Cordage Institute

International Standard

TEST METHODS FOR FIBER ROPE

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PART I PREFACE AND PREPARATION

1. **Scope**
   1.1   The **General Test Methods** (Sections 7, 8, and 9) are intended for use with the applicable Cordage
             Institute Synthetic Fiber Rope Standards. These determine rope size, linear density, and uncycled
             breaking strength.
   1.2   The **Special Test Methods** (Sections 10 through 14) are not called for in Cordage Institute Rope
             Standards. These test methods are recommended for use on marine ropes, for engineered systems,
             and for other special purpose ropes where applicable. These determine uncycled strain, cycled
             breaking strength and strain, wet uncycled breaking strength and strain, and wet cycled strength and
             strain.
   1.3   The values stated in inch-pound units are official. The SI units may be used.

2. **Terminology**
   2.1   Force: A physical influence exerted on the test specimen which causes it to deform.
   2.1.1   Breaking Force: The maximum force recorded during a break test on a rope.
   2.1.2   Uncycled Breaking Force: The breaking force of a rope which has not been cycled before the break
             test.
   2.1.3   Cycled Breaking Force: The breaking force of a rope which has been cycled from initial tension to a
             specified peak cyclic force for a specified number of cycles before the break test. In this standard, the
             rope is cycled ten times to 20% (or alternately 30%) of uncycled breaking force before the break test to
             determine cycled breaking force.
   2.1.4   Reference Tension: A low tension applied while measuring diameter or circumference and the length
             of the linear density specimen.
   2.1.5   Initial Tension: A low tension force applied before measuring Δ Length. Δ Length is then measured
             from the Initial Length between gage marks at this initial tension.
   2.1.6   Gage Length: The length between gage marks of the rope at Initial Tension.
   2.1.7   Uncycled Gage Length: The gage length measured before first application of load to the rope.
   2.1.8   Cycled Gage Length: The gage length measured after the rope has been loaded and cycled and then
             returned to initial tension.
   2.1.9   Trough Cyclic Force: The lowest force applied during a force cycle.

2.2   Delta Length *(ΔL):* The change in length over a gage length of a rope during application of tension force.

2.2.1   Immediate ΔLength: The delta length from the cycled gage length measured at a particular tension.

2.2.2   Uncycled ΔLength: The delta length from the uncycled length measured at a particular applied force during the first tension cycle.

2.2.3   Overall ΔLength: The delta length from the uncycled gage length measured at a particular tension.

2.2.4   Permanent ΔLength: The delta length from the uncycled gage length measured at initial tension after the rope has been tensioned or cycled.

2.3   Strain *(Є):* the ratio of Δlength to the length of rope over a particular gage length.

2.3.1   Overall **n%** strain *(OЄn%):* The strain at a specified **n** percent of break strength expressed as a percent of the uncycled gage length.

2.3.2   Overall Breaking Strain *(OBЄ):* The overall strain at breaking of a rope.

2.3.3   Permanent Strain *(PЄ):* The strain at initial tension after a rope has been cycled to a specified Peak Cyclic Force for a specified number of cycles, expressed as a percent of uncycled gage length.

2.3.4   Uncycled Strain *(UЄn%):* The strain on the first application of tension measured at a particular tension.

2.3.5   Immediate **n%** Strain *(IЄn%):* The strain at a specified **n** percent of break strength expressed as a percent of the cycled gage length.

2.3.6   Stiffness, EA: Stiffness is the slope of a load vs. strain curve. This value is independent of length. EA is commonly used in mechanics as the spring constant multiplied by length.

Note: EA is used here to represent length-independent stiffness. It is analogous to the EA used in engineering mechanics. It can be used in the equation $= PL/EA$ to calculate the stretch of rope of a given length L under a given tension P. When used with rope, the term E is not simply equal to the Young's Modulus of the fiber material because the effective stiffness is influenced by the geometry of the rope design. The value of E measured for two ropes can be significantly different, even though the material is the same and the construction appears similar. Also, it is difficult to precisely designate the area, A, of a fiber rope structure. When calculating stiffness for different rope sizes, a consistent method of designating area must be used.

3. Other Standards

3.1   ASTM D4268 "Standard Test Methods for Testing Fiber Ropes" is based on the original version of this standard, CI 1500, and thus is similar. This revised version of that standard incorporates many changes and corrections in an easily understood and followed format. ASTM D4268 can be procured from ASTM Customer Service, 100 Barr Harbor Dr., W. Conshohocken, PA 19428.

3.2   This Cordage Institute "Standard Test Methods for Fiber Ropes" replaces the Cordage Institute CIA-3 "Standard Test Methods for Fiber Ropes" STM-6/80 with regard to strength and elongation.

3.3   This Cordage Institute "Standard Test Methods for Fiber Ropes" is recommended as an alternative for the Federal Test Method MIL-STD-191: Method 6015.

3.4   Other Cordage Institute Standards specify the properties of particular types of fiber ropes, including CI 1201 Fiber Ropes: General Standard, available from the Cordage Institute Headquarters as listed on page 1.

3.5   Oil Companies International Marine Forum (OCIMF), "Guidelines for the Purchasing and Testing of Hawsers for Single Point Moorings (SPM's)". This can be obtained from Witherby & Co., Ltd., 32 Aylesbury Street, London, EC1R 0ET.

3.6   Additional definitions of rope terminology can be found in Cordage Institute Standard CI-1403 and in the American Society of Civil Engineers (ASCE) *Glossary of Marine Fiber Rope Terms.* This can be obtained from ASCE, 345 East 47th St., New York, NY 10017.

4. Precautions and Hazards

4.1   This standard does not address all of the safety problems and hazards associated with its use. These test methods may involve hazardous materials, operations, and equipment. It is the responsibility of the user to establish and follow appropriate safety and health practices when carrying out these methods.

4.2   Rope testing for breaking force and elongation can be dangerous. A tensioned rope, associated hardware, or the test machine may break without any detectable warning. A considerable amount of energy is immediately released when a rope breaks. A broken rope may snap back and whiplash out of the test machine in any direction to a distance essentially as long as the rope itself. Items originally attached to the rope or to the test machine may be thrown for considerable distances. Also the broken rope may strike and propel loose objects for considerable distances in any

direction.

4.3 Persons conducting and witnessing rope testing must be made aware of the dangers involved and the precautions necessary to avoid injury. The test machine containing the rope specimen should be remote from operators and observers or should be enclosed within a cover that will contain the rope after it breaks.

4.4 All persons who are in the vicinity of the test machine while the rope specimen is under tension should wear appropriate safety protection gear, such as glasses and helmets.

4.5 A strength determined by these test methods is not necessarily an accurate indication of the force at which that rope might break in other circumstances and situations. Type and quality of termination, rate of force application, prior conditioning, and previous force applications to the rope can significantly influence breaking strength. A rope bent around a post, capstan, pulley or sheave may break at a significantly lower force. A knot or other distortion in a rope may significantly reduce breaking strength.

5. Test Equipment

5.1 Force Application Test Machine (for Linear Density Test)

5.1.1 The test machine used for taking length measurements used in determining linear density shall have sufficient force and stroke capacity to apply the reference tension for the rope specimen.

5.1.2 For rope sizes 16 mm (5/8 in.) nominal diameter and smaller, the test machine shall be long enough to accommodate the gage length given in 6.2.2.

5.1.3 For rope sizes greater than 16 mm (5/8 in.) nominal diameter, the test machine shall be long enough to accommodate the gage length given in 6.2.3.

5.1.4 The test machine shall be equipped with a force measuring and indicating device. The force measuring and indicating device shall be accurate within ± 5% of the reference tension for the rope specimen.

5.1.5 The force measuring and indicating device shall be calibrated by a recognized independent calibration agency. The calibration shall be done with a reference load cell traceable to applicable national standards. This calibration shall have been conducted within the previous year. An original certificate attesting to this calibration, certified by the calibration agency, shall be available for examination, and a copy of this test certificate shall be made available upon request.

5.2 Force Application Test Machine (for Break Test)

5.2.1 The test machine used for determining breaking force shall have sufficient force capacity, bed length, and stroke to conduct the tests as specified here. The test machine shall be capable of applying the force at the specified rate (9.4.2) in a continuous and essentially constant manner throughout the entire stroke required to break the rope specimen.

5.2.2 For rope sizes 16 mm (5/8 in.) nominal diameter and smaller, the test machine shall be long enough to accommodate the gage length given in 6.2.2. For break strengths greater than 500,000 lb, the force measuring device may be a pressure gage in the hydraulic cylinder, provided that the hydraulic cylinder and pressure gage are calibrated as a system to the above stated accuracy.

5.2.3 For rope sizes greater than 16 mm (5/8 in.) nominal diameter, the test machine shall be long enough to accommodate the gage length given in 6.2.3.

5.2.4 If elongation and extension are to be measured, the test machine in the closed position shall have a clear distance sufficient to accommodate a rope specimen providing a gage length sufficient to achieve an accuracy of at least ±10% for the Δ length at 50% breaking force, as determined by Tables 1T and 1M (pages 12 and 13).

5.2.5 The testing machine shall be equipped with a force measuring and indicating device. The force measuring and indicating device shall be accurate within ±1% of the estimated breaking force of the test specimen over the entire intended force range. The force indicating device shall temporarily or permanently preserve a record of the maximum force experienced during the test.

5.2.6 The force indication device shall be calibrated by a recognized independent calibration agency. The calibration shall be done with a reference load cell traceable to applicable national standards. This calibration shall have been conducted within the previous 12 months. An original certificate attesting to this calibration, certified by the calibration agency, shall be available for examination, and a copy of this test certificate shall be made available upon request.

5.2.7 For break testing of ropes with spliced eyes, the diameters of the test machine pins shall be at least twice the nominal diameter of the ropes to be tested.

5.3 Diameter or Circumference Measuring Device: The diameter and circumference of the rope may be measured by several alternative methods and devices.

5.3.1   If calipers are used, place the caliper feet in contact at least two strand crowns along each side of the rope, and apply a moderate compression. Secure the caliper feet in this position. Remove the calipers from the rope. Measure the distance between the caliper feet with a suitable calibrated scale.

5.3.2   If a calibrated measuring tape is used, wrap it around the rope, apply a moderate tension, and read the circumference while it is still in contact with the rope.

5.3.3   If a calibrated direct diameter measuring "Pi" tape is used, wrap it around the rope, apply a moderate tension, and read the diameter while it is still in contact with the rope.

5.3.4   If a low-stretch non-calibrated thread or tape is used, wrap it once around the rope. Apply a moderate tension and cut or mark the thread or tape at the point of overlap. Then remove the cut or marked portion of the thread or tape from the rope. Measure the circumference as the length of the cut or marked portion with a suitable calibrated scale.

5.3.5   If circumference was measured, convert to diameter by dividing by Pi. Record the diameter in inches or millimeters as appropriate.

5.4   Weighing Device:

5.4.1   The weighing device shall be a calibrated balance or scale capable of measuring the mass of the specimen to an accuracy of ± 0.25%.

5.4.2   The weighing device shall be calibrated by a recognized independent calibration agency. The calibration shall be done with reference weights traceable to applicable national standards. This calibration shall have been conducted within the previous year. An original certificate attesting to this calibration, certified by the calibration agency, shall be available for examination, and a copy of this test certificate shall be made available upon request.

5.5   Length and Delta Length Measuring Device: Linear measurements of the rope length and Δ Length may be made by several alternative methods and devices.

5.5.1   The length of specimens may be measured with a calibrated flexible tape or long rigid ruler capable of measuring the length of the specimen to an accuracy of ±1 mm (±1/16 in.).

5.5.2   The ΔLength of specimens may be measured directly with the length measuring device described in 5.5.1. The device should not be handled in the vicinity of the rope while it is under high tension. The measuring device may instead be mounted on the rope and parallel to its axis before tension is applied. The device may be attached to the rope at one gage mark and may be secured to the rope near the other mark such that it will slide relative to that other mark as the specimen elongates. With this arrangement, the position of that other mark relative to the sliding measuring device may then be observed and recorded from a distance.4

5.5.3   The Δ Length of specimens may be measured by a system of electronic length measuring and recording devices. The gage points of two such devices may be mounted on the specimen at the gage marks. The Δ L may then be determined by the relative difference between the two measurements of gage mark positions. Such a measuring system shall be capable of continuously measuring and recording the distance between the two gage marks to an accuracy of ± 5 mm (±0.25 in.).

6. Specimen Preparation

6.1   When the rope to be tested has been mounted on a reel or spool or packaged in a coil, the spool, reel or coil shall be mounted such that it can rotate about its axis. The rope shall then be pulled off in a direction perpendicular to that axis, taking care not to distort or twist the rope. While the rope is still on the reel, spool or coil, or while it is removed, a line shall be marked along the rope specimen surface and parallel to its axis, using a crayon or other suitable marking device. Then when the rope specimen is mounted on the test bed, it shall be arranged such that the marked line is parallel to the rope axis.

6.2   For types of rope, which are not normally spliced, the rope specimen shall be terminated by a method, which is typically used for the type and size of rope, as recommended by the manufacturer, or as specified in the particular standard or specification, which is applicable to that rope type.

6.2.1   For spliced ropes, the splices shall be made in accordance with the particular standard for that type of rope, by using Cordage Institute Splicing Standards; or if no such standard exists, in accordance with the rope manufacturer's instructions.

Note: Poor splicing can result in poor test results, which do not reflect the actual strength of the rope. Persons preparing the specimen for testing must be trained and experienced in splicing rope of the particular size and type.

6.2.2   For rope sizes 5/8 in. (16 mm) nominal diameter and smaller, the rope specimen shall have a clear

distance of at least 1 ft. (300 mm) between grips or rope specimen terminations.

6.2.3 For rope sizes greater than 5/8 in. (16 mm) nominal diameter, the rope specimen shall have a clear distance of at least 6 ft (1800 mm) between ends of splices or other rope specimen terminations.

6.2.4 If Δ Length is to be measured, the specimen length shall provide a gage length sufficient to achieve an accuracy of at least ±10% for the strain at 50% break strength, as determined by Table 1T or 1M.

6.3 Unless specified, "standard conditioning" of the rope specimen is not required.
Note: Some textile testing standards call for testing in a "standard environment" with strictly controlled temperature and humidity. This precaution is normally not necessary for synthetic fiber rope products. It may be necessary or desirable for some natural fiber ropes, especially cotton.

6.4 In preparation for wet testing (13. and 14.), the entire specimen shall be soaked in fresh water for a period of between 22 and 26 hours and shall be tested as soon as practical after removal from the water. If there is a delay of more than 12 but less than 24 hours after soaking, the specimen shall be soaked for 2 hours before testing. If there is a delay of more than 24 hours, the original soaking procedure shall be repeated. The water temperature shall be between 59° and 77° F (15° and 25° C).

PART II GENERAL TEST METHODS

7. Determination of Diameter, Size Number, Reference Tension, and Initial Tension

5.1 Purpose: Reference Tension is a low tension force which is applied to the rope specimen during the measurement of linear density. Initial tension is a low tension force which is applied to the rope while measuring gage length as a base for measuring change in length. The nominal diameter of the rope must be known to calculate Reference Tension and Initial Tension. Some standards and specifications require that, for a specific rope size, the measured diameter or circumference be within a stated tolerance.
Note: The Cordage Institute Rope Standards state rope size as a nominal diameter, but this diameter is not a precise linear measurement which can be made on the rope. Rope size is determined from the linear density (weight per unit length) of the rope (8.) with reference to the applicable Cordage Institute Rope Standard.
Note: Because of the soft, flexible nature of fiber rope, reproducible measurements of diameter, circumference and length cannot be made on the untensioned rope. When mounted in a test machine, the rope hangs in a catenary unless a tension is applied. Thus it is common practice to apply a low Reference Tension to the rope specimen when taking initial length measurements.
Caution: Where actual rope diameter is important for a particular application, then that diameter should be specified and measured, by an appropriate adaptation of the test methods given here.
Caution: A warehouse, shop, or field measurement of rope nominal diameter or circumference is not a good indication of rope size, even when made in accordance with this method. Such a measurement should not be used as a basis for determining rope strength. Instead, rope strength should be determined by referencing the rope size, as indicated on the rope package or in the rope documentation, with strength tables given in rope industry standards or manufacturer's literature. If the rope size is in doubt, then it should be determined by the linear density test method (8.).

7.2 Determination of Preliminary Rope Diameter for Use in Calculating Reference Tension: If the nominal rope diameter is known, use it to calculate the Reference Tension. If the diameter is not known, measure it while the rope is lightly tensioned by hand using one of the means and techniques given in 5.3.

7.3 Calculation of Reference Tension: Calculate Reference Tension using one of the following equations. The use of equation 1 is preferred. Equation 2 may be used if measurements made in SI units.

Inch-Pound Units: $RT_p = 50\, d^2$ (1)

SI Units: $RT_N = 0.35\, D^2$ (2)

Where:

RT_p = Reference Tension in Pounds

d = Diameter in inches.

RT_N = Reference Tension in Newtons

D = Diameter in millimeters

7.4   Specimen Preparation:
7.4.1   For determining diameter and size number, the rope may be held by grips or bollards, or may be terminated by knots or other non-standard means, even though such terminations might not be suitable for the other test methods.
7.4.2   For rope sizes 5/8 in. (16 mm) nominal diameter and smaller, prepare a test specimen with at least 1 ft (300 mm) of clear distance between the terminations. For rope sizes larger than 5/8 in. (16 mm) nominal diameter, prepare a test specimen with at least 6 ft (1800 mm) of clear distance between the terminations.
7.5   Test Procedure for Determining Diameter and Size Number:
7.5.1   Place the rope in the force application test machine for linear density test (5.1) with the marked line on the rope (6.1) parallel with the rope axis.
7.5.2   Apply the Reference Tension (7.3) to the specimen.
7.5.3   While the rope is under Reference Tension, measure the diameter or circumference using one of the means and techniques described in 5.3.
7.5.4   Make such measurements at three or more points along the length of the rope. For rope sizes 5/8 in. (16 mm) nominal diameter and smaller, these points should be no closer than 2 in. (50 mm) from each other or from a termination. For ropes greater than 5/8 in. (16 mm) nominal diameter, these points should be no closer than 1 ft (300 mm) from each other or from a termination.
7.6   Calculation of Diameter and Size Number: Average the three or more measurements.
7.6.1   If diameter was measured, convert to inches if necessary and then multiply by Pi (3.1416) to convert to size number. Record the size number (without units).
7.6.2   If circumference was measured, divide by Pi (3.1416) to convert to diameter. Record the diameter (with units).
7.7   Recalculation of Reference Tension: If the average diameter determined in 7.6 differs from the diameter determined in 7.2 by more than 10%, then recalculate Reference Tension by the formulae given in 7.3 using the new average diameter. Then repeat steps 7.5 and 7.6. This may be done using the same rope specimen provided it has not been subjected to a force substantially above Reference Tension.
7.8   Calculation of Initial Tension: In preparation for change in length measurements (10,12), calculate the Initial Tension.

Inch-Pound Units: $IT_P = 200\, d^2$ (3)

SI Units: $IT_N = 1.38\, D^2$ (4)

Where:

      IT_P = Initial Tension in Pounds

      d = Diameter in inches.
      IT_N = Initial Tension in Newtons
      D = Diameter in millimeters

7.9   Actual Diameter: Where the Cordage Institute Standard for a particular type of rope includes a test method for determining the Actual Diameter of a rope, that test method shall be used.

8.   Determination of Linear Density
8.1   Purpose: Linear density (mass / unit length) determines the size a synthetic fiber rope. For convenience, the rope size is designated by nominal diameter or Size Number, which is a function of linear density. The relationship between linear density and nominal diameter or circumference is given in the Cordage Institute Standard for the particular type of rope.
Note: The Linear Density Determination can be performed on new, unused ropes in order to determine the rope size (with reference to rope standard tables, provided that the rope is not wet or has been previously exposed to water or moisture.
8.2   Specimen Preparation: Prepare the rope specimen in accordance with 6.1 and 6.2.
8.2.1   For determining linear density, the rope may be held by grips or bollards, or may be terminated by knots or other non-standard means, even though such terminations might not be suitable for other test methods. The same specimen that was used to determine diameter (7.) may be used for this test, provided that it has not been subjected to a force substantially above Reference Tension.
8.3   Test Procedure for Linear Density:

8.3.1   Place the specimen in the force application test machine for linear density test (5.1) with the marked line on the rope (6.1) parallel with the rope axis.

8.3.2   Apply the Reference Tension (7.3) to the specimen.

8.3.3   For rope sizes 5/8 in. (16 mm) nominal diameter and smaller, place a gage mark on the rope at a distance of at least 1 in. (25 mm) from one termination. From this first gage mark, measure along the rope axis to a minimum distance of 10 in. (250 mm) with an accuracy of ± 0.1 in. (2 mm) to a point no closer than 1 in. (25 mm) from the other termination.

8.3.4   For rope sizes greater than 5/8 in. (16mm) nominal nominal diameter, place a gage mark on the rope at a distance of at least 0.5 ft (150 mm) from one termination. From this first gage mark, measure along the rope axis to a minimum distance of 5 ft (1500 mm) with an accuracy of ± 0.2 in. (5mm) to a point no closer that 0.5 ft (150 mm) form the other termination. Place a second mark on the specimen at this measured point. For large ropes, adhesive tape should be placed tightly around the rope at each of these points and the marks should then be made on these tapes (to prevent the rope from unraveling when cut).

8.3.5   Remove the tension from the rope specimen. Remove the rope from the test machine. Cut the rope at the first mark, and cut the rope again at the second mark, making the cuts perpendicular to the rope axis.

8.3.6   Weigh the cut rope specimen on the weighing device (5.4) to an accuracy of ±1%.

8.4   Calculation of Linear Density. Calculate the linear density of the specimen.

Inch-Pound Units: $LD_P = 100 \times P/F$ (5)

SI Units: $LD_K = 100 \times K/M$ (6)

Where

LD = Linear Density in pounds per 100 feet
P = Mass in pounds
F = Length in feet
LD_K = Linear Density in ktex (kilogram per meter)
K = Mass in kilograms
M = Length in meters

9.   Determination of Uncycled Strength (Breaking Force)

9.1   Purpose: The uncycled strength (breaking force) of a rope is specified in Cordage Institute Rope Standards. This test method determines the strength of a rope which has not been subjected to cycling. This test may be conducted in conjunction with Determination of Uncycled Strain (10.).
Note: Standards and specifications of fiber rope properties are for new, unused ropes. Old and used ropes may be tested using these methods, but the test results may be different from the values given in specifications and standards. In the case of used rope, the term uncycled means that the particular rope specimen has not been cycled in the test machine before conducting the break force test.

9.2   Precautions: See 4.

9.3   Specimen Preparation: Prepare the specimen in accordance with 6.1 and 6.2.

9.4   Test Procedure: Place the rope specimen in the test machine with the marked line on the rope (6.3) parallel with the rope axis. (If strain is also to be determined, take the required length measurements at initial tension, 10.4).

9.4.1   Increase the force applied to the rope until it breaks. (If strain is also to be determined, take the required length measurements, 10.4).

9.4.2   The rate of travel of the pulling cross head during the break test shall be such that the rope is loaded to 20% of its estimated breaking force in not less than 2 sec. nor more than 200 sec. The crosshead shall then continue to move at approximately that rate of travel without pause except for the brief pauses to take measurements called for in 10.4.3 or 10.4.4 until the rope breaks.

9.4.3   If this rate of travel is not achieved or sustained, the rope test may proceed to break, but the results of that test shall not be published or used in determining averages, unless they are consistent with other tests conducted on rope of the same set of specimens conducted at the same time. At least one additional break test shall be conducted after making appropriate adjustments to the rate of travel or deadman position.

9.5   Record the breaking force (maximum force applied to the rope). Record the point at which the rope broke, e.g. between splices, at end of splice, at crotch of splice, in back of eye, or other description of

break location.

PART III SPECIAL TEST METHODS

10. Uncycled Strain

10.1   Purpose: The strain of a rope is an important consideration in some applications. This method determines the strain to break of a new, uncycled fiber rope during first application of force. It also determines the strain at several intermediate forces. This test is generally conducted in conjunction with the Determination of Uncycled Strength (9.), or alternatively as the first step in the Determination of Cycled Strength (11.) and Cycled Strain (12.). (See Appendix A for discussion of strain.)

10.2   Precautions: See also 4.

10.2.1   When a manual length measurement technique is to be used and the strength of the rope is not known, a first specimen should be tested to determine the approximate breaking force without taking Δ length measurements. These Δ length measurements may then be made on subsequent tests.

10.2.2   When a manual Δ length measuring technique is used which requires standing close to the tensioned rope without a cover or shield, then Δ length should not be measured at greater than 50% of estimated breaking force.

10.3   Preparation: As per 9.3 plus the following.

10.3.1   The specimen shall be long enough to provide a minimum gage length in accordance with 6.2.4, as determined by Tables 1T or 1M (pages 12 and 13).
Note: These minimum gage lengths are proportional to the expected Δ length and strain of the rope with consideration of the accuracy to which lengths and changes in length can be measured. They are necessary to achieve a reasonable accuracy.

10.3.2   If a longer gage length is specified in the rope specification, then that minimum gage length shall be used.

10.3.3   If the approximate strain of the rope at 50% is not known, then a conservative estimate of the strain should be used in determining the minimum gage length from Table 1T or 1M.

10.3.4   If the strain which is measured in this test would require a minimum gage length which is more than 10% longer than that minimum gage length which was used (through interpolation of the tables), then the test shall be repeated using that longer gage length. That longer gage length shall then be used on subsequent Δ Length tests on the particular category of rope.

10.4   Test Procedure: As per 9.4, plus the following:

10.4.1   Before applying substantial force to the rope, apply the Initial Tension (7.8).

10.4.2   Place a first gage mark on the rope at least 0.5 ft (150 mm) from one termination. From this first gage mark, measure along the rope axis to the minimum distance specified in Table 1T or 1M. Place a second gage mark on the specimen at this measured point. The rope shall be of sufficient length that this second gage mark is at least 0.5 ft. (150 mm) from the other termination. Measure the distance between these gage marks to an accuracy of ±0.1 in. (±3 mm) This is distance **A**.

10.4.3   Automatic Technique: Attach the gage points of an automatic length recording device to the rope at the two marks. Record or plot the force and the corresponding length continuously as the force is increased. The test may be paused momentarily at 50% of the expected break force to remove the length recording device if necessary.

10.4.4   Manual Technique: At 20% of the expected breaking force of the rope, measure the distance between the marks to an accuracy of ±0.25 in (±6 mm). This is distance **B20%**. At 50% of the breaking force, measure the distance between the marks to an accuracy of ±0.25 in (±6 mm). This is distance **B50%.** The pauses taken to make these measurements should be as short as possible.
Note: If possible, the same length measuring device should be used when measuring the length between marks both at Initial Tension and at the above prescribed forces.

10.5   Calculation of Uncycled Strain: Calculate the Uncycled at 20% and 50% Strains:

$$U\epsilon n\% = (Bn\% – A) / A \qquad\qquad\qquad (7)$$
where:

$\quad\quad\quad$ **Uϵ n%** = Uncycled Strain at **n%** of breaking force
$\quad\quad\quad$ **A** $\quad$ = Original distance measured at Initial Tension
$\quad\quad\quad$ **Bn%** $\quad$ = Distance measured at **n%** of breaking force

10.5.1   If a record or plot of Δ Length vs. tension was taken, calculate uncycled strains at 10%, 20%, 30%, 40%, 50%, and at other higher 10% increments of the expected breaking force as can safely be

accomplished. Plot a force-strain curve accordingly. If appropriate, extrapolate the curve to the approximate strain at the rope's break strength.

10.5.2   The strains shall be stated as "Uncycled Strain" with reference to the percent of breaking force at which they were measured, for example "Uncycled strain at 50% Tension = 0.058".

11. Determination of Cycled Strength (Breaking Force)

11.1   Purpose: The strength of a rope can change during the first several force cycles. This test method determines the breaking force of a rope which has been cycled ten times to a moderate force. This test is usually conducted with the Cycled Strain Test Methods (12).
Note: Generally the average break strength increases and the statistical scatter of break strength decreases due to application of a few force cycles, as splices become set and the rope elements become more aligned.

11.2   Precautions: See 4.

11.3   Specimen Preparation: As per 9.3.

11.4   Test Procedure: As per 9.4, plus the following:

11.4.1   If Δ Length is to be measured, take the required length measurements (10.4).

11.4.2   Cycle the rope ten times from a Trough Cyclic Force equal to the Initial Tension (7.5) to a Peak Cyclic Force equal to 20% of the estimated breaking force. (If Δ L is to be measured, take the required length measurements, 10.4).

11.4.3   Alternatively, cycle the rope ten times from a Trough Cyclic Force equal to the Initial Tension (7.3) to a Peak Cyclic Force equal to 50% of the estimated breaking force.
Note: This alternative complies with the Oil Companies International Marine Forum (OCIMF) "Guidelines for the Purchasing and Testing of SPM Hawsers".

11.4.4   During cycling, the rate of travel of the testing machine moving-cross-head may be adjusted to achieve the required rate of travel prescribed in 9.4.2.

11.4.5   If Δ Length measurements are to be taken, refer also to 12.4.

11.4.6   On the eleventh cycle, apply force to the rope at the rate prescribed in 9.4.2 until it breaks.

11.5   Record the breaking force (maximum force applied to the rope). Record the point at which the rope broke (see 9.5).

12. Determination of Permanent Strain, Overall Strain and Immediate Strain

12.1   Purpose: The strain of a rope at any particular force changes as a result of cycling. This Test Method determines the strain of a rope on the tenth cycle to a moderate force and the permanent strain after that cycle. It is applicable for ropes which are intended for an engineered application where cycled strain and/or stiffness are important. This test is generally conducted with the Cycled Break Strength Test Method (11.). (See Appendix A for discussion of strain.)

12.2   Precaution: As per 10.2.

12.3   Preparation: As per 9.3 and 10.3.

12.4   Test Procedure: As per 9.4 plus the following:

12.4.1   Before applying substantial force to the rope, while the rope is at Initial Tension, mark the rope and measure the Initial Length per 10.4.

12.4.2   Automatic Technique: Attach the gage points of an automatic length recording device to the rope at the two marks. Before the tenth cycle, with the rope held at Initial Tension (7.5), manually measure the length between the marks to an accuracy of ±1%. This is distance ***C.*** During the tenth cycle, record or plot the force and the corresponding Δ Length continuously as the force is increased to the designated Peak Cyclic Force.

12.4.3   Manual Technique: Before the tenth cycle, with the rope held at the Initial Tension, measure the distance between the two marks. This is Distance ***C***. During the tenth cycle, pause at 20% of breaking force, and at this force measure the distance between the marks to an accuracy of ±1%. This is distance ***D20%.*** If the designated Peak Cyclic Force is 50% (OCIMF Alternative), resume application of force. Then pause at 50% of breaking force and measure the distance between the marks to an accuracy of ±1%. This is distance ***D50%.*** The pauses taken to make these measurements should be as short as possible.

12.4.4   Reduce the force to Initial Tension. Maintain this Trough Cyclic Tension for at least 1 and not more than 2 minutes. The automatic length measuring device may be removed if necessary at this time.

12.4.5   After at least 1 but not more than 2 minutes at Initial Tension, apply force to the rope at the rate prescribed in 9.4.2 until it breaks.

12.5   Calculation of Permanent Strain: Calculate the permanent strain:
                $P\epsilon = (C - A) / A$ (8)
                Where
                            $P\epsilon$ = Permanent Strain
                            C = Length at Initial Tension after cycling
                            A = Length at Initial Tension before cycling
12.5.1   The permanent strains shall be stated with reference to the percent of breaking force at which they
                were measured, for example "Permanent Strain at 50% Tension = 0.058". If the rope was cycled more
                or fewer than 10 times or cycled to other than 20% of estimated new breaking strength before taking
                the measurements, that fact should also be included in the data statement, for example "Permanent
                Strain at 50% Tension after 200 cycles to 50% = 0.062".
12.6   Calculation of Immediate Strain: Calculate immediate strain at each force:
                $I\epsilon n\% = (Dn\% - C) / C$ (9)
                Where:
                            $I\epsilon n\%$ = Immediate Strain at **n%** of Breaking Force after cycling
                            $Dn\%$ = Length at **n%** of Breaking Force after cycling
                            C = Length at Initial Tension after cycling
12.6.1   If a record or plot of Δ L vs. force was taken, determine the lengths **Dn%** at 10%, 20%, 30%, 40%,
                50%, and at other higher 10% increments of breaking force as can safely be accomplished. If
                appropriate, extrapolate the curve to the approximate Δ L at the rope's breaking force. Calculate
                respective immediate strains **I𝜖 n%** as described in 12.6.2. Plot a force-strain curve accordingly.
                The strains shall be stated with reference to the percent of breaking force at which they were
                measured, for example "Immediate Strain at 50% Tension = 0.058". If the rope was cycled more or
                fewer than 10 times or cycled to other than 20% of estimated new breaking strength before taking the
                measurements, that fact should also be included in the data statement, for example "Immediate Strain
                at 50% Tension after 200 cycles to 50% = 0.062".
12.7   Calculation of Stiffness: Using the immediate strain calculated in 12.6, the stiffness from initial tension
                to n% can be determined:

$$EA_{n\%} = \frac{(BF) \cdot n\%}{I\varepsilon_{n\%}}$$ (10)

            Where:
                            $EA_{n\%}$ = Stiffness from initial tension to **n%** of Breaking Force after cycling
                              BF = Breaking Force
                              $n\%$ = percent Breaking Force where **Dn%** was measured in 12.4.3
                        $I\epsilon n\%$ = Immediate Strain at **n%** of Breaking Force after cycling

            Unless otherwise specified $EA_{20\%}$ the stiffness from initial tension to 20% should to be reported.

            Note: The above calculation assumes a linear relationship between load and strain. Although this is a
            reasonable estimation for most synthetic ropes, it is not exact. More precise values for stiffness can be
            determined by reducing the calculation range around a particular load of interest.
12. 8   Calculation of Overall Strain: Calculate the overall strain at each force:
                $O\epsilon n\% = (Dn\% - A) / A$ (11)
                Where:
                            $O\epsilon n\%$ =Overall Strain at **n%** of Breaking Force after cycling
                            $Dn\%$ =Length at **n%** of Breaking Force after cycling
                            A =Length at Initial Tension before cycling
12.8.1   If a record or plot of Δ L vs. force was taken, determine the lengths **Dn%** at 20% and 50%. If
                appropriate, extrapolate the curve to the approximate Δ L at the rope's breaking force. Calculate
                respective overall strains **O𝜖 n%** as described in 12.7.1.
12.8.2   The overall strains shall be stated with reference to the percent of breaking force at which they were
                measured, for example "Overall Strain at 50% Tension = 0.068". If the rope was cycled more or fewer
                than 10 times or cycled to other than 20% of estimated new breaking strength before taking the

measurements, that fact should also be included in the data statement, for example "Overall Strain at 50% Tension after 200 cycles to 50% = 0.075".

13. Wet Uncycled Strength and Strain

13.1   Purpose: The uncycled strength and strain of some ropes are affected by exposure to water. This test method determines the strength and strain of a rope which has been soaked in fresh water for 24 hours but has not been subjected to cycling. It is applicable to ropes which will be used in the marine environment and other critical services which are exposed to water.
Note: The properties of nylon rope is significantly affected by exposure to water. After a nylon rope is exposed to water, these wet properties will generally persist, even though that rope may have become physically dry.
Note: Exposure to salt water will probably not produce significantly different effects than the wet effects determined by this test in fresh water. However, salt water may have adverse effects on the test machine therefore saltwater should not be used in these tests.

13.2   Precaution: As in 10.2.

13.3   Specimen Preparation: As per 9.3 and 10.3, plus the following:

13.3.2   The specimen shall be soaked as described in 6.4.

13.4   Test Procedure: As in 9.4 and 10.4.

13.5   Record the breaking force as in 9.5.

13.6   Calculate and record the Permanent Strain as in 10.5.

14. Wet Cycled Strength and Strain

14.1   Purpose: The cycled strength and strain of some ropes are affected by exposure to water. This test method determines the strength and strain of a rope which has been soaked in fresh water for 24 hours and has then been cycled ten times to a moderate force. It is appropriate to ropes which will be used in the marine environment and other critical services which will be exposed to water.
Note: Application of many force cycles can significantly decrease rope strength. A test method for determining the wet cyclic force performance of large fiber ropes is given in the OCIMF "Guidelines for the Purchasing and Testing of SPM Hawsers".
Note: Also see notes after 11.1 and 13.1.

14.2   Precaution: As in 10.2.

14.3   Specimen Preparation: As in 9.3 and 10.3 plus the following:

14.3.1   The specimen shall be soaked as described in 6.4.

14.4   Test Procedure: As in 11.4 and 12.4.

14.5   Record the breaking force as in 9.4.

14.6   Calculate and record the Permanent Strain as in 12.5.

14.7   Calculate and record the Immediate Strain as in 12.6.

14.8   Calculate and record the Overall Strain as in 12.7.

APPENDIX A

Table 1T: Minimum Gage Length Required to Achieve ±10% Accuracy (Inches)					
		Gage Length, Inches			
Anticipated Strain at 50% of Break Strength	**Manual Measurement**	**Instrumented Measurement Accuracy Between Trough and Peak Elongations. Inches**			
		±0.2 in	±0.16 in	±0.12 in	±0.08 in
0.01	600	400	320	240	160
0.02	300	200	160	120	80
0.03	200	135	108	80	60
0.04	150	100	80	60	40
0.05	120	80	64	48	
0.06	100	67	56	40	
0.07	86	58	48		
0.08	75	52	40		
0.09	67	48			
0.10	60	44			
0.11	55	40			
0.12	50				
0.13	46				
0.14	43				
0.15	40				

Examples:

The anticipated strain at 50% of breaking force is .06 (typical of polyester)

If the length measurements will be made manually, the length between gage marks should be a minimum of 100 inches to determine strain within a ±10% accuracy.

If the length measurements will be taken by an instrumentation system having an accuracy of ±0.12 in., the length between gage marks should be a minimum of 40 in.

APPENDIX A

Table 1M: Minimum Gage Length Required to Achieve ±10% Accuracy (Metric)					
Gage Length, mm					
Anticipated Strain at 50% of Break Strength	**Manual Measurement**	**Instrumented Measurement Accuracy Between Trough and Peak Elongations. mm**			
		±5 mm	±4 mm	±3 mm	±2 mm
0.01	15,000	10,000	8,000	6,000	4,000
0.02	7,500	5,000	4,000	3,000	2,000
0.03	5,000	3,400	2,700	2,000	1,350
0.04	3,800	2,500	2,000	1,500	1,000
0.05	3,000	2,000	1,600	1,200	
0.06	2,500	1,700	1,350	1,000	
0.07	2,200	1,450	1,150		
0.08	1,900	1,250	1,000		
0.09	1,700	1,150			
0.10	1,500	1,000			
0.11	1,400				
0.12	1,300				
0.13	1,200				
0.14	1,100				
0.15	1,000				

Examples:

The anticipated strain at 50% of breaking force is .06 (typical of polyester)

If the length measurements will be made manually, the length between gage marks should be a minimum of 2,500 mm to determine strain within a ±10% accuracy.

If the length measurements will be taken by an instrumentation system having an accuracy of ±3 mm, the length between gage marks should be a minimum of 1,000 mm.

APPENDIX A

DETERMINING CHANGE-IN-LENGTH PROPERTIES OF SYNTHETIC FIBER ROPES

The change in length of a synthetic fiber rope at any particular applied tension is an important property in many applications. The methods in which that change in length are defined and calculated are important in determining its significance and use. The method by which that change in length is measured can be very important to its accuracy.

Strain is here defined as the ratio of change in length from a measured gage length. CI 1500-00 "Standard Test Methods for Fiber Rope" includes methods for determination of both the overall and immediate strain of a rope. These properties are not the same. Overall strain is the ratio of the change in length from the original length of the rope related to that origial length. Immediate strain is the ratio of the change in length of the rope from its initial length immediately before application of tension, related to that initial length before application of tension.

This Appendix to C1 1500 explains the distinction between these two properties. It discusses the methods by which the change-in-length measurements are taken and the properties are calculated. It explains the rationale and calculation methods for the Minimum Gage Length requirements given in Tables 1T and 1M (pages 16 and 17).

Explanation of Terminology

Gage marks are marks placed near the ends of a new, uncycled rope in order to perform subsequent change-in-length measurements.

Gage length is the distance between these gage marks and is the rope length from which change in length is measured. A minimum gage length is required in order to achieve a desired accuracy of strain. That minimum gage length is given in Table 1T or 1M.

Initial tension is a very low force which is applied to the rope to remove looseness and catenary while gage length is measured. It is typically about 1% of the break strength of the rope. It is calculated from the nominal diameter of the rope using methods given in Cl 1500.

The *uncycled gage length* is the distance measured between the gage marks on the new, uncycled rope while it is at initial tension.

Delta Length is the dimensioned change in rope length measured at a particular applied force during a particular tension cycle. Here delta length will be designated by ΔL ("delta ell").

Strain is the ratio of this ΔL to a particular gage length. Here strain will be designated by the Greek character Δ ("epsilon"). These terms are consistent with materials engineering practice.

Uncycled ΔL is the change in rope length measured at a particular applied force during the first tension cycle. Uncycled strain is the ratio of this uncycled ΔL to the original gage length. This concept is shown in Figure A-1.

Permanent ΔL is the change in rope length measured at initial force after the rope has experienced one or a number of tension cycles. *Permanent strain* is the ratio of this permanent ΔL to the uncycled gage length.

Cycled gage length is the distance measured between the gage marks after a rope has been cycled and then returned to the *initial tension.* It is the sum of the uncycled gage length and the permanent ΔL.

Overall ΔL is the change in rope length measured at a particular applied force during a particular tension cycle from its original gage length. *Overall strain* is the ratio of this overall ΔL to the original gage length. This concept is shown in Figure A-1.

Immediate ΔL is the change in rope length measured at a particular applied force during a particular tension cycle from its cycled gage length immediately before that cycle. *Immediate strain* is the ratio of this immediate L to this cycled gage length. This concept is shown in Figure A-1.

On the first tension cycle, overall and immediate ΔL are the same. After the rope has been subjected to one or a number of tension cycles, its cycled gage length will almost always be longer than its uncycled gage length. Thus after the first cycle, immediate ΔL will generally be less than original ΔL.

ΔL is measured in units of length, for example inches or mm. Strain is usually expressed in terms of a dimensionless ratio but may be expressed as a percentage. The applied force at which the strain was measured should be stated, either as an absolute value or as a percentage of break strength.

Calculation of Uncycled Strain

Data for the uncycled Δ L is taken on the first tension cycle. The uncycled strain is calculated from that uncycled Δ L on the basis of the uncycled gage length of the rope. The equation given in CI 1500 for the uncycled $\boldsymbol{\epsilon}$ is:

$$U\boldsymbol{\epsilon}\, n\% = (Bn\% – A) / A \tag{A-1}$$

where: $U\boldsymbol{\epsilon}\, n\%$ = uncycled strain at $n\%$ of break strength
          A = uncycled gage length
          $B\, n\%$ = length at $n\%$ of break strength.

Calculation of Permanent Strain

After being cycled and then returned to initial tension, the length of the rope will generally be longer than before cycling. This change in length as measured at initial tension is the permanent Δ L. CI 1500 gives the following equation for Permanent Strain after cycling:

$$P\boldsymbol{\epsilon} = (C – A) / A \tag{A-2}$$

where: $P\boldsymbol{\epsilon}$ = permanent strain
          C = cycled gage length
          A = uncycled gage length

Calculation of Immediate Strain

The Immediate Strain at any applied force is calculated with reference to the gage length of the rope before the particular cycle. The following equation for Immediate $\boldsymbol{\epsilon}$ is used in CI 1500.

$$I\boldsymbol{\epsilon}\, n\% = (Dn\% – C) / C \tag{A-3}$$

where: $I\boldsymbol{\epsilon}\, n\%$ = immediate strain at $n\%$ of break force during cycle
          C = cycled gage length at beginning of cycle
          $D\, n\%$ = length at $n\%$ of break strength during cycle

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Calculation of Overall Strain

The Overall Strain at any applied force is calculated with reference to the original gage length of the rope before any cycling. It is calculated by the following equation:

$$O\boldsymbol{\epsilon}\, n\% = (Dn\% – A) / A \tag{A-4}$$

where: $O\boldsymbol{\epsilon}\, n\%$ = overall strain at $n\%$ of break force during cycle

The overall $\boldsymbol{\epsilon}$ at a particular $n\%$ of break strength after a particular number of cycles can be calculated for a rope having an uncycled gage length A with knowledge of permanent strain and immediate strain by the following:

$$Overall\ \boldsymbol{\epsilon} = A \times P\boldsymbol{\epsilon} / [A + (L \times P\boldsymbol{\epsilon}) \times I\boldsymbol{\epsilon}] \tag{A-5}$$

And Original Strain can be calculated by the following:

$$O\boldsymbol{\epsilon} = P\boldsymbol{\epsilon} + [1 + (1 \times P\boldsymbol{\epsilon}) \times I\boldsymbol{\epsilon}] \tag{A-6}$$

Engineering Significance of Original and Immediate Strain

Overall and immediate strain are both important properties for the engineering of rope systems. These properties are sometimes more important than rope strength when selecting a rope for a particular application and when designing the system which utilizes that rope.

When there is concern that the change in length of a rope in service may cause it to become excessively long for a particular purpose, then overall strain and permanent strain are the property of interest. For example, in standing rigging, excessive length change might be intolerable, or sufficient length adjustment may be required.

When there is concern with the dynamic response of a system, then immediate strain is of principal concern. High energy absorption is important in tow ropes and hawsers. Immediate strain is also very important in climbing and safety ropes. A rappelling rope or work-support rope should have little immediate strain in order to control the position of the climber or worker. A fall arrest rope should have much immediate strain to prevent imparting excessive shock load to the "faller".

Measuring Strain in the Test Lab

The accuracy to which strain is measured and calculated depends critically on the length between gage marks as well as on the accuracies to which the individual measurements are taken. If the length between gage marks is too short, then a small inaccuracy in making measurements can result in a large error in the calculated strain. This is especially true if the strain is small.

Each calculated strain is the difference between a measurement X taken at initial test tension and another measurement Y taken at the prescribed tension force. Using these measurements, the strain is calculated by:

$$\epsilon = (Y - X) / X \qquad (A\text{-}7)$$

where: ϵ = strain

X = distance measured at initial tension

Y = distance measured at applied force

As an example, let the true value of X = 100 in. and the true value of Y = 106 in. Then the true strain is 0.06. This is typical of the strain at 50% of breaking strength of a polyester or polypropylene rope after ten cycles to 50% of breaking strength.

$$\epsilon = (106 - 100) / 100 = 0.06$$

The calculation error percent is defined as the   (A-8)

Error = 100 (true value − perceived value) / true value

If an error of 0.5 in. is made in each reading, such that X = 100.5 in. and Y = 105.5 in., then the perceived strain is 0.05.

$$\epsilon = (105.5 - 100.5) / 100.5 = 0.05$$

This produces an error of almost 17% from the true strain value.

Error = 100 (0.06 − 0.05) / 0.06 = 16.67%

Errors from Manual Length Measurements

When the measurements are taken "manually" through the use of a calibrated tape or ruler held alongside the rope, errors can be introduced by the following:

the manner in which the tape is positioned and held at the first gage mark,

the manner in which the tape is stretched between the first and the second gage mark, and

the manner in which the tape is read over the second mark.

Very small errors in each of these acts can add up to a significant error. For example, an error of 0.1 in. when positioning the tape at the first mark, an error of 0.2 in. when stretching the tape, and another error of 0.2 in. when reading the tape at the second mark produce an accumulated error of 0.5 in.

These sources of inaccuracy are probably much more significant than the calibration accuracy of the measuring tape and the accuracy to which the force is applied. If the same tape is used for all measurements, then the accuracy of that tape is of little significance.

The Tables 1T and 1M in the Cordage Institute CI 1500 "Standard Test Method for Fiber Rope" are based on calculations similar to the above example.

In the Tables, the manual case assumes that X is measured with an accuracy of ±0.2 in. (±5 mm) and that Y is measured with an accuracy of ±0.4 in. (±10 mm). The X measurement, which is taken at the very low initial tension, can be made carefully without much regard for safety and time. The Y measurement is taken while the rope is under relatively high tension. When taken manually, this measurement must be made quickly, with concerns for the hazards involved and for delaying completion of the test. Thus the Y measurement will probably not be as accurate as the X measurement.
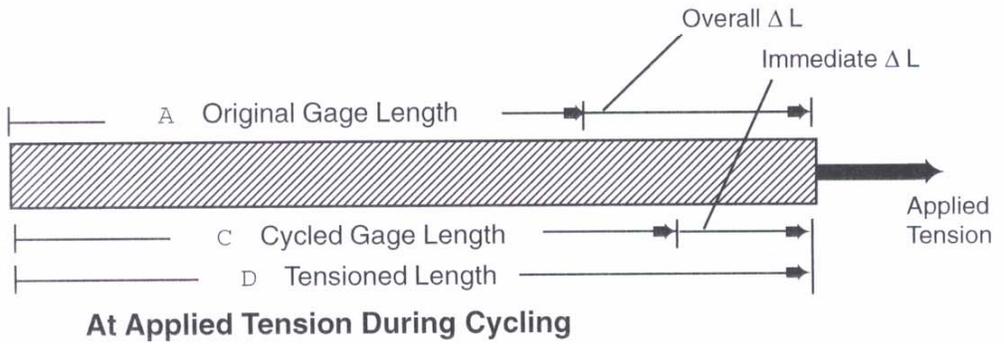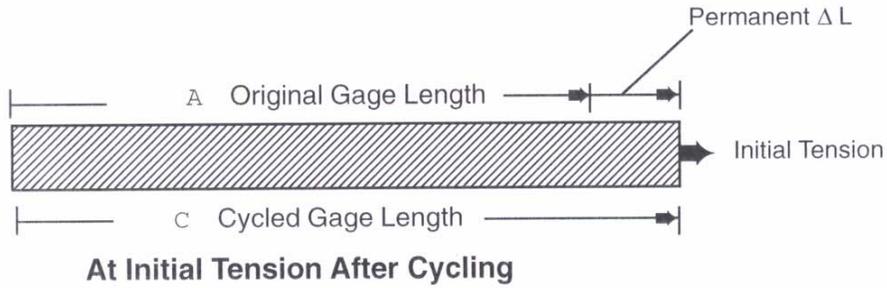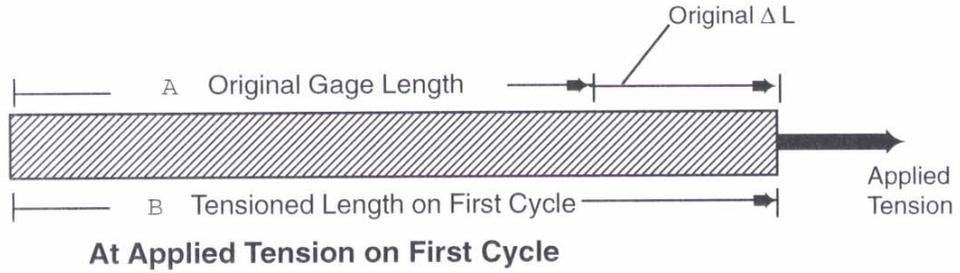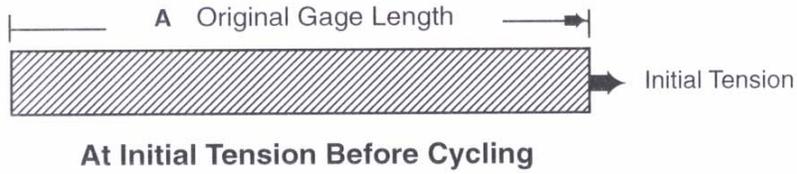
Other Considerations in Laboratory Length Measurements

Using a highly accurate tape or ruler when manually measuring rope length does little to increase the accuracy of the measurement. The apparent discrepancy between the accuracy prescribed for the tape or ruler in 5.5.1 and that prescribed for the electronic device in 5.5.3 takes into account that the calibrated accuracy of the tape or ruler will be distorted by the method in which it is employed, whereas the measurement accuracy of the electronic device is absolute and not distorted. (Numbers refer to paragraphs in CI 1500 Test Standard.)

Mechanical or electronic length measuring and recording devices which are attached directly to the moving cross-head of the test machine are generally not suitable for determining strain in accordance with these methods. Such a measuring system measures the overall length of the rope between termination points. It measures the change in length and slippage within the splices or other terminations in addition to the change in length of the rope between terminations.

Mechanical and electronic length measuring and recording devices should thus be used only to measure length between the gage marks placed on the undisturbed length of rope beyond the terminations.

Figure A-1. Illustration of Change-in-Length Measurements

A Original Gage Length

Initial Tension

At Initial Tension Before Cycling

Original Δ L

A Original Gage Length

Applied Tension

B Tensioned Length on First Cycle

At Applied Tension on First Cycle

Permanent Δ L

A Original Gage Length

Initial Tension

C Cycled Gage Length

At Initial Tension After Cycling

Overall Δ L

Immediate Δ L

A Original Gage Length

Applied Tension

C Cycled Gage Length

D Tensioned Length

At Applied Tension During Cycling

Cordage Institute International Guideline CI 1401-06 • Safer Use of Fiber Rope • May 2006

Purpose

This Guideline is provided to help in the selection and safer use of cordage products. Compliance with Cordage Institute Standards and Guidelines does not guarantee safe use under all circumstances, and the Institute disclaims any responsibility for any accidents that may occur.

1. Overview

There are inherent risks in the use of rope and cordage because such products are subject to highly variable conditions that change over time. Therefore, Design Factor selections and Working Load Limits must be calculated with consideration of exposure to risk and actual conditions of use for each application. If in doubt, consult an experienced engineer or other qualified individual regarding the design, application and selection of a rope product.

2. Minimum Breaking Strength

The Minimum Breaking Strength (MBS) is the force that a given rope is required to meet or exceed in a laboratory test when it is new and unused. MBS values are given in Cordage Institute Standards and individual manufacturers' specifications.

3. Working Load / Working Load Limit

The Working Load (WL) is the weight or force applied to rope or cordage in a given application.

The Working Load Limit (WLL) is a guideline for the maximum allowable capacity of a rope product and **should not be exceeded**.

Applied loads higher than a specified WLL can overstress and damage fibers, resulting in premature rope failure. The Working Load of an application should not exceed the WLL of the rope for optimal product performance and the safety of personnel and property.

4. Design Factors

The Design Factor (DF) is the ratio between the MBS and WL. This value is the margin of safety for an application. For a particular application, the factors affecting rope behavior and the degrees of risk to life, personnel and property must be considered when setting a DF.

Commercial and industrial users must determine a DF based on actual service conditions and establish operating procedures for a specific application. A "general use" consumer must also assess his application and determine conditions of use and hazards that may apply.

As a rule, the more severe the application, the higher the DF needs to be. Selection of a DF in the general range between 5:1 and 12:1 is recommended. A design factor at the low end of this range should only be selected with expert knowledge of conditions and professional estimate of risk. DF at or above the high end of the range should be used for more severe conditions of use. When in doubt, always select the highest practical DF, or contact the manufacturer for additional guidance. Engineering assistance may be necessary to determine the service loads and risks and to set the appropriate DF.

Considerations in the Selection of a Design Factor

• Experience is the best guide for determining a DF. Select a DF value used in a similar application that proved successful.

• Consider increasing the Design Factor if:
  - Problems have previously been observed in similar applications
  - Injury, death or loss of property may result if rope fails
  - Loads are not accurately known
  - High or continuous dynamic loads are anticipated (See Section 6)
  - Shock loads are anticipated
  - Extensive cyclic loads are likely to occur
  - Tension is on the rope for long periods
  - Knots are used, as knots can reduce strength by as much as 50%
  - Operators are not well trained
  - Operation/use procedures are not well defined and/or controlled.
  - Severe abrasion is likely to occur from exposure to rough surfaces or cutting edges, or by contamination from dirt and grit.

Expert Guidance is Strongly Suggested for the Following Situations

• Rope is used constantly over pulleys or around a small bend.
• Rope is used at elevated temperature that may glaze, weaken or melt the fibers.
• Rope is used in the presence of hazardous chemicals.
• Rope is not new and is of unknown properties and/or prior use.
• Rope is not inspected frequently or adequately.
• Rope will be in service for long periods that may lose strength due to fatigue.

CI Guideline 2003 Fibers for Cable, Cordage, Rope and Twine explains some of the effects of elevated temperature and chemicals on synthetic fibers.

5. Calculation of Values

After the WL has been estimated and the DF for an application has been determined, a rope can be selected by calculating the necessary new rope Minimum Breaking Strength. The required MBS is determined by multiplying the Working Load by Design Factor. WL*DF=MBS. For example, an application with a Working Load of 3 tons and a Design Factor of 10 would require an rope with MBS = 3*10 = 30 tons.

Similarly, the Working Load Limit of a new rope is determined by dividing the Minimum Breaking Strength by the Design Factor for a given application. MBS÷DF=WLL. Examples of WLL, based on a DF of 5:1 and 12:1, are given in individual Cordage Institute Standards. The WLL in CI standards are for new ropes with standard terminations.

6. Dynamic Loading

Nearly all rope in use is subject to Dynamic Loading to some degree. Whenever a load is picked up, stopped, moved or swung there is an increased force due to the acceleration or dynamics of the movement. The more rapidly or suddenly such actions occur, the greater the forces. In extreme cases, the force sustained by the rope may be two, three, or even more times the static load. (e.g., when picking up a tow on a slack line or using a rope to stop a falling object) Therefore, in applications such as towing lines, lifelines, safety lines, climbing ropes, etc., the DF must reflect the added risk involved. If significant dynamic load is foreseen, a DF at or above the high end of the range should be considered. Loads should be handled slowly and smoothly to minimize dynamic effects.

Users should also be aware that dynamic effects are greater on a low-elongation rope, such as manila, than a high-elongation rope, such as nylon. Also note that dynamic effects are more significant on short segments of rope as opposed to longer ones.

Excessive dynamic loading will shorten the life of a line and/or cause premature failure.

7. Recoil/Snapback Safety Warning

When a tensioned rope breaks, an attachment fails, or either are suddenly released, the energy in the rope will cause it or the attachment to recoil back in unpredictable directions with great force, resulting in possible injury or death to persons in its path. Persons should never stand in line with or in the general path of rope under tension to avoid snapback injuries.

8. Special Applications

The DF ranges can be lower or higher than recommended in applications where actual field experience has proven successful, where a recognized standard or specification exists, where qualified professionals have made a thorough engineering analysis of all conditions of use and/or a regulatory agency has granted specific permission. In such controlled cases, breaking strength, elongation, energy absorption, and other factors, including operating procedures, must be evaluated during the selection of the Design Factor.

In addition to the above, more specific guidelines should be considered for applications such as life safety and marine use.