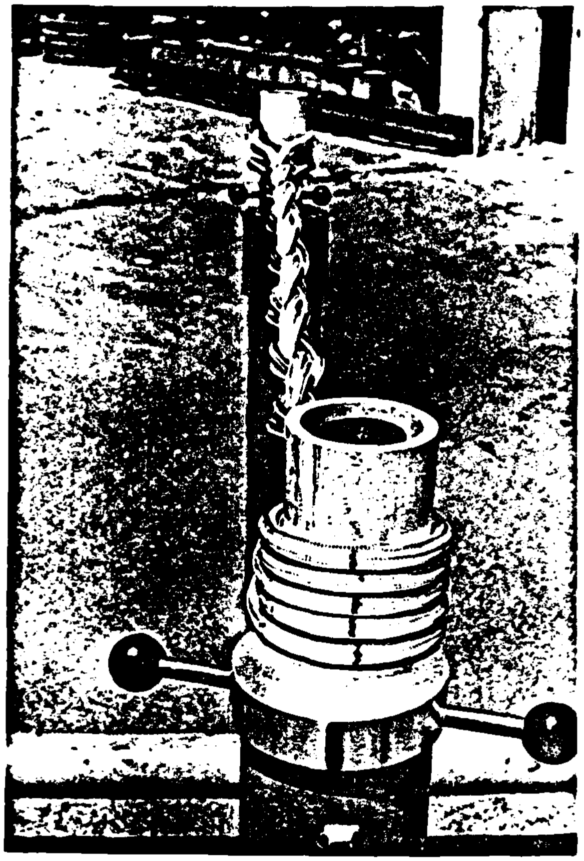


FIGURE 62.

VERIFICATION OF ORIGINAL REFERENCE MARK ORIENTATION

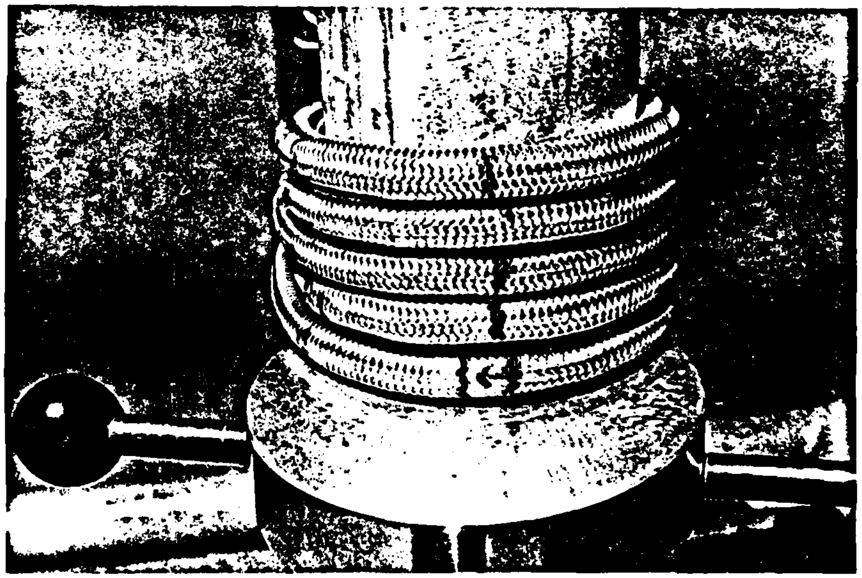


FIGURE 63. ADJUSTMENT OF ORIGINAL REFERENCE MARK TO ALLOW FOR SPLICE FORESHORTENING

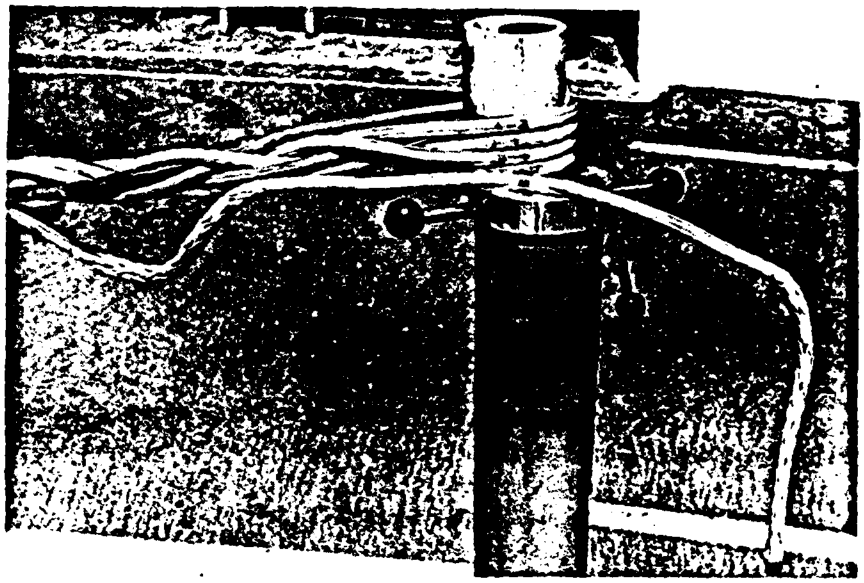


FIGURE 64. ROPE JACKET REMOVED FOR PREPARATION OF EYE SPLICE

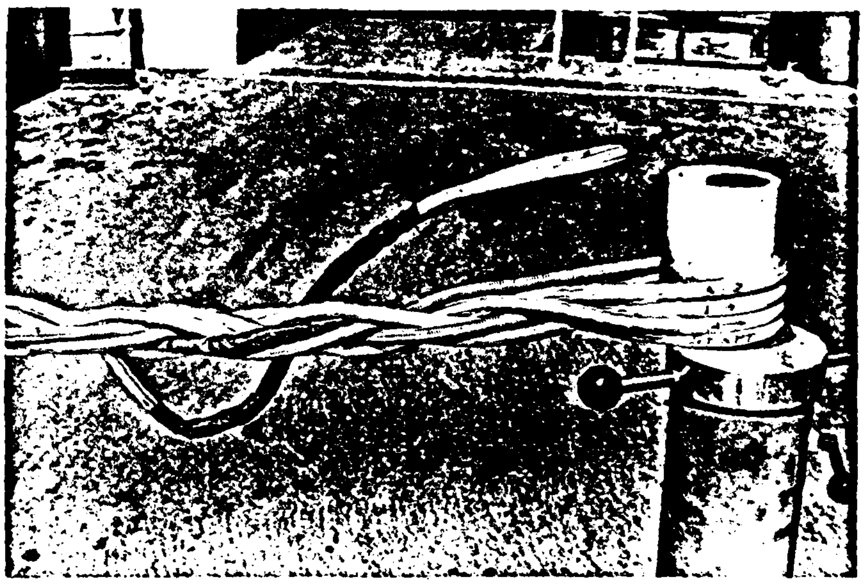


FIGURE 65. COMPLETED EYE SPLICE

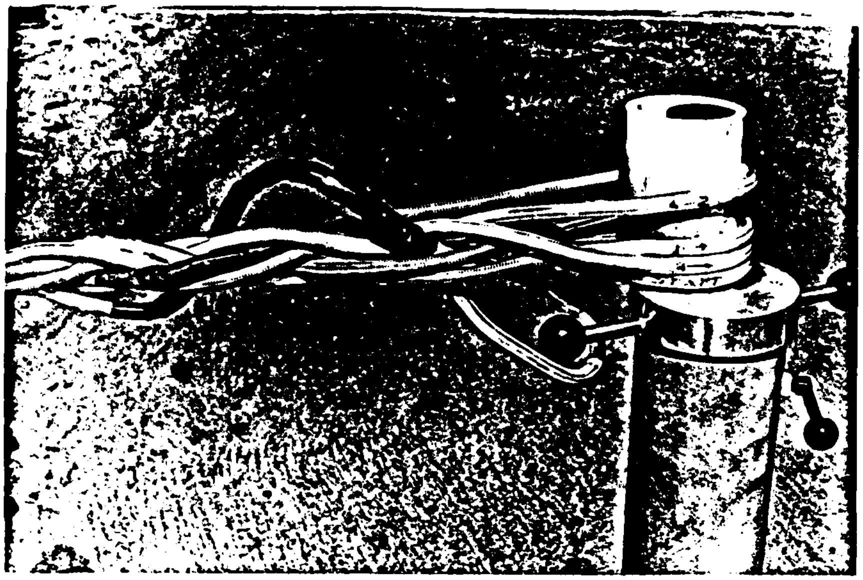


FIGURE 66. PLAITING OF FINAL EYE SPLICE STRAND

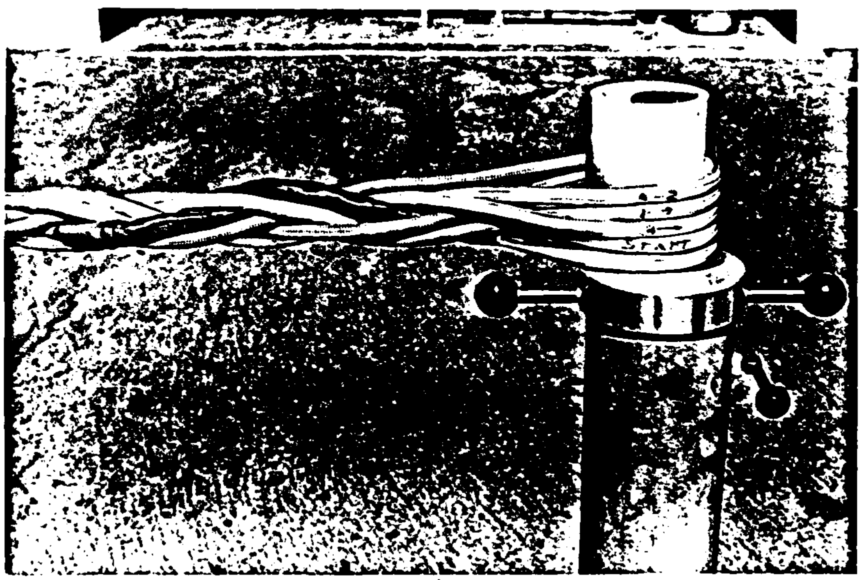


FIGURE 67. COMPLETED EYE SPLICE IN FINAL ORIENTATION

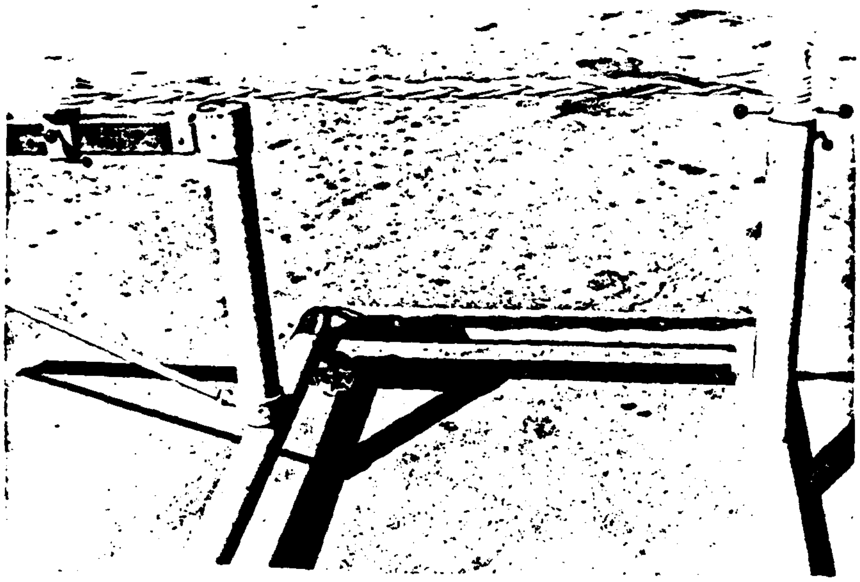


FIGURE 68. COMPLETE PLAITED ROPE

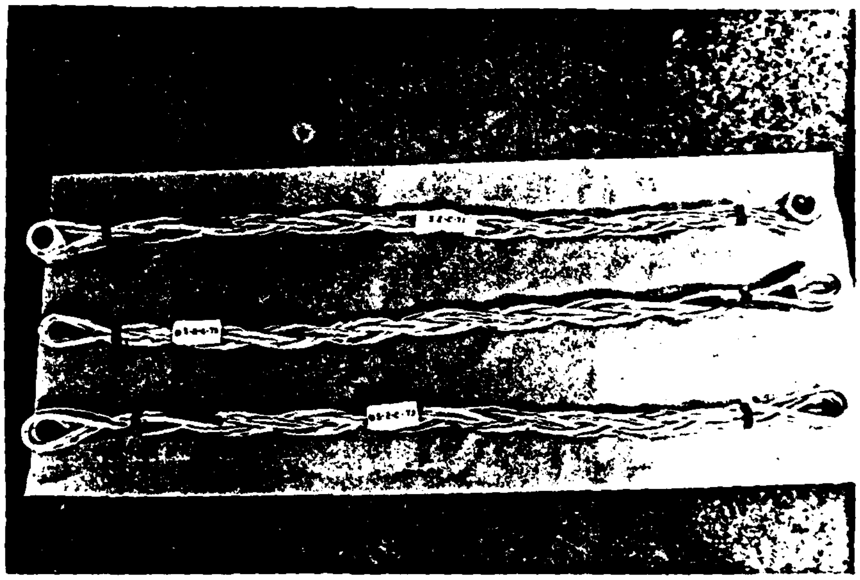
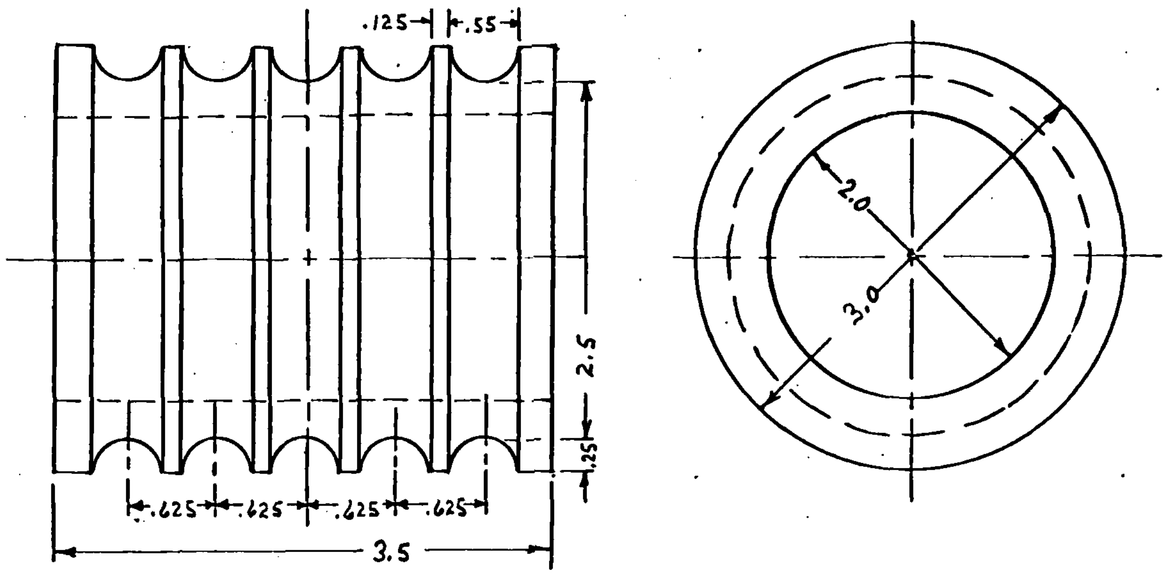
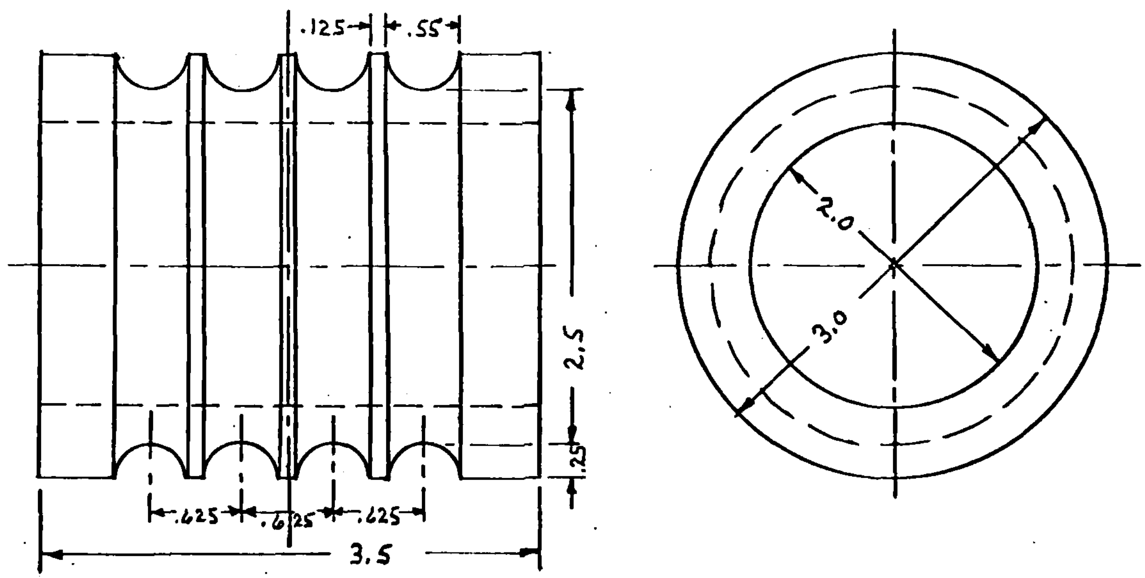


FIGURE 69. TYPICAL SAMPLES OF PLAITED ROPE, ONE WITH SPOOLS INSTALLED

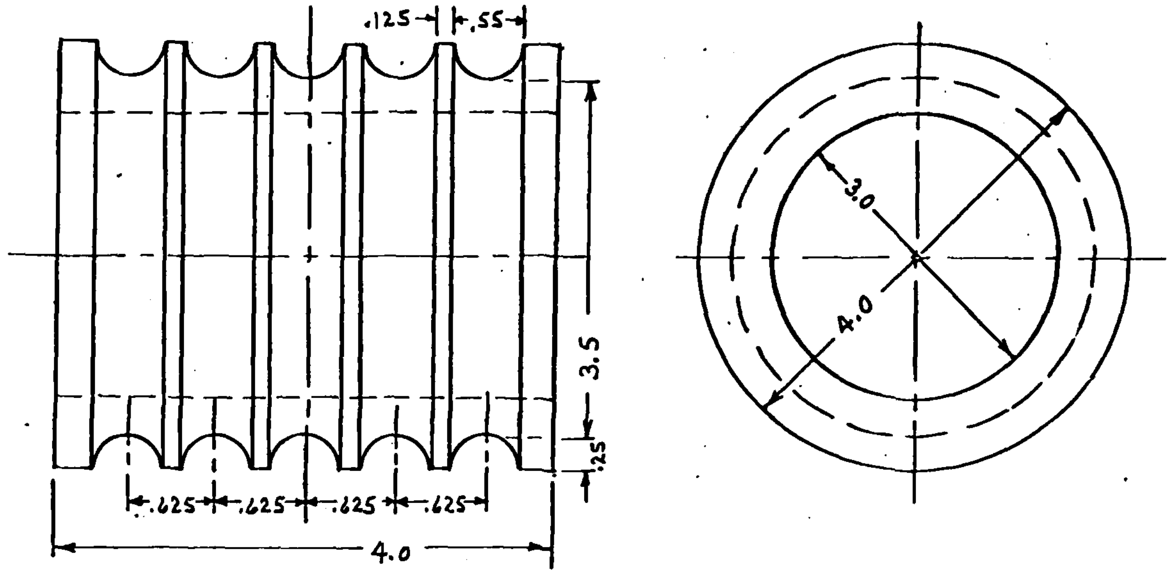


Five-Groove Spool

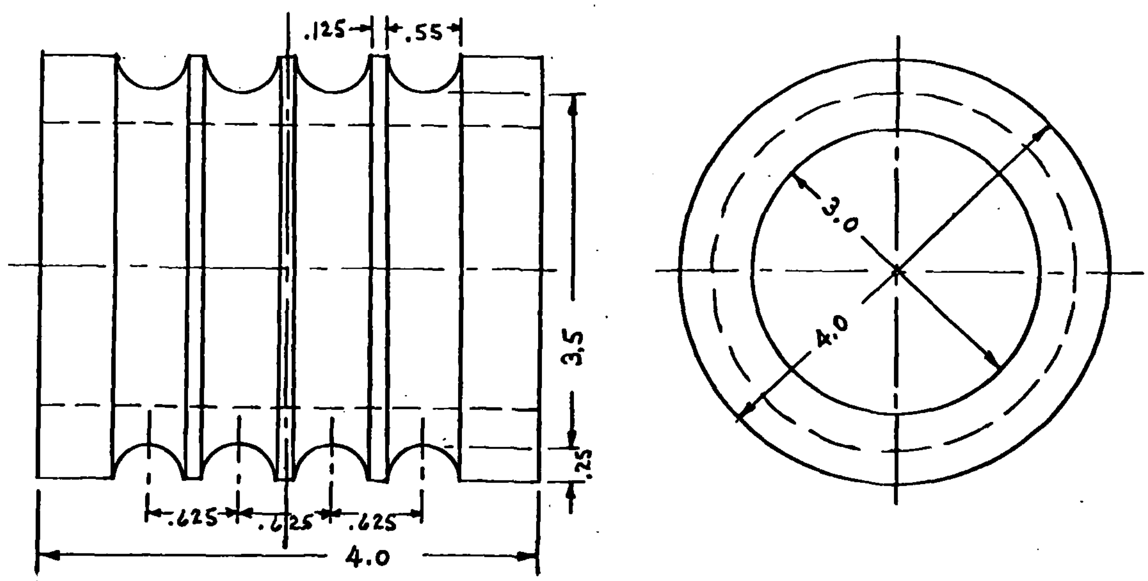


Four-Groove Spool

FIGURE 70. SPOOL GEOMETRY FOR S-2-C SPECIMENS



Five-Groove Spool



Four-Groove Spool

FIGURE 71. SPOOL GEOMETRY FOR S-2-D SPECIMENS

TABLE 4. SUMMARY OF TEST RESULTS FOR ROPE S-2

Specimen Number	Termination Type	Fatigue Test Parameters D/d	T_{max}, lb	Cycles	Breaking Load, lb	Failure Location
S-2-D-T1	Grommet Eyes-D	--	--	--	169,000	Rope Body
-T2	Ditto	--	--	--	163,000	Ditto
-T3	"	--	--	--	174,000	"
S-2-D-CST-L1	"	--	25,000	30,000	140,000	Rope Body
-CST-M1	"	--	50,000	30,000	146,000	Ditto
-CST-H1	"	--	75,000	30,000	160,500	"
S-2-D-CTOS-L1	"	10	25,000	30,000	115,000	Sheave
-CTOS-L2	"	10	25,000	30,000	98,000	Ditto
-CTOS-LM1	"	10	37,500	4,655	114,000	"
-CTOS-LM2	"	10	37,500	4,655	37,500	"
-CTOS-M1	"	10	50,000	419	126,000	"
-CTOS-M2	"	10	50,000	419	50,000	"
S-2-D-CTOS-L3	"	14	25,000	30,000	143,500	Sheave
-CTOS-L4	"	14	25,000	30,000	140,500	Ditto
-CTOS-LM3	"	14	37,500	30,000	110,000	"
-CTOS-LM4	"	14	37,500	30,000	86,500	"
-CTOS-M3	"	14	50,000	2,099	115,000	"
-CTOS-M4	"	14	50,000	2,099	50,000	"
S-2-C-T1	Grommet Eyes-C	--	--	--	142,000	Spool
-T2	Ditto	--	--	--	141,000	Ditto
-T3	"	--	--	--	132,000	"
S-2-C-CST-L1	"	--	25,000	30,000	121,000	Spool
-CST-M1	"	--	50,000	30,000	122,000	Ditto
-CST-H1	"	--	75,000	30,000	140,000	"

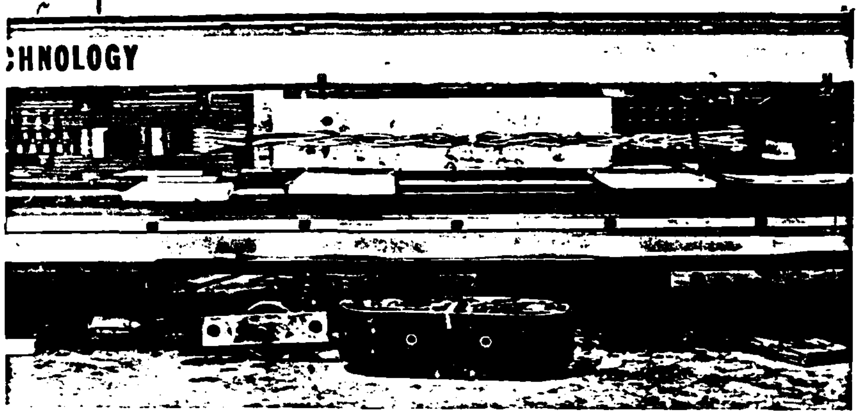


FIGURE 72. S-2 SPECIMEN INSTALLED IN TEST MACHINE

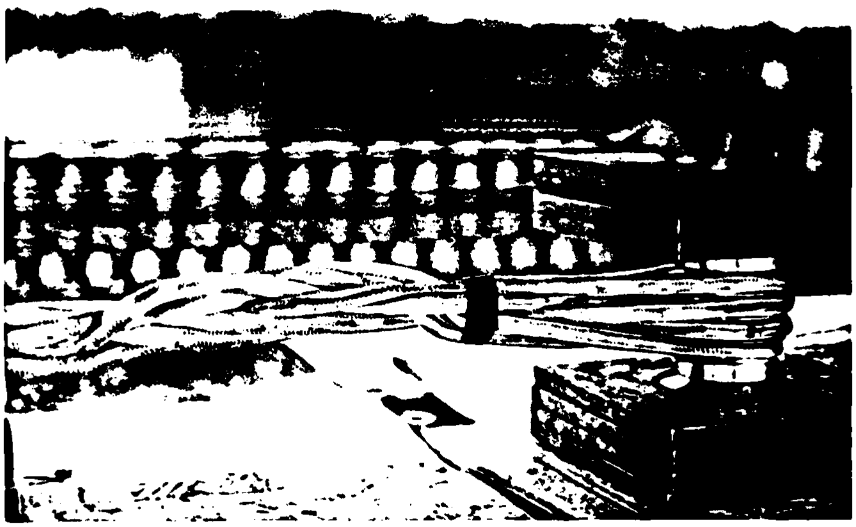
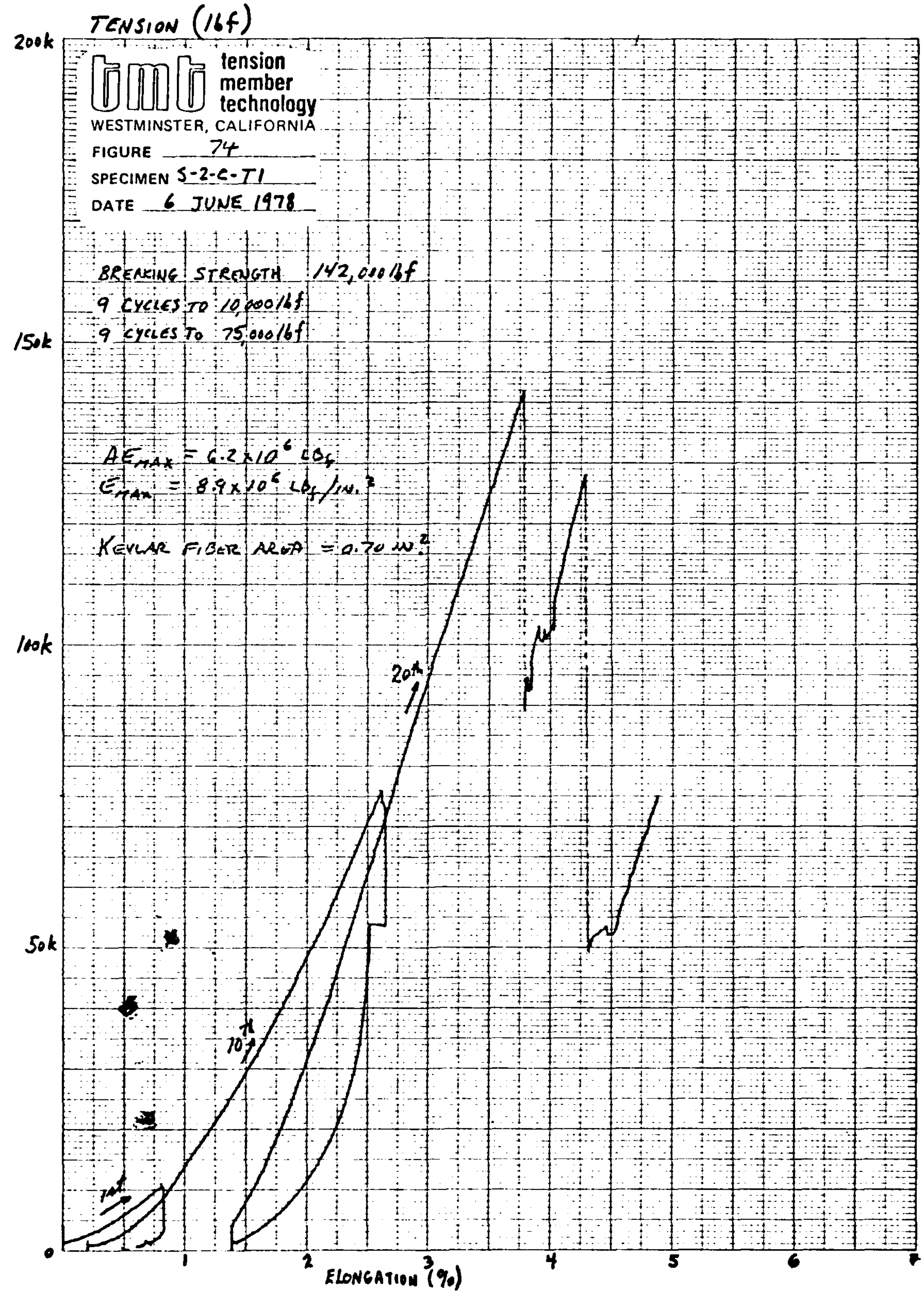
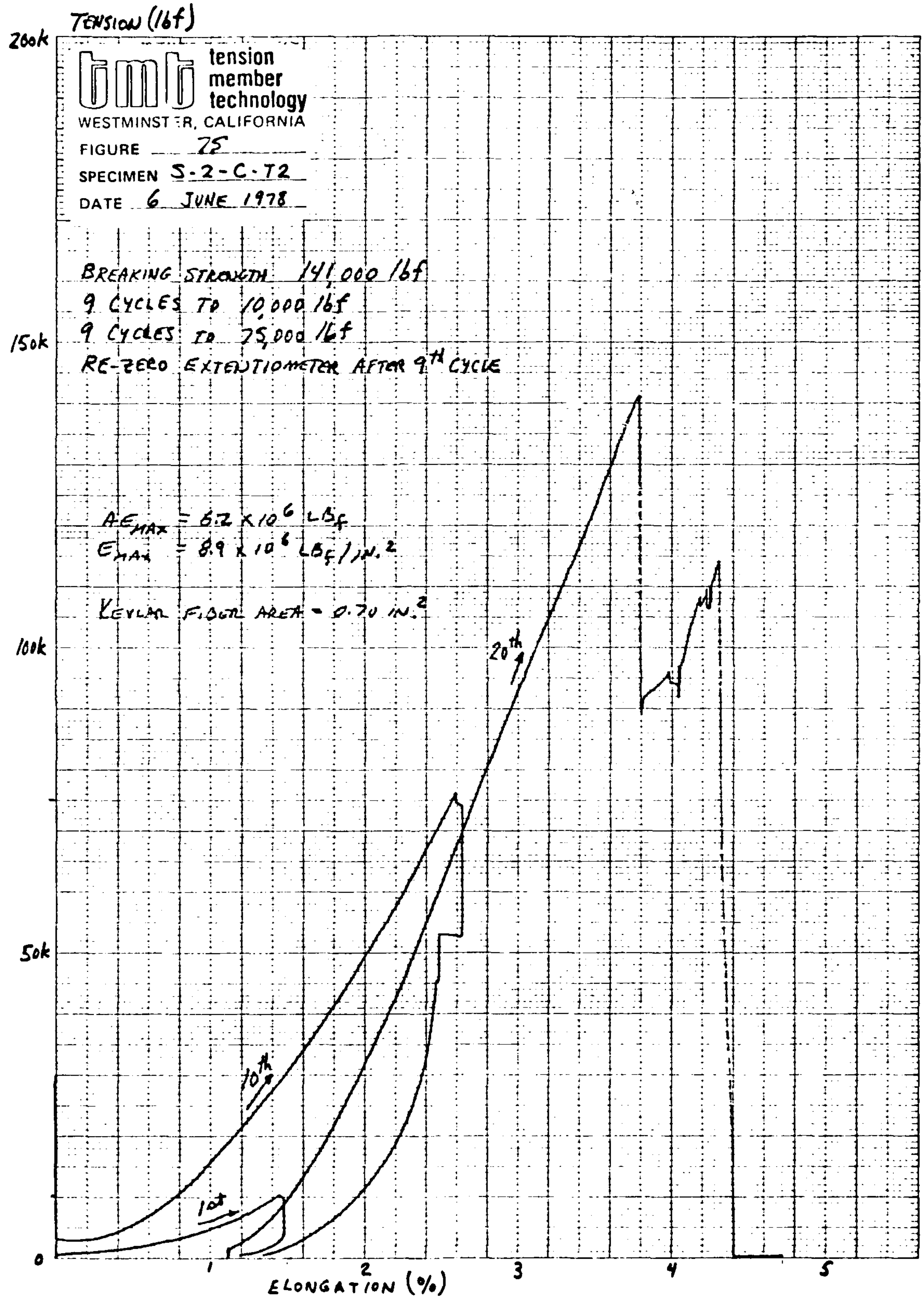
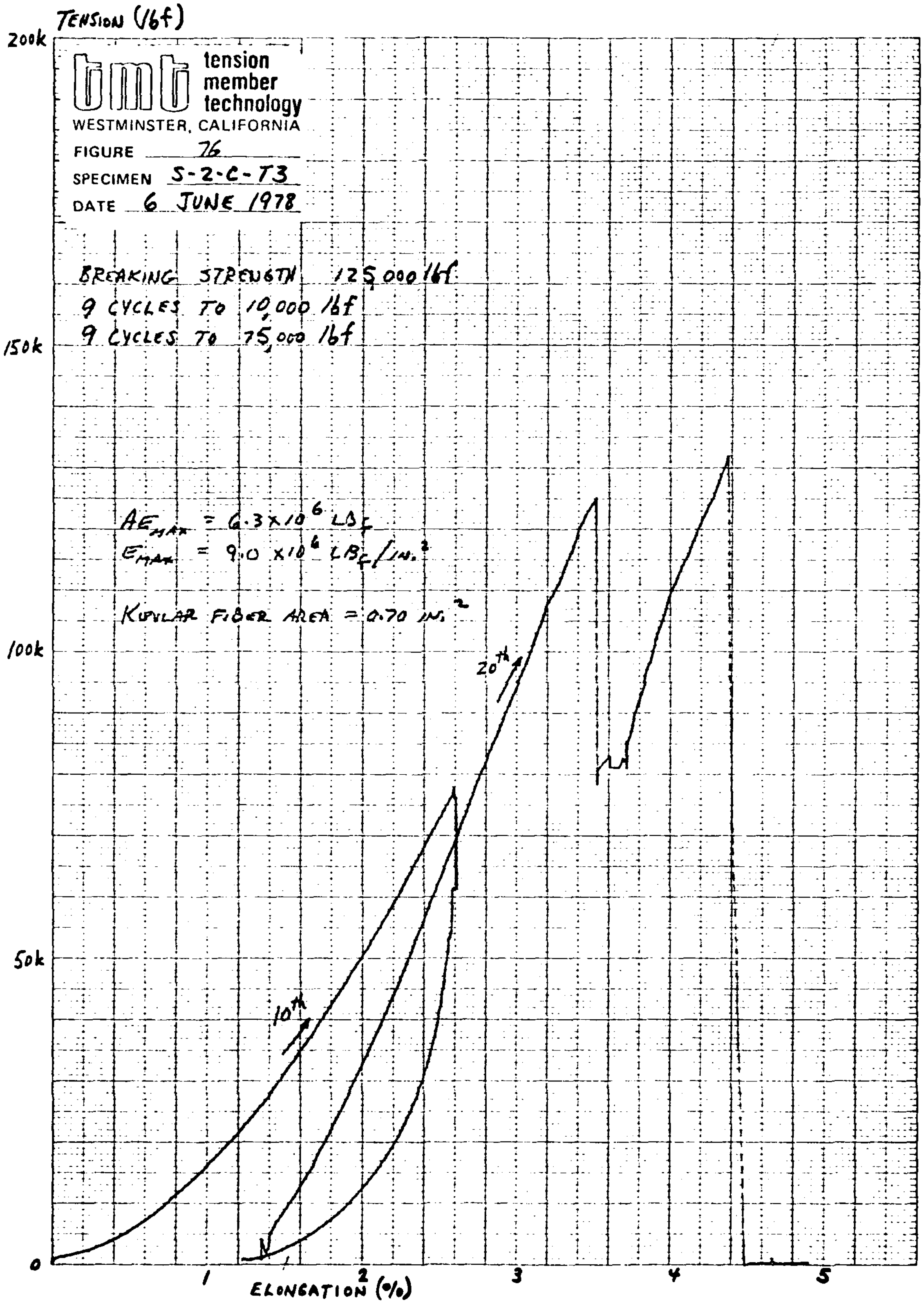
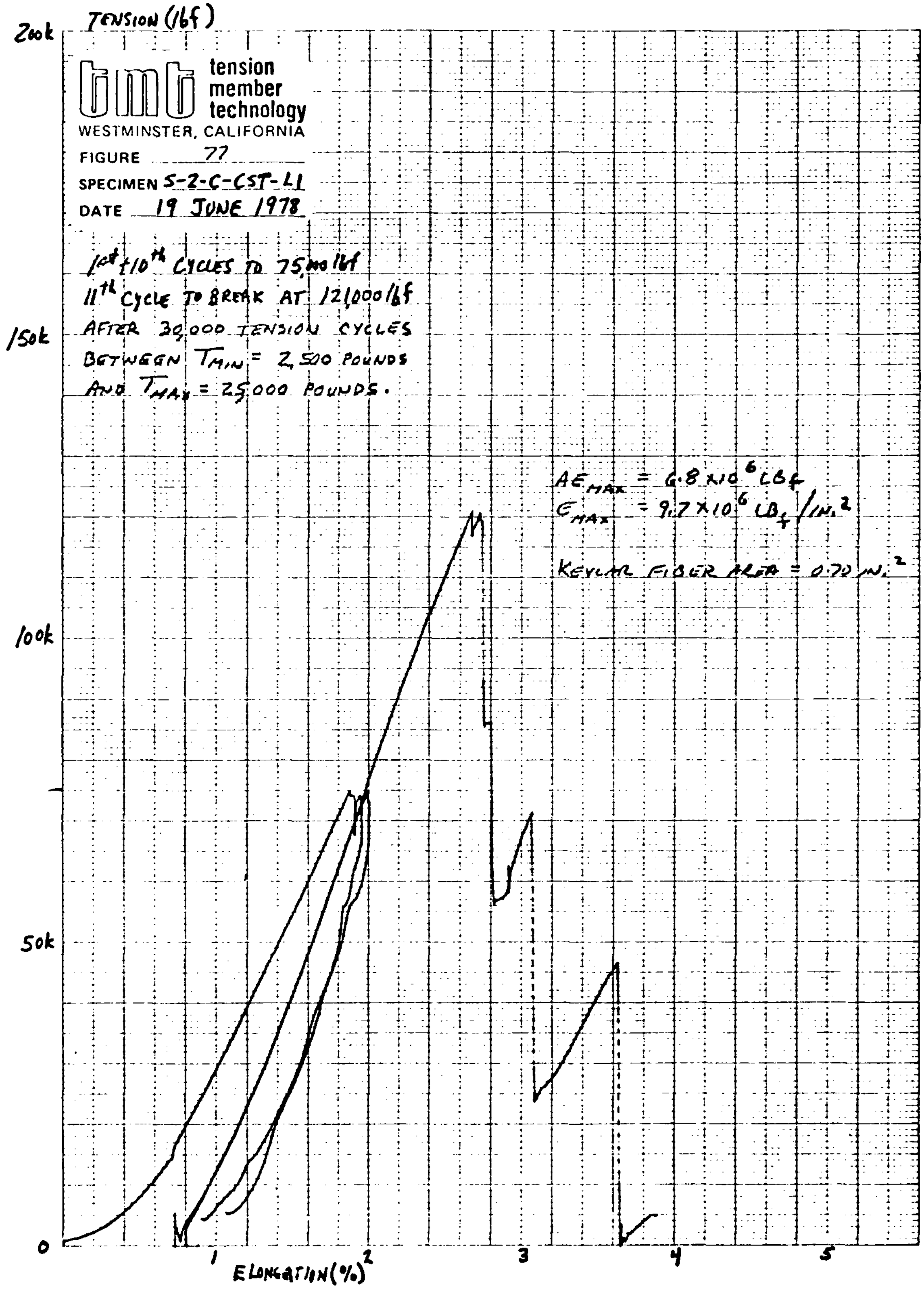


FIGURE 73. S-2 SPECIMEN AFTER LOWER STRAND FAILURE AT SPOOL

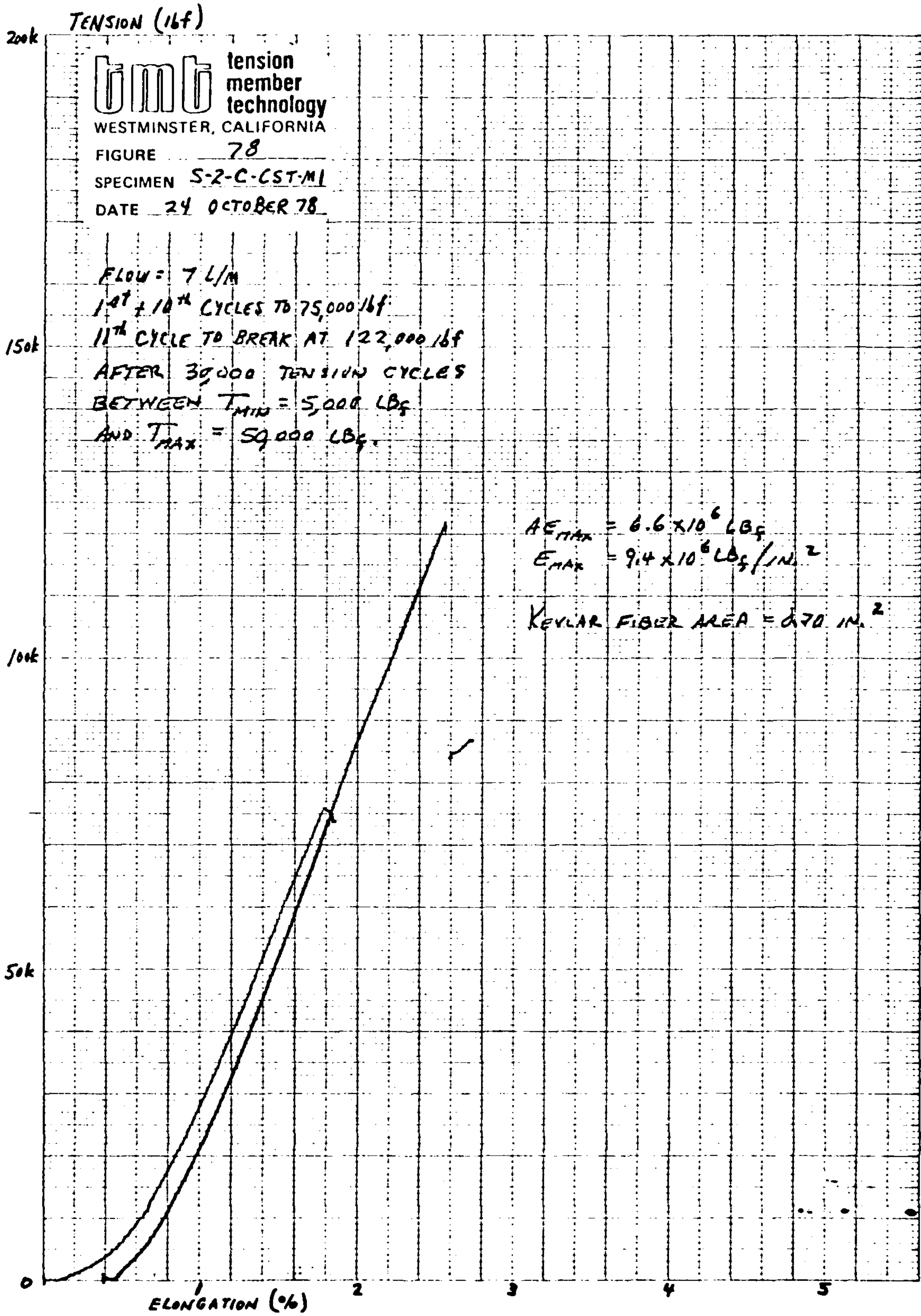

TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 74
SPECIMEN S-2-C-T1
DATE 6 JUNE 1978
BREAKING STRENGTH 142,000 lbf
9 CYCLES TO 10,000 lbf
9 CYCLES TO 75,000 lbf
AE_MAX = 6.2 x 10^6 LBf
E_MAX = 8.9 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.70 IN.^2
1st
10th
20th
1
2
3
4
5
6
7
ELONGATION (%)


TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 75
SPECIMEN S-2-C-T2
DATE 6 JUNE 1978
BREAKING STRENGTH 141,000 lbf
9 CYCLES TO 10,000 lbf
9 CYCLES TO 75,000 lbf
RE-ZERO EXTENTIOMETER AFTER 9th CYCLE
AE_MAX = 6.2 x 10^6 LBf
E_MAX = 8.9 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.70 IN.^2
200k
150k
100k
50k
0
20th
10th
1st
1
2
3
4
5
ELONGATION (%)

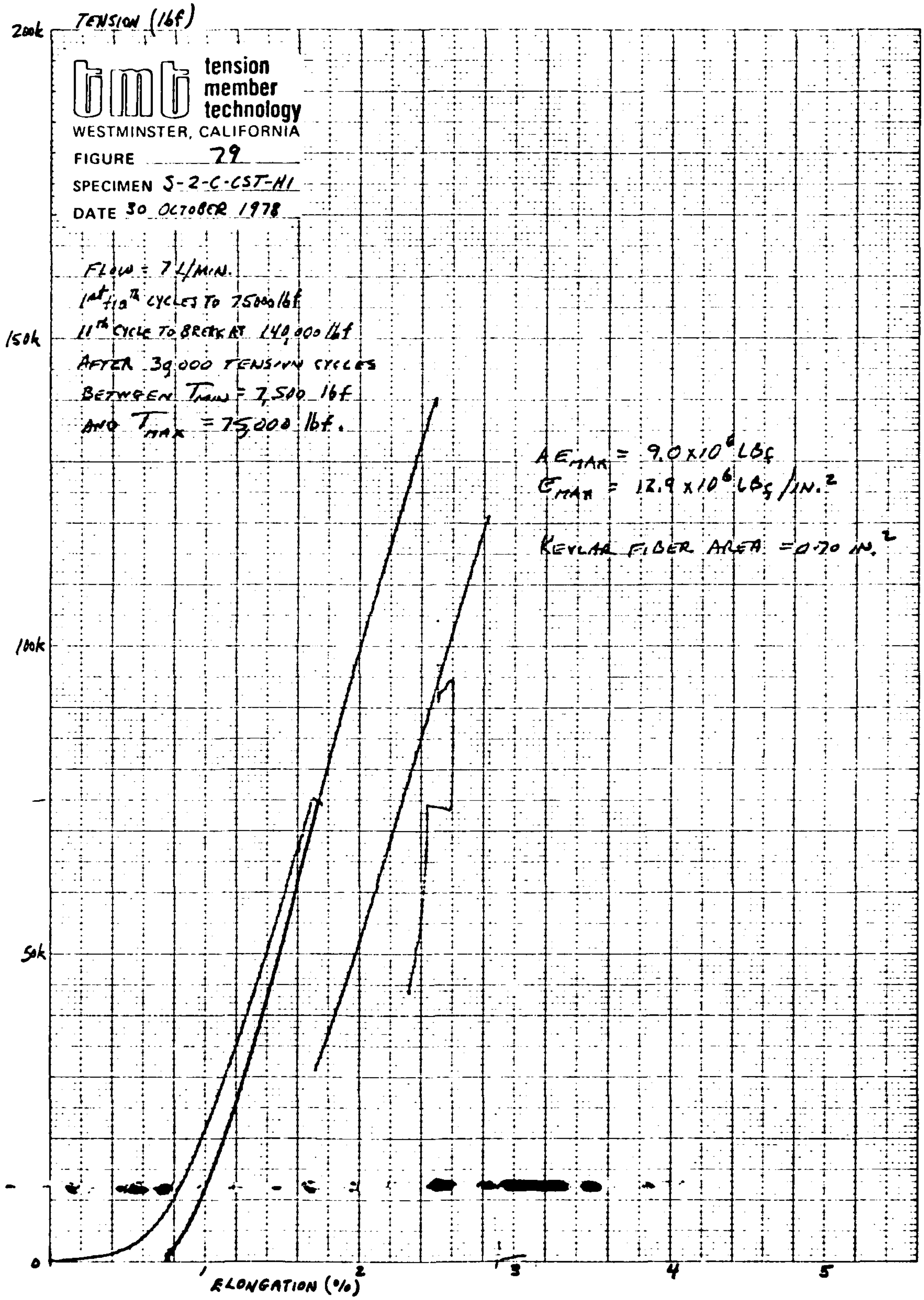

TENSION (lbf)
200k
150k
100k
50k
0
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 76
SPECIMEN S-2-C-T3
DATE 6 JUNE 1978
BREAKING STRENGTH 125,000 lbf
9 CYCLES TO 10,000 lbf
9 CYCLES TO 75,000 lbf
$AE_{MAX} = 6.3 \times 10^6$ LBf
$E_{MAX} = 9.0 \times 10^6$ LBf/IN.^{2}
KEVLAR FIBER AREA = 0.70 IN.^{2}
20th
10th
1
2
3
4
5
ELONGATION (%)

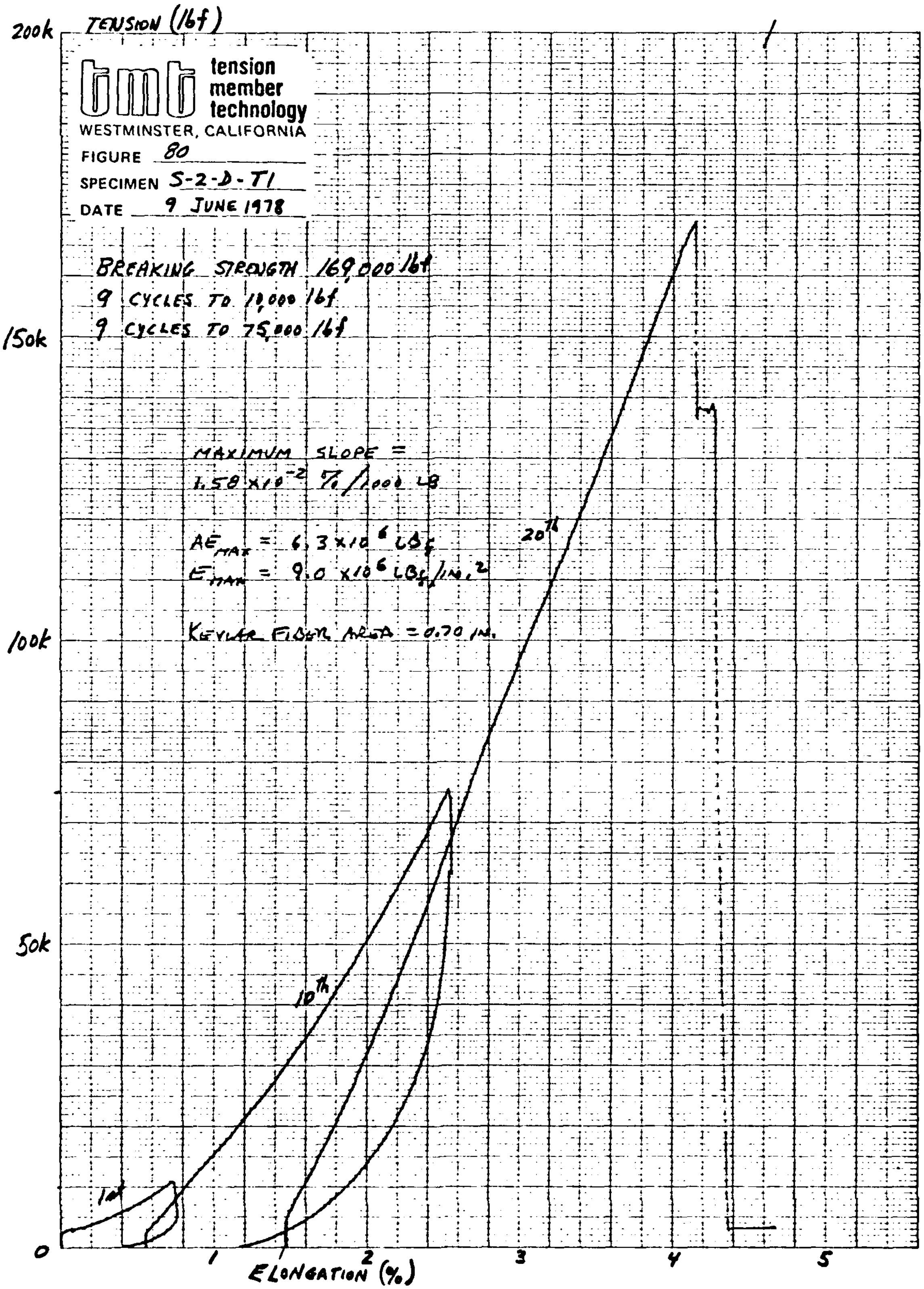


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 77
SPECIMEN 5-2-C-CST-L1
DATE 19 JUNE 1978
1st + 10th CYCLES TO 75,000 lbf
11th CYCLE TO BREAK AT 121,000 lbf
AFTER 30,000 TENSION CYCLES
BETWEEN T MIN = 2,500 POUNDS
AND T MAX = 25,000 POUNDS.
AE MAX = 6.8 x 10^6 LBf
E MAX = 9.7 x 10^6 LBf / IN.^2
KEVLAR FIBER AREA = 0.70 IN.^2
1
2
3
4
5
ELONGATION (%)

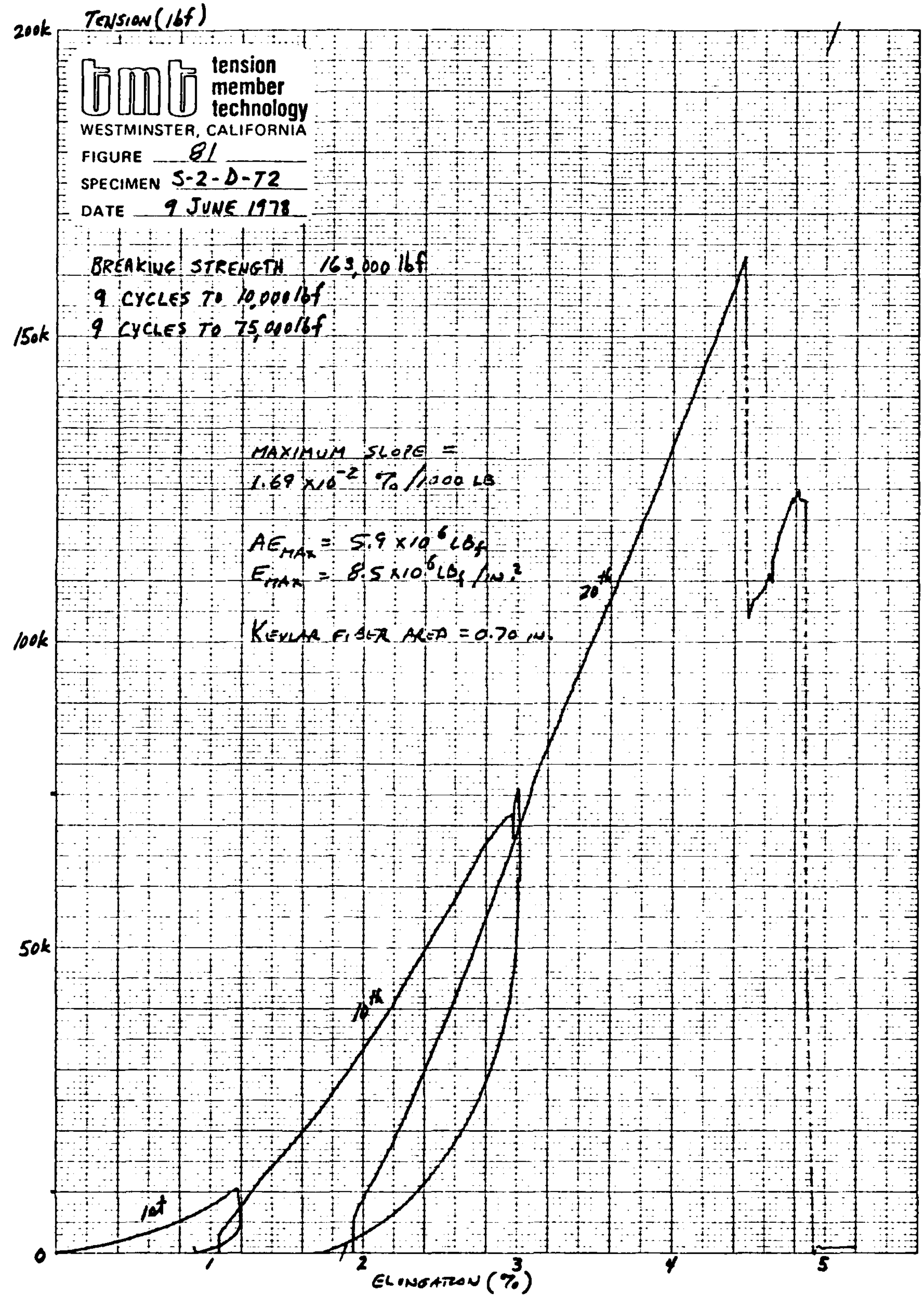


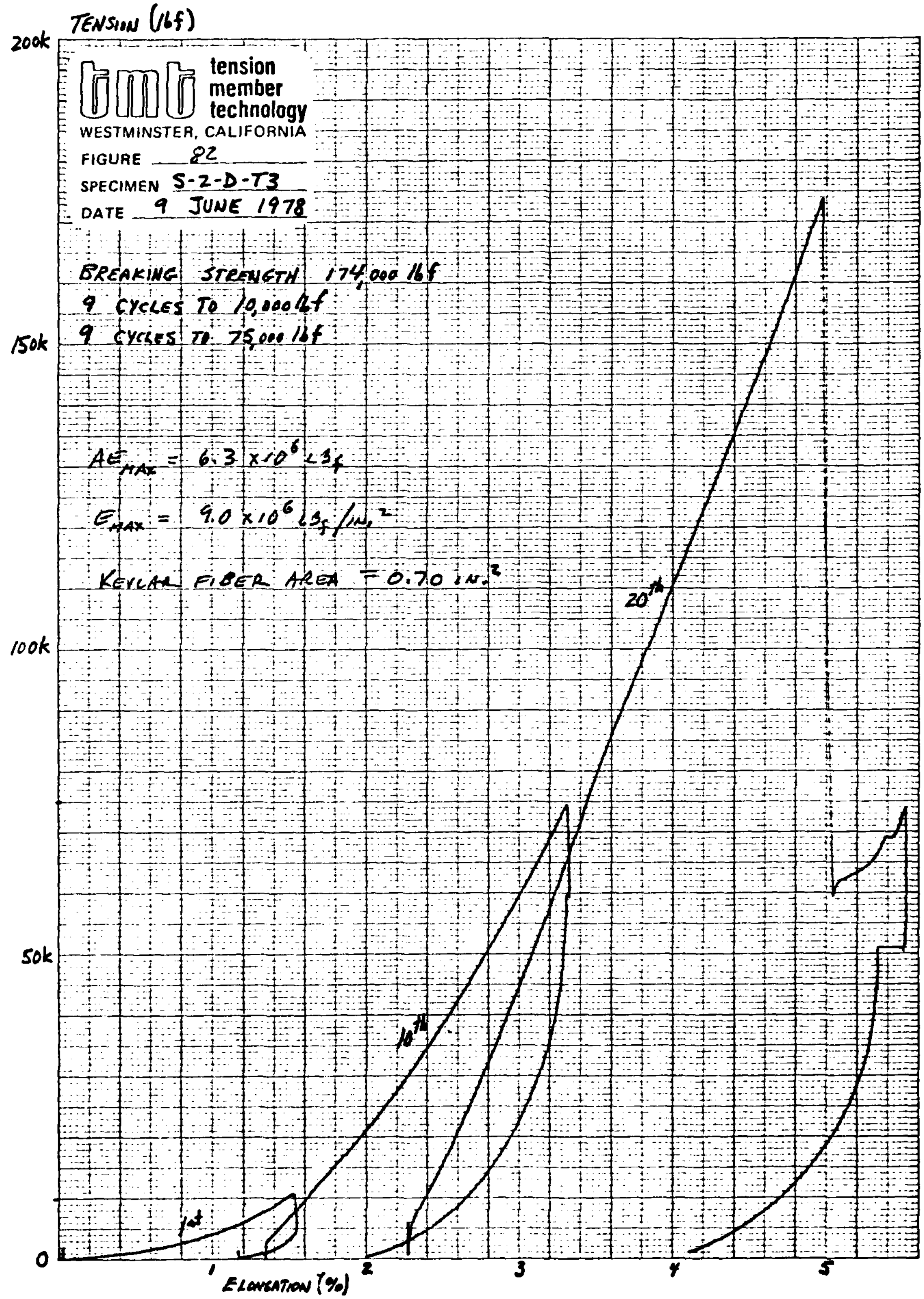
TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 78
SPECIMEN S-2-C-CST-M1
DATE 24 OCTOBER 78
FLOW: 7 L/M
1st + 10th CYCLES TO 75,000 lbf
11th CYCLE TO BREAK AT 122,000 lbf
AFTER 30,000 TENSION CYCLES
BETWEEN T_{MIN} = 5,000 LBf
AND T_{MAX} = 50,000 LBf.
$AE_{MAX} = 6.6 \times 10^6$ LBf
$E_{MAX} = 9.4 \times 10^6$ LBf/IN.^{2}
KEVLAR FIBER AREA = 0.70 IN.^{2}
1
2
3
4
5
ELONGATION (%)

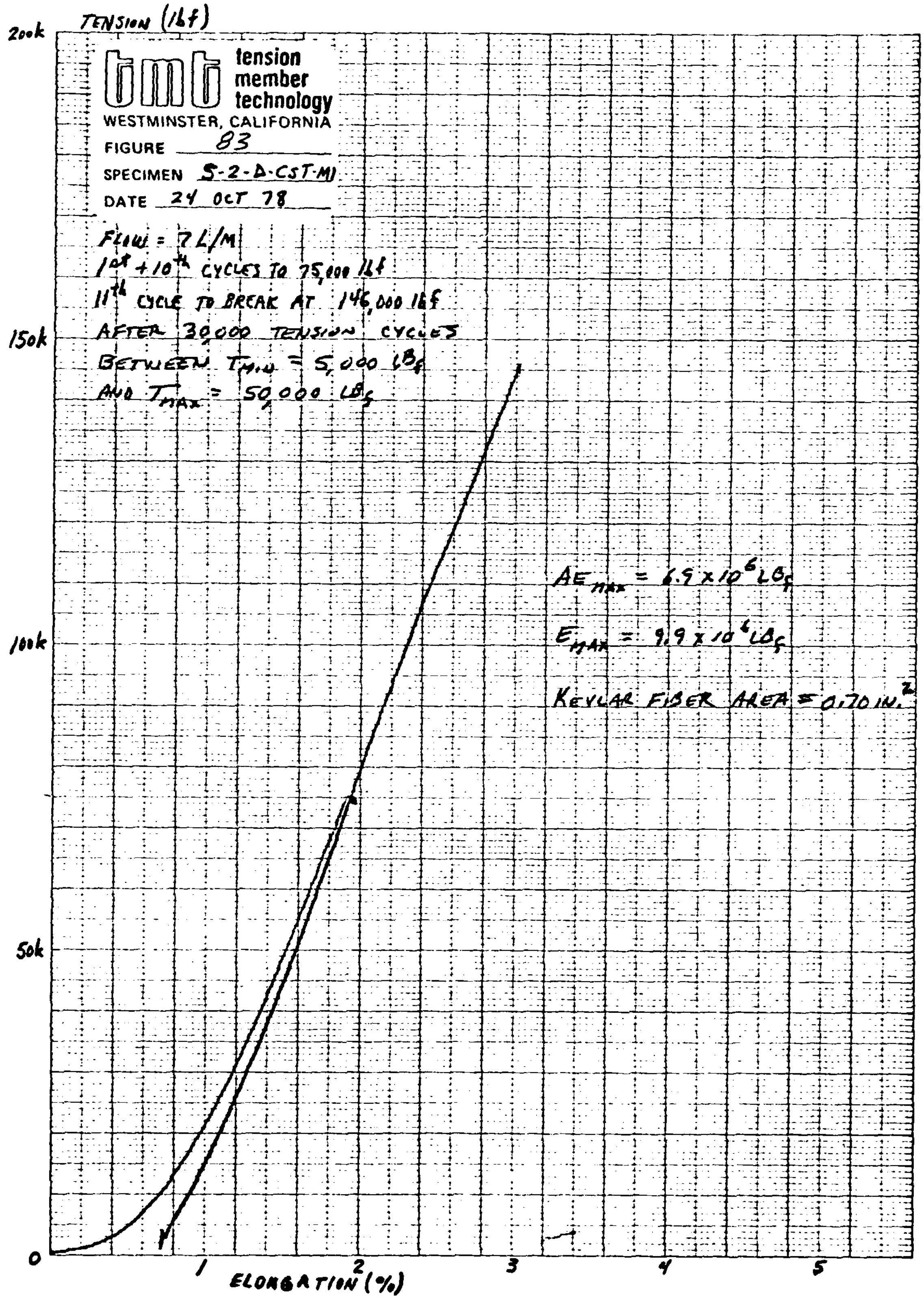

TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 79
SPECIMEN S-2-C-CST-H1
DATE 30 OCTOBER 1978
FLOW = 7 L/MIN.
1st thru 10th CYCLES TO 75000 lbf
11th CYCLE TO BREAK AT 140,000 lbf
AFTER 30,000 TENSION CYCLES
BETWEEN Tmin = 7,500 lbf
AND Tmax = 75,000 lbf.
AE MAX = 9.0 x 10^6 LBf
E MAX = 12.9 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.70 IN.^2
1
2
3
4
5
ELONGATION (%)



200k
TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 80
SPECIMEN S-2-D-T1
DATE 9 JUNE 1978
BREAKING STRENGTH 169,000 lbf
9 CYCLES TO 10,000 lbf
9 CYCLES TO 75,000 lbf
150k
MAXIMUM SLOPE =
1.58 x10^-2 %/1000 LB
AE_MAX = 6.3 x10^6 LBf
E_MAX = 9.0 x10^6 LBf/IN.^2
20th
KEVLAR FIBER AREA = 0.70 IN.
100k
50k
10th
1st
0
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 81
SPECIMEN S-2-D-72
DATE 9 JUNE 1978
BREAKING STRENGTH 163,000 lbf
9 CYCLES TO 10,000 lbf
9 CYCLES TO 75,000 lbf
MAXIMUM SLOPE =
1.69 x 10^-2 %/1000 LB
AE_MAX = 5.9 x 10^6 LB_f
E_MAX = 8.5 x 10^6 LB_f/IN.^2
KEVLAR FIBER AREA = 0.70 IN.
1st
10th
20th
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 82
SPECIMEN S-2-D-T3
DATE 9 JUNE 1978
BREAKING STRENGTH 174,000 lbf
9 CYCLES TO 10,000 lbf
9 CYCLES TO 75,000 lbf
$AE_{MAX} = 6.3 \times 10^6$ lbs
$E_{MAX} = 9.0 \times 10^6$ lbs/in.^{2}
KEVLAR FIBER AREA = 0.70 in.^{2}
1st
10th
20th
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 83
SPECIMEN S-2-D-CST-M1
DATE 24 OCT 78
FLOW = 7 L/M
1st + 10th CYCLES TO 75,000 lbf
11th CYCLE TO BREAK AT 146,000 lbf
AFTER 30,000 TENSION CYCLES
BETWEEN T_MIN = 5,000 LBf
AND T_MAX = 50,000 LBf
AE_MAX = 6.9 x 10^6 LBf
E_MAX = 9.9 x 10^6 LBf
KEVLAR FIBER AREA = 0.70 IN.^2
1
2
3
4
5
ELONGATION (%)

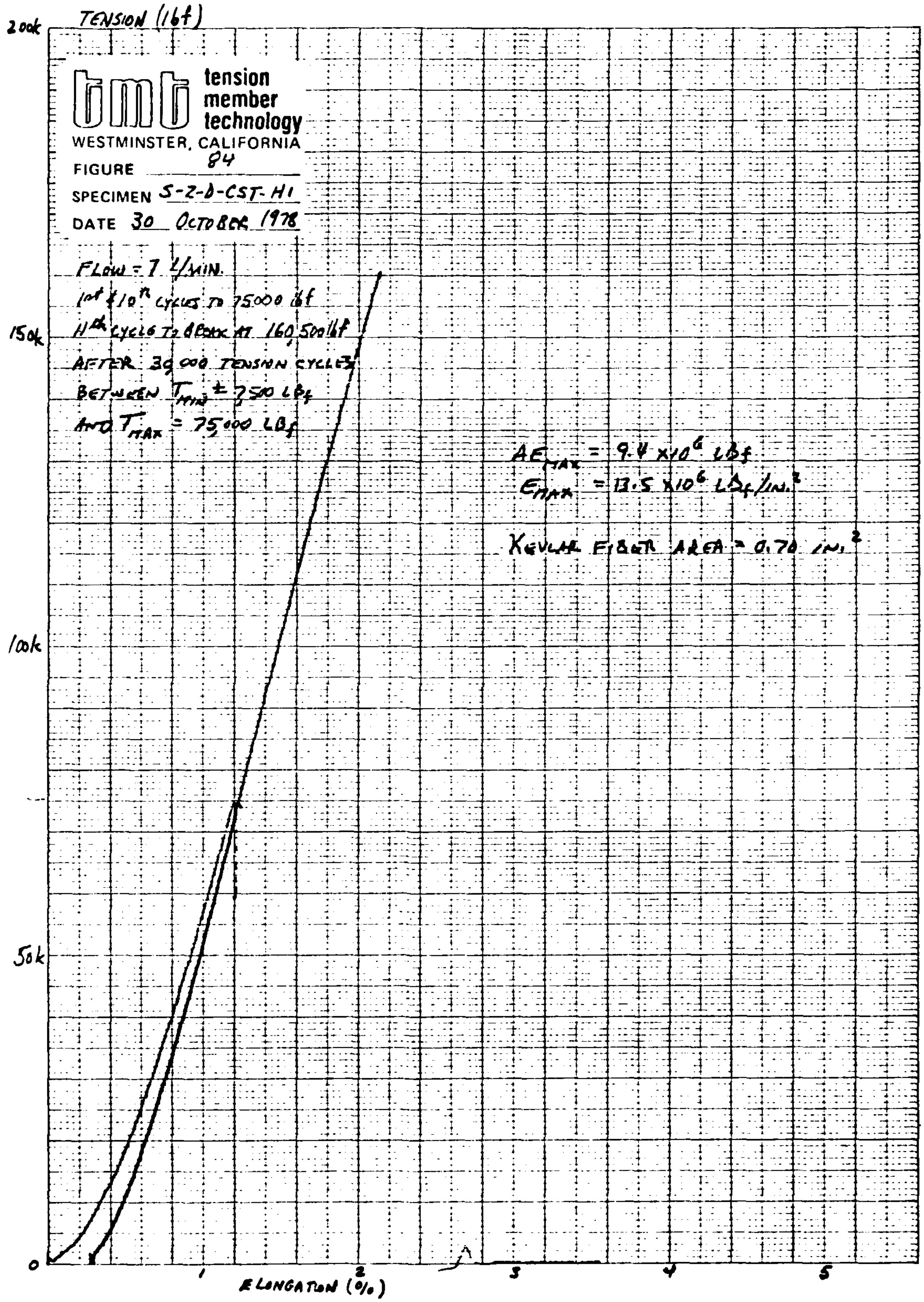
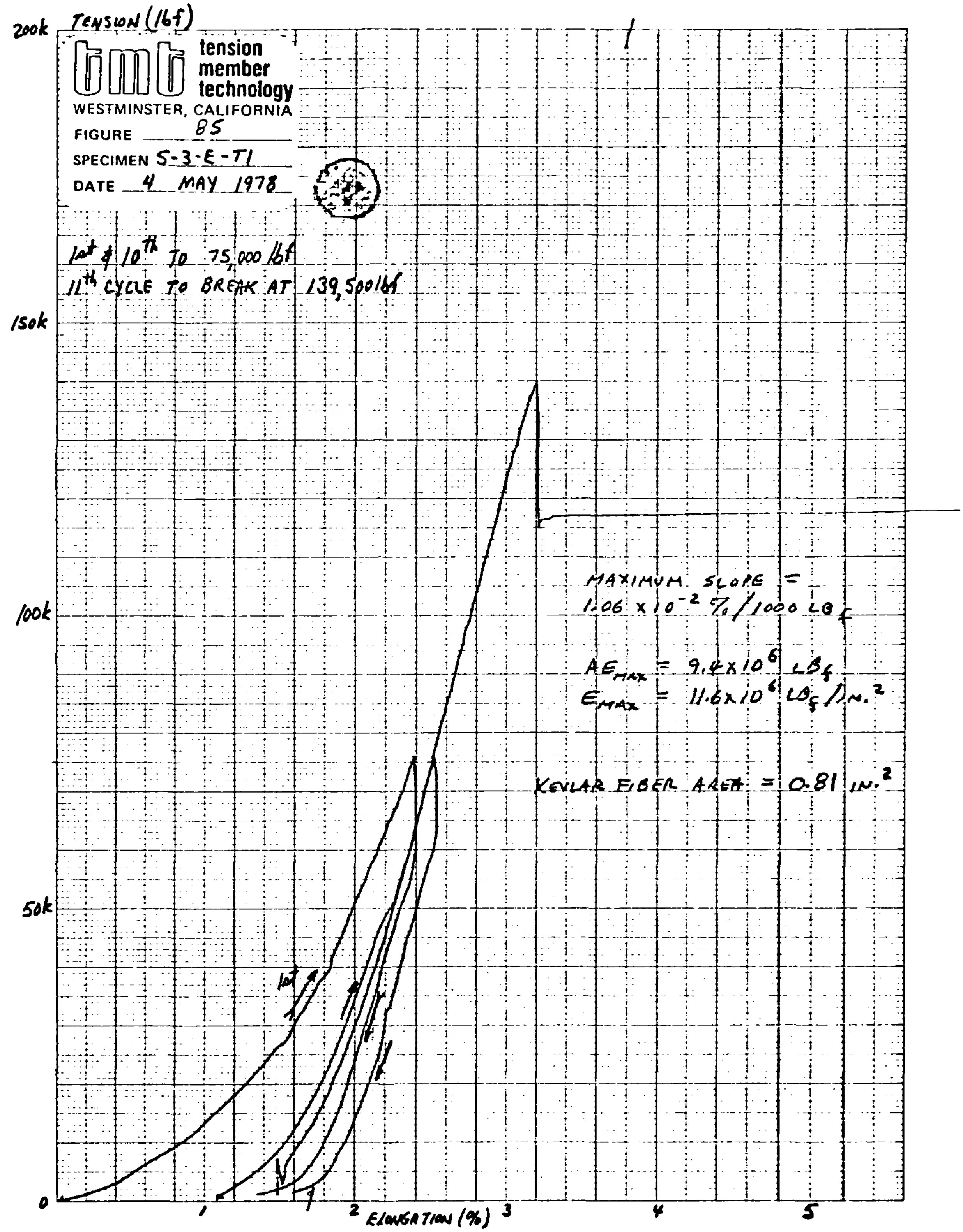
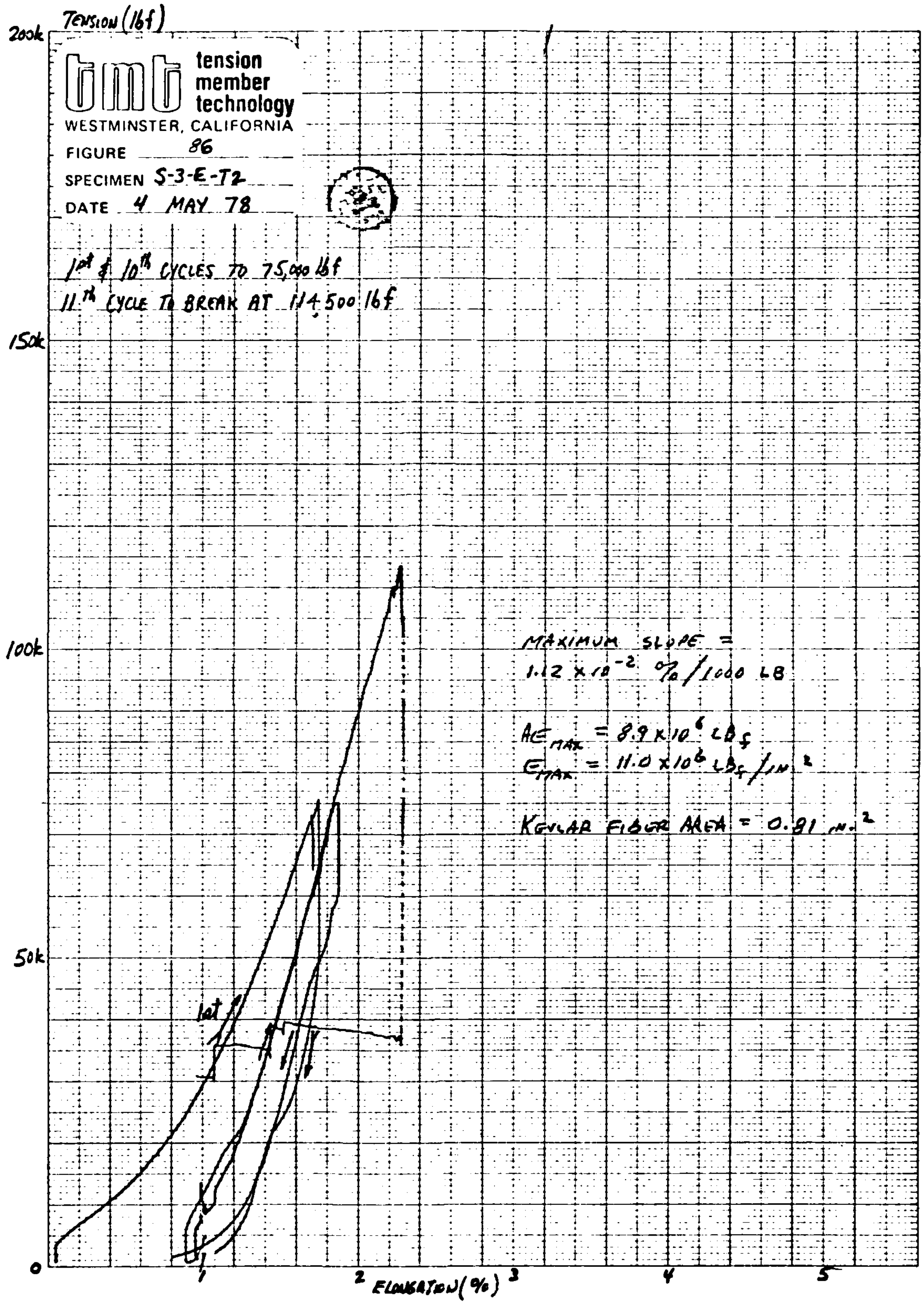

TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 84
SPECIMEN S-2-D-CST-H1
DATE 30 OCTOBER 1978
FLOW = 7 l/MIN.
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO BREAK AT 160,500 lbf
AFTER 39,000 TENSION CYCLES
BETWEEN TMIN ± 7500 LBf
AND TMAX = 75,000 LBf
AEMAX = 9.4 x10^6 LBf
EMAX = 13.5 x10^6 LBf/IN.²
KEVLAR FIBER AREA = 0.70 IN.²
1
2
3
4
5
ELONGATION (%)

TABLE 5. SUMMARY OF TEST RESULTS FOR ROPE S-3

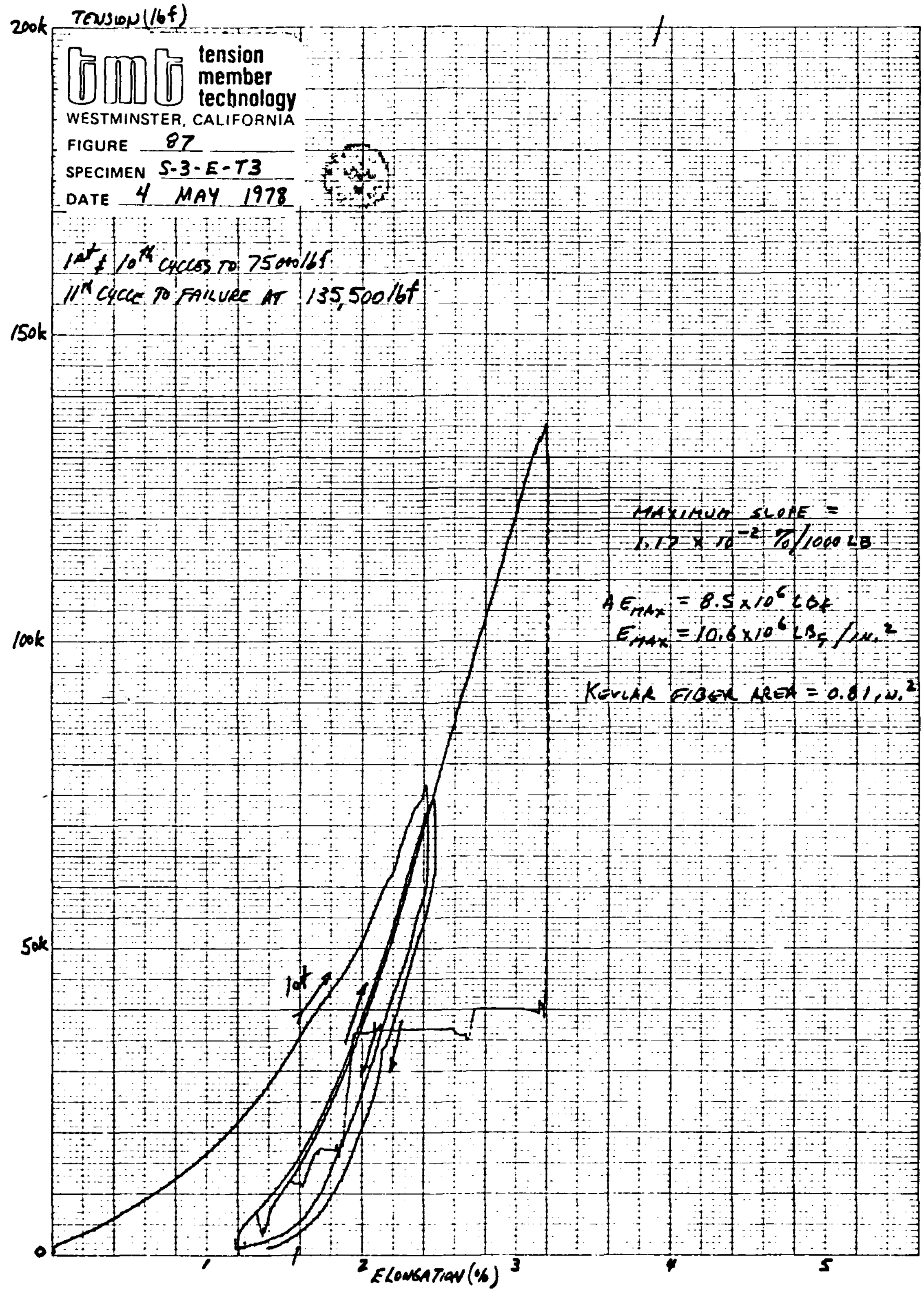
Specimen Number	Termination Type	Fatigue Test Parameters D/d	Fatigue Test Parameters T_{max}, lb	Fatigue Test Parameters Cycles	Breaking Load, lb	Failure Location
T1	Epoxy Sockets	--	--	--	139,500[a]	Socket
T2	Ditto	--	--	--	113,500[a]	Ditto
T3	"	--	--	--	135,500[a]	"
CST-L1	"	--	25,000	30,000	145,000[a]	"
CST-M1	"	--	50,000	30,000	137,000[a]	"
CST-H1	"	--	75,000	2,030	75,000[a]	"
CTOS-L1	"	10	25,000	30,000	131,000	"
CTOS-L2	"	10	25,000	30,000	127,000	"
CTOS-M1	"	10	50,000	30,000	122,500	Sheave
CTOS-M2	"	10	50,000	30,000	77,500	Ditto
CTOS-H1	"	10	75,000	2,303	119,000	"
CTOS-H2	"	10	75,000	2,303	75,000	"
CTOS-L3	"	14	25,000	30,000	120,500	Socket
CTOS-L4	"	14	25,000	30,000	114,000	Socket
CTOS-M3	"	14	50,000	30,000	125,000	Sheave
CTOS-M4	"	14	50,000	30,000	114,000	Sheave
CTOS-H3	"	14	75,000	2,579	108,500	Socket
CTOS-H4	"	14	75,000	2,579	75,000	Sheave

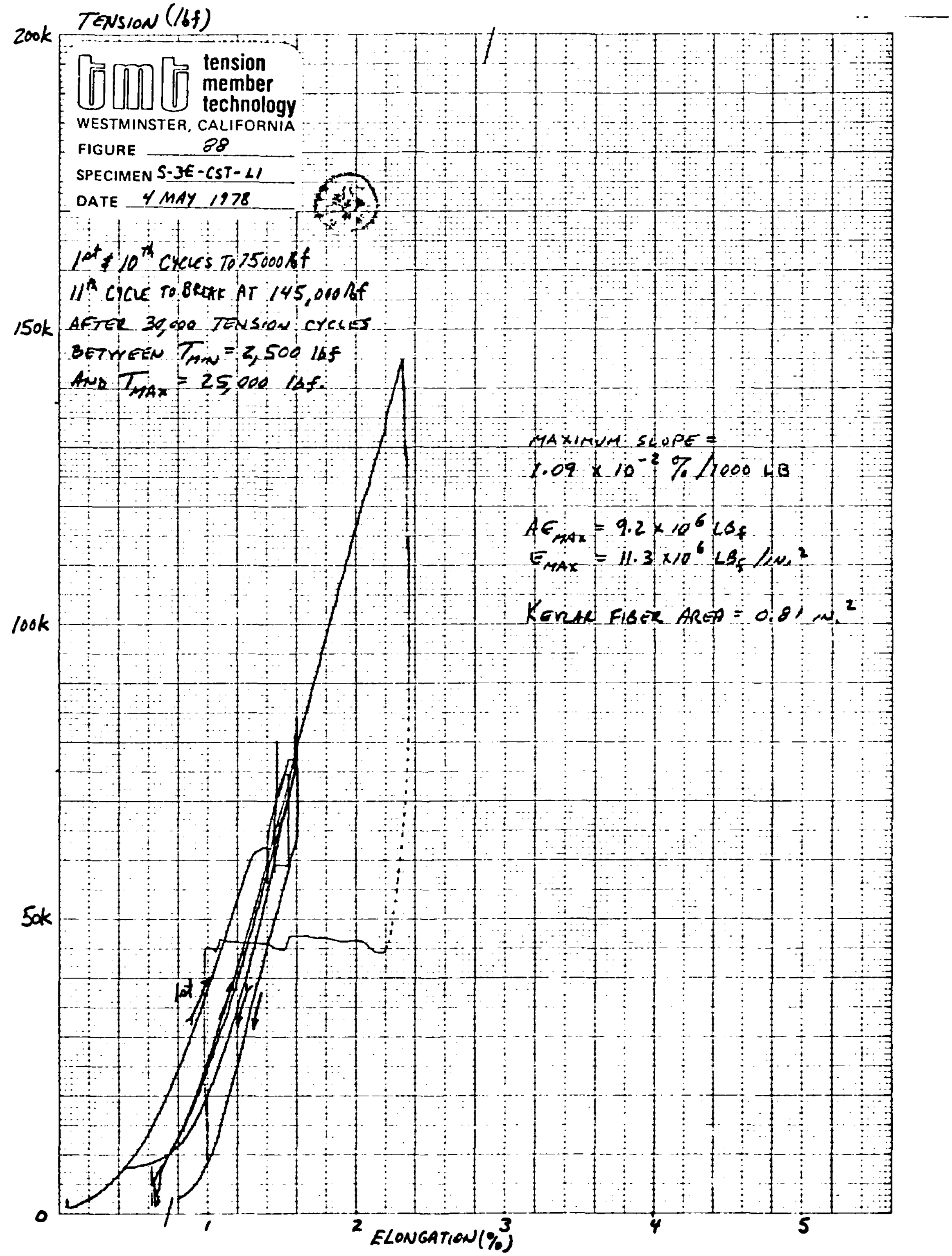
(a) Modified socketing resin used for these specimens.

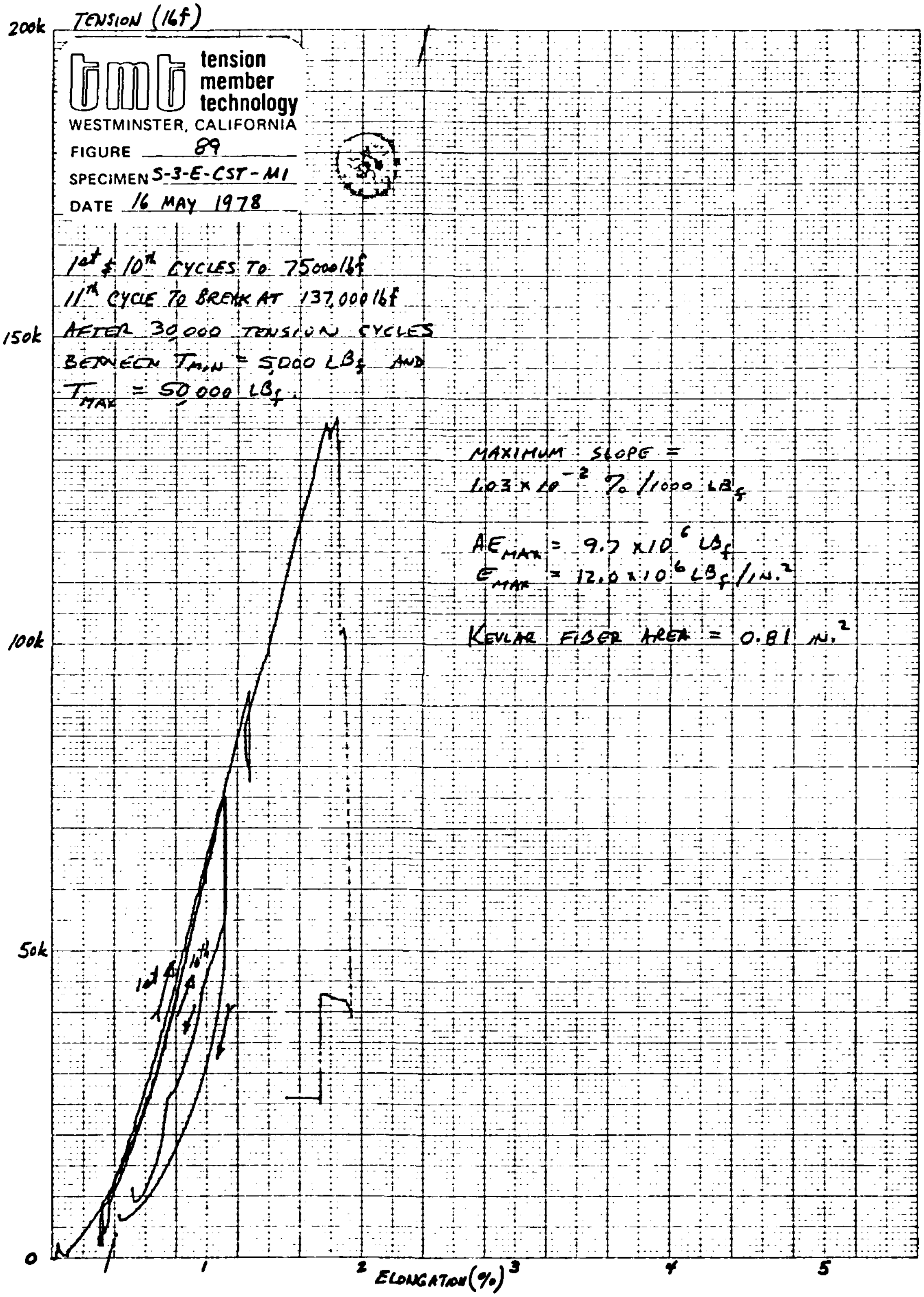

TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE B5
SPECIMEN S-3-E-T1
DATE 4 MAY 1978
1st & 10th TO 75,000 lbf
11th CYCLE TO BREAK AT 139,500 lbf
MAXIMUM SLOPE = 1.06 x 10^-2 %/1000 LBf
AEMAX = 9.4 x 10^6 LBf
EMAX = 11.6 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.81 IN.^2
1st
1
2
3
4
5
ELONGATION (%)



tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 86
SPECIMEN S-3-E-T2
DATE 4 MAY 78
1st & 10th CYCLES TO 75,000 lbf
11th CYCLE TO BREAK AT 114,500 lbf
TENSION (lbf)
200k
150k
100k
50k
0
1
2
3
4
5
ELONGATION (%)
1st
MAXIMUM SLOPE =
1.12 x 10^-2 %/1000 LB
AE_MAX = 8.9 x 10^6 LBf
E_MAX = 11.0 x 10^6 LBf/IN^2
KEVLAR FIBER AREA = 0.81 IN^2


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 87
SPECIMEN S-3-E-T3
DATE 4 MAY 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO FAILURE AT 135,500 lbf
MAXIMUM SLOPE = 1.17 x 10^-2 %/1000 LB
AE_MAX = 8.5 x 10^6 LBf
E_MAX = 10.6 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.81 IN.^2
1st
1
2
3
4
5
ELONGATION (%)


TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 88
SPECIMEN S-3E-CST-L1
DATE 4 MAY 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO BREAK AT 145,000 lbf
AFTER 30,000 TENSION CYCLES
BETWEEN T MIN = 2,500 lbf
AND T MAX = 25,000 lbf.
MAXIMUM SLOPE =
1.09 x 10^-2 % /1000 LB
AE MAX = 9.2 x 10^6 LBf
E MAX = 11.3 x 10^6 LBf /in.^2
KEVLAR FIBER AREA = 0.81 in.^2
1st
1
2
3
4
5
ELONGATION (%)

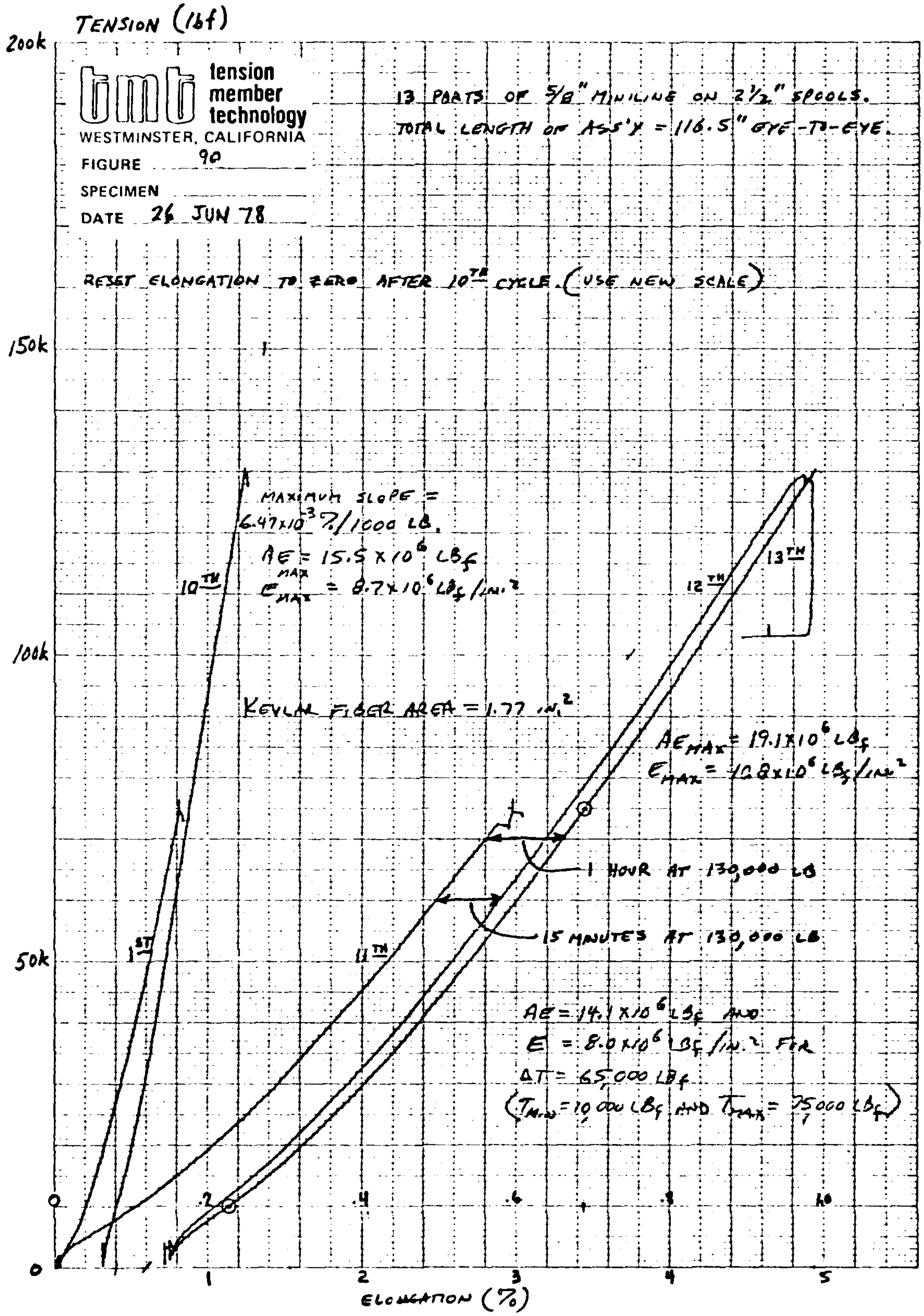


TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 89
SPECIMEN S-3-E-CST-M1
DATE 16 MAY 1978
1st & 10th CYCLES TO 75000 lbf
11th CYCLE TO BREAK AT 137,000 lbf
AFTER 30,000 TENSION CYCLES
BETWEEN T_MIN = 5000 LBf AND
T_MAX = 50 000 LBf.
MAXIMUM SLOPE =
1.03 x 10^-2 % /1000 LBf
AE_MAX = 9.7 x 10^6 LBf
E_MAX = 12.0 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 0.81 IN.^2
200k
150k
100k
50k
0
1st
10th
1
2
3
4
5
ELONGATION (%)

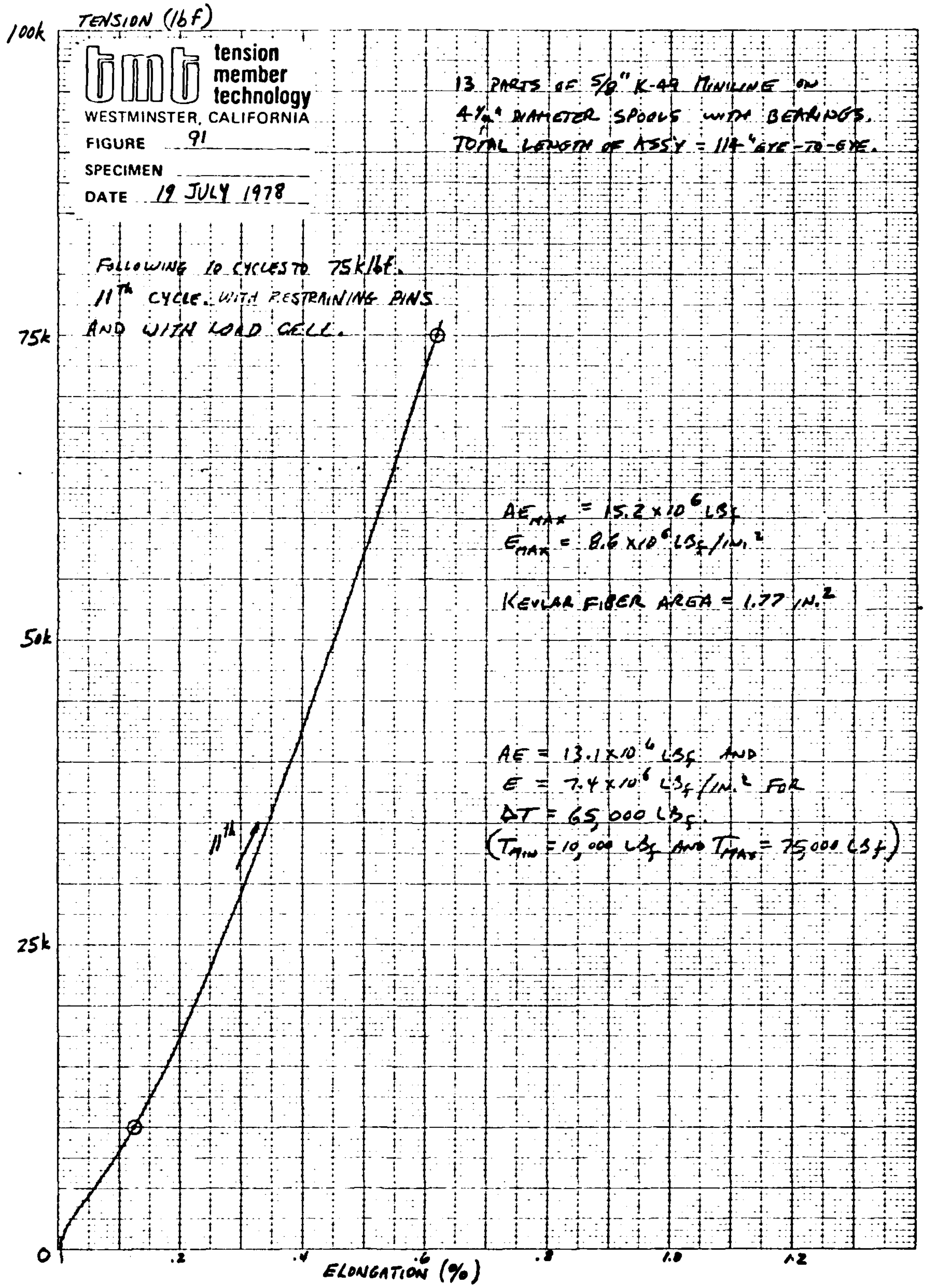
TABLE 6. COMPARISON OF "SMALL" ROPE CONSTRUCTIONS

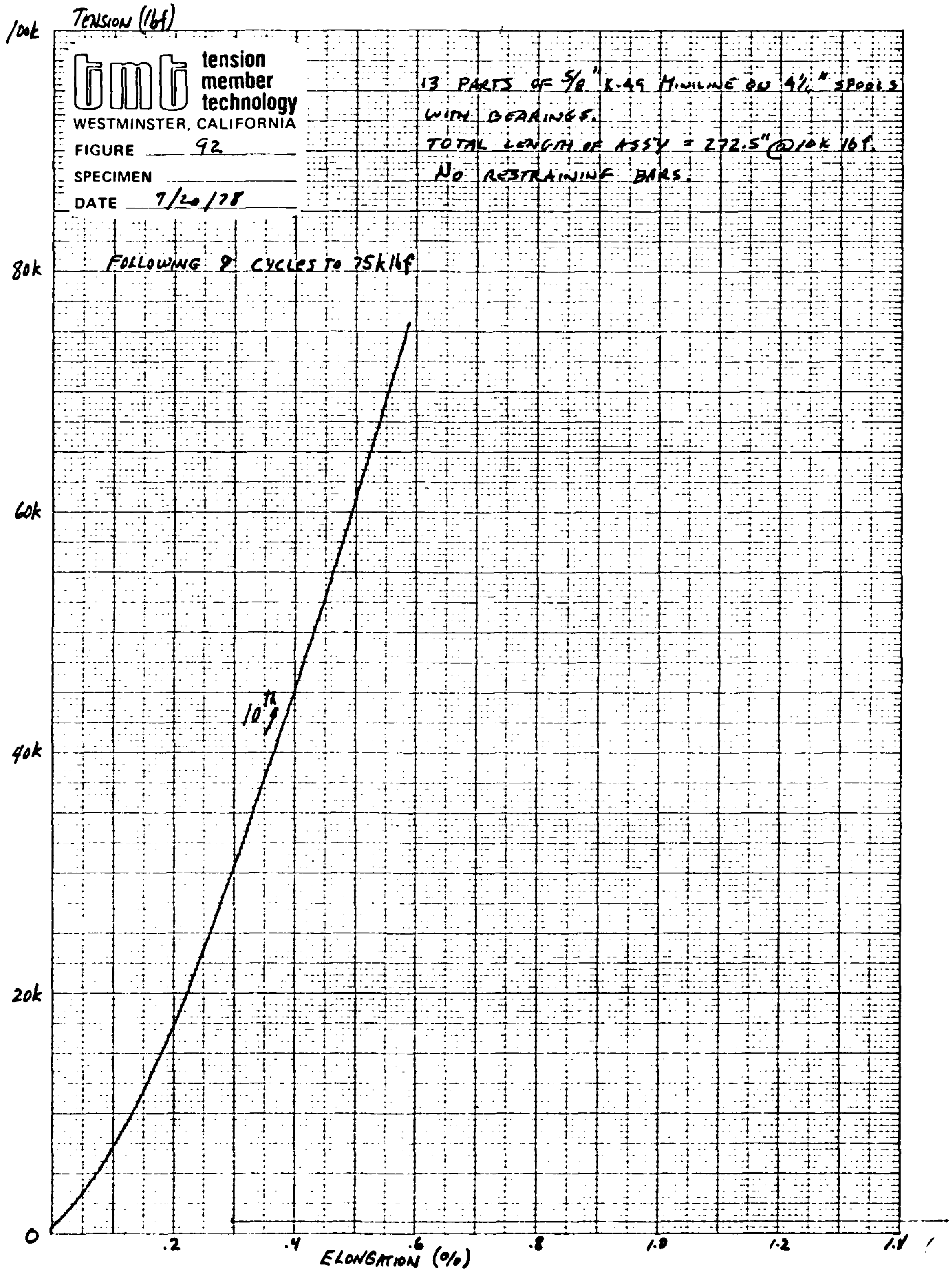
Parameter	Rope S-1	Rope S-2	Rope S-3
Maximum measured breaking load, lbf	181,000	174,000	145,000[a]
Kevlar fiber area, in.^{2}	0.86	0.70	0.81
Maximum fiber stress, lbf/in.^{2}	210,000	249,000	179,000[a]
AE (maximum), lbf	12.0×10^6	9.4×10^6	9.7×10^6
E (maximum), lbf/in.^{2}	14.0×10^6	13.5×10^6	12.0×10^6
CST performance	Good	Good	Fair[a]
CTOS performance	Good	Poor	Good

(a) Measured performance may have been impaired due to the use of a modified socketing resin.

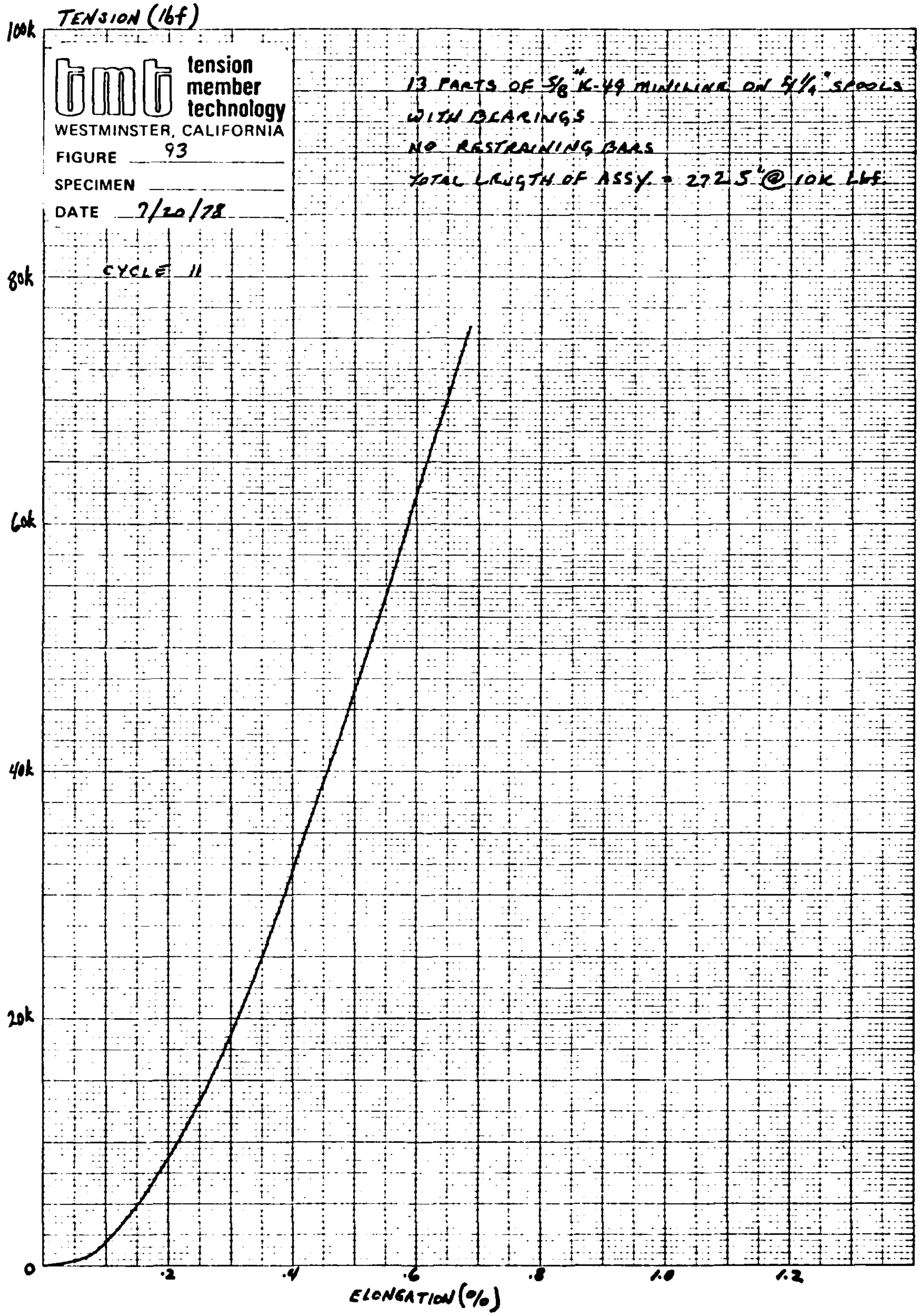


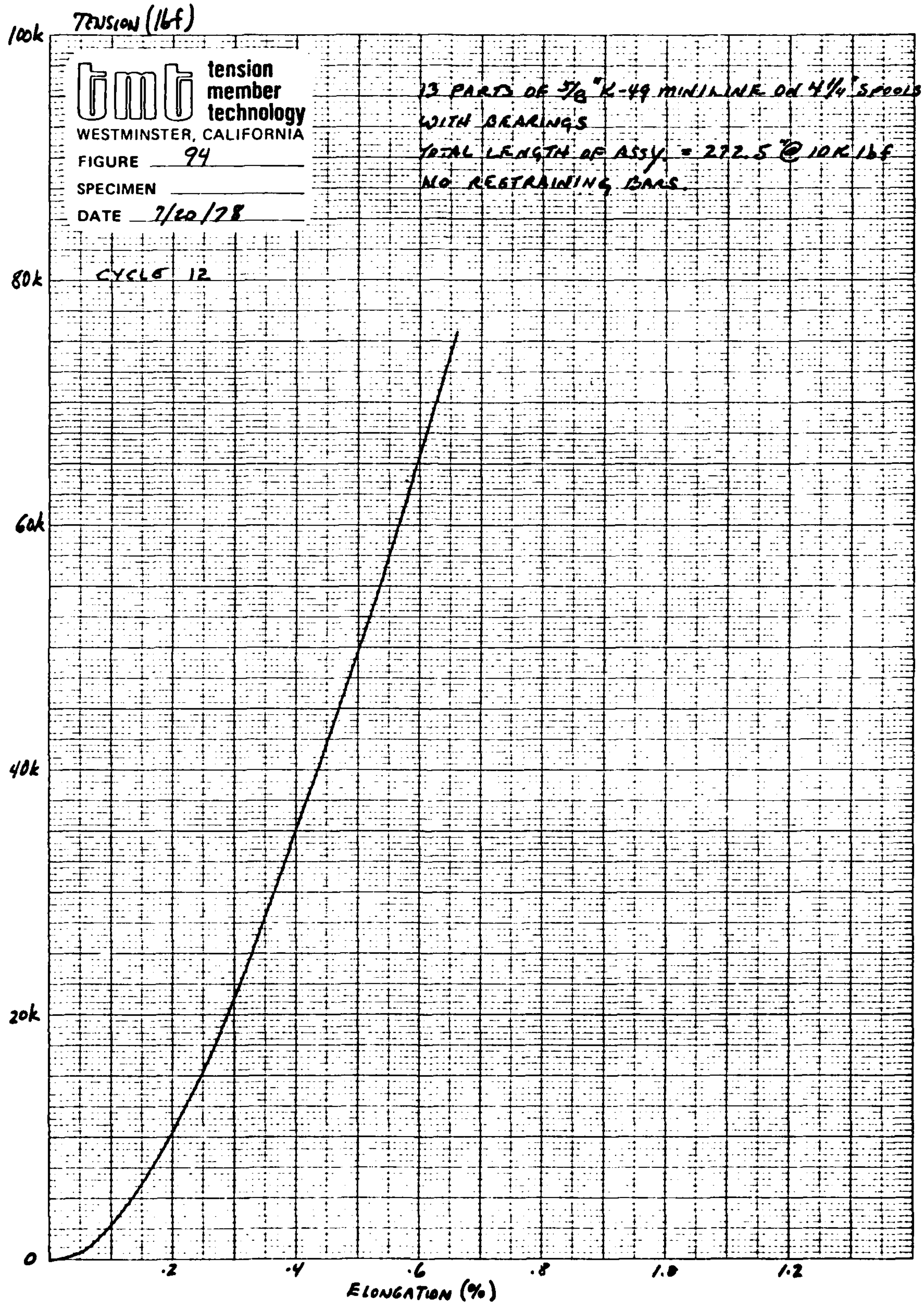
TENSION (lbf)
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 90
SPECIMEN
DATE 26 JUN 78
13 PARTS OF 5/8" MINILINE ON 2 1/2" SPOOLS.
TOTAL LENGTH OF ASS'Y = 116.5" EYE-TO-EYE.
RESET ELONGATION TO ZERO AFTER 10TH CYCLE. (USE NEW SCALE)
MAXIMUM SLOPE = 6.47x10^-3 %/1000 LB.
AE = 15.5 x 10^6 LBf
E MAX = 8.7 x 10^6 LBf/IN.^2
10TH
1ST
11TH
12TH
13TH
KEVLAR FIBER AREA = 1.77 IN.^2
AE MAX = 19.1 x 10^6 LBf
E MAX = 10.8 x 10^6 LBf/IN.^2
1 HOUR AT 130,000 LB
15 MINUTES AT 130,000 LB
AE = 14.1 x 10^6 LBf AND
E = 8.0 x 10^6 LBf/IN.^2 FOR
ΔT = 65,000 LBf
(T MIN = 10,000 LBf AND T MAX = 75,000 LBf)
0
.2
.4
.6
.8
1.0
1
2
3
4
5
ELONGATION (%)

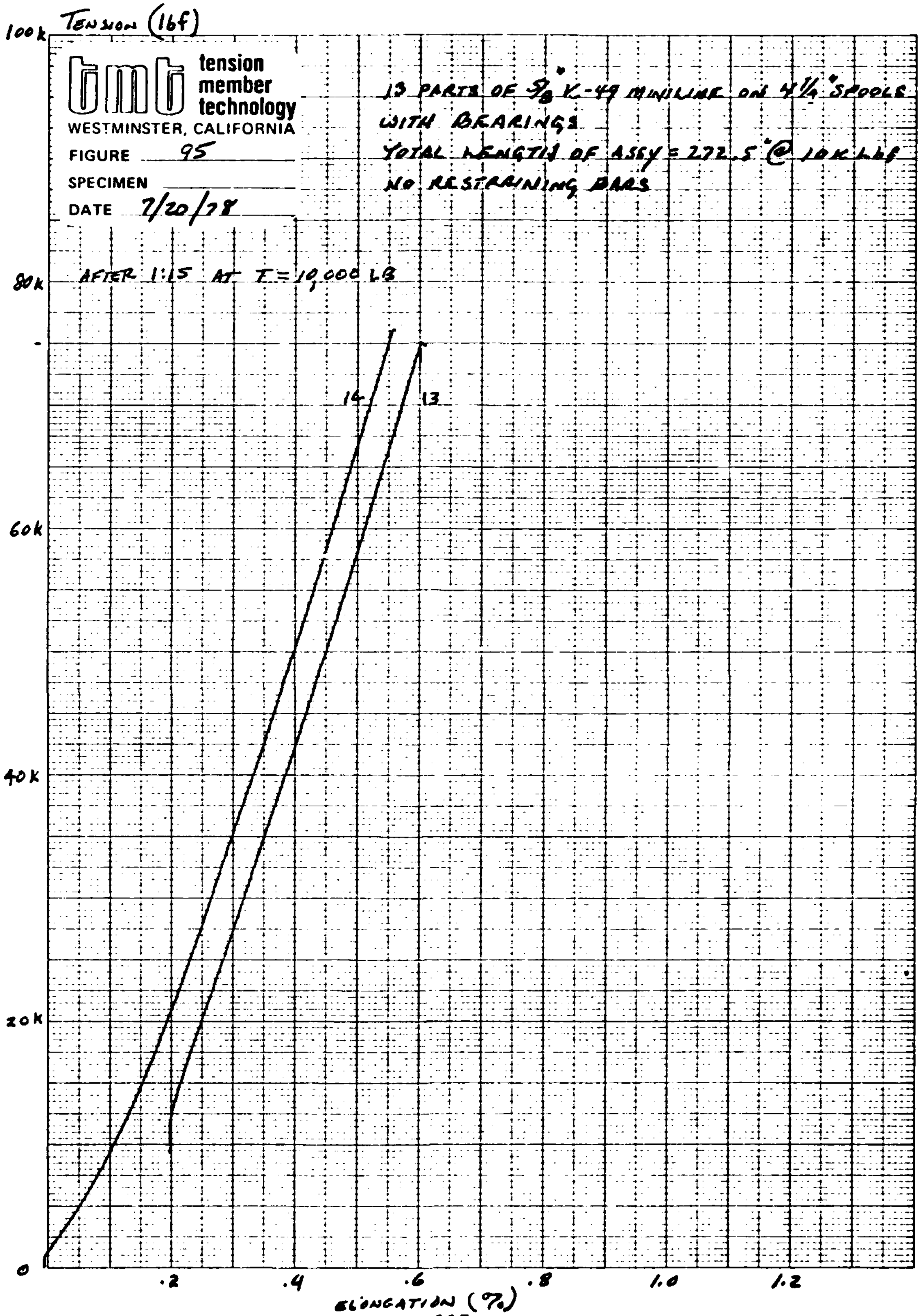

TENSION (lbf)
100k
75k
50k
25k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 91
SPECIMEN
DATE 19 JULY 1978
13 PARTS OF 5/8" K-49 MINILINE ON
4 1/4" DIAMETER SPOOLS WITH BEARINGS.
TOTAL LENGTH OF ASSY = 114" EYE-TO-EYE.
FOLLOWING 10 CYCLES TO 75klbf.
11th CYCLE. WITH RESTRAINING PINS
AND WITH LOAD CELL.
$AE_{MAX} = 15.2 \times 10^6$ LBf
$E_{MAX} = 8.6 \times 10^6$ LBf/IN.^{2}
KEVLAR FIBER AREA = 1.77 IN.^{2}
$AE = 13.1 \times 10^6$ LBf AND
$E = 7.4 \times 10^6$ LBf/IN.^{2} FOR
ΔT = 65,000 LBf.
(T_{MIN} = 10,000 LBf AND T_{MAX} = 75,000 LBf)
11th
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)



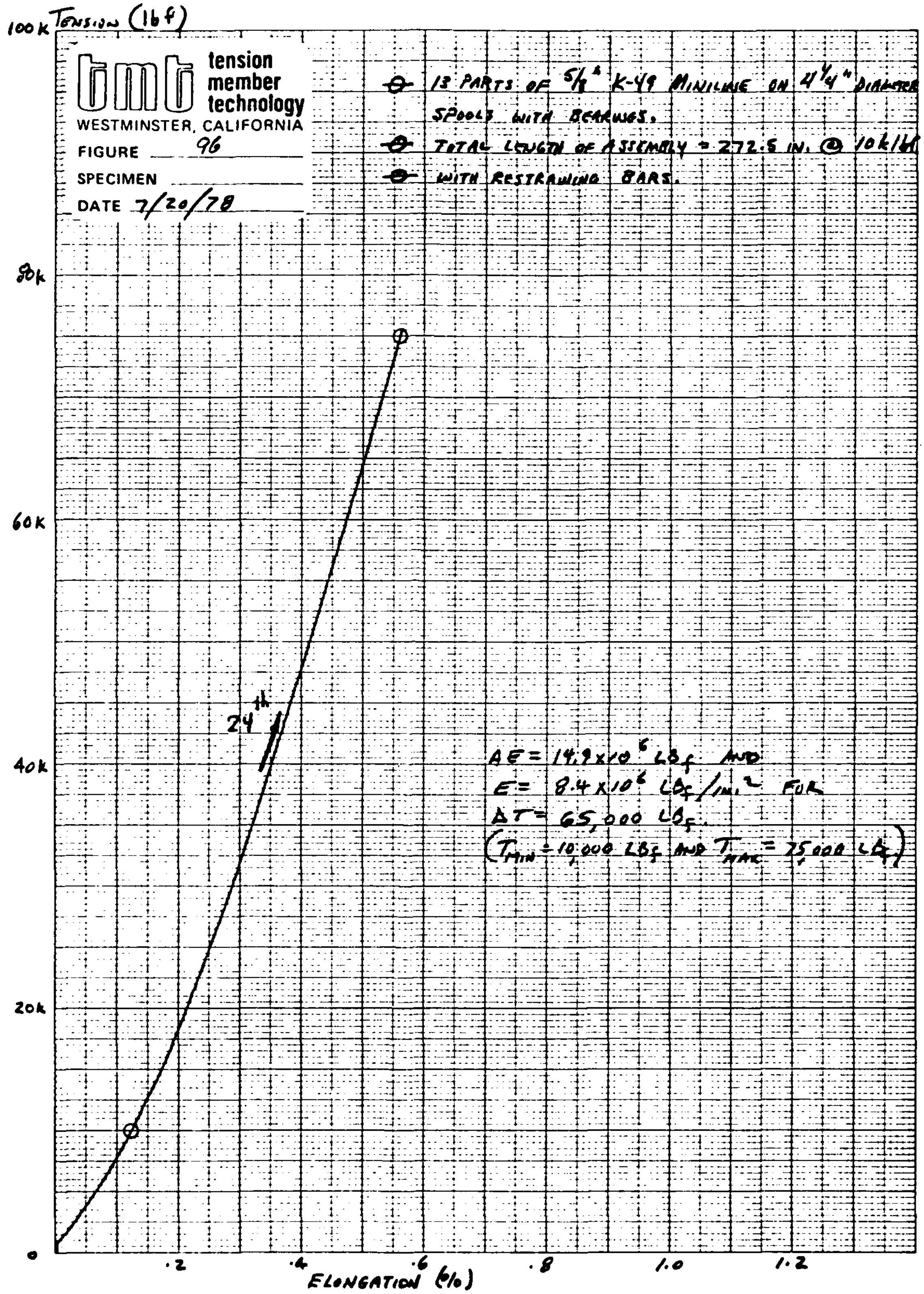
Tension (lbf)
100k
80k
60k
40k
20k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 92
SPECIMEN
DATE 7/20/78
13 PARTS OF 5/8" K-49 MINILINE ON 4½" SPOOLS WITH BEARINGS.
TOTAL LENGTH OF ASSY = 272.5" @10k lbf.
NO RESTRAINING BARS.
FOLLOWING 9 CYCLES TO 75klbf
10th
.2
.4
.6
.8
1.0
1.2
1.4
ELONGATION (%)


TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 93
SPECIMEN
DATE 7/20/78
CYCLE 11
13 PARTS OF 5/8" K-49 MINILINE ON 5 1/4" SPOOLS
WITH BEARINGS
NO RESTRAINING BARS
TOTAL LENGTH OF ASSY = 272.5' @ 10K LBF
100k
80k
60k
40k
20k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)

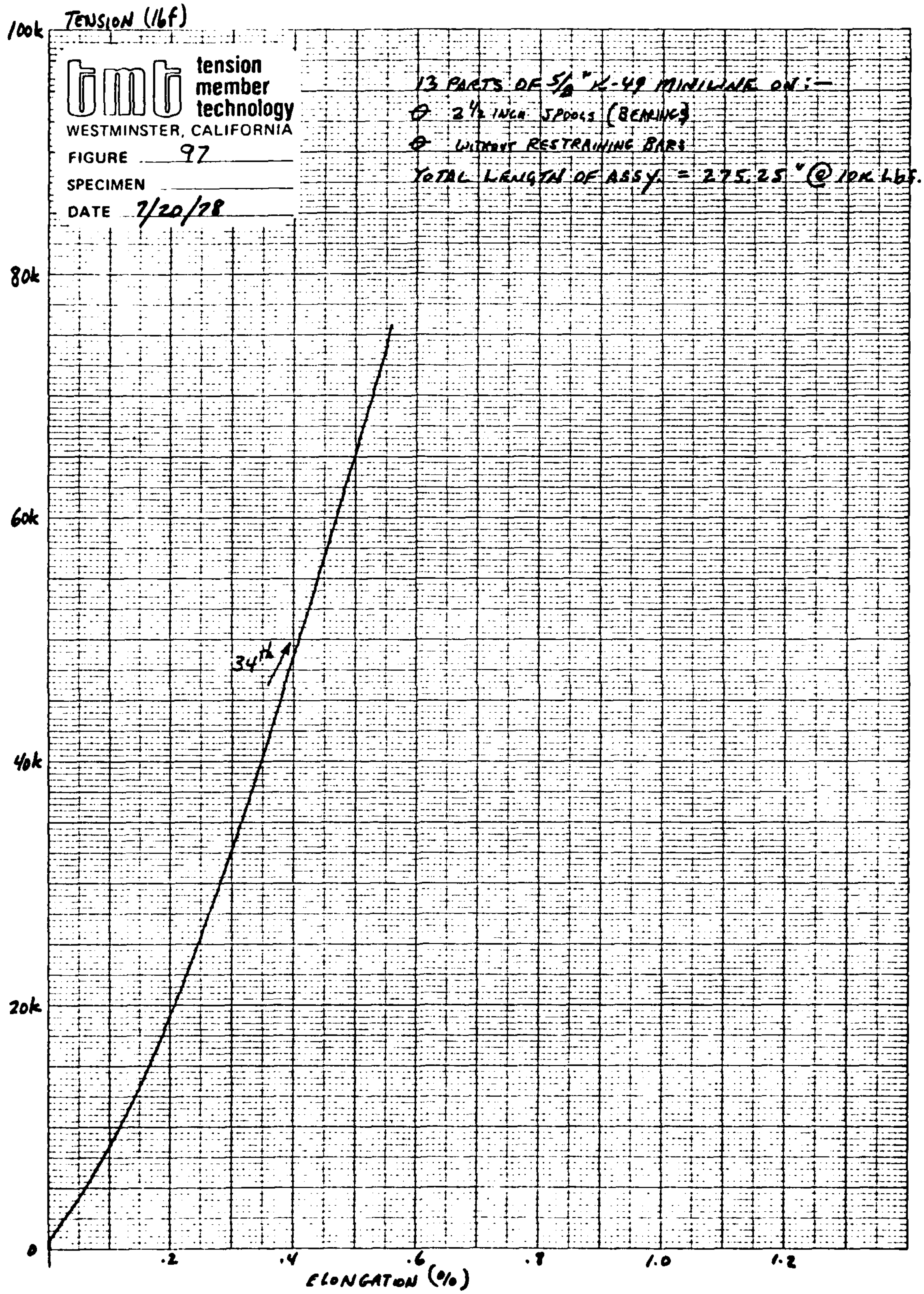

TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 94
SPECIMEN
DATE 7/20/78
13 PARTS OF 5/8" K-49 MINILINE ON 4 1/4" SPOOLS
WITH BEARINGS
TOTAL LENGTH OF ASSY. = 272.5" @ 10K lbf
NO RESTRAINING BARS.
CYCLE 12
100k
80k
60k
40k
20k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)



TENSION (lbf)
100k
80k
60k
40k
20k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 95
SPECIMEN
DATE 7/20/78
13 PARTS OF 9/16" K-49 MINILINE ON 4 1/4" SPOOLS
WITH BEARINGS
TOTAL LENGTH OF ASSY = 272.5" @ 10K LBF
NO RESTRAINING BARS
AFTER 1:15 AT T = 10,000 LB
14
13
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)



100K TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 96
SPECIMEN
DATE 7/20/78
13 PARTS OF 5/8" K-49 MINILINE ON 4 1/4" DIAMETER SPOOLS WITH BEARINGS.
TOTAL LENGTH OF ASSEMBLY = 272.5 IN. @ 10k lbf
WITH RESTRAINING BARS.
80K
60K
40K
20K
0
24th
AE = 14.9 x 10^6 LBf AND
E = 8.4 x 10^6 LBf/IN.^2 FOR
ΔT = 65,000 LBf.
(TMIN = 10,000 LBf AND TMAX = 75,000 LBf)
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)


TENSION (lbf)
100k
80k
60k
40k
20k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 97
SPECIMEN
DATE 7/20/78
13 PARTS OF 5/8" K-49 MINILINE ON:—
2 1/2 INCH SPOOLS (BEARINGS)
WITHOUT RESTRAINING BARS
TOTAL LENGTH OF ASSY. = 275.25" @ 10K LBS.
34K
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)

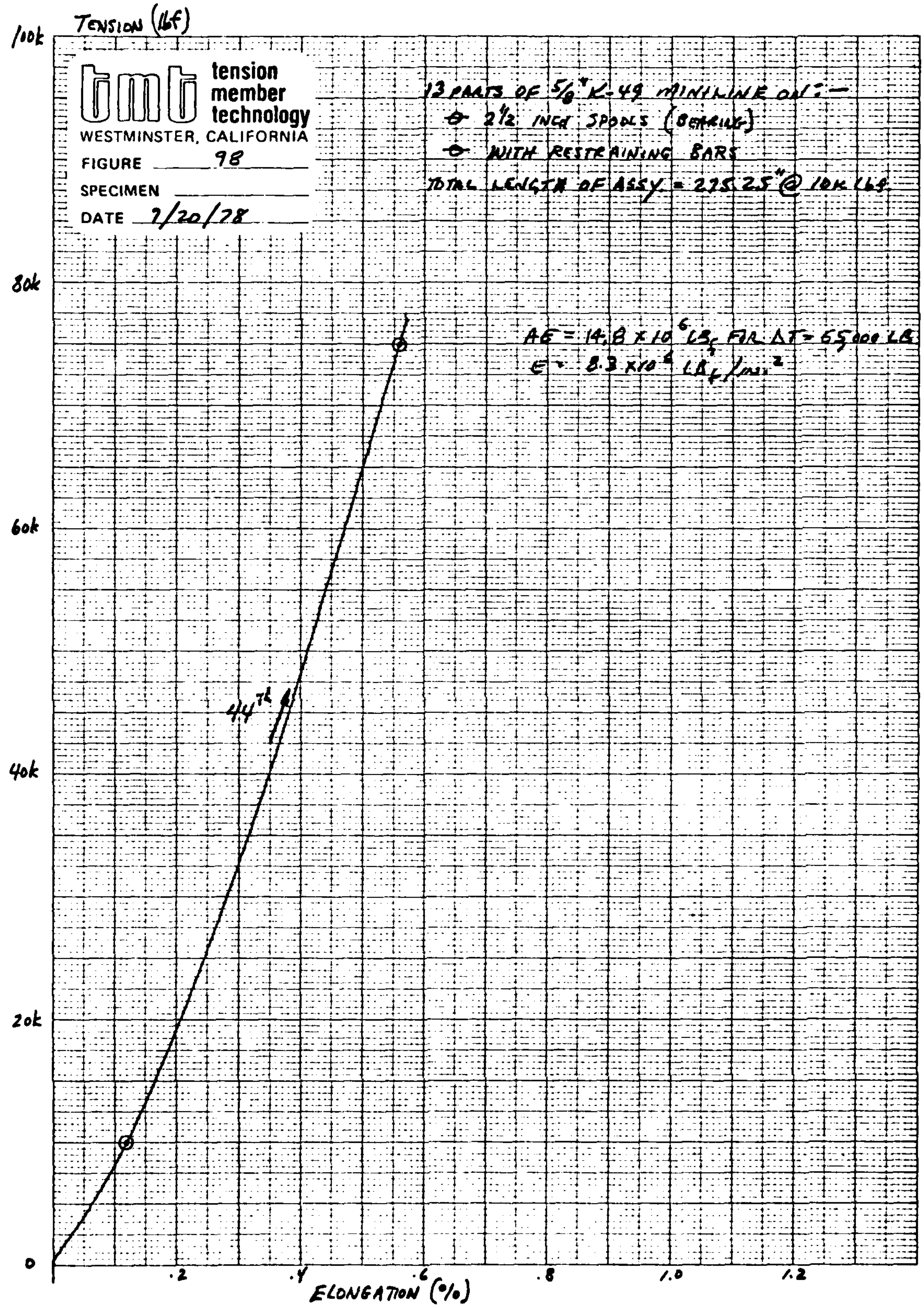

TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 98
SPECIMEN
DATE 7/20/78
13 PARTS OF 5/8" K-49 MINILINE ON:—
2½ INCH SPOOLS (BEARING)
WITH RESTRAINING BARS
TOTAL LENGTH OF ASSY = 275.25" @ 10K LBS
AE = 14.8 x 10^6 LBf FOR ΔT = 65000 LB
E = 8.3 x 10^6 LBf/in^2
100k
80k
60k
40k
20k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)

TABLE 7. FABRICATION HISTORY FOR BRIDGE CABLE SPECIMEN 1
ASSEMBLED FROM 5/8-INCH DIAMETER KEVLAR-49 MINILINE

Specimen Number 1 - TO

Material: 5/8-inch K-49 Miniline, From Spool Number 2,

(A) Load cycles during assembly of 15 parts,
8 groove bearing sheaves:

			Load, lbs	Length of Rope, inches	Comments
(a)	With drum grip termination		5,000	271	
(b)	With splice termination		5,000	271-1/4	
(c)	Load cycles	1	0-75,000	272-7/16	at 75,000 lbs
		2	0-75,000	--	
		3	0-75,000	Hardware change (1/2" to 1" restraining pins)	
		4	0-75,000	--	
	(Loading rate	5	0-75,000	--	
	75,000 lbs in	6	0-75,000	272-1/2	at 75,000 lbs
	60 seconds)	7	0-75,000	--	
		8	0-75,000	--	
		9	0-75,000	--	
		10	0-75,000	272-5/8	at 75,000 lbs recorded load versus elongation
(d)	Length determination		5,000	271-7/16	

Specimen Number 1 - TI

			Load, lbs	Length of Rope, inches	Comments
(a)	With drum grip termination		5,000	271	
(b)	With splice termination		5,000	271-1/16	
(c)	Load cycles	1	0-75,000	272-9/16	at 75,000 lbs
		2	0-75,000	--	
		3	0-75,000	--	
		4	0-75,000	--	
		5	0-75,000	--	
		6	0-75,000	--	
		7	0-75,000	--	
		8	0-75,000	--	
		9	0-75,000	--	
		10	0-75,000	272-11/16	at 75,000 lbs recorded load versus elongation

Specimen Number 1 - TOI (Completed assembly of 1 - TI plus 1 - TO)

		Load, lbs	Length of Rope, inches	Comments
(a)	Completed assembly	0-10,000	271-1/8	at 10,000 lbs
(b)	Proof load	0-260,000		Recorded load versus elongation
(c)	Final measurement	0-10,000	271-1/2	at 10,000 lbs

TABLE 8. FABRICATION HISTORY FOR BRIDGE CABLE SPECIMEN 2 ASSEMBLED FROM 5/8-INCH DIAMETER KEVLAR-49 MINILINE

Specimen Number 2 - TI

Material: 5/8-inch K-49 Miniline, From Spool Number 3

(A) Load cycles during assembly of 15 part, 8 groove bearing sheaves:

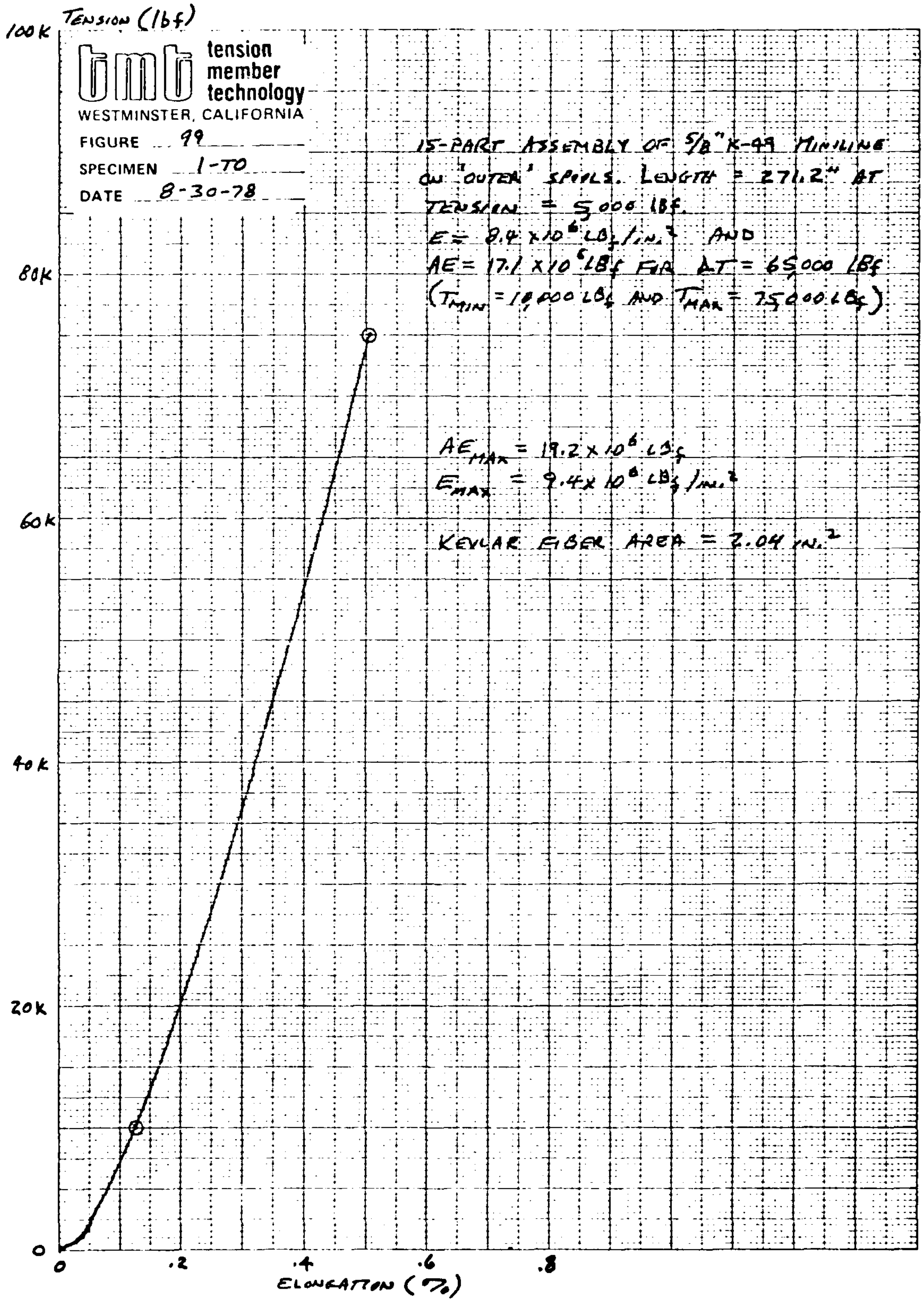
		Load lbs	Length of Rope, inches	Comments
(a)	With drum grip termination	5,000	271	
(b)	With splice termination	5,000	271-1/32	
(c)	Load cycles 1	0-75,000	272-19/32	at 75,000 lbs
	2	0-75,000	--	
	3	0-75,000	--	
	4	0-75,000	--	
	5	0-75,000	--	
	6	0-75,000	--	
	7	0-75,000	--	
	8	0-75,000	--	
	9	0-75,000	--	
	10	0-75,000	272-11/16	at 75,000 lbs recorded load versus elongation

Specimen Number 2 - TO

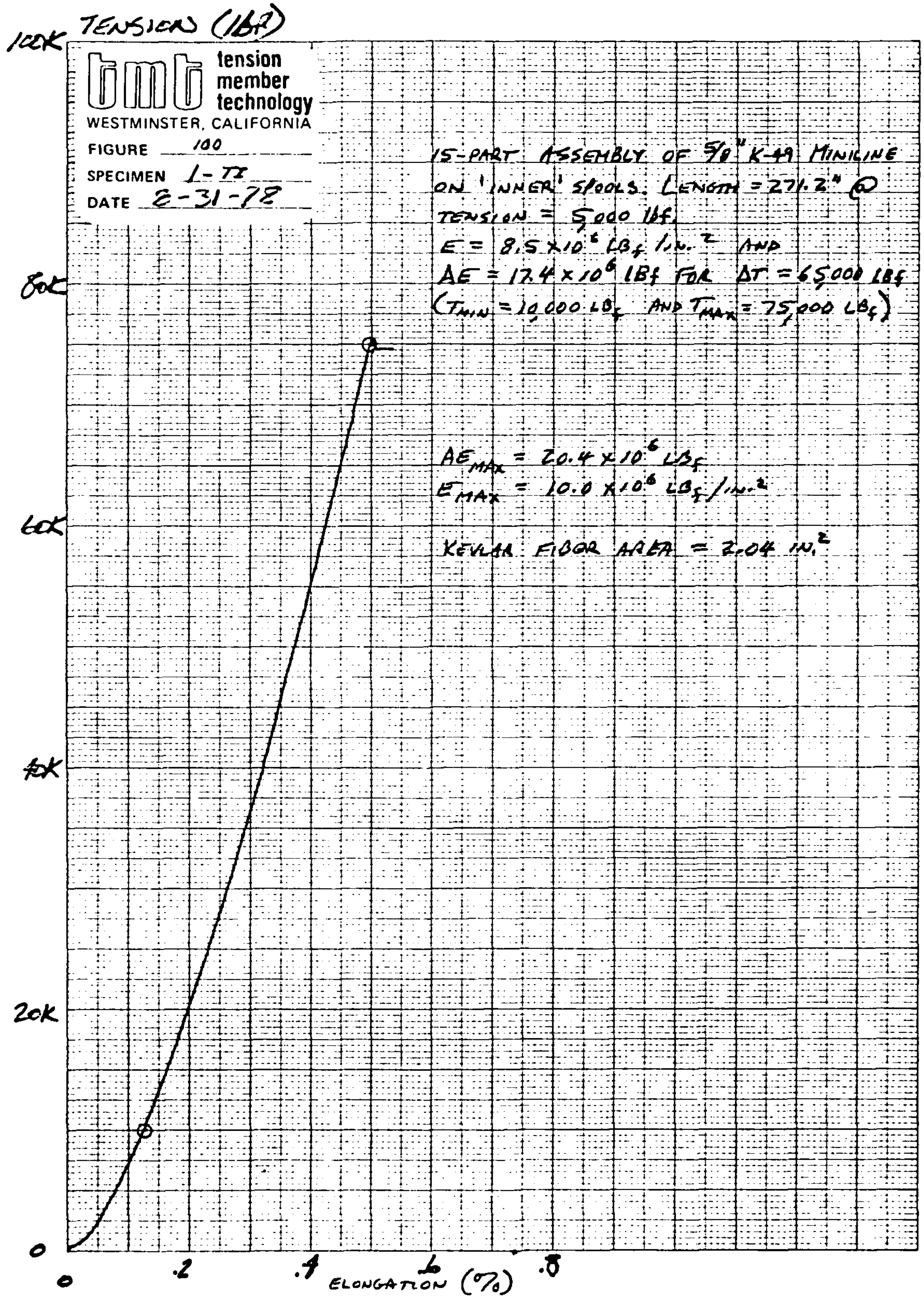
		Load lbs	Length of Rope, inches	Comments
(a)	With drum grip termination	5,000	271	
(b)	With splice termination	5,000	271	
(c)	Load cycles 1	0-75,000	272-11/32	at 75,000 lbs
	2	0-75,000	--	
	3	0-75,000	--	
	4	0-75,000	--	
	5	0-75,000	--	
	6	0-75,000	--	
	7	0-75,000	--	
	8	0-75,000	--	
	9	0-75,000	--	
	10	0-75,000	272-17/32	at 75,000 lbs recorded load versus elongation

Specimen Number 2 - TOI (Completed assembly of 2-TI plus 2-TO)

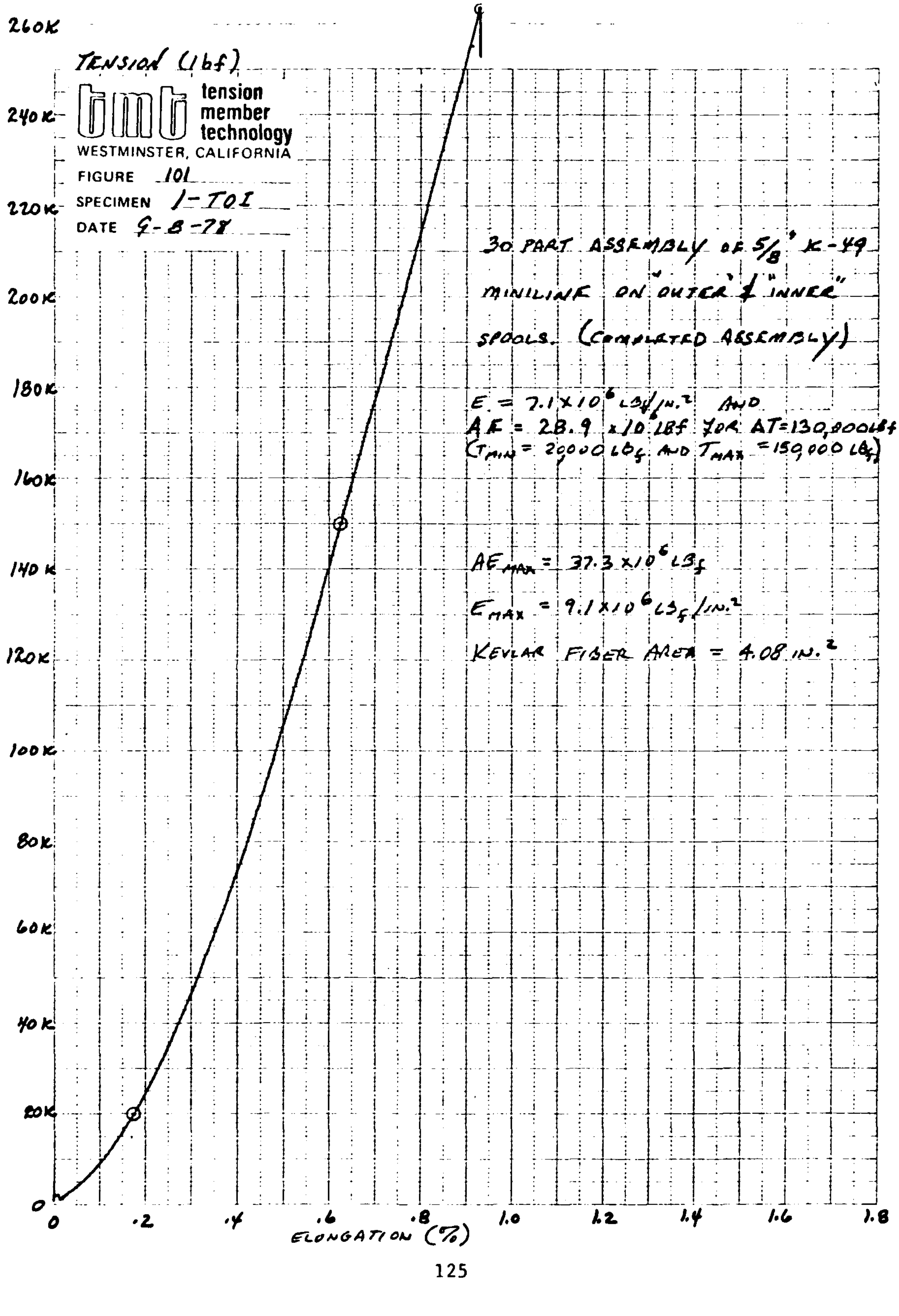
		Load lbs	Length of Rope, inches	Comments
(a)	Completed assembly	0-10,000	--	
(b)	Proof load	0-260,000	--	recorded load versus elongation
(c)	Final measurement	0-10,000	271-9/16	at 10,000 lbs



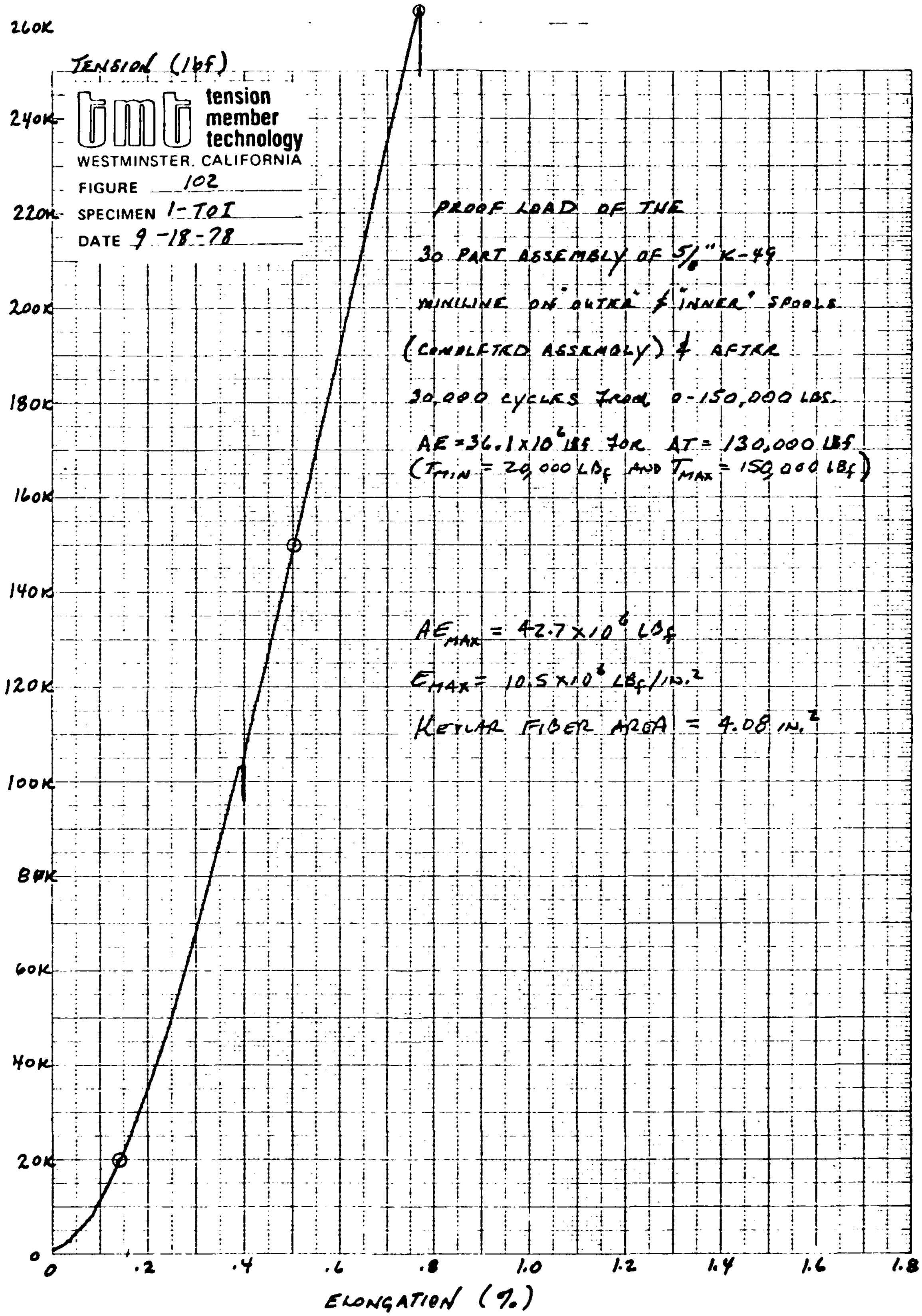
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 99
SPECIMEN 1-TO
DATE 8-30-78
15-PART ASSEMBLY OF 5/8" K-49 MINILINE ON "OUTER" SPOOLS. LENGTH = 271.2" AT TENSION = 5000 lbf.
E = 8.4 x 10^6 LBf/in.^2 AND
AE = 17.1 x 10^6 LBf FOR ΔT = 65,000 LBf
(TMIN = 10,000 LBf AND TMAX = 75,000 LBf)
AEMAX = 19.2 x 10^6 LBf
EMAX = 9.4 x 10^6 LBf/in.^2
KEVLAR FIBER AREA = 2.04 in.^2
100K
80K
60K
40K
20K
0
0
.2
.4
.6
.8
ELONGATION (%)

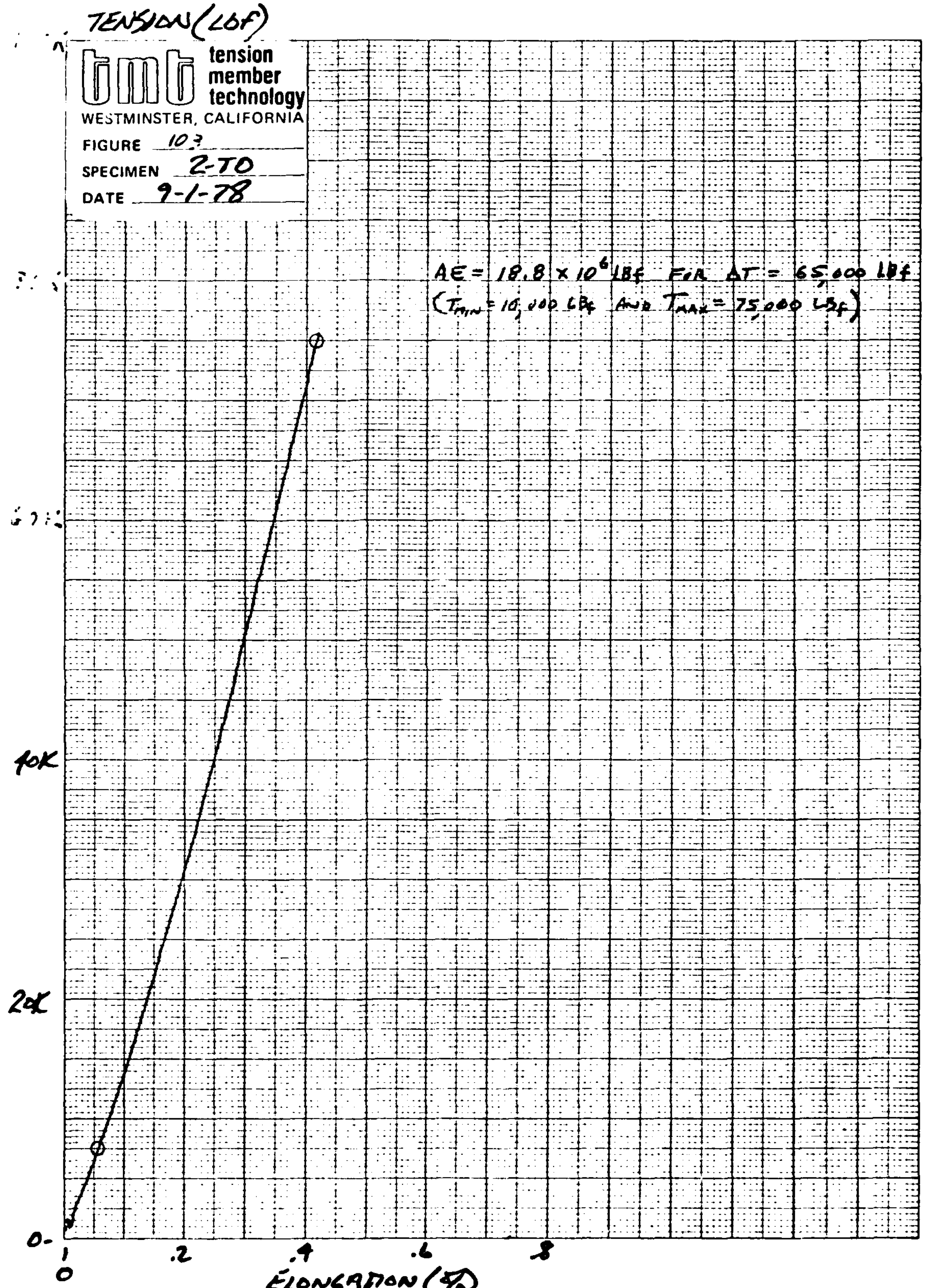


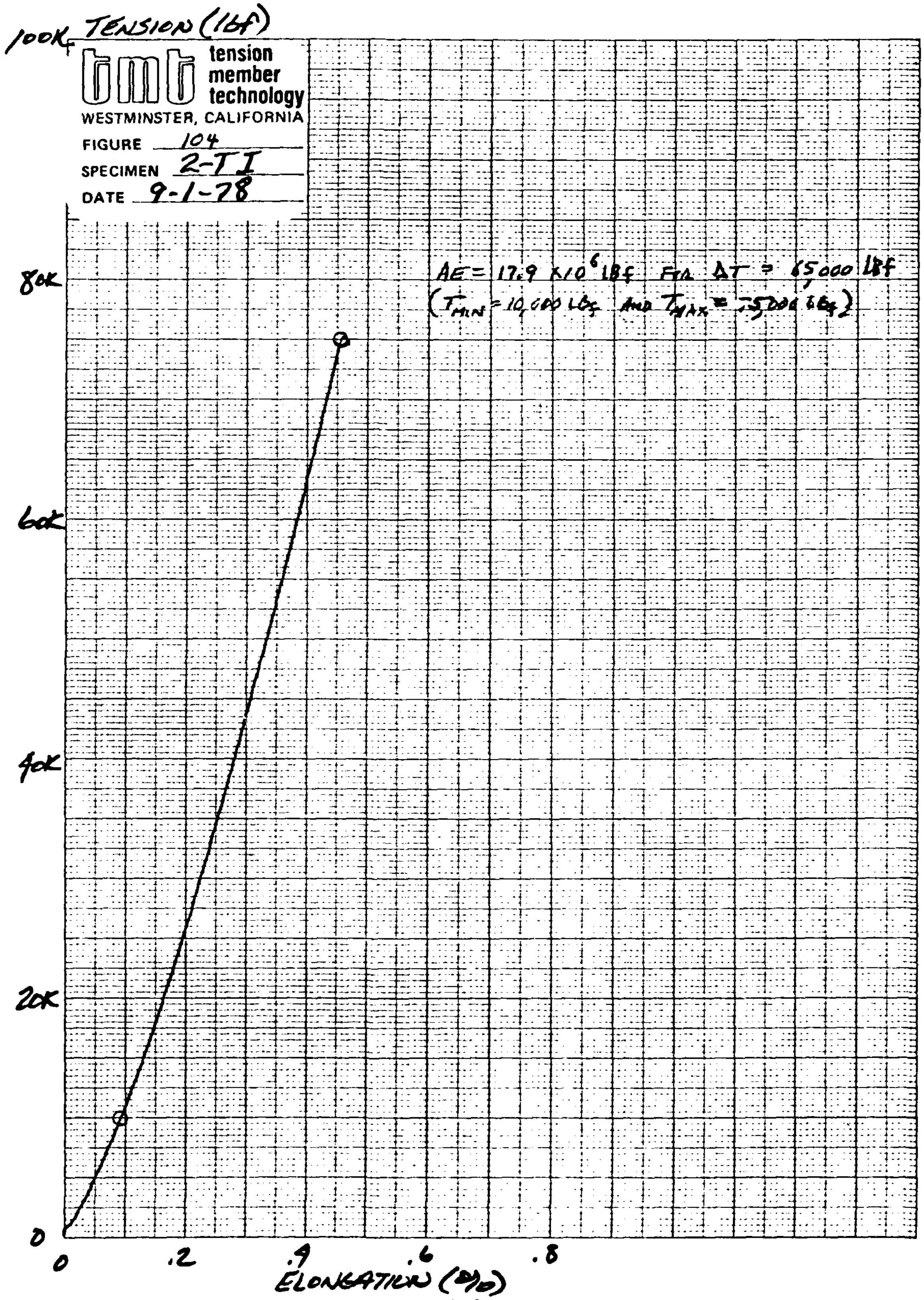
TENSION (lbf)
100K
80K
60K
40K
20K
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 100
SPECIMEN 1-TI
DATE 8-31-78
15-PART ASSEMBLY OF 5/8" K-49 MINILINE
ON 'INNER' SPOOLS. LENGTH = 271.2" @
TENSION = 5,000 lbf.
E = 8.5 x 10^6 LBf/in.^2 AND
AE = 17.4 x 10^6 lBf FOR ΔT = 65,000 LBf
(TMIN = 10,000 LBf AND TMAX = 75,000 LBf)
AEMAX = 20.4 x 10^6 LBf
EMAX = 10.0 x 10^6 LBf/in.^2
KEVLAR FIBER AREA = 2.04 in.^2
0
.2
.4
.6
.8
ELONGATION (%)



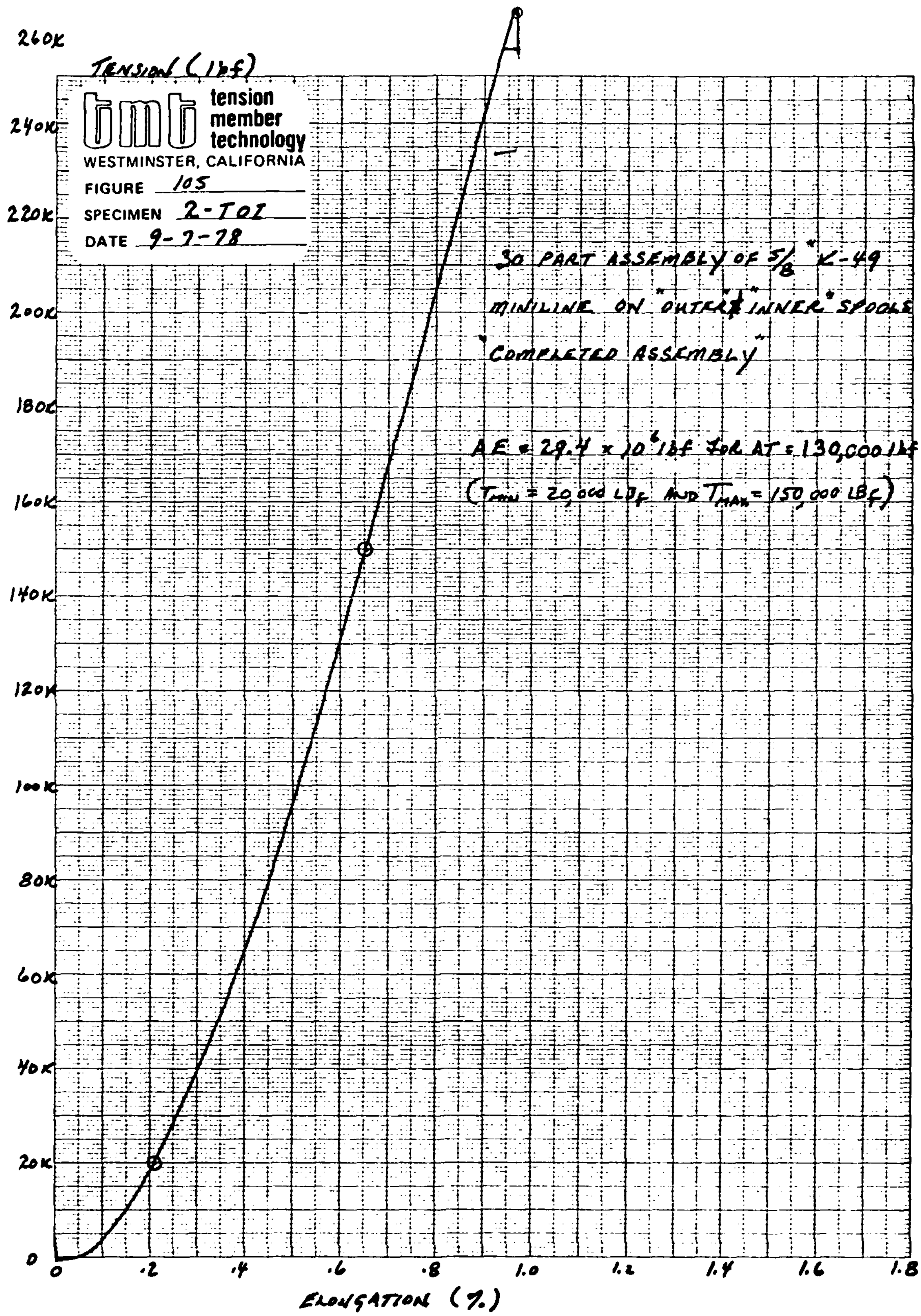
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 101
SPECIMEN 1-T0I
DATE 9-8-78
30 PART ASSEMBLY OF 5/8" K-49
"MINILINE" ON "OUTER" & "INNER"
SPOOLS. (COMPLETED ASSEMBLY)
E = 7.1 x 10^6 LBf/IN.^2 AND
AE = 28.9 x 10^6 LBf FOR ΔT=130,000LBf
(TMIN = 20,000 LBf AND TMAX = 150,000 LBf)
AEMAX = 37.3 x 10^6 LBf
EMAX = 9.1 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 4.08 IN.^2
260K
240K
220K
200K
180K
160K
140K
120K
100K
80K
60K
40K
20K
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
ELONGATION (%)


260K
TENSION (lbf)
240K
220K
200K
180K
160K
140K
120K
100K
80K
60K
40K
20K
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 102
SPECIMEN 1-TOI
DATE 9-18-78
PROOF LOAD OF THE
30 PART ASSEMBLY OF 5/8" K-49
MINILINE ON "OUTER" & "INNER" SPOOLS
(COMPLETED ASSEMBLY) & AFTER
30,000 CYCLES FROM 0-150,000 LBS.
AE = 36.1 x 10^6 LBf FOR ΔT = 130,000 LBf
(T_MIN = 20,000 LBf AND T_MAX = 150,000 LBf)
AE_MAX = 42.7 x 10^6 LBf
E_MAX = 10.5 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 4.08 IN.^2
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
ELONGATION (%)

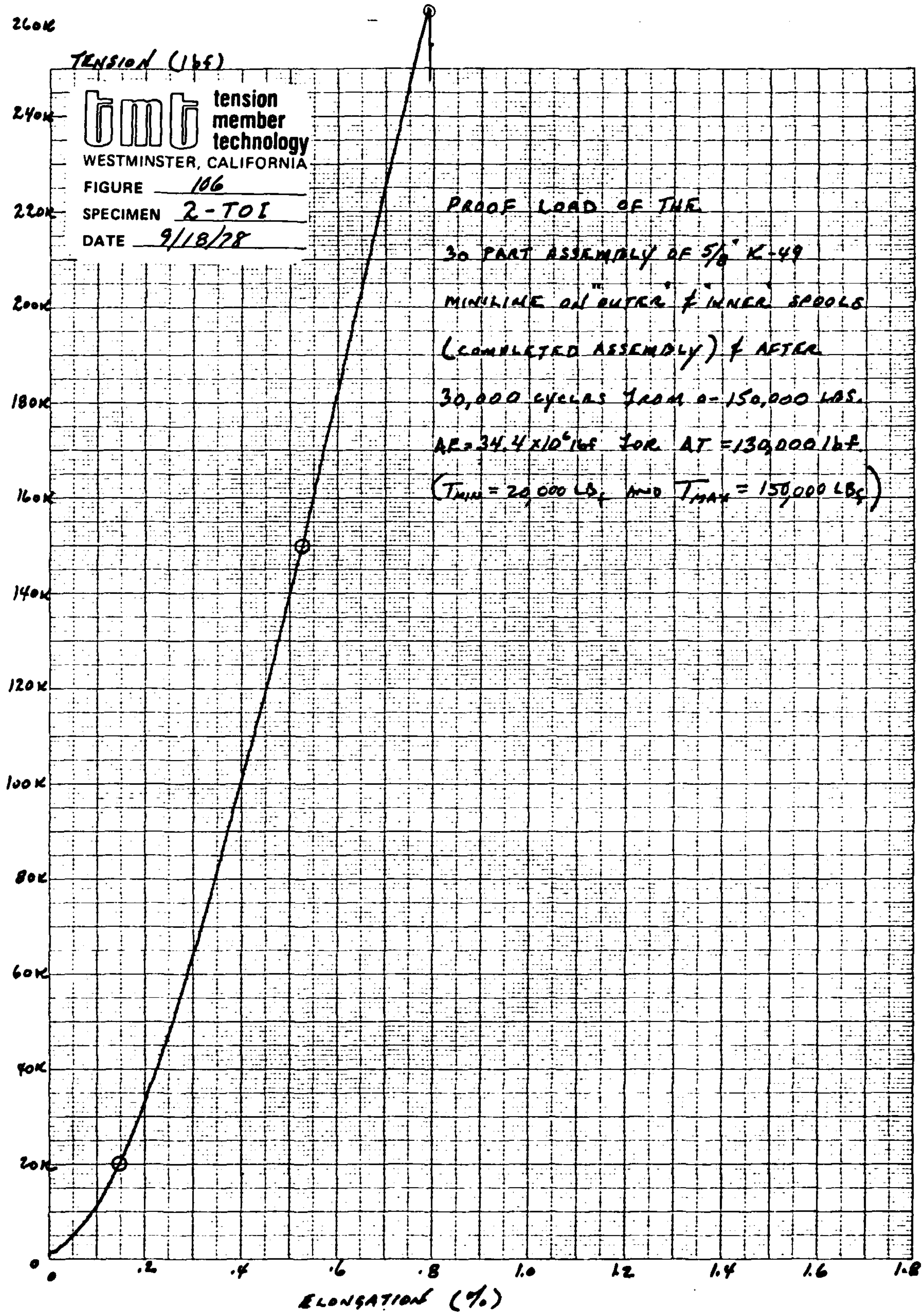

TENSION (LBF)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 103
SPECIMEN 2-TO
DATE 9-1-78
AE = 18.8 × 10^6 LBf FOR ΔT = 65,000 LBf
(T_MIN = 10,000 LBf AND T_MAX = 75,000 LBf)
40K
20K
0
.2
.4
.6
.8
ELONGATION (%)



100K
TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 104
SPECIMEN 2-T I
DATE 9-1-78
AE = 17.9 x10^6 lbf FOR ΔT = 65,000 lbf
(T_MIN = 10,000 lbs AND T_MAX = 75,000 lbs)
80K
60K
40K
20K
0
0
.2
.4
.6
.8
ELONGATION (%)



TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 105
SPECIMEN 2-T02
DATE 9-7-78
260K
240K
220K
200K
180K
160K
140K
120K
100K
80K
60K
40K
20K
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
ELONGATION (%)
30 PART ASSEMBLY OF 5/8" K-49 MINILINE ON "OUTER" & "INNER" SPOOLS "COMPLETED ASSEMBLY"
AE = 29.4 x 10^6 lbf FOR ΔT = 130,000 lbf
(Tmin = 20,000 LBf AND TMAX = 150,000 LBf)


TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 106
SPECIMEN 2-TOI
DATE 9/18/78
PROOF LOAD OF THE
30 PART ASSEMBLY OF 5/8" K-49
MINILINE ON "OUTER" & "INNER" SPOOLS
(COMPLETED ASSEMBLY) & AFTER
30,000 CYCLES FROM 0-150,000 LBS.
AE=34.4x10^6 lbf FOR ΔT=130,000 lbf
(T_MIN = 20,000 LBf AND T_MAX = 150,000 LBf)
260K
240K
220K
200K
180K
160K
140K
120K
100K
80K
60K
40K
20K
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
ELONGATION (%)

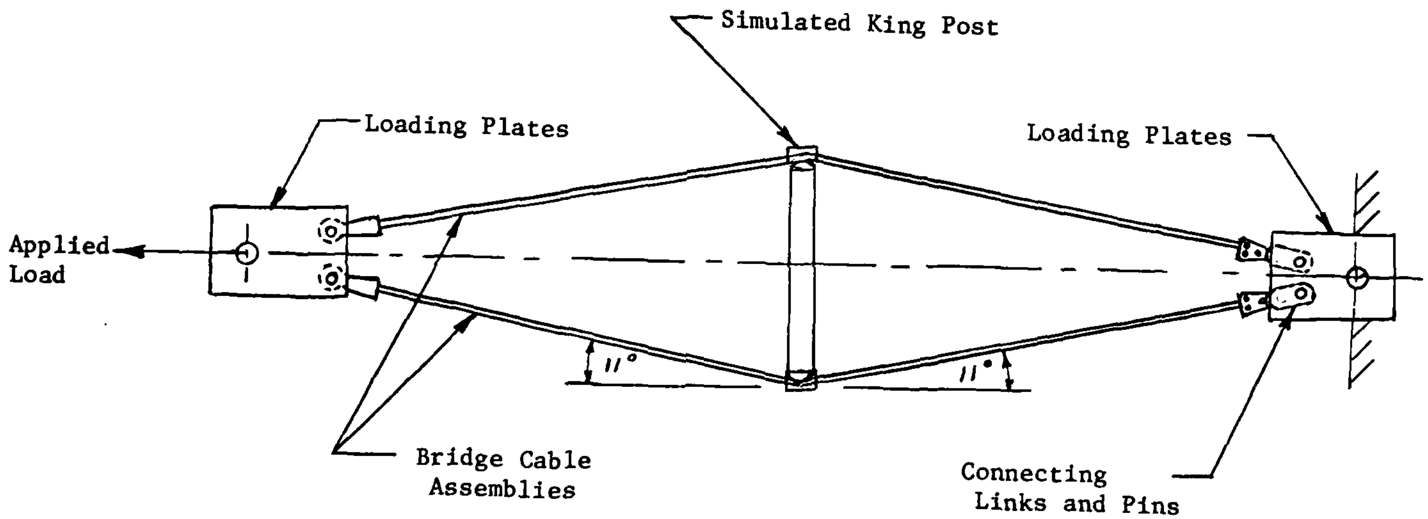


FIGURE 107. DIAGRAM OF APPARATUS USED FOR CYCLIC-TENSION FATIGUE TESTS OF FULL-SCALE BRIDGE CABLE ASSEMBLIES

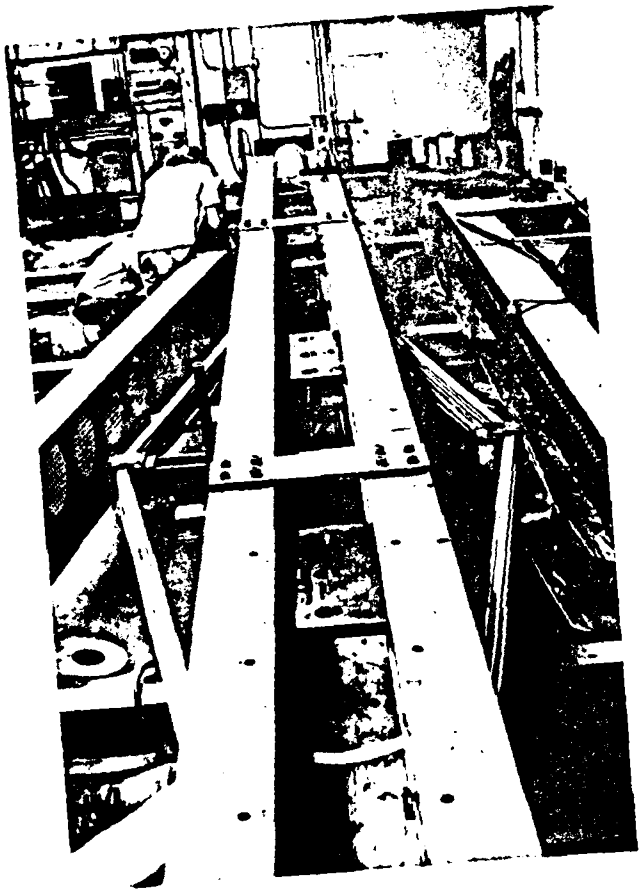


FIGURE 108. A PAIR OF BRIDGE CABLES DURING CYCLIC TENSION TESTING OVER SIMULATED KING POST

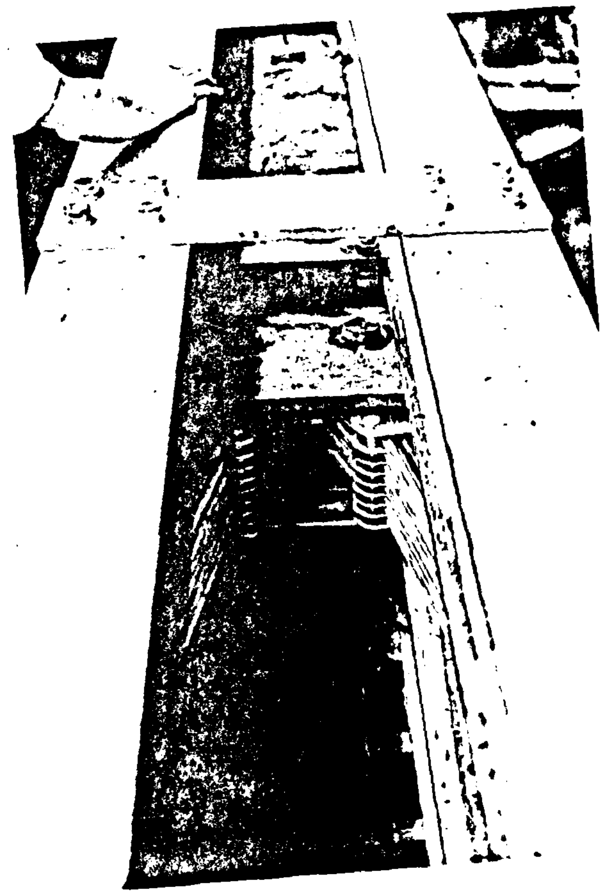


FIGURE 109. BRIDGE CABLE ATTACHMENT TO TENSIONING MECHANISM

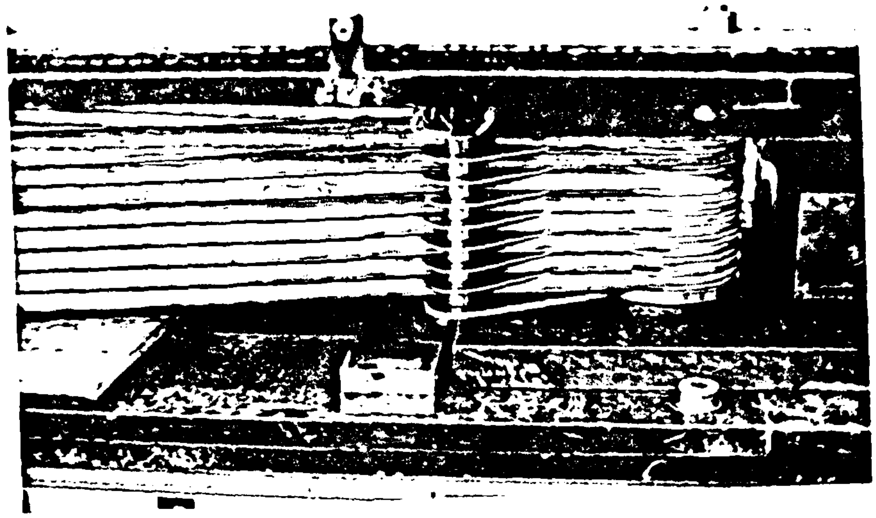


FIGURE 110. NESTED SPOOL ASSEMBLY AT FIXED END OF TEST MACHINE

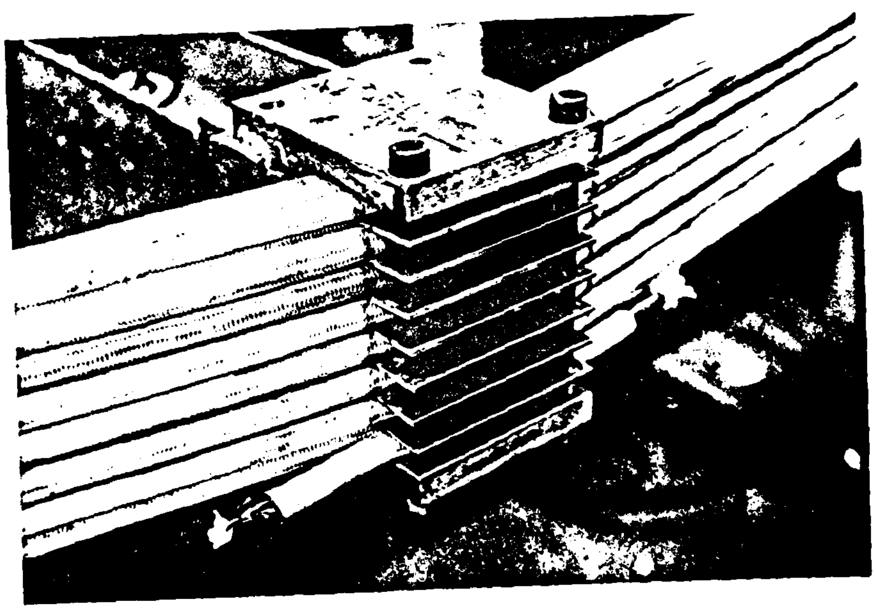


FIGURE 111. END OF SIMULATED KING POST

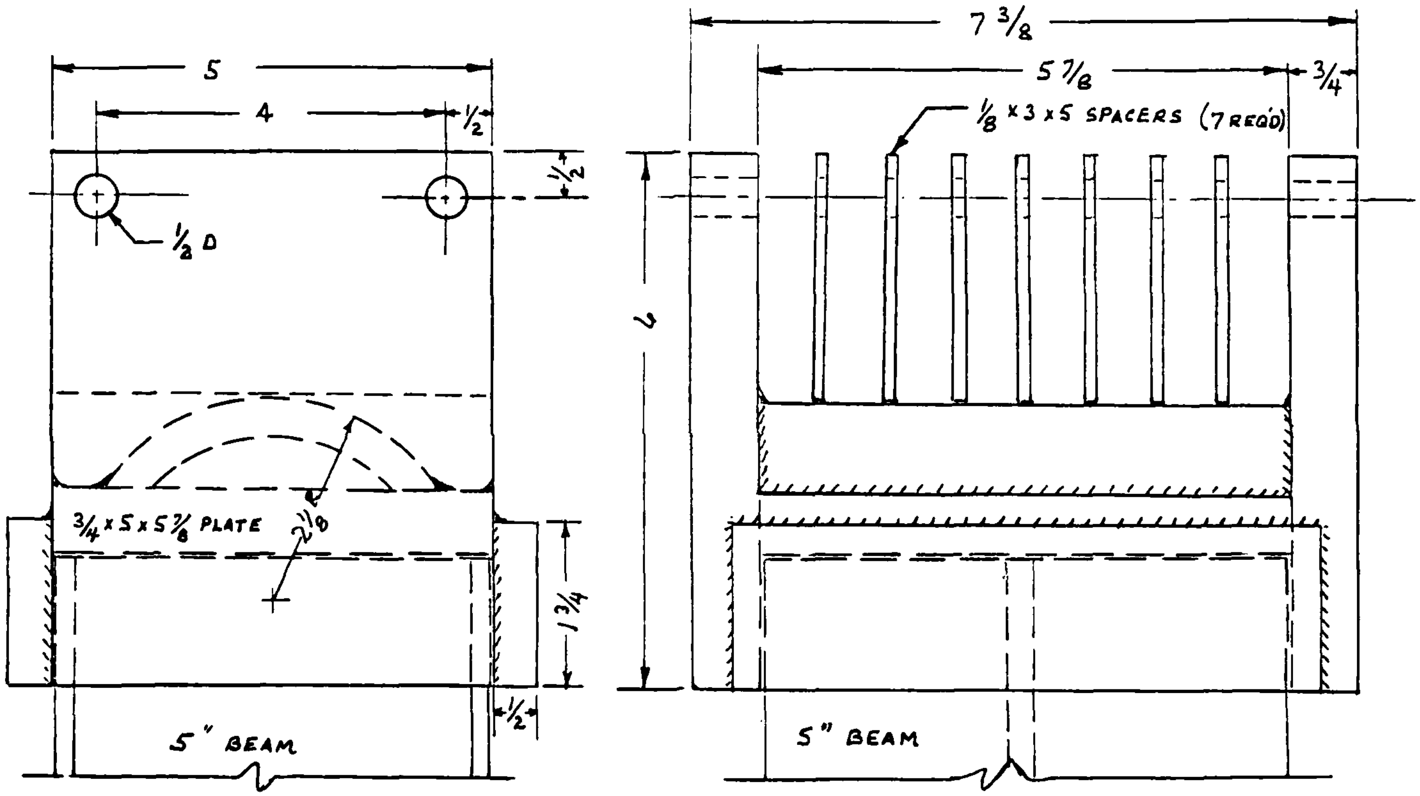


FIGURE 112. SIMULATED KING POST END FITTING

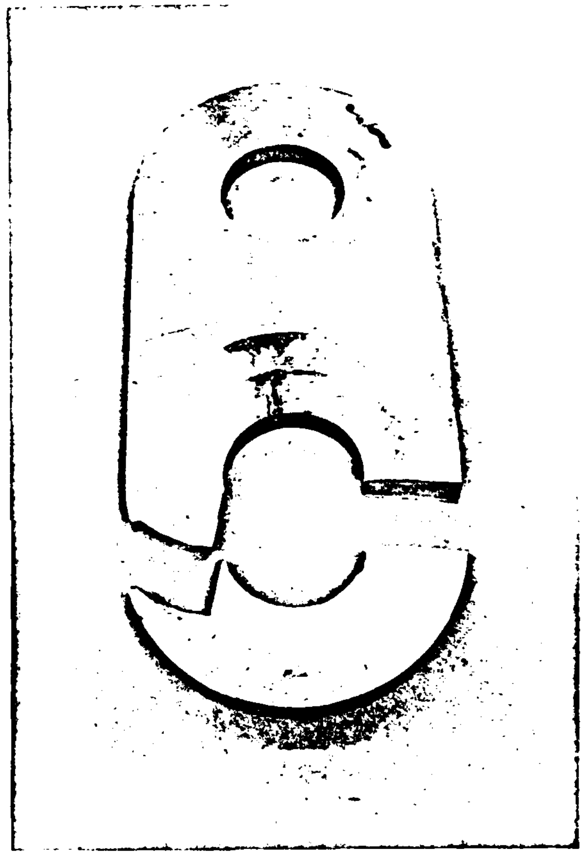
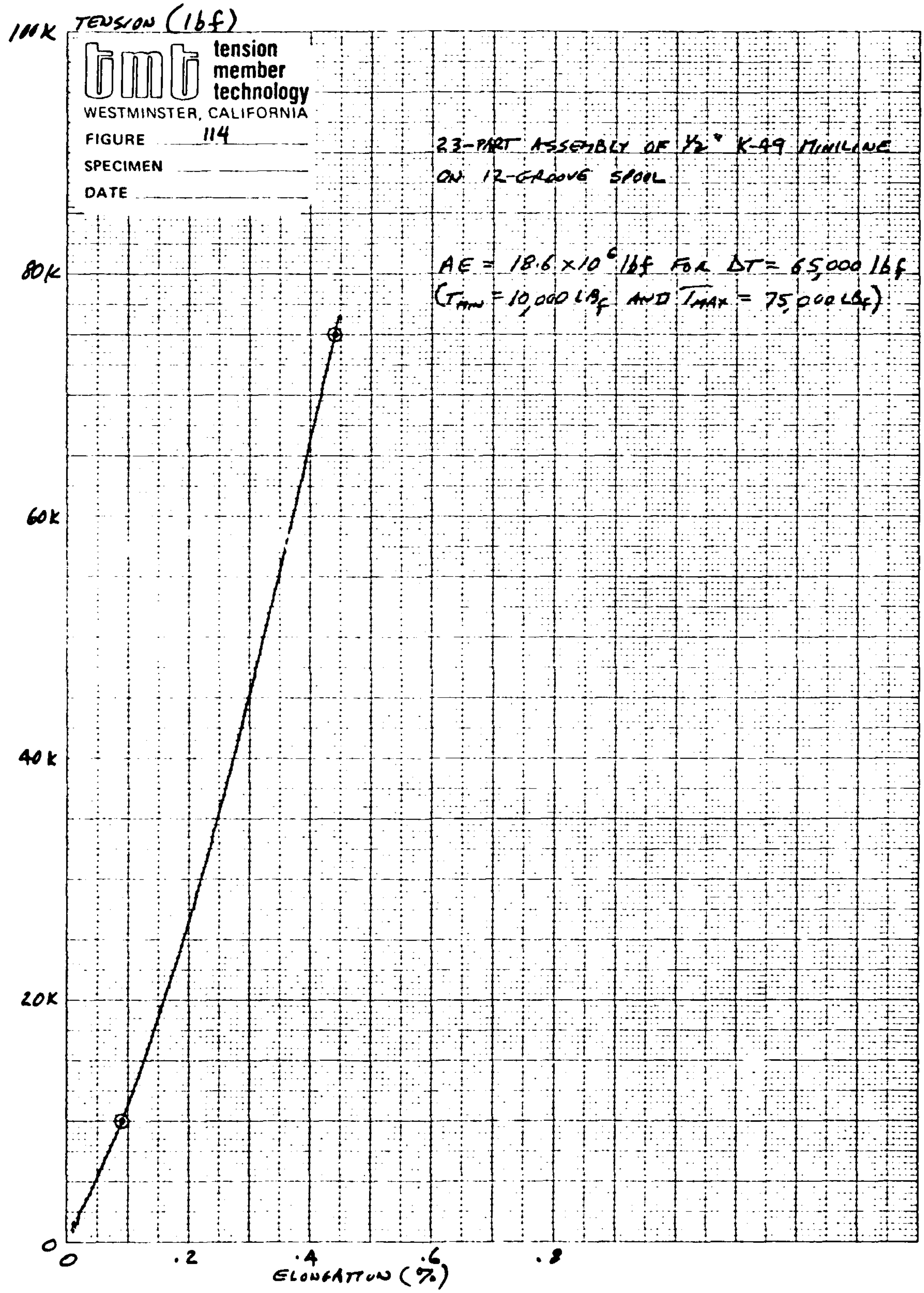


FIGURE 113. FAILED CONNECTING LINK



100K TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 114
SPECIMEN
DATE
23-PART ASSEMBLY OF 1/2" K-49 MINILINE ON 12-GROOVE SPOOL
AE = 18.6 x 10^6 lbf FOR ΔT = 65,000 lbf
(T_MIN = 10,000 LBf AND T_MAX = 75,000 LBf)
80K
60K
40K
20K
0
0
.2
.4
.6
.8
ELONGATION (%)

TABLE 9. FABRICATION HISTORY FOR BRIDGE CABLE SPECIMEN 1
ASSEMBLED FROM 1/2-INCH DIAMETER KEVLAR-49 MINILINE

Specimen Number 1/2 - 1 - TO

Material: 1/2-inch K-49 Miniline, From Spool Number A

(A) Load cycles during assembly of 19 part, 10 groove bearing sheaves:

			Load, lbs	Length of Rope, inches	Comments
(a)	With drum grip termination		5,000	270-7/8	
(b)	With splice termination		5,000	270-7/8	
(c)	Load cycles	1	0-60,000	--	
		2	0-60,000	--	
		3	0-60,000	--	
		4	0-60,000	--	
	(Loading rate	5	0-60,000	--	
	75,000 lbs in	6	0-60,000	--	
	60 seconds)	7	0-60,000	--	
		8	0-60,000	--	
		9	0-60,000	--	
		10	0-60,000		Recorded load versus elongation

Specimen Number 1/2 - 1 - TI

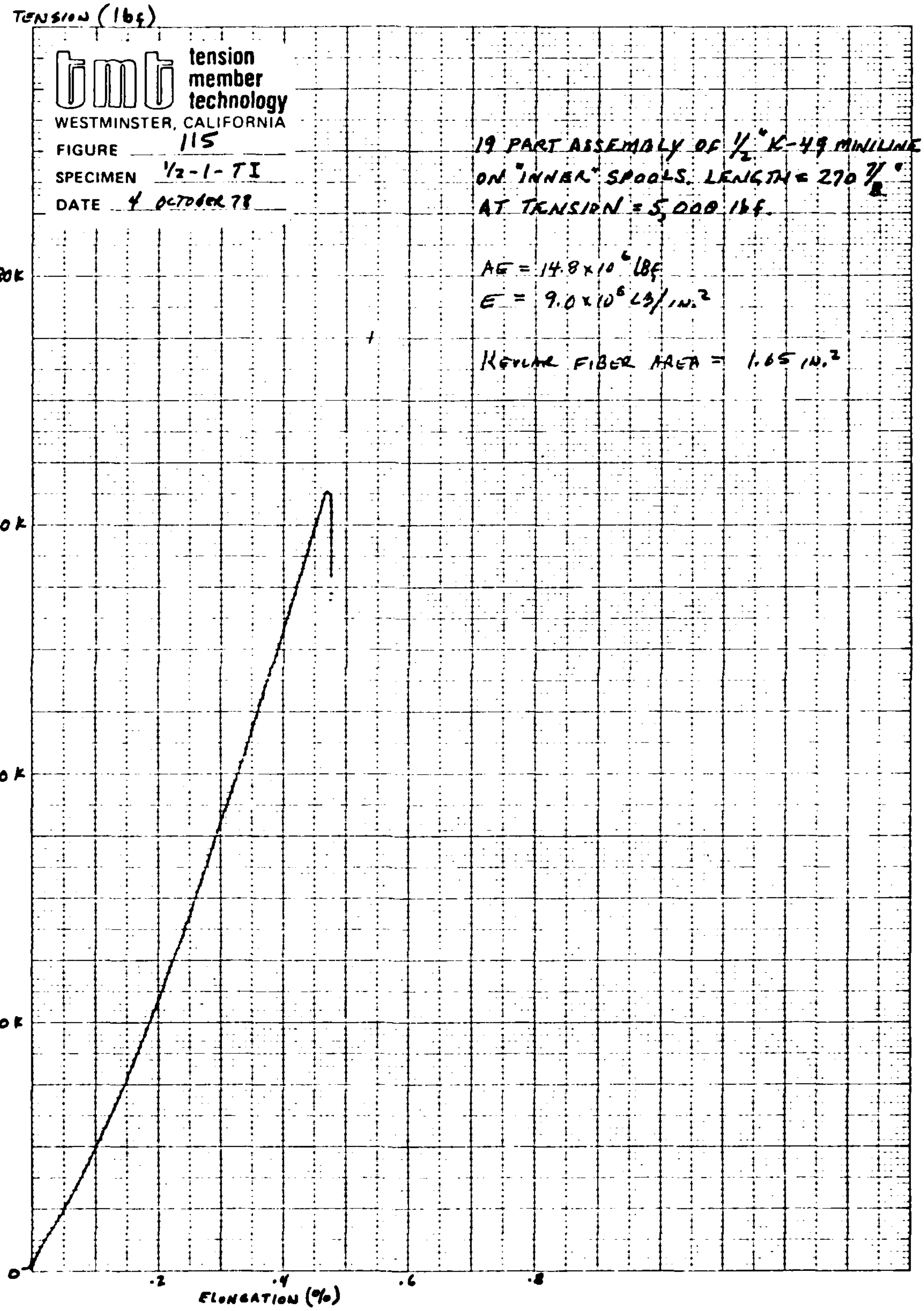
			Load, lbs	Length of Rope, inches	Comments
(a)	With drum grip termination		5,000	270-7/8	
(b)	With splice termination		5,000	270-7/8	
(c)	Load cycles	1	0-60,000	--	
		2	0-60,000	--	
		3	0-60,000	--	
		4	0-60,000	--	
		5	0-60,000	--	
		6	0-60,000	--	
		7	0-60,000	--	
		8	0-60,000	--	
		9	0-60,000	--	
		10	0-60,000	--	Recorded load versus elongation

Specimen Number 1/2 - 1 - TOI (Completed assembly of 1/2 - 1 - TI plus 1/2-1-TO)

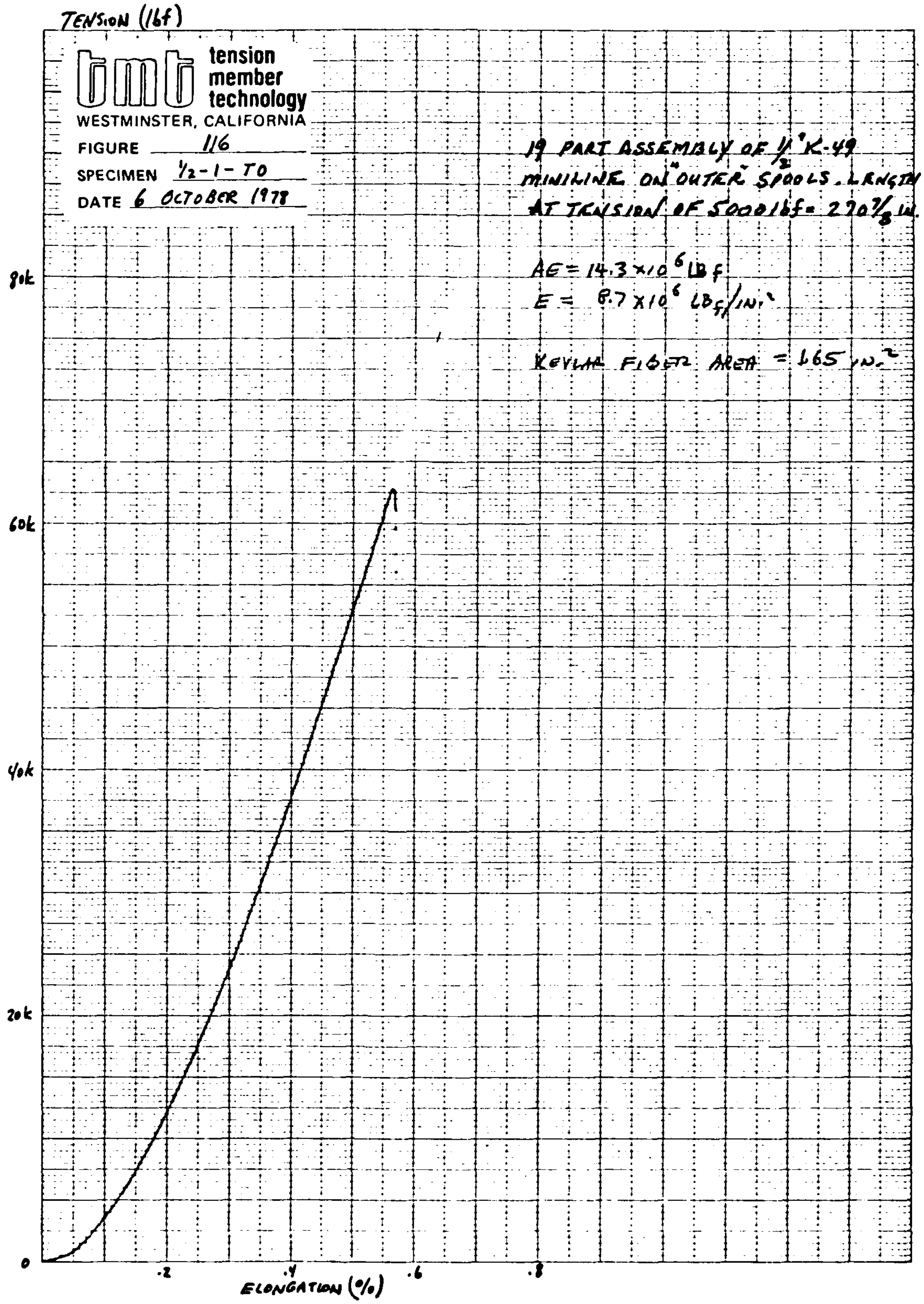
		Load, lbs	Length of Rope, inches	Comments
(a)	Completed assembly	0-10,000	276-3/16	
(b)	Proof load	0-150,000	--	Recorded load versus elongation

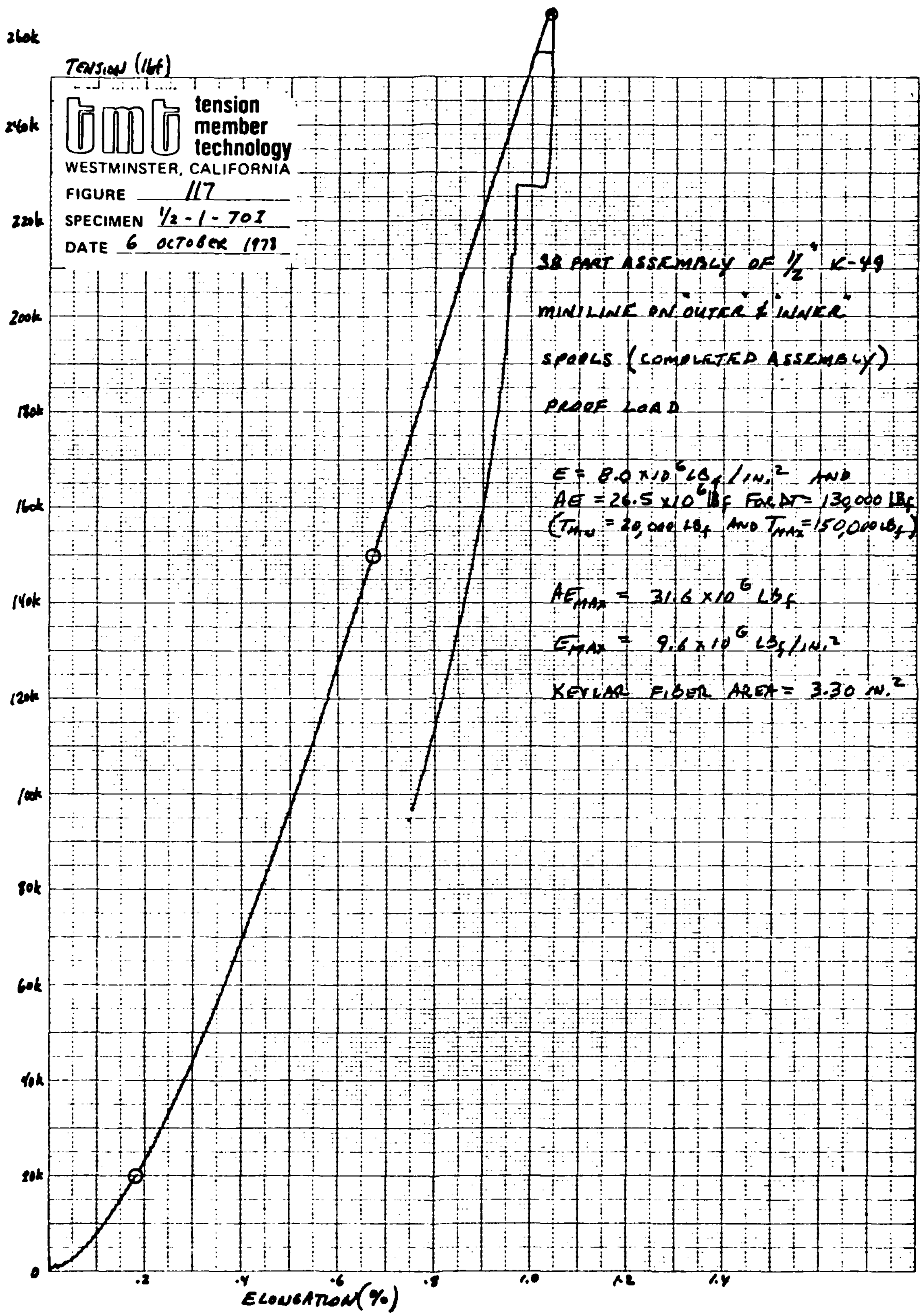
TABLE 10. FABRICATION HISTORY FOR BRIDGE CABLE SPECIMEN 2 ASSEMBLED FROM 1/2-INCH DIAMETER KEVLAR-49 MINILINE

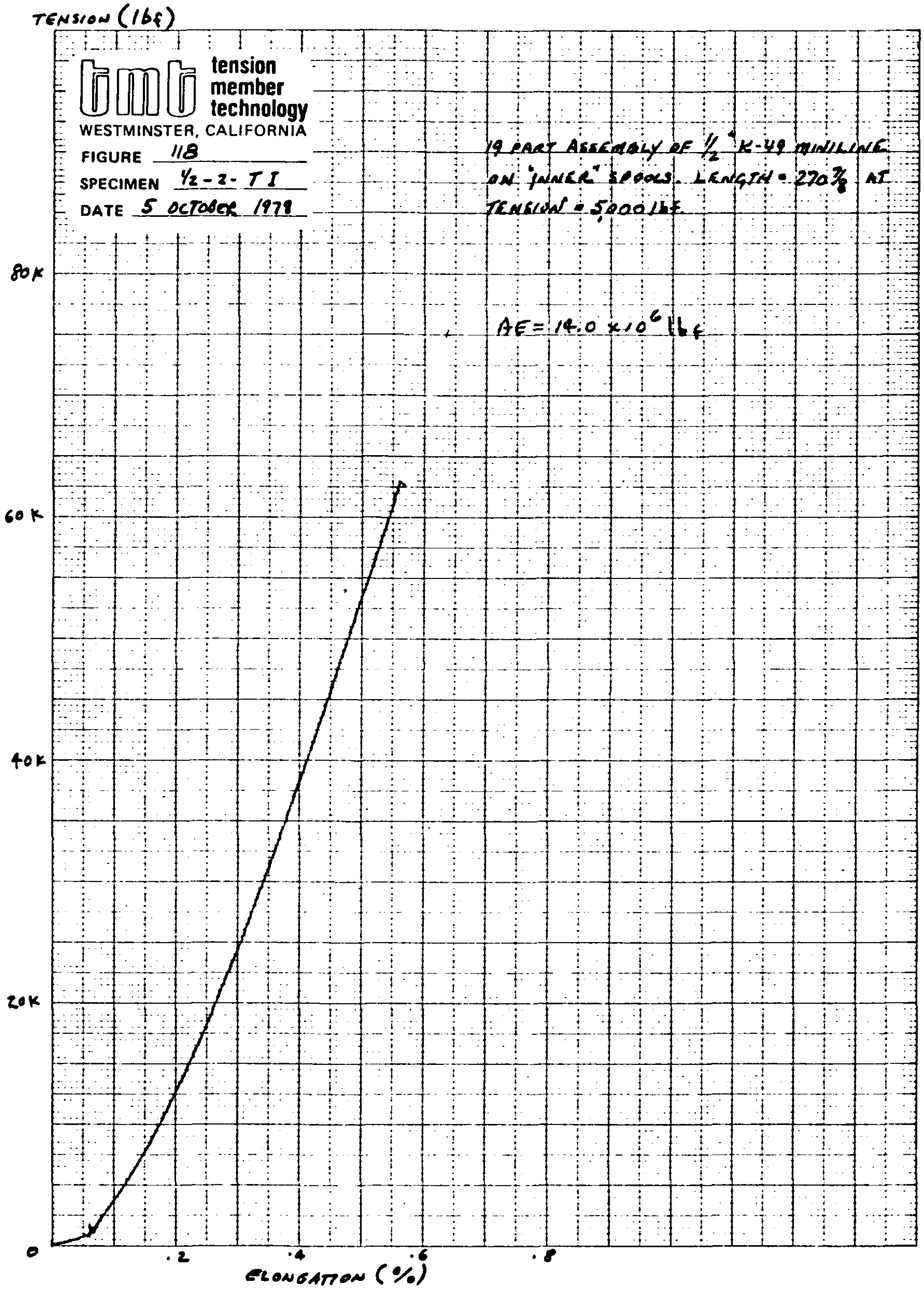
		Load, lbs	Length of Rope, inches	Comments
Specimen Number 1/2 - 2 - TI				
Material: 1/2-inch K-49 Miniline, From Spool Number B				
(A) Load cycles during assembly of 19 part, 10 groove bearing sheaves:				
(a) With drum grip termination		5,000	270-3/4	
(b) With splice termination		5,000	270-7/8	
(c) Load cycles	1	0-60,000	--	
	2	0-60,000	--	
	3	0-60,000	--	
	4	0-60,000	--	
	5	0-60,000	--	
	6	0-60,000	--	
	7	0-60,000	--	
	8	0-60,000	--	
	9	0-60,000	--	
	10	0-60,000	--	Recorded load versus elongation
Specimen Number 1/2 - 2 - TO				
(a) With drum grip termination		5,000	270-7/8	
(b) With splice termination		5,000	270-29/32	
(c) Load cycles	1	0-60,000	--	
	2	0-60,000	--	
	3	0-60,000	--	
	4	0-60,000	--	
	5	0-60,000	--	
	6	0-60,000	--	
	7	0-60,000	--	
	8	0-60,000	--	
	9	0-60,000	--	
	10	0-60,000	--	Recorded load versus elongation
Specimen Number 1/2 - 2 - TOI (Completed assembly of 1/2-2/TI plus 1/2-2-TO)				
(a) Completed assembly		0-10,000	276-3/16	
(b) Proof load		0-150,000	--	

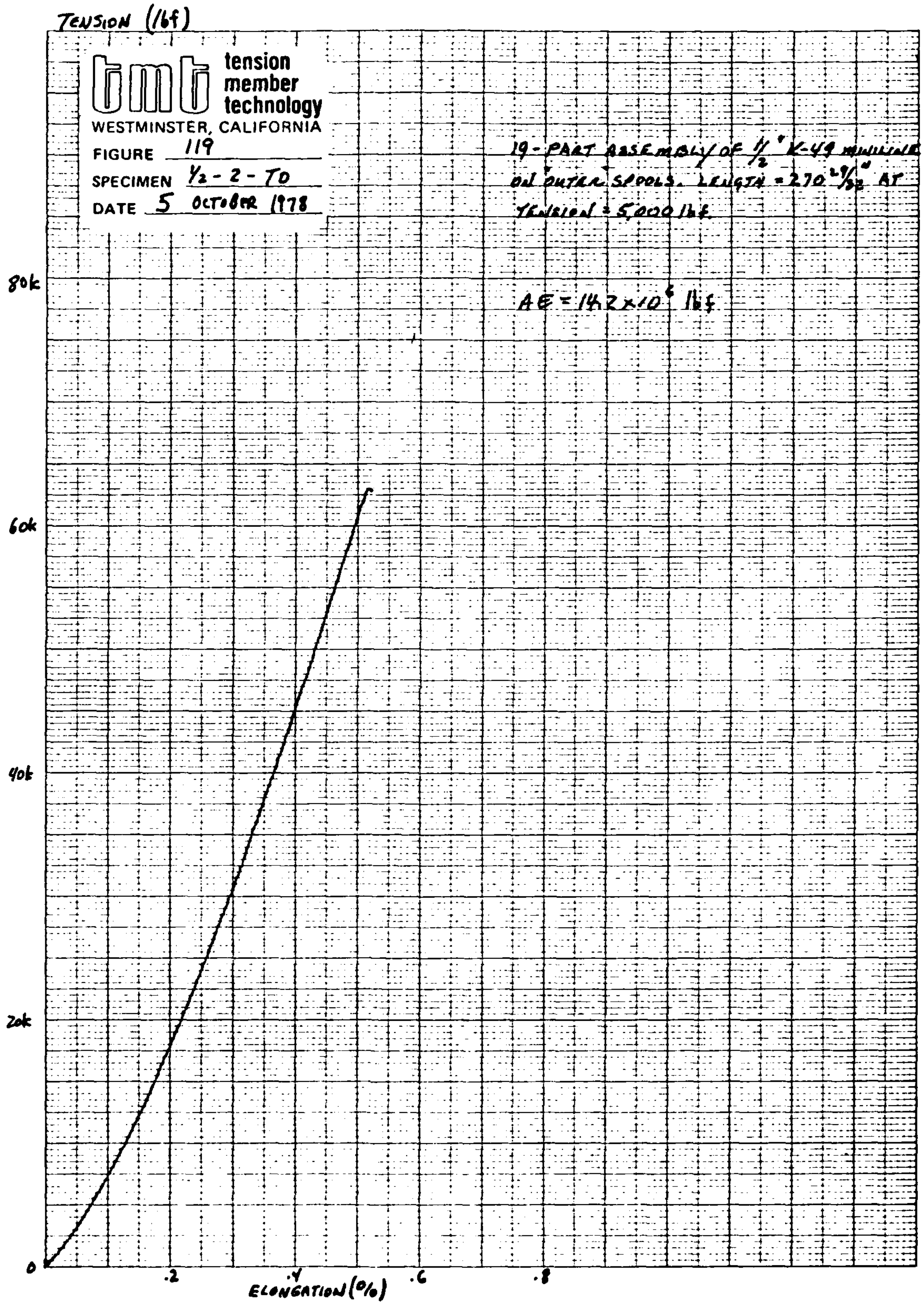


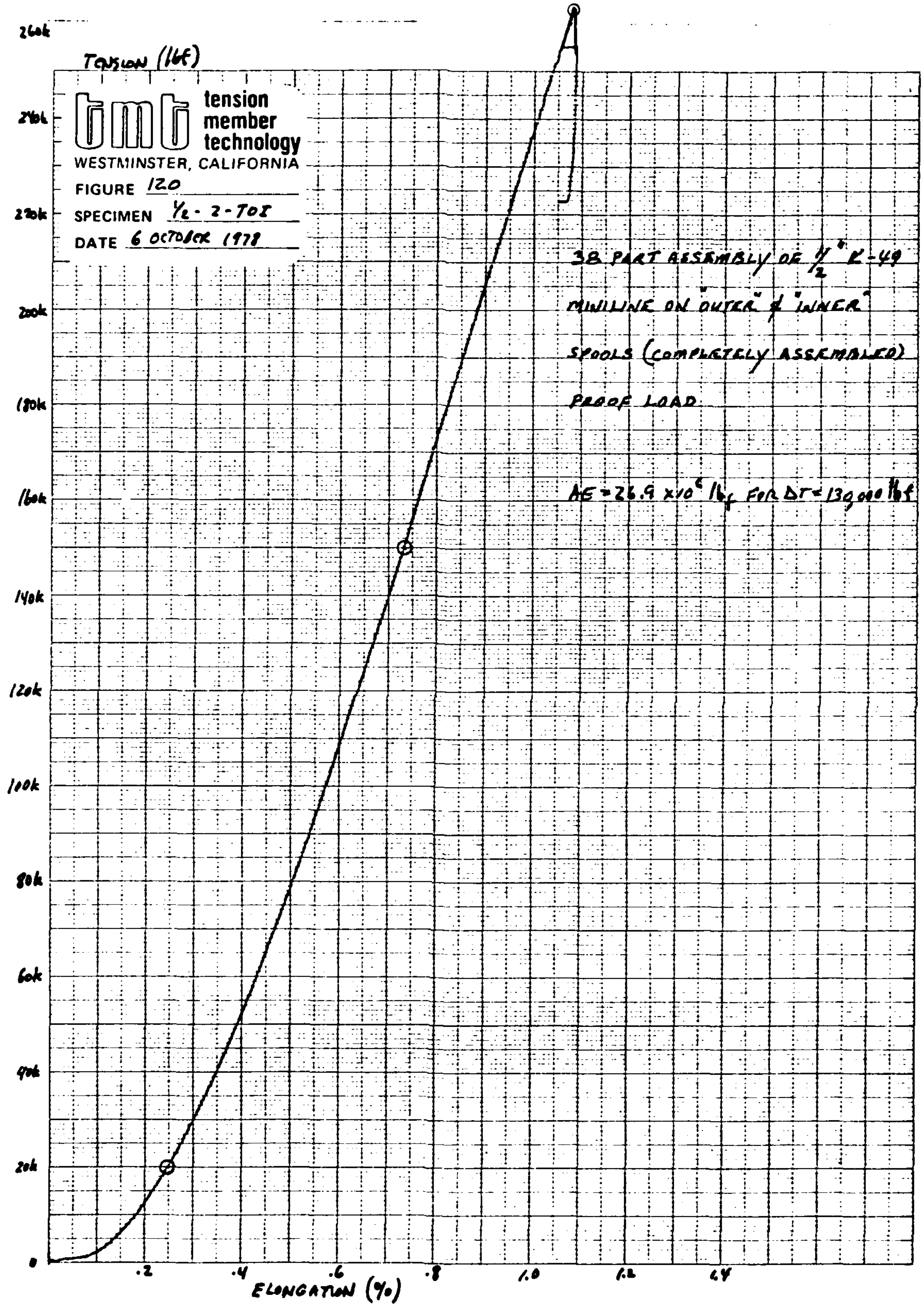
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 115
SPECIMEN 1/2-1-TI
DATE 4 OCTOBER 78
19 PART ASSEMBLY OF 1/2" K-49 MINILINE ON "INNER" SPOOLS. LENGTH = 270 7/8" AT TENSION = 5,000 lbf.
AE = 14.8 x 10^6 lbf
E = 9.0 x 10^6 lb/in.^2
KEVLAR FIBER AREA = 1.65 in.^2
80K
60K
40K
20K
0
.2
.4
.6
.8
ELONGATION (%)

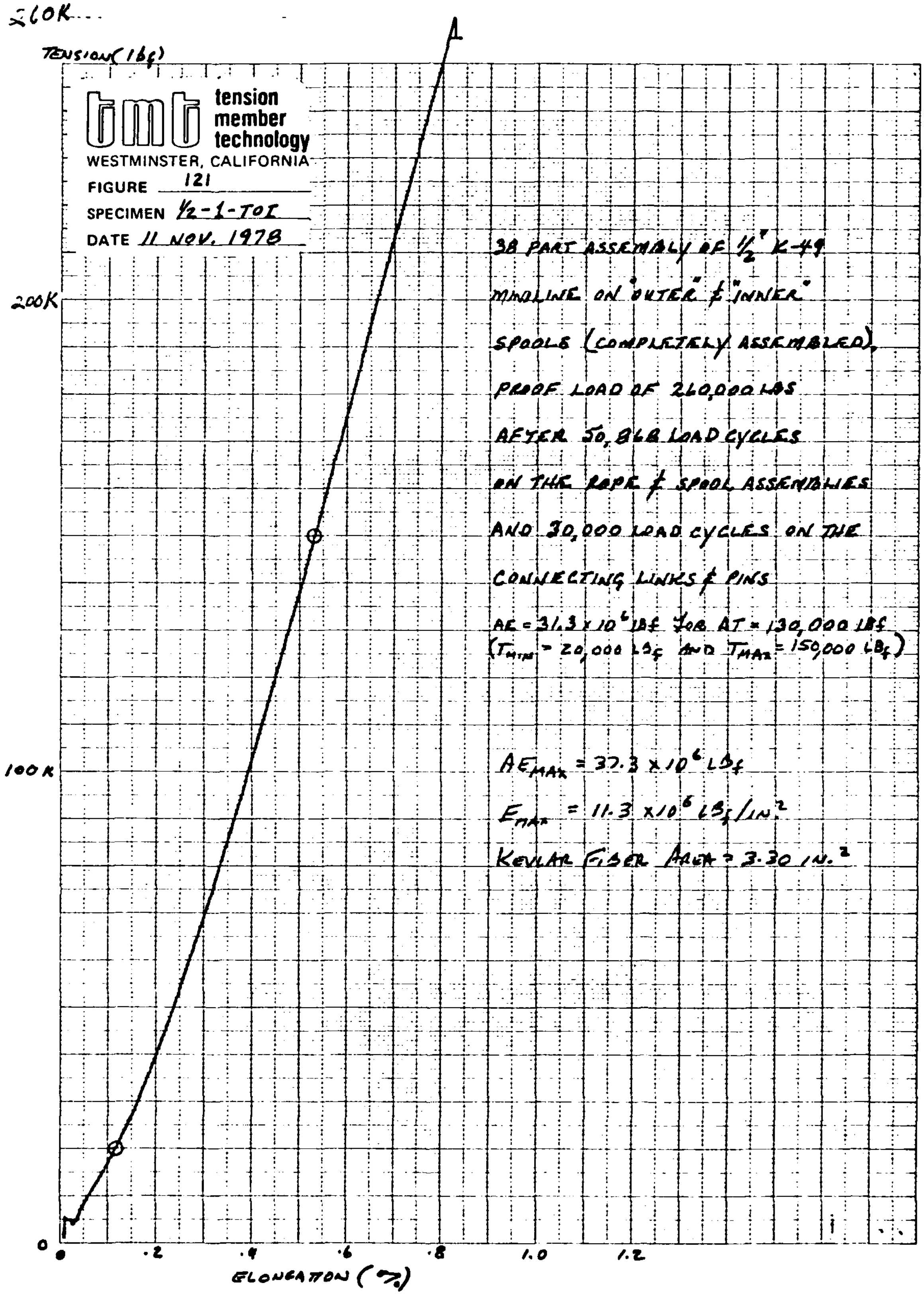

TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 116
SPECIMEN 1/2-1-TO
DATE 6 OCTOBER 1978
19 PART ASSEMBLY OF 1/2" K-49
MINILINE ON "OUTER" SPOOLS. LENGTH
AT TENSION OF 5000 lbf = 270 7/8 IN.
AE = 14.3 x 10^6 LBf
E = 8.7 x 10^6 LBf/IN.^2
KEVLAR FIBER AREA = 1.65 IN.^2
80k
60k
40k
20k
0
.2
.4
.6
.8
ELONGATION (%)

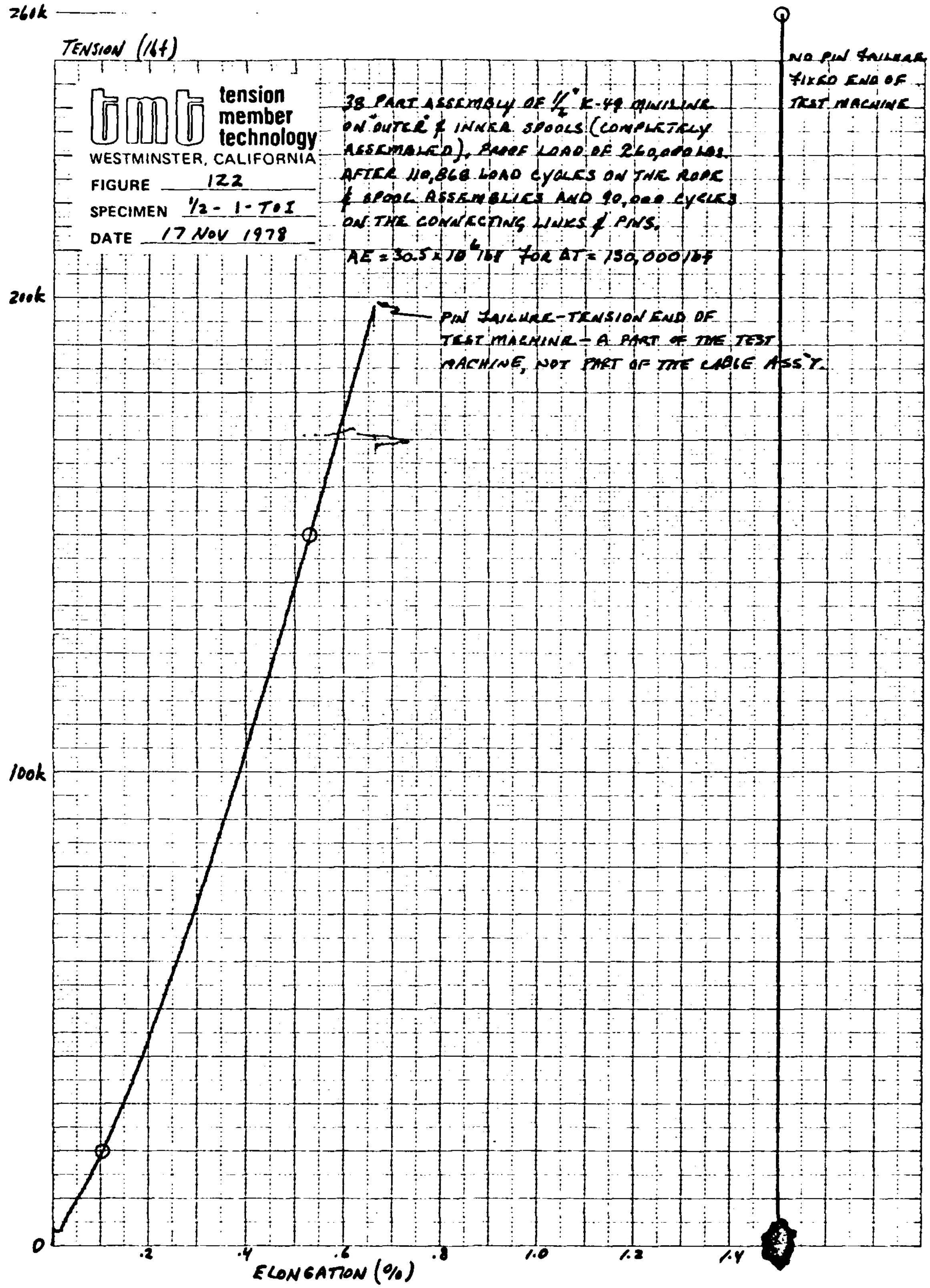

TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 117
SPECIMEN 1/2 - 1 - 70I
DATE 6 OCTOBER 1978
38 PART ASSEMBLY OF 1/2" K-49
MINILINE ON "OUTER" & "INNER"
SPOOLS (COMPLETED ASSEMBLY)
PROOF LOAD
E = 8.0 x 10^6 LBf / IN.^2 AND
AE = 26.5 x 10^6 LBf FOR ΔT = 130,000 LBf
(T_MIN = 20,000 LBf AND T_MAX = 150,000 LBf)
AE_MAX = 31.6 x 10^6 LBf
E_MAX = 9.6 x 10^6 LBf / IN.^2
KEVLAR FIBER AREA = 3.30 IN.^2
260k
240k
220k
200k
180k
160k
140k
120k
100k
80k
60k
40k
20k
0
.2
.4
.6
.8
1.0
1.2
1.4
ELONGATION (%)

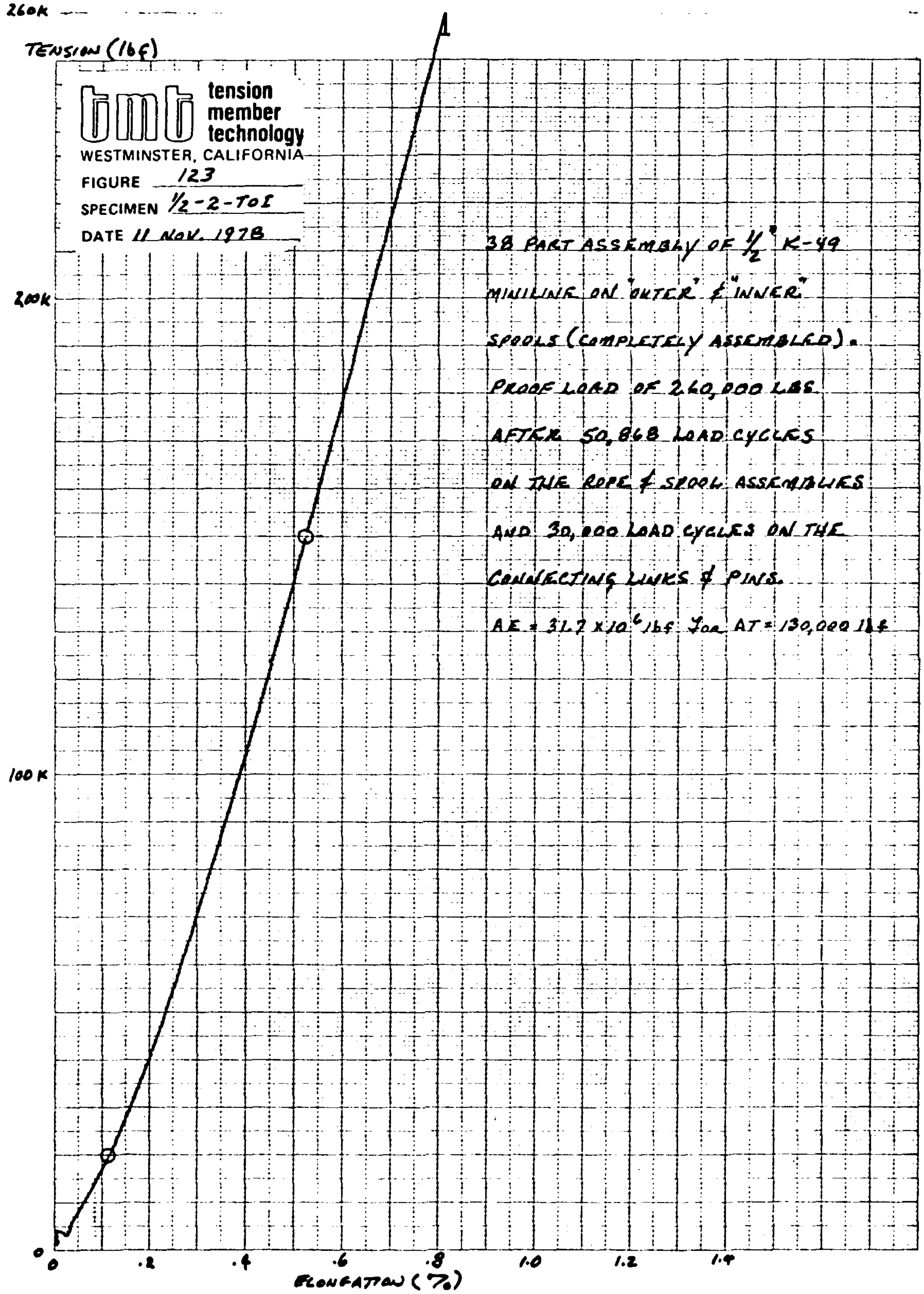

TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 118
SPECIMEN 1/2-2-T I
DATE 5 OCTOBER 1978
19 PART ASSEMBLY OF 1/2" K-49 MINILINE ON "INNER" SPOOLS. LENGTH = 270 7/8 AT TENSION = 5000 lbf.
AE = 14.0 x 10^6 lbf
80K
60K
40K
20K
0
.2
.4
.6
.8
ELONGATION (%)


TENSION (lbf)
tmb tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 119
SPECIMEN 1/2 - 2 - TO
DATE 5 OCTOBER 1978
19-PART ASSEMBLY OF 1/2" K-49 MINILINE ON OUTER SPOOLS. LENGTH = 270 29/32" AT TENSION = 5000 lbf.
AE = 14.2 x 10^6 lbf
80k
60k
40k
20k
0
.2
.4
.6
.8
ELONGATION (%)


260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 120
SPECIMEN 1/2 - 2 - 70I
DATE 6 OCTOBER 1978
240k
220k
200k
180k
160k
140k
120k
100k
80k
60k
40k
20k
0
38 PART ASSEMBLY OF 1/2" K-49
MINILINE ON "OUTER" & "INNER"
SPOOLS (COMPLETELY ASSEMBLED)
PROOF LOAD
AE = 26.9 x10^6 lbf FOR ΔT = 130,000 lbf
.2
.4
.6
.8
1.0
1.2
1.4
ELONGATION (%)


260K
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 121
SPECIMEN 1/2-1-TOI
DATE 11 NOV. 1978
38 PART ASSEMBLY OF 1/2" K-49
MOORLINE ON "OUTER" & "INNER"
SPOOLS (COMPLETELY ASSEMBLED),
PROOF LOAD OF 260,000 LBS
AFTER 50,868 LOAD CYCLES
ON THE ROPE & SPOOL ASSEMBLIES
AND 30,000 LOAD CYCLES ON THE
CONNECTING LINKS & PINS
AE = 31.3 x 10^6 lbf FOR ΔT = 130,000 lbf
(T_MIN = 20,000 lbf AND T_MAX = 150,000 lbf)
AE_MAX = 37.3 x 10^6 lbf
E_MAX = 11.3 x 10^6 lbf/in.^2
KEVLAR FIBER AREA = 3.30 in.^2
200K
100K
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)


260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 122
SPECIMEN 1/2 - 1 - T01
DATE 17 NOV 1978
38 PART ASSEMBLY OF 1/4" K-49 MINILINE ON OUTER & INNER SPOOLS (COMPLETELY ASSEMBLED), PROOF LOAD OF 260,000 LBS. AFTER 110,868 LOAD CYCLES ON THE ROPE & SPOOL ASSEMBLIES AND 90,000 CYCLES ON THE CONNECTING LINKS & PINS.
AE = 30.5 x 10^6 lbf FOR ΔT = 130,000 lbf
NO PIN FAILURE FIXED END OF TEST MACHINE
PIN FAILURE - TENSION END OF TEST MACHINE - A PART OF THE TEST MACHINE, NOT PART OF THE CABLE ASS'Y.
200k
100k
0
.2
.4
.6
.8
1.0
1.2
1.4
ELONGATION (%)


260K
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 123
SPECIMEN 1/2-2-TOI
DATE 11 NOV. 1978
38 PART ASSEMBLY OF 1/2" K-49
MINILINE ON "OUTER" & "INNER"
SPOOLS (COMPLETELY ASSEMBLED).
PROOF LOAD OF 260,000 LBS
AFTER 50,868 LOAD CYCLES
ON THE ROPE & SPOOL ASSEMBLIES
AND 30,000 LOAD CYCLES ON THE
CONNECTING LINKS & PINS.
AE = 31.7 x 10^6 lbf for AT = 130,000 lbf
200K
100 K
0
0
.2
.4
.6
.8
1.0
1.2
1.4
ELONGATION (%)

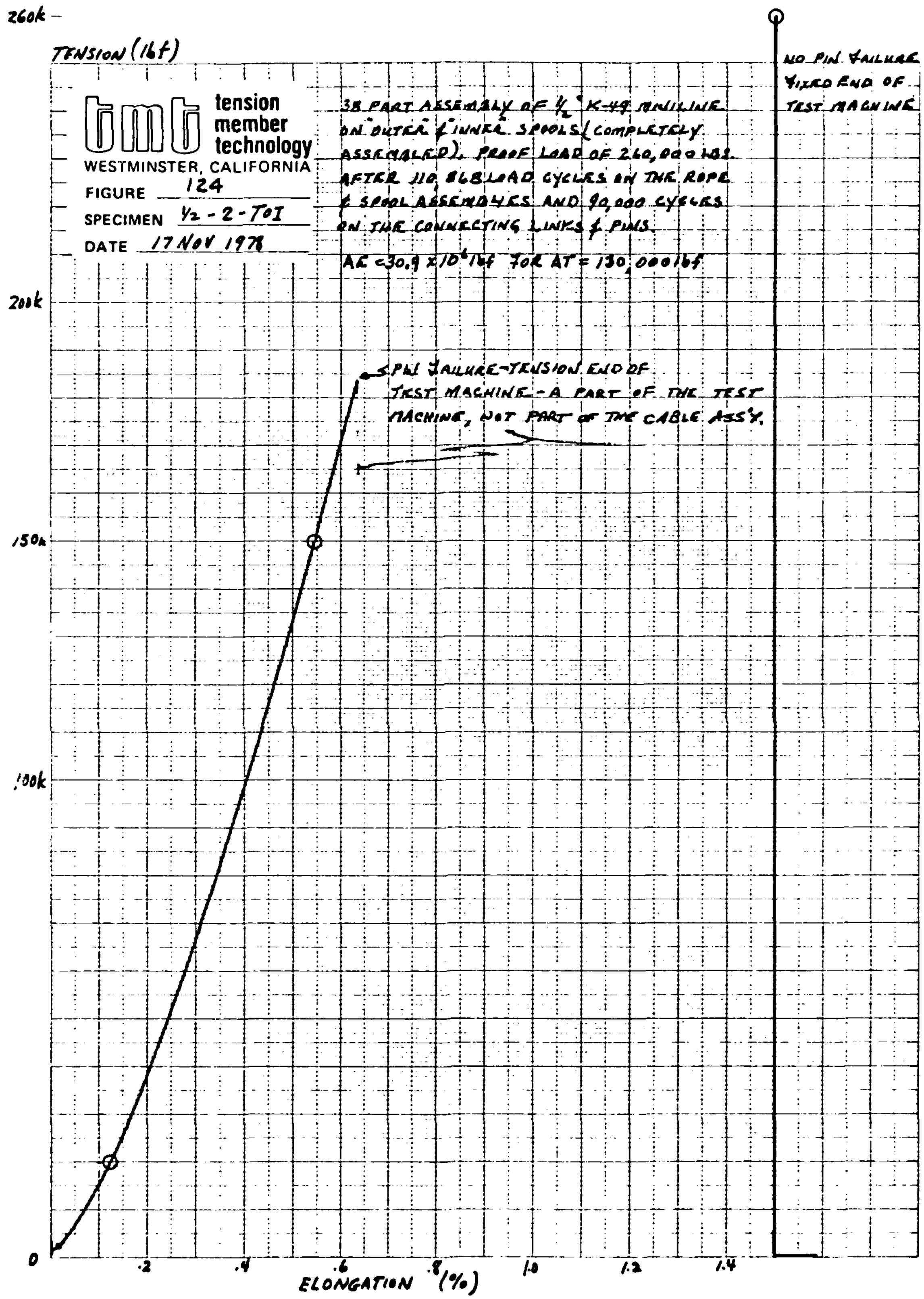

260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 124
SPECIMEN ½ - 2 - T0I
DATE 17 NOV 1978
38 PART ASSEMBLY OF ½" K-49 UNILINE ON OUTER & INNER SPOOLS (COMPLETELY ASSEMBLED). PROOF LOAD OF 260,000 LBS. AFTER 110,868 LOAD CYCLES ON THE ROPE & SPOOL ASSEMBLIES AND 90,000 CYCLES ON THE CONNECTING LINKS & PINS.
AE ≈ 30.9 x 10⁶ lbf FOR AT = 130,000 lbf
NO PIN FAILURE FIXED END OF TEST MACHINE
PIN FAILURE - TENSION END OF TEST MACHINE - A PART OF THE TEST MACHINE, NOT PART OF THE CABLE ASS'Y.
200k
150k
100k
0
.2
.4
.6
.8
1.0
1.2
1.4
ELONGATION (%)

TABLE 11. RESULTS OF CYCLIC-TENSION FATIGUE TEST OF MINILINE END SPLICE

Time of Length Measurement	Gauge Length at 5,000 Pounds, inches
Prior to initial proof loading	73-1/16
After 8,670-pound proof load[a]	73-3/32
After 30,000 tension cycles[b]	73-3/8
After 8,670-pound proof load	73-3/8
After 60,000 more tension cycles[b]	--
After 8,670-pound proof load	73-7/16

(a) Proof load held for three minutes.

(b) T_{min} = 500 pounds, T_{max} = 5,000 pounds.

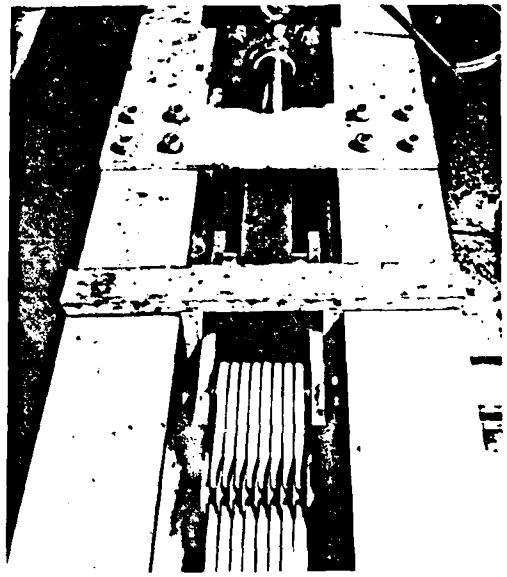


FIGURE 125. TENSION END OF LOAD FRAME

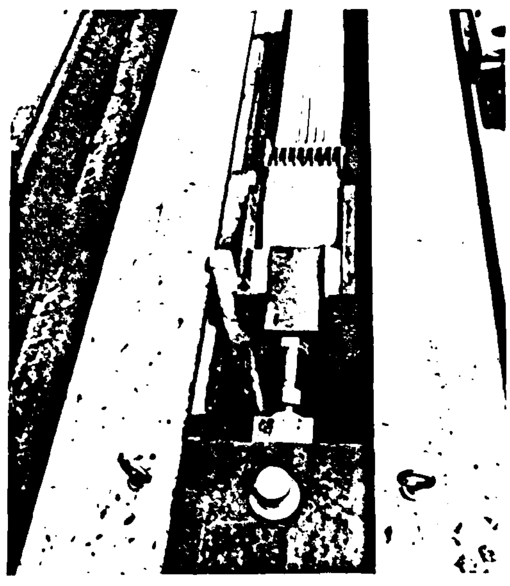


FIGURE 126. FIXED END OF LOAD FRAME

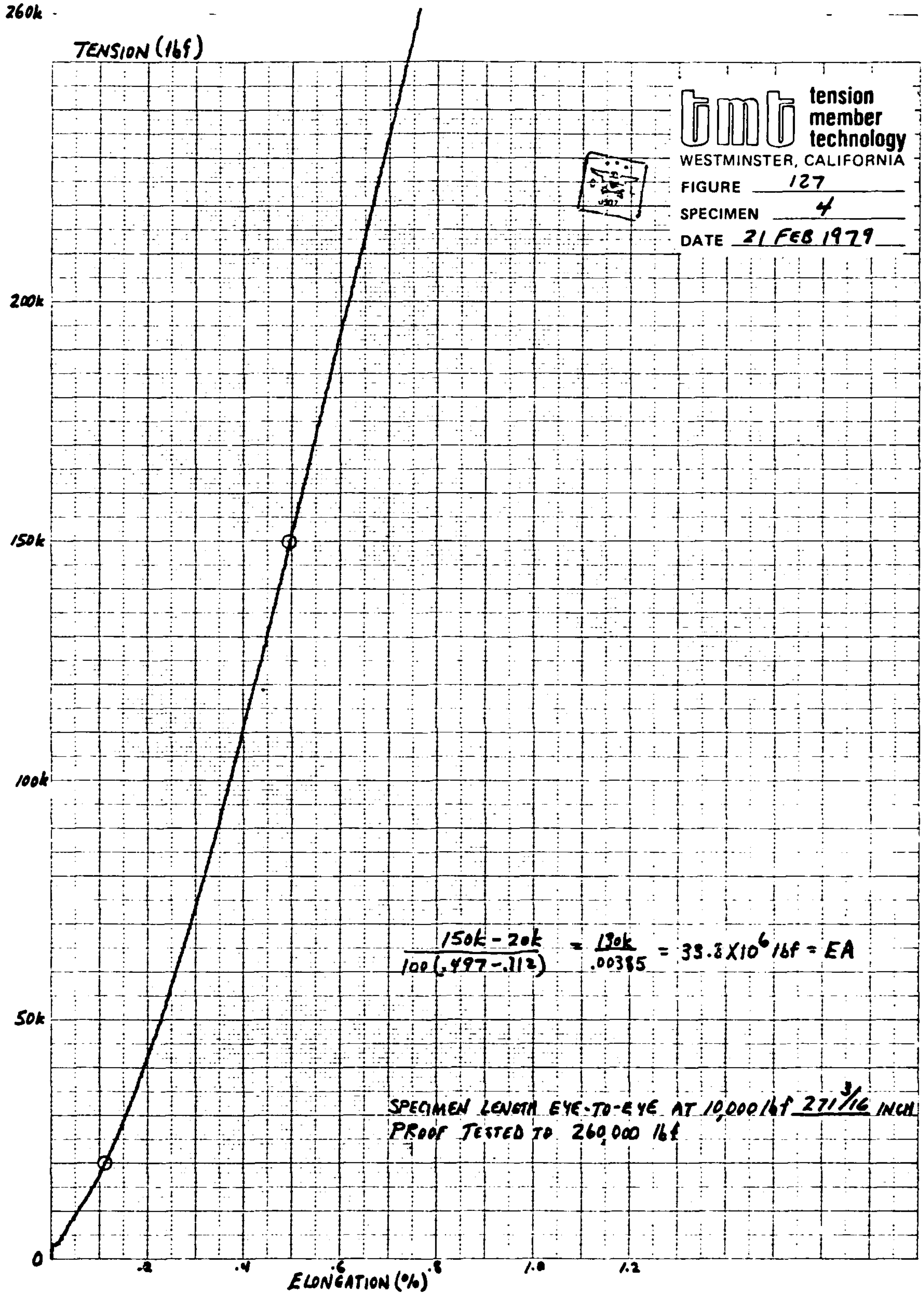
TABLE 12. PHYSICAL CHARACTERISTICS OF DELIVERABLE BRIDGE CABLE ASSEMBLIES

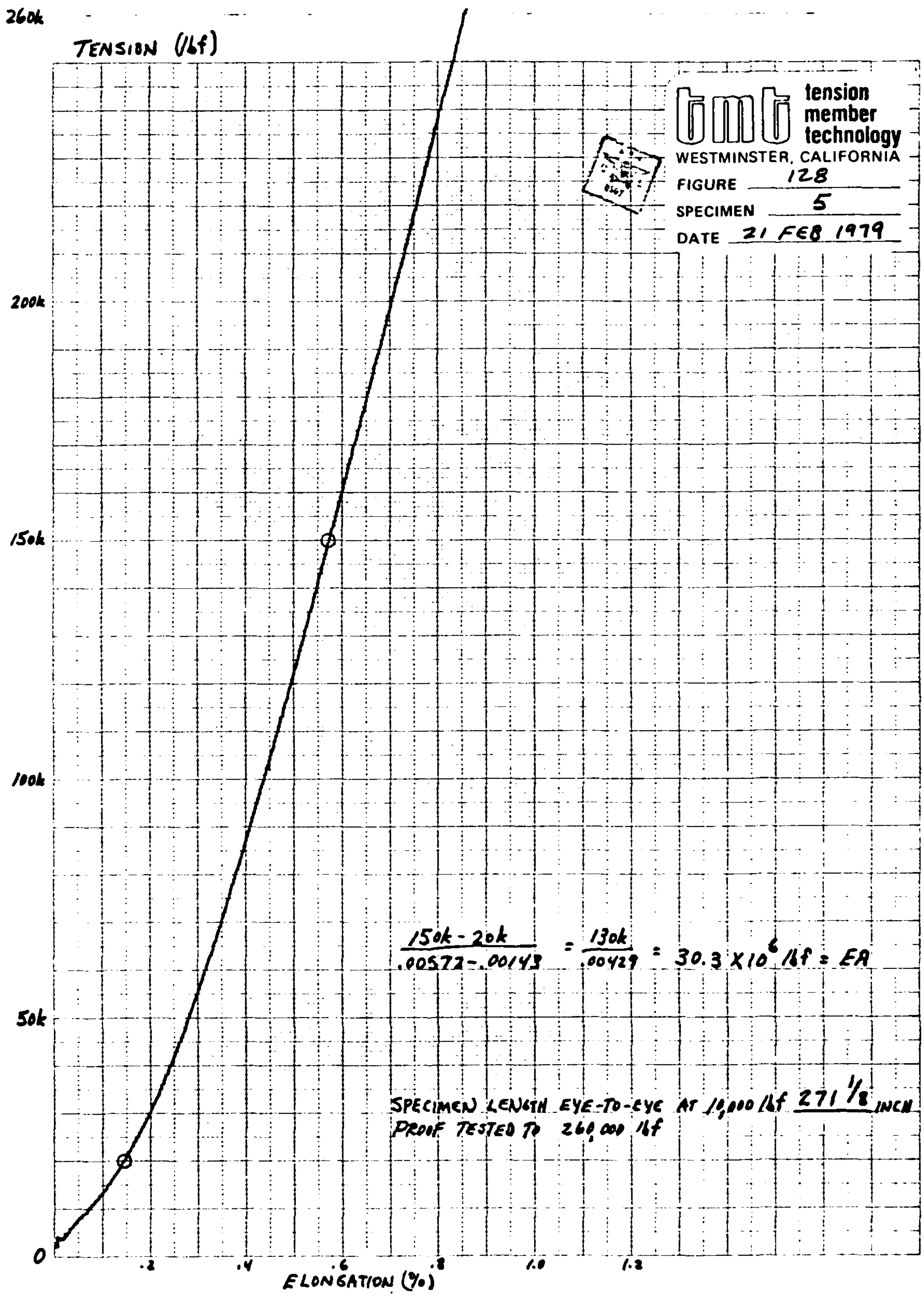
	Bridge Cable Conditioning			Final 260,000-Pound Proof Load	
Rope Number	Initial Length at 10,000 Pounds, inches	Conditioning Time at 50,000 Pounds, hours	Final Length at 10,000 Pounds, inches	Length at 10,000 Pounds inches	AE for ΔT=130,000 Pounds, 10^6 Pounds
4	270-7/8	16.5	271-1/16	271-3/16	33.8
5	270-11/16	16.5	271-1/16	271-1/8	30.3
6	270-7/8	16.5	271-1/16	271-3/16	31.9
7	270-3/4	17.0	271	271-1/8	32.4
8	270-3/4	17.0	271	271-1/8	31.9
9	270-3/4	18.0	271-1/8	271-3/16	31.3
10	270-3/4	16.5	271-1/16	271-1/16	31.6
11	270-3/4	18.5	271-1/4	271-5/16	31.7
12	270-3/4	20.0	271-1/16	271-1/8	31.9
13	270-3/4	17.5	271	271-1/16	31.7

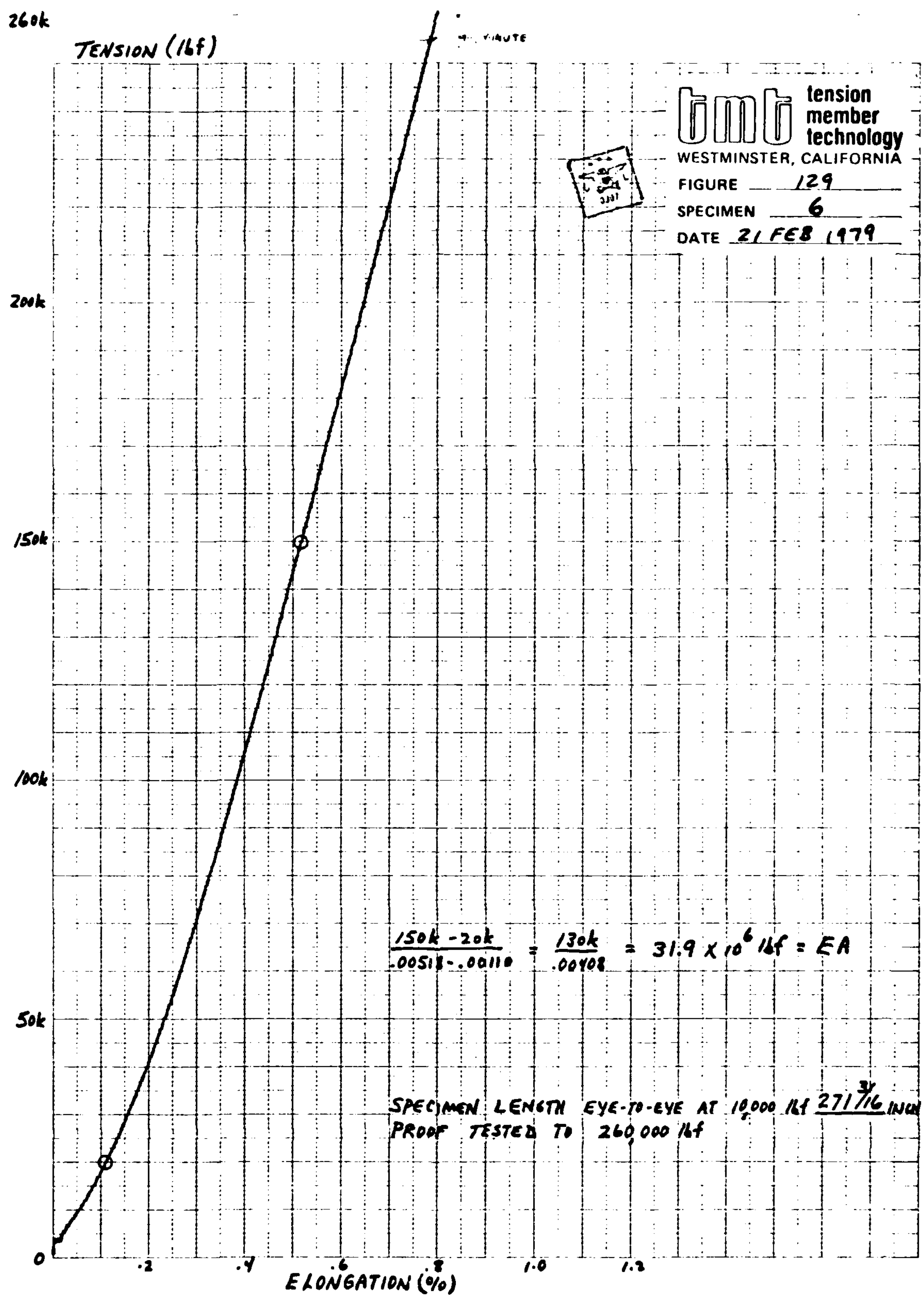
NOTES: Each of 16 connecting pins were proof loaded to 260,000 pounds in conjunction with the above rope proof loading.

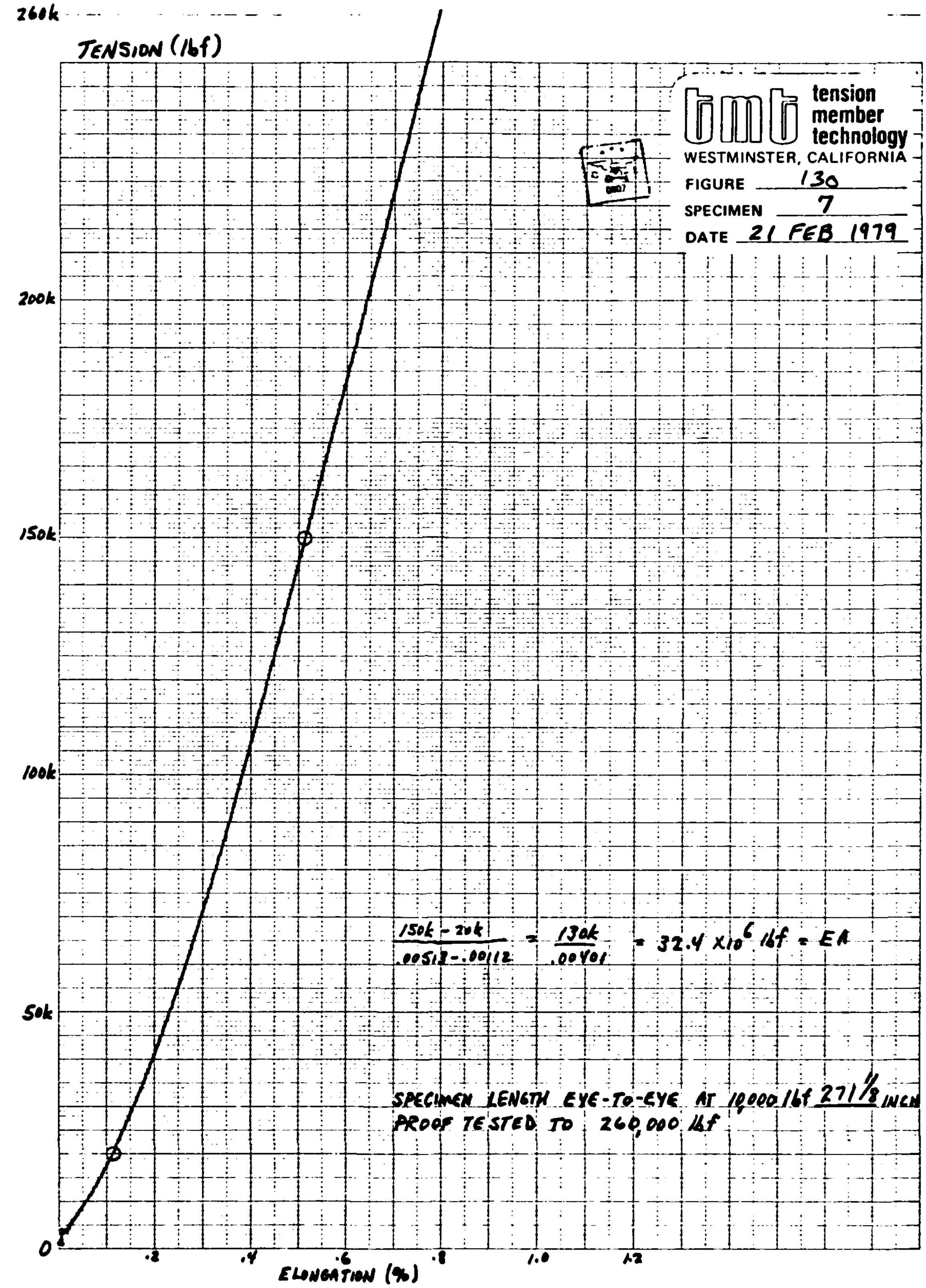
Each of 16 connecting links were proof loaded to 130,000 pounds tension in a separate test set-up for convenience.

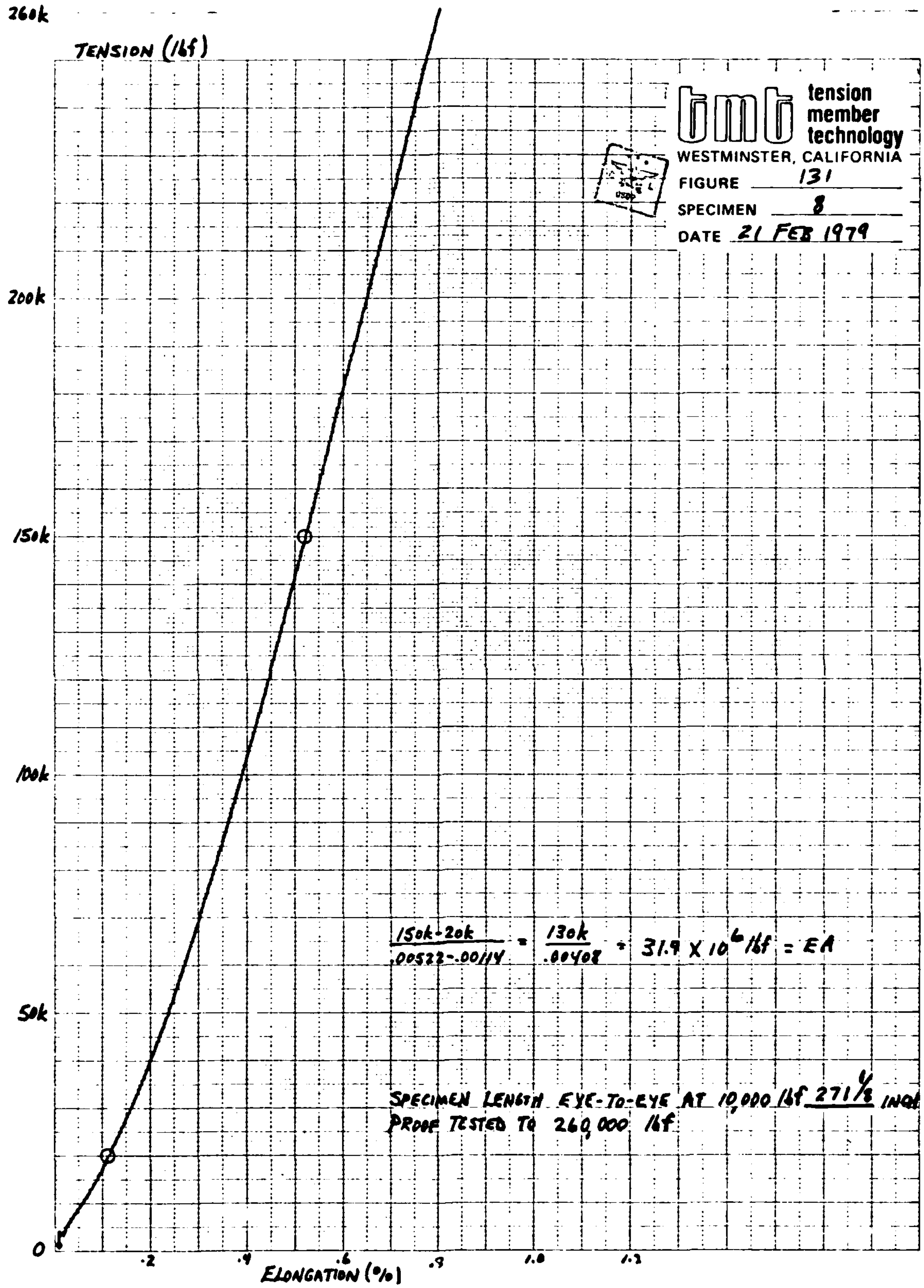
Tests witnessed by: T. Sugita, K. Harris, and G. Wilber, February 21 and 22, 1979.

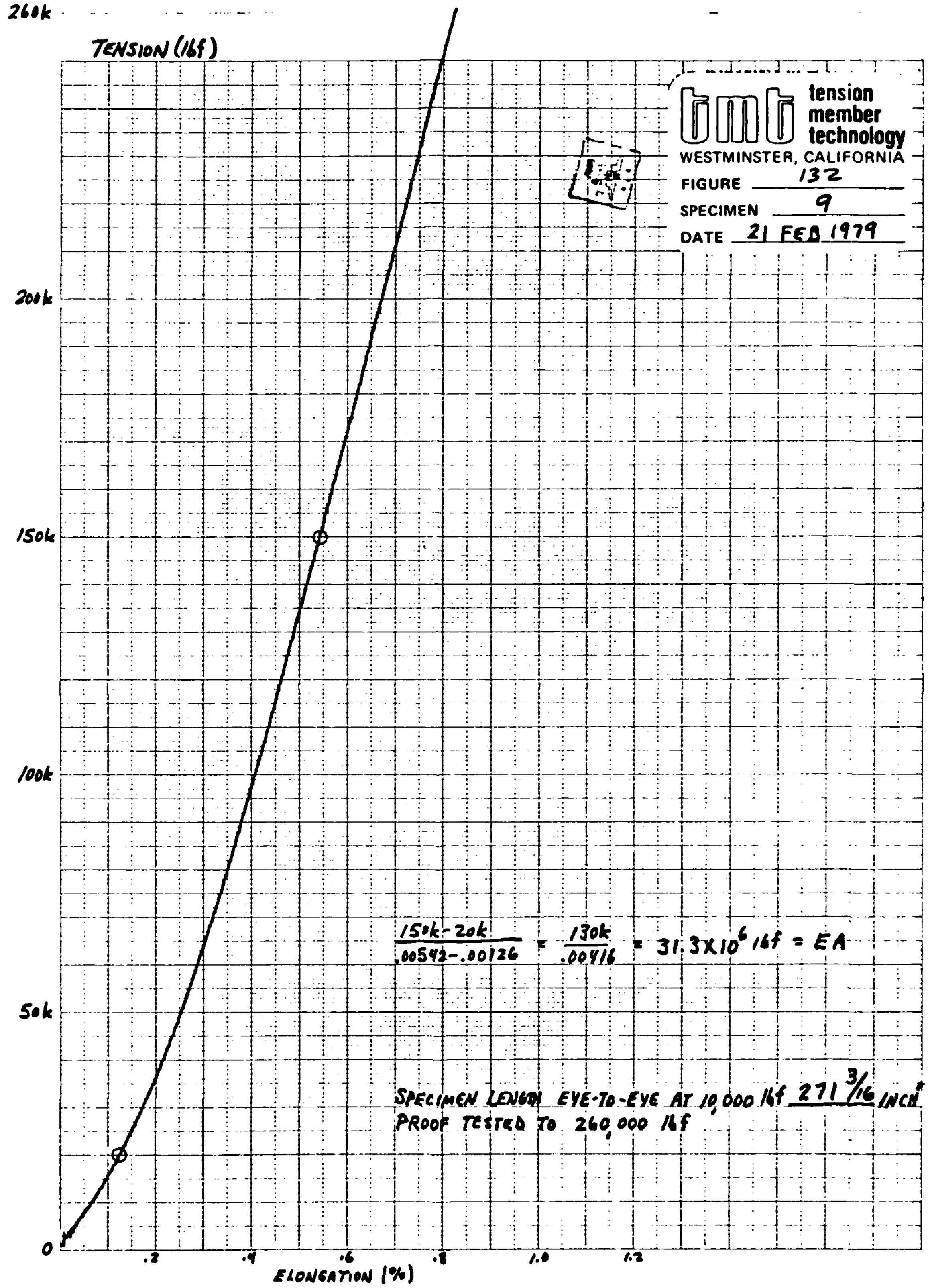

TENSION (lbf)
260k
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 127
SPECIMEN 4
DATE 21 FEB 1979
(150k - 20k) / 100(.497-.112) = 130k / .00385 = 33.8X10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 3/16 INCH
PROOF TESTED TO 260,000 lbf


260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 128
SPECIMEN 5
DATE 21 FEB 1979
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
150k - 20k / .00572 - .00143 = 130k / .00429 = 30.3 X 10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 1/8 INCH
PROOF TESTED TO 260,000 lbf

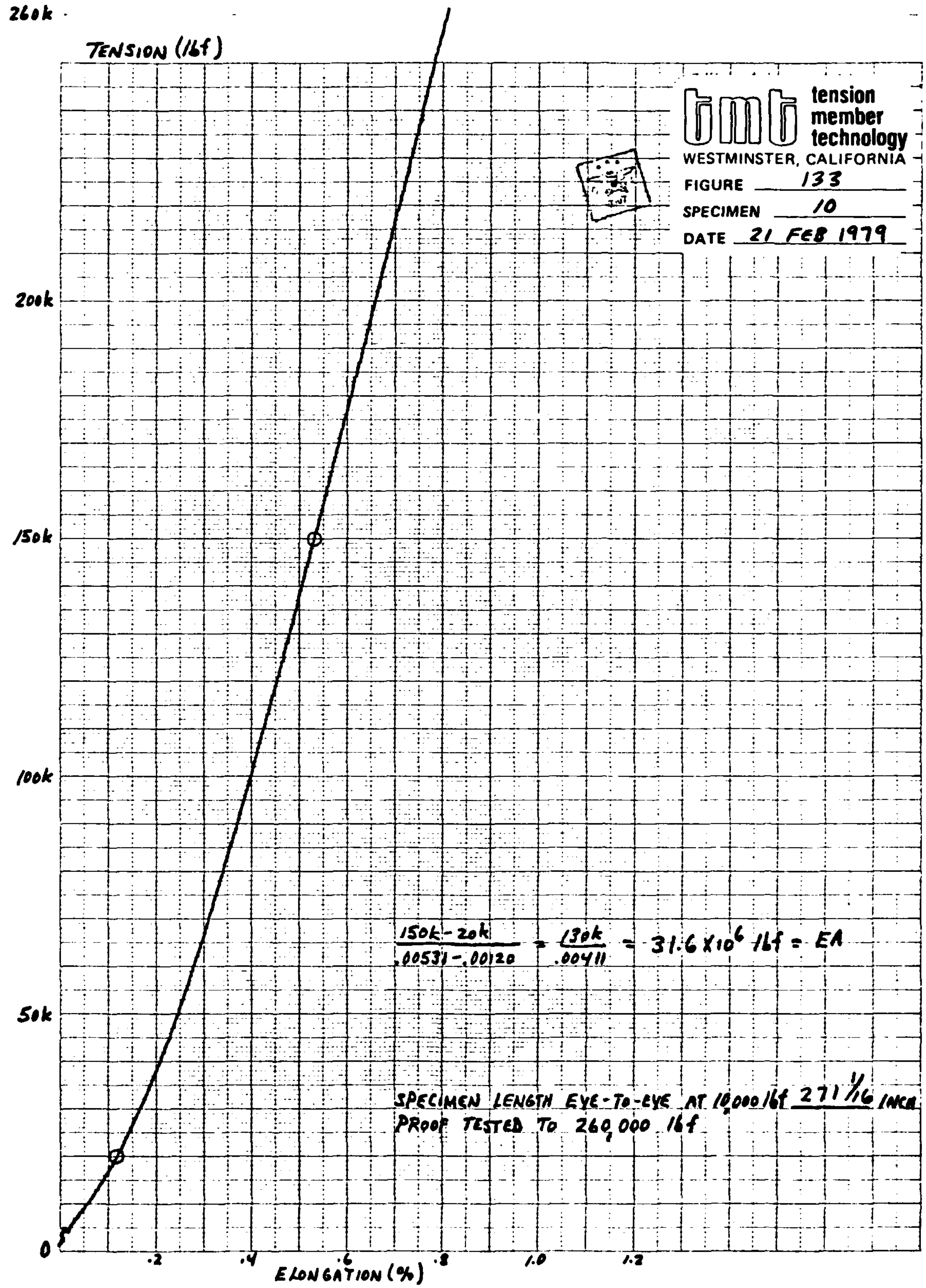

260k
TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 129
SPECIMEN 6
DATE 21 FEB 1979
200k
150k
100k
50k
0
150k - 20k / .00518 - .00110 = 130k / .00408 = 31.9 X 10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 3/16 INCH
PROOF TESTED TO 260,000 lbf
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)

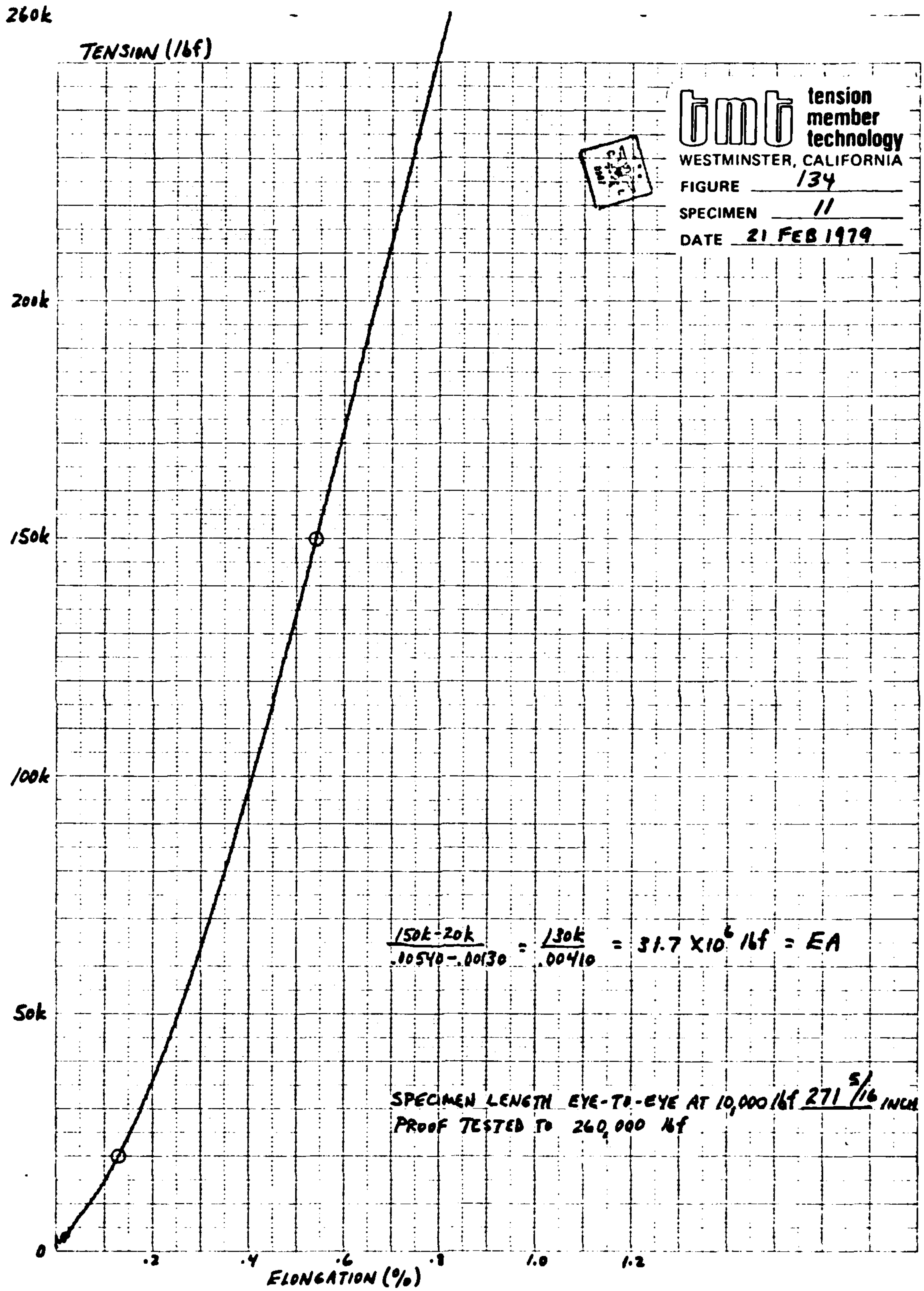

260k
TENSION (lbf)
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 130
SPECIMEN 7
DATE 21 FEB 1979
150k - 20k / .00513 - .00112 = 130k / .00401 = 32.4 x10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 1/8 INCH
PROOF TESTED TO 260,000 lbf

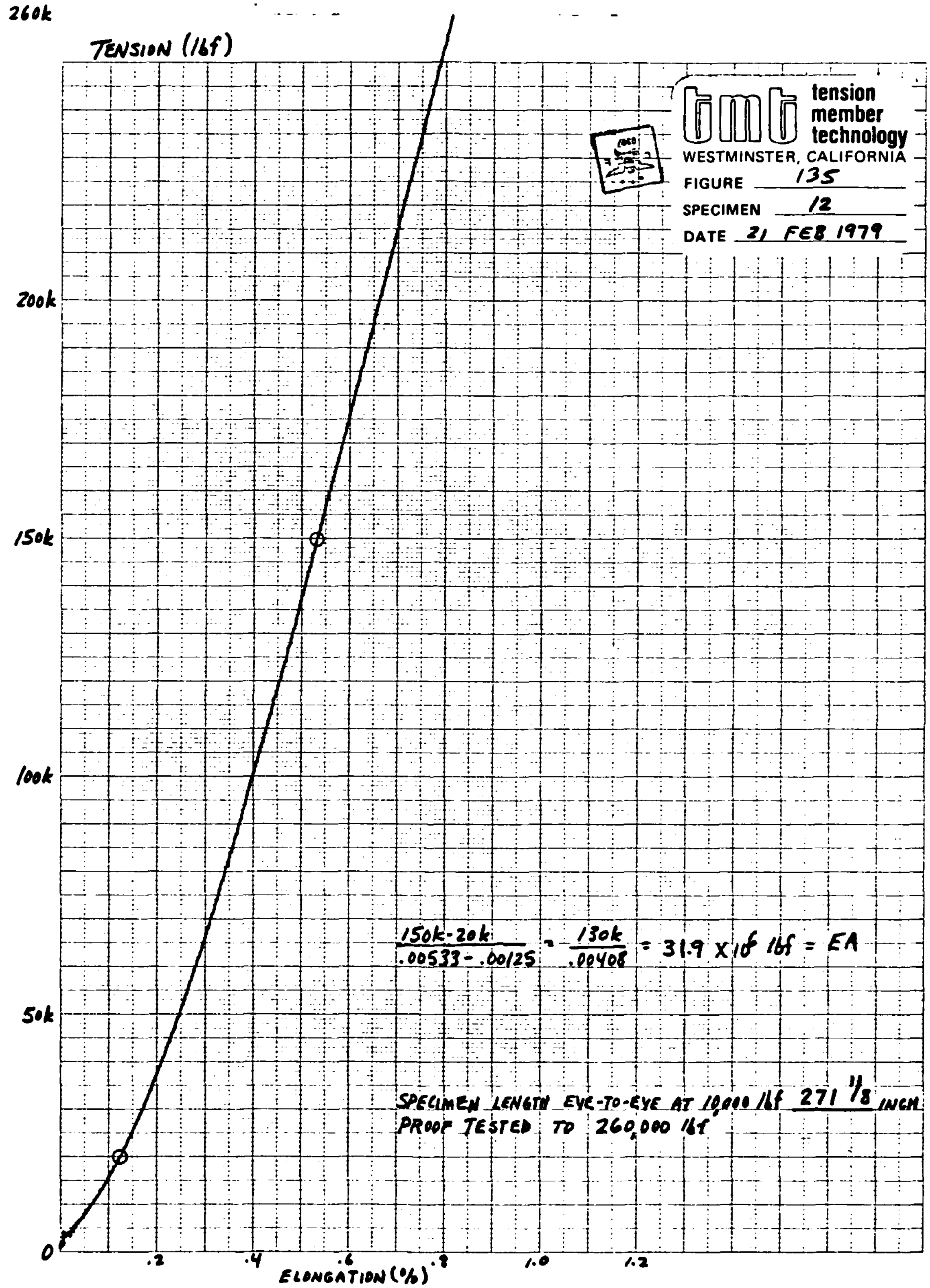

260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 131
SPECIMEN 8
DATE 21 FEB 1979
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
$\frac{150k - 20k}{.00522 - .00114} = \frac{130k}{.00408} = 31.9 \times 10^6$ lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 1/8 INCH
PROOF TESTED TO 260,000 lbf



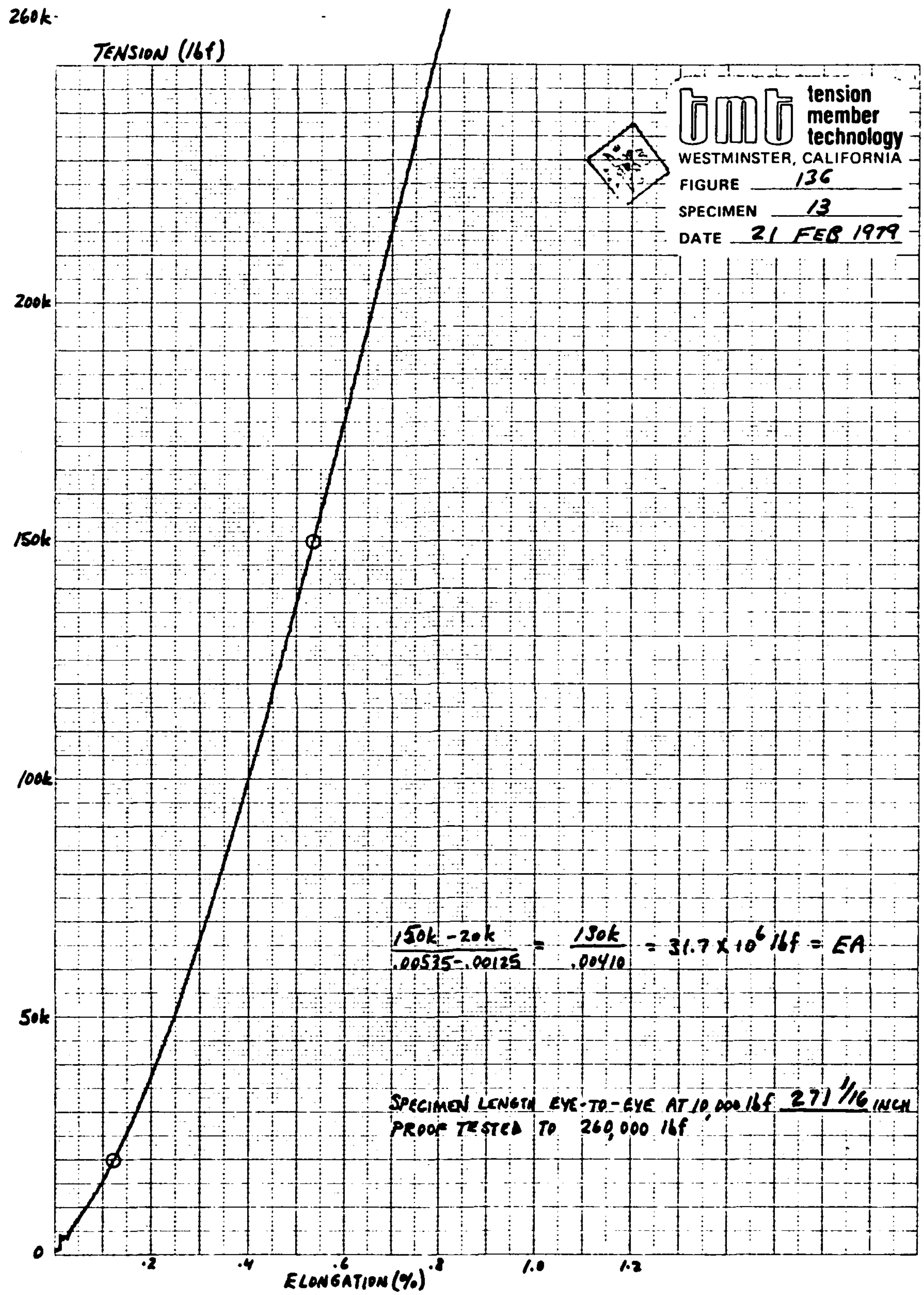
260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 132
SPECIMEN 9
DATE 21 FEB 1979
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
$\frac{150k-20k}{.00542-.00126} = \frac{130k}{.00416} = 31.3\times10^6$ lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 3/16 INCH
PROOF TESTED TO 260,000 lbf


260k
TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 133
SPECIMEN 10
DATE 21 FEB 1979
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
$\frac{150k - 20k}{.00531 - .00120} = \frac{130k}{.00411} = 31.6 \times 10^6$ lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 1/16 INCH
PROOF TESTED TO 260,000 lbf


260k
TENSION (lbf)
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 134
SPECIMEN 11
DATE 21 FEB 1979
150k-20k / .10540-.00130 = 130k / .00410 = 31.7 X10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 5/16 INCH
PROOF TESTED TO 260,000 lbf



260k
TENSION (lbf)
tension
member
technology
WESTMINSTER, CALIFORNIA
FIGURE 135
SPECIMEN 12
DATE 21 FEB 1979
200k
150k
100k
50k
0
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)
150k-20k / .00533-.00125 = 130k / .00408 = 31.9 x 10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 1/8 INCH
PROOF TESTED TO 260,000 lbf


260k
TENSION (lbf)
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 136
SPECIMEN 13
DATE 21 FEB 1979
200k
150k
100k
50k
0
150k - 20k / .00535 - .00125 = 130k / .00410 = 31.7 X 10^6 lbf = EA
SPECIMEN LENGTH EYE-TO-EYE AT 10,000 lbf 271 1/16 INCH
PROOF TESTED TO 260,000 lbf
.2
.4
.6
.8
1.0
1.2
ELONGATION (%)

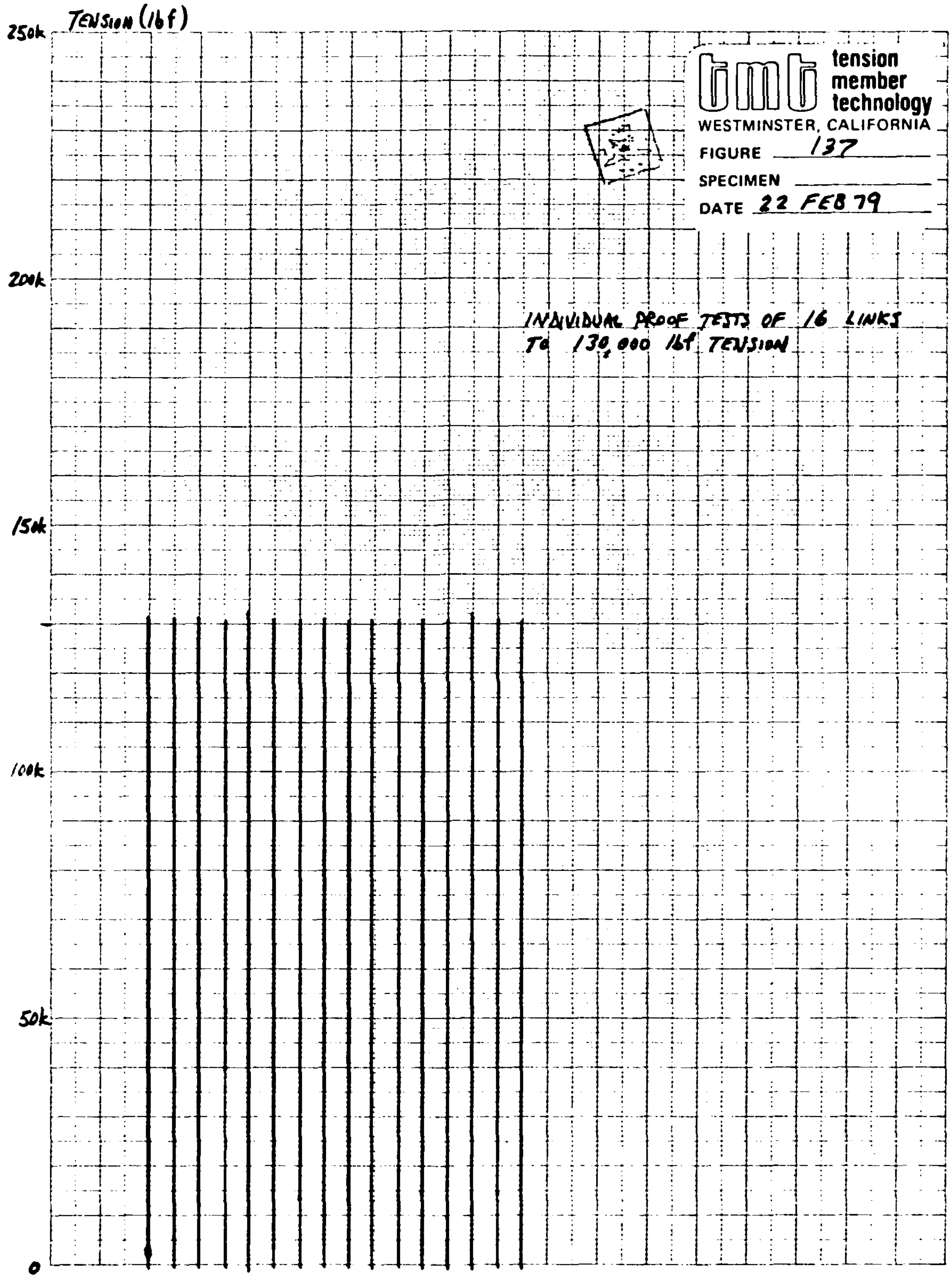

TENSION (lbf)
250k
200k
150k
100k
50k
0
tension member technology
WESTMINSTER, CALIFORNIA
FIGURE 137
SPECIMEN
DATE 22 FEB 79
INDIVIDUAL PROOF TESTS OF 16 LINKS
TO 130,000 lbf TENSION

TABLE 13. LABORATORY INSTRUMENTATION

The following is a listing of the description, model, serial number, and latest calibration date of the instrumentation used during the acceptance proof-testing.

Himmelstein System 6 Instrumentation System

Model	-	6-138
Serial Number	-	6-269.3976
Calib. Date	-	24 August 1978

Differential Elongation Sensor

Model	-	TMT-2
Serial Number	-	1
Calib. Date	-	13 February 1979

TMT Load Cell, 500,000 lbf

Model	-	1650
Serial Number	-	135
Calib. Date	-	24 August 1978

Hewlett-Packard X-Y Recorder

Model	-	HP-7044A
Serial Number	-	1605A01638
Calib. Date	-	24 April 1978

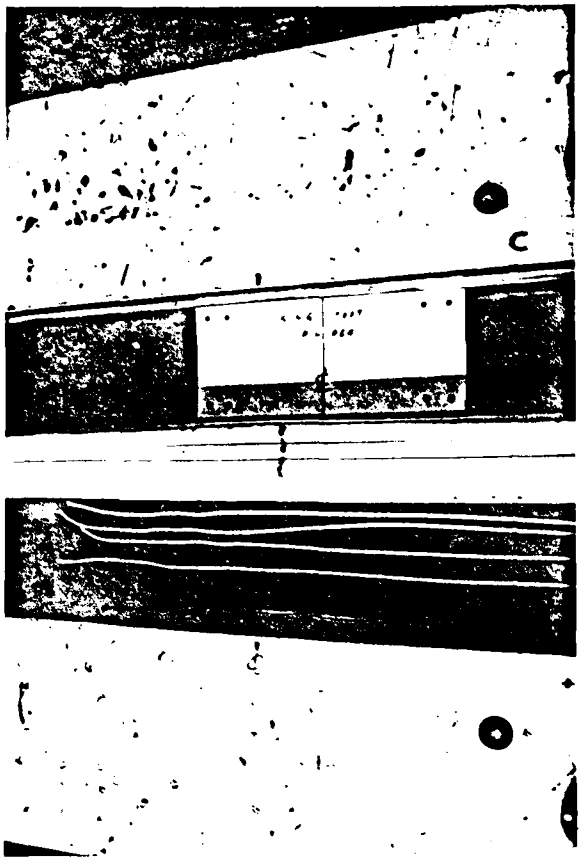


FIGURE 138.

KING POST DIVIDER AND LACES PRIOR TO INSTALLATION INTO BRIDGE CABLES

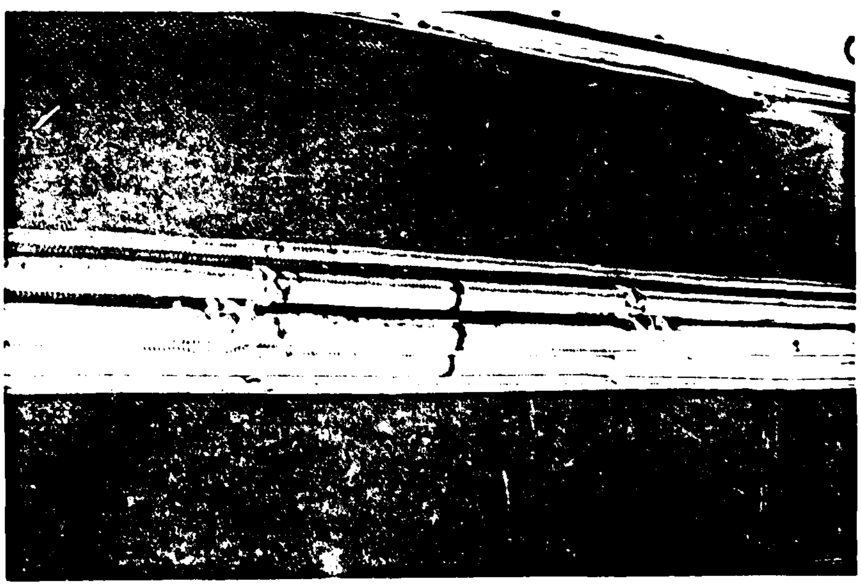


FIGURE 139. KING POST DIVIDER INSTALLED AND LACED INTO BRIDGE CABLE

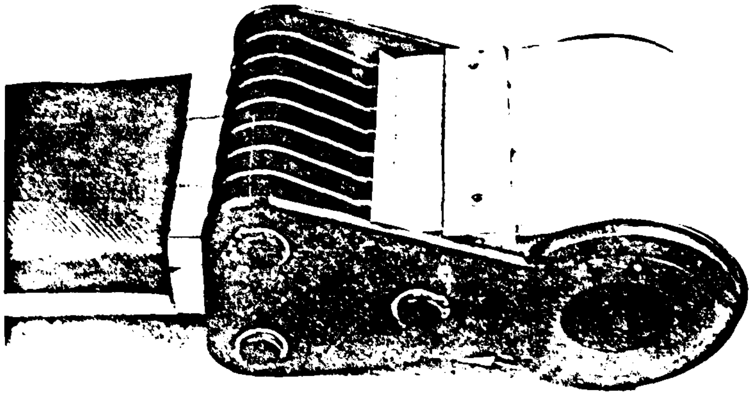


FIGURE 140. PROTECTIVE COVER INSTALLATION

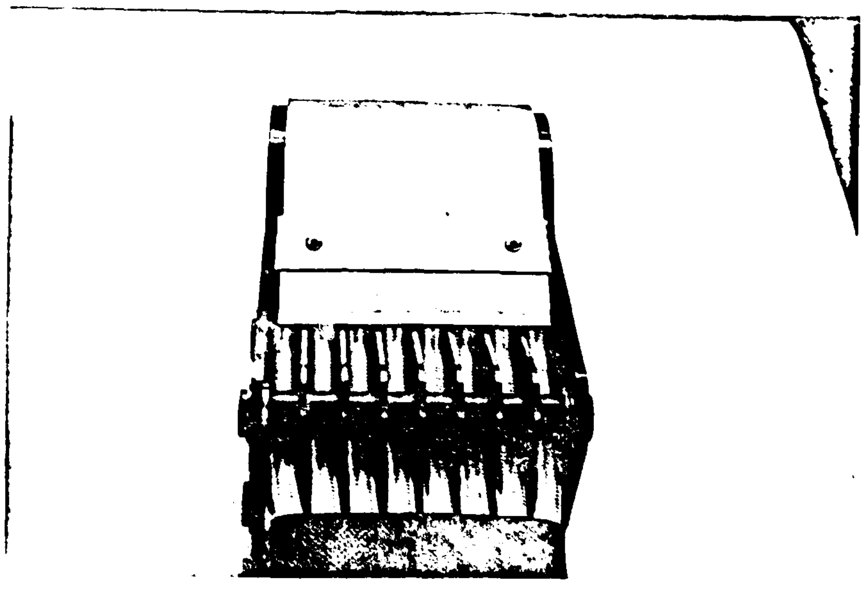


FIGURE 141. PROTECTIVE COVER INSTALLATION

APPENDIX A

SPLICING INSTRUCTIONS FROM WALL ROPE COMPANY

WALL ROPE uniline® NEW BEDFORD ROPE

Instructions for Splicing & Terminating

Uniline rope can be spliced easily and the finished job will give 100% of the break strength of the rope. The method used employs the "Chinese Finger Grip" principle. This procedure is quite different from that used for regular ropes and therefore the following instructions are offered.
TOOLS REQUIRED ARE SIMPLE: 1.sharp knife 2.flexible waterproof cement 3.heavy whipping cord or twine.

The Eye Splice

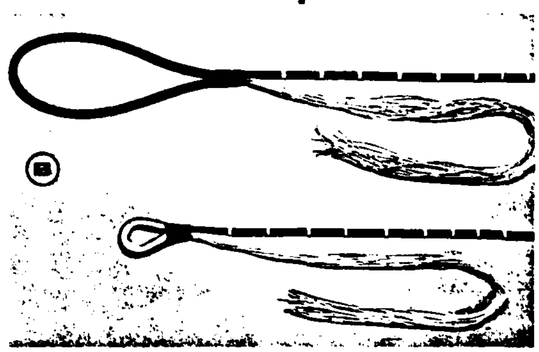
Step 1

A

REMOVE THE BRAIDED UNILINE COVER FOR A LENGTH EQUAL TO 90 TIMES THE DIAMETER OF THE ROPE. (FOR EXTREMELY HIGH LOADING OR UNUSUALLY SEVERE CONDITIONS—REMOVE 120 TIMES THE DIAMETER OF THE ROPE...ALSO RECOMMENDED FOR ROPES OVER 1½" DIAMETER). (See Table on Page 4 For Lengths).

A simple method for removing the cover is shown in PHOTOGRAPH A. It is easiest to have the rope under some tension, as between two vises. Care must be used not to damage the core yarns excessively.

Step 2



FORM THE EYE AND CLAMP OR LASH (OR FIT AROUND THIMBLE AND LASH).

NOTE: For the rest of the splicing procedure a little tension should be applied to the rope. (See Photo C).

Step 3

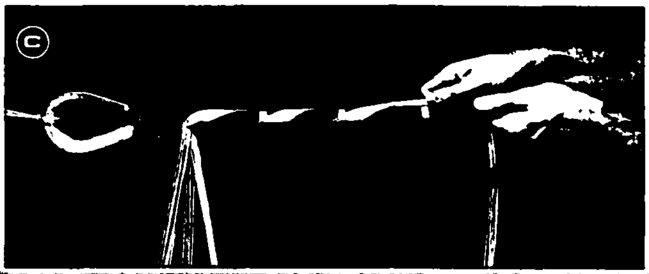
MARK OFF ROPE AS FOLLOWS: MARK 6 SPACES, EACH SPACE BEING EQUAL TO 6 TIMES THE DIAMETER OF THE ROPE — PLUS — 3 SPACES EQUAL TO 4 TIMES THE DIAMETER OF THE ROPE. (See Photo B).(See table - Page 4 for lengths)

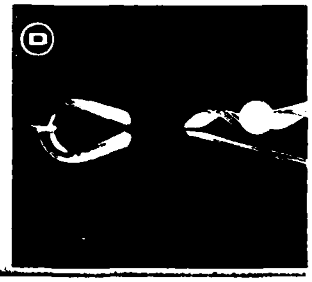
Note: For extremely high loading or unusually severe conditions (also recommended for ropes over 1½" diameter). Mark as follows:
MARK 2 SPACES, EACH SPACE BEING EQUAL TO 9 TIMES THE DIAMETER OF THE ROPE —PLUS— 6 SPACES EQUAL TO 6 TIMES THE DIAMETER OF THE ROPE—PLUS—3 SPACES EQUAL TO 4 TIMES THE DIAMETER OF THE ROPE. (See Photo B) (See Table, Page 4, For Lengths).

Step 4

SEPARATE THE CORE YARNS AND DIVIDE INTO 4 EQUAL BUNDLES.

A pair of pliers helps. Start at the bitter end.





Step 5

INDIVIDUALLY WRAP THE 4 CORE YARN BUNDLES AROUND THE ROPE TO THE LAST MARK (ONE AT A TIME AND ALTERNATELY IN OPPOSITE DIRECTIONS) SO THAT BUNDLE #1 AND #3 ARE GOING IN ONE DIRECTION AND BUNDLE #2 AND #4 ARE GOING IN THE OPPOSITE DIRECTION. MAKE SURE THAT EACH WRAP CROSSES OVER AT EACH MARK. TAPE OR LASH EACH BUNDLE AT THE LAST MARK.

Keep bundles flat when wrapping around the rope. To make a better looking job, the first and second bundles

Step 6

CUT YARN BUNDLES 1 & 2 OFF SHORT AFTER TAPING OR TYING AT THE LAST MARK.

Step 7

VERY TIGHTLY WHIP THE BARE ROPE IMMEDIATLY AFTER THE LAST MARK FOR A DISTANCE EQUAL TO APPROXIMATELY TWO TIMES THE DIAMETER OF THE ROPE. (See Photo F).

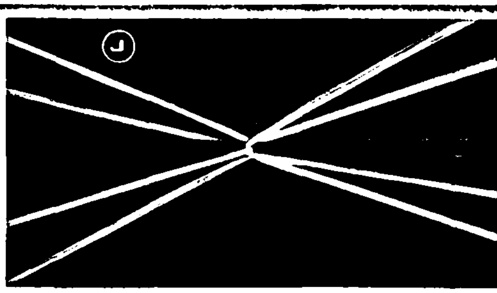
A flexible waterproof cement should be applied to the rope where it is to be whipped and again on top of the whipping. (e.g.—contact or neoprene cement)

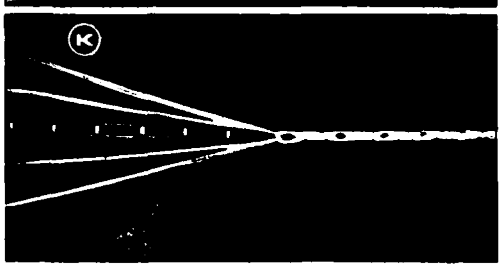
Step 8

LAY YARN BUNDLES 3 AND 4 OVER THE WHIPPING DONE IN STEP 7 AND LASH THEM SECURELY TO THE BODY OF THE ROPE BELOW THE WHIPPED SECTION FOR A DISTANCE EQUAL TO APPROX. TWO TIMES THE DIAMETER OF THE ROPE. (See Photo G)

The second whipping should start as close as possible to the end of the first whipped section. In this way any pull on the tails forms a self snubbing device. Again, an adhesive should be applied before and after whipping.

Alternately, two thicknesses of heavy duty shrink tubing or Punch Lok





The End to End Splice

[illegible]

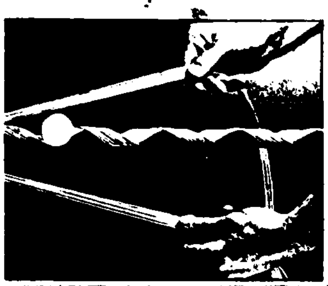
STEP 1 BOTH ENDS ARE STRIPPED BACK AS FOR THE EYE SPLICE ABOVE (See Photo A[illegible]

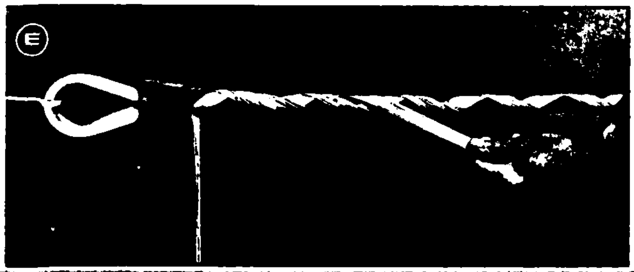
STEP 2 THE YARNS FROM EACH END ARE SEPERATED AND SEGREGATED INTO FOUR BUNDLES.

STEP 3 THE BUNDLES ARE NOW INTERMESHED SO THAT THE YARN BUNDLES ARE PASSING EACH OTHER AS SHOWN. (See Photo J)

STEP 4 THE CORE YARNS FROM ONE ROPE ARE TEMPORARILY CLAMPED OR TIED TO THE OTHER SO THAT SOME TENSION MAY BE APPLIED.

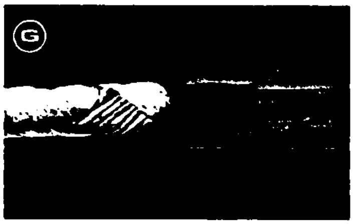
STEP 5 THE ROPES ARE NOW [illegible] AND SPLICED IN BOTH DIRECTIONS USING THE TECHNIQUE SHOWN FOR STEPS [illegible] THROUGH [illegible] UNDER THE EYE SPLICE (See [illegible]





should be wrapped so that they are slightly short of the marks. The third and fourth bundles are then wrapped next to them, slightly beyond the marks but abutting one and two. (See Photos C, D and E)

The splice at this point will develop the full strength of the rope after all wraps are in place. However, the continued holding power of the splice depends on the tails being secured to the main body of the rope; particularly if the splice is to be run over sheaves or other obstructions that might push it back. For short term emergency use or for testing purposes the tails can be wrapped one or two more times and securely taped but FOR NORMAL USE THE FOLLOWING PROCEDURES ARE RECOMMENDED:



Clamps can be used. In either case the snubbing concept described above should be maintained.

Only a few pounds of holding power are needed for tails 3 & 4 but the performance of the snubbing concept is important.

Step 9

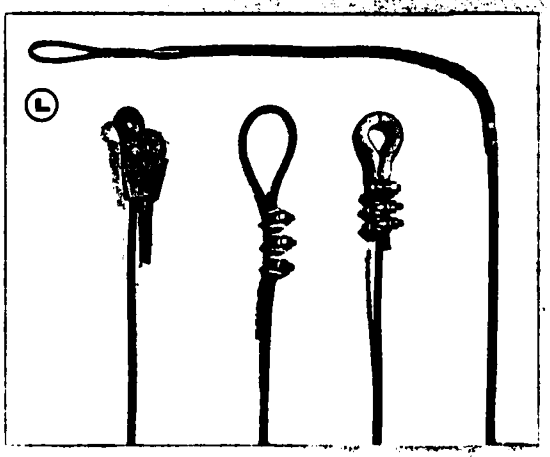
FOR PROTECTION, THE ENTIRE SPLICE SHOULD BE SERVED WITH HEAVY WHIPPING CORD OR TWINE.

When serving, neoprene or other adhesive should be applied liberally before and after serving to improve performance against abrasion. Shrink tubing or heavy tape can be used for serving if the use is not severe.

NOTE: The only purpose of this last step is to protect the splice from cutting or chafing. The choice of protection therefore depends on severity of service.

(Completed Uniline Splice)

Alternate Terminations for Uniline



A number of mechanical terminations have been used with Nylon and Polyester Uniline and have been proven more successful than with standard constructions of rope. The most successful is the KELLEMS DUA-pull GRIP manufactured by the KELLEMS DIVISION OF HARVEY HUBBELL, INC. of Stonington, Connecticut (Shown at top in Photo L). The other terminations shown in Photograph L can be used providing the working load does not exceed 20% of the breaking strength of the rope (as shown on page [illegible]). Wedge Clamp, U-Bolts, Combination Thimble Clip (left to right). U-Bolts (Wire Rope Clips) are a fast way of getting an eye on Uniline rope in the field without the use of special tools. These can be put on as tightly as possible without damage to the rope. U-Bolts, as for wire rope, should be attached with the [illegible] as in Photograph [illegible].

Note: Special [illegible] Uniline [illegible] [illegible]

Space Marks for uniline Rope Splices†

STANDARD SPLICE
6 SPACES EQUAL TO 6 x ROPE DIAMETER **PLUS** 3 SPACES EQUAL TO 4 x ROPE DIAMETER
Length of cover to be removed equal to 90 x rope diameter

SPECIAL SPLICE*
2 SPACES EQUAL TO 9 x ROPE DIAMETER **PLUS** 6 SPACES EQUAL TO 6 x ROPE DIAMETER **PLUS** 3 SPACES EQUAL TO 4 x ROPE DIAMETER
Length of cover to be removed equal to 120 x rope diameter

*To be used where extremely high loads or unusually severe conditions are anticipated. Also recommended for ropes over 1½" dia.

BREAK STRENGTH
NYLON & POLYESTER UNILINE

Size Diameter (")	Break Strength*
½	10,000
⅝	16,000
¾	23,000
⅞	31,400
1	40,900
1⅛	51,800
1¼	64,000
1⅜	77,400
1½	92,200
1⅝	108,000
1¾	125,000
2	164,000

*NOTE:
(1) Break strength for Kelvar is approx. 2½ times that of above. Above figures may vary ±5%.
(2) A 5 to 1 safety factor is recommended for Uniline.
(3) Refer to Bulletin UN-100 for weights.

SPACES CALCULATED FOR VARIOUS ROPE SIZES (IN INS.)

ROPE SIZE	ADDED FOR SPECIAL SPLICE	STANDARD SPLICE		LENGTH TO STRIP		COMPLETED SPLICE LENGTH	
	2 Spaces 9 x Dia.	6 Spaces 6 x Dia.	3 Spaces 4 x Dia.	Standard	Special	Standard	Special
3/8"	3½"	2¼"	1½"	34"	45"	20"	27"
7/16	4	2¾	1¾	40	53	24	32
1/2	4½	3	2	45	60	26	35
5/8	5½	4	2½	56	75	34	45
3/4	7	4½	3	68	90	39	53
7/8	8	5½	3½	79	105	47	63
1	9	6	4	90	120	52	70
1⅛	10	7	5	102	135	62	82
1¼	11	8	5	113	150	68	90
1⅜	12	8	6	124	165	72	96
1½	14	9	6	135	180	78	106
1⅝	15	10	7	147	195	88	118
1¾	16	11	7	158	210	94	126
2	18	12	8	180	240	104	140

†The number of wraps shown are minimum for good rope practice. In the same way that extra tucks are somtimes used in special cases for 3-strand rope splices, extra wraps can be added, if required, for Uniline. It is suggested that any extra wraps be added to the section where spaces are 4 times the rope diameter.

APPENDIX B

PHYSICAL PROPERTIES OF VASCOMAX 300 VM

VascoMax 300 VM

Physical Properties

Average Coefficient of Thermal Expansion (70° - 900°F)	5.6×10^{-6} in./in./°F
Modulus of Elasticity	27.5×10^{6} psi
Density	.289 lbs./cu. in. (8.0 g/cc)
Thermal Conductivity at 68°F	14.6 BTU/(ft)(hr)(°F)
at 122°F	14.9 BTU/(ft)(hr)(°F)
at 212°F	15.6 BTU/(ft)(hr)(°F)

Nominal Analysis

Nickel	18.50%	
Cobalt	9.00	
Molybdenum	4.80	
Titanium	.60	
Aluminum	.10	
Silicon	.10	max.
Manganese	.10	max.
Carbon	.03	max.
Sulfur	.01	max.
Phosphorus	.01	max.
Zirconium	.01	
Boron	.003	

Nominal Annealed Properties

Hardness	32 R_C
Yield Strength	110 ksi
Ultimate Strength	150 ksi
Elongation	18%
Reduction of Area	72%

Nominal Room Temperature Properties of VascoMax 300 VM after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in $4.5\sqrt{A}$ %	Reduction of Area %
¾" Round	Longitudinal	54.3	294.0	290.0	11.8	56.6
1¼" Round	Longitudinal	54.7	296.0	293.0	11.6	55.8
3" Round	Longitudinal	54.0	293.7	286.8	10.3	46.6
6" Square	Longitudinal	53.9	284.6	277.8	9.8	43.9
	Transverse	54.3	283.2	277.1	6.6	28.4
.250" Sheet	Transverse	55.1	314.6	309.7	7.7	35.0

Test Temp. °F	.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation in $4.5\sqrt{A}$ %	Reduction of Area %
600	245.6	256.8	12.0	61.8
800	227.7	240.1	14.0	61.3
900	194.8	210.9	17.3	68.4
950	172.9	189.1	22.0	76.5
1000	153.2	168.0	24.0	77.2

FIGURE 1. Effect of test temperature on the tensile properties of VascoMax 300 VM solution annealed for one hour at 1500°F., air cooled and aged three hours at 900°F.

Condition	Compressive Strength		Rockwell "C" Hardness
	Proportional Limit ksi	0.2% Offset Yield Strength ksi	
Solution Annealed	105.0	150.0	31.0
Aged	272.0	317.5	53.5

FIGURE 3. Samples solution annealed for 30 minutes at 1500°F., air cooled and aged 3 hours at 900°F. as indicated. Average of 3 tests per condition.

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	426.0	422.6 - 432.3	1.45
3.0	420.5	419.4 - 421.8	1.43
5.0	417.9	411.3 - 427.4	1.42
6.25	418.4	412.9 - 423.4	1.42
7.0	414.0	403.9 - 425.8	1.41
9.0	420.3	411.3 - 423.4	1.43

*Based on smooth bar tensile strength of 293.5 ksi.

FIGURE 2. Effect of stress concentration factor, K_t, on the tensile properties of VascoMax 300 VM solution annealed for one hour at 1500°F., air cooled and aged three hours at 900°F.

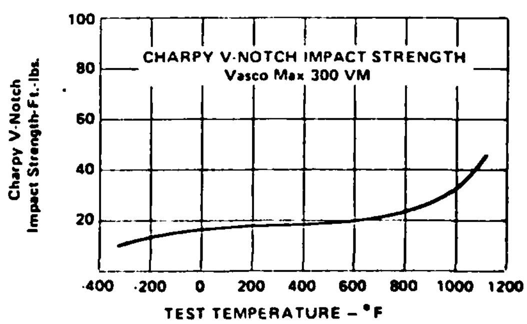


FIGURE 4. Effect of test temperature on the Charpy V-Notch impact strength of VascoMax 300 VM. All specimens solution annealed at 1500°F. for 30 minutes, air cooled and aged at 900°F. for 3 hours.

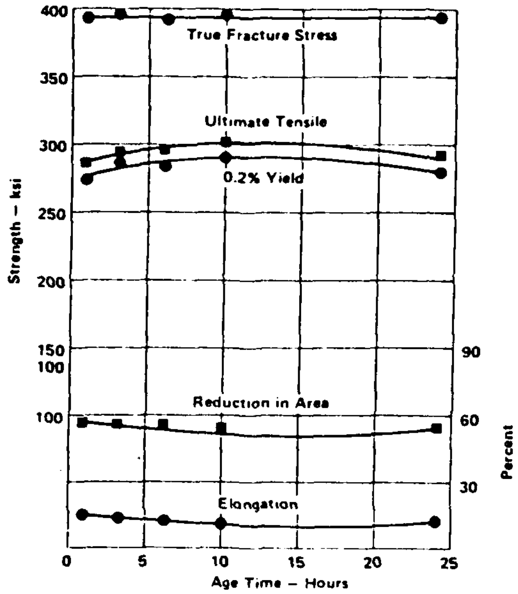


FIGURE 5. Effect of aging time at 900°F. on the tensile properties of VascoMax 300 VM. Specimens were solution annealed for 30 minutes at 1500°F., air cooled and aged at 900°F. for the times indicated.

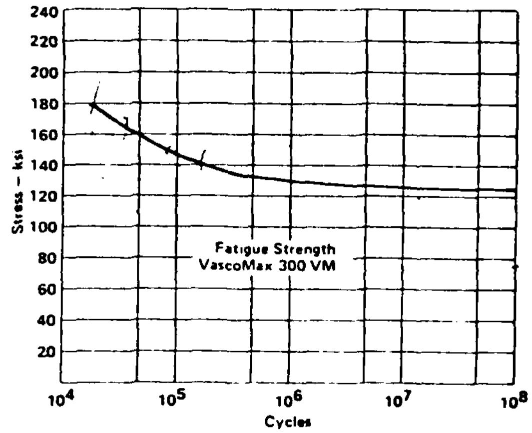


FIGURE 6. R.R. Moore rotating beam fatigue tests on production bar stock of VascoMax 300 VM. All samples solution annealed at 1500°F. for 30 minutes, air cooled and aged at 900°F. for 3 hours.

All data pertains to bars of small cross section unless stated otherwise.

Effect of Various Aging Treatments on the Tensile Properties of .125" Thick VascoMax 300 VM Sheet*

Solution Annealing Temperature °F	Aging Temperature °F	Aging Time Hours	.2% Offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation, % in. 1"	Elongation, % in. 2"	Reduction of Area %
1500	850	3	294.8	309.5	7.0	3.5	34.2
1500	900	1	296.9	306.7	8.2	4.2	38.6
1500	900	3	313.9	316.8	6.8	3.4	32.5
1500	900	6	314.2	321.2	7.5	3.7	33.2
1500	950	3	305.6	308.1	8.0	4.0	33.6

*Standard ASTM sheet tensiles solution annealed for 30 minutes at the indicated temperatures, air cooled and aged as shown.

FIGURE 7.

Effect of Sheet Thickness on the Tensile Properties*

Sheet Thickness Inches	.2% Offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation, % in.** 1"	Elongation, % in.** 2"
.250	315.1	320.8	9.0	5.0
.125	313.9	316.8	6.8	3.4
.090	308.2	312.7	6.0	3.2
.065	301.4	307.2	5.0	3.0
.045	291.9	295.0	4.0	2.0
.025	294.0	296.0	2.0	1.0

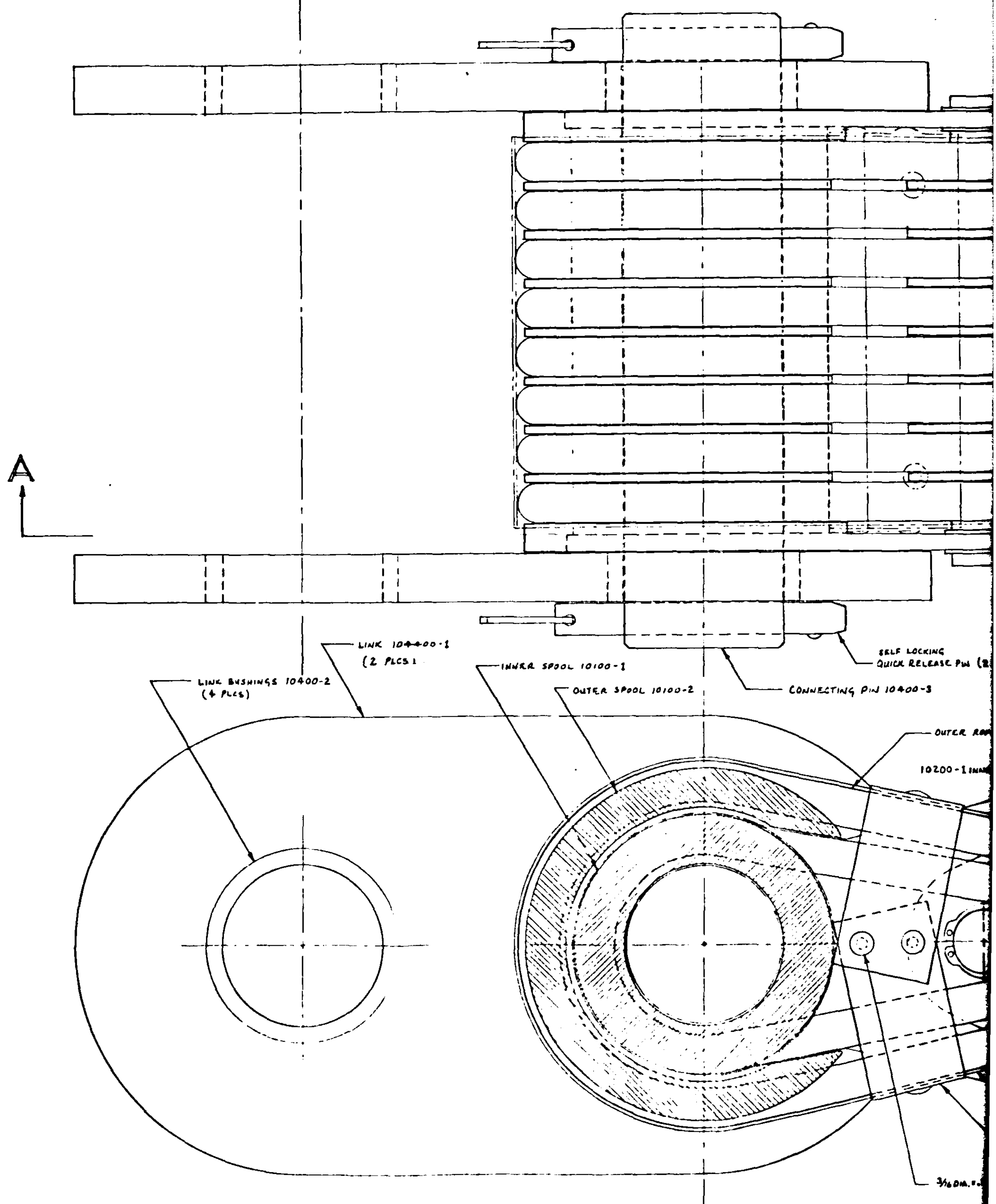
*Standard ASTM sheet tensiles solution annealed at 1500°F. for 15 minutes, air cooled and aged 3 hours at 900°F

**The change in elongation with thickness is not caused by a change in material ductility, but is due to changing the geometry of the test specimen. For correct elongation measurements a gage length of $4.5\sqrt{A}$ should be used; not a fixed 1" or 2" gage length.

FIGURE 8.

APPENDIX C

DRAWINGS OF DELIVERABLE BRIDGE
REINFORCEMENT CABLE ASSEMBLIES



SECTION A-A

C-1

REVISIONS				
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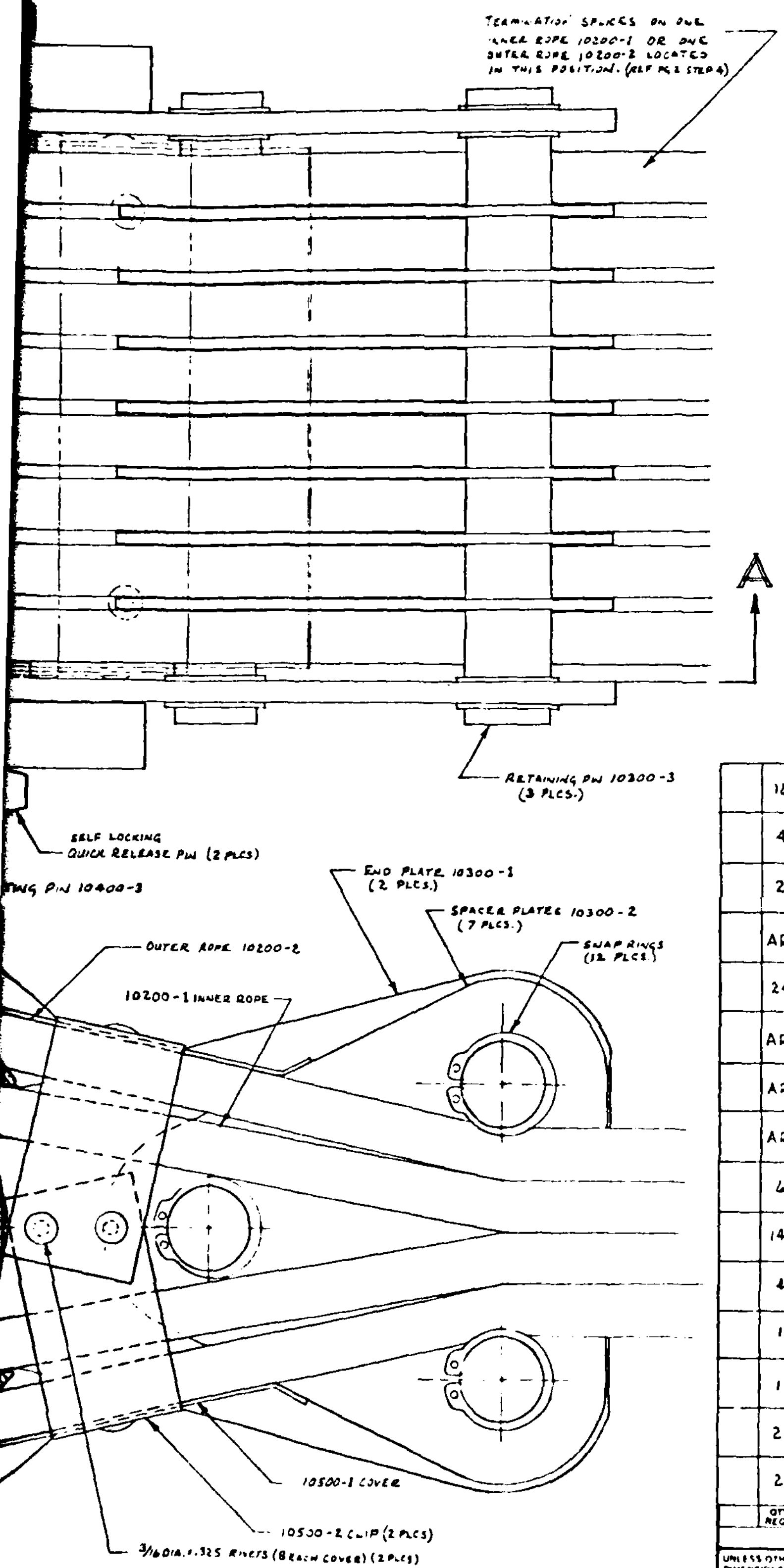

	QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	
	16			RIVETS, 3/16 IN. DIA x .325 DOMED BLIND	STAINLESS STEEL	
	4		10500-2	CLIP	304 STAINLESS STEEL	
	2		10500-1	COVER	304 STAINLESS STEEL	
	AR			SELF LOCKING PINS 98320A515, 1/2 IN. DIA x 3.5 IN. GRIP LENGTH	CADMIUM PLATED STEEL	
	24			TRUARC RETAINING RINGS 5160-98-S-ZD OR 5160-98-S-MF	STEEL - CAD PLATE OR ANOD.	
	AR		10400-3	CONNECTING PIN	CVM VASCOMAX 300	
	AR		10400-2	LINK BUSHING	LASALLE 1144 HI STRESS RD.	
	AR		10400-1	LINK	CVM VASCOMAX 300	
	6		10300-3	RETAINING PIN	6061-T651 AL.	
	14		10300-2	SPACER PLATE	7075-T651 AL.	
	4		10300-1	END PLATE	6061-T651 AL.	
	1		10200-2	OUTER ROPE	5/8 IN. DIA KEVLAR 49	
	1		10200-1	INNER ROPE	5/8 IN. DIA KEVLAR 49	
	2		10100-2	OUTER SPOOL	6061-T6511 AL.	
	2		10100-1	INNER SPOOL	6061-T6511 AL.	

PARTS LIST

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
.XX
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MATERIAL
FINISH
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CONTRACT NO

APPROVALS	DATE
DRAWN H. WOLFE	3/7/73
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ISSUED	

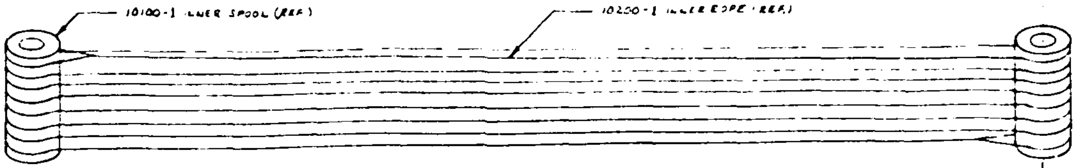
tmt tension member technology
15961 golden west circle westminster california 92683 (714) 898 5641

BRIDGE ROPE ASSY.

SIZE D | FSCM NO | DWG NO 10200 | REV
SCALE | SHEET 1 OF 2

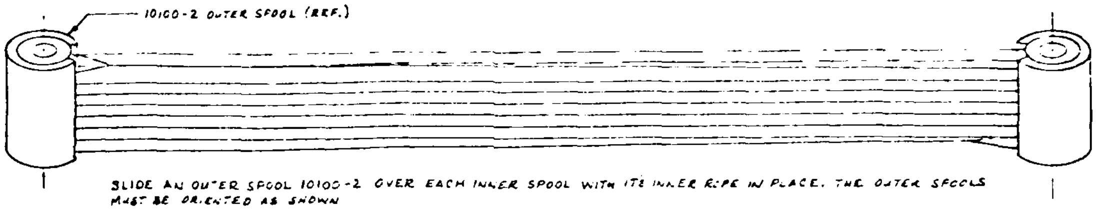
BRIDGE ROPE ASSEMBLY INSTRUCTIONS

1



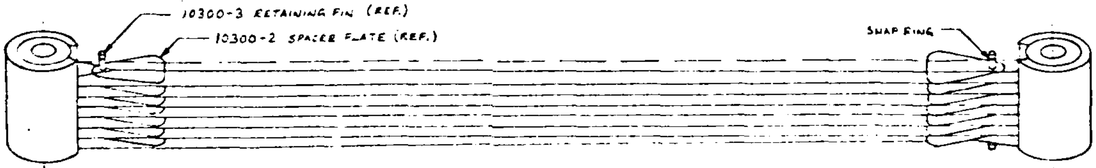
INSTALL AN INNER SPOOL 10100-1 INSIDE EACH END OF AN INNER ROPE 10200-1. FORCE THE ROPE STRANDS INTO EACH RESPECTIVE GROOVE AS FAR AS POSSIBLE. CARE SHOULD BE EXERCISED NOT TO CROSS ANY STRANDS

2



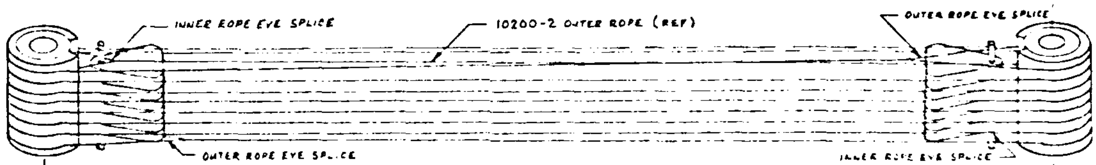
SLIDE AN OUTER SPOOL 10100-2 OVER EACH INNER SPOOL WITH ITS INNER ROPE IN PLACE. THE OUTER SPOOLS MUST BE ORIENTED AS SHOWN

3



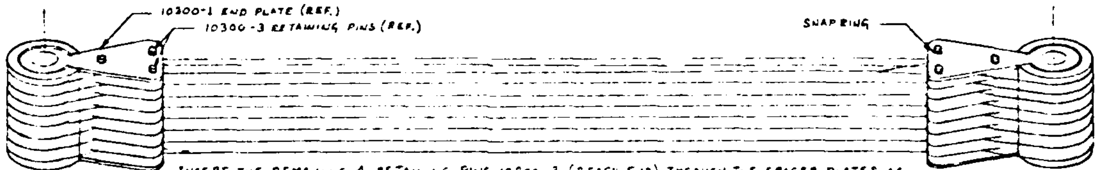
POSITION SEVEN SPACER PLATES 10300-2 BETWEEN THE INNER ROPE STRANDS AT EACH END AS SHOWN. INSERT THE INSIDE RETAINING PINS 10300-3, ONE AT EACH END, THROUGH THE SPACER PLATES AND BETWEEN THE STRANDS OF THE INNER ROPE. INSTALL THE INNER 4 SNAP RINGS.(2 EACH PIN)

4



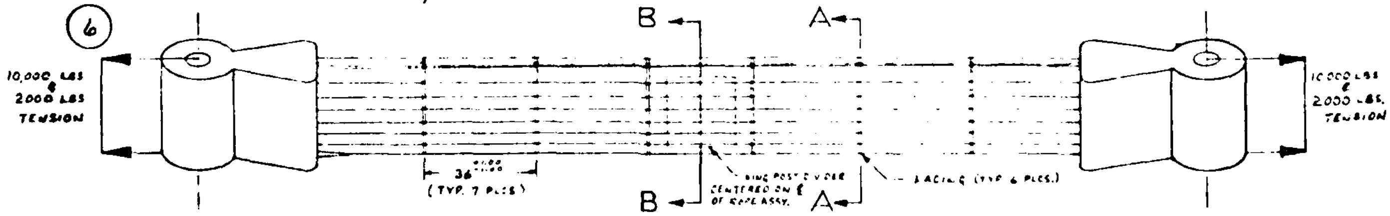
POSITION AN OUTER ROPE 10200-2 OVER AND INTO THE OUTER SPOOL GROOVES. INSERT THE OUTER ROPE STRANDS BETWEEN THE RESPECTIVE SPACER PLATES AND IN AGAINST THE INNER ROPE STRANDS. CARE MUST BE EXERCISED NOT TO CROSS ANY STRANDS AND TO ORIENT THE OUTER ROPE EYE SPLICES OPPOSITE THE INNER ROPE EYE SPLICES.

5



INSERT THE REMAINING 4 RETAINING PINS 10300-3 (2 EACH END) THROUGH THE SPACER PLATES AS SHOWN AND SECURE THE INNER AND OUTER ROPE STRANDS BETWEEN THESE PINS. INSTALL THE 8 REMAINING INNER SNAP RINGS ON THE RETAINING PINS. POSITION THE 4 END PLATES 10300-1 (2 EACH END) INSIDE THE OUTER SPOOL RECESS AND OVER THE RETAINING PINS. INSTALL THE 12 OUTER SNAP RINGS TO THE 6 RETAINING PINS AS SHOWN THEREFORE SECURING THE INNER ROPE, OUTER ROPE, INNER SPOOL, OUTER SPOOL, SPACER PLATES, END PLATES, AND RETAINING PINS INTO ONE COMPOSITE ROPE ASSEMBLY OF 2 END FITTINGS WITH 5/8 IN 24 KEVLAR ROPE TENSION MEMBERS INBETWEEN.

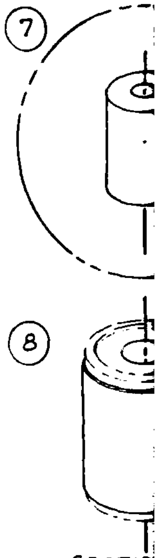
6



INSTALL THE ROPE ASSEMBLY IN A LOADING FRAME. WITH APPROXIMATELY A 10,000 LB TENSION LOAD ADJUST THE INDIVIDUAL STRANDS TO INSURE EQUAL LOAD SHARING IN ALL THE STRANDS. AT A 2000 LB TENSION LOAD LACE THE KEVLAR ROPE STRANDS TOGETHER AS SHOWN IN SECTION A-A, 6 SEPERATE LACINGS IN THE 7 EQUAL SPACES BETWEEN THE END FITTINGS. INSTALL AND FIX THE KINGPOST DIVIDER IN THE CENTER OF THE ROPE ASSEMBLY AS SHOWN IN SECTION B-B AND SECTION C-C. WITH NO TENSION LOAD ON THE ASSEMBLY REMOVE ALL SLACK IN THE 6 LACINGS. TERMINATE THE LACINGS WITH A SQUARE KNOT. TRIM AND FUSE WITH HEAT THE SQUARE KNOT ENDS AS SHOWN IN SECTION A-A.

7

8



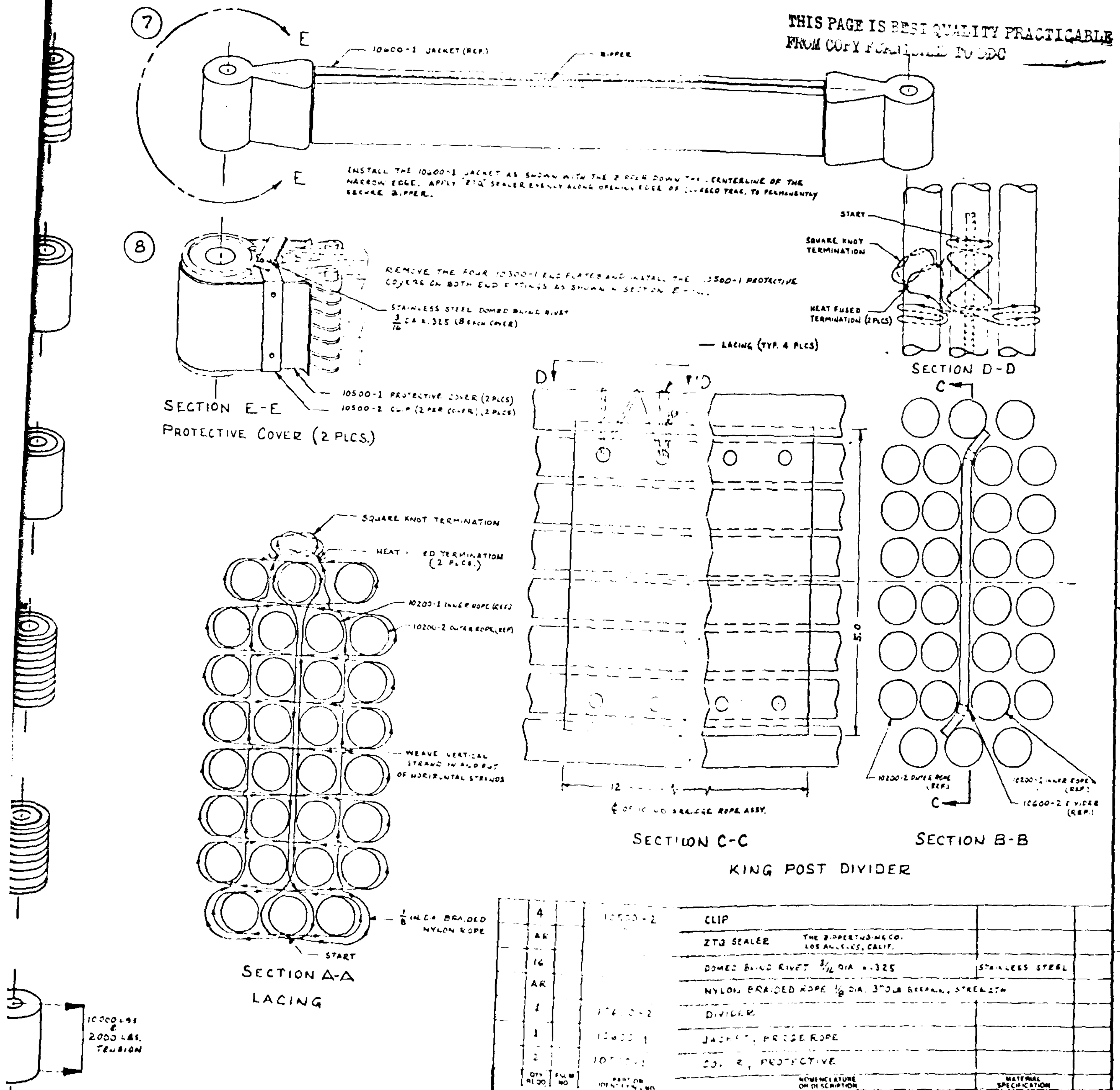
SECTIO

PROTECT

C-2

ZONE	REV	DESCRIPTION	DATE	APPROVED

REVISIONS



QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION		MATERIAL SPECIFICATION
4		10500-2	CLIP		
AR			ZTQ SEALER	THE ZIPPERTUBING CO. LOS ANGELES, CALIF.	
16			DOMED BLIND RIVET 3/16 DIA x .325		STAINLESS STEEL
AR			NYLON BRAIDED ROPE 1/8 DIA. 3700 LB BREAKING STRENGTH		
1		10600-2	DIVIDER		
1		10600-1	JACKET, BRIDGE ROPE		
2		10500-1	COVER, PROTECTIVE		

PARTS LIST

NEXT ASSY	USED ON
APPLICATION	

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MATERIAL

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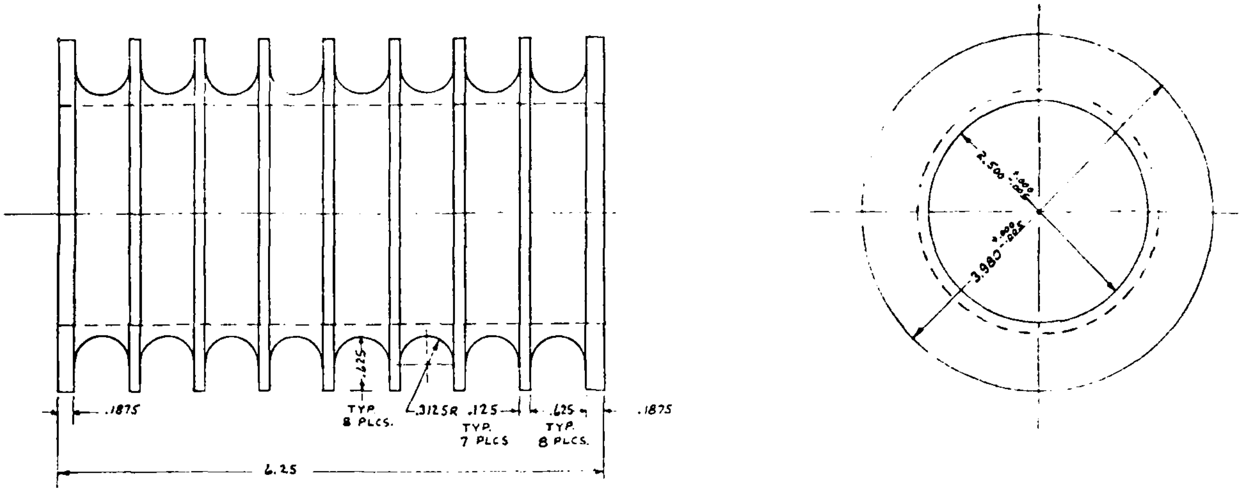
CHECKED		
ISSUED		

tension member technology
15161 Golden West Circle, Westminster, California 92683, (714) 898-5641

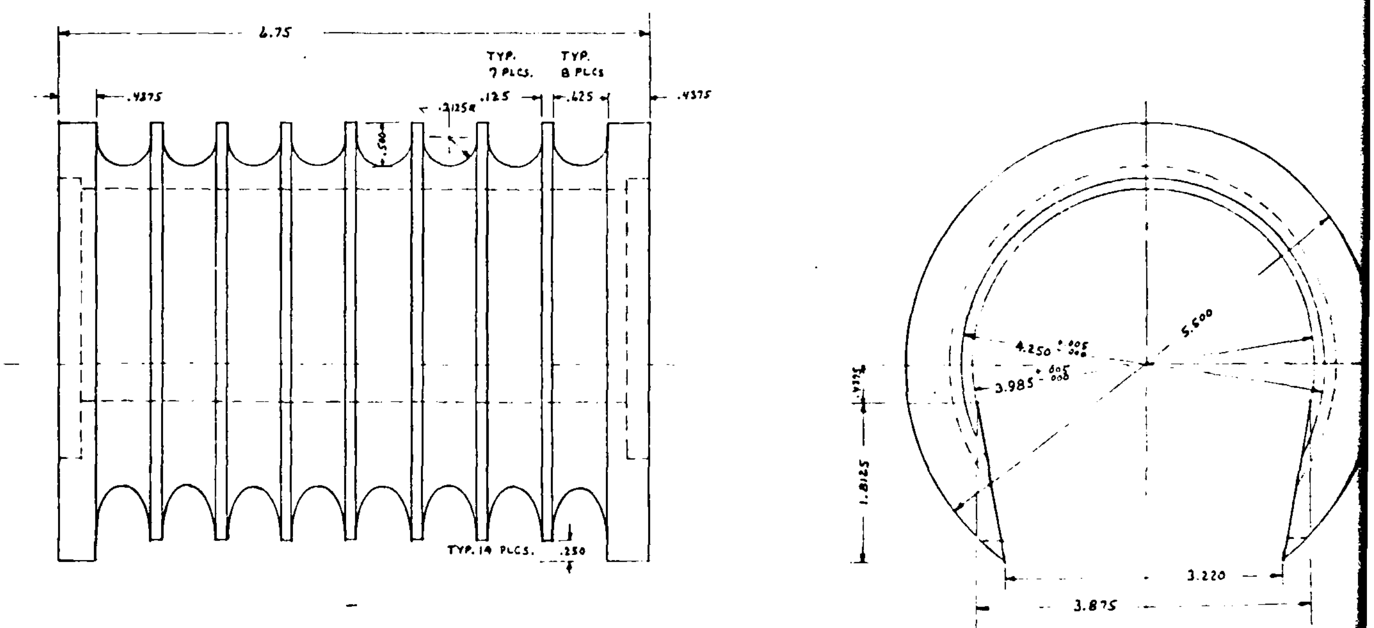
BRIDGE ROPE ASSY.

SIZE D | FSCM NO | DWG NO 1 | REV

SCALE | SHEET 2 OF 2



-1 INNER SPOOL



-2 OUTER SPOOL

AD-A086 058 TENSION MEMBER TECHNOLOGY WESTMINSTER CA F/G 11/9
MILITARY ADAPTATION OF KEVLAR FOR PORTABLE BRIDGE REINFORCEMENT--ETC(U)
JUN 80 H D WOLFE, P T GIBSON DAAK70-78-C-0024

UNCLASSIFIED NL

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END
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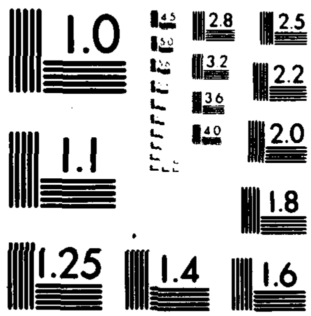
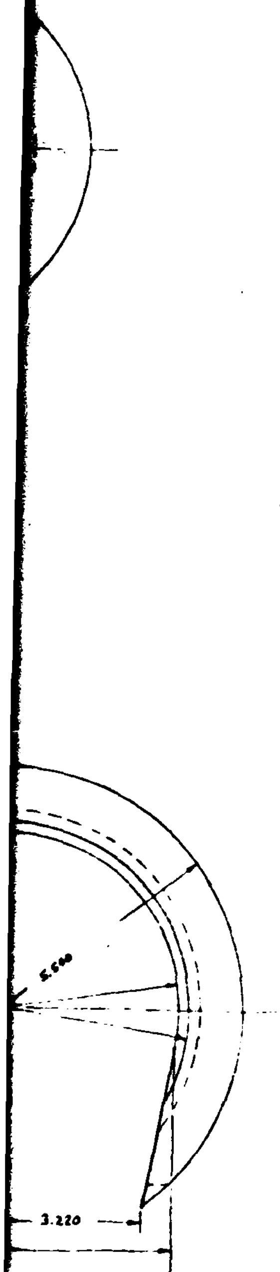


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A



NOTES:

REMOVE ALL BURRS AND SHARP EDGES.

HARD ANODIZE ALL PARTS PER MIL-A8625 TYPE III WITH DICROMATE SEAL.

IDENTIFY ALL PARTS WITH A RUBBER STAMP AND 73X SERIES BLACK MARKING INK

...PRACTICABLE
FROM ...DDC

	QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	
	2		-2	OUTER SPOOL	6061-T6511 AL	
	2		-1	INNER SPOOL	6061-T6511 AL	

PARTS LIST

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10000	

APPLICATION

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MATERIAL: 6061-T6511 AL

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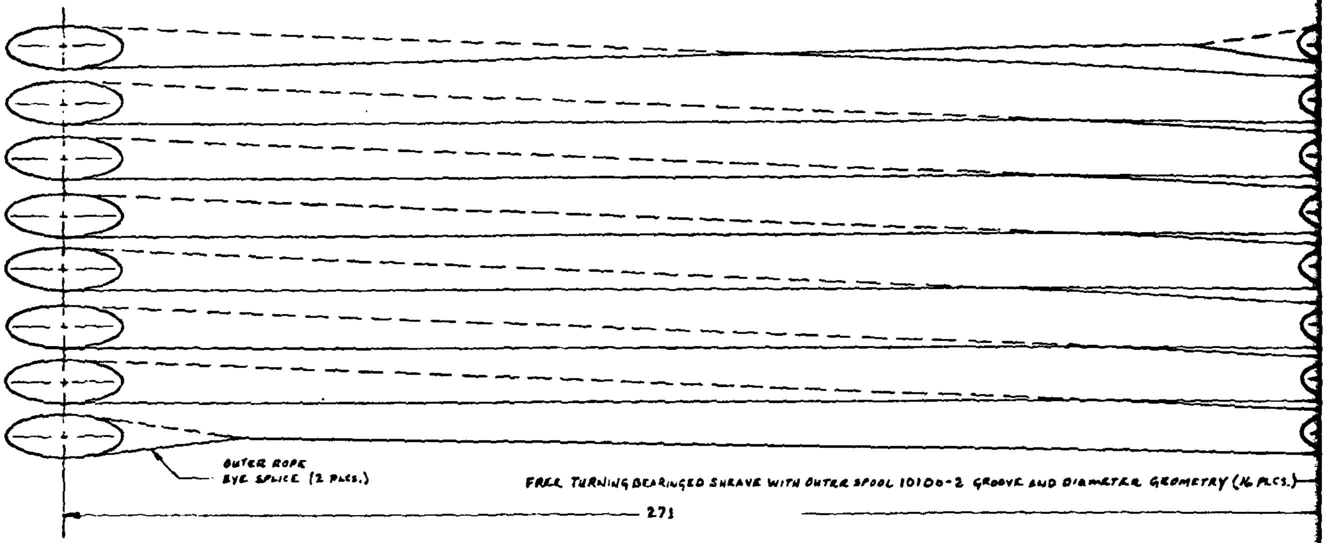
tension member technology
15161 golden west circle westminster california 92683 (714) 898 5641

SPOOL, INNER
SPOOL, OUTER

SIZE: D | FSCM NO | DWG NO: 10100 | REV

SCALE: 1 | SHEET 1 OF 1



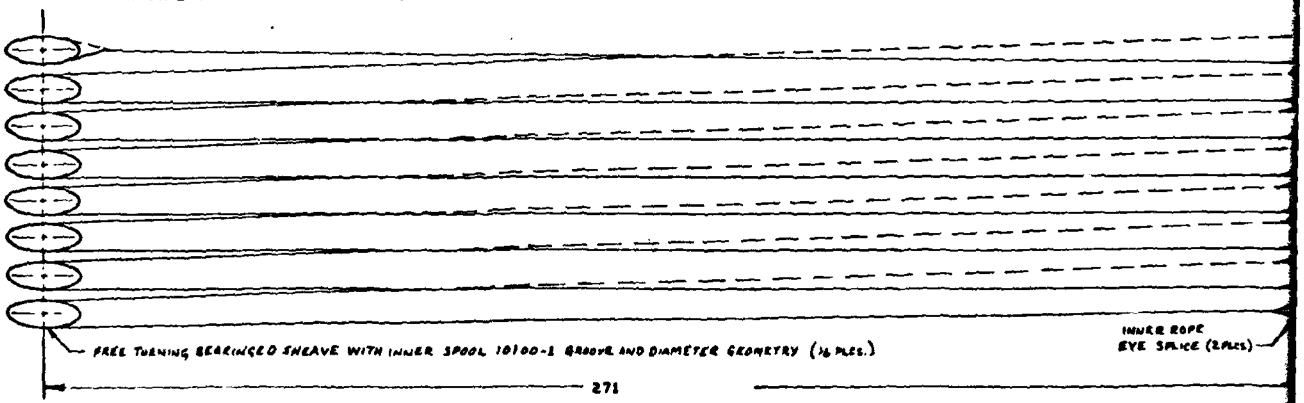
OUTER ROPE 10200-2

SUGGETED METHOD OF ASSEMBLY FOR 10200-1 AND 10200-2 ROPES.

A. PERFORM AN EYE SPLICE PER EYE SPLICE INSTRUCTIONS ON THE MINILINE FREE END FROM THE SUPPLY SPOOL. TRANSFER THE MINILINE SUPPLY TO TWO STACKS OF 8 INTERMEDIATE BEARINGED SHEAVE ASSEMBLIES WHICH REPRESENT THE INNER SPOOL 10100-1 OR OUTER SPOOL 10100-2. THE SHEA[VE] ASSEMBLIES SHOULD BE POSITIONED ON PINS APPROX. 270 ½ IN. APART. ON THE FINAL MINILINE WRAP SUFFICIENT LENGTH MUST REMAIN TO CLAMP WHILE ESTABLISHING FINAL CENTERLINE DIMENSION OF 270 ¾ IN. AT A TENSION OF 5000 LBS., AND ALSO TO PERFORM THE CONCLUDING EYE SPLICE. CARE MUST BE EXERCISED NOT TO [IN]DUCE TWIST IN THE MINILINE IN THESE OPERATIONS. END PLATES 10300-1, SPACER PLATES 10300-2, AND RETAINING PINS 10300-3 SHOULD BE POSITIONED AT THE OF THE ROPE WHICH REPRESENT THE FINAL END FITTING CONFIGURATION. FOR THE 10200-1 ROPE ASSEMBLY DUMMY 5/8 IN DIA. SPACER ROPES 12 IN LONG ARE P[LACED] BETWEEN SPACER PLATES, OUTER RETAINING PINS, AND THE 10200-2 ROPE STRANDS. THESE DUMMY ROPES REPRESENT THE 10200-2 ROPE DIMENSION ON FI[NAL]

B. POISTION THE TWO STACKS OF SHEAVES, ROPE, AND HARDWARE IN A LOAD FRAME CAPABLE OF APPLYING A TENSION LOAD OF 75000 LBS. BETWEEN THE SHEAVE CENTERLINES, AND KEEPING THE CENTERLINES PARALEL TO EACH OTHER.

C. THROUGH A TRIAL AND ERROR PROCESS OF CLAMPING AND REPOSITIONING THE FREE END OF THE MINILINE AND WITH A TENSION OF 5000 LBS. APPLIED BETW[EEN] THE SHEAVE CENTERLINES ESTABLISH THE DESIRED CENTERLINE DIMENSION OF 270¾ IN.. DURING THIS PROCEDURE THE INDIVIDUAL ROPES MAY BE DE[...] TO ASSURE A UNIFORM LOAD IN EACH STRAND.



INNER ROPE 10200-1

D. CLAMP OR MARK THE MINILINE FREE END RELATIVE TO THE STRAND IT IS TO BE EYE SPLICED TO. PERFORM THE SPLICE PER EYE SPLICE INSTR[UCTIONS] TO COMPLETE THE CONTINUOUS MINILINE ROPE 10200-1 OR 10200-2.

E. WHILE STILL IN THE LOAD FRAME APPLY A CONSTANT LOAD OF 75,000 LBS. TENSION FOR A PERIOD OF 16 TO 18 HOURS TO REMOVE CONSTRUCTIONAL ST[RETCH]. THE ROPE IS NOW READY FOR FINAL ASSEMBLY ON THE 10100-1 OR 10100-2 SPOOLS.

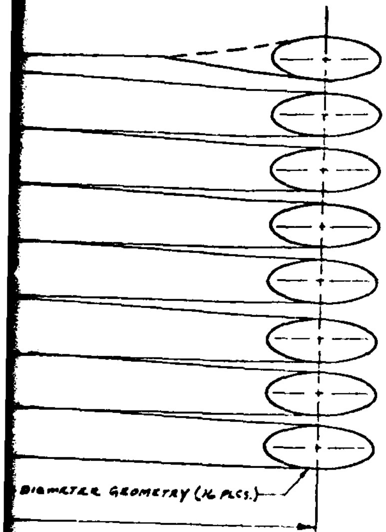
F. CLAMPING THE STRANDS AT BOTH ENDS BETWEEN WOODEN BLOCKS WILL HELP PRESERVE THE STRAND TO STRAND RELATIONSHIP WHILE REMOVING ASSEMBLY SHEAVES AND STORAGE PRIOR TO FINAL ASSEMBLY ON THE SPOOLS. IT IS RECOMMENDED THAT EACH INNER AND OUTER ROPE BE IDENT[IFIED] FOR MATCHING INNER AND OUTER ROPE ASSEMBLIES FROM THE SAME MINILINE SUPPLY REEL OR PRODUCTION RUN.

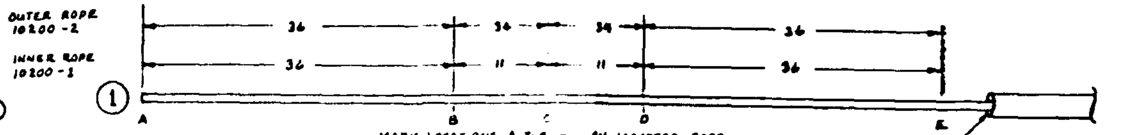
G. ADDITIONAL PROCEDURE AND ASSEMBLY TECHNIQUES ARE DESCRIBED AND PHOTOGRAPHICALLY DISPLAYED IN TENSION MEMBER TECHNOLOGY REPORT NO.

C-4

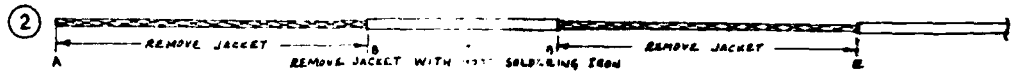
ZONE	REV	REVISIONS DESCRIPTION	DATE	APPROVED

EYE SPLICE 5/8 in. MINILINE

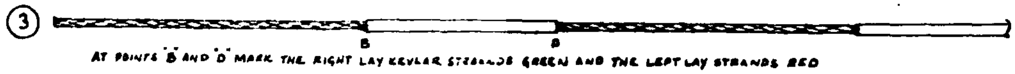




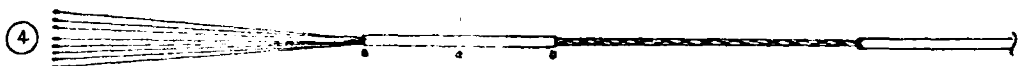
MARK LOCATIONS A-THRU-E ON JACKETED ROPE
POSITION A 40 in. SECTION OF 1.0 in. DIA POLYOLEFIN SHRINK TUBING AHEAD OF SPLICE



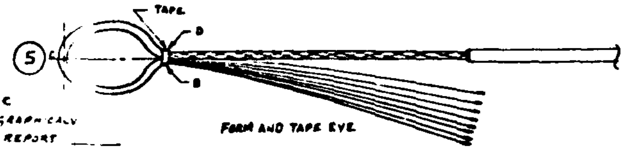
REMOVE JACKET WITH HOT SOLDERING IRON



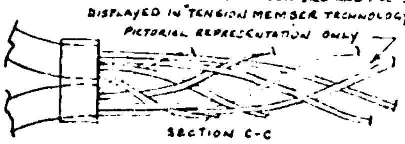
AT POINTS "B" AND "D" MARK THE RIGHT LAY KEVLAR STRANDS GREEN AND THE LEFT LAY STRANDS RED

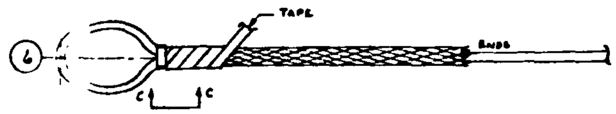


SEPARATE THE KEVLAR STRANDS INTO 8 GROUPS OF TWO EACH AND TAPE THE ENDS WITH ELECTRICAL TAPE

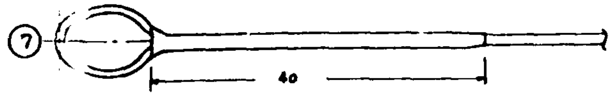


COMPLETE BRAID SPLICE TUCKING TECHNIQUE AND PROCEDURES ARE DESCRIBED AND PHOTOGRAPHICALLY DISPLAYED IN "TENSION MEMBER TECHNOLOGY" REPORT ——





MAKE 12 TUCKS STARTING AT POINTS B-D — BEGINNING WITH A GREEN STRAND AND ALTERNATING GREEN AND RED STRANDS IN ORDER. MILK THE SLACK OUT OF THE SPLICE AND PULL ON ENDS OF STRANDS. ENSURE PROPER EYE ORIENTATION AND TAPE ENTIRE SPLICE WITH ELECTRICAL TAPE.

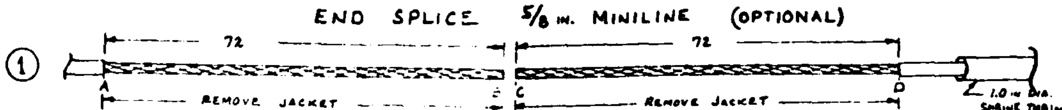


SLIDE THE PREVIOUSLY POSITIONED 40 in. SECTION OF 1.0 in. DIA POLYOLEFIN SHRINK TUBING OVER THE ENTIRE SPLICE, SHRINK THE TUBING TO THE SPLICE GEOMETRY BY HEATING. THIS COMPLETES THE KEVLAR MINILINE EYE SPLICE.

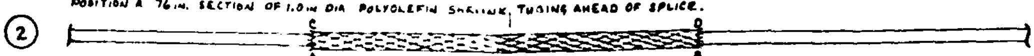
TRANSFER THE MINILINE SUPPLY SPOOL
...TER SPOOL 10100-2. THE SHEAVE
...N TO CLAMP WHILE ESTABLISHING THE
... CARE MUST BE EXERCISED NOT TO INTRO-
... SHOULD BE POSITIONED AT THE ENDS
... SPACER ROPES 12 in. LONG ARE PLACED
10200-2 ROPE DIMENSION ON FINAL ASSY.
... OF 75000 LBS. BETWEEN THE PIN

...SION OF 5000 LBS. APPLIED BETWEEN
...R INDIVIDUAL ROPES MAY BE DEFLECTED

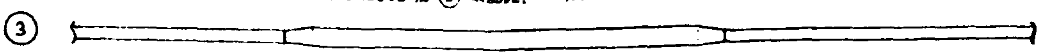
END SPLICE 5/8 in. MINILINE (OPTIONAL)



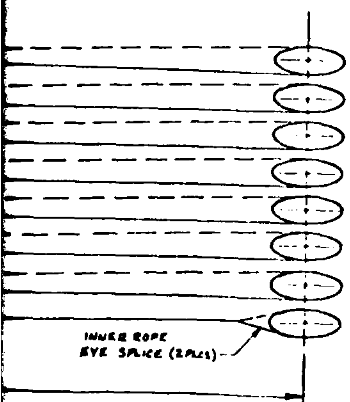
REMOVE JACKET WITH HOT SOLDERING IRON — AT POINTS . AND "D" MARK THE RIGHT LAY KEVLAR STRANDS GREEN AND LEFT LAY RED.
POSITION A 76 in. SECTION OF 1.0 in. DIA POLYOLEFIN SHRINK TUBING AHEAD OF SPLICE.



SEPARATE THE KEVLAR STRANDS INTO 8 GROUPS OF TWO EACH AND TAPE THE ENDS WITH ELECTRICAL TAPE AS IN (4) ABOVE
PERFORM THE BRAID SPLICE AS DESCRIBED IN (5) ABOVE. — TAPE ENTIRE SPLICE WITH ELECTRICAL TAPE AS IN (6) ABOVE.



SLIDE THE PREVIOUSLY POSITIONED 76 in. SECTION OF 1.0 in. DIA. POLYOLEFIN SHRINK TUBING OVER THE ENTIRE SPLICE. SHRINK THE TUBING TO THE SPLICE GEOMETRY BY HEATING. THIS COMPLETES THE KEVLAR MINILINE END SPLICE.



...LICE PER EYE SPLICE INSTRUCTIONS,
... REMOVE CONSTRUCTIONAL STRETCH.
...ATIONSHIP WHILE REMOVING THE
... AND OUTER ROPE BE IDENTIFIED TO
...MBER TECHNOLOGY REPORT NO. ——

PARTS LIST

	QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION
	AR			PVC ELECTRICAL INSULATING TAPE	7 MIL x 3/4 in.
	AR			HEAT SHRINK TUBING 1.0 in. DIA.	WHITE POLYOLEFIN SP301
	1		10200-2	OUTER ROPE ASSY.	5/8 in. DIA KEVLAR 49 MINILINE
	1		10200-1	INNER ROPE ASSY.	5/8 in. DIA KEVLAR 49 MINILINE

NEXT ASSY	USED ON
10000	
APPLICATION	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
.XX
.XXX

MATERIAL: KEVLAR 49 MINILINE

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS		DATE
DRAWN	N WOLFE	3/7/77
CHECKED		
ISSUED		

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... California 92683
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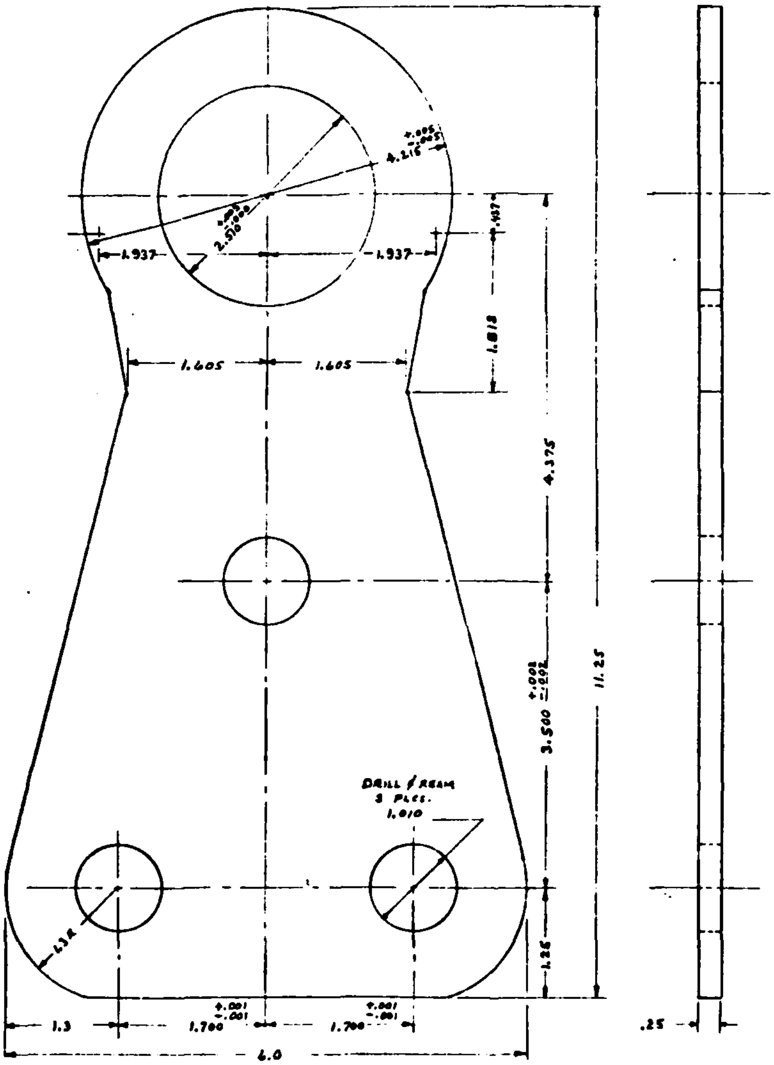
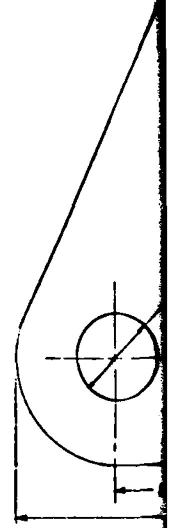
ROPE -ASSY.

SIZE D | FSCM NO | DWG NO 10200 | REV
SCALE NONE | SHEET 1 OF 1

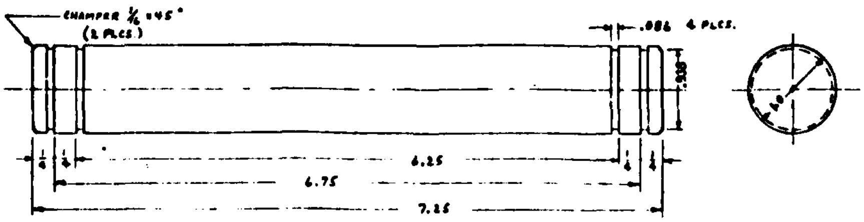
8 7 6 5



-1 END PLATE



-2



-3 PIN

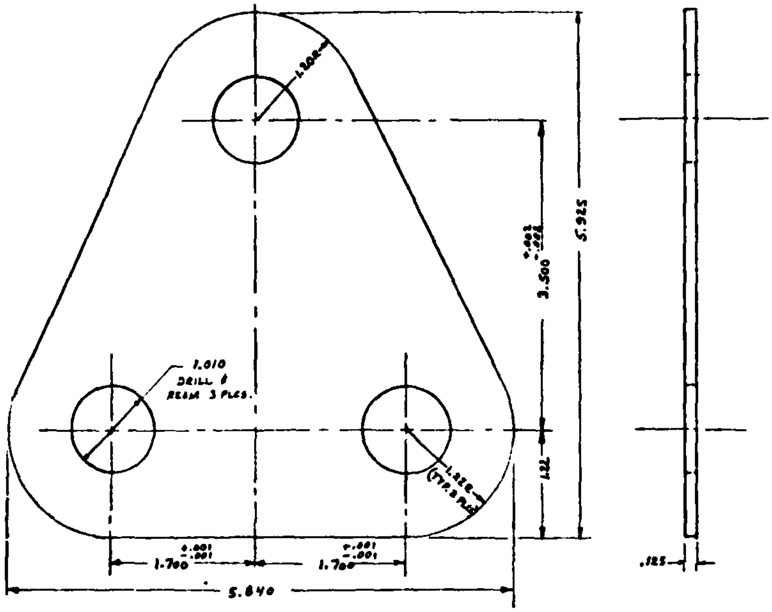
C-5

8 7 6 5

DWG NO	SH	REV

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED



-2 SPACER PLATE

NOTES:

REMOVE ALL BURRS AND SHARP EDGES

HARD ANODIZE ALL PARTS PER MIL-A8625 TYPE III WITH DICHROMATE SEAL.

IDENTIFY ALL PARTS WITH A RUBBER STAMP AND 73 X SERIES BLACK MARKING INK.

2

	QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	
	6		-3	PIN	6061-T651 AL	
	14		-2	SPACER PLATE	7075-T651 AL	
	4		-1	END PLATE	6061-T651 AL	

PARTS LIST

NEXT ASSY	USED ON
10000	

APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
.XX
.XXX

MATERIAL: ALUMINUM

FINISH:

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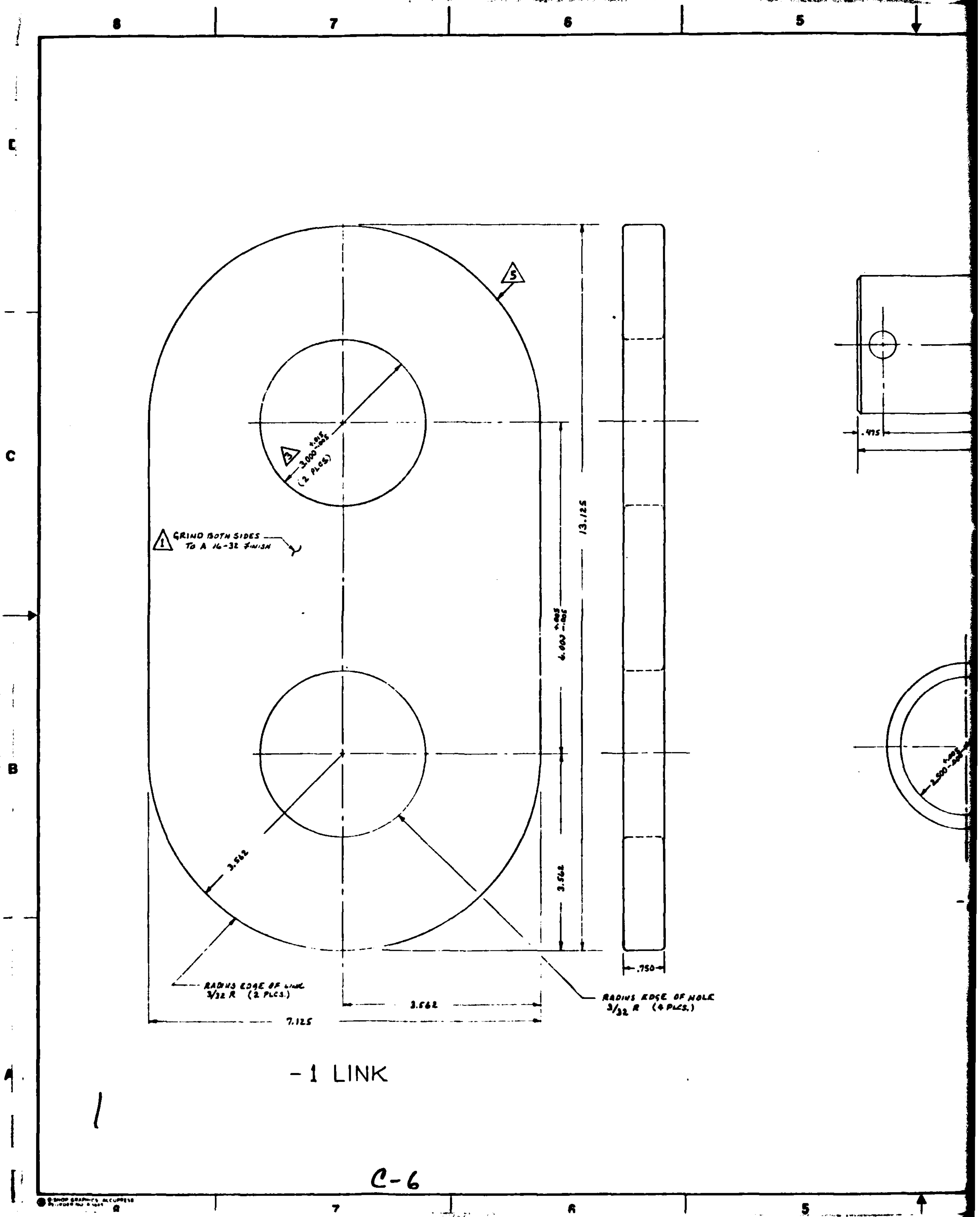
PLATE, END
PLATE, SPACER
PIN

SIZE: D | FSCM NO | DWG NO: 10300 | REV

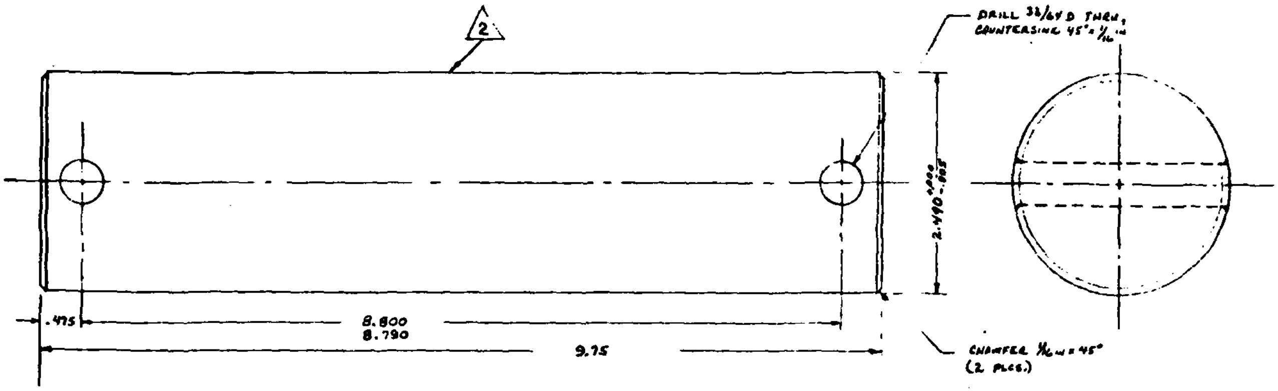
SCALE | SHEET 1 OF 1


GRIND BOTH SIDES TO A 16-32 FINISH
3.000 +.015 -.005 (2 PLCS)
13.125
6.000 +.005 -.005
3.562
3.562
3.562
RADIUS EDGE OF LINK 3/32 R (2 PLCS.)
RADIUS EDGE OF HOLE 3/32 R (4 PLCS.)
7.125
.750
.475
-1 LINK
C-6

DWG NO	SH	REV

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED



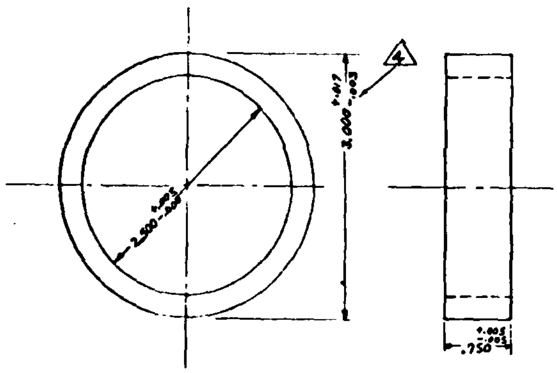
-3 PIN

NOTES:

1. SEQUENCE OF FABRICATION: ROUGH GRIND NOMINAL PLATE TO A 64 FINISH, MILL LINK TO GIVEN GEOMETRY, FINISH GRIND PLATE TO A 16-32 FINISH REMOVE ALL NICKS SCRATCHES AND TOOL MARKS.
2. GRIND PIN TO GIVEN DIAMETER (16 FINISH), FAB. TO GIVEN GEOMETRY, HEAT TREAT TO R_c 54-55 PER MIL H6875 (900°/925°F MIN 6 HRS)
3. HOLE DIAMETER WILL DECREASE .002 IN. AFTER HEAT TREAT
4. EACH BUSHING IS TO BE INDIVIDUALLY SIZED TO A GIVEN -1 LINK HOLE REF. NOTE 3 TO PROVIDE A .0015 TO .0020 INTERFERENCE OR PRESS FIT.
5. HEAT TREAT TO R_c 54-55 PER MIL H6875 (900°/925°F MIN. 6 HRS)

REMOVE ALL BURRS AND SHARP EDGES

IDENTIFY ALL PARTS WITH A RUBBER STAMP AND 72X SERIES BLACK MARKING INK.



-2 BUSHING

2

QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION
1		-3	PIN	CVM VASCOMAX 300 BAR NATURAL
2		-2	BUSHING	LA SALLE 1144 HI STRESS RD
1		-1	LINK	CVM VASCOMAX 300 BAR NATURAL

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE FRACTIONS DECIMALS ANGLES .XX .XXX

MATERIAL: CVM VASCOMAX 300

FINISH

CONTRACT NO.

APPROVALS		DATE
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ISSUED		

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LINK
BUSHING
PIN

SIZE D | FSCM NO | DWG NO 10400 | REV

SCALE 1 | SHEET 1 OF 1

NEXT ASSY	USED ON
10 000	

APPLICATION

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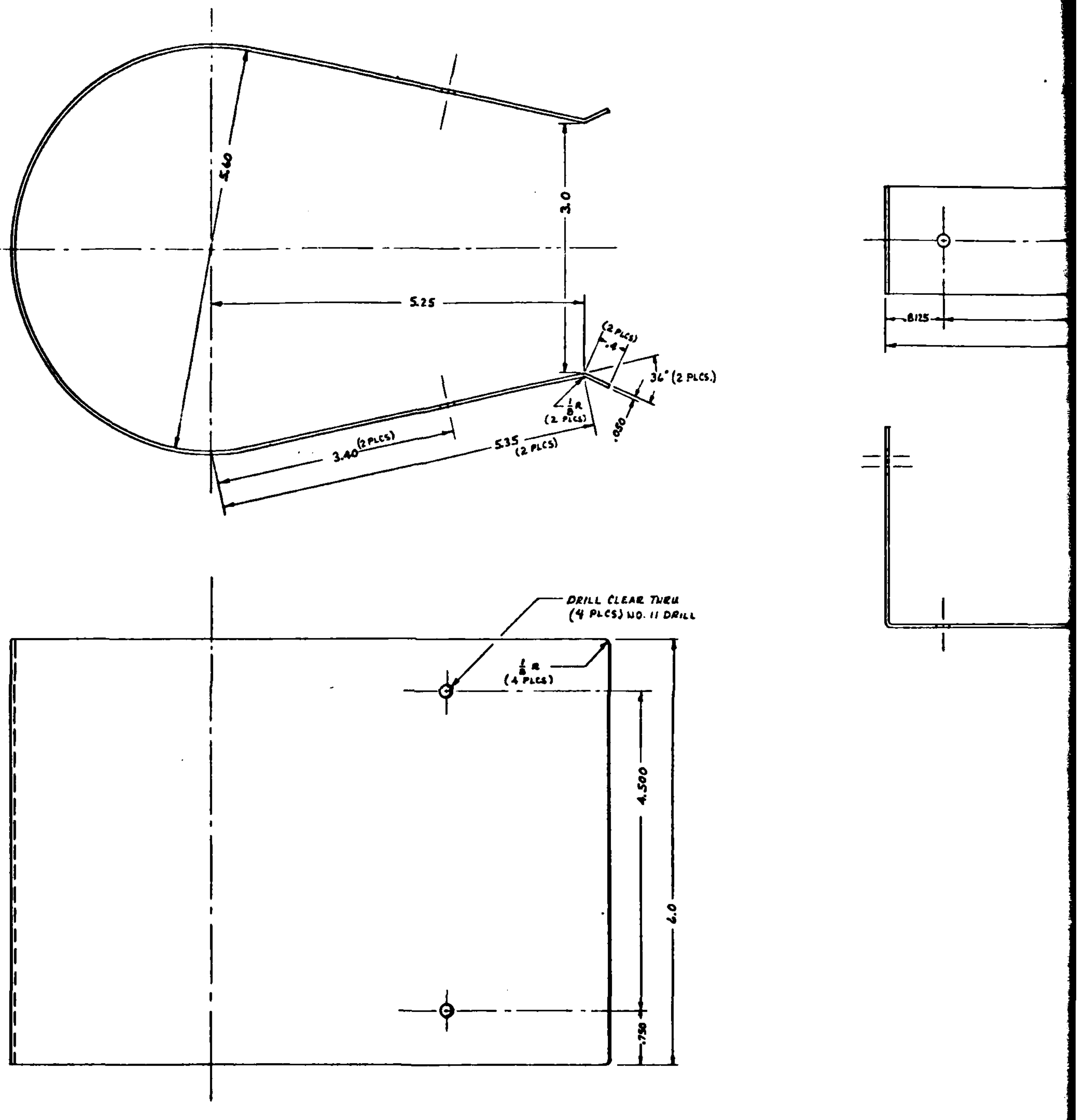
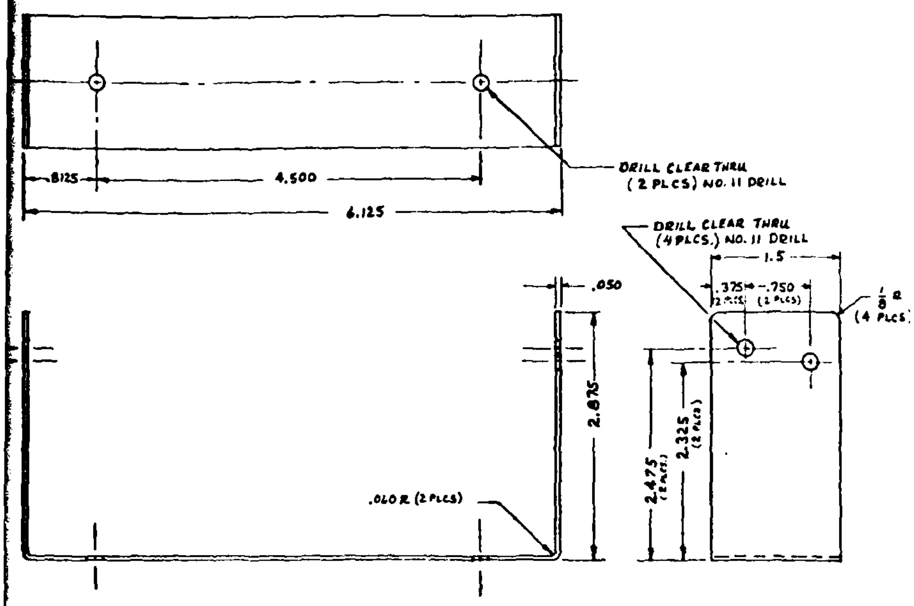

5.60
3.0
5.25
(2 PLCS)
.4
36° (2 PLCS.)
1/8 R
(2 PLCS)
.050
3.40 (2 PLCS)
5.35 (2 PLCS)
.8125
DRILL CLEAR THRU
(4 PLCS) NO. 11 DRILL
1/8 R
(4 PLCS)
4.500
6.0
.750

-1 COVER

DWG NO	SH	REV

REVISIONS

ZONE	REV	DESCRIPTION	DATE	APPROVED



-2 CLIP

NOTES:
REMOVE ALL BURRS AND SHARP EDGES.
IDENTIFY ALL PARTS WITH A RUBBER STAMP AND 73X SERIES BLACK MARKING INK.

QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION		MATERIAL SPECIFICATION
4		-2	CLIP	304 STAINLESS STEEL ANNEALED	MIL-S-5059
2		-1	COVER	304 STAINLESS STEEL ANNEALED	MIL-S-5059

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
.XX
.XXX

MATERIAL
304 STAINLESS STEEL ANNEALED

FINISH

CONTRACT NO

APPROVALS		DATE
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CHECKED		
ISSUED		

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COVER
CLIP

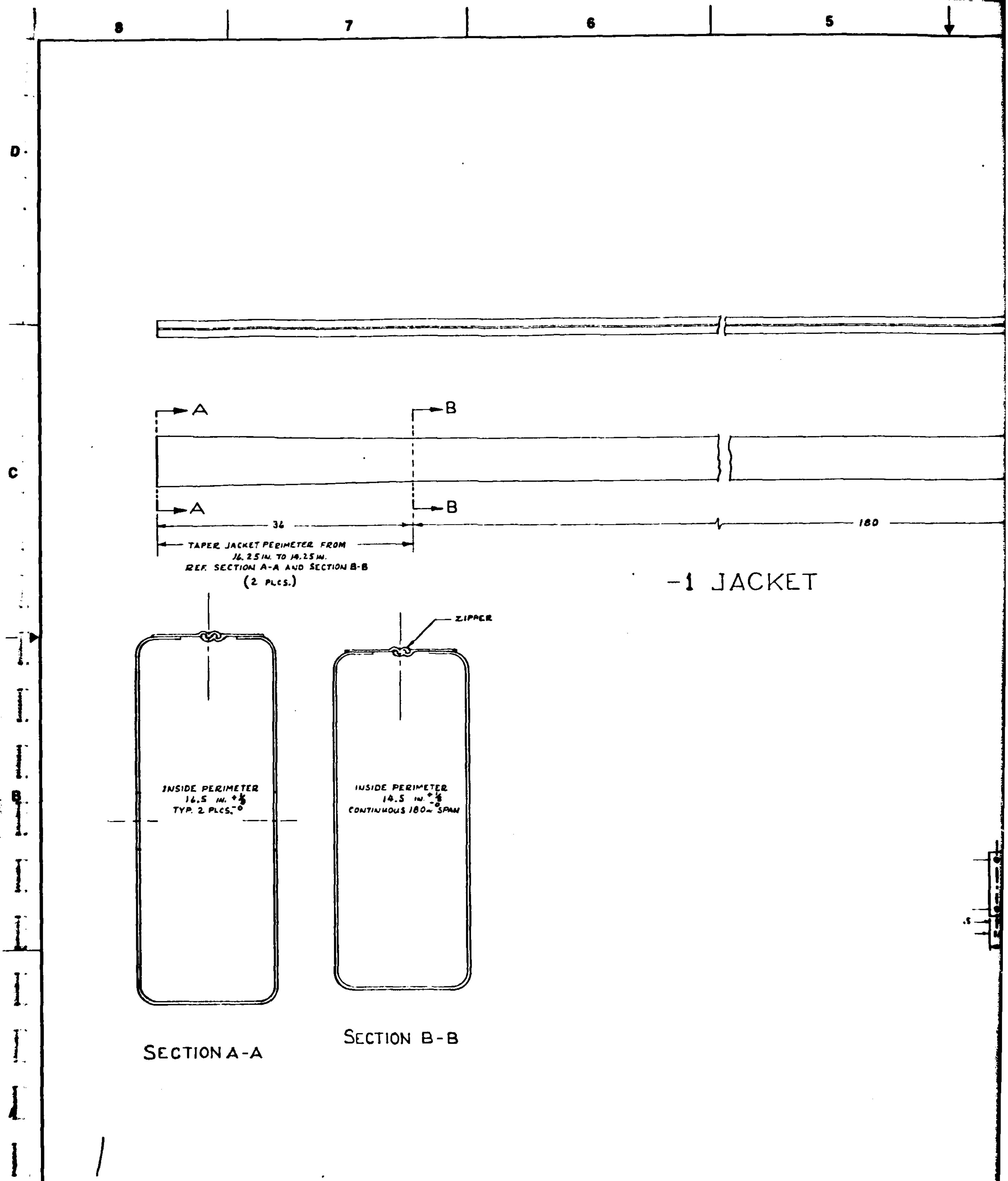
SIZE D | FSCM NO | DWG NO 10500 | REV

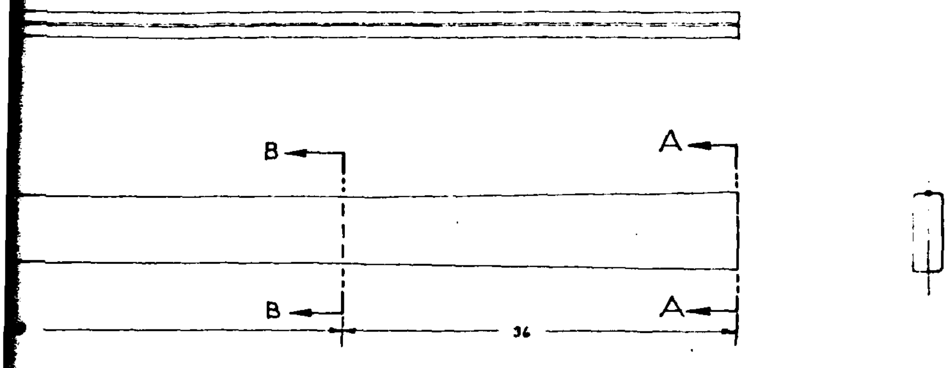
SCALE | SHEET

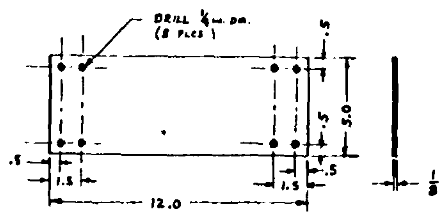
NEXT ASSY	USED ON

APPLICATION

DO NOT SCALE DRAWING


8
7
6
5
D
C
B
A
B
A
B
36
180
TAPER JACKET PERIMETER FROM
16.25 IN. TO 14.25 IN.
REF. SECTION A-A AND SECTION B-B
(2 PLCS.)
-1 JACKET
ZIPPER
INSIDE PERIMETER
16.5 IN. +1/8 -0
TYP. 2 PLCS.
INSIDE PERIMETER
14.5 IN. +1/8 -0
CONTINUOUS 180 IN SPAN
SECTION A-A
SECTION B-B





-2 DIVIDER

NOTES:

MARK ALL PARTS WITH RUBBER STAMP AND 73A SERIES BLACK MARKING INK.

1		10600-2	DIVIDER		NEOPRENE - IMPREGNATED BELTING
1		10600-1	JACKET	B PERFTUBING CO L.A CALIF	
QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION		MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
.XX
.XXX

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
APPLICATION	

CONTRACT NO.

APPROVALS	DATE
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ISSUED	

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JACKET DIVIDER

SIZE	FSCM NO	DWG NO	REV
D		10600	

SCALE 1/4 SHEET 1 OF 1