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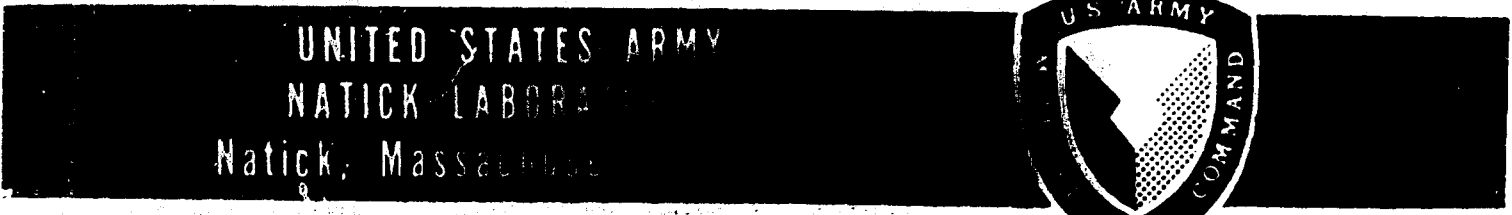


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# EXTENT AND CAUSE OF DETERIORATION OF NYLON MOUNTAIN CLIMBING ROPE

by  
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 Boston Naval Shipyard

March 1966



Clothing and Organic  
 Materials Division  
 TS 135

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## FOREWORD

A study of the factors influencing the deterioration of nylon climbing rope has long been overdue. The protection afforded by a rope depends upon its ability to stop a fall adequately. While, in many instances, proper belaying of the rope will reduce the impact that must be sustained, there is still a substantial part of the energy from a falling man that must be absorbed by the rope. Since the rope's energy-absorbing ability is a function of its strength and elongation, any use factor that would influence these properties would also influence its protective potential.

The preliminary investigations reported here make it evident that appreciable deterioration takes place in nylon climbing rope through the mechanism of surface abrasion. Energy loss may be in excess of 50 percent yet there may be only superficial evidence of damage. Accordingly, it is important to keep nylon climbing ropes under constant close scrutiny and to remove from service any ropes that show evidence of damage. As with other life-saving items used by the military, such as parachutes and body armor, continuing surveillance and control is essential to ensure maximum serviceability and protection at all times.

We wish to acknowledge the support received for this work from the Army Limited War Laboratory and particularly from Mr. Robert L. Woodbury of that agency for his insight into this problem and for his interest and help with this project.

Most of the test results reported were obtained through the cooperation and under the direction of the late Mr. Leo J. Sheehan of the Materials Laboratory of the Boston Naval Shipyard. We wish to acknowledge his excellent cooperation, without which this study could not have been conducted, and to extend our thanks to his staff.

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### Abstract

An analysis was made of 20 nylon mountain climbing ropes which had been in use for periods up to 18 years, to discover the extent and cause of deterioration in strength and energy-absorbing ability and changes in hardness and stiffness. It was found that loss in strength and energy-absorbing ability arise primarily from fiber abrasion which occurs at the surface of the rope. The nature of the rope construction is such that surface abrasion affects each of the three strands of the rope and all of the yarns in each strand except the few which constitute the so called "inner-core." There is no evidence that sunlight damage occurred to any significant extent in these ropes. The amount of abrasion and loss of strength were directly related to the amount of use (not age) for those ropes that had more quantitative use histories. A Use Index (computed from the number of days of use) may be used to estimate rope deterioration. The extent of hardening and stiffening of the ropes was found to vary over a wide spectrum, but the causal factors were not determined.

EXTENT AND CAUSE OF DETERIORATION OF NYLON MOUNTAIN  
CLIMBING ROPE

I. Conclusions And Recommendations

The overall purpose of this study was to examine a series of nylon climbing ropes that had been used in the field and to determine the character, extent, and cause of their deterioration. While not all of the answers to the deterioration problem were found, considerable information was obtained, conclusions were drawn, and recommendations were made for further studies and for specific remedial action. It was concluded, in general, that:

- 1) A significant amount of deterioration occurs during the use of nylon mountain climbing ropes. This deterioration is directly related to the amount and type of use; it is not related to the age of the rope.
- 2) The deterioration due to use arises primarily from fiber abrasion at the surface of the rope. This surface abrasion, by virtue of the rope construction, affects each of the three strands and all of the yarns in each strand except the few which constitute the so-called "inner core".
- 3) Deterioration of climbing ropes is evidenced primarily by losses in strength and energy-absorbing ability. The elongation of the ropes does not change to any great extent during use; thus the loss in energy-absorbing ability is a direct result only of the loss in strength.
- 4) There is no evidence that ultraviolet radiation causes significant deterioration of ropes following their exposure to sunlight.
- 5) A Use Index, based primarily on the number of days of actual climbing use, correlates with the strength loss sustained during use and consequently may be used as a rough predictor of its residual service life. Obviously, the more reliable the use history the more reliable will be the Use Index.
- 6) An important change that occurs in many nylon mountain climbing ropes during use is a hardening and stiffening which, while not necessarily a form of deterioration, nevertheless has a profound influence on their knot-holding ability and, consequently, on their serviceability. This study was not able to shed any light on the probable cause of hardening. It may be related to a processing parameter such as heat setting but this has not been proved unequivocally.

Detailed analysis of the data showed that:

- 1) Distribution of the yarns in the "inner core" of each strand compared to the total yarns in the strand ranged from 10 to 20 percent.
- 2) Strength loss of the ropes ranged from 9 to 62 percent, with an average of 39.2 percent. The major cause of strength loss was fiber breakage.
- 3) The hardness of the ropes ranged from 17 to 140 pounds, with an average of 52.2 pounds. Stiffness ranged from 3.7 to 8.6 "bending length" inches, with an average of 5.9 inches. The correlations between hardness and stiffness and between hardness and knotting ability were only moderate.
- 4) The Use Indexes, as computed by one rater, ranged from 20 to 220, with an average of 111.6. The correlation coefficients of strength, energy, and abrasion measurements with Use Index ranged, for this rater, from 0.53 to 0.66 in an 18-rope series and from 0.67 to 0.77 in an 11-rope series that had more quantitatively exact use histories.
- 5) The "Bates" ropes (two ropes that were subjected to detailed rheological and X-ray study) showed no evidence of ultra-violet or sunlight deterioration. Their nylon fluidity increased 0.1 and 0.2 rhes respectively, but this is not considered indicative of photochemical deterioration. These ropes did show evidence of surface abrasion of fibers, which would explain their losses in strength and in energy-absorbing ability.

It is recommended that:

- 1) A system be devised for keeping a record of the days that each military nylon mountain climbing rope is used. Pending further analysis and study, any rope with a total number of climbing days in excess of 100 (from this study roughly equivalent to a 20% strength loss) should be withdrawn from service as a potential climbing hazard.
- 2) Selected samples from supplies of nylon climbing ropes in the field be sampled and analyzed with a view to determining their level of deterioration.
- 3) A non-destructive test be developed for assaying the extent of fiber breakage due to surface abrasion.
- 4) Subjective evaluations of hardness and stiffness be made periodically. Any ropes that vary markedly from the average should be withdrawn from service.

5) Further research be conducted to determine the cause of the hardening of some ropes with use and to develop manufacturing and finishing procedures that will minimize this change.

6) A rope structure be developed in which the ratio of "inner core" yarns to the total yarns would be raised so as to reduce the number of yarns that would be subjected to surface abrasion. Any such changes must be made without influencing the critical strength and energy-absorbing properties of the rope.

## II. Background

Rope was one of the first industrial products to be made of nylon. Nylon is ideal for this application because of its high tenacity, low density, and high flexibility. The experience of sportsmen and of military personnel provides ample evidence of the soundness of the decision to use nylon for mountain climbing ropes. However, as with many high performance materials, there has been a tendency to expect an infinite service life from nylon and to neglect to check for subtle changes in its physical and chemical properties that could influence its serviceability and even the safety of its use.

It has recently been brought to the attention of Army R&D personnel that some nylon climbing ropes become stiff and are correspondingly unable to hold a knot, thus forming a serious hazard to the climber (1). Also, the relatively poor resistance of nylon\* to ultraviolet (sunlight) radiation has been considered a well established fact and thus a limiting factor in many applications of nylon (2). For these reasons the U. S. Army Natick Laboratories considered it desirable to conduct a study to determine the nature and amount of deterioration which occurs in nylon ropes as a result of their continued use. For such a study it was essential to obtain ropes with a known use history.

## III. Materials

Eighteen nylon mountain climbing ropes which had been in use for as long as eighteen years were made available to the Natick Laboratories through the cooperation of Col. A. H. Jackman (3), formerly of the Office of The Quartermaster General, and Mr. A. E. Peterson (4) of Washington, D.C. These ropes had been used by sixteen members of a mountain climbing club under various climbing conditions, in various parts of the country, and for various periods of time. The climbers gave: the ages of the ropes; a synopsis of the conditions under which each rope had been used since purchase; a description of the storage conditions in terms of temperature, humidity, and presence of light; and also such general comments as they wished (Appendix A). As might be expected, some of the information about the ropes was quite comprehensive and detailed

while some was rather sketchy and incomplete. Nevertheless, these ropes provided a pedigreed group and it was felt worthwhile to analyze them comprehensively in the laboratory and to assess their degree of deterioration as a basis for possible future specification action.

In addition to the eighteen, two ropes (Special A & B) that had been in use since 1946 were submitted by Mr. Robert H. Bates. These two ropes were subjected to special analyses involving nylon fluidity determinations and X-ray diffraction and photomicrographic study.

These twenty samples represented many types of rope that varied widely in circumference and linear density. The yarn construction ranged from 1 to 7 ply, the yarns per strand from 7 to 19 (with both "S" and "Z" twists in the strand yarns), and the colors from a light beige to a rather dark olive green. Although the great variety of the ropes prevented their performance characteristics from being related to specific structural features, it did permit average levels and ranges of performance to be determined and these were useful in characterizing the rope population (see Fig. 1, representing cumulative distributions of four selected properties of 18 of the 20 ropes studied).

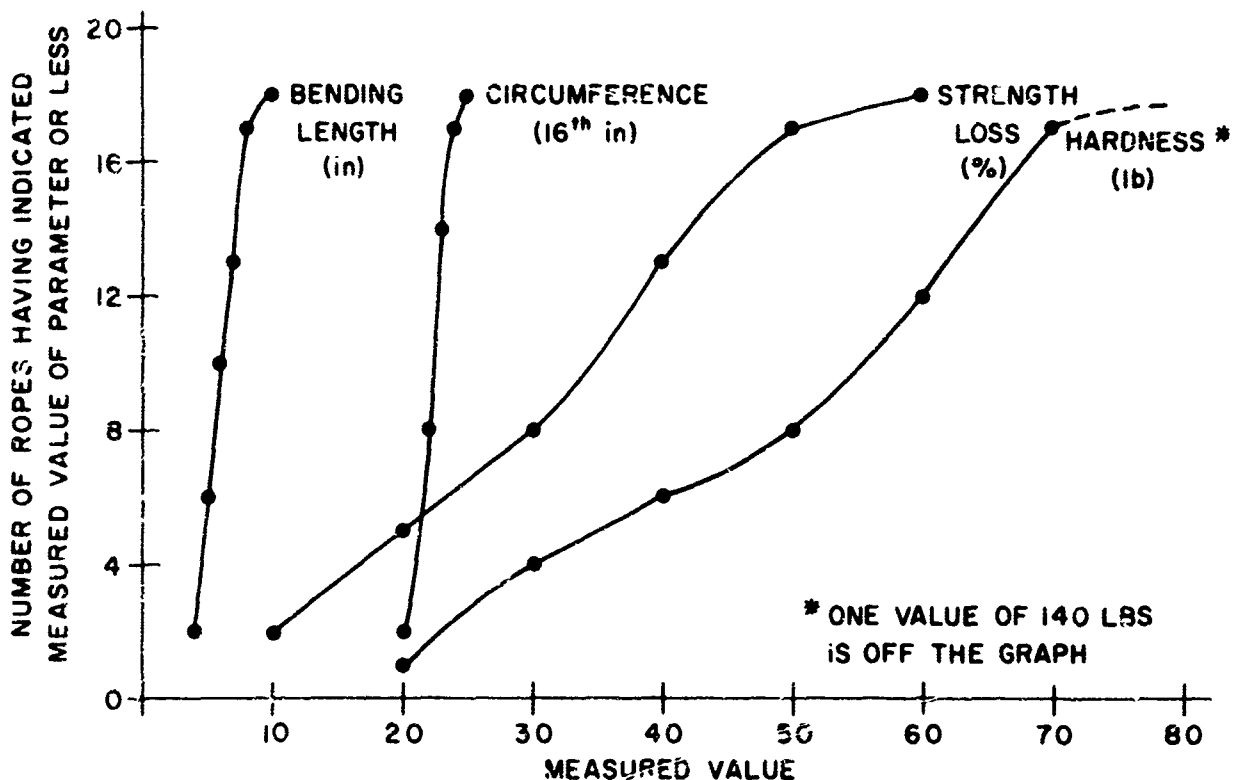


Figure 1. Cumulative distribution of selected properties of 18 nylon climbing ropes

#### IV. Test Procedures

The laboratory tests can be divided into three categories: those used to evaluate physical properties and construction, those used to evaluate mechanical properties, and those used to evaluate fiber abrasion and chemical or microscopic changes.

##### A. Physical Properties

Tests to determine rope circumference, linear density, the number of yarns per strand, the ply of the strand yarns, the twist of the yarns, and the distribution of the yarns in the strand were carried out in accordance with the standard procedures contained in Specifications MIL-R-2688 and CCC-T-191b.

##### B. Mechanical Properties

1. Strength and Elongation. Strength and elongation measurements were made on a screw-operated tensile machine of the constant-rate-of-extension type. The rate of extension used was 3 inches per minute. A load-cell weighing system was used having ranges of from 10 to 20 thousand pounds. There was no motion in the weigh head.

Even though the testing machine was of the constant-rate-of-extension type, percent elongation could not be determined from the displacement of the jaws alone, because it was not uniform along the entire rope length - the spliced area stretched at a different rate from the unspliced area. Furthermore, while elongation could be observed under low loads, it had to be estimated at high loads because of the hazard of being near the rope at break. The procedure used was as follows: First, the elongation of a 30-inch gauge length measurement was observed on the unspliced area of the rope at 20 percent of the break load as determined on a pretested sample. (It was assumed that the rates of elongation of the spliced and unspliced areas of rope would become approximately equal at 20 percent of breaking load and would remain equal up to break.) Then the extension was measured as the load was increased from 20 to 50 percent of the breaking load. Since, with a constant rate of extension, elongation is proportional to time, that which would occur between 50 and 100 percent of load could be computed from the elongation observed at between 20 and 50 percent of load on the basis of the relative difference in the time intervals required for each. Elongation at break was arrived at by adding the two - the elongation at up to 50 percent of load and the computed elongation at between 50 and 100 percent of load. While there are some inherent errors in this procedure, the relative elongation values obtained are meaningful and useful in comparative studies of this type.

In order to adjust the strength values for the different sizes and weights of the ropes, "breakin length" was also computed to express the breaking strength in terms of the length of rope, the weight of which would equal its breaking strength (i.e., breaking strength ft/lb).

In addition, the percentage of strength loss was computed based:

- 1) upon a standard breakin length of 80,000 feet, which is the usual breaking length for nylon 66, type 300
- 2) upon the breaking length of the unused control rope (T-916)

2. Energy-Absorbing Ability. From the elongation and breaking strength data, the following energy parameters were computed:

- 1) energy in foot-pounds required to stretch one foot of rope to rupture
- 2) energy in foot-pounds required to stretch one pound of rope to rupture
- 3) percentage energy loss based upon the standard foot-pounds (23,800) required to stretch one pound of nylon, type 300 to rupture
- 4) percentage energy loss based upon the foot-pounds required to stretch one pound of the unused control to rupture.

3. Hardness. The test for hardness (5) was based upon the force necessary to open the rope, by means of a manin spike, sufficiently wide to allow one strand to be passed through. The spike was 1 1/4 inches long and had a 5/8-inch taper per foot and a spatulate end for starting the opening. The spike was inserted manually between the rope strands until the rounded end protruded. The rope with the inserted spike was then mounted in a hydraulic compression machine operating at a rate of 6 inches per minute. The load necessary to spread the rope strands to a diameter of 1/2-inch was measured. The reported values represent the averages of three measurements taken 5 feet apart on each rope. The apparatus is shown in Figure 2.

4. Stiffness (bending length). An index of the force required to bend a rope in a direction normal to its own axis, as a basis for comparison with the hardness test, was arrived at by means of the Peirce Cantilever Test (6). The rope sample was allowed to slide parallel to its axis along a horizontal platform.

When the tip of the rope extending beyond the platform was "depressed under its own weight to the point where the line joining the tip to the edge of the platform made an angle of  $41\text{-}1/2^\circ$  with the horizontal" (6), the length of the overhang was measured. One-half of this length was taken as the "bending length" of the specimen.

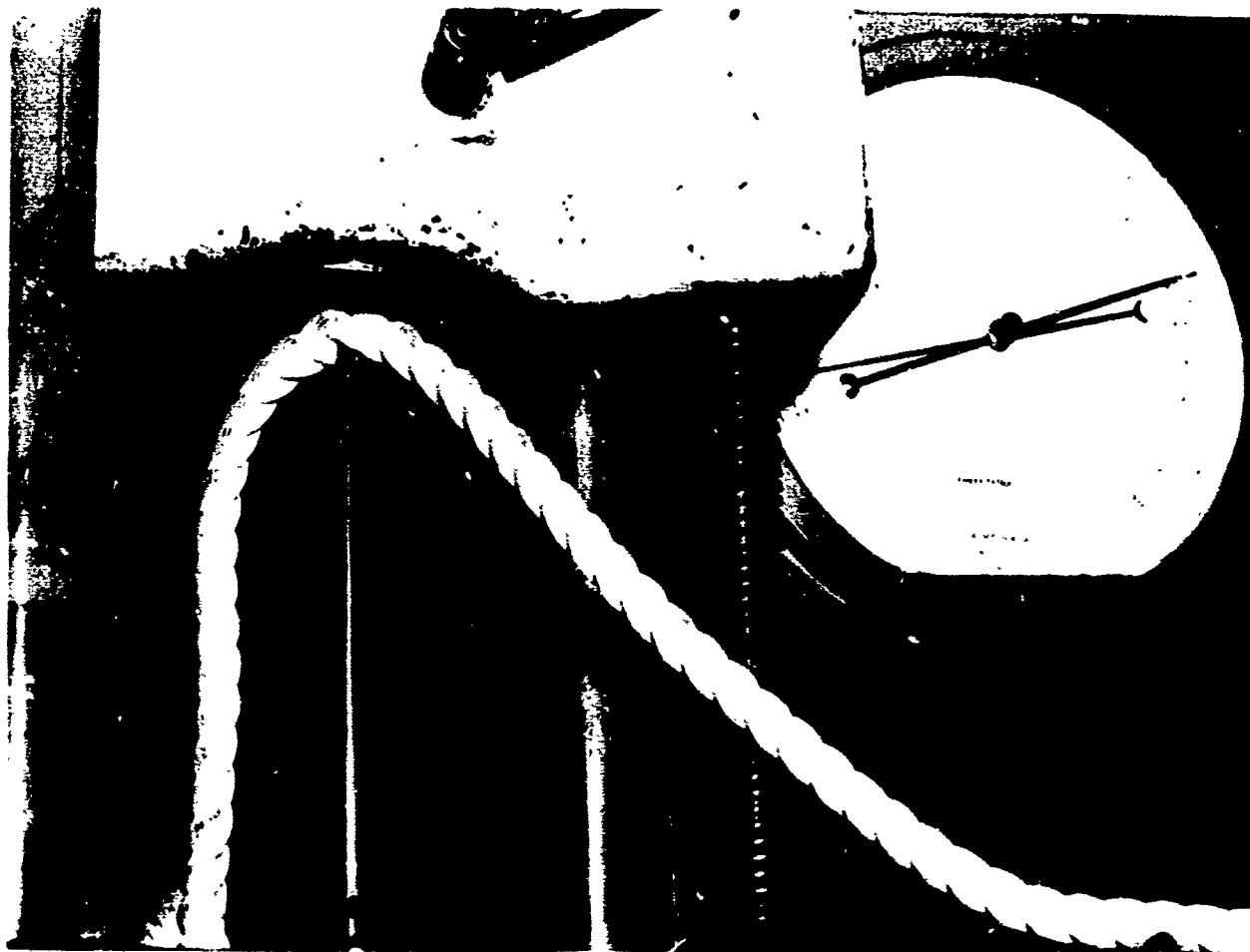


Figure 2. Apparatus used in the nylon rope hardness test

5. Knotting Ability. Various types of knots are used in climbing but the essential characteristic of each is that it must hold when stress is applied. The knotting behavior of a rope depends upon its stiffness and its coefficient of friction at the surface. Because stiffer ropes deform less during knotting, they have less bearing surface and a lower coefficient of friction. Since the same elements are involved in tying and untying a knot, in the interest of testing simplicity only that force and energy required to tie a knot were evaluated; it was assumed that the lower the force required to tie a knot the greater would be the ease with which the knot would hold.



In the knotting test, a 24-inch length of rope was tied loosely into an overhand knot. The two ends were inserted into the upper and lower jaws, respectively, of an Instron tensile tester, using a gauge length of 10 inches and a cross head and chart speed of 5 in./min. The force required to reduce the greatest dimension of a loose knot to 2-1/4 inches was recorded, using a cardboard template for measuring the distance. Corresponding measurements of energy were made by means of an integrator coupled to the Instron output.

6. Compressibility. Since it was apparent that the knot behavior test, using a constant dimension, is influenced by rope diameter, a compression test was devised which is related to both the stiffness of the rope and, as a corollary, to the force required to knot it. In this test, rope diameter was measured by compressing a flat segment in the Instron with a force of 5 pounds and recording the resultant thickness. Then the rope was looped in a vertical plane and the end of the loop inserted between the flat jaws of an Instron Compression tester, having a diameter of 3 inches, so that the edge of the loop reached just to the center of the jaws. At the cross-head and chart speed of 1 in./min. the force and energy required to compress the loop to a value of 2-1/2 times the rope thickness was measured. In order to maintain the loop in a vertical plane and to prevent the upper part from sliding to the side of the lower part, the rope was supported by hand. In this test, the stiffer the rope the greater is the force and energy required to compress it to the final dimension. The energy-absorption values reported are subject to a small correction because the weight of the loop of rope affected the sensing jaw and also because of the slight force that had to be applied to it in order for some of the stiffer ropes to fit within the specified 3-inch gauge length.

### C. Deteriorative Change

1. Fiber Abrasion. A 5-inch length of rope (equivalent to 3 turns) was selected from that section visually judged to be the worst from the standpoint of abrasion. This length was carefully weighed and unlaid and the individual fibers combed out. The broken fibers were separated from the unbroken fibers and weighed. The weight of the broken fibers compared to the weight of the original 5-inch length of rope, expressed to the nearest five percent value, constituted the measure of fiber abrasion. In conducting this test it was assumed that those fibers not remaining intact through three full turns would contribute to a weak spot in the rope and consequently to a loss in strength. This test will measure only the minimum amount of rope damage, since many of the fibers are weakened but still intact after abrasion and are thus not included. On the other hand, it is possible that testing would include some fibers that might have been ruptured from causes other than abrasion, such as by local tensile failure, fatigue failure, or cutting.

2. Changes Detected by Chemical, Microscopic, and X-Ray Study. The chemical and microscopic damage in exposed nylon ropes is difficult to assess because of the rapid changes that occur and the different rates of change between the fibers on the outside and those in the core of the rope. The outer layers change the most rapidly; the fibers in the core may remain relatively sound even after long periods of exposure.

Among the many tests used for determining the extent of deterioration of nylon following exposure to sunlight are those that measure the increase in the fluidity of dispersions of nylon in formic acid or meta cresol. In this study a simpler procedure was also used involving the measurement of the extent of the solubility of the nylon in a ferric chloride solution. Twenty gram sections of various areas of rope were placed for 30 minutes in a 3 percent ferric chloride solution at a temperature just under the boiling point. The nylon was washed with 1/2 percent hydrochloric acid and then neutralized with ammonia, rinsed, and dried.

As a separate phase of this study photomicrographs were made on the two Bates ropes at 10X and 200X to show gross areas of wear on the surface and changes in the morphology of the single nylon filaments.

Also, X-ray diffraction patterns of fiber bundles removed from the damaged and undamaged areas of these ropes were photographed to determine whether the orientation of the crystals or the crystal structure itself was altered by their use history.

In addition, fluidity determinations (7) in 100 ml. of 90 percent formic acid were made on dispersions of 11 gm of nylon fibers taken from damaged and undamaged sections of the Bates ropes.

#### D. Correlation Analysis

In order to relate the change in observed properties with the history of the ropes in terms of days of use and severity of use, a Use Index was developed and applied to each rope, based on information submitted by the climbers. If the number of days of use was furnished on a monthly or a yearly basis, these data were summed and corrected for qualitative statements of severity. If the number of days was not given, the length of use was estimated based on the qualitative statements alone. The Use Index was computed by three individuals to whom the results of the objective tests had not been made available. Correlation studies were made based on the Use Index, the age in years, and the product of the Use Index and the age in years.

The average results and the standard deviation (Tables I-VII), as well as the linear correlation coefficients between the variables (Tables VIII-X); using a WIZ Program (Appendix D) devised for a GE 225 computer, were computed for each set of objective measurements.

## V. Test Results

### A. Physical Property Changes

The specification for the constructional characteristics of climbing rope is quite flexible, the major requirement being that the rope contain three strands. The circumference, density, number of yarns per strand, the ply of the strand yarns, and the twist of the yarns may vary widely provided the mechanical performance requirements of the specification are met. The experimental ropes provided an unusual cross section of the possible variations in construction.

1. Circumference.(Table I) The ropes studied (exclusive of the Bates) varied in circumference from 20 to 25 sixteenths of an inch, with the average just under  $23/16$  (1.4) inches. The most commonly used military nylon climbing rope is  $1-1/4$  ( $20/16$ ) inches in circumference, with an allowable tolerance of  $\pm 1/8$  ( $2/16$ ) inch (see military specification for nylon climbing rope, App. B). Thus, on the basis of the upper limit, the maximum allowable circumference would be  $22/16$  inches, or just  $1/16$  inch less than the average value found.

The greater average circumference of the experimental ropes (and also of the control rope T-916), assuming they were within the specification limits to begin with, could be due to either shrinkage or to mechanical factors occurring during use and producing fiber or yarn displacement. Shrinkage would result in an increase in linear density (weight per unit length) or, correspondingly, a decrease in the foot/pound evaluation.

2. Linear Density.(Table I) Examination of the foot/pound data showed that all of the eighteen experimental ropes measured over the 17 foot/pound minimum specification requirement for  $1-1/4$  inch rope and much above the requirement when adjusted by the minus tolerance of 10 percent for dyed rope, which would bring the figure to 15.3 foot/pound. Accordingly, the shrinkage explanation of the increase in circumference mentioned above is not tenable. As a matter of fact, the length increase in the ropes probably occurred because of the use to which they had been subjected. If we assume that the ropes originally had been close to the modal value of the specification, then the most likely explanation of the increase in circumference lies in fiber or yarn displacement due to surface abrasion.

TABLE I

Three-Strand Rope Constructional Factors

<u>Sample Number</u>	<u>Circumference</u> (in 10th of in.)	<u>Linear Density</u> (ft/lb)
(T-916) Control	23	17.6
Special "A" (Bates)	24	18.4
Special "B" (Bates)	23	18.1
Experimental		
2	23	19.1
3	23	18.0
4	20	26.3
5	20	25.3
6	24	18.6
7	22	18.9
8	22	18.1
9	23	18.1
10	25	18.1
11	24	18.1
12	22	19.1
13	22	17.7
14	23	18.1
15	24	19.1
16	22	19.5
17	22	18.1
18	23	19.1
19	23	18.1
Avg. of Experimental	23	19.3
Std Dev. of Experimental	1.3	2.4
Specification Requirement for 1-1/4 inch rope	20 ± 2	17.0 (-1.7)

The eighteen used ropes varied in linear density from 17.7 to 26.3 feet/pound. The average value was 19.3 and the standard deviation 2.4. The greater length per unit weight than the specification minimum coupled with the greater average circumference than the nominal specification requirement (which would tend to indicate a lower length per unit weight than was actually noted), leads to the conclusion that significant unrecovered elongation or permanent set may have occurred during the use life of the majority of the ropes. Permanent set is not necessarily a shortcoming, since it is accompanied by an increase in strength as a result of mechanical conditioning. However, a reduction in elongation, if reflected in a loss in energy-absorbing capacity, might be a serious disadvantage.

3. Yarns Per Strand (Table II) The number of yarns per strand varied from 7 to 19. The average was 12.8 and the standard deviation 5.2. The modal value, however, was 19 yarns per strand, while the next most frequent value was 10.

TABLE II

Yarn Distribution in Strands

Ply and Twist of Yarns

Sample No.	<u>Yarns in Strand</u>		<u>Inner Core (unabraded)</u>		<u>Outer Core (abraded)</u>		
	Tot.	Inner Core	Outer Layer	Ply & Twist Strand Yarns	Singles Twist	Ply & Twist Strand Yarns	Singles Twist
(T-916) Control	10	2	8	1	Z	1	Z
Special "A"							
(Bates)	19	3	16	3S	Z	3Z	S
Special "B"							
(Bates)	19	3	16	3S	Z	3Z	S
Experimental							
2	19	3	16	3S	Z	3Z	S
3	10	0	10	--	-	1	Z
4	7	0	7	--	-	1	Z
5	7	0	7	--	-	6Z	S
6	19	3	16	3S	Z	3Z	S
7	10	1	9	1	Z	1	Z
8	8	1	7	7S	Z	7Z	S
9	10	0	10	--	-	1	Z
10	19	3	16	3S	Z	3Z	S
11	19	3	16	3S	Z	3Z	S
12	10	0	10	--	-	1	Z
13	10	1	9	1	Z	1	Z
14	8	1	7	7S	Z	7Z	S
15	19	3	16	3Z	S	3Z	S
16	19	3	16	3Z	S	3Z	S
17	10	1	9	1	Z	1	Z
18	8	1	7	7S	Z	7Z	S
19	19	3	16	3S	Z	3Z	S
Ropes 2-19							
Average	12.8					2.9	
Mode	19.0					3.0	
Std. Dev.	5.2					2.1	

4. Yarn Ply. (Table II) Yarn ply ranged from 1 to 7. The average was 3 (numerically 2.9) and the standard deviation was 2 (numerically 2.1). The modal value of the yarn ply was 3 and the next most frequent value was 1.

5. Yarn Twist. (Table II) The twist direction of the yarns followed a typical pattern. In a ply construction, the conventional twist direction of the singles yarns was "S" and of the ply yarns "Z". When the yarns were unplied, the twist of the singles yarn was "Z". Thus, with a "Z" twist in the unplied yarns, we had an "S" twist in the strands and, finally, a "Z" twist in the rope. This was general in all of the eighteen experimental samples and the control. However, as is discussed in more detail in the following section, significant differences in yarn twist were evident in about half of the ropes, depending upon the specific location of the yarn in the strand.

6. Yarn Distribution in Strand. When each strand of the ropes was unlayed, it was observed that the yarns in thirteen of the eighteen ropes (No. 2 through No. 19) distributed themselves between what could be called the inner core and the outer layer. Later in the report, in the discussion of fiber abrasion, photographs show the outer and inner portions of a single strand of Rope No. 2 (see Figure 3). All of the yarns in the outer layer were found on the surface of the strand and thus showed some evidence of surface abrasion. These outer-layer yarns probably moved very little during use, since their inner surface showed little or no evidence of abrasion. The yarns in the inner core did not come to the surface of the individual strands at all and consequently did not come to the surface of the rope. The inner-core yarns showed no evidence of abrasion.

As shown in Table II, of the thirteen ropes that showed the core effect, seven were of a 19-yarns-per-strand construction, with 3 yarns in the inner core and 16 yarns in the outer layer; three were of a 10-yarns-per-strand construction, with 1 yarn in the inner core and 9 yarns in the outer layer; and three were of an 8 yarns-per-strand construction, with 1 yarn in the inner core and 7 yarns in the outer layer. Of the balance of 5 ropes which did not show a core construction, three were of a 10-yarns-per-strand construction and 2 were of a 7-yarns-per-strand construction. The control rope was of a 10-yarns-per-strand construction, with 2 yarns in the inner core and 8 in the outer layer. Ropes A and B (the Bates ropes) were of a 19-yarns-per-strand construction, with 3 yarns in the core and 16 in the outer layer, a distribution characteristic of the other 19-yarns-per-strand ropes.

It is of interest to note that in all of the ropes (except Nos. 15 and 16) that showed an inner core/outer layer type of construction in which plied yarns were used, the direction of twist observed in the inner core yarns was the reverse of that noted in the outer layer yarns. Thus, in the outer layer if the singles yarns were "S" and the ply yarns were "Z" then in the inner core the singles would be "Z" and the ply yarns "S". In Nos. 15 and 16 the twist was the same in both inner and outer yarns.

The distribution of yarns between the inner core and the outer layer has considerable significance in terms of reducing the effect of surface abrasion on the strength of the rope. As will be shown later in this report (see Table X), there was a strong correlation between fiber abrasion and strength loss. Since fiber abrasion occurs at the surface of the rope, construction in which the maximum number of yarns are situated in the inner core would sustain the least amount of fiber abrasion. In the case of the ropes in which 3 of the 19 yarns were in the inner core, 15.7 percent of the total yarn substance was protected from abrasion; this compares to 12.5 percent for the 8-yarn strands and 10 percent for the 10-yarn strands, in both of which 1 yarn was in the center. From this standpoint, the control rope (T-916) is superior to the others, having 20 percent of its total yarn substance in the center (2 yarns out of 10).

The rope manufacturer can exercise some control in the distribution of yarns in the strand. The finer the yarns he uses in the construction, the more yarns will form the inner core. In addition, during the strand-making operation, the location of the individual yarns in the register will determine which of the yarns will go to the center and which will constitute the outer layer.

The relative importance of the inner-core yarns in supporting stress and absorbing energy will depend upon the quality of the yarns used as well as upon the position of the yarns in the strand, particularly with respect to the angle which the yarn makes with the long direction of the rope. The inner-core yarns that are relatively straight as compared to the outer-layer yarns are the first to participate in the stress-support mechanism; they contribute a higher level of stress-bearing capacity to the rope structure. However, if a considerable differential exists between the elongation of the inner-core yarns and that of the outer layer (if the inner elongation is less), then it is probable that, upon application of stress, the inner-core yarns will rupture first, since they reach their ultimate elongation before the outer layer yarns do. In this situation, the level of stress support that can be furnished by the inner yarns will be equivalent to the load at which the elongation of the outer layer yarns reaches the rupture-

elongation point of the inner-core yarns.

It is possible that surface abrasion in a rope can be decreased by the proper placement of yarns in the inner core and by the use of yarns that will tend to migrate toward the center as well as provide optimum surface abrasion and energy absorption. Such a development will require careful investigation since the mechanical interactions are quite complex.

## B. Mechanical Property Changes

1. Strength and Elongation. The breaking strength of the experimental ropes ranged from 1660 to 4100 pounds (Table III). The average was 2550 and the standard deviation 630. The minimum allowable breaking strength in specification MIL-R-1688B (Rope, Climbing, Nylon) is 3400 pounds for 1-1/4 inch circumference rope and 2400 pounds for 1-1/8 inch circumference rope. The control rope (T-916) had a breaking strength of 3980 pounds. Comparison of the experimental ropes, all of which equalled or exceeded a 1-1/4 inch circumference, with the specification requirements for a 1-1/4 inch rope shows that only one would still meet the requirements. However, nine would meet the strength requirement for a 1-1/8 inch rope. Only two of the ropes (Nos. 4 and 5) appeared to have been in the 1-1/8 inch category when new, and both of these were below the 2400-pound requirement. Thus, it may be assumed at least in terms of specification requirements, that there had been a significant change in strength as a result of use.

In order to analyze the ropes, which varied widely in original morphology and structure, on a more comparable basis, breaking length measurements were used as indexes of actual strength. (Breaking length is relatively independent of the weight or density of the materials, provided that they are somewhat homogeneous with respect to textile classification.) The breaking length (that length which would break under its own weight) of new type 300 nylon rope was taken as 80,000 feet. In terms of the minimum specification requirements, the 1-1/4, 1-1/8, and 3/4-inch ropes would have breaking length requirements of 58,000, 55,000, and 49,000 feet, respectively. The 80,000 figure is well above these requirements and corresponds to a structure having a tenacity of 2.5 grams/denier. Assuming an initial tenacity of 6.0 grams/denier for type 300 nylon fiber, a tenacity of 2.5 grams/denier would represent a translational efficiency of 41.7 percent in going from fiber to rope. Since Himmelfarb (8) reports a 45.0 percent translation efficiency for nylon going from fiber to rope, the 80,000-foot breaking length value appears to be a reasonable basis for comparison. The breaking lengths of the test ropes ranged from approximately 30,000 to 72,000 feet, the average being approximately 47,000 and the standard deviation 10,000. The control was 70,000 feet or a proximately 12 percent less than the 80,000 standard.



TABLE III

Strength and Elongation of Ropes

Sample No.	Breaking Strength (lb)	Breaking Length (ft)	Strength Loss based on		Breaking Elongation (%)
			Standard*	Control**	
(T-916) control	3,980	70,050	12	0	50.0
Special "A" (Bates)	2,850	52,450	35	25.2	50.6
Special "B" (Bates)	3,370	61,000	24	13.0	50.0
Experimental					
2	2,125	40,600	51	42.0	45.5
3	3,116	56,200	30	19.8	47.7
4	1,725	45,400	43	35.2	45.6
5	2,050	51,900	35	25.9	50.6
6	3,265	60,700	24	13.3	51.0
7	2,375	44,900	44	35.9	54.6
8	3,280	59,400	26	15.2	49.0
9	2,460	44,500	44	36.5	43.3
10	1,660	30,050	62	57.1	40.8
11	2,300	41,650	48	40.5	43.3
12	2,200	42,000	48	40.0	40.0
13	4,100	72,600	9	-3.6	49.1
14	2,100	38,000	52	45.8	50.2
15	3,000	57,300	28	18.2	45.8
16	2,700	52,650	34	24.8	42.6
17	3,000	54,300	32	22.5	42.5
18	2,000	38,200	52	45.5	49.5
19	2,500	45,250	43	35.4	48.8
Avg of Experimental	2,550	48,640	39.2	30.6	46.7
Std Dev of Experimental	630	10,300	12.9	14.7	4.0
Type 300 Nylon rope (Std.) min spec req:					
1 1/4 in. circum.	3,400				35.0
1-1/8 in. circum.	2,400				35.0

\* Estimated as 80,000-ft breaking length for type 300 nylon

\*\* 70,050-ft breaking length of T-916 control

Computation of strength loss, based on the 80,000-foot breaking length standard, ranged from 9 to 62 percent, the average loss being 39.2 percent and the standard deviation 12.9 percent. Four of the ropes showed strength losses greater than 50 percent, ten lost more than 40 percent, and 15 more than 30 percent. Based on the T-916 control the average strength loss was 30.6 percent and the standard deviation was 14.7 percent. Obviously, these ropes had been subjected to a type of use that resulted in highly significant loss in strength. It appeared that a major portion of the strength loss could be explained by fiber breakage occurring as a result of abrasion. (See Results, Deteriorative Changes, Fiber Abrasion.)

The elongation of the ropes at the breaking point, or "breaking elongation" (Table III), as estimated from measurements made at 20 and 50 percent of the ultimate strength, varied very little from rope to rope. The range was from 40.0 to 54.6 percent, the average 46.7 percent and the standard deviation 4.0 percent. The control rope was 50 percent, or just 3.3 percent higher than the average for the used ropes. The reduction in elongation could be associated with the mechanical conditioning that the ropes had been subjected to in use. As pointed out above (discussion on circumference), repeated loadings over long intervals result in a progressive decrease in the amount of residual permanent set in viscoelastic materials. This decrease is usually accompanied by an irreversible increase in the length of the structure and a corresponding decrease in the rupture elongation. In experiments with type 300 filament nylon yarn, Susich (9) found that elongation at break decreased from 21.4 to 15.8 percent after mechanical conditioning for 50 cycles at 80 percent of breaking elongation. The immediate increase in length was 6.3 percent but this dropped to 5.0 percent after 1 hour of relaxation. In terms of general order of magnitude, the decreases in elongation noted for the experimental ropes was consistent with that noted by Susich for nylon yarn. However, the length per unit weight of the ropes, in comparison with the control and specification requirements, appeared to be higher than could be accounted for by mechanical conditioning alone, particularly since the conditioning certainly must have been at much less than the 80 percent level used for the nylon yarns.

2. Energy-Absorbing Ability. In mountain climbing rope, an important performance parameter is energy-absorbing ability, which is fundamental to the arresting of a fall (10). In a static type of belay, the rope must completely absorb the kinetic energy of the fall. In a dynamic belay, friction of the rope sliding over a support absorbs some of the energy, reducing that which must be absorbed by the rope in stretching. In either circumstance, the contribution of the rope to energy absorption is a function of both

its strength and its elongation. If the stress-strain curve were perfectly linear, the energy would be one-half the product of the breaking strength and breaking elongation. Since the stress-strain curve in ropes is not linear, the energy equals the area under the stress-strain curve.

For the ropes in this test, the breaking elongations were quite uniform. The average value was 46.7 percent with a small standard deviation of 4.0 percent. Breaking strengths varied widely. The average was 2550 pounds and the standard deviation 630 pounds (Table III). Consequently, the variation in energy-absorbing ability was related more to the variations in strength than to the variations in elongation.

Because more energy is required to stretch 2 feet of rope than to stretch 1 foot of rope, the energy results (Table IV) are given in terms of foot-pounds per foot or, as an alternative, of foot-pounds per pound of rope. The average energy expressed as foot-pounds per foot was 444, with a standard deviation of 138; the average energy expressed in foot-pounds per pound was 8486, with a standard deviation of 2434. The coefficient of variation for foot-pounds per foot was 31.1 percent and for foot-pounds per pound 28.7 percent. Equivalent coefficients for breaking strength and elongation were 24.8 and 8.6 percent. The relatively closer agreement between the coefficients for energy-absorbing ability and breaking strength than between the coefficients for energy absorption and elongation would tend to confirm the observation that the changes in strength during use influenced the energy-absorbing ability of the ropes to a greater extent than did changes in elongation.

Energy losses, computed on the basis of the 23,800 foot-pounds per pound energy-absorbing ability of nylon 300 at a breaking length of 80000 feet ranged from 44.0 to 74.6 percent, with an average of 64.4 percent and a standard deviation of 10.2 percent. Energy losses, computed on the basis of the T-916 control rope, ranged from none at all to 68.3 percent, with an average of 33.0 percent and a standard deviation of 20.1 percent. In fact, one of the used ropes (No. 13) had an energy-to-rupture, in terms of foot-pounds per pound, that was 6.1 percent greater than that of the control rope. In terms of this fundamental concept of rope performance, many of the ropes had reached the point where their serviceability was seriously impaired and where they should have been withdrawn from service.

TABLE IV

Energy-Absorbing Ability of Ropes

<u>Sample No.</u>	<u>Energy to Rupture</u>		<u>Energy Loss</u>	
	<u>(ft-lb/ft)</u>	<u>(ft-lb/lb)</u>	<u>(based on 23,800 ft-lb/lb standard for type 300 Nylon)</u> <u>(%)</u>	<u>(based on ft-lb/lb of T-916 control)</u> <u>(%)</u>
(T-916) Control	714	12,566	47.2	0
Special "A" (Bates)	513	9,439	60.3	24.9
Special "B" (Bates)	622	11,258	52.7	10.4
Experimental				
2	316	6,036	74.6	61.7
3	547	9,846	58.6	21.6
4	306	8,048	67.2	36.0
5	389	9,842	58.6	21.7
6	641	11,923	50.0	5.1
7	475	8,978	62.3	28.6
8	549	9,937	58.2	20.9
9	326	5,901	74.6	53.0
10	220	3,982	83.3	68.3
11	360	6,516	72.6	48.1
12	319	6,093	74.4	51.5
13	753	13,328	44.0	-6.1
14	367	6,643	72.1	47.1
15	598	11,422	52.0	9.1
16	511	9,965	58.1	20.7
17	478	8,652	63.6	31.1
18	364	6,952	70.8	44.7
19	480	8,688	63.5	30.9
Avg of Experimental	444	8,486	64.4	33.0
Std Dev of Experimental	138	2,434	10.2	20.1

3. Hardness. Hardening of rope is not necessarily an indication of deterioration; it appears to be related to changes in physical properties arising from the interaction of complex force systems. It is believed that, under some conditions, hardness may increase during normal storage as a result of a previous history of heat-setting. The extent of heat-setting, in terms of time and temperature, may influence the amount of hardening which occurs, but no studies have been conducted to relate different degrees of heat-setting with subsequent hardening. The hardness of the experimental ropes ranged from 17 to 140 pounds (Table V). The average was 52.2 pounds and the standard deviation 27.2 pounds. If the high value of 140 pounds is eliminated, the range of hardness was from 17 to 69 pounds. Undoubtedly, the 140-pound value indicates that this rope was significantly different from the others.

Although hardness does not appear to be significantly related to deterioration, it is certainly important in the functioning of the rope. The subject of hardness and its significance and relationship to rope processing parameters deserves attention and should be investigated in detail. (For a related study, see Appendix C.)

4. Stiffness. The stiffness (bending length) of the experimental ropes ranged from 3.66 to 8.58 inches (Table V). The average was 5.90 and the standard deviation 1.43 inches.

The relationship between hardness and stiffness is rather complex. While hardness, as measured in this study, involves a centripetal-type force which is directed toward the central axis of the rope and must be overcome by the marlinespike as it is forced between the strands, stiffness represents the ability of the rope to bend under its own weight. In this series of ropes, where the linear density range was narrow, the major factors determining stiffness were inherent in the fibers and in the rope structure itself, hence both these factors contributed to hardness as well.

The association between hardness and stiffness is demonstrated by a coefficient of correlation of .57, of which 32 percent of the variance is explained by the relationship between the two variables. This modest correlation indicates that common features must have influenced these parameters.

That other variables also exerted an influence becomes very evident when one compares the hardness and stiffness of rope No. 17. The hardness of this rope (140 lb) was much beyond that which would have been predicted from its stiffness.

All of the ropes were stiffer and all but one harder than the control, which emphasized that stiffness and hardness are functions of use and storage conditions. It is not obvious from any of the data what the intrinsic changes in the ropes were which led to the marked increase in hardness and stiffness, but two of the factors that might have been responsible were changes in the fiber from exposure to the elements or from storage, and compacting of the fibrous structure in the yarn from weathering, shrinkage, or mechanical conditioning. A detailed study should be made of the mechanism of stiffening following processing, use, and storage in order to determine those design parameters which could slow down the rate at which stiffening occurs.

5. Knotting Ability. The maximum force required to tie an overhand knot in the ropes ranged from 7.9 to 81.5 pounds (Table V). The average force was 33.7 and the standard deviation was 19.1 pounds.

On the basis of a 24-inch length of rope tied into a 2-1/4 inch knot, it would be expected that the effective distance, which is the controlling factor in energy consumption, would be relatively constant. For the greater part of the knot-tying process, this was the case and the maximum force build-up did not occur until the end of the test. However, the value of the dimensional changes occurring near the end of the test varied appreciably from rope to rope and led to energy consumption that was not exactly proportional to the maximum recorded force. The energy consumed ranged from 16.05 to 182.40 inch-pounds. The average energy was 72.30 and the standard deviation was 42.30 inch-pounds. The control rope registered lower in maximum force (7 lb) and energy consumption (10 in-lb) than any of the experimental ropes; so, again, use was found to increase the test values.

6. Compressibility. The compression data obtained from the ropes appears to be closely related to the knotting data. The compression force ranged from 9.5 to 39.5 pounds. The average was 19.6 and the standard deviation 8.6 (Table V). As was noted in the knot tests, the control rope had the lowest value. Thus it appears that all of the factors relating to the inherent mobility of the rope structure are influenced by use in much the same way as are the strength characteristics. Accordingly, from the standpoint of rope efficiency, it would be expedient to pay more attention to achieving a structure in rope design that, with continual use, will sustain the least amount of strength loss and the least increase in stiffness.

TABLE V

Sample No.	Hardness (lb)	Stiffness (in.)	Force to Knot (lb)	Energy to Knot (in-lb)	Thickness (in.) (under 5-lb pressure)	Compressibility	
						Force to Compress Loop to 2.5 x Thickness (lb)	Force to Compress Loop to 2.5 x Thickness (lb)
(T-916) Control	24	3.35	7.0	10.00	0.50	3.0	
Special "A" (Bates)	21	3.37	18.5	38.00	0.50	7.0	
Special "B" (Bates)	47	5.54	32.0	60.65	0.48	20.0	
Experimental							
2	17	3.66	19.0	35.70	0.48	9.5	
3	54	5.83	43.0	91.05	0.47	22.5	
4	31	5.08	7.0	16.05	0.39	11.0	
5	36	5.75	8.0	20.95	0.40	12.0	
6	26	4.41	30.0	63.75	0.48	13.5	
7	65	7.56	21.5	51.95	0.44	23.0	
8	69	8.58	62.0	143.80	0.46	32.0	
9	45	6.81	25.0	56.05	0.48	19.5	
10	28	3.94	49.5	93.00	0.50	10.5	
11	27	4.54	21.0	38.95	0.48	12.5	
12	64	7.37	81.5	182.40	0.45	39.5	
13	62	7.52	49.0	91.90	0.47	19.5	
14	60	6.50	29.0	67.75	0.46	24.0	
15	41	4.60	18.0	30.70	0.49	12.5	
16	57	4.81	38.5	78.55	0.48	15.0	
17	140	6.66	46.5	102.90	0.47	30.0	
18	60	7.14	34.0	79.45	0.47	28.0	
19	58	5.37	24.5	55.95	0.50	19.0	
AVG of Experimental	52.2	5.90	33.7	72.3	.47	19.6	
Std Dev of Experimental	27.2	1.43	19.1	42.3	.03	8.6	

C. Deteriorative Changes

1. Fiber Abrasion. As pointed out under the description of test methods, fiber abrasion may be caused by many factors, but the ultimate effect is the same: the breaking strength of the rope is reduced and there is a corresponding reduction in its energy-absorbing ability. Among the experimental ropes, the range of percentage weight loss was from zero for rope No. 13 (the rope that had a higher energy-absorbing ability than the new control) to 45 percent. The average was 26.1 percent and the standard deviation 12.9 percent (Table VI). The correlation coefficient

TABLE VI

Age, Use Index, and Fiber Abrasion of Eighteen Ropes

<u>Sample No.</u>	<u>Age</u> (in years)	<u>Use Index</u> (Rater W)	<u>Product of Use</u> <u>Index and Age</u> (Rater W)	<u>Fiber Abrasion</u> (% weight loss)*
Std (T-916)				
Control				0
Special "A" (Bates)				20
Special "B" (Bates)				10
Experimental				
2	19	182	3458	40
3	16	109	1744	15
4	14	166	2324	30
5	11	150	1650	25
6	18	152	2736	15
7	12	200	2400	25
8	13	135	1755	10
9	16	95	1520	35
10	18	220	3960	40
11	18	60	1080	30
12	18	180	3240	40
13	14	20	280	0
14	11	200	2200	45
15	10	60	600	20
16	13	100	1300	15
17	14	140	1960	20
18	6	200	1200	45
19	18	180	3240	20
Avg of				
Experimental	14.4	141.6	2040	26.1
Std Dev of				
Experimental	3.6	56.8	1010	12.9

\*Rounded out to nearest 5%



between strength loss and fiber abrasion was a high 0.87, of which over 75 percent of the variance could be explained in terms of the relationship between the two variables.

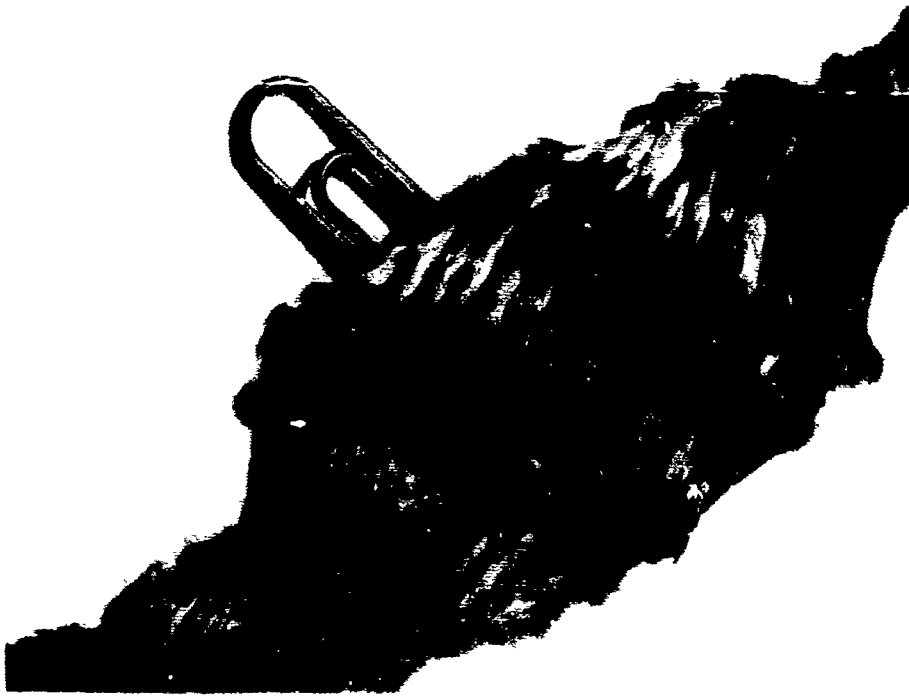
A detailed analysis was made of rope No. 2, which had a strength loss of 42 percent, to account for its high loss in view of the absence of significant ultraviolet deterioration and only visual evidence of surface abrasion. From the gross appearance of this rope, it could be concluded that only a small portion of the surface fibers had been seriously abraded and that a substantial core of unabraded fibers should exist. But, when the rope was unlayed and each strand was untwisted to show its inner structure, only three of the nineteen yarns comprising the strand were found to be free from abrasion (Figure 3b). The balance of sixteen yarns all appeared at the surface of a short portion of the rope, due to migration of the yarns in the strand and to the path of the strand in the rope structure itself. Thus, fiber breakage at any point on the surface could seriously influence the strength of each of the sixteen yarns and consequently of the whole strand and rope.

2. Nylon Fluidity and Ferric Chloride Solubility. The nylon fluidities obtained from different areas of the Bates ropes (A and B) and from the control rope are given in Table VII. Rope A showed an average increase in fluidity of 0.1 rhes and rope B of 0.2 rhes. Neither of these increases is indicative of chemical deterioration. Because a comparison (11) of tensile loss vs. fluidity for nylon tapes that had been exposed to sunlight (ultra-violet radiation) revealed that fluidity at this level is not reflected in any strength loss, the strength loss and hardness changes observed in these two ropes must have arisen from causes other than exposure to sunlight.

TABLE VII

Nylon Fluidity of "Bates" Ropes  
(rhes)

	<u>Rope A</u>		<u>Rope B</u>		<u>Control</u>	
	<u>Inside</u>	<u>Outside</u>	<u>Inside</u>	<u>Outside</u>	<u>Inside</u>	<u>Outside</u>
unexposed area						
(100% area)	1.5	1.5	1.6	1.7	1.4	1.4
exposed area	1.5	1.5	1.7	1.5	---	---



a. Outer portion



b. Inner portion

Figure 3. Outer and inner portions of a single strand of rope No. 2, showing inner core construction

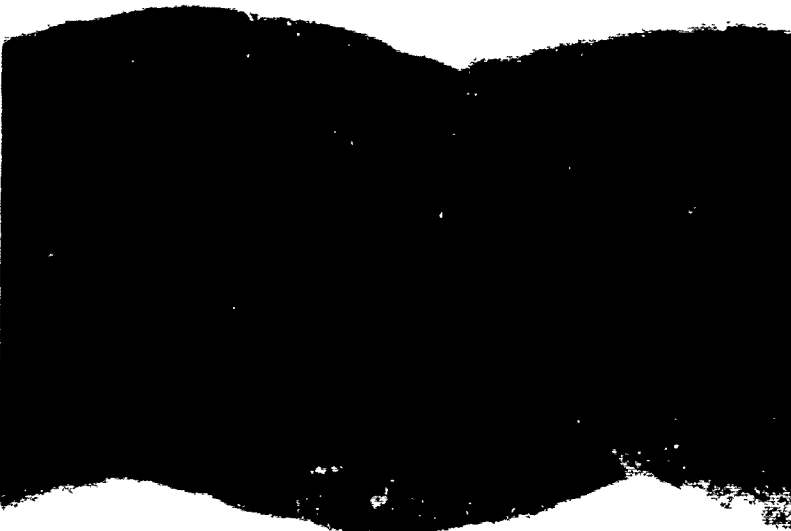
All of the ropes in this series lost less than 5 percent of their original weight in the ferric chloride solubility test; this indicates no significant weathering damage. It is probable that, if the ferric chloride test had been limited to the outer fibers of the rope, higher solubilities would have been measured. However, since gross deterioration of the rope structure was the major criterion of interest, it is assumed that weathering did not have an important influence on functional properties.

3. Filament Structure Damage. Figure 4 shows a 10x magnification of the control rope (Figure 4a) and two similar magnifications of rope A: one (Figure 4b) taken from an unabraded area near the end of the rope, and one (Figure 4c) taken from an abraded area. In the abraded area of the rope, single filaments appear separated from the yarn body. The number of these filaments is a function of the degree of damage. Near the end of the rope, where it was not subjected to any significant abrasive action, very few single filaments appeared, whereas from the abraded area many broken filaments were detected.

Figure 5 shows a 200x magnification of single filaments removed from the control and rope A. The control rope (Figure 5a) shows perfectly uniform filaments and no disturbance of the surface structure. Rope A (Figure 5b) shows evidence of a thickening at the broken filament end, fibrillation of the fiber surface, and, in some instances not shown on the photograph, there was a sticking together of broken fiber ends.

4. Changes in X-ray Diffraction Patterns. Figure 6 shows X-ray diffraction patterns of fiber bundles removed from the control rope and from damaged areas of ropes A and B. The pattern for the control rope is typical of an oriented fiber pattern of high tenacity nylon. While the patterns for the other two ropes (A & B) appear somewhat different from that of the control, it is believed that these differences may have arisen more from the difficulty in handling the damaged areas than from any effect on the crystal lattices of the nylon which may have been induced by the damage. For example, the interference arcs with the maxima are symptomatic of difficulties in the proper alignment of intact and broken fiber ends; the presence of the diffuse interference pattern of the rope is also believed to be a testing artifact.

The results of the specific analyses made on the later ropes confirmed the evidence of the absence of solar radiation damage in the other eighteen ropes. The photographs also confirmed that there was fiber breakage due to abrasion and they showed the manner in which such breakage occurs. This breakage could account for the observed loss in the strength of the ropes. The X-ray data are not indicative of any particular trend and no indications were found of the possible cause of the stiffening of the ropes.



a. Control rope



b. Rope A, near end, unabraded



c. Rope A, abraded area

Figure 4. Comparison of abraded and unabraded areas of rope surface (magnification 10x)



a. Fiber from control rope



b. Fiber from Rope A

Figure 5. Single filaments removed from rope (magnification 200x)

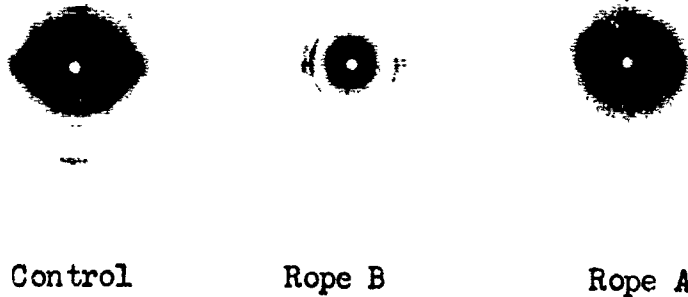


Figure 6. X-ray diffraction patterns of fiber bundles

#### D. Correlation Between Objective Data and Use Histories

It was assumed, initially, that the extent of deterioration in the ropes as measured by strength loss, energy loss, and fiber abrasion would be a reflection of either the amount of use to which the rope had been subjected or the age of the rope. It was found that age was not a significant factor in governing deterioration but use history was (Table VI). The degree of correlation between use and objective measurements of deterioration could have been influenced by a number of factors: the validity of the use history; the validity of the interpretation of the use history by the rater; and, of course, the significance of the relationship between the use history and the objective measures.

Eleven of the eighteen ropes had use histories that were found to be quantitative; seven had histories that were more qualitative than quantitative (Appendix A). Accordingly, correlations were made (Appendix D) using all eighteen samples (Table VIII) and only the eleven that had the more complete histories (Table IX). Three raters (W, P, and J) were used to compute the Use Indexes of the ropes. They agreed that the Indexes would be arrived at by counting the total days of use using a judgment factor if days were not explicitly stated. For example, rope No. 2, with documented use during a) three 1-month climbs (90 days) b) two climbs per month for 3 years (72 days) and c) occasional use around the house over a 19-year period (20 days) would be considered as having a use index of 182. Despite this understanding, agreement between the raters for the rest of the eighteen ropes was not good; the correlation coefficients of their Use Indexes were 0.24, 0.44, and 0.65.

However, for the 11-sample group, which was based on more quantitative use histories, the correlation coefficients between the raters were 0.61, 0.66, and 0.87. Using Fisher's Z-transformation (Appendix E) to test the significance of the differences among these correlation coefficients, it was found that in the 18-sample study the three coefficients were not significantly different from each other, the greatest difference being 1.6 standard deviation. However, in the 11-sample study, the differences were even less, the greatest being 0.74 standard deviations.

While, on a strictly statistical basis, the correlation coefficients for the Use Indexes were not significantly different among the three raters, the correlation coefficients between the objective test measurements and the Use Indexes were quite different among the three raters.

TABLE VIII  
Correlation Coefficients (above 0.50)  
Between Use Index and Objective Measures  
of Eighteen-Rope Series

<u>Use Index</u>	<u>Rater (W)</u>	<u>Rater (P)</u>	<u>Rater (J)</u>
Rater (W)		0.65	-
Rater (P)	0.65		-
Rater (J)	-	-	
<u>Breaking Strength (lb)</u>	-0.65	-0.55	-
<u>Breaking Length (ft)</u>	-0.65	-0.52	-
<u>Strength Loss (%)</u>			
Based on 80,000-ft	0.66	0.51	-
Based on breaking length of T-916 control	0.65		
<u>Energy to Rupture</u>			
(ft-lb/ft)	-0.57	-	-
(ft-lb/lb)	-0.53	-	-
<u>Energy Loss (%)</u>			
Based on 23,800 ft-lb/lb	0.54	-	-
Based on ft-lb/lb of T-916 control	0.54		
<u>Fiber Abrasion (%)</u>	0.60	0.55	-

Note: (-) indicates a correlation coefficient below 0.50.

The correlations were based on those characteristics that appeared to be related to deterioration, i.e., changes in strength and energy and in the amount of fiber abrasion. (In a preliminary trial, harness showed such poor correlation with the Use Index for all three raters that correlations were not made for it or for the related factors of stiffness, knotting characteristics, and compression.)

TABLE IX

Correlation Coefficients Between  
Use Index and Objective Measures of  
Eleven-Rope Series\*

	<u>Rater (W)</u>	<u>Rater (P)</u>	<u>Rater (J)</u>
<u>Use Index</u>			
Rater (W)		0.87	0.66
Rater (P)	0.87		0.61
Rater (J)	0.66	0.61	
<u>Breaking Strength (lb)</u>	-0.72	-0.73	-0.53
<u>Breaking Length (ft)</u>	-0.72	-0.71	-0.62
<u>Strength Loss (%)</u>			
Based on 80,000 ft breaking length	0.72	0.71	0.62
<u>Energy to Rupture</u>			
(ft-lb/ft)	-0.72	-0.70	-0.60
(ft-lb/lb)	-0.67	-0.64	-0.65
<u>Energy Loss (%)</u>			
Based on 23,800 ft-lb/lb	0.68	0.64	0.66
<u>Fiber Abrasion</u>	0.77	0.76	0.50

\* The eleven-rope series represented those ropes having more quantitative use histories

In the eighteen-sample correlation study, the correlation coefficients with the objective measures ranged from 0.53 to 0.66 for Rater W, from 0.35 to 0.55 for Rater P, and from 0.05 to 0.15 for Rater J. Thus, although the Z-transformations showed good agreement among the three raters in the correlation coefficients of the Use Index, the actual data in the eighteen-sample correlation study indicated a difference in the rating tendencies of the raters. In the eleven-sample correlation series, the results were quite different. The



correlation coefficients ranged from 0.67 to 0.77 for Rater W, from 0.64 to 0.76 for Rater P, and from 0.50 to 0.65 for Rater J. Obviously, the correlation coefficients improved when the Use Index data were more quantitative.

When the good correlation of the eleven-sample series is taken into consideration, and the relatively fair correlation of the eighteen-sample series, it becomes apparent that deterioration was related to the use of the rope. Thus, it can be assumed that the longer a rope is used, the greater will be its deterioration.

Using the data obtained in the eleven-sample series, it is possible to find Use Indexes which correspond to different degrees of deterioration. These relationships could be used as a basis for establishing cut-off points in the use-life of a rope, beyond which additional use could become hazardous. For example, if a 30-percent deterioration, in terms of strength loss, is considered to be the maximum tolerable amount from the standpoint of safe performance, it can be determined by reference to Figure 7 that this corresponds to

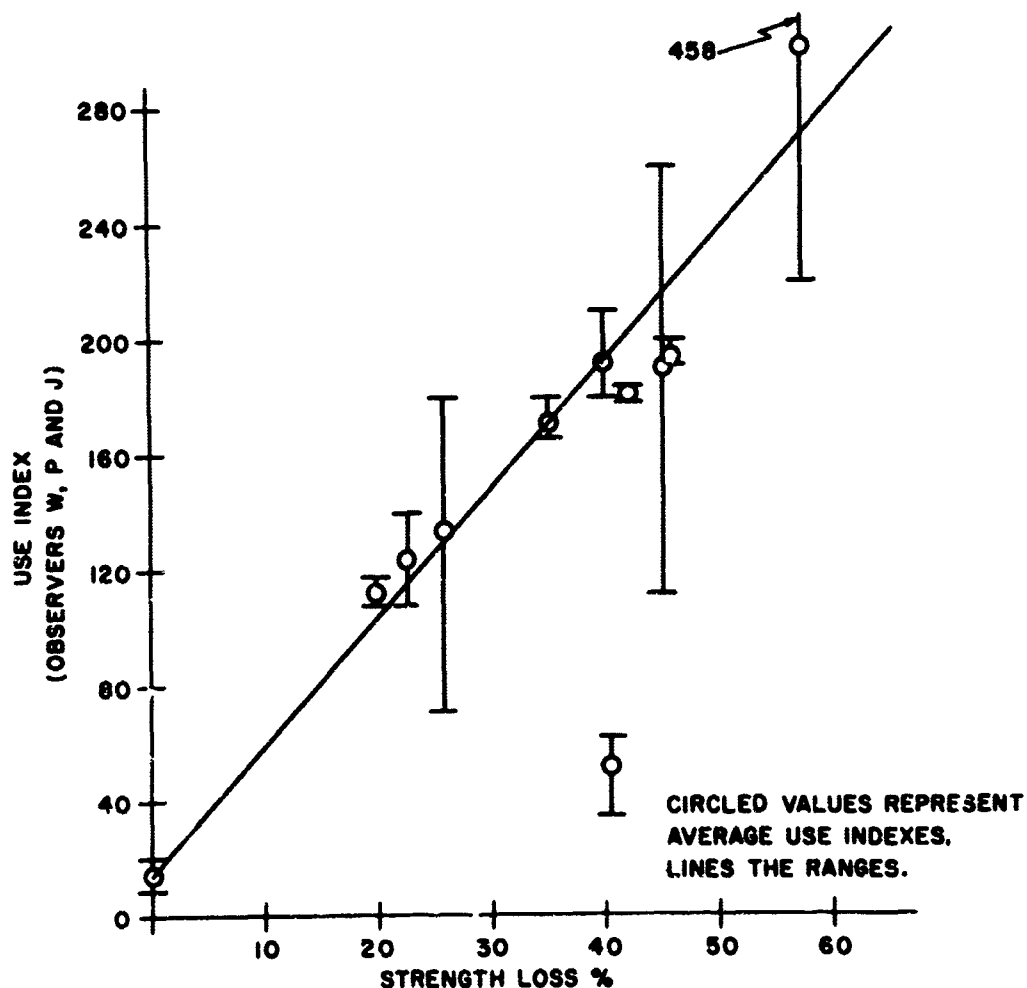


Figure 7. Correlation of Use Index With strength loss (11-rope series)

a Use Index of 150 days. It is possible that log books could be associated with climbing ropes and, after a fixed number of days of climbing use, the rope could automatically be retired from service. However, the data in this report are not sufficiently extensive to permit an unqualified statement as to the validity of the Use Index. Nevertheless, as an initial control measure, it might be well to consider disqualifying ropes from further use after 100 days of field climbing use.

As mentioned, correlation of the various objective measurements with the chronological age of the rope in years was not meaningful. The correlation coefficients found for strength, abrasion, and energy ranged from a low of 0.01 to a high of 0.24. The age of the ropes ranged from 6 to 19 years (Table VI), with the average age being 14.4 years and the standard deviation 3.6 years. Five of the ropes were 18 years old, causing a clustering of values at this age that might have added to the difficulty of finding a correlation with age. Nevertheless, there was a sufficiently broad range of ages to demonstrate that age alone cannot be considered the chief cause of degradation. When the Use Index and age were multiplied together, a factor was obtained which showed a better correlation with deterioration than did age alone. This would be expected because of the high correlation between use and deterioration. There is no basis for assuming that any real interaction exists between age and use history.

#### E. Correlation Between Objective Measures

Some of the correlation coefficients obtained between the objective measurements made in this study (Table X) are discussed in general terms below:

1. The knot tying force (in pounds) is significantly (r value of 0.93) related to the knot tying energy (in inch-pounds) required, and somewhat (r value of 0.69) related to the compression force.

2. The knot tying energy is fairly closely (r value of 0.78) related to the energy required to compress a loop of rope compression energy. Apparently knotting involves a complex interaction of tensile, compressive, and bending forces, which make the prediction of knot-holding ability rather difficult.

3. The force (in pounds) required to compress a rope to 2-1/2 times its thickness (compression force) is significantly (r value of 0.93) related to the compression energy (in inch-pounds) required. The high variability of the ropes in strength and the low variability in elongation, making energy differences more closely related to strength differences, appears to carry over to the knotting and compression data also.

4. Hardness is fairly closely associated with both the compression energy (0.64) and compression force (0.66), but is slightly less closely related to bending length (stiffness) (0.57). The fact that so many of the correlation coefficients related to hardness, bending length, and knotting characteristics are either highly or fairly significant suggests that these parameters could prove to be a fruitful area for further study. It is probable that more intensive analysis would provide clues to the serious problem of rope stiffening and the reduction in knot-holding ability.

5. The significant correlation between strength loss and energy loss (0.87) provides further evidence that deterioration of the ropes was a result of changes in strength and not in elongation. In addition, the equivalent correlation (r value of 0.87) between strength loss and fiber abrasion enables us to conclude that the strength loss sustained by the rope was a direct consequence of the surface abrasion of individual fibers, and that their cutting, fracture, and rupture was translated into a corresponding reduction in strength.

6. The inverse relationship (-0.69) between circumference and linear density may have some significance. The fact that it is not even higher indicates that some external factor, such as the observed surface abrasion, must have been operating to increase the circumference of the rope without a corresponding change in its linear density.

TABLE X

Correlation Coefficients Between Various Objective Measures of Eighteen-Rope Series

	<u>Knot Tying Force</u>	<u>Knot Tying Energy</u>	<u>Compression Force</u>	<u>Hardness</u>	<u>Strength Loss</u>	<u>Circumference</u>
Knot tying energy	0.93					
Compression energy		0.78	0.93	0.61		
Compression force			0.69	0.66		
Stiffness				0.57		
Energy loss					0.87	
Fiber abrasion					0.87	
Linear density						-0.69

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Appendix A

Individual Use Histories  
of Nylon Mountain Climbing Ropes

Identification: No. 2 (SBH).  
7/16 in. Nylon. 120 ft.

Age: 1945

1. Used in three one-month summer climbing occasions (3 years) in Western Canada. These involved rocks, snow and ice.

2. Then used on local rockclimbing areas (Washington, D. C.) for about 3 years; estimated 2 days per month throughout year.

3. Subsequently retired to occasional utility use around house: painting jobs, used to secure ladders, tree surgery work. On tree work, served to lower cut limbs of several hundred pounds weight.

Storage: Kept in a basement locker in D. C. area, close to cement floor; summers very humid. This sometimes resulted in fungous growth on rope. Never exposed to solvents.

Identification: No. 3 (AEP)  
7/16 in. Nylon. 120 ft.

Age: 1947-1948 (estimated; not exactly known).

Use: 1. Used on one intensive mountaineering trip of 1-month duration when new; this involved rocks and snowfields.

2. Then used 1 to 2 years for rock climbing in Washington, D. C. area, 2 to 3 days per month throughout year. It may have been used in a few cave trips.

3. Next used as safety rope when cleaning gutters and repairing roof from about 1950 to 1957; estimated 4 days per year. Not used since then.

Storage: Kept coiled, usually hanging from a 20 d. spike in dry attic in Washington, D. C.; reached high summer temperatures (at least 100-110°F at times) and normal D. C. humidity; cold and dry in winter. Never stored in a small closed space and not exposed to solvents.

Identification: No. 4 (JLS)  
3/8 in. Nylon. 120 ft.

Age: Purchased 16 June 1950

Use:

1. Used as climbing rope 1950-1956 at local rock climbing areas near Washington, D. C., approximately 2 days per month.
2. Used on 3 week expedition to Canadian Rockies (Lyells) in 1954. Much of this use was on snowfields.
3. Last used in 1957 as hoist to pull 14 ft. rowboat up steep bank.
4. Rope has never been used in caves.

Storage:

Summer: Usually kept in clothes closet of a ground floor apartment in Washington, D. C. area; occasionally left in car trunk during week.

Winter: Kept in car trunk.

Identification: No. 5 (MLK)  
7/16 in. Nylon. 120 ft.

Age: 1953

Use: Used quite regularly for rock climbing on week-ends for 3 years, in Washington, D. C. area. Climbers have been caught by it many times but never in a severe free fall.

Storage: Generally stored in a dry and dark closet on second floor of apartment in D. C. area. Occasionally, it has been left from one week-end to next in rear of station wagon.

Identification: No. 6 (HFS)  
7/16 in. Nylon. 120 ft.

Age: Early in 1946

Use:

1. Used extensively for weekend rock climbing in Washington, D. C. area.
2. Colorado Rockies in 1949 and 1950, about 1 month each year.
3. In 1950, it was lost in Colorado Mountains at 12,000 feet for 10 days.
4. Also used for tree surgery and has been left in trees for several days at a time on several occasions.

Storage:

Generally kept in an open place (on shelf) in dry basement, -- normal D.C. humidity. Not stored in a closet and not exposed to solvents.

NOTE: This is an Army rope bought a few months after World War II.

Identification: No. 7 (H. & J. K.)  
7/16 in. Nylon, 70 ft.

Age: Purchased May, 1952 (odd length from an Army coil).

Use:

"Rope was put in service in June, 1952. It was used extensively in lead rock climbing for a period of five years. It held no bad falls during this time. However, the rock on which it was used is an extremely coarse granite with high abrasive qualities.

"During this time, it was used for very little ice and snow climbing, and consequently, has had comparatively little wetting and freezing.

"Since retirement from use in climbing, the rope has been used for belay practice. The belay practice rigging had a 6 in. sheave instead of a carabiner for the rope to run over (a wooden sheave). The dummy in use weighed approximately 165 pounds. Twenty to twenty-five falls varying in height from 10 to 20 feet of free fall, were held. The rope shows scorching and fusing where it ran over the pulley in stopping these falls.

Storage:

"During the 6-1/2 years we have had the rope, it has been stored in our truck. There it has been protected from rain and snow, but has undergone extreme temperature changes. Temperatures in the truck have varied from well over 100°F to minus 30°F."



Identification: No. 8 (TMS)  
7/16 in. Nylon. 120 ft.

Age: October, 1951  
Manufactured by Plymouth Cordage Co.  
Bought Oct. 1951 from Abercrombie & Fitch.

Use:

1. Mountaineering trips in Western U.S. 1953 & 1955.
2. Also used on weekend trips around Washington, D. C. Used for climbing and rappelling.
3. Has been used in Potomac River, while swimming, several times.
4. In 1955, it was stretched excessively in making an aerial traverse; since that time, it has seemed unusually stiff.

Storage:

Since 1951, rope has been in trunk of car about 90% of time, usually draped over spare tire.

Identification: No. 9 (EM)  
7/16 in. Nylon. 105 ft.

Age: Bought in 1946 from a large lot sold by Plymouth Cordage (?) to Chris Scoredos of Washington, D.C.

Use:

1948-1952. Local weekend rock climbing; took several static falls. (Seven foot dynamic fall in 1950).

1951. Taken on trip to Western mountains but not extensively used.

1952. Rope retired from service, but used 2 or 3 times since then.

Storage:

When used, normally carried on outside of pack exposed to sunlight.

Generally stored in dark bedroom closet in Washington or New Haven.

Identification: No. 10 (AW - Rope A)  
7/16 in. Nylon. 120 ft.

Age: Procured approximately 1946.

Use:

Not used 1946 - 1948.

Used extensively from 1948 to 1958.

It has been used almost every year on one-month mountaineering expeditions involving snow, rock and bush. From 1953 on, it was also used extensively for local (D.C.) rockclimbing, principally on mica schist and quartzite rock. It was used once on a trip into Schoolhouse Cave where it was employed as a fixed rope (down a mud slope). It has been used in rappelling and belaying and has been exposed both to sunshine and rain.

In 1958, after cave trip, it was washed in a stream to remove cave mud and air dried. It was observed after this trip that rope showed signs of disintegration near one end. This had not been observed before entering cave but was observed immediately on exiting from cave; this could not be correlated with any known use or strain. Rope was retired after this cave trip.

Storage: Up to 1953 or 1954, stored indoors.

Since then, rope has been stored on a screened back porch, open to atmospheric conditions but sheltered from rain and, to a large extent, from direct sunshine.

Identification: No. 11 (AW - Rope B)  
7/16 in. Nylon. 120 ft.

Age: Procured approximately 1946.  
(Same time as No. 10)

Use:

Used only a few times on local rock climbs from 1946 to 1953.

Since 1953, it has been used primarily on expeditions, with occasional use on local rock climbs. Most of use has been in last two years. Total use comparatively limited compared with Rope No. 10.

Storage: (Same as Rope 10)

Up to 1953 or 1954, stored indoors.

Since then rope has been stored on a screened back porch, open to atmospheric conditions but sheltered from rain and to a large extent, from direct sunlight.

Identification: No. 12 (JM)  
7/16 in. Nylon. 120 ft. (Columbian mfr.)

Age: Acquired in summer of 1946.

Use:

1. This rope has had a more varied career than perhaps any of this first group.

2. Use has included:

- a) Three 2-3 week mountain climbing trips.
- b) Seven years of local (D.C.) rock climbing; this has been occasional weekend use.
- c) It has been used as a safety rope in river swimming and on rubber boat trips. Owner has done considerable white water boating.
- d) It was used once in heavy surf after a hurricane (salt water immersion). It was used to tie a group of men together; there were no severe strains but considerable sand abrasion.
- e) Rope has been subjected to wet freezing.
- f) Most extensive use has been in cave climbing. It has been used several times each year on such trips.
- g) Cave use loads rope with clayey mud. This has been removed by washing in a washing machine, -- using "Tide" detergent. Drying was done, promptly after washing, in a well ventilated basement.
- h) Rope may have been used once to tow a car.

Storage: Storage has been in dry basements between trips.

Identification: No. 13 (AEP)  
7/16 in. Nylon. 120 ft.

Age: Probably purchased in 1950 or 1951. (A survey of cancelled checks could pinpoint this if necessary).

Use:

1. This rope has seen very little use.
2. It was used perhaps half a dozen times on local rock climbs up to February 1959.
3. It had a very stiff and inflexible "feel".
4. Used in one cave trip in February 1959; it was used in lining packs across a gorge and also as a safety rope. It came out completely soaked with mud. After trip, it was washed and dried.
5. This rope is submitted as being an almost unused specimen.

Storage: Stored coiled in a dry attic in Washington, D.C., nearly always hung from a spike; no paints or solvents were involved.

Identification: No. 14 (JFC)  
7/16 in. Nylon. 120 ft. (Red center mark made with  
Higgins red india ink; one end is blue.)

Age: Purchased May 1953.

Use:

1. Estimated 30 days rock climbing in 1953  
50 " " " " 1954  
40 " " " " 1955  
10 days mountaineering in 1955  
50 days rock climbing in 1956  
10 " " " " 1957  
3 " " " " 1958  
Not used in 1959.  
Total: 183 days rock climbing; 10 days mountaineering.
2. Typical rock climbing has been practice climbing in nearby D.C. areas and on Seneca Rocks in West Virginia. It was used one day in Schoolhouse Cave.
3. Mountaineering has been in Grand Tetons.
4. It has been used on 2 climbs of Devil's Tower, Wyoming.
5. Rope caught one free fall of 15 feet for 150 pound man. Rope ran through 2 carabiners, perfect dynamic belays; one channel piton was bent. Man had single loop around waist; he was not bruised, so judges that stress could not have been too great.
6. Another free fall involved another 150 pound man. Fall was about 10 feet. Rope passed through one carabiner and around smooth rock. Belayer (J.F.C.) hardly felt shock; most was taken up by friction on rock.
7. Rope has been used on about a dozen 2 to 3 foot free practice falls.
8. Rope has rarely been dragged over rocks when climbing.

Storage: Always stored in normal coiled condition. Usually hung on a peg in room with indirect lighting (no direct sunlight) reaching rope. It was stored for a few months in a small ventilated closet on top of camping equipment. No history of exposure to solvents is known. Storage was in usual ambient indoor temperatures for D.C. area.

Identification: No. 15 (BA-1)  
7/16 in. Nylon. 120 ft.

Age: 10 years

Use:

1. Used for climbing each year in 19 year life.
2. Climbing has been mainly on rock in Tetons, but also some snow and glacier work.
3. It has become water soaked many times but "seems to retain its supple characteristics."
4. Never subjected to any excessive strain, such as in free falls.
5. Used extensively for rappelling, doubled, through carabiner.

Storage:

Practically always stored in dark and dry places between periods of use.

Identification: No. 16 (BA-2)  
7/16 in. Nylon. 120 ft.

Age: 13 years.

Use and Storage:

1. Rope was used in climbing for first 7 years.
2. "Since then, it has been used inside of a large hay barn, to hold the heavy hay door up in place. For that reason, it has been under tension over about 75 ft. of its length for the past 6 years, -- stretched with no support from beneath. In this spot, it has received considerable moisture from exhaled vapor from cattle below during winters -- has been dry during summers".

NOTE: This could be an interesting specimen. In an earlier letter, Mr. Adams estimates there was about 500 pounds tension on rope. (AEP)

Identification: No. 17 (ACL)  
7/16 in. Nylon. 120 ft.

Age:

Purchased Dec. 1950 from Plymouth Cordage.

Use:

1. Weekend rock climbing use: "It was used about 3 times a month in 1951 on Sunday or weekend practice climbs on schist or quartzite in D.C. area. From 1952-54, it was used about once a month on weekend practice climbs, usually on Sierra granite or in Southern California practice areas, seasonally on Sierra snow. From 1955-58, it was used about once a month on D.C. practice climbs".

2. Expedition type climbs:

1951 - Devil's Tower, Wyo. Sustained one 20 ft. free fall.

1952 - Canadian Rockies, Assiniboine Area, mostly on snow.

1953 - Waddington area (Coast Range, British Columbia), mostly on snow.

1954 - None.

1955 - Mt. Whitney, California, area, mostly on rock.

1956 - None.

1957 - None.

1958 - Colorado Front Range and Boulder, Colo., area, three weeks, mostly on rock.

Schoolhouse Cave, West Virginia, used as a safety rope on three trips. Wet clay mud and dolomite rock.

Storage:

Storage has been dry, either in attic or utility room. No known exposure to fumes or solvents.

Identification: No. 18 (EH)  
7/16 in. Nylon. 120 ft. ("Plymouth, heat-set nylon")

Age: 6 years.

Use:

1. Where Used: Primarily in New England, New York and Washington, D.C. for rock climbing. Also used on following mountaineering trips: 5 climbs in Tetons, 2 climbs in Canadian Selkirks and on Alaska glaciers.

2. How Used: Rock and snow climbing.

3. Length of Use: Almost every weekend for 2 years in Washington, D.C.; other 4 years, 12 to 20 climbing days per year.

4. Rope usually used for safety, rappels and belaying, a little tension climbing, one leader fall.

Storage: Warm, dry room under cover.

Identification: No. 19 (AJK)  
7/16 in. OD Nylon. 120 ft.

Age: New in 1946.

Use:

1. In 1946 it was used on a mountain climbing trip; stretched across a river that had to be ferried; it was subjected to very severe strains. (Location of trip not given).

2. It was used on another mountain climbing trip in 1947. This was in British Columbia and involved rock, snow and ice.

3. From 1947 to 1951 or 1952 it was used extensively on rock climbs in the Washington, D.C., area.

4. "Rope was more or less retired in 1951 or 1952. Nevertheless, it has had a great deal of use, and my guess is that one can say it has had at least six months of wear as a climbing rope." (Quoting from letter from Kauffman).

Storage:

Apparently stored in an apartment with camping gear; not kept on floor, not subjected to fumes or solvents, and not stored in direct sunlight.

Locale:

Washington, D.C.



Appendix B

Military Specifications

"Rope, Climbing Nylon"

**MIL-R-1688B**

**20 SEPTEMBER 1963**

**SUPERSEDING**

**MIL-R-001688A(GL)**

**11 OCTOBER 1963**

**MIL-R-1688**

**22 NOVEMBER 1949**

## **MILITARY SPECIFICATION**

# **ROPE, CLIMBING, NYLON**

*This specification has been approved by the Department of Defense and is mandatory for use by the Departments of the Army, the Navy, and the Air Force.*

### **1. SCOPE**

**1.1 Scope.** This specification covers nylon climbing rope.

**1.2 Classification.** The nylon climbing rope shall be furnished in one type in the sizes specified (see 6.1).

### **2. APPLICABLE DOCUMENTS**

**2.1** The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

### **SPECIFICATIONS**

#### **FEDERAL**

CCC-T-191 — Textile Test Methods.

#### **MILITARY**

MIL-C-3131 — Cordage; Preparation for Delivery of.

### **STANDARDS**

#### **MILITARY**

MIL-STD-105 — Sampling Procedures and Tables for Inspection by Attributes.

(Copies of specifications and standards, required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

### **3. REQUIREMENTS**

**3.1** Preproduction sample approval. When specified, before production is commenced, the supplier shall submit an 90 foot sample of the rope which he proposes to furnish to the contracting officer for approval.

**3.2** The requirements specified in 3.7, 3.9 and 3.10 apply only to rope purchased directly by the Government. All other requirements apply to rope purchased as a component for an end item by a supplier, and to rope purchased directly by the Government.

**3.3** Standard sample. The rope shall match the standard for shade and shall be equal to or better than the standard sample with respect to all characteristics for which the standard is referenced (see 6.2).

**3.4** Materials. The rope shall be fabricated from bright, virgin, continuous-filament nylon fiber. The nylon shall be long chain polymer made of hexamethylene diamine and adipic acid or a long chain polymer of epsilon amino caproic acid (see 4.2.5).

**MIL-R-1688B**

**3.5 Physical requirements.** The ropes shall be of three strand construction and the natural or dyed rope shall conform to the requirements

specified in table I when tested as specified in 4.2.5.

**TABLE I. Physical requirements**

Circumference (nominal)	Tolerance plus or minus	Diameter (approximate) <sup>1</sup>	Length per pound (minimum) <sup>2</sup>	Breaking strength (minimum)	Elongation (minimum)	Load P 50d <sup>3</sup>	Turns (maximum)	10 (minimum)
Inches	Inches	Inches	Feet	Pounds	Percent	Pounds	Inches	Inches
¾	± 1/16	¾	47.0	1050	35.0	3	7.8	7.0
1 1/8	± 1/16	¾	23.0	2400	35.0	7	12.4	11.1
1 1/4	± 1/8	¾	17.0	3400	35.0	9.5	14.3	12.9

<sup>1</sup> Not a specification requirement, included for information only.  
<sup>2</sup> A minus tolerance of 10 percent is allowed for dyed rope.

**3.5.1 Elongation.** The elongation of the ropes shall be not less than 35 percent at the breaking point when tested as specified in 4.2.5. Changes due to splice slippage shall not be considered in this determination.

**3.5.2 Resistance to backturning.** The rope shall be so constructed as to have a firm lay with a high degree of resistance to backturning (nubbing of kinking in the strand) upon removal of afterturn from the rope.

**3.6 Finish.** No extraneous material shall be added for the purpose of weighting the rope. The extractable matter of the finished rope shall not exceed 4.0 percent and the loss in breaking strength shall not exceed 10.0 percent after heat aging when tested as specified in 4.2.5.

**3.7 Moisture content.** The moisture content of the rope as received shall not exceed 5.0 percent when tested as specified in 4.2.5 (see 6.3).

**3.8 Color.** Unless otherwise specified the rope shall be dyed Olive Drab No. 7.

**3.8.1 Matching.** The shade of the dyed and finished rope shall match the standard sample under natural (north sky) daylight or artificial daylight, having a color temperature of 7500° Kelvin and shall be a good approximation to the standard sample under incandescent lamplight at 2800° Kelvin (see 6.2).

**3.8.2 Colorfastness.** The dyed and finished rope shall show fastness to weathering equal to or better than the standard sample when tested as specified in 4.2.5. When no standard sample

has been established, the dyed rope shall show good fastness to weathering when tested as specified in 4.2.5.

**3.9 Identification ticket.** Each coil of rope shall have a ticket attached with not finer than 5 ply cotton string doubled to not less than 8 inches in length. The tickets shall be made of 20-point paper stock. The color shall be manila, and be light in intensity to permit easy reading of printed, stamped, typed, or penciled markings. The ticket shall have clipped corners at the end where a reinforcing patch (with or without a metal eyelet) is firmly affixed for attaching the tying string or wire. The ticket shall be legibly printed with the following information:

- Stock number
- Nomenclature
- Specification number
- Length
- Contract number and date
- Supplier's name.

**3.10 Put-up.** Unless otherwise specified, the rope shall be put up in coils in lengths specified in table II for the respective sizes:

**TABLE II. Put-up**

Rope circumference	Coil length feet	
	(min.)	(max.)
¾	196	204
1 1/8	196	204
1 1/4	117	123

The rope, put up in coils as specified in table II, shall be in one continuous piece and so wound that each turn and layer is free from entanglement. The ends of all rope shall be cut off squarely and securely whipped or heat sealed to prevent fraying or untwisting.

**3.11 Workmanship.** The finished rope shall be clean, free from objectionable odor, and shall conform to the quality and grade of product established by this specification. The occurrence of defects shall not exceed the applicable acceptable quality levels established by this specification.

**4. QUALITY ASSURANCE PROVISIONS**

**4.1 Responsibility for inspection.** Unless otherwise specified in the contract or purchase order the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

**4.1.1 Preproduction sample inspection.** When required, the preproduction sample submitted in

accordance with 3.1, shall be visually inspected for appearance, color and finish. The sample shall be tested for physical and chemical characteristics in accordance with 4.2.5, to the extent applicable.

**4.2 Inspection.** Sampling and inspection shall be performed in accordance with Standard MIL-STD-105, except where otherwise indicated.

**4.2.1 Inspection of components.** Quality assurance provisions for components described shall be in accordance with subsidiary specifications and drawings referenced to the extent applicable except that this specification shall govern in the event of conflict.

**4.2.2 Examination of the end item for visual defects.** Defects found during this examination shall be classified in accordance with the defects listed below and regardless of their proximity to each other, except where two or more defects represent a single local condition, in which case only the more serious defect shall be counted. The sample unit for this examination shall be one coil. The lot size for this examination shall be expressed in units of coils of the specified size and length of rope. The acceptable quality level shall be 1.5 major defects and 4.0 total defects (major and minor combined) per 100 units. The inspection level shall be Level III of Standard MIL-STD-105.

*Visual examination—defects*

Examine	Defect	Classification		
		Critical*	Major	Minor
Appearance and workmanship.	Cut, any . . . . .	X		
	Chafed or damaged. . . . .	X		
	Kinks, darting yarns <sup>1</sup> broken or loose ends, bulged strands . . . . .	X		
	Knots, splice, searing, melting or fusing together of ends to make a continuous length. . . . .	X		
Color. . . . .	Other than specified . . . . .		X	
	Not uniform. . . . .			X
Cleanness . . . . .	Spot or stain, clearly visible <sup>2</sup> . . . . .			X
	Objectionable odor. . . . .			X
Identification ticket. . . . .	Omitted, incorrect, illegible, insecurely attached . . . . .			X
Backturning. . . . .	Evidence of nubbing or kinking on removal of afterturn. . . . .		X	

<sup>1</sup> Darting yarns are internal yarns which project through the cover yarns of the strand at intervals along the rope.

<sup>2</sup> At normal inspection distance (approximately 3 feet).

\*Note. One hundred percent (100%) inspection shall be performed for critical defects on each lot found acceptable under the sampling and inspection for major and total defects. Any length of rope found to contain a critical defect shall be rejected and returned to the supplier.

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**4.2.3 Examination for length and winding.** The sample unit for this examination shall be one coil. The inspection level shall be level L-6 and the acceptable quality level shall be 4.0 percent defective. For lots consisting of 500 or fewer units, the sample size shall be 10 and the acceptable number 1. The lot size shall be the number of units in the inspection lot. Defects shall be as listed in 4.2.3.1 and 4.2.3.2 below.

**4.2.3.1** Defects with regard to length shall be considered to exist if any of the following are determined during inspection:

- (a) Length of unit less than or more than length specified.
- (b) Length of unit less than marked on ticket.

**4.2.3.2** Defects with regard to winding shall be considered to exist if any of the following are determined during inspection:

- (a) Improperly or not firmly wound resulting in kinks, knots, entangling or slippage during unwinding or otherwise affecting free unhampered unwinding of rope.
- (b) Frayed ends not cut off squarely or neatly.
- (c) Ends not securely whipped or heat treated to prevent fraying or untwisting.

**4.2.4 Examination of preparation for delivery requirements.** An examination shall be made to determine that packaging, packing and marking requirements of section 5 of this specification are complied with. Defects shall be scored in accord-

ance with list below. The sample unit shall be one shipping container fully prepared for delivery with the exception that it need not be sealed. Defects of closure listed below shall be examined on shipping containers fully prepared for delivery. The lot size shall be the number of shipping containers in the end item inspection lot. The inspection level shall be L-4 and the AQL shall be 4.0 defects per hundred units.

<i>Examine</i>	<i>Defect</i>
Marking (exterior and interior).	Omitted, incorrect, illegible, of improper size, location, sequence, or method of application.
Materials	Any component missing. Any component damaged.
Workmanship	Inadequate application of components, such as: incomplete closure of case liners, container flaps, loose strapping, inadequate stapling. Bulging or distortion of containers.
Packaging	Not as specified. Coils not secured as specified.
Packing	Not as specified.
Weight	Gross weight exceeds requirements.

**4.2.5 Testing of the end item.** The methods of testing specified in Specification CCC-T-191, wherever applicable and as listed in table IV shall be followed. The physical and chemical values specified in section 3 apply to the result(s) of the determination(s) made on a sample unit for test purposes as specified in the applicable test methods. The sample size and acceptance and rejection number shall be in accordance with table III. The sample unit for testing shall be 80 feet of rope. The lot size shall be expressed in units of coils.

**TABLE III. Sampling for tests**

Number of coils in lot	Number of samples	Acceptance number for each test characteristic	Rejection number for each test characteristic
15 and under	2	0	1
16 to 40	3	0	1
41 to 110	5	0	1
111 to 300	7	0	1
301 to 500	10	0	1
501 and over	15	0	1

TABLE IV. Test methods<sup>1</sup>

Characteristic	Specification reference	Test method	Number of determinations per individual sample unit	Results reported as—
Material.....	3.4	<sup>2</sup>		
Strand.....	3.5	Visual	1	Pass or fail
Circumference.....	3.5	4.2.5.1	3	Average of 3 determinations to nearest 1/16 inch.
Length per pound.....	3.5	4.2.5.2	1	Reported to nearest 0.1 foot
Breaking strength				
Initial.....	3.5	4106 <sup>3</sup>	3	Average of 3 determinations to nearest 10 lbs.
After aging.....	3.6	4106 and 4.2.5.3	2	Average of 2 determinations to nearest 10 lbs. calculated to nearest 0.1 percent.
Length per turn x 10.....	3.5	4.2.5.4	3	Average of 3 determinations to nearest 0.1 inch.
Elongation.....	3.5.1	4106 <sup>4</sup>	3	Average of 3 determinations to nearest 0.1 percent.
Finish (weighting).....	<sup>5</sup>			
Extractable matter.....	3.5	4.2.5.5	2	Average of 2 determinations to nearest 0.1 percent.
Moisture content.....	3.7	2600	2	Average of 2 determinations to nearest 0.1 percent.
Colorfastness to weathering..	3.8.2	4671 <sup>5</sup>	1	Pass or fail

See notes below table.

<sup>1</sup> Tests to determine compliance with specification requirements including quantity of delivery may be made under prevailing atmospheric conditions except in settlement of dispute in which case the tests shall be made upon material which has reached equilibrium under Standard Conditions as defined in Specification CCC-T-191.

<sup>2</sup> Requirement accepted on basis of supplier's certification of compliance thereto.

<sup>3</sup> Method 4106 shall be followed except that the load "P" shall be as specified in table I for the respective size.

<sup>4</sup> Elongation at the breaking point may be determined autographically.

<sup>5</sup> Unless otherwise specified, the apparatus shall be as specified in method 5804, except that:

- (a) Delete from title "(National Weathering Unit)."
- (b) The specimens shall be exposed for forty standard hours.
- (c) The filters shall not be removed when testing.
- (d) Water-spray nozzles shall be mounted horizontally (the water-spray assembly vertically) in the test chamber inside the specimen rack and so placed that the water shall strike the specimens evenly over their entire length in the form of a fine spray in sufficient volume to cover specimens immediately on impact. The apparatus shall be so operated that the specimens are exposed to successive cycles of 102 minutes of light without spray and 15 minutes of light with spray.
- (e) The rack shall rotate about the arc at a uniform speed of one revolution per minute.
- (f) The pressure of the water entering the spray shall be 12-18 p.s.i. inclusive.
- (g) The black panel thermometer shall be mounted on the test panel rack and readings taken at a point where maximum heat is developed and where water spray is not striking the panel. The black panel temperature at the exposure plane of the specimen rack shall be 155° plus or minus 10° F., when the filters are in place and 175° plus or minus 10° F. when the filters are removed.
- (h) Attention is called to manufacturers who own equipment which operates at one cycle in two hours. This equipment may continue to be used. However, the one cycle per minute shall be the standard procedure in the event of dispute.

**4.2.5.1 Determination of circumference.** The circumference shall be measured with the specimen under the load "P" specified in table I for the respective size. With the specimen under this load a fiber shall be passed snugly around the rope and cut where it overlaps. The cut length shall be straightened and measured to the nearest 1/32 inch. This determination shall be repeated at least three times in different positions not less

than two turns of rope apart. The average of these determinations shall be the circumference of the rope.

**4.2.5.2 Determination of length per pound.** A minimum of 12 feet of rope shall be subjected to the load "P" specified in table I for the respective size. While under this tension a distance of twelve feet shall be accurately measured, cut out

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of the specimen and accurately weighed to within plus or minus 0.5 percent of its total weight. The length per pound shall then be calculated utilizing the 12 foot measurement obtained under load.

**4.2.5.3 Breaking strength after heat aging.** Two breaking strength specimens prepared as specified in Method 4106 shall be heated for 5 days in a convection air oven at  $175^{\circ} \pm 2^{\circ}$  F. After aging, the specimens shall be allowed to reach equilibrium under Standard Conditions before being tested for strength. The percent change in strength shall be calculated based on the average strengths initially and after heat aging. Breaking strength shall be calculated in accordance with Method 4106.

**4.2.5.4 Determination of turn.** Determination of turn shall be made by taking a straight length of the sample rope and measuring the length parallel to the axis of the rope of ten complete spirals of one strand. The turn is one-tenth of this measurement, but for convenience the requirement of table I is for ten times the turn.

**4.2.5.5 Determination of extractable matter.** A sample of rope weighing approximately 5 grams shall be placed in a tared weighing bottle and dried to constant weight at  $105^{\circ}$ – $110^{\circ}$  C. After the bone dry weight has been determined, the specimen shall be transferred to a soxhlet extraction apparatus for a minimum of twenty extractions, using reagent grade petroleum ether (boiling point range  $30^{\circ}$  to  $65^{\circ}$  C.) as the solvent. The petroleum ether shall then be evaporated from the extract in the tared flask at a temperature of  $105^{\circ} \pm 5^{\circ}$  C. to constant weight, cooled in a desiccator and weighed. This is the "weight of extractable matter." The percent extractable matter present is calculated from the following formula:

$$\text{Percent extractable matter} = \frac{\text{Weight of extractable matter} \times 100}{\text{Weight of dry specimen}}$$

### Military custodians:

Army—GL  
Navy—MC  
Air Force—MOA

## 5. PREPARATION FOR DELIVERY

**5.1 Packaging.** Packaging shall be level A or C as specified (see 6.1).

**5.1.1 Levels A and C.** The rope put up as specified, shall be packaged in accordance with the applicable requirements of Specification MIL-C-3131.

**5.2 Packing.** Packing shall be Level A, B or C as specified (see 6.1).

**5.2.1 Levels A, B or C.** The rope shall be packed in accordance with the applicable requirements of Specification MIL-C-3131.

**5.3 Marking.** In addition to any special marking required by the contract or order, shipments shall be marked in accordance with Specification MIL-C-3131.

## 6. NOTES

**6.1 Ordering data.** Procurement documents should specify the following:

- (a) Title, number and date of this specification.
- (b) Put-up, if other than specified (see 3.10).
- (c) Selection of applicable levels of packaging and packing (see 5.1 and 5.2).
- (d) Size required (see 1.2).
- (e) When the preproduction sample is required (see 3.1).

**6.2 Standard sample.** For access to the standard sample, address the procuring office issuing the invitation for bids.

**6.3 Adjustment for high moisture content.** Material furnished containing an excess of moisture will be accepted by an adjustment in weight to the 5 percent moisture content.

### Preparing activity:

Army—GL  
Project No. 4020-0029

APPENDIX C

ROPE HARDNESS TESTING;  
SUMMARY OF OBSERVATIONS

by

L. J. Sheehan, Textile Technologist  
Boston Naval Shipyard

Test No. 13117A

25 May 1959

Reviewed by

R. T. Sadler, Jr.  
Supvy. Materials Engineer

Approved by

M. B. Graham  
Head, Laboratory Branch



MEMORANDUM REPORT

Test No: 13117A

Subject: Rope hardness testing; summary of observations

Reference: (a) BUSHIPS Cordage Program, NS-031-003

1. During evaluation of the early types of nylon ropes in connection with reference (a), it was found that certain rope constructions, although flexible and spliceable when received, developed excessive hardness in storage. It was observed that the aged ropes could not be satisfactorily knotted, spliced, or bent on holding devices owing to stiffness. Service trials with these ropes proved unsuccessful, primarily because of these difficulties.

2. Study of the rope constructions employed in the unsatisfactory ropes showed that, in general, three basic high-twist yarn systems were used, namely: (1) groups of one size of large singles yarn; (2) groups of large size multiple plied yarns; (3) large multiple plied yarns of varying sizes grouped with the smaller yarns encasing the large yarns. The strand and rope turns employed varied according to the yarns sizes, but in general the turn combinations were designed to yield ropes having high resistance to back-turn and fore-turn. To further assure attainment of these goals the manufacturers had heat-set their products and thus imposed shrinkage to lock the nylon yarns in place. These ropes by virtue of their construction were overly hard and difficult to employ aboard ship.

3. With the adoption of balanced plied cord system for manufacture of nylon ropes it became possible to design nylon ropes with any degree of softness and flexibility, and with no tendency to harden in storage. In order to assure procurement of suitable nylon rope having the necessary handling qualities, a study was initiated to find a quantitative non-destructible means of differentiating between ropes of good and poor utility from the standpoint of hardness.

4. It was at first believed that flexibility tests might possibly serve to screen out unsuitable rope structures. A search of the literature disclosed that numerous methods have been employed for assessing flexibility of textile materials. In general only two basic systems were employed, namely, cantilever bend methods and angle of lay measurements. It was apparent that the latter method would not be applicable to nylon ropes because of the wide range of angular ratios which can be employed in manufacture of ropes using continuous filament elastic fibers. A review of the cantilever systems for assessing flexibility disclosed that for each range of flexibility the test methods were different, as indicated below:

<u>Method</u>	<u>Flexibility of Material</u>
Simple Cantilever	Limp
Weighted Cantilever	Moderate
Double Cantilever	Stiff
Heart Loop	Very Limp
Circular Loop	Moderate
Pear Loop	Soft curly
Dynamic Cantilever Pendulum	Very stiff

For example, with a flexible material a single self-weight cantilever angle of deflection or a heart loop method was used. With harder and less flexible materials a weighted cantilever bending length or circular loop method was used. With very hard, stiff materials a dynamic weighted swinging pendulum method was employed. The literature further indicated that the different methods could not be inter-related and that values from one method would not predict the range of values from another method.

5. A comparison of cantilever flexibility values with the practical indices of knotability and spliceability showed no correlation. Further it was found that bending resistance (flexibility) measurements varied widely in nylon ropes, depending on the method employed. It was concluded that the cantilever bending methods, although satisfactory for a relative ranking of the flexibility of nylon ropes, could not serve as an index of utility. The flexibility tests measured the resistance to bending over relatively long lengths of ropes. In contrast, the bending quality indicative of knotting and splicing properties could only be found in short bends.

6. Analysis of the bends in knots and splices indicated that the bending resistance of the rope strands was the major factor contributing to hardness and stiffness of nylon ropes. A study of the art of rope splicing pointed to the primary difficulty in hard nylon ropes, namely the great effort necessary to force the strands apart with a marline spike to make room for the marrying strand. It was also noted that with each additional tuck the required force increased. In view of this, it was concluded that the resistance to strand displacement could be used as an index of hardness and stiffness.

7. It was decided to simulate the opening action of rope splicing by measuring the resistance in a compression testing machine. Experiments were conducted using a 1/4 inch tapered marline spike inserted between the rope strands and forced inward in a compression testing machine at 6" per minute. Load measurements were taken at each 1/8 inch increment of pene-

tration. The ropes included in the tests were of various constructions and sizes ranging from 1-1/8" to 5 1/2" circumferences. The strand constructions were coded alphabetically and typed numerically, as follows, for easy identification:

<u>Type</u>	<u>Description</u>
1	Strands formed with balanced plied yarns and layed into ropes as described in MIL-R-1734A, of 15 October 1957.
2	Strands formed with large multi-plyed yarns encased by smaller multi-plyed yarns layed into ropes and heated to set the lay.
3	Strands formed with high twist large singles yarns layed into ropes and heated to set the lay.
4	Strands formed with large low twist core yarns encased by smaller high twist multiple plied yarns, layed up tightly into ropes.

8. The results of the tests are plotted in Figures 1 and 2. It may be noted that with small nylon ropes there was a deflection in slope of the resistance curves at strand openings of 1/2" to 5/8". A similar deflection can be noted in the curves of large nylon ropes between 7/8" and 1" strand openings. It was observed that flattening occurred in the rope strands at these openings. Beyond these openings the rope became stranded as one strand pulled tight against the other two strands in portions adjacent to the site of opening. With hard ropes the strands became permanently distorted at the indicated opening. With softer ropes no permanent distortion occurred at any strand opening.

9. For inspection purposes it was decided that the test should measure the resistance at an opening of 1/2" for small ropes, and 1" for large ropes. A limiting value would apply in each case. Also, it was decided that the wet hardness should be measured. Wetting of nylon rope hastens relaxation shrinkage and thereby causes the fibers to compact in the rope structure. Hardening and stiffening observed in stored ropes resulted from the same phenomenon, induced by changes in humidity during storage. In order to preclude hardening in storage, it was apparent that a limit should be placed on the wet hardness of new nylon ropes, as well as on the dry hardness.

10. On the basis of the tests, the following method is recommended as an inspection procedure for evaluating the hardness quality of nylon ropes:

"A length of nylon rope shall be secured at each end to prevent unlaying. A 1/4 inch marline spike, conforming to type I of Specification MIL-M-15926, shall be inserted between the strands until visible on the opposite side. The spike shall be inserted at least 5 feet from the end or 5 feet from an area which has been subjected to a previous hardness test. The rope with the spike inserted shall be mounted in a compression testing machine in such a manner that the force necessary to push the spike

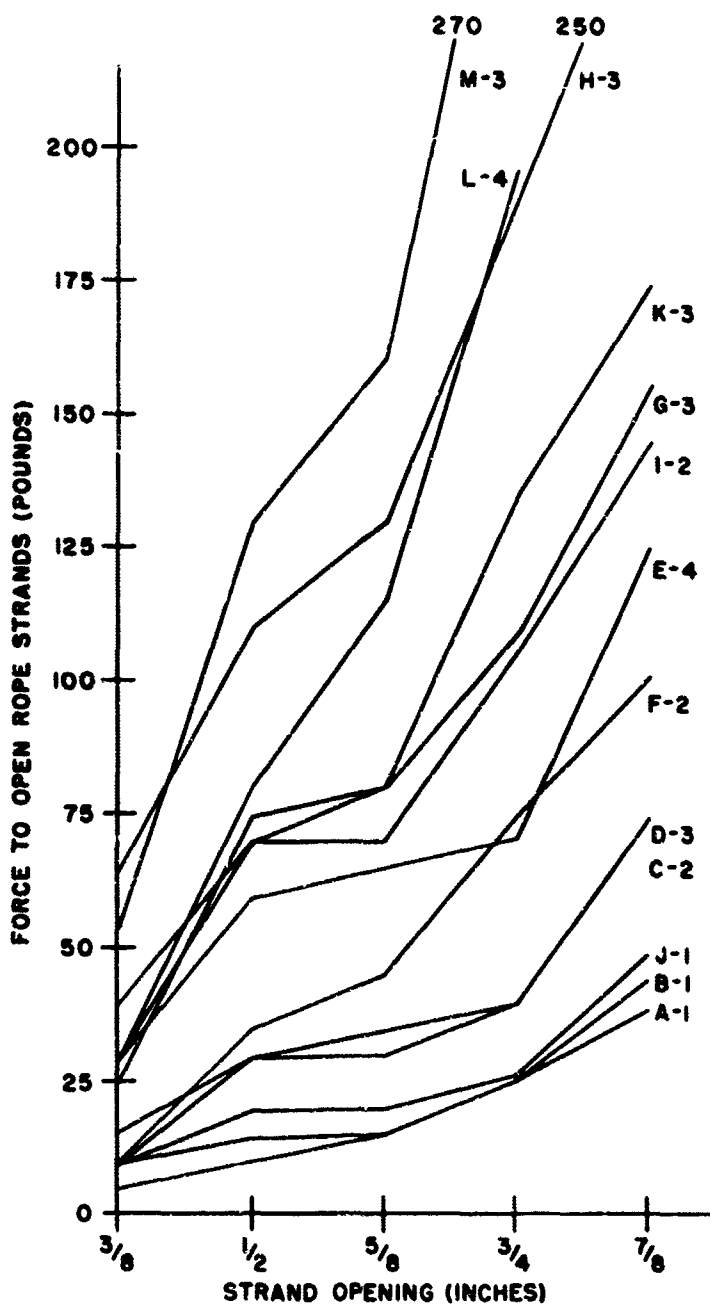


Figure 1. Strand Resistance Curves of Small Nylon Ropes

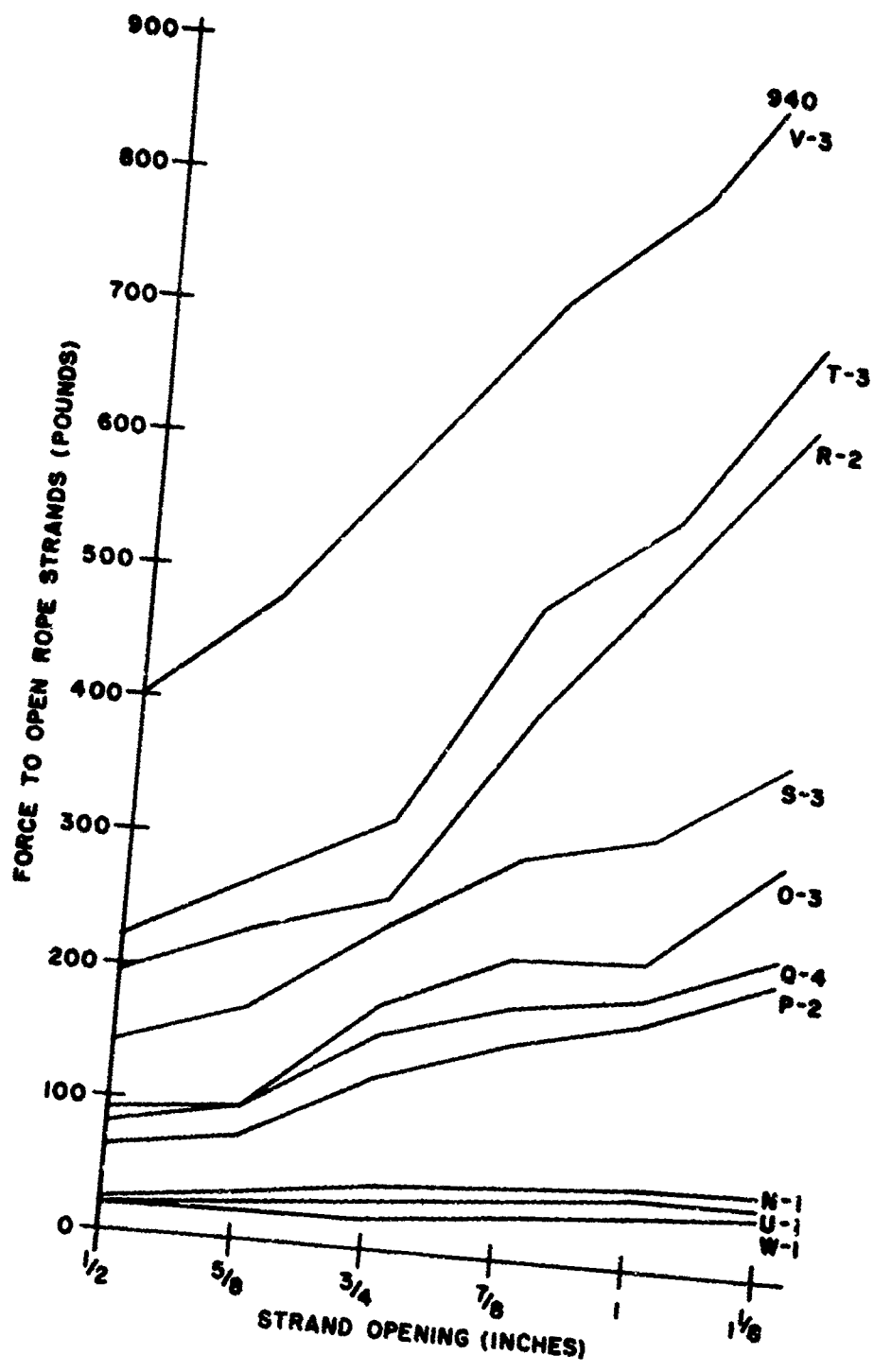


Figure 2. Strand Resistance Curves of Large Nylon Ropes

through the rope can be measured. The rate of loading shall be 6 inches per minute. The load necessary to force the spike into the rope to the 1/2" diameter mark shall be measured on ropes up to 2-3/4" circumference. The 1 inch diameter mark shall be used for larger nylon ropes. At least three test results shall be averaged for reporting the hardness values.

The above tests shall be conducted on the dry nylon rope and after it has been immersed in tap water at room temperature for 16 hours and drained for 2 hours."

11. Based on experience over the past four years, the following hardness limitations are recommended for nylon rope, using the test method described above:

<u>Size</u>	<u>Dry Rope</u>	<u>Wet Rope</u>
Up to 2-3/4" circ.	5 lbs.	25 lbs.
3" to 10" circ.	20 lbs.	100 lbs.

12. In connection with the subject of hardness testing it may be of interest to discuss the various factors which influence rope hardness. Many factors enter into this property, as follows:

a. Fiber size and shape. Fibers of largest cross-section have the greatest bending and torsional rigidity to resist deformation. Consequently ropes made of large fibers will exhibit greater hardness and stiffness than those made of smaller fibers. The shape of the fiber influences rope hardness by frictional effects imposed when contact surfaces are increased. For example, fibers of circular cross-section in contact with each other offer less frictional resistance than fibers having a pentagonal cross-section like manila. The irregular fibers will produce a harder rope than the circular fibers under the same manufacturing conditions.

b. Fiber finish. Nylon finishes which lubricate the fiber lower the frictional resistance and impart degrees of freedom for fiber movement, thus lowering the hardness of the rope structure.

c. Recovery and relaxation shrinkage. The recovery and shrinkage forces of nylon fibers are relatively high in total amount. Because each force develops at a different time, the total effect was not noticed by early investigators of nylon rope. The recovery from tension and torsion takes place in two parts, the greater portion being instantaneous and the remainder within 24 hours. The relaxation shrinkage, however, is influenced by time, temperature, and moisture. Its reaction time can vary from a few minutes to many months. The total effect of these two forces in nylon rope is to compact the fibers as their length is reduced and their diameter increased. In ropes having the twist and lay combinations usually employed for natural fiber ropes, these contracting forces compress fibers together and change their shape from circular to polygonal. The fibers in this state have little freedom of motion. The rope structure therefore exerts

considerable resistance to deformation, and consequently exhibits extreme hardness.

d. Yarn construction and twist. High twist singles nylon rope yarns are unstable when employed directly in strand forming and rope laying operations. Unbalanced elastic forces cause them to spring apart. Ropes made of singles yarns will kink, and form strand cockles on handling. Due to the high recovery characteristics of nylon, the yarn construction should be such that the fiber strains are at the minimum necessary for compacting the fibers. These strains must be opposed by a balancing force to prevent displacement of the fibers in yarn. The balancing forces can only be developed by plying the singles in such a manner that each singles yarn contacts the other yarns in the plied structure. This requirement limits the number of singles in a ply to two or three. This type yarn structure can be attained by a variety of twist ratios, but in no instance should the twists be so high as to place the fibers in a position of high strain. This would cause them to retract and shrink in the rope structure, resulting in progressive hardening.

e. Effect of yarn diameter. The diameter of nylon yarns employed in ropemaking should be as large as possible for better distribution and lowering of stresses from twisting and plying. The yarn size, however, is limited by the rope size desired and the minimum hardness required to compact the structure. In small rope structures, the yarn size should not be so large that the strand does not have a central core for positioning the cover yarns.

f. Effect of yarn position in strands. The position of yarn in the strand should remain constant throughout the strand length. Should the yarn move from its assigned position, it will crowd between other yarns in periods along the length. This condition will locally upset the strand density, resulting in hard spots which become distorted in service.

g. Effect of strand and rope turn. The strand and rope turn ratios have the same effect on the rope that singles and ply twists have on plied yarns. In the rope structure, the plied yarns react in the same manner as individual fibers in the yarn structure. It is imperative that the turn relationships be balanced, and of low magnitude, to offer a twist reservoir capable of absorbing back and fore turns encountered in service. If high turn combinations are employed in strand and rope manufacture, locked stresses will be impressed in the yarns. Overly hard and unstable ropes will result.

h. Effect of heating on nylon ropes. Nylon fibers possess a relatively high inherent contracting force amounting to 0.4 grams per denier. This force can be released by the action of water and/or heat, resulting in shrinkage in length and swelling in girth. The shrinkage and swelling of the fibers amount to approximately 12%. Two-thirds of the shrinkage occurs in a relatively short time and the remainder occurs over a long period of time depending on the amount of compressional forces imparted during rope manufacture. The total relaxation of the contracting forces can take place

in 24 hours in a soft rope structure, or in many months in a very hard rope structure. In either case the rope will become more compact. The reason for this behavior is that the outer nylon yarns react first and thereby compress the inner fibers. The subsequent shrinking of the inner yarns and fibers is retarded by the compression and concomitant increased frictional effects. The available interstitial space has been reduced to a minimum, and there is insufficient cross-sectional area to accommodate increased fiber girth. Consequently in these structures the inner fibers assume a polygonal cross-section when they are compressed to occupy the voids.

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IDENTIFICATION OF SMALL NYLON ROPES

<u>Rope Code and Type</u>	<u>Circumference (inches)</u>	<u>Age (months)</u>
A-1	1-1/2"	2
B-1	1-1/2"	24
C-2	1-1/8"	18
D-3	1-1/8"	18
E-4	1-1/8"	18
F-2	2-1/8"	18
G-3	2-1/8"	18
H-3	2-1/8"	18
I-2	2-1/2"	18
J-1	2-1/2"	36
K-3	2-1/2"	18
L-4	1-3/4"	18
M-3	1-3/4"	18

IDENTIFICATION OF LARGE NYLON ROPES

<u>Rope Code and Type</u>	<u>Circumference (inches)</u>	<u>Age (months)</u>
N-1	3	1
O-3	3	18
P-2	3	18
Q-4	3	18
R-2	3-3/4"	18
S-3	3-3/4"	18
T-3	4-1/2"	18
U-1	4-1/2"	1
V-3	5-1/2"	18
W-1	5-1/2"	1

Appendix D

Computer Program

for

Coefficient of Correlation

## MEMORANDUM FOR RECORD

SUBJECT: Coefficient of Correlation Computer Program - G-003

1. INTRODUCTION

The computer program summarized in this report was written to compute standard deviations, variances, and the coefficient of correlation for two sets of variables. The program is limited to 100 values for each of the two variables.

2. PROGRAM DESCRIPTION

The program finds the variances ( $s^2$ ), standard deviation (S), and correlation coefficient (r) through solution of the following equations:

$$(1) \bar{X} = \frac{\sum X}{N} \qquad \bar{Y} = \frac{\sum Y}{N}$$

$$(2a) S_x^2 = \frac{\sum X^2}{N-1} - \frac{(\sum X)^2}{N(N-1)} \quad ; \quad S_y^2 = \frac{\sum Y^2}{N-1} - \frac{(\sum Y)^2}{N(N-1)}$$

$$(2b) S_x^2 = \frac{\sum X^2}{N} - \bar{X}^2 \quad ; \quad S_y^2 = \frac{\sum Y^2}{N} - \bar{Y}^2$$

$$(3) S_x = \sqrt{S_x^2} \quad ; \quad S_y = \sqrt{S_y^2}$$

$$(4) r = \frac{\sum (XY) / N - \bar{X}\bar{Y}}{S_x S_y}$$

The value of N can be no greater than 100. Whenever N is less than 40, the variances are computed by Equations (2a); otherwise, Equations (2b) are used. The program reads N and the data and computes the correlation; then it automatically goes on to the next data card to read N and the corresponding data. The process continues until an "END" card appears in the data to halt the program.

3. OPERATING INSTRUCTIONS3.1 Deck Make-Up

The program is written in WIZ. The object program followed by the deck of data cards is placed behind WIZPAC, and a normal WIZ load is executed. The answers should follow.

3.2 Tape Drives

Not applicable

### 3.3 Input

The number of input cards is determined by the amount of data available. The first data card contains one value for N, the number of values for each of the two variables. This card is followed by card(s) containing the data in the following order:  $x_1, y_1, x_2, y_2, x_3, y_3, \dots, x_n, y_n$ . It is imperative that the number of individual readings following N is equal to 2N.

If it is desired to compute more than one correlation, the card containing  $y_n$  is followed by another card containing the value N for the second correlation, which is followed by the data as described in the previous paragraph.

The last card containing  $y_n$  must be followed by an "END" card.

The values of N and the input data must follow the rules for WIZ data cards.

### 3.4 Data Display

The output consists of a series of tables, usually on one page. In the first column are a list of values followed by  $\$ X(J)$ ; this is a list of the values for the variable X. The list of values for the variable Y is similarly placed in the second column. The third column contains the value of J for each row. Following these tables on the 9 succeeding lines are the values for  $\Sigma X, \Sigma Y, \bar{X}, \bar{Y}, \Sigma(X^2), \Sigma(Y^2), S_x^2, S_y^2$ , and  $\Sigma(XY)$ , respectively. The last line contains  $S_x, S_y$ , and  $r$ . A typical output for this program is attached.

## 4. VARIABLE DICTIONARY

$N = J$   
 $\Sigma X = \text{SUMX}$   
 $\bar{X} = \text{AVX}$   
 $\Sigma Y = \text{SUMY}$   
 $\bar{Y} = \text{AVY}$   
 $\Sigma(X^2) = \text{X SQUARE}$   
 $\Sigma(Y^2) = \text{Y SQUARE}$   
 $S_x^2 = \text{VARX}$   
 $S_y^2 = \text{VARY}$   
 $\Sigma(XY) = \text{PRODKY}$   
 $S_x = \text{SX}$   
 $S_y = \text{SY}$   
 $r = \text{R}$

1.900000+01	\$ X(J)	9.500000+00	\$ Y(J)	-1	\$ -J
4.300000+01	\$ X(J)	2.250000+01	\$ Y(J)	-2	\$ -J
7.000000+00	\$ X(J)	1.100000+01	\$ Y(J)	-3	\$ -J
8.000000+00	\$ X(J)	1.200000+01	\$ Y(J)	-4	\$ -J
3.000000+01	\$ X(J)	1.350000+01	\$ Y(J)	-5	\$ -J
2.150000+01	\$ X(J)	2.300000+01	\$ Y(J)	-6	\$ -J
6.200000+01	\$ X(J)	3.200000+01	\$ Y(J)	-7	\$ -J
2.500000+01	\$ X(J)	1.950000+01	\$ Y(J)	-8	\$ -J
4.950000+01	\$ X(J)	1.050000+01	\$ Y(J)	-9	\$ -J
2.100000+01	\$ X(J)	1.250000+01	\$ Y(J)	-10	\$ -J
8.150000+01	\$ X(J)	3.950000+01	\$ Y(J)	-11	\$ -J
4.900000+01	\$ X(J)	1.950000+01	\$ Y(J)	-12	\$ -J
2.900000+01	\$ X(J)	2.400000+01	\$ Y(J)	-13	\$ -J
1.800000+01	\$ X(J)	1.250000+01	\$ Y(J)	-14	\$ -J
3.850000+01	\$ X(J)	1.500000+01	\$ Y(J)	-15	\$ -J
4.650000+01	\$ X(J)	3.000000+01	\$ Y(J)	-16	\$ -J
3.400000+01	\$ X(J)	2.800000+01	\$ Y(J)	-17	\$ -J
2.450000+01	\$ X(J)	1.900000+01	\$ Y(J)	-18	\$ -J
6.070000+02	\$ SUMX				
3.372222+01	\$ AVX				
3.535000+02	\$ SUMY				
1.963888+01	\$ AVY				
2.665450+04	\$ XSQUARE				
8.186249+03	\$ YSQUARE				
3.638300+02	\$ VARI				
7.317074+01	\$ VARY				
1.396000+04	\$ PRODX				
1.907433+01	\$ SX	8.553990+00	\$ SY	6.9433348-01	\$ R

Appendix E

Utilization of the Fisher "Z"  
Transformation for Comparing the  
Significance of "r" Values.

U. S. ARMY NATICK LABORATORIES

NATICK, MASSACHUSETTS

MATERIAL EXAMINATION REPORT

REPORT NO:

8270

INITIATED:

November 1963

REPORTED:

December 1963

SUBMITTED TO:

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PREPARED BY:

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COPIES TO:

Mr. C. J. Pope

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TITLE:

Utilization of the Fisher "z" transformation technique for comparing the significance of "r" values.

INTRODUCTION:

In connection with a study of the correlation of laboratory abrasion testers (1) an analysis was made using the Fisher z-transformation to determine the significance of the differences between correlation coefficients ("r") of 0.7 and 0.8; 0.7 and 0.9; and 0.8 and 0.9. The original study was made on 15 fabrics differing in fiber composition, weave type, and weight and utilized the common abrasion instruments employed in the Army Natick Laboratories. Correlation coefficients were computed from a program established for the GE 225 computer. Subsequently regression equations were computed and it was desired to establish the relative significance of the equations in terms of the significance of the "r" values.

PROCEDURE:

Values of "z" and the standard deviation of "z" ( $\sigma_z$ ) were computed as suggested by Mode (2) according to the following equations:

$$z = \frac{1}{2} \log_e \frac{1+r}{1-r}$$

$$\text{and } \sigma_z = \frac{1}{N-3}$$

The "z" values corresponding to each of the two "r" values being compared can be computed from:

$$z_1 = 1.15129 \log_{10} \frac{1+r_1}{1-r_1}$$

or obtained from a table of values of "z" (2).

Since the distribution of "z" is approximately normal, we let

$$z' = \frac{z_1 - z_2}{\sqrt{N-3}} = z_1 - z_2 (\sqrt{N-3})$$

which gives the number of standard deviations separating the two r values.

Thus:

$$z(0.8 - 0.7) = \frac{1.095 - .865}{.288} = .8$$

$$z(0.9 - 0.7) = \frac{1.47 - .865}{.288} = 2.1$$

$$z(0.9 - 0.8) = \frac{1.47 - 1.095}{.288} = 1.3$$

The value of .8 sigma is consistent with the hypothesis that an "r" of 0.8 is not significantly different from an "r" of 0.7.

On the basis "r" values of 0.7 and above were considered of sufficient significance to warrant the use of computed regression equations.

Detailed computations are shown on the attached table.

#### REFERENCES

- (1) "Correlation and Regression Analysis of Laboratory Abrasion Testers". MER No. 8267, October 1963.
- (2) Mode, E. B., "Elements of Statistics", Prentice - Hall, 1951.



$z_1 = 1.15129 \log_{10} \frac{1+r_1}{1-r_1}$		
.7	.8	.9
$\log_{10} \frac{1.7}{.3} = .753$	$\log_{10} \frac{1.8}{.2} = .954$	$\log_{10} \frac{1.9}{.1} = 1.279$
$z_1 = .865$	$z_2 = 1.095$	$z_3 = 1.47$

ANALYSIS IN "MODE" FOR $r_1$ AND $r_2$ + $N_1$ AND $N_2$
$\sigma_{z_1-z_2}^2 = \sigma_{z_1}^2 + \sigma_{z_2}^2$ $= \frac{1}{N_1-3} + \frac{1}{N_2-3}$ $z' = \frac{(z_1 - z_2) - (\rho_1 - \rho_2)^*}{\sigma_{z_1} - \sigma_{z_2}}$ <p>By NULL HYPOTHESIS, <math>\rho_1 - \rho_2 = 0</math></p> $\therefore z' = \frac{z_1 - z_2}{\left(\frac{1}{N_1-3} + \frac{1}{N_2-3}\right)^{\frac{1}{2}}}$ <p>* <math>\rho = \pm</math> OF <math>\rho</math> (true correlation coefficient)</p>

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) U.S. Army Natick Laboratories Natick Massachusetts 01760		2a REPORT SECURITY CLASSIFICATION Unclassified	
		2b GROUP	
3. REPORT TITLE  EXTENT AND CAUSE OF DETERIORATION OF NYLON MOUNTAIN CLIMBING ROPE			
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) June 1963 to July 1965			
5 AUTHOR(S) (Last name, first name, initial)  Weiner, Louis I. and Sheehan, Leo J.			
6 REPORT DATE March 1966		7a TOTAL NO OF PAGES 74	7b NO OF REFS 11
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10 AVAILABILITY/LIMITATION NOTICES  Distribution of this document is unlimited. Release to CFSTI is authorized.			
11 SUPPLEMENTARY NOTES		12 SPONSORING MILITARY ACTIVITY Clothing and Organic Materials Division U.S. Army Natick Laboratories Natick, Massachusetts 01762	
13 ABSTRACT  An analysis was made of 20 nylon mountain climbing ropes which had been in use for periods up to 18 years, to discover the extent and cause of deterioration in strength and energy-absorbing ability and changes in hardness and stiffness. It was found that loss in strength and energy-absorbing ability arise primarily from fiber abrasion which occurs at the surface of the rope. The nature of the rope construction is such that surface abrasion affects each of the three strands of the rope and all of the yarns in each strand except the few which constitute the so called "inner-core." There is no evidence that sunlight damage occurred to any significant extent in these ropes. The amount of abrasion and loss of strength were directly related to the amount of use (not age) for those ropes that had more quantitative use histories. A Use Index (computed from the number of days of use) may be used to estimate rope deterioration. The extent of hardening and stiffening of the ropes was found to vary over a wide spectrum, but the causal factors were not determined.			

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Deterioration	8		9			
Rope	9		9			
Nylon	9		9			
Mountains	9		4			
Climbing	9		4			
Analysis (Structural)			8			
Abrasion	10					
Surfaces	10					
Fiber	10					

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