**Cordage Institute**

**International Guideline**

# Determination of Cordage Institute Minimum Breaking Strengths

**CI 2002-14**
May 2014

## 1. Scope

1.1 This guideline is intended for use by the Cordage Institute (CI) Technical Committee to determine recommendations for the Minimum Break Strength (MBS) of various fiber rope products for publication in the CI Cordage and Rope Standards. This Guideline is not intended for use with Life Safety Ropes.

1.2 A subcommittee for a particular rope category may deviate from this procedure after review and approval of the Technical Operating Committee and General committee.

1.3 These guidelines are not intended for routine use in testing of rope products for compliance with CI Rope Standards. It is the responsibility of individual manufacturers to establish and to follow suitable testing procedures to assure that rope products comply with CI Standards.

1.4 Ropes of a particular size designation may be significantly stronger than the MBS given in CI Standards.

1.5 For rope products designed and intended for a specific application, such as Life Protection, performance may be determined based on the requirement of the particular application

## 2. Reference

2.1 CI 1500: Test Methods for Fiber Rope.

## 3. Terminology

3.1 Measured Diameter ($D_m$): The actual diameter measured of a tested specimen.

3.2 Measured Linear Density ($LD_m$): The actual linear density measured of a tested specimen.

3.3 Measured Break Strength ($BS_m$): The actual break strength measured of a tested specimen.

3.4 Proposed Nominal Diameter ($D_{prop}$): The Nominal Diameter of a proposed new rope type

3.5 Proposed Linear density ($LD_{prop}$): The linear density proposed for a given Nominal Diameter value.

3.6 Predicted Break Strength ($BS_{pred}$) The Break Strength predicted based on regression analysis of $BS_m$ vs. $LD_{m.}$

3.7 Proposed Minimum Break Strength ($MBS_{prop}$): The minimum break strength for a given nominal rope size.

3.8 Minimum Strength Tolerance Band (MSTB): The percentage subtracted from the Predicted Break Strength to determine the ($MBS_{prop}$). A MSTB of 10% is used for non-life safety products. 10% is used as a simplified value to represent two standard deviations, which has been accepted as a typical distribution on cordage testing.

3.9 Sample: A set of ropes taken from production by a manufacturer.

3.10 Specimen: A particular rope taken from the sample and tested.

3.11 Rope Category: A classification of rope based on its construction and generic fiber content as defined in the relevant CI Standard.

## 4. Summary of Procedure

4.1 Rope samples of a specific product of several sizes from various manufacturers are tested. Regression analysis is then used to determine the best fit curves for Measured Diameter vs. Measured Linear Density and Measured Linear Density vs. Measured Break Strength. The Proposed Linear Density for a given rope category is then determined by the best fit of Diameter vs. Linear Density. The proposed Break strength for each size of a given rope category is then determined by subtracting the MSTB (10%) from the best fit prediction of Break Strength.

## 5. Sample Collection

5.1 When a rope category is under consideration for strength determination, the Cordage Institute membership shall be notified, along with any other manufacturers known to produce the particular type of rope. The CI Technical Subcommittee shall provide directions for testing or for submitting rope samples for testing, to all respondents who indicate an interest in the project.

## 6. Sampling

6.1 Test samples shall be selected from standard production runs. Where feasible, selection shall be done from production over several or many non-consecutive runs of the particular product.
6.2 As many different sizes as feasible should be sampled.
6.3 At least four test specimens shall be tested from each test sample, one for testing linear density and three for testing break strength.
6.4 Each rope test specimen shall be of sufficient length to prepare a test specimen with splices as described in CI 1500 Test Methods for Fiber Rope

## 7. Testing

7.1 The testing may be conducted by the manufacturer, a testing laboratory chosen by the manufacturer or a testing laboratory designated by the CI Technical Subcommittee to perform such tests.
7.2 Test at least one specimens from each sample for the Linear Density($LD_m$) and Diameter ($D_m$). For each rope test sample, determine the Linear Density and Diameter in accordance with CI 1500 Test Methods for Fiber Rope.
7.3 Test at least three specimens from each sample for the Breaking Force. For each rope test sample, determine the Breaking Force in accordance with CI 1500 Test Methods for Fiber Rope, after cycling to either 20% or 50% of the rope's breaking strength as instructed by the CI Technical Subcommittee for that category of rope.
7.4 For each test, the Measured Linear Density ($LD_m$), Measured Diameter ($D_m$), Measured Break Strength ($BS_m$), Cycle Load History, and the location and nature of the break shall be reported.

## 8. Data Analysis

8.1 Linear Density
8.1.1 Use least squares best fit regression analysis to determine a best fit curve of $D_m$ vs. $LD_m$ using $D_m$ as the independent variable, and $LD_m$ as the dependent variable. A power function shall be used to normalize the data. The Formula used is:

$$LD_m = a \times (D_m)^b$$

a and b are constants determined by the regression analysis.

8.1.2 Calculate a proposed Linear Density for each Nominal Diameter that will be specified by the standard under development. The Formula used is:

$$LD_{prop} = a \times (D_{prop})^b$$

Where: a & b are the constants determined by the regression analysis in 8.1.1 above.

Note: Diameter is considered to be nominal by CI standards, with a +/- tolerance stated in the footnotes of the applicable rope standard.

8.2 Break Strength

8.2.1 Use regression analysis to determine a best fit curve of $BS_m$ versus $LD_m$ using $LD_m$ as the independent variable, and $BS_m$ as the dependent variable. A power function shall be used to normalize the data. The Formula used is:

$BS_m = c \times (LD_m)^d$

c and d are constants determined by the regression analysis.

8.2.2 Calculate a Predicted Break Strength for each Nominal Diameter that will be specified by the standard under development. The Formula used is:

$BS_{pred} = c \times (LD_{prop})^d$

Where: c & d are the constants determined by the regression analysis in 8.2.1 above.

8.3 Calculate a Proposed Minimum Break Strength for each Nominal Diameter that will be specified by the standard under development. The Formula used is:

$MBS_{prop} = BS_{pred} \times (1 - MSTB)$

8.4 The CI Technical Subcommittee may propose the development of a regular and high performance standard for the category of rope under consideration. This may be appropriate in cases where different grades of fiber are used, or other technologies such as heat setting or pre-stretching are used.

## 9. Determination of Cordage Institute Rated Strengths

9.1 The Chair of the CI Technical Subcommittee shall conduct (or arrange for conducting) the data analysis called for above in order to establish the equation for use in calculating rated strengths.

9.2 The CI Technical Subcommittee shall then use the specified equation to calculate a rated strength for each rope size that is to appear in the designated CI rope standard.

9.3 Upon approval by the CI Board of Directors, the resulting rope strength value(s) are used in Cordage Institute technical documents.

## 10. Handling of Confidential Data

10.1 The manufacturers shall submit their test data directly to the Cordage Institute's Technical Director, or to a designated person or organization that has an appropriate confidentiality agreement with the Cordage Institute.

10.2 The recipient of the data shall code the identities of the manufacturers and then submit the data sets to the Chair of the appropriate Subcommittee of the CI Technical Committee.

## 11. Report

11.1 The responsible CI Technical Subcommittee shall prepare a report giving the data sets (without manufacturers' identifies), detailing the data analysis, and providing the resulting table of rope strengths.

11.2 The report shall be retained by the Cordage Institute for the duration of the standard or until it is superseded by another report.

**EXAMPLE:**

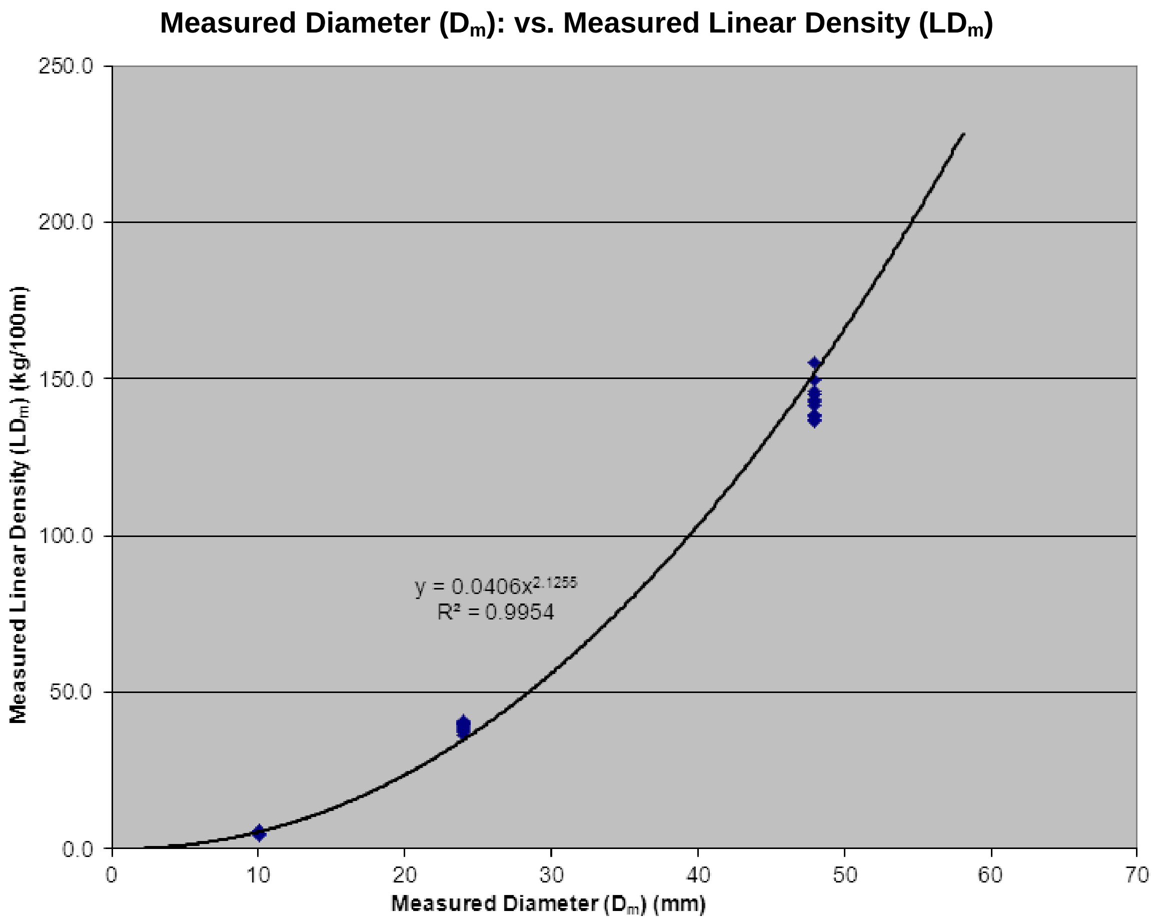
This provides an example of the calculations involved in determining CI standard strength values.

Three manufacturers of nylon 3-strand rope submit test data for three rope sizes.

Testing per Section 7 yields the following test results:

| Manufacturer | Index | Measured Diameter ($D_m$) (mm) | Measured Linear Density ($LD_m$) (kg/100m) | Measured Break Strength ($BS_m$) (kN) |
|---|---|---|---|---|
| **Mfg. A** | specimen 1 | 10 | 5.1 | 20.9 |
| **Mfg. A** | specimen 2 | 10 | 4.5 | 17.3 |
| **Mfg. A** | specimen 3 | 10 | 5.2 | 19.6 |
| **Mfg. A** | specimen 4 | 10 | 4.9 | 20.0 |
| **Mfg. A** | specimen 5 | 10 | 5.3 | 16.9 |
| **Mfg. B** | specimen 1 | 10 | 5.1 | 17.3 |
| **Mfg. B** | specimen 2 | 10 | 5.2 | 18.7 |
| **Mfg. B** | specimen 3 | 10 | 5.5 | 16.8 |
| **Mfg. B** | specimen 4 | 10 | 5.4 | 16.9 |
| **Mfg. B** | specimen 5 | 10 | 5.2 | 18.5 |
| **Mfg. C** | specimen 1 | 10 | 5.2 | 17.1 |
| **Mfg. C** | specimen 2 | 10 | 5.2 | 16.1 |
| **Mfg. C** | specimen 3 | 10 | 5.2 | 16.2 |
| **Mfg. C** | specimen 4 | 10 | 5.1 | 14.9 |
| **Mfg. C** | specimen 5 | 10 | 5.2 | 16.4 |
| **Mfg. A** | specimen 1 | 24 | 39.9 | 114.5 |
| **Mfg. A** | specimen 2 | 24 | 37.5 | 137.9 |
| **Mfg. A** | specimen 3 | 24 | 37.7 | 133.4 |
| **Mfg. A** | specimen 4 | 24 | 38.4 | 120.1 |
| **Mfg. A** | specimen 5 | 24 | 39.7 | 122.8 |
| **Mfg. B** | specimen 1 | 24 | 40.4 | 106.1 |
| **Mfg. B** | specimen 2 | 24 | 39.9 | 107.2 |
| **Mfg. B** | specimen 3 | 24 | 39.0 | 104.3 |
| **Mfg. B** | specimen 4 | 24 | 40.5 | 105.0 |
| **Mfg. B** | specimen 5 | 24 | 39.7 | 105.2 |
| **Mfg. C** | specimen 1 | 24 | 39.4 | 113.9 |
| **Mfg. C** | specimen 2 | 24 | 36.5 | 111.7 |
| **Mfg. C** | specimen 3 | 24 | 39.7 | 137.9 |
| **Mfg. C** | specimen 4 | 24 | 40.0 | 119.2 |
| **Mfg. C** | specimen 5 | 24 | 41.2 | 122.8 |
| **Mfg. A** | specimen 1 | 48 | 149.7 | 441.3 |
| **Mfg. A** | specimen 2 | 48 | 146.3 | 434.8 |
| **Mfg. A** | specimen 3 | 48 | 142.7 | 439.2 |
| **Mfg. A** | specimen 4 | 48 | 155.4 | 442.6 |
| **Mfg. A** | specimen 5 | 48 | 145.2 | 403.9 |
| **Mfg. B** | specimen 1 | 48 | 138.0 | 384.3 |
| **Mfg. B** | specimen 2 | 48 | 142.6 | 381.4 |
| **Mfg. B** | specimen 3 | 48 | 143.5 | 383.0 |
| **Mfg. B** | specimen 4 | 48 | 145.1 | 387.0 |
| **Mfg. B** | specimen 5 | 48 | 141.2 | 377.9 |
| **Mfg. C** | specimen 1 | 48 | 138.4 | 458.2 |
| **Mfg. C** | specimen 2 | 48 | 137.7 | 471.5 |
| **Mfg. C** | specimen 3 | 48 | 136.9 | 440.4 |
| **Mfg. C** | specimen 4 | 48 | 136.8 | 438.6 |
| **Mfg. C** | specimen 5 | 48 | 137.2 | 467.1 |

Use regression analysis to determine a best fit curve of $D_m$ vs. $LD_m$ using $D_m$ as the independent variable, and $LD_m$ as the dependent variable. A power function shall be used to normalize the data. The Formula used is: $LD_m = a \times (D_m)^b$




Constants a & b are determined to be:

a=0.0406

b=2.1255

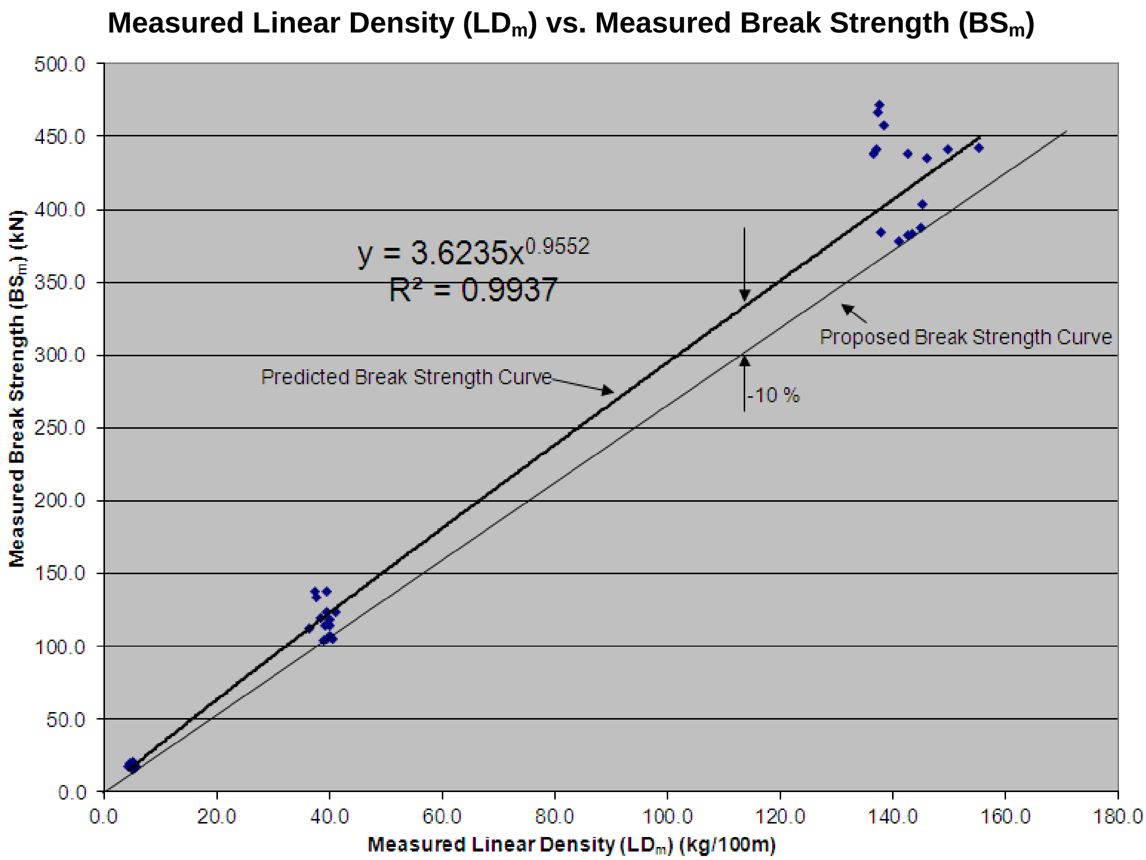
Calculate a proposed Linear Density for each Nominal Diameter that will be specified by the standard under development.

For example:

The Proposed Linear Density ($LD_{prop}$) for a rope with a 14mm Proposed Nominal Diameter ($D_{prop}$)

$LD_{prop} = a \times (D_{prop})^b = 0.0406 \times (14)^{2.1255} = 11.1$ kg/100m

Use regression analysis to determine a best fit curve of $BS_m$ versus $LD_m$ using $LD_m$ as the independent variable, and $BS_m$ as the dependent variable. A power function shall be used to normalize the data. The Formula used is: $BS_m = c \times (LD_m)^d$




Constants c & d are determined to be:

c=3.6235

d=0.9552

Calculate a Predicted Break Strength for each Nominal Diameter that will be specified by the standard under development.

For example:

The Predicted Break Strength ($BS_{pred}$) for a rope with a Proposed Linear Density ($LD_{prop}$) of 11.1kg/100m is

$$BS_{pred} = c \times (LD_{prop})^d = 3.6235 \times (11.1)^{0.9552} = 36.1 \text{ kN}$$

Calculate a Proposed Minimum Break Strength for each Nominal Diameter that will be specified by the standard under development.
For example:

$$MBS_{prop} = BS_{pred} \times (1 - MSTB) = 36.1 \times (1 - 0.1) = 32.4 \text{ kN}$$

So, for the proposed standard, a 14mm rope would be 11.1 kg/100m with a MBS of 32.4kN

**⚠ WARNING**

The use of rope and cordage products has inherent safety risks which are subject to highly variable conditions and which may change over time. Compliance with standards and guidelines of the Cordage Institute does not guarantee safe use under all circumstances, and the Institute disclaims any responsibility for accidents which may occur. If the user has any questions or uncertainties about the proper use of rope or cordage or about safe practices, consult a professional engineer or other qualified individual.

**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 in a particular application and should not be exceeded.

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

**4. Design Factors**

The Design Factor (DF) is the ratio between the minimum breaking strength and working load, (MBS/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, industrial and "general use" consumers should determine a DF based on actual service conditions and establish operating procedures for a specific application. The consumer must also assess his application and determine any hazards that may exist.

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**. This specific range of values does not apply to Life Safety ropes and/or rope products designed and manufactured for specific engineered services.** 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. 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. Expert guidance is strongly suggested when shock loads are possible and/or when the rope is used for lifting purposes.

***Considerations in the Selection of a Design Factor***

• Select a DF value supported by industry standards, best practices, and/or regulations.
• All components of the system should be considered when determining the DF
• 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 reduce strength
  - Operators are in training or are not well experienced
  - Operation/use procedures are not well defined and/or controlled.
  - Abrasion may 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 cause strength loss 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 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 are given in some individual Cordage Institute Standards. The WLL in CI standards are for new ropes with standard terminations.

**6. Dynamic Loading**

A dynamic load is any load that is not static, such as a live load or a wind load. If not properly taken into account, dynamic loading could shorten the service life of a rope and may even cause failure.

Dynamic load effects are influenced by the stiffness or modulus of the rope and are more severe when using low-stretch rope. Dynamic load effects are more severe on short sections of rope. In extreme dynamic loading cases, the forces sustained by the rope may be two, three or more times the static load.

When an object is moved the force on the rope increases due to acceleration or deceleration. The more rapidly or suddenly such actions occur, the greater the forces. Objects should be moved slowly and smoothly to minimize dynamic effects whenever possible.

When dynamic loading is anticipated, the Design Factor should be calculated based on the dynamic instead of the static load. The advice of a qualified individual should be used in calculating the Design Factor.

**7. Recoil/Snapback Safety Warning**

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

**8. Special Applications**

The DF ranges can be raised or lowered for applications where 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.

When warning tags are provided by the product manufacturer, they should be attached to each rope per industry or application specific guidelines.