U. S. NAVY
WIRE-ROPE HANDBOOK

VOLUME I

ON

DESIGN AND ENGINEERING
OF WIRE-ROPE SYSTEMS

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DESIGN AND ENGINEERING
OF WIRE-ROPE SYSTEMS

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TABLE OF CONTENTS

LIST OF FIGURES

Figure Number and Title | Page

LIST OF TABLES

1. INTRODUCTION

Volume I of the Wire-Rope Handbook is the first of three concurrently published volumes dealing with Navy usage of wire rope. It is intended for persons concerned with designing wire-rope systems, selecting wire rope for these systems, and understanding the effects of various operating conditions on the behavior and life of wire rope. Some technical background is assumed in the presentation of material in this volume.

The purpose of this volume is to provide the engineer with the basic descriptive information necessary to use wire rope in the safest and most efficient manner, and to avoid the more common pitfalls. Topics include wire-rope description and nomenclature; wire-rope properties; sheaves and rollers; drums, winches, and capstans; fittings and terminations; miscellaneous hardware; wire-rope retirement criteria; and applications information.

Specific design data and analysis methods are presented in Volume II. This volume is technically oriented and complements Volume I with a large amount of state-of-the-art technical data, including the most recent developments in analysis methods.

User information is presented in Volume III. This volume is intended for shipboard personnel or riggers and it covers the use of wire rope from initial delivery, through installation on the equipment and maintenance during use, to inspection and final removal.

2. WIRE-ROPE DESCRIPTION AND NOMENCLATURE

Wire ropes generally consist of three basic structural components: wire, strand, and core. In almost all cases, individual wires are wound helically around a central wire to form a strand while the strands, in turn, are wound helically about a core to form the complete rope structure. This construction is shown schematically in Figure 2-1.

Any load carried by the rope is supported by the wires in the rope strands, with the tension being distributed nearly equally among all the wires. As the rope is pulled and flexed during operation, the wires in the strands move slightly relative to one another in response to changing stresses. The strands themselves also slide relative to each other, equalizing the more significant stresses in the rope. As these wire and strand motions take place, the core maintains rope geometry and supports the strands, preventing them from collapsing or slipping out of position relative to one another when subjected to radial pressure. If the rope passes over a drum or sheave, the core keeps the rope construction from flattening and distorting.

Before discussing each of these wire-rope components in further detail, several dimensional characteristics of wire rope should be mentioned.

2.1. ROPE DIMENSIONS

2.1.1. Diameter

The diameter of a wire rope is defined as the diameter of the smallest circle which completely encloses the rope cross section.

2.1.2. Lay Length

The lay length is the pitch of a wire rope and is the distance measured along the rope axis in which a strand makes one complete turn around the rope.

2.1.3. Lay Angle

The lay angle of a wire rope is defined as the arc tangent of the ratio of the rope circumference to the lay length.

2.2. WIRE MATERIALS

The most important component in a wire rope is the wire. High strength per unit cross-sectional area and good ductility are the two most important rope wire characteristics.

The wire used in wire rope is most commonly manufactured from a high-strength, high-carbon material known commercially as "plow steel". This is a high-strength, high-carbon steel that can be cold-drawn to various degrees to form

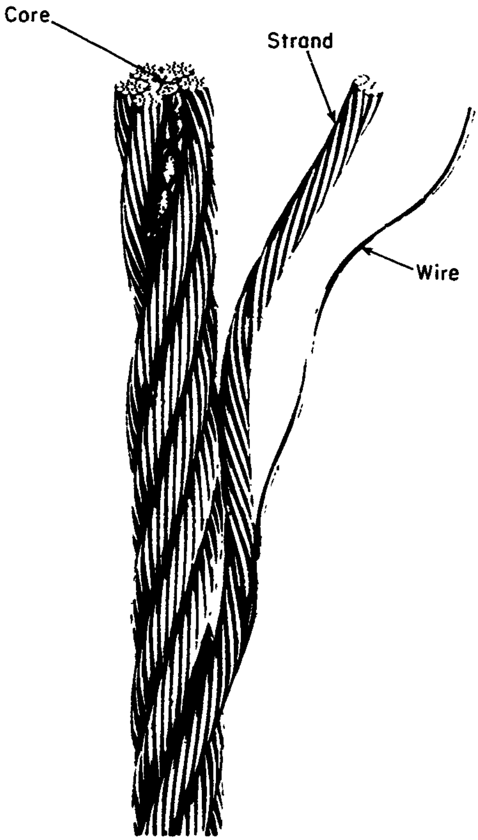


Figure 2-1. Wire-Rope Components

wires of various strength levels (or grades). Some nonplow steel grades are also available. (See Section 3.1. Wire-Rope Materials, page 3-1, for more detailed information.) Wires made from stainless steel, bronze, copper, and other materials are also used to produce wire rope for special applications.

Smaller wires contribute to wire rope flexibility, but decrease rope resistance to abrasion and wear. The opposite is true for larger diameter wires. Wire diameters are chosen in specific strand constructions to provide the amount of flexibility and wear resistance needed in each application. Rope wires generally range from 0.010 inch to 0.200 inch in diameter, although wires with diameters as small as 0.004 inch and as large as 0.250 inch are occasionally used.

2.3. STRAND CONSTRUCTIONS

The design of the wire-rope strand determines many of the properties of the finished wire rope. The size and number of wires and their placement in the strand largely determines the flexibility, resistance to corrosion and wear, and ultimate strength of the strand. A typical strand is made of layers of wire laid about a central wire in a radially symmetrical pattern as shown in Figure 2-2.

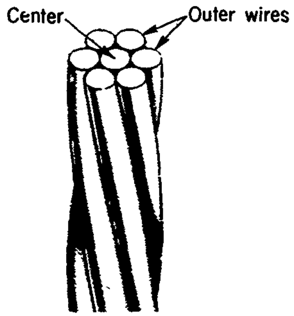


Figure 2-2. Parts of a Wire Strand

The simplest strand consists of two wires laid together. More complex strands involve a larger number of wires. The relative flexibility of a strand generally increases with a larger number of wires. Any strand made of wires of equal diameter and containing no center is called a "centerless strand". Several examples of centerless strands are shown in Figure 2-3.

Seven wires of essentially equal diameter pack quite closely together when six of the wires are laid about the seventh. This simple formation of wires laid about a single-wire center is known as a single-layer strand. The center wire may be exactly the same size as the outer wires but is commonly slightly larger. Figure 2-4 shows several single-layer strands.

With multiple-layer strands, the designs become more complicated and difficult to construct. Even in the relatively simple case where 12 wires of equal diameter are to be laid over a single-layer strand, the problem of stabilizing all the wires must be considered. The second layer of wires may not fit smoothly onto the first, unless the lay angle of the two layers is slightly different. A different lay angle requires a different set up of the machine that makes the strand, so the formation of a two-layer strand with equal-diameter wires may have to be accomplished in two operations. Any such strand which requires more than one stranding operation to develop is called a "multiple operation strand" (Figure 2-5).

To develop multilayered strands in a single operation so that the wires fit together without crossing over, it is necessary to vary the size of the wires in each layer. There are two commonly used stranding techniques of this type. In one method, the number of wires in the outer and inner layers is kept equal so that the outer wires can rest in the valleys of the layer beneath. Thus, the diameter of the second-layer wires is larger than that of the first; the diameter of the third-layer wires, larger than that of the second, and so on. The wires in any one layer, however, are all of the same diameter. This strand type is called "Seale construction", and is illustrated in Figure 2-6.

One limitation for multilayer strands of Seale construction is that the wires in the outer layers may become so large that the flexibility of the rope is impaired. This problem can be reduced for many single-operation strands if the number of wires in each succeeding layer are doubled to form what is known as a "Warrington construction". If this is done, however, it is usually necessary to use two sizes of wire in the outside layer, placing smaller wires on the crowns of the interior wire layer and larger wires in the valleys. Two typical Warrington strand constructions are shown in Figure 2-7.

Another single-operation strand sometimes used in wire rope is known as the "filler-wire construction" and it is formed in the same way as Warrington strand using double the number of wires in each succeeding layer, except that this construction has equal-sized wires in the entire outer layer and small "filler wires" occupy the valleys between the wires of the sublayers. The wires of each layer rest between the sublayer and filler wires. Several examples of filler-wire strand are shown in Figure 2-8.

Two or more of the above stranding techniques are often combined in making a single strand. These hybrid forms are described by listing the name of each successive strand type from the second layer to the outside layer. This nomenclature is illustrated in the examples shown in Figure 2-9.

2.3.1. Nonstandard Strands

In addition to the standard strand arrangements, several special strand constructions have been developed for specific uses.

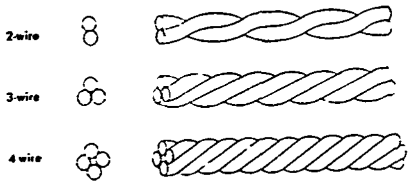


Figure 2-3. Centerless Strands

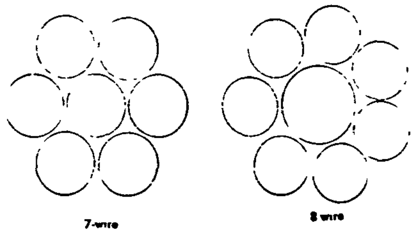


Figure 2-4. Examples of Single-Layer Strands

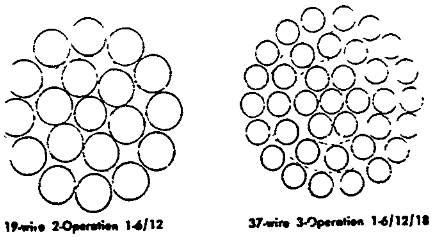
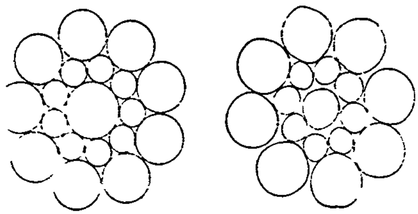
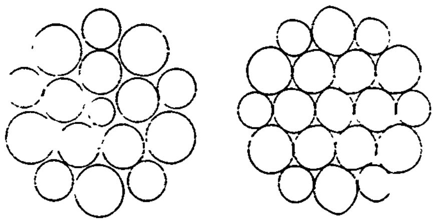


Figure 2-5. Examples of Multiple-Operation Strands



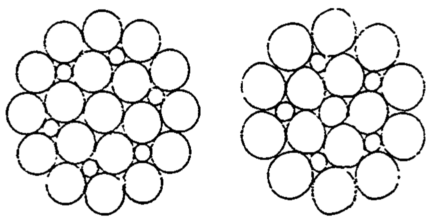
19-wire Seale 1-9-9 17-wire Seale 1-8-8

Figure 2-6. Examples of Seale Strands



16-wire Warrington 1-5-(5+5) 19-wire Warrington 1-6-(6+6)

Figure 2-7. Warrington Strand



25-filler wire strand 1-6-6f-12 21-wire filler wire 1-5-5f-10

Figure 2-8. Filler-Wire Strand

One such construction is the fiber-centered strand, in which a fiber core replaces the wire center of a single-layer or multiple-operation strand (Figure 2-10). A flexible and elastic strand is created, but one which has limited strength. This strand is also more easily crushed than solid-wire strands.

Another special construction is the flattened strand configuration, in which the round wire center is replaced either by a large, triangularly shaped wire or by a group of smaller wires arranged in a triangle. The result is a strand cross section shaped like a triangle with rounded sides (Figure 2-11). These strands are then laid together like wedges of a pie to form a relatively smooth-surfaced rope.

Other special strand configurations include locked and half-locked coil cables. Since these are generally used as independent members rather than as strands in a rope, they will be discussed in Section 2.5. Wire-Rope Categorization.

2.4. CORE USES AND TYPES

The core of a wire rope supports the strands and maintains the shape of the rope construction. As a wire rope is loaded, the helical lay of the strands causes them to press inward toward the rope axis. The core supports this pressure and prevents the strands from rubbing and crushing. The core also maintains the position of the strands during bending. Wire-rope cores are either fiber or metallic.

2.4.1. Fiber Cores

Wire-rope cores made from fiber are used extensively. They resemble common fiber rope and can be made of sisal, manila, cotton, or synthetic fibers such as polypropylene or nylon. A fiber core is initially round, but radial pressure from the strand redistributes the core material until it fills most of the available core space, hence providing uniform support for the strands. The advantages of a fiber core include good rope flexibility and high elasticity. With a fiber core, strand-to-core nicking seen in independent wire-rope-core ropes is also avoided, but strand-to-strand nicking is not prevented. One of the disadvantages of a fiber core is that it does not withstand high loads or bearing pressures and if such conditions develop, the core material may crush allowing the rope to distort. In addition, fiber cores decompose at high temperatures and may deteriorate with age.

2.4.2. Metallic Cores

2.4.2.1. Strand Cores

Metallic strand cores are made in the same manner as wire-rope strands. They may be constructed similarly to the outer strands or they may be made of smaller, more numerous wires for added flexibility.

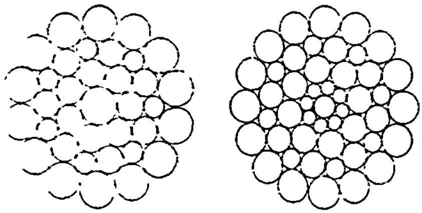


Figure 2-9. Combination Strands

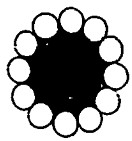


Figure 2-10. A Fiber-Centered Strand

Figure 2-11. Flattened-Strand Configurations

Strand cores provide better outer-strand support than all other core types, but they are also the least flexible.

A special type of strand core is the armored core, which is a fiber-centered single-layer wire strand. This core is more flexible than a solid-strand core and provides better support than a fiber core.

2.4.2.2. Independent Wire-Rope Cores

An independent wire-rope core (IWRC) is designed in the same fashion as a small wire rope. The IWRC provides a good combination of qualities of both previously mentioned core types, since it is more crush-resistant than fiber core and possesses better flexibility than a strand core.

2.5. WIRE-ROPE CATEGORIZATION

A classification system is commonly used which defines a specific wire-rope construction in terms of four major parameters: the number of strands, the number and arrangement of wires in the strands, the direction and type of lay, and the type of core.

2.5.1. Direction and Type of Lay

The term "laying" refers to the placing of a strand in its helical position in a rope while "stranding" refers to the placing of wires in a strand. A strand may be "laid" in one of two directions. In a rope designated right lay, the strands or wires circle the core in a clockwise direction as they recede from the observer. In a left-lay rope, the strands are wrapped in the opposite direction. Right-lay rope is the most common.

In a regular-lay rope, the lay direction of the wires in the strands is opposite to the lay direction of the strands in the rope. If the lay direction of the wires in the strands is the same as those of the strands in the rope, the rope is called Lang lay. If the lay direction of the wires in the strands alternates from strand to strand, the rope is called alternate lay. Another type of alternate-lay rope, called special alternate lay, consists of a pair of Lang-lay strands separated by a regular-lay strand (resulting in four regular-lay and two Lang-lay strands in the completed rope). Figure 2-12 illustrates these lay types and directions.

Regular-lay ropes provide best resistance to kinking, twisting, crushing, and distortion. Lang-lay ropes are more resistant to wear, abrasion, and bending fatigue. Alternate-lay and special alternate-lay ropes reduce scrubbing and clamp slippage but are otherwise a poor compromise between both regular- and Lang-lay ropes.

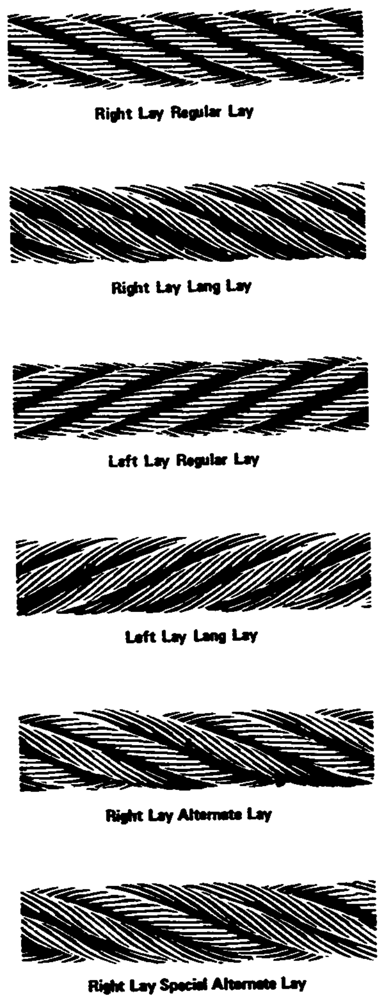


Figure 2-12. Direction and Type of Lay

2.5.2. Wire and Strand Nomenclature

When describing the construction of a wire rope, a notation is used which denotes the number of strands in the rope, the number of wires in each strand, and the strand configuration. For example, a six-strand rope, with 21 wires per strand and a Seale strand construction would be called a 6 x 21 Seale in the standard nomenclature.

2.5.3. Classification of Wire-Rope Constructions

A classification system for wire-rope constructions has evolved from the limited rope designs available in the past. Originally, all ropes were made from equal-sized wires, which meant that all strands were either single-layer produced in one operation or multiple-layer produced in several operations. Thus, the only strands commonly manufactured were seven-wire strands (single-layer), 19-wire strands (two operations), and 37-wire strands (three operations). Sixty-one-wire strands (four operations) were made occasionally, but the small wires in this strand construction were susceptible to abrasion and wear; this strand construction found limited application except in very large-diameter ropes. The most widely used wire-rope classifications have been, and still are, 6 x 7, 6 x 19, 6 x 37, and 8 x 19.

With the introduction of other strand configurations, the four initial rope types have become headings for broad categories of rope construction. Rope constructions of a given category, diameter, and material may have various numbers of wires per strand, but they generally have about the same breaking strength. Brief descriptions of the four main rope constructions and the less commonly used 6 x 61 and 6 x 91 constructions are given below:

- 6 x 7 (Coarse-Laid): Ropes having six strands of from 3 to 14 wires each, but not more than 9 outer wires per strand. Coarse-laid rope has excellent resistance to abrasion and wear because of the large-diameter wires, but it displays poor bending fatigue characteristics.

- 6 x 19 (Flexible): Ropes having six strands with from 16 to 26 wires per strand (including filler wires), but not more than 12 outer wires per strand. Flexible rope provides a compromise between coarse-wire abrasion resistance and fine-wire fatigue resistance.

- 6 x 37 (Extra-Flexible): Ropes having six strands of 27 to 49 wires per strand (including filler wires), but not more than 18 outer wires per strand. This class rope has superior flexibility and is recommended where abrasion and wear is not an important factor. In the larger-diameter sizes it has ample abrasion and wear resistance, and may replace the stiffer 6 x 19 class.

- 8 x 19 (Extra-Flexible Hoisting Rope): Ropes having eight strands of 16 to 26 wires per strand (including filler wires). Construction for construction, this class of rope is somewhat less resistant to wear and abrasion than 6 x 19 rope but is more flexible than 6 x 19. It is less flexible than 6 x 37 and has less strength than either 6 x 19 or 6 x 37 for the same diameter, because of its larger core. The 8 x 19 class rope is a choice for conditions of severe bending, wear, and abrasion under relatively light loads. The large percentage of core area (usually fiber) to strand area makes this class susceptible to crushing, distortion, and greater stretch.

- 6 x 61 (Extra Flexible): Ropes having six strands of 50 to 74 wires per strand (including filler wires), but not more than 24 outer wires per strand. This class rope is similar in characteristics to a 6 x 37 construction and is normally used in applications requiring rope diameter greater than 2 inches.

- 6 x 91 (Extra Flexible): Ropes having six strands of at least 75 wires per strand (including filler wires), but not more than 30 outer wires per strand. This class rope is normally used in applications requiring very large-diameter rope in excess of 2½ inches in diameter.

Other wire-rope constructions have been developed for special applications. Flattened-strand construction rope contains six strands, and is made from triangularly shaped wire strands of various numbers of wires per strand (see Section 2.3.1. Special Strand Constructions). Flattened-strand rope has greater structural compactness, and is stronger than regular rope of a comparable diameter. The compact structure resists crushing under heavy loads. When flattened-strand rope is used on sheave or drum grooves, it contacts the groove surface at more points than a comparable round rope, which reduces crown wear on the outer wires.

Running ropes and mooring lines are sometimes made from fiber-centered strands, and hence do not fit the standard classifications. They are quite flexible, but weaker for the same diameter than the all-metal constructions. They are not normally used in Navy wire-rope applications.

Marlin-clad rope is a 5 x 19 construction rope, each strand of which is tightly wrapped with a tar-fiber coating. The marlin forms a cushion for the strands, shields them against external wear and strand-to-strand friction, and protects the hands of workmen handling the rope. Marlin-clad rope has a low tensile strength for its diameter.

Ropes that resist rotation can be obtained in several constructions, each of which has a specific name and certain inherent properties. Nonrotating (or nonspinning) wire ropes are made in a 19 x 7 (or 18 x 7) construction consisting of a 7 x 7 (or 6 x 7 fiber core) left Lang-lay inner rope covered by twelve 7-wire right regular-lay strands.

Spin-resistant wire ropes are made in an 8 x 19 construction, usually with right regular-lay strands and a 7 x 7 left Lang-lay independent wire-rope core. This rope is usually considered to be somewhat stronger and crush resistant than a 19 x 7 nonrotating rope but it does not have equal non-spinning properties.

Torque-balanced ropes are made in a 3-strand construction (most commonly 3 x 19). In this construction the strand lays are designed to produce a torque in tension equal to, but opposite in direction from, the torque created under load by the opposing rope lay. These ropes, if properly constructed, are the most rotation-free under tension of any rope construction currently available.

Tiller rope consists of 6, 6 x 7 fiber-core ropes closed about a fiber core. The construction is called 6 x 6 x 7, or 6 x 42. Tiller rope is exceedingly flexible, but quite susceptible to abrasion damage and distortion.

Spring-lay rope consists of six ropes laid about a main fiber core. Each rope consists of three 19-wire steel strands and three fiber strands laid alternately about a fiber center. This low-strength rope combines flexibility with high elasticity (low modulus).

Wire strands are occasionally used as complete support members instead of being incorporated into rope. These single strands are constructed of from 3 to 61 wires and are often used as guy strands, or bridge cable.

Other constructions include track strand, smooth coil track strand, locked coil track strand, and half-locked coil track strand. Track strand is a special wire strand. Smooth coil track strand is a multiple-operation strand of equal-sized round wires. Each successive layer is laid in the opposite direction. Locked coil track strand and half-locked coil track strand are multiple-operation strands in which at least the outer wires, and often some of the layers beneath, are made of shaped interlocking wires. These wires may be rectangular, S-shaped, or H-shaped, the latter alternating with round wires. The smooth surface of these constructions significantly reduces the impact which occurs when small-diameter carriage wheels roll over other types of cable used as track. The interlocking construction also prevents broken outer wires from protruding.

Flat rope consists of small wire ropes laid side by side, left-laid rope adjacent to right-laid rope, and held in position with wire or seizing strand. The thickness of the rope is determined by the size of the rope strands, while the width is governed by the number of these ropes used. Flat rope can wind upon itself, like a ribbon, on a drum only slightly wider than the rope, eliminating some space problems. However, this construction is used infrequently.

Many other special constructions are also available. Illustrations of the above rope constructions are found in Figure 2-13.

2.6. WIRE COATINGS

Wire to be used in wire ropes is often coated to retard corrosion. The most common coating is zinc ("galvanizing"), but aluminum ("aluminizing") is also used in some cases. See Section 3.1.4. on Metallic Coatings (Page 3-3) for more discussion of aluminizing versus galvanizing. Wire may also be coated with copper to achieve electrical conduction properties.

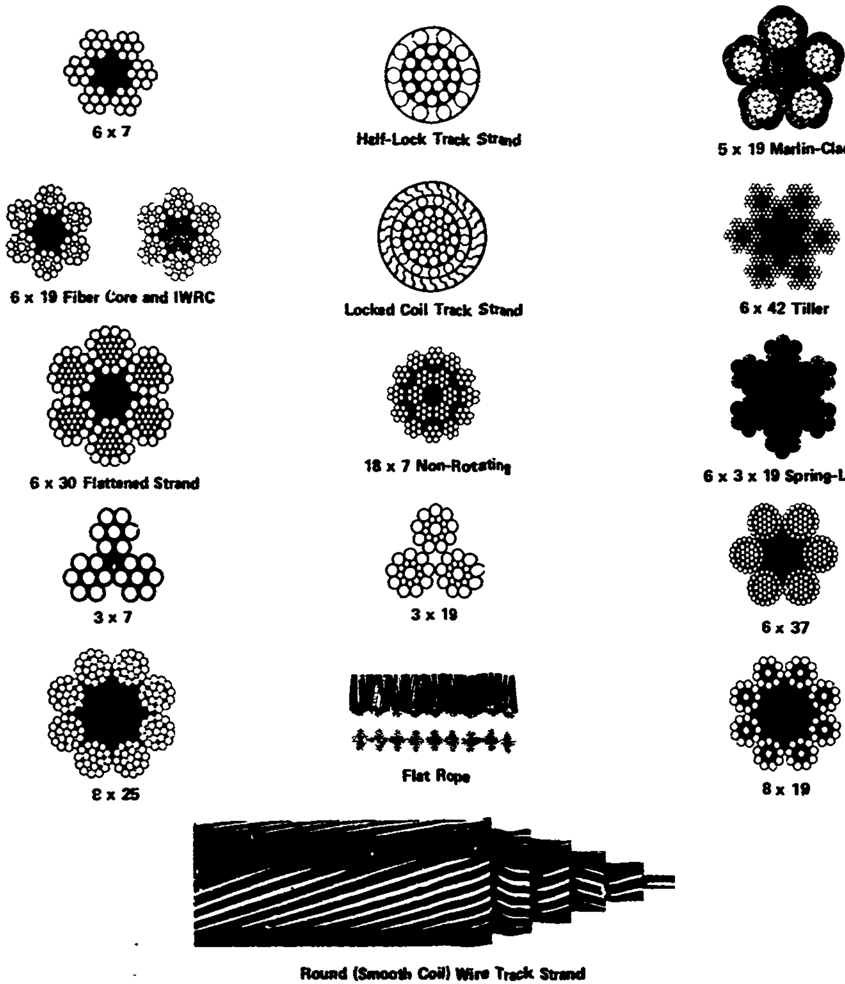


Figure 2-13. Examples of Some Rope Constructions

Strand and rope coatings include marlin strand wraps and plastic rope jacketing. Strands are sometimes tightly wrapped with tarred marlin and are laid into a 5 x 19 construction to form a marlin- or fiber-clad rope. The marlin affords corrosion protection, interstrand cushioning, and protection to a workman's hands. Some manufacturers provide a galvanized rope which is encased in clear or colored protective nylon, polyethylene, or other plastic jacket material.

2.7. PREFORMED WIRE ROPE

Preforming is a shaping process which greatly reduces the tendency of the wires and strands within the rope to straighten and causes them to retain their formed shape within the rope construction. In the past, preformed ropes were the exception; today almost all ropes are preformed, with the exception of some elevator ropes and cable tool driller ropes.

The preforming process is completed by passing the wires and/or strands over a series of offset rollers which plastically deform them into a helical shape before they are laid around the core. Results of the preforming can be seen in Figure 2-14: the wires and strands tend to remain in their proper position in the rope, even when cut or broken. Because the strands are preformed and tend to maintain their shape, the rope is easier to handle, cut ends do not have to be seized as tightly to prevent unlaying, and there is less tendency for the rope to kink. Preforming also relieves some of the stresses within the wires which would otherwise have been created in the rope manufacturing process. Preforming also permits the more general use of Lang-lay constructions. Wickering (broken wires protruding from the rope surface) is reduced, thus reducing the possibility of damage to equipment, to other sections of the rope, and injury to workmen. In general, preforming increases wire-rope life.

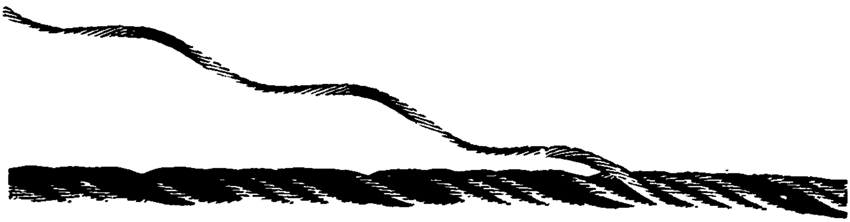


Figure 2-14. Preformed Wire Rope

2.8. PRESTRESSED WIRE ROPE

Occasionally wire rope is prestressed before it is installed to remove constructional stretch or elongation. Its greatest benefit is in installations using stationary strands and stationary IWRC rope where elongation must be limited (with a higher rope modulus of elasticity), and specific lengths must be maintained.

The prestressing process is performed by subjecting the rope to a predetermined load for a period of time sufficient to allow the wires and strands to deform to a stable well-packed configuration that they would eventually achieve through service. Prestressing is normally not performed on fiber-core ropes and is almost never recommended for ropes that will be used in running rigging. Some Navy experience has also shown that the desired effects of prestressing may be reduced appreciably if the rope is recoiled or wound onto a small reel after stretching.

3. WIRE-ROPE PROPERTIES

Choosing the right wire rope for a particular application is a matter of compromise, combined with experience and judgement. The best rope for any job is one which will provide optimum performance in the conditions under which it will be operated, for the minimum cost. This is almost always a trade-off process: a rope which is a superior choice in regard to one property may be a poor choice because of other factors. For example, rope constructions with superior bending-fatigue resistance are often more susceptible to damage by abrasion and wear. If the user attempts to minimize both bending fatigue and abrasion by using a coarse-construction rope and installing larger sheaves, he will trade off the advantage in increased equipment costs, increased system size, and possibly other system-design changes.

The process of choosing a rope which provides the best balance of properties is a subtle one. The correct rope for any specific application depends on so many factors that few wire-rope systems are designed exactly alike. Experience is often the best guide in wire rope selection and system design.

3.1. WIRE-ROPE MATERIALS

Most wire ropes are made of carbon steel wire. Other metals are employed only in situations where the rope is to be used under unusual service conditions.

3.1.1. Carbon Steel

Carbon steel rope wire is available in six common grades. Table 3-1 lists these grades and briefly summarizes their properties.

Table 3-1. GRADES OF STEEL COMMONLY AVAILABLE FOR WIRE-ROPE MATERIAL

Name	Wire Characteristics
Extra-Improved Plow Steel	High strength and resistant to abrasion. Somewhat susceptible to bending fatigue. Used under severe load conditions.
Improved Plow Steel	Quite strong and abrasion-resistant.
Plow Steel	Less strong and abrasion-resistant than Improved Plow Steel; it is decreasing in popularity.
Mild Plow Steel	Even lower in strength and abrasion resistance. Nearly obsolete.
Traction Steel	A special grade designed for traction-type elevators. It is almost never used in other applications.
Iron Grade	Very soft and ductile. Nearly obsolete.

The final grade of a wire after drawing depends principally on the percent reduction and heat treatment. For the same chemistry a wire drawn from a large-diameter rod will be stronger than an equal-diameter wire drawn from a smaller rod because the first wire will have received more mechanical work hardening. Wires drawn according to particular grade specifications will also vary in strength depending on the finished wire diameter, with small-diameter wires displaying higher tensile strengths than larger-diameter wires of the same grade. Figure 3-1 illustrates the relationship between wire diameter and strength for common grades of carbon steel wire.

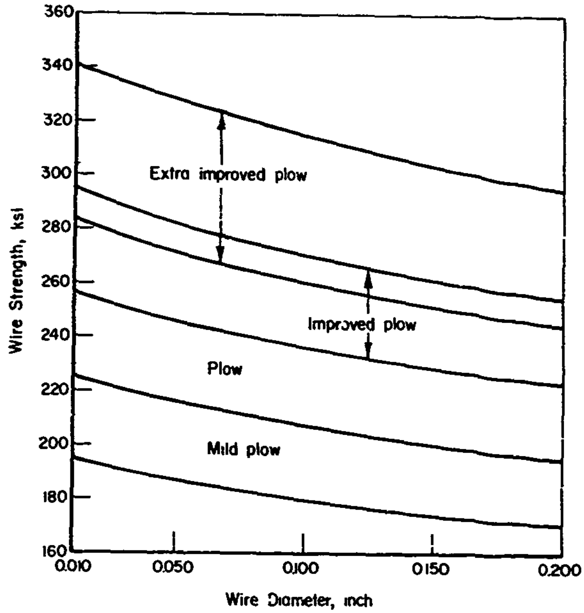


Figure 3-1. Carbon Steel Wire Breaking Strengths (from AISI Specification XYZ14 on Alloy Steel Wire)

3.1.2. Stainless Steels

Stainless steel wire is used primarily for its corrosion and/or temperature resistance. The two grades most often used contain 18 percent chromium and 8 percent nickel and are designated "Type 304" and "Type 302" by the American Iron and Steel Institute (AISI). Type 304 stainless steel rope may be made as strong as commonly used carbon steel rope.

Type 316 stainless steel has better corrosion resistance than Type 304, but it is less fatigue-resistant than carbon steel and is lower in tensile strength (by about 25 percent) than Type 304 stainless steel. Type 305 is about equal in strength and fatigue-resistance to Type 316, but it is superior in situations where its nonmagnetic properties and high thermal expansion coefficient can be used to advantage.

3.1.3. Special Materials

Wire ropes made from bronze, phosphor bronze, copper, or monel wire generally display good corrosion resistance but they abrade easily, fatigue quickly, and display low tensile strengths. Obviously, these special wire materials are used to greatest advantage in situations where corrosion is the dominant cause of rope degradation. Radio antenna lines and lifelines are examples of applications in which phosphor bronze wire rope is sometimes used.

3.1.4. Metallic Coatings

Coating of wires with zinc, aluminum, tin, or copper retards the onset of corrosion as long as the coating remains on the wire. This is true because aluminum and zinc are more corrosion-resistant than steel and they are more anodic. A rope wire made with a steel center and an aluminum or zinc coating will resist initial corrosive action and the steel wire center will remain essentially uncorroded even after corrosive action on the nonferrous surface metal has taken place because the corrosion process preferentially removes zinc or aluminum before steel.

Galvanizing is the process of coating steel with zinc and is by far the most common practice used to retard rusting in wire rope. Tests have indicated that the rate of corrosion of zinc under average atmospheric conditions is about one-tenth to one-twentieth that of mild unprotected steel.

In hot-dip galvanizing, the zinc is applied by passing the wire through a molten zinc bath. This can be done either as the final step in the wire-making process, or as an intermediate stage, with the coated wire being further drawn at a later stage. The first method produces wires galvanized to finished size while wire manufactured according to the second procedure is known as "drawn galvanized". Ropes made from finally galvanized wire are generally used in applications requiring only limited wire-rope flexibility since they are less resistant to bending fatigue than ropes made with uncoated wire of the same grade. Finally galvanized wires are approximately 10 percent lower in strength than uncoated wire. Drawn galvanized wire, on the other hand, can be produced at strength levels essentially equivalent to that of uncoated wire, with the only strength loss being attributable to the lower-strength zinc coating on the wire's surface. Rope made from drawn galvanized wire has been shown to be at least as fatigue resistant as uncoated wire in noncorrosive environments and considerably more resistant to fatigue damage than bare wire in corrosive environments.

Electrogalvanized wire for rope has tensile properties similar to drawn galvanized wire and can be, according to some reports, even better in fatigue- and corrosion-resistance than the drawn galvanized wire. Care must be taken to avoid hydrogen embrittlement in its manufacture, however.

Regardless of the coating method, corrosion protection is directly related to the thickness of the zinc coating. Some typical coating thicknesses are shown in Table 3-2.

Table 3-2. WEIGHT OF ZINC COATING IN ROPE AND STRAND WIRES[(a)]

Galvanized at Finish Sizes		Drawn Galvanized Wire	
Wire Diameter Inches	Minimum Weight of Zinc Coating Ounce per Square Foot	Wire Diameter Inches	Minimum Weight of Zinc Coating Ounce per Square Foot
0.010 - 0.015	0.05	0.010 - 0.015	0.05
0.0155 - 0.027	0.10	0.0155 - 0.028	0.10
0.028 - 0.047	0.20	0.029 - 0.060	0.20
0.048 - 0.054	0.40	0.061 - 0.090	0.30
0.055 - 0.063	0.50	0.091 - 0.140	0.40
0.064 - 0.079	0.60		
0.080 - 0.092	0.70		
0.093 - larger	0.80		

(a) Federal Specification RR-W-410C, Wire Rope and Strand, p. 26 (1968).

Aluminum is also occasionally used as an anodic coating to prevent corrosion of steel wires. Reports indicate that it provides protection comparable to zinc in some corrosive environments. Considerable caution should be used, however, especially if the coating develops cracks or partially wears off, since experiments evaluating the weight loss of iron in couple combination with zinc and aluminum indicate that iron corrodes from 2 to 10 times as fast in the presence of aluminum as it does in the presence of zinc.

Tin is occasionally used as a coating. In some cases steel wire is coated with copper to increase electrical conductivity. It is important to note that tin and copper are less anodic than steel, and may accelerate corrosion of the steel if the coating is broken. Therefore, it is essential that the steel wires remain completely covered for adequate corrosion protection when these coating materials are used.

Plastic-coated wire rope has been available in small sizes for some time. It is said to be somewhat more fatigue resistant than uncoated rope, at least at high design factors. Some plastic-coated and plastic-filled ropes have recently been introduced in larger sizes, but no published laboratory fatigue data are known for these sizes. An unbroken coating effectively prevents corrosion, but if it is pierced, the protection is lost and may actually serve as a retainer for the corrosive medium. The type of plastic used depends on particular requirements of each application.

3.2. FIBER-CORE MATERIALS

Fiber cores are used extensively in wire rope. They resemble common hemp or manila rope in appearance before they are closed within a rope. The traditional fiber material is sisal; recently, however, synthetic fibers have been introduced. Some of the synthetic cores appear to have superior resistance to rotting and absorption properties. The most popular synthetic core fiber is polypropylene. Data available on the relative resistance of natural- and synthetic-fiber-core ropes to axial and bending fatigue are inconclusive.

In general, the main purpose of the fiber core is to resist compression and to withstand the high radial pressures created by tensile loads on the helically wrapped wire strands. The tensile strength of the fiber core is not normally considered when calculating the strength of the wire rope. The fiber core also serves, at least initially, as a reservoir for lubricant within a wire rope. Most manufacturers of wire rope, however, recommend that other lubricants be applied externally during usage, to supplement the core lubricant.

Two special types of fiber core are made of asbestos and cotton. An asbestos core is used in high-temperature operations where standard fiber core material would char and fall apart. Cotton core is sometimes used in small ropes if other rope core materials are not available.

3.3. WIRE-ROPE LUBRICANTS

The main purpose of a wire-rope lubricant is to reduce internal friction so that the rope runs smoothly and to coat the wires so that corrosion is inhibited. To be most effective, the lubricant should maintain these characteristics for the full range of operating temperatures. Ideally, the lubricant should penetrate the rope core easily and adhere strongly to the wire surfaces. In many applications it is desirable that the lubricant provide corrosion protection even under seawater, and that it be transparent so that a visual inspection for broken wires can be made easily.

In most cases, however, a lubricant must be selected based on a compromise between desired properties. There are two basic kinds of lubricants: heavy greases and light oils. Most grease-type lubricants provide adequate corrosion protection for moderate rope usage conditions, but internal penetration is almost always poor unless the lubricant is well heated during application. Heavy lubricants may also become ineffective at low temperatures and may cake and fall off as the rope is flexed during operation. They also tend to be heavy, messy, and opaque. A thorough rope cleaning is necessary before inspections since broken wires may be invisible on a rope covered with heavy grease. If such a lubricant is used on a fiber-core rope, the rope core may dry out or absorb corrosive moisture and eventually break up.

Light oil lubricants are thinner, clearer, and penetrate the interior of a wire rope more easily, and are less prone to solidify than heavy lubricants. In addition, they are effective when applied in light coatings and are readily adaptable to continuous, automatic lubrication systems. The corrosion protection provided by light oils is sufficient for most operations, but may not be sufficient for underwater rope usage.

3.4. WIRE-ROPE BREAKING STRENGTH

The breaking strength of a wire rope is determined largely by the tensile strength of the wires making up the rope, the metallic area of the rope, and the rope construction. The strength of the wire material depends on the type and grade of material used. Breaking strengths of widely used wire materials are given in Section 3.1. Wire-Rope Materials. Small-diameter wires can be made somewhat stronger per unit area while retaining adequate ductility than larger-diameter wires of the same material. The approximate metallic cross-sectional area of wire rope for various constructions is given in Table 3-3. The actual area will vary depending on the construction within each classification. The accuracy of the figures is sufficient, however, for strength calculations in the design of wire-rope systems.

Table 3-3. METALLIC AREA OF WIRE ROPE AND STRAND

Rope or Strand Classification	Approximate Metallic Area of Section, A, in^2		
	FC[a]	IWRC[b]	WSC[c]
6 x 7	$0.38\ d^2$ [d]	$0.44\ d^2$	$0.46\ d^2$
6 x 19	$0.40\ d^2$	$0.45\ d^2$	$0.47\ d^2$
6 x 37	$0.41\ d^2$	$0.47\ d^2$	$0.49\ d^2$
8 x 19	$0.35\ d^2$	--	--
Flattened-Strand (6 x 25, 6 x 30)	$0.44\ d^2$	$0.48\ d^2$	--
Galvanized Bridge Rope	--	$0.47\ d^2$	--
Galvanized Strand: 1 x 7		$0.60\ d^2$	
Galvanized Strand: 1 x 19		$0.58\ d^2$	
Track Strand: Smooth Coil		$0.58\ d^2$	
Track Strand: Locked Coil		$0.68\ d^2$	
Galvanized Bridge Strand		$0.60\ d^2$	

(a) Fiber Core.

(b) Independent Wire-Rope Core.

(c) Wire Strand Core.

(d) d = Nominal Rope Diameter, inches.

Tables of wire-rope breaking strengths are given in Federal Specification RR-W-410, "Wire Rope and Strand", for most standard wire-rope configurations. These data are not presented here for the sake of brevity, but several comments related to these data are useful. The breaking strength values reported take into account variations in tensile strength with wire size.

Normally, the acceptance breaking strength of a wire rope may be as much as 2½ percent below or as much as 15 percent above the catalog breaking strength. However, in some few cases breaking strength values have exceeded catalog values by as much as 40 percent. Also, IWRC ropes display strength levels about 7.5 percent above fiber-core ropes, but are not used so much for their higher strength as they are for their increased constructional stability and resistance to lateral deformations under high-load conditions.

The type of termination affects a wire rope's breaking strength substantially. Within a rope system where several types of end fittings are used, the system's load-bearing capability is largely dependent on the least efficient termination. When a rope is loaded statically over a sheave, its breaking strength is reduced below that developed in a straight pull. For sheave-to-rope-diameter ratios greater than 24, most commonly used rope constructions lose only about 5 percent of their strength. However, rope strengths fall considerably below tensile breaking strength values for smaller D/d ratios.

The term "safety factor" has traditionally been used to describe the ratio of the initially installed rope breaking strength to the working load on the rope. Since a rope's breaking strength gradually decreases with usage, the calculated "factor of safety" really applies only to the new rope, and the actual "factor of safety" decreases somewhat as the rope is used. With these considerations in mind, the choice of a safety factor for a particular application depends on:

1. The type of rope terminations used.
2. Potential acceleration (and deceleration) forces on the rope.
3. The rope length.
4. The size and configuration of sheaves and drums within the system.
5. Potentially abrasive and/or corrosive conditions.
6. Frequency and method of rope inspection.
7. The criticality of the application or the possibility of loss of life and/or property due to rope failure.

For specific recommendations on wire-rope design factors, consult Section 9. APPLICATIONS INFORMATION.

3.5. ELASTIC PROPERTIES

There are two factors which contribute to the lengthening of a wire rope as it is placed under load. One element is the elongation of the individual wires. The magnitude of this elongation is governed by the wire material properties. The other elongation factor results from the movement of the rope wires relative to one another.

Most wire ropes are constructed from cold-drawn high-carbon steel wire which has an elastic modulus of approximately 29 x 10^6 psi. Special application wire ropes are made from other materials which include stainless steel - 28 x 10^6 psi modulus; monel (a nickel-copper alloy) - 26 x 10^6 psi modulus; and phosphor bronze - 16 x 10^6 psi modulus. The higher the modulus, the lower the elongation of the wire material for a given load.

The rope construction determines the amount of elongation due to relative wire movement. In general, a rope with a large number of small wires will stretch more under a given load than one with fewer and larger wires. Fiber-core ropes stretch more than ropes with wire-rope or wire-strand cores.

Some permanent elongation takes place during initial loading of a new rope. This permanent lengthening is called constructional stretch, and occurs because of a slight rearrangement of the rope wires, and some localized yielding of the wire material at locations of high cross-wire or adjacent-wire contact stresses. Table 3-4 shows the amount of constructional stretch to be anticipated for several types of round-strand wire rope.

Table 3-4. CONSTRUCTIONAL STRETCH FOR SEVERAL TYPES OF WIRE ROPE

Rope Type	Approximate Constructional Stretch, %		
	Light Loads Design Factor > 8	Moderate Loads Design Factor = 6	Heavy Loads Design Factor < 5
6 Strand, Wire-Strand or Wire-Rope Core	0.10 - 0.25	0.25 - 0.50	0.50 - 1.00
6-Strand, Fiber Core	0.25 - 0.50	0.50 - 0.75	0.75 - 1.50
8-Strand, Fiber Core	0.40 - 0.75	0.75 - 1.00	1.00 - 2.00

Figure 3-2 illustrates a typical wire-rope load-elongation curve for the first and tenth loading and unloading cycles. Constructional stretch is shown as the nonrecoverable permanent deformation. After a small number of cycles the load-elongation behavior stabilizes and can be approximated by curve B in Figure 3-2. It is important to note that the magnitude of constructional stretch is somewhat dependent on the maximum load level experienced. If, for example, the rope in Figure 3-2 had been loaded to 30 percent of its breaking strength, the resultant constructional stretch would have been only about two-thirds of that shown. However, subsequent loading to 55-65 percent of its breaking strength would have resulted in the additional constructional stretch.

Some uses of wire rope, such as guy wires and bridge cables, require that the load-elongation behavior be uniform and repeatable. For these applications, ropes are preloaded to a level higher than the expected working load so that most of the constructional stretch is removed before installation.

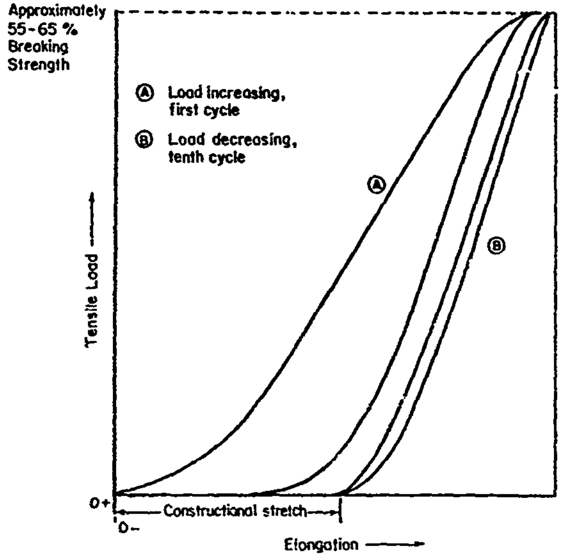


Figure 3-2. Typical Load-Elongation Behavior of Wire Rope

In computing an elastic elongation for a wire rope, the following formula may be employed:

$$\Delta L = \frac{(\Delta P)\ (L)}{(A)\ (E)} ,$$

where ΔL = change in rope length, inches

ΔP = change in rope load, pounds

L = rope length, inches

A = metallic cross-sectional area, $inches^2$

E = elastic rope modulus, pounds/$inches^2$.

Tables 3-3 and 3-5 list the approximate values of metallic area and elastic rope modulus that may be used with the above equation to compute elastic elongation. The elongation values determined from these data are representative of ropes in good condition made from uncoated carbon-steel wires that are loaded in tension, with the ends restrained from rotating. Elongation calculations for wire rope made from other than carbon-steel wire should include modified elastic rope modulus values that reflect the alternate material's wire modulus. For example, a 6 x 7 fiber-core wire rope made from phosphor-bronze wire will have an elastic rope modulus approximately ½ as great as one made of carbon-steel wire because of the proportionately lower wire modulus.

Table 3-5. ELASTIC MODULUS OF COMMONLY USED CARBON-STEEL WIRE ROPE AND STRAND

Rope or Strand Classification	Approximate Elastic Modulus, E, lb/in^2
6 x 7 Fiber Core	13.0×10^6
6 x 19[(a)] Fiber Core	12.0×10^6
6 x 37[(b)] Fiber Core	11.0×10^6
8 x 19 Fiber Core	9.0×10^6
6 x 7 IWRC or WSC[(c)]	15.0×10^6
6 x 19 IWRC or WSC	14.0×10^6
6 x 37 IWRC or WSC	13.0×10^6
Flattened-Strand Rope (6 x 25, 6 x 30)	13.0×10^6
Tiller Rope	6.0×10^6
Galvanized Bridge Rope (Prestressed)	20.0×10^6
1 x 7 Strand	21.0×10^6
1 x 19 Strand	14.0×10^6
1 x 37 Strand	17.0×10^6
Tramway/Track Strand, Locked or Smooth Coil (Prestressed)	24.0×10^6
Galvanized Bridge Strand	$23\text{-}24 \times 10^6$

(a) 16-26 wires per strand.

(b) 27-49 wires per strand.

(c) IWRC: Independent Wire-Rope Core; WSC: Wire Strand Core.

If the fiber core in a wire rope dries out and begins to break down, the strands will no longer be properly supported. The strands will gradually collapse together and cause a decrease in rope diameter, and an increase in lay length. This process of core degradation causes an increase in the constructional stretch. Ultimately, the elastic modulus of the rope also increases.

3.6. FLEXIBILITY/HANDLEABILITY

Flexibility is a measure of the ease with which a wire rope may be bent, and is characterized by its handleability. A wire rope is flexible because of the helical pattern of wires within the strands and strands within the rope. The degree of flexibility depends therefore on the number, size, and arrangement of the wires in the strands and the total number of strands. Generally ropes increase in flexibility with more wires per strand and a greater number of strands per rope. Hence, the common rope constructions listed in order of increasing flexibility are as follows: 6 x 7, 6 x 19, 8 x 19, and 6 x 37. Lang-lay ropes tend to be more flexible than regular-lay ropes. The core material also contributes to or detracts from flexibility. A fiber core will offer less bending resistance than a wire-strand core or an independent wire-rope core.

Many users tend to select a more flexible rope construction in situations where reduced sheave sizes are being considered. This choice should be made with some caution, however, since the smaller wires of the more flexible constructions are more susceptible than the large-wire constructions to crushing and distortion in small sheave applications. This is particularly true in situations where the rope loads and radial pressures on the sheave are high. A compromise between flexibility and resistance to radial pressure is often necessary.

3.7. ROTATIONAL CHARACTERISTICS

Wire rope has a tendency to rotate under load due to the helical construction of the wires and strands. If one end of a rope is used to maintain a freely suspended load or is attached to a swivel, the rope will rotate until the torsional forces in the wires are balanced. For 6- and 8-strand ropes, the direction of rotation will depend upon the direction of strand lay in the rope.

Generally, a regular-lay rope will rotate less under load than a Lang-lay rope because the direction of wire lay is opposite that of the strand lay. (A Lang-lay rope should almost never be used without rotational restraints.) Also, a rope with an independent wire-rope core or a wire-strand core will have less rotation under load than a fiber-core rope.

If a load is to be suspended from two ropes, it may be advisable to use one right-lay and one left-lay rope to balance the torsional forces developed in each rope.

Low-rotation ropes are constructed in such a way that the tendency for the rope to rotate is significantly reduced; however, this rotational tendency is almost never completely eliminated. There are three types currently used: an 18-strand rope design generally made with seven wires per strand (commerically known as nonrotating); an eight-strand construction with 19 wires per strand (commercially known as spin resistant); and a three-strand centerless rope construction (commercially known as torque balanced). The 18-strand type has inner and outer strands of opposite lay, so that rotation under load of the rope lengthens the outer lay and shortens the inner lay. This counterbalancing effect usually results in relatively low rope rotation under load. Occasionally this 18-strand construction is used with 19 wires per strand to increase rope flexibility. The 8-strand spin-resistant construction is normally made with right regular-lay strands and a left Lang-lay independent wire-rope core so that the strands and core provide counterbalancing torques. The 3-strand (3 x 7, 3 x 19, etc.) torque-balanced construction is made with the strand lay and wire lay oriented in opposite directions, so that the strands and wires develop counteracting torsional forces.

Of the three commercially available classifications of low-rotation ropes, the 3-strand torque-balanced rope is the most rotation resistant. Comparatively, the 8 x 19 spin-resistant construction is usually considered to be somewhat stronger and more crush resistant than an 18 x 7 (or 19 x 7) nonrotating construction, but it does not have equal nonspinning properties. With all three low-rotation ropes, the tendency to rotate is reduced, but is not completely eliminated. Depending on the extent of actual rotation, there is also some tendency for these ropes to kink if the supported load is suddenly decreased or removed.

3.8. ABRASION RESISTANCE

Abrasion is characterized by a loss of metal from the crowns of the outer wires, as shown in Figure 3-3, as the rope is run over sheaves and drums. and dragged over stationary objects. Abrasion resistance varies with the wire material and grade, wire size, and rope construction.

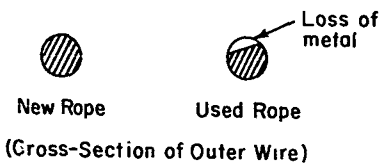


Figure 3-3. Abrasive Wear

There is some evidence that stronger and tougher wire materials display a greater resistance to abrasion. For example, extra-improved-plow steel is generally considered to be somewhat more resistant to abrasion than improved-plow steel. The first signs of rope wear occur rapidly because of the small contact surface of each outer wire (initially, line contact only) and the resulting high pressures on the wires. As wear takes place, the area of contact increases in size, reducing the pressures and the rate of wire abrasion.

Large outer wires tend to wear more slowly than smaller wires because they develop a larger wear surface which reduces the contact pressure on sheaves and drums. Therefore, the coarse-wire-rope constructions are generally more abrasion resistant than fine-wire constructions.

The wear surface that forms on the outer wires is elliptical in shape. As shown in Figure 3-4, a Lang-lay rope develops a greater length of contact per wire than regular-lay rope. Therefore, Lang-lay ropes are more abrasion resistant and their wear rate is somewhat slower than regular-lay rope. Because the wear surface is greater, the wear of sheaves and drums is also less.

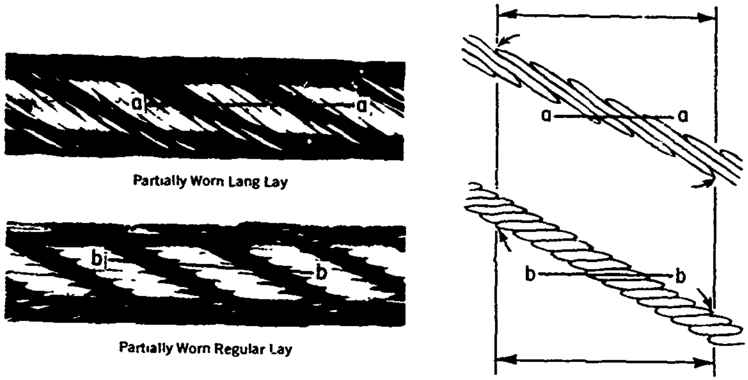


Figure 3-4. Wear Pattern on Rope Strand

It is sometimes stated that abrasion resistance is inversely proportional to bending-fatigue resistance. Generally, coarse-wire constructions are more resistant to abrasion and less resistant to bending fatigue than fine-wire constructions, but details of the rope constructions must also be considered before estimates of abrasion and fatigue resistance are established.

Abrasion can cause frictional heating between the outer wires and the surface they are passing over. If this localized heating occurs rapidly in a carbon-steel rope, the outer wires may undergo a phase transformation to untempered martensite, a brittle phase of steel. Although this transformation occurs only on the wire surface, the most severe bending stresses also occur at that point. The combination of high bending stresses and brittle martensite allows cracks to form quickly, causing early wire breakage and premature rope failure.

3.9. BENDING-FATIGUE RESISTANCE

As a wire rope passes over a sheave, the wires in the rope are forced to bend in one direction. Then, as the rope leaves the sheave, the wires are forced back to their original configuration. This constant flexing motion of the rope wires promotes the initiation of fatigue cracks at critical locations within the rope. Once fatigue cracks have initiated they will propagate as a result of combined bending, tension, and contact stresses, and eventually cause failure when the combined stresses within each wire exceed the fracture toughness of the material. If the rope remains in service too long, a large number of wires will eventually fail, and the unbroken wires will be overloaded to the point that the entire rope will fail, perhaps quite unexpectedly and catastrophically.

Rope constructions differ in their resistance to bending fatigue. Generally, ropes with smaller wires and more flexible constructions operate more efficiently under severe bending conditions. Table 3-6 gives the approximate bending-fatigue-life factors for various rope constructions. Since 6 x 25 filler-wire rope is commonly used for operation over sheaves, it has been chosen as the baseline construction. In contrast, a 6 x 37 construction rope withstands about 33 percent more bending-fatigue cycles on the average than 6 x 25 filler wire under identical service conditions, while a 6 x 19 Seale construction survives about 20 percent fewer cycles. These estimates are based on rope failure due to bending alone.

Table 3-6. RELATIVE BENDING-LIFE FACTORS

Rope Construction	Bending-Life Factor
6 x 7	.57
18 x 7	.67
6 x 19 Seale	.80
6 x 25 Flattened Strand	.80
6 x 30 Flattened Strand	.80
6 x 21 Filler Wire	.87
6 x 25 Filler Wire	1.00
6 x 31	1.07
6 x 29 Filler Wire	1.14
8 x 19 Seale	1.14
6 x 36 Seale-Filler Wire	1.20
6 x 37	1.33
6 x 43 Filler Wire	1.33
8 x 19 Warrington	1.33
6 x 41 Seale-Filler Wire	1.37
8 x 25 Filler Wire	1.43
6 x 46 Seale-Filler Wire	1.44
6 x 42 Tiller Rope	2.00

The bending-fatigue life of a wire rope can often be increased (if the ends are restrained from rotating) by using Lang-lay rather than regular-lay rope. Preformed ropes are also more resistant to bending fatigue than nonpreformed rope.

Sheave size and design factor must also be considered if the fatigue life of a wire rope is to be maximized. A reduction in the load level (an increase in the design factor) or an increase in the sheave-bending radius usually results in a substantial increase in the number of bending cycles to failure. Figure 3-5 illustrates the effect of load level on the number of bending cycles to rope fatigue failure. The effect of sheave diameter is discussed later in Section 4.5. Sheave-to-Rope-Diameter Ratio. Volume II of this handbook also contains a large quantity of laboratory data on bending fatigue of wire rope for various test conditions.

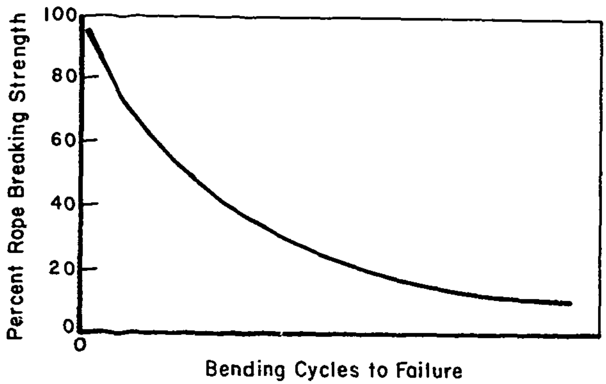


Figure 3-5. Effect of Load Level on Rope Fatigue Life

3.10. RESISTANCE TO CORROSION

Corrosion is a chemical interaction between a chemical substance (moisture, acids, alkalies, or other destructive agents) and a material substrate (which, in this handbook refers specifically to the wires of a rope). The design of wire ropes makes them particularly susceptible to corrosion because the spaces between strands and wires act as reservoirs for corrosive fluid that are slow to dry out. On stationary metal objects the corrosive medium usually forms a protective rust layer that prevents further attack; but wire ropes are normally used in such a way that the rust layer is worn off as soon as it forms. Wire ropes used in industrial or marine environments are particularly subject to rapid corrosion.

Corrosion accelerates wire-rope deterioration. It reduces rope metallic area, limits flexibility, and leads to uneven wire surfaces that may cause damage to equipment and internal damage to the rope. Corrosion within a wire rope is almost impossible to detect visually, which makes it extremely difficult to determine the true condition of a corroded rope.

Since corrosion acts upon wire surfaces, one possible approach to achieve better corrosion resistance is to minimize the amount of corrosion-susceptible surface material. This is sometimes done by using a corrosion-resistant wire material such as stainless steel or a nonferrous metal such as copper, phosphor bronze, or monel. However, the strength and fatigue resistance of these materials is generally lower than carbon steel. All grades of carbon steels are quite susceptible to corrosion.

A more widely used method for protecting against corrosion is to coat the wires with a material more anodic than steel, usually zinc. Because the zinc is more anodic, it corrodes rather than the steel wire. Protection, of course, lasts only as long as the zinc coating remains on the wires, so a heavier coating provides longer protection than a thin one.

Plastic coatings are also sometimes used on smaller diameter wire ropes and cables. They have been found effective as long as they do not split or wear through. If the plastic coating does break open, however, it provides no anodic protection and may actually serve as a reservoir for corrosive fluids.

Another approach for reducing the effect of corrosion is to reduce the surface-area-to-cross-sectional area ratio of the wires in the rope by using larger diameter wires. Coarse-wire constructions are more resistant to corrosion than fine-wire constructions, but they are, as mentioned earlier, less resistant to bending fatigue.

Good lubrication can serve as one of the most effective protections against corrosion. A coating of lubricant helps to seal the wire surfaces from the atmosphere, reducing corrosion; and unlike a zinc coating, lubricants are renewable. Lubricants also tend to be absorbed within the fiber core (if there is one), thereby reducing the absorption of corrosive fluids.

Cathodic protection, although not often used, has been shown to be quite effective in preventing corrosion of wire rope in seawater. This is a complex subject and beyond the scope of this handbook. Considerable published research has been done on this subject by several sources, however, especially by the Naval Research Laboratory.

3.11. CRUSHING RESISTANCE

Crushing is rope distortion caused by high transverse pressures. It may occur when a rope is bent over an undersize sheave, bent over a sheave under high load, forced into an undersize sheave groove, wound onto a smooth drum under high load, or at cross-over points on a grooved drum with multiple-rope layers.

Coarse-rope constructions (with a small number of large wires) and flattened-strand ropes (with high metallic packing efficiency) provide some measure of resistance to crushing, but the most effective resistance is provided by metallic cores.

3.12. TEMPERATURE EFFECTS

Minor variations in temperature have little effect on the performance of wire rope although these temperature changes may affect the lubricant. When heated, some lubricants become thin and drip off; when cooled, some oils and greases become stiff and less effective.

Most natural-fiber and synthetic-core materials remain relatively unaffected at temperatures in the range of 200 F. However, as indicated above, temperatures in the range of 200 F can cause lubricant bleeding and certainly will cause rapid oxidation of the lubricant producing an increase in viscosity and gumming. Should temperatures exceed 300 F, natural fibers and most synthetics char or soften and the use of metallic or asbestos cores may be necessary. At temperatures above 400 F, the strength of metallic core ropes also decreases. The percent reduction in strength is approximately 15% at 500 F and 30% at 600 F. Sustained usage at temperatures in excess of 400 F may also cause metallurgical changes in a carbon-steel rope with accompanying strength reductions. Some stainless steel wire materials have been found to be more resistant to metallurgical changes in this temperature range.

The effect on wire rope of low temperatures (in the range 0 F and lower) is not clear, except for its known detrimental effect on lubricants. No published data are available for wire-rope performance at low temperatures under normal loads.

4. SHEAVES AND ROLLERS

Sheaves and rollers are rotating machine elements used to support wire rope and often to provide a change in its direction of travel. Sheaves and rollers of various sizes are used in a variety of orientations in a typical wire-rope system. Sheaves are normally grooved but many rollers are plain faced. The material used to manufacture these components varies, but it is usually some grade of iron or steel. Sheave grooves or roller bodies may be covered with replaceable liners of a material either harder or softer than that of the body.

4.1. GROOVE DESIGN

Figure 4-1 shows the cross section of a sheave groove, together with the important angles and dimensions. The groove contour has a significant effect on the overall cost and safety of a wire-rope system. If, for instance, the groove diameter is too large for the rope being used, it will not provide the proper support for the rope. When rope tension is applied, the high radial pressures will tend to flatten and distort the rope section. This distortion weakens the rope and increases fatigue damage, leading to early failure.

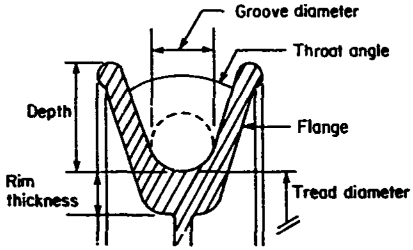


Figure 4-1. Sheave Groove

If the groove diameter is too small for the rope being used, the rope will not fit properly in the groove. This problem may be caused by installation of the wrong size rope or through extensive wear on the sheave. Use of a rope in an undersized groove concentrates rope wear along two lines of contact and leads the rope structure to become unbalanced, the core to distort, and severe notching to occur between and within the rope strands. Abrasive wear is accelerated and, at the same time, more work is required to drive the rope over the sheave. The end result is an increase in operating costs and early rope retirement or failure.

To obtain the maximum useful service life from both sheaves and rope, and to assure safe operation, it is, therefore, essential that the sheave-groove diameter be maintained at the proper size. This is especially true for new ropes, which are usually made slightly oversize to allow for "pulling down" during the break-in stage. The sheave groove must always be larger than the actual rope diameter. Table 4-1 lists recommended groove clearances for various rope sizes. These clearances are correct for most applications. Slightly less clearance may be used if the rope always runs directly onto and off the sheave, and slightly more clearance is desirable if large fleet angles are involved. (See Section 4.7. Sheave Fleet Angle.) Generally, however, the recommended groove diameter is given by the nominal rope diameter plus the appropriate groove clearance as given in Table 4-1.

Table 4-1. SHEAVE GROOVE OVERSIZE*

Nominal Rope Diameter, Inches	Allowable Oversize (New), Inch	Minimum Oversize (Worn), Inch
Up to 5/16	1/32	1/64
3/8 - 3/4	1/16	1/32
13/16 - 1-1/8	3/32	3/64
1-3/16 - 1-1/2	1/8	1/16
1-9/16 - 2-1/4	3/16	3/32
2-5/16 and Over	1/4	1/8

*Except for personnel elevator ropes. See text.

As the sheave wears, the groove diameter decreases and replacing or regrooving the sheave may become necessary when a new rope is installed. Generally, in the interest of economy, the groove clearance may be allowed to decrease to half that recommended for a new sheave before sheave maintenance or replacement is necessary. In other words, the minimum groove diameter is normally defined as the nominal rope diameter plus 1/2 the normal groove clearance. One exception is the traction-type elevator which should have grooves no more than 1/32-inch and no less than 1/64-inch larger than the nominal rope diameter.

The sheave-throat angle must be chosen to provide the maximum degree of rope support while still allowing the rope to leave the sheave without unnecessary scrubbing against the flange. Obviously, a zero degree throat angle results in the rope being supported around half its circumference, or 180 degrees. This is normally not recommended; however, since severe scrubbing and abrasion of the rope may be caused even by small fleet angles or transverse rope vibrations. This detrimental condition is particularly evident when the flange depth is large relative to the rope diameter.

A very large throat angle alleviates the scrubbing problem, but adequate strand support is then jeopardized. Also, the width between the flanges is increased which adds to the weight and cost of the sheave. For a 6-strand rope, the maximum throat angle for support is 60 degrees. In actual practice, however, the maximum throat angle considered is usually 45 degrees. To avoid severe scrubbing against the flanges, the minimum throat angle should normally be 30 degrees.

The design of a sheave requires a compromise between many parameters. As the sheave groove wears, the groove diameter decreases, the effective throat angle changes, the tread may become scored, and the sheave circumference may go "out of round". All these factors can have a harmful effect on the rope performance, and a periodic review must be made to determine whether sheave reconditioning is required. Both the flange and rim thickness should provide enough material to make remachining possible. The sheave should also be designed to minimize rotational inertia, however, since excessively heavy sheaves can slip as the rope is started or stopped, leading to abrasion of the crown wires and possibly to the formation of untempered martensite in steel wires.

Table 4-2 gives the recommended proportions of the sheave rim in terms of the nominal rope diameter.

Table 4-2. RECOMMENDED SHEAVE RIM DIMENSIONS

Depth	1-1/2 d*
Rim thickness, steel	1 d
Rim thickness, cast iron	1-1/8 d
Flange thickness	1/2 d

*d = nominal rope diameter.

4.2. MATERIALS

In order to prevent excessive wear on the sheave and subsequent damage to the rope, it is necessary to keep the radial pressures between the sheave groove and the rope at a reasonable level. The magnitude of pressure is dependent upon the rope tension, the rope diameter, and the tread diameter of the sheave; and it may be calculated using the following equation:

$$P = \frac{2T}{Dd}$$

where P = radial pressure, pounds/inch^2

T = rope tension, pounds

D = sheave tread diameter, inches

d = rope diameter, inches.

The maximum recommended radial pressure is a function of the sheave material and the rope construction. Table 4-3 gives values for use in the design of wire-rope systems. These values are approximate, representing desirable limits to avoid excessive groove wear.

Table 4-3. MAXIMUM ALLOWABLE RADIAL PRESSURE

Rope Construction	Rope Lay	Sheave Groove Material					
		Cast Iron	Rubber	Cast Steel	Chilled Cast Iron	Manganese Steel	Chromium Alloy
6 x 7	Regular	295*	340	550	655	1500	--
6 x 7	Lang	340	375	615	720	1680	--
6 x 19, Seale	Regular	380	450	720	880	2000	--
6 x 19, Seale	Lang	425	500	800	970	2200	--
6 x 19, Filler-Wire Warrington	Regular	500	560	900	1100	2500	4000
6 x 19, Filler-Wire Warrington	Lang	565	615	1020	1210	2820	--
6 x 37	Regular	595	670	1075	1320	3000	--
6 x 37	Lang	680	740	1220	1450	3400	--
8 x 19	Regular	600	--	1075	1540	3000	--
8 x 19	Lang	700	--	1250	1700	3500	--
6 x 25 / 6 x 30 Flattened Strand	--	800	--	1450	--	4000	--

*Maximum radial pressure in pounds/inch^2.

4.3. GROOVE LINERS

Some sheaves are designed with a groove tread made up of replaceable liner segments. Use of replaceable liners can lead to reduced sheave costs in two ways. First, only the liner segments must be made of a high-grade steel or other high-cost material, while the remainder of the sheave may be made of some less costly material. And second, when the groove has worn to the operating limits, only the liner segments need be replaced, rather than the entire sheave.

The sheave liner support angle should be as small as possible, to provide enough material for wear when the liners are machined. Figure 4-2 shows the groove liner and the support angle; this angle may be somewhat less than 135 degrees, but never less than 120 degrees for proper support. The flanges must be designed so that the rope cannot scrub on them when the maximum fleet angle is experienced.

If the liner segments are bolted in place, the bolts must be checked periodically to keep them tight. Otherwise, serious damage to the rope may result.

Elastomers have been used successfully on both sheaves and rollers as a lining material to minimize rope wear. When rubber is used to line an operating sheave, the rope tension should be kept low to avoid rapid deterioration of the rubber (see Table 4-3). If properly designed, rubber support rollers help reduce transverse vibration. Since the coefficient of

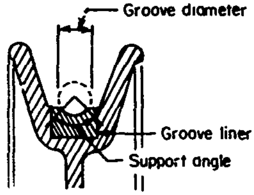


Figure 4-2. Sheave Groove Liner

friction of rubber to steel is higher than that of steel to steel, rubber-lined sheaves and rollers also tend to follow a moving rope with less slippage. Rubber-lined rollers may be either flat-faced (cylindrical) or grooved.

4.4. BEARINGS

Regardless of the type of sheave bearings selected for a particular application (sleeve, needle-collar or ball bearings, etc.), their purpose is to support the sheave when it is loaded by the rope, allow relatively free sheave rotation, and guide and align the sheave. Sheave alignment may only be maintained if the bearings are not loose and prevent sheave wobbling. Sheave vibration can significantly shorten useful rope life and out-of-balance sheaves may cause damage to the sheave bearings. There is always some frictional loss associated with a sheave bearing, and it is important to minimize this loss. Frequent and adequate lubrication of sheave bearings helps to maximize operating efficiency.

The static bearing load on a sheave may be computed if the rope tension (maximum) and the wrap angle are known. Referring to Figure 4-3, the bearing load is defined as:

$$L_B = 2T \sin \frac{\theta}{2} \quad ,$$

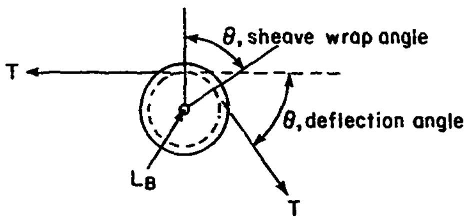


Figure 4-3. Bearing Load

where L_B = bearing load, pounds

T = rope tension, pounds

θ = sheave wrap angle (or deflection angle), degrees.

4.5. SHEAVE-TO-ROPE DIAMETER RATIO

When a wire rope is subjected to bending around a sheave, drum, or roller, two effects must be considered. They are (1) the loss of rope strength due to bending, and (2) the fatigue effect of bending.

Repeated bending of a wire rope causes continued flexing of each wire, and small cracks develop at stress concentration points along the wire. As the rope passes onto and off the sheaves, these cracks propagate until the remaining metallic cross-sectional area is unable to carry the bending and tension load and the wire breaks. If bending cycles continue, more and more wires will break until the remaining rope strength is unable to sustain the operating load, and the rope itself breaks.

Laboratory rope bending fatigue life has been shown to vary with load level (design factor), wrap angle, the ratio of sheave tread diameter to nominal rope diameter, and rope construction. Generally, the lower the operating load level, the greater the rope fatigue life; however, the relationship is not linear. In the normal operating range the trend is to a greater increase in fatigue life than the reduction in load. In other words, halving the load will more than double the fatigue life, if all other variables are held constant.

Tests and experience have shown that there is a relationship between the sheave-to-rope diameter ratio and the number of rope bending cycles to fatigue failure. The approximate relationship is shown in Figure 4-4 for a 6 x 25 filler-wire rope. Note that rope bending fatigue life decreases faster than the decrease in sheave-to-rope diameter ratio. The curve in Figure 4-4 may be used to estimate the effect on bending-fatigue life of changing sheave size. For example, if a 1-inch rope is being used on a 20-inch sheave, ($D/d = 20$), and the sheave is replaced with a 24-inch sheave ($D/d = 24$), the approximate increase in bending-fatigue life can be calculated by comparing the relative values. For a D/d of 20, the relative life is 9, while for a D/d of 24, it is 14. Therefore, an approximate increase of 56 percent in the bending-fatigue life of the 1-inch rope can be expected by changing from a 20-inch to a 24-inch sheave. It must be emphasized that this information is useful only in predicting the effect of sheave-to-rope diameter ratio on rope bending fatigue life; and that estimating the actual service life also requires consideration of other operating conditions such as abrasion, corrosion, vibration, crushing, and rope speed.

As a result of a combination of laboratory testing and field experience, certain sheave sizes may be recommended for each rope size and construction. When the operating conditions cause rope deterioration primarily because of bending stresses, the sheave-to-rope diameter ratios in the first column of Table 4-4 are recommended. The ratios in the second column are preferred when other factors, such as corrosion or abrasion, are present. If space requirements are restrictive and a shorter rope life is acceptable, a ratio

Table 4-4. RECOMMENDED SHEAVE-TO-ROPE DIAMETER RATIOS

Rope Construction	Primarily Bending	Preferred	Minimum	Absolute Minimum
6 x 7	72	63	42	28
6 x 8	72			
18 x 7	54	54	36	
6 x 17 Filler Wire			34	
6 x 19 Seale	51	45	34	
6 x 25 Flattened Strand	51	45	30	
6 x 30 Flattened Strand	51	45		
6 x 19	45		30	20
6 x 19 Warrington			30	
6 x 21 Filler Wire	45	39	30	
5 x 19			20	20
6 x 25 Filler Wire	41	36	26	
8 x 19 Seale	36	31	24	
6 x 29 Filler Wire	33		23	
6 x 31	38	33	22	16
6 x 33				16
6 x 36 Seale-Filler Wire	31		21	
8 x 19 Warrington	31	27	18	
8 x 25 Filler Wire	29		19	
6 x 12				14
6 x 24				14
6 x 37	29	27	18	14
6 x 41 Seale-Filler Wire	28		19	
6 x 43 Filler Wire	27		18	
6 x 46 Seale-Filler Wire	25		17	
6 x 42 Tiller Rope	20	18	14	

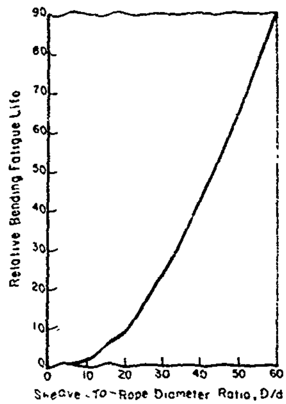


Figure 4-4. Relative Bending-Fatigue Life Versus D/d

between the values in the second and third columns may be chosen. Under no circumstances should a sheave be selected that will result in a ratio below those found in the last column.

It should be remembered that decreases in sheave or drum diameters increase not only the rope bending stresses, but also the contact stresses between the sheave and the outer rope wires. These pressures lead to accelerated wear and increased abrasion of the rope in the sheave groove. Also, reverse bends and high loads greatly reduce fatigue life.

As long as more than one rope lay contacts the sheave or drum, there is essentially no effect on bending fatigue life of varying the wrap angle. In other words, as long as at least one rope lay contacts the sheave, full bending is produced, and an increase in wrap angle will not result in a decrease in bending-fatigue life. When less than one rope lay contacts the sheave, the effect is not fully understood, and is discussed in the section on small wrap angles which follows. Figure 4-5 offers a convenient means of determining the condition of use for operating ropes.

4.6. SMALL WRAP ANGLES

A small wrap angle is defined as the condition in which less than one rope lay length is in contact with a sheave or roller. Sheaves and rollers operating at small wrap angles are known as fairlead, knuckle, or curve (when two or more are used in succession) or supporting (when the wrap angle is nearly 0 degrees).

In designing supporting rollers, it is important to make them large enough in diameter to allow smooth rope operation. If the rollers are too small, the rope will vibrate as each strand passes over it. To avoid this problem,

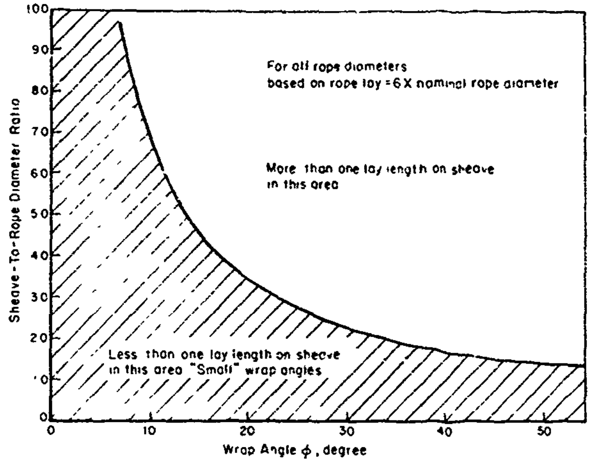


Figure 4-5. Wrap Angle Versus D/d for One Rope Lay Length

flat rollers, or rollers with grooves much wider than the rope should have a diameter at least nine times that of the rope, while rollers with grooves the same size and contour as the rope should have a diameter at least six times the nominal rope diameter. If a series of sheaves or rollers are used to support a running rope, installation at irregular intervals tends to dampen rope vibration.

The effect of small wrap angles on bending fatigue life is not clearly understood. In Figure 4-6 the number of bending cycles to failure is plotted as a function of specific wrap angle. Some evidence indicates (Curve B) that tests conducted at specific wrap angles less than 1 result in shorter fatigue lives than bending fatigue tests performed with 180-degree bends. Other results (Curve A) show a monotonic decrease in fatigue life for tests involving wrap angles up to 1 specific wrap angle. Regardless of which trend is actually correct, it is obvious that specific wrap angles greater than approximately 0.25 are about as damaging as 180-degree bends.

For changing the direction of operating ropes, it is better to use one sheave with full bending than several small wrap angle sheaves. However, when design constraints dictate the use of several sheaves, spacing between sheaves should be equal, as should their sheave tread diameters.

4.7. SHEAVE FLEET ANGLES

The fleet angle of a wire rope on a sheave is defined as the angle made by the plane of the sheave and the rope centerline as shown in Figure 4-7. Ideally, this fleet angle should be zero for a sheave in a wire-rope system. A large fleet angle causes excessive sheave flange wear and can greatly

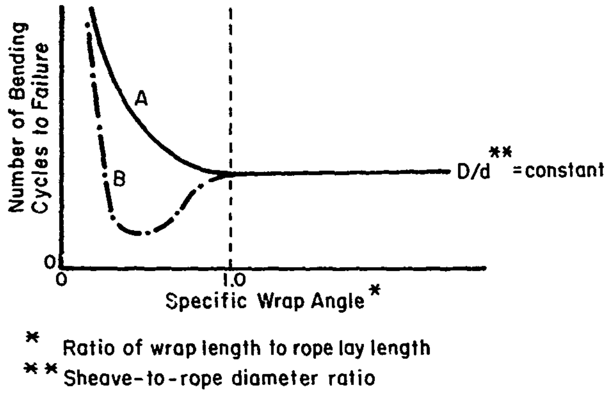


Figure 4-6. Effect of Wrap Angle on Bending-Fatigue Life

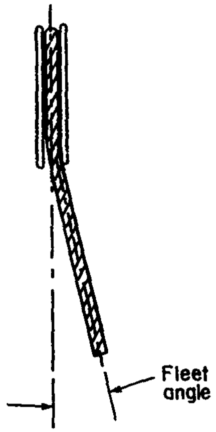


Figure 4-7. Sheave Fleet Angle

accelerate fatigue failure of the rope. In systems with substantial fleet angles, the bending radius of the rope over the flange is usually less than the tread radius of the sheave, and the rope bending stresses are thus increased. When a pair of sheaves or a sheave and a drum cannot be placed directly in line with each other, a maximum fleet angle of 1.5 degrees should be used. This angle is equivalent to 1 foot of misalignment in a run of 38 feet between the sheave/rope positions.

4.8. MULTIPLE-PART REEVING (BLOCKS AND TACKLE)

To maximize the service life of a wire rope, it should be reeved (or threaded) through a block and tackle system with a minimum number of sheaves and the fewest possible reverse bends. Reverse bends, as shown in Figure 4-8, occur

Figure 4-8. Reverse Bend

when the rope bends over a sheave in one direction, then under another in the opposite direction within a distance short enough so that a section of the rope traverses both sheaves. Bending fatigue due to this condition will reduce life to half of that experienced with only single-direction bends.

When a wire rope is reeved in multiple parts to support a load, as on cranes and hoists, or blocks and tackles, the amount of tension in the rope depends upon whether the rope is moving. When the system is stationary, the tension in every part of the rope is approximately equal to the total supported load divided by the number of rope parts attached to the load. However, when the rope is pulled at a constant speed, the rope tension is increased due to the sheave bearing friction and the resistance of the rope to bending (i.e., the friction effect due to the relative motion between individual wires as the rope is bent around the sheave). The net result is that the tension increases as the rope passes over each succeeding sheave, so that the lowest tension is at the fixed end of the rope and the highest tension is at the drum end. Factors affecting this increase in rope tension include the number of rope parts supporting the load, the type of sheave or block bearings, the total number of sheaves or blocks (including idlers) around which the rope operates, the sheave-to-rope diameter ratio, and to some extent the rope construction.

The common approach to predicting the difference in rope tension is conservative compared to actual measurements, even though the effects of rope construction and sheave-to-rope diameter ratio are not considered. According to this method the rope tension at the drum is as follows:

$$T = \text{LEAD LINE FACTOR} \times L \quad ,$$

where T = rope tension at the drum, pounds

L = total load on the system, pounds

and

$$\text{LEAD LINE FACTOR} = \frac{1}{N \times \text{EFFICIENCY}}$$

where N = number of rope parts supporting the load

and

$$\text{EFFICIENCY} = \frac{K^N - 1}{K^S N\ (K-1)}$$

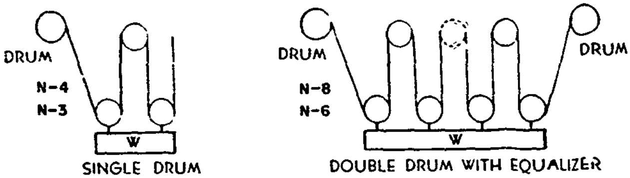
where K = constant depending upon type of bearing

S = total number of sheaves, including idlers.

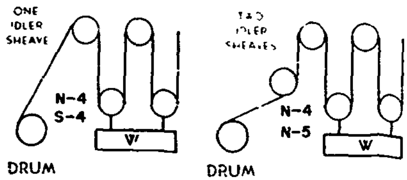
For plain sheave bearings, K is usually about 1.09, while for antifriction roller bearings, K may be as low as 1.04. Table 4-5 lists calculated values of Lead Line Factor for several reeving systems. These values also apply when the rope is dead-ended at the lower block. Note particularly that in the case of a double-drum arrangement, the equalizer sheave is not counted, since the rope normally does not travel over it. Also the values of N and S are halved in computing the efficiency of a double-drum system. Other cases may be calculated using the equations above.

It is important to note the effect of idler sheaves in Systems C and D; for example, when N = 4 and roller bearings are used, the addition of a single idler sheave increases the final rope tension by almost 4 percent while two idler sheaves will increase the tension by 8 percent. If plain bearings are used, the rope tension increases are 9 percent and almost 19 percent, respectively.

Table 4-5. LEAD LINE FACTORS FOR COMPUTING ROPE TENSION IN MULTIPLE-PART REEVING



System A System B



System C System D

N	Lead Line Factors							
	System A		System B		System C		System D	
	Plain Bearing	Roller Bearing	Plain Bearing	Roller Bearing	Plain Bearing	Roller Bearing	Plain Bearing	Roller Bearing
2	.522	.510	.500	.500	.568	.530	.620	.551
3	.362	.346	--	--	.395	.360	.431	.375
4	.283	.265	.261	.255	.309	.275	.336	.286
5	.236	.216	--	--	.257	.225	.280	.234
6	.204	.183	.181	.173	.223	.191	.243	.198
7	.182	.160	--	--	.199	.167	.216	.173
8	.166	.143	.141	.132	.181	.148	.197	.154
9	.153	.130	--	--	.167	.135	.182	.140
10	.143	.119	.118	.108	.156	.123	.170	.128
11	.1[illegible]5	.110	--	--	.147	.114	.160	.119
12	.1[illegible]	.101	.102	.091	.140	.106	.152	.111
13	.122	.096	--	--	.133	.100	.145	.104
14	.116	.091	.091	.080	.128	.095	.140	.099
15	.114	.086		--	.124	.090	.135	.094

5. DRUMS, WINCHES, AND CAPSTANS

For systems employing moving wire rope, some means must be provided for driving the rope. There is also often a requirement for storing rope which is not working. Whenever both driving and storage are necessary in a single operation, a drum may be used. Capstans have no storage provision and are used only to drive a rope. The sections which follow cover the important factors to consider in designing both drums and capstans.

5.1. PLAIN-FACED DRUMS

Most drums are cylindrical with flanges at the ends to contain the rope. Drums are either plain-faced (smooth) or grooved. Plain-faced drums are generally not recommended for several reasons. First, the flat drum surface provides no guide for the rope as the first layer is wound on, although positioning of this first layer is very important since it provides a foundation for subsequent layers. The small contact area between the rope and drum also results in very high rope-to-drum pressures, which cause excessive rope wear and distortion and considerably reduced operating life. These high contact pressures may also produce scoring or corrugations in the drum surface which will harm any other ropes placed on the drum.

Although plain-faced drums have many disadvantages, there are certain situations where the economy of a smooth drum outweighs the reduction in rope operating life. It is definitely advantageous in these applications to use a starter strip to provide the proper helix angle for the wraps of the first layer (see Figure 5-1). It is also important to make sure that the drum surface is absolutely flat so that the rope does not pile up or become entangled.

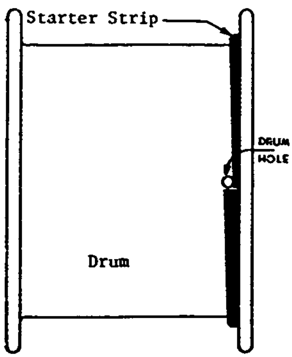


Figure 5-1. Starter Strip

5.2. GROOVED DRUMS

Grooved drums are generally superior to plain-faced drums because they offer better control and uniformity of rope winding. The drum grooves also aid in winding multiple rope layers if all layer transitions are accomplished properly.

The contour of drum grooves should be the same as that of sheaves, and Table 4-1 on page 4-2 may be referenced for recommended groove clearances. The radial pressure between the first layer of rope and the drum may be calculated according to the equation given on page 4-3. An appropriate drum surface material may then be selected from Table 4-3 (page 4-4).

Grooving provides circumferential support for the rope that helps to reduce drum-to-rope pressures. Minimum radial pressures can be obtained with half-rope-diameter deep grooves (180 degrees of support), but they are normally not used because of the severe rope abrasion that also results. Groove support angles of 150 degrees or less are normally used, as shown in Figure 5-2. Deep grooves can be used to advantage in exceptional situations, however, such as when a swinging load or other condition causes the rope to lead onto the drum with an abnormal fleet angle (for example, an overhead crane with a suspended load).

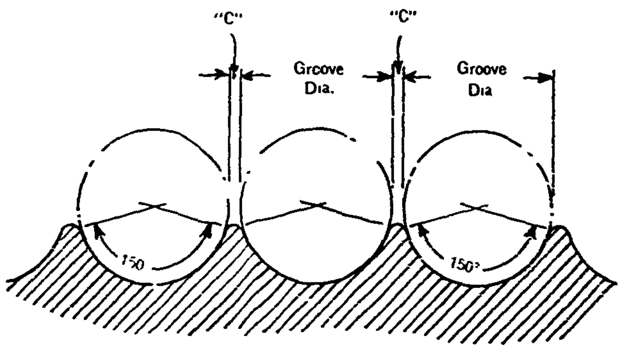


Figure 5-2. Maximum Groove Support Angle

Drum grooves must also have the proper pitch, or distance from groove-center to groove-center, to allow sufficient but not excessive clearance between adjacent rope turns. This is essential to keep the moving rope from crowding and scrubbing against rope already on the drum. In multiple-layer winding, the drum pitch should be wide enough to prevent contact between the load rope and the adjacent wrap on the drum at the maximum fleet angle. Table 5-1 gives the recommended minimum clearances and groove pitch for

Table 5-1. MINIMUM ALLOWABLE DRUM GROOVE PITCH

Nominal Rope Diameter, Inches	Groove Pitch, Inches	Clearance* Inches
1/4	9/32	1/32
5/16	11/32	1/32
3/8	13/32	1/32
7/16	15/32	1/32
1/2	17/32	1/32
9/16	19/32	1/32
5/8	21/32	1/32
3/4	25/32	1/32
7/8	59/64	3/64
1	1 3/64	3/64
1 1/8	1 11/64	3/64
1 1/4	1 5/16	1/16
1 3/8	1 7/16	1/16
1 1/2	1 9/16	1/16
1 5/8	1 23/32	3/32
1 3/4	1 27/32	3/32
1 7/8	1 31/32	3/32
2	2 3/32	3/32
2 1/8	2 7/32	3/32
2 1/4	2 11/32	3/32

*Clearance = Groove Pitch - Nominal Rope Diameter.

various rope sizes. When large drums are used, it may be necessary to increase groove pitch slightly to avoid rope damage.

If heavy loads and extreme pressures are experienced, a reduction in clearance between grooves to one half that in Table 5-1 will help to prevent the upper layer wraps from cutting into the wraps underneath and will probably result in better overall service. Some scrubbing will occur with new ropes under this condition, but this is not serious since the rope usually reduces somewhat in diameter after initial usage.

Higher drum pressures result when multiple rope layers are used. This factor must be considered in the structural design of a new drum or crushing may result. A discussion of drum pressures created by multiple rope layers is given in Bibliography Entry No. 66.

Rope cross-over points on a multiple layer drum create especially high rope compression stresses and those points within the rope can become damaged. Therefore, the number of cross-overs are normally minimized on multiple-layer drums or the severity of the cross-overs are reduced by "facing out" the drum in the appropriate areas to create "soft" cross-overs.

The diameter of a drum should normally be chosen on the basis of safety and economy. As a first approximation, the drum may be considered as though it were a sheave and a drum diameter chosen based on the recommended sheave sizes given in Table 4-4. Where bending is the primary factor affecting rope life, however, the drum diameter may be somewhat smaller than the sheaves in the system, since the rope goes on and off the drum only once during each payout and retrieval cycle and the rope goes on and off every sheave twice in the same time period. This reduced number of bends is especially significant on those machines where the rope travel is short and the rope section operating on and off the drum never reaches any of the sheaves.

5.3. HELICAL GROOVING

Helical grooving, shown in Figure 5-3, forms a rope path progressing at a uniform rate across the face of the drum like the threads of a screw. The distance advanced across the face during one revolution of the drum is called the pitch of grooving. Helical grooving can be either right or left hand, similar to right or left hand threads.

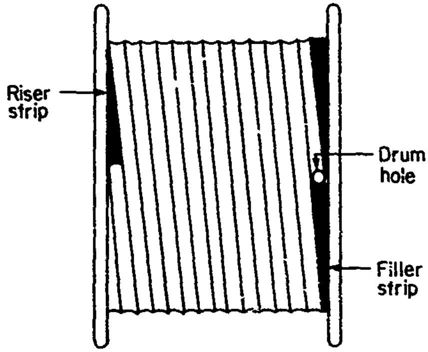


Figure 5-3. Helically Grooved Drum

For a single layer wire rope winding, helical grooving is recommended, since the rope's advancement across the drum is smooth and uniform and there are no cross-overs to start a rope whipping action.

Helical grooving can be made deep enough to afford excellent circumferential support for the rope. With helical grooving, the path of the rope is definitely controlled and is always the same regardless of the actual rope diameter. At the end of the first layer, the rope always arrives at the flange at the same point. If the winding is to continue onto a second layer, a riser strip can be installed permanently on the drum in the best position for the change of layers.

For each wrap on the second layer of a helically grooved drum, the rope must make two crossovers. A crossover is the place where the rope, which has been following the valley formed by two wraps on the layer underneath, crosses over one of the wraps into the adjacent valley. Since the second layer must progress across the drum opposite the helical path of the first layer, each second layer wrap must first make the crossover to bring it back to the relative position from which it started, and then a second crossover to advance in the proper direction across the drum. Besides lateral displacement at each crossover, the rope must raise slightly at these points above the position it occupies around the remainder of the drum circumference.

The periodic displacement of the rope at the crossovers may produce rope whipping. This can become quite severe if the time interval between each crossover coincides with the natural frequency of rope vibration.

If the rope winds onto a third layer, each wrap must wind over two of the crossovers on the second layer. At each of these points it again raises to a higher position with respect to the remainder of the circumference. However, the third layer is essentially smooth and helical laterally--similar to the rope on the first layer, except for the raised positions. A fourth layer of rope winds on the drum in a manner similar to the second, and so forth.

After two or three layers have been wound on the drum the points of layer change on the rope become very uneven and increasingly abusive to the rope. Because of this problem helical grooving is generally recommended only for single-layer drum systems.

5.4. PARALLEL GROOVING

Parallel grooving, as shown in Figure 5-4, has the drum face cut with a series of concentric grooves parallel to the drum flanges. When winding on a drum of this type, each wrap on the first layer follows a groove around the drum until it is within a short distance of the starting point, where the rope is forced to cross over to the adjacent groove. The second groove is then followed until the rope comes around to the first crossover, where it is again forced over into the next groove. There is one crossover for each wrap on the first layer, whereas with helical winding there are none.

The drum grooves are usually cut so that the crossovers are part of the grooving. Each groove has a crossover to the next groove at the correct place and angle. The entire first layer winding is thus completely controlled regardless of rope wear. With this arrangement, a riser strip can be permanently positioned on the drum. It is also possible to make use of deeper grooving, thereby affording better support for the rope. The only disadvantage to parallel grooving is that crossovers are required in the first layer, which may induce rope vibration and whipping.

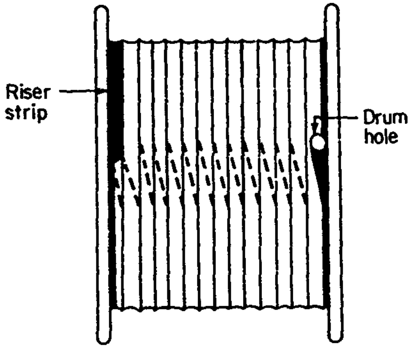


Figure 5-4. Parallel-Grooved Drum

The second layer on a parallel grooved drum is similar to the first: most of each wrap winds parallel to the drum flanges, and has one crossover per wrap. Each wrap in the second layer must pass over a crossover on the first layer and make a crossover in the opposite direction to advance the winding back toward the starting flange. The third layer is similar to the first, and the fourth like the second. Since the crossovers on succeeding layers generally occur on top of each other, the vertical displacement of the rope can become quite large in relation to the remainder of the winding. However, with parallel grooving it is possible to keep the winding relatively smooth at the change of layers in multi-layer drum applications. In this respect parallel grooving is superior to helical grooving.

5.5. COUNTERBALANCE GROOVING

Counterbalance grooving (or LeBus grooving, as it is sometimes called) is similar to parallel grooving, but provides greater uniformity of winding, particularly when the rope must be wrapped in many layers.

Counterbalance grooving is made so that each wrap of rope winds parallel to the drum flange for a distance about half the circumference around the drum, then follows a short crossover to complete half the drum circumference. The crossover displaces the rope laterally by half the pitch of the grooving.

Around the other half of the drum circumference each wrap again winds parallel to the flange for a distance, and then follows another short crossover to a point one full circumference from the start. At this point the lateral displacement totals the full groove pitch.

The grooving for this type of winding is similar to parallel grooving except that for half the drum circumference the grooves are laterally displaced from those on the other half by half the groove pitch, and between these two halves the grooves make short crossovers to guide the rope properly. The two crossover areas are usually on opposite sides of the drum, or 180 degrees apart.

Since the lateral displacement of each crossover is one-half the pitch of the grooving, or one-half the displacement of the crossovers encountered with other types of winding, there is a decreased tendency for the rope to whip. However, if the interval between these displacements coincides with the rope's natural period, whipping can still become severe. The crossover locations may be changed to some unequal angular displacement (e.g., 200 degrees/160 degrees) to minimize rope resonant response.

When crossover areas are spaced opposite each other (180 degrees apart), raised portions of the winding also occur opposite each other. These raised sections can become quite large when multiple layers are involved. If the raised sections are 180 degrees apart, however, the drum remains essentially balanced and can be operated even at relatively high speeds.

Since the change of layers can be controlled better with counterbalance winding than with other systems, this grooving method is normally preferred for multilayer spooling.

5.6. NUMBER OF LAYERS

On many installations, the character of the drum winding is the determining factor in the life of the rope. Where this is the case, rope life expectancy decreases with--(1) a decrease in drum diameter; (2) an increase in the number of layers in the winding; (3) use of a plain-faced rather than grooved drum; and (4) uneven or nonuniform winding.

When it is economical to use a drum large enough to wind the rope in a single layer, a helically grooved drum should be chosen. The principal concern with such a design is to insure that the fleet angle is small enough that the rope will not pull out of a groove and cause open winding, or scrub against adjacent wraps.

For two-layer winding, rope scrubbing is about equal for helical, parallel, or counterbalance grooving. Considering the change in layers, helical or counterbalance grooving is somewhat preferrable since a permanent riser strip can be used. Parallel winding is nearly as good, however, if cross-overs are included as part of the grooving.

For winding in three layers, better control of the rope results from use of either parallel or counterbalance grooving. For winding in more than three layers, control of the winding is most positive, particularly at the trans-itions between layers with counterbalance winding.

5.7. STARTER, RISER, AND FILLER STRIPS

The primary function of starter, riser, and filler strips is to control drum winding and to minimize rope abuse. The steel starter strip should be made of medium carbon steel, tapered horizontally (see Figure 5-1) and be of uniform height throughout its entire length. The height should be equal to the nominal diameter of the rope to be used on the drum.

5.7.1. Helically Grooved Drums

Where more than one layer of rope is wound, it is essential to provide a uniform transition from one layer to the next. This can be accomplished by the use of properly designed riser and filler strips.

The riser strip elevates the rope from the first layer to the proper height for starting the second, and supports it at this elevation until the first crossover on the second layer takes place.

After the rope is raised to the proper height, the riser strip should continue around the circumference of the drum at the same thickness, supporting the rope until it leaves the flange and starts the second layer across the drum. The horizontal tapered section of the riser strip should continue for a sufficient distance around the drum to prevent any possibility of the rope wedging against the flange (usually about 5/8 of the drum circumference).

If the rope is to be wound in more than two layers, the riser strip should be placed so that the end of the tapered rise is directly opposite the start of the first wrap. Experience has shown that this helps accomplish a smoother change from the second to third layers, and better winding on the third.

Where two full layers or more are to be wound on a drum, the use of a filler strip is recommended. It prevents the last wrap of the second layer from dropping into and becoming wedged in the gap between the drum flange and the first wrap on the first layer. The filler strip has a uniform thickness equal to the height of the rope on the first layer and a horizontal taper which conforms to the drum grooving. A filler strip should cover approximately 3/4 of the drum circumference and be placed with the widest end adjacent to the rope where it enters the drum grooving from the attachment.

5.7.2. Parallel Grooved Drums

A starter strip is necessary on a parallel grooved drum if no crossovers have been cut to help the first wrap cross over to the second groove. This strip should be of uniform thickness, equal in height to the nominal rope diameter, and tapered horizontally from zero to the groove pitch in a distance of about 20 times the rope diameter. It should be curved to fit the drum and acts as a filler strip, as well as a starter to support a second layer winding. If the drum face has crossovers cut in the grooving, the starter strip is needed only as a filler to properly support the last wrap on the second layer.

A riser strip is necessary for multilayer winding on parallel grooved drums. Shown in Figure 5-4, it has two tapers and is made with a curvature to fit the drum. The tapered rise elevates the rope from the base to the level of the second layer in a distance about 20 times the diameter of the rope. The remainder of the strip is tapered horizontally to zero also in a distance equal to 20 rope diameters. This design fills the gap between the last crossover and the flange, thereby giving the rope proper support after it has been raised to start the second layer.

If crossovers are cut in the grooving, the crossover area is controlled and the riser strip may be fixed permanently in the proper location. If no crossovers are cut, the crossover area opposite the starting flange changes with rope wear, so the riser must be designed to be moved around the circumference at the flange.

5.7.3. Counterbalanced Drums

Counterbalance spooling uses strips of complex design which will not be described here. However, their basic function is the same--to guide the rope and fill in gaps adjacent to the flanges, thereby avoiding any unnecessary scrubbing an abrasion to the rope.

5.8. DRUM CAPACITY

To estimate the length of rope that may be wound on a drum or shipping reel, or that is already stored there, the following formula may be used:

$$L = K \times A \times B \times (A + D)$$

where L = rope length, feet*

K = constant depending on the rope diameter, shown in Table 5-2

A = depth of rope on drum, inches

B = width between drum flanges, inches

D = diameter of drum barrel, inches.

Figure 5-5 illustrates these drum dimensions. The clearance between the outer layer of rope and the edge of the drum flanges should be large enough to protect the rope from damage if the reel is rolled over small sharp obstructions; two inches is usually recommended unless rope fittings require greater clearance. The values of K in Table 5-2 are for normal oversize of ropes when delivered new; an increase in drum capacity of up to 10 percent or more may be realized as the rope wears and pulls down in diameter. The rope tension has an effect on the drum capacity as high tensions can cause the rope to flatten somewhat. The tabulated values also assume that the rope is wound on uniformly; nonuniform winding may reduce drum capacity by 10 percent or more. A final assumption is that each layer contains the same

*This length should include rope for the "dead wraps" on the drum. The Navy normally recommends a minimum of 2-1/2 wraps to remain on the drum at maximum pay-out.

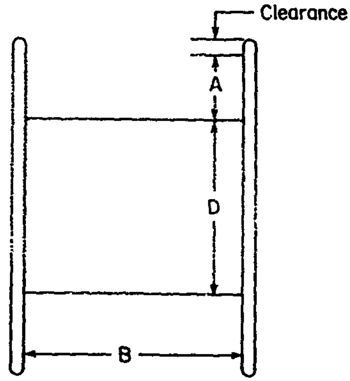


Figure 5-5. Drum Dimensions

Table 5-2. CONSTANT, K, FOR COMPUTING ROPE LENGTH ON DRUM

Nominal Rope Diameter, inches	K	Nominal Rope Diameter, inches	K	Nominal Rope Diameter, inches	K
1/16	49.8	5/8	.607	2	.0597
3/32	23.4	11/16	.506	2 1/8	.0532
1/8	13.6	3/4	.428	2 1/4	.0476
9/64	10.8	13/16	.354	2 3/8	.0419
5/32	8.72	7/8	.308	2 1/2	.0380
3/16	6.14	1	.239	2 5/8	.0344
7/32	4.59	1 1/8	.191	2 3/4	.0316
1/4	3.29	1 1/4	.152	2 7/8	.0289
5/16	2.21	1 3/8	.127	3	.0266
3/8	1.58	1 1/2	.107	3 1/8	.0244
7/16	1.19	1 5/8	.0886	3 1/4	.0224
1/2	.925	1 3/4	.0770	3 3/8	.0208
9/16	.741	1 7/8	.0675	3 1/2	.0200

number of rope wraps, which results in very little error unless the width between flanges is quite small compared to depth of rope on the drum.

5.9. DRUM FLEET ANGLES

As already mentioned in the section on Sheaves and Rollers, the fleet angle has a significant effect on the operational life of a rope because of the scrubbing which can occur against the sheave flanges. In the case of a rope winding on a drum, an incorrect fleet angle may not only increase rope scrubbing but may also lead to improper spooling. The drum fleet angle is shown in Figure 5-6. This angle is controlled by the distance, L, between the head sheave axis and the drum axis, the location of the sheave centerline relative to the drum, and the width between the drum flanges.

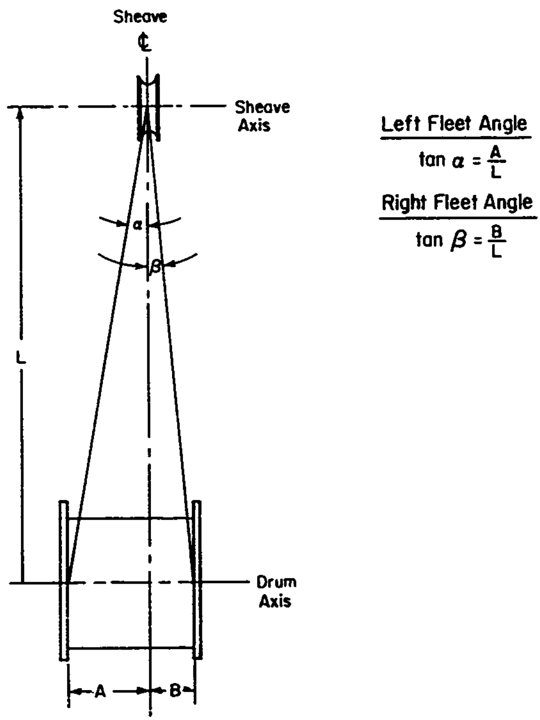


Figure 5-6. Drum Fleet Angles

The fleet angle on a drum can be either too large or too small; care should be taken to avoid these extremes. To insure consistent and uniform winding, particularly at the transition from one rope layer to the next, the maximum fleet angle should not exceed 1-1/2 degrees (except in the case of very large drum diameters, where the maximum allowable fleet angle may be somewhat less). To assure that the rope will cross back and start each layer without piling up, the minimum fleet angle should be no less than 1/2 degree.

If the rope is wound on the drum with a uniform helix, calculation of the maximum fleet angle must be modified to take the helix angle into account. The tangent of the helix angle is equal to the groove (or rope winding) pitch divided by the drum tread circumference. The actual fleet angle may be calculated, as in Figure 5-7, by adding or subtracting the helix angle from the initially calculated fleet angle. The total fleet angle should in most cases be kept within the maximum and minimum values recommended above.

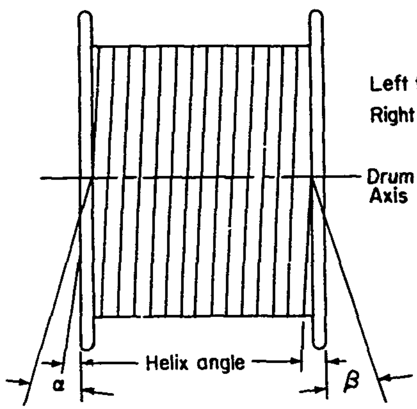


Figure 5-7. Total Drum Fleet Angle

For large drums, the total fleet angle may be sufficient to cause the rope to scrub against the adjacent wrap on the drum, even when the fleet angle is less than the recommended 1-1/2 degrees. The formula for the total fleet angle which will just cause contact is given as follows:

$$\tan \phi = \frac{X}{\sqrt{Y^2 + Y(D+d)}} ,$$

$$\text{where } X = 3h - \frac{\sqrt{h^2 + 8d^2}}{2}$$

$$Y = \sqrt{d^2 - (X-h)^2}$$

D = drum diameter, inches

d = rope diameter, inches

h = groove pitch, inches.

This equation applies only when the lead rope is pulled toward the adjacent wrap, as in the right total fleet angle of Figure 5-7. The equation has been plotted in Figure 5-8 for various ratios of groove pitch, to rope diameter, and for various drum-to-rope diameter ratios.

5.10. LEVEL-WIND SYSTEMS

One means of assuring correct and uniform winding of a rope on a drum is to incorporate a level-wind system. Such a system usually consists of a sheave mounted close to the drum between the lead sheave and the drum, and a full-width shaft across which the sheave may traverse. Level-wind systems are generally classified as either driven or passive.

A driven or mechanical level-wind system has the guide sheave mounted on a carriage assembly that rides on the cross-shaft. This shaft may also act as a lead screw, having threads cut in it that are both right- and left-hand. A pawl attached to the carriage fits in the thread groove so that as the screw is turned through a gear drive to the drum, the sheave is driven across the face of the drum. When the sheave reaches one flange, the pawl shifts to pick up the opposite threads, and the sheave is driven in the opposite direction. The carriage assembly may also be driven by other methods, but the important factor is the positive relation between drum revolution and carriage movement, such that one drum revolution moves the sheave over one groove pitch in the direction of winding. The design of such a system can be quite sophisticated, and its final adjustment is critical. If the carriage is misaligned so that it leads or lags the drum movement by too much, the rope will be forced to scrub severely or open wind and the transition between layers will not be accomplished smoothly. Moreover, if the rope is allowed to go slack, the rope may open- or cross-wind and put the entire winding procedure out of phase. However, a properly adjusted and maintained level-wind system will improve drum winding efficiency and increase rope life, especially in high-speed winch systems.

A passive level-wind system also involves a sheave riding on a cross-shaft. In this case, however, the shaft pivots on short lever arms at its ends. The shaft is always pivoted in the direction that the rope is being layed or unlayed so that the combination of rope tension and position of the rope on the drum cause the sheave to move along the shaft. This system is also quite sensitive to the adjustment of the cross shaft arms, and must be checked frequently. Careful and frequent lubrication of the moving parts is mandatory; any roughness or binding in their movement may result in nonuniform rope winding. As with the driven level-wind system, the rope must not be allowed to go slack or misspooling may occur.

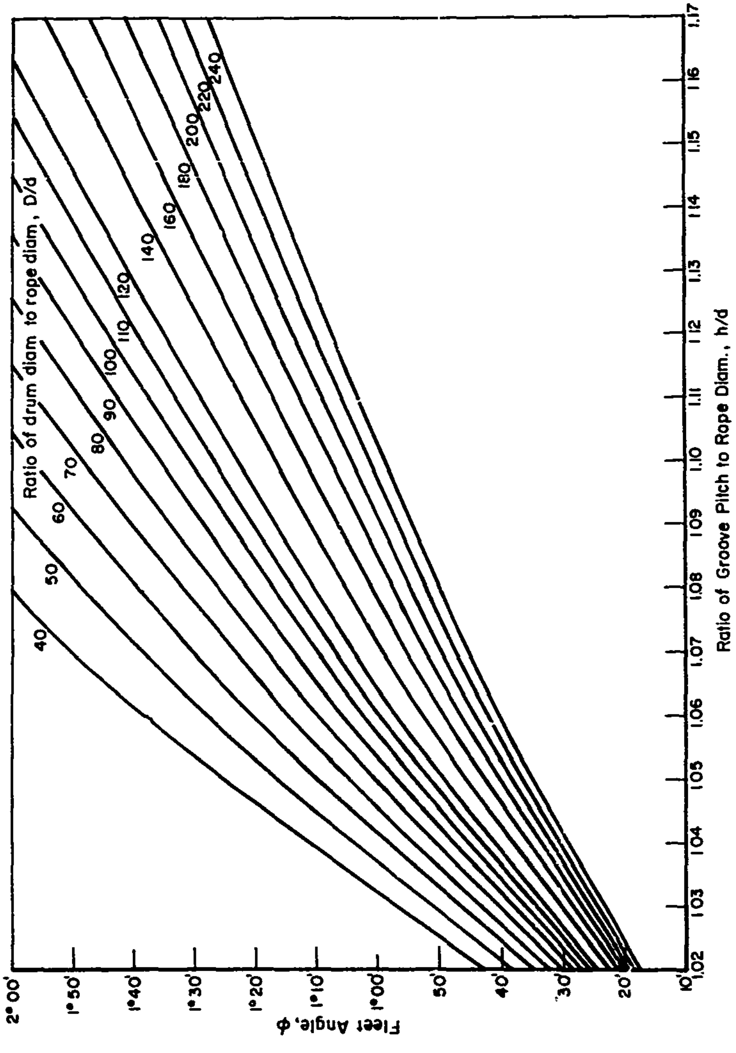


Figure 5-8. Total Fleet Angle Which Will Just Cause Contact Between Adjacent Rope Wraps

5.11. CAPSTAN DRIVES

Capstan drives develop tension in the rope due to the friction between them and the rope. The variables controlling the function of these devices then, are the coefficient of friction between the rope and the drum or sheave, the total included angle of contact, and the tensions in the two rope ends. Capstan drives are used for reasons of economy, safety, space, or, sometimes, necessity. (For example, rope tension cannot be applied to an endless conveyor by using a drum.) Safety is the chief reason for using capstans on passenger elevators; a drive sheave usually takes less space and is lighter than a drum capable of driving and storing a long length of rope.

When the rope is operated on a capstan drive with either smooth spools or U-grooved sheaves or drums, the relationship between the high- and low-tension side of the rope is:

$$\frac{T_1}{T_2} = e^{fn\pi}$$

where T_1 = rope high tension, pounds

T_2 = rope low tension, pounds

f = coefficient of friction

n = total number of 180° (half-wraps) on driving sheaves.

Table 5-3 gives the coefficients of friction for common sheave materials and rope conditions. Table 5-4 is provided to minimize the necessary calculations.

One type of friction drive is the elliptical spool, shown in Figure 5-9. The rope is wrapped completely around the spool and the spool can be operated in either direction. As the spool is turned, the high-tension rope moves toward the edge of the spool until the spool-to-rope friction is overcome and the rope starts to slide back down. This constant sliding requires that the spool surface be made quite hard to resist wear; if the elliptical shape is distorted or worn, the drive will not function properly. Several wraps may be put on the spool to increase the differential tension in the ropes.

Figure 5-10 shows several types of drum (or sheave) friction drives. The number of half-wraps, n, is indicated to emphasize that only wraps on the powered drum are counted. It should be noted, too, that the maximum rope tension does not depend on the diameter of the driving sheave or drum, only on the arc of contact.

In some cases, despite a significant shortening of rope life, V-grooved drums are selected because of their higher gripping power. The tension ratio equation then becomes

$$\frac{T_1}{T_2} = e^{fn\pi/\sin\frac{\omega}{2}}$$

where ω = included groove angle, degrees.

Table 5-3. COEFFICIENTS OF FRICTION, "f"

Rope Condition	Surface Material		
	Steel	Wood	Rubber
Dry	.120	.235	.495
Wet	.085	.170	.400
Greasy	.070	.140	.205

Table 5-4. VALUES OF TENSION RATIO (T_1/T_2) FOR VARIOUS NUMBERS OF WRAPS AND COEFFICIENTS OF FRICTION.

n Half Wraps	Values of Tension Ratio for Listed Values of "f"								
	.070	.085	.120	.140	.170	.205	.235	.400	.495
1	1.25	1.31	1.46	1.55	1.71	1.90	2.09	3.51	4.73
2	1.55	1.71	2.12	2.41	2.91	3.62	4.38	12.3	22.4
3	1.94	2.23	3.09	3.74	4.96	6.90	9.16	43.4	106.
4	2.41	2.91	4.52	5.81	8.47	13.1	19.1	152.	501.
5	3.00	3.80	6.58	9.02	14.4	25.0	40.0	535.	2390.
6	3.75	4.96	9.60	14.0	24.7	47.7	83.9	1875.	--
7	4.66	6.48	14.0	21.8	42.1	91.0	175.	--	--
8	5.81	8.47	20.4	33.8	72.0	175.	365.	--	--
9	7.24	11.0	29.6	52.5	122.	330.	765.	--	--
10	9.02	14.4	43.4	81.5	210.	625.	1600.	--	--
11	11.2	18.8	63.4	126.	360.	1200.	--	--	--
12	14.0	24.7	91.9	196.	610.	2280.	--	--	--
13	17.5	32.2	135.	305.	1040.	--	--	--	--
14	21.8	42.1	196.	475.	1790.	--	--	--	--
15	27.2	54.6	285.	740.	--	--	--	--	--

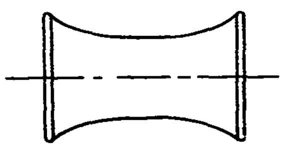


Figure 5-9. Elliptical Spool

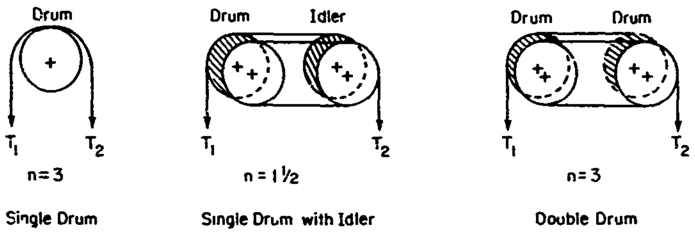


Figure 5-10. Types of Friction Drives

For the best compromise between gripping power and rope damage, this angle is usually chosen between 30 and 40 degrees.

In a very few cases, the rope speed is high enough to make the centrifugal force on the rope a significant factor. For rope speeds above about 25 feet per second, the following force should be subtracted from both T_1 and T_2 in the tension ratio equation:

$$t = \frac{wv^2}{g}\ \text{, pounds}$$

where w = weight of rope, pounds per foot

v = rope velocity, feet per second

g = 32.2 feet per second^2 (acceleration due to gravity).

Another type of friction drive is the grip wheel, so named because the sheave is made with a series of grips around the circumference of each flange which squeeze the sides of the rope to hold it. As the rope enters the groove, the grips move in to grab the rope, while at the point where the rope leaves the sheave, the grips release it. The grip wheel is not usually recommended because it requires frequent adjustment and considerable maintenance to keep it operating properly. If it grabs the rope too tightly, the rope may be severely damaged; while if the squeeze is too light, slippage will result.

6. FITTINGS AND TERMINATIONS

In general, a wire-rope fitting is any component or device that attaches to a wire rope. A wire-rope termination is any device used as an end-fitting on a wire rope. Fittings and terminations can range from the very simple to the very large and complicated. The fittings to use depend on the rope application and the installation conditions. Certain fittings--poured sockets, for example--are more susceptible to bending and vibrational fatigue than others. Other fittings, like clips and clamps, will not develop the full wire-rope breaking strength. Seizings, splicings, clips and clamps, fiege fittings, and wedge sockets may be applied in the field; but swage sockets require a swaging press. Clips may be applied in minutes; but epoxy sockets require many hours' curing time.

Fittings come in a wide variety of materials, from iron, bronze, copper, and stainless steel to drop forged, cast, and/or case-hardened carbon steels. Steel fittings are often galvanized or painted to retard rust. Epoxy sockets combine a metal basket with polymer "gripping material"; occasionally plastic sheaths are added to zinc sockets to damp out rope vibrations. Care must always be taken to use fittings of a material compatible with the rope material.

Fittings are often evaluated in terms of their efficiency: the fraction of the rope ultimate breaking strength which they are capable of sustaining. Efficiencies range from 100 percent (for properly installed zinc and swage fittings) to a low of near 0 percent for improperly installed sockets.

Susceptibility to vibration is greatest in fittings in which the total holding strength is developed close to the nose or live end of the fittings. In such an arrangement, rope vibrations cease suddenly and discontinuously at the nose and considerable shear and bending stresses are experienced so that the rope rapidly develops fatigue damage at this point. The problem can be considerably reduced if the discontinuity is removed by distributing the holding pressure throughout the length of the termination, by sheathing the live end of the rope immediately beyond the socket with some kind of flexible material of variable stiffness, or by using several fittings with low individual efficiency (e.g., clips), but relatively good overall efficiency.

6.1. TYPES OF FITTINGS AND TERMINATIONS

6.1.1. Zinc Sockets

Zinc sockets (sometimes referred to as "poured sockets", or "spelter sockets") are cone-shaped receptacles with a hole about the size of the rope diameter at the small end and a fitting--usually an eye for attaching other fittings--at the large end. The rope is placed in the socket through the small end. The individual wires of the rope are unlaid and broomed out in the cone-shaped socket basket and molten zinc is poured into the basket, gripping the wires. A typical zinc socket is shown in Figure 6-1.

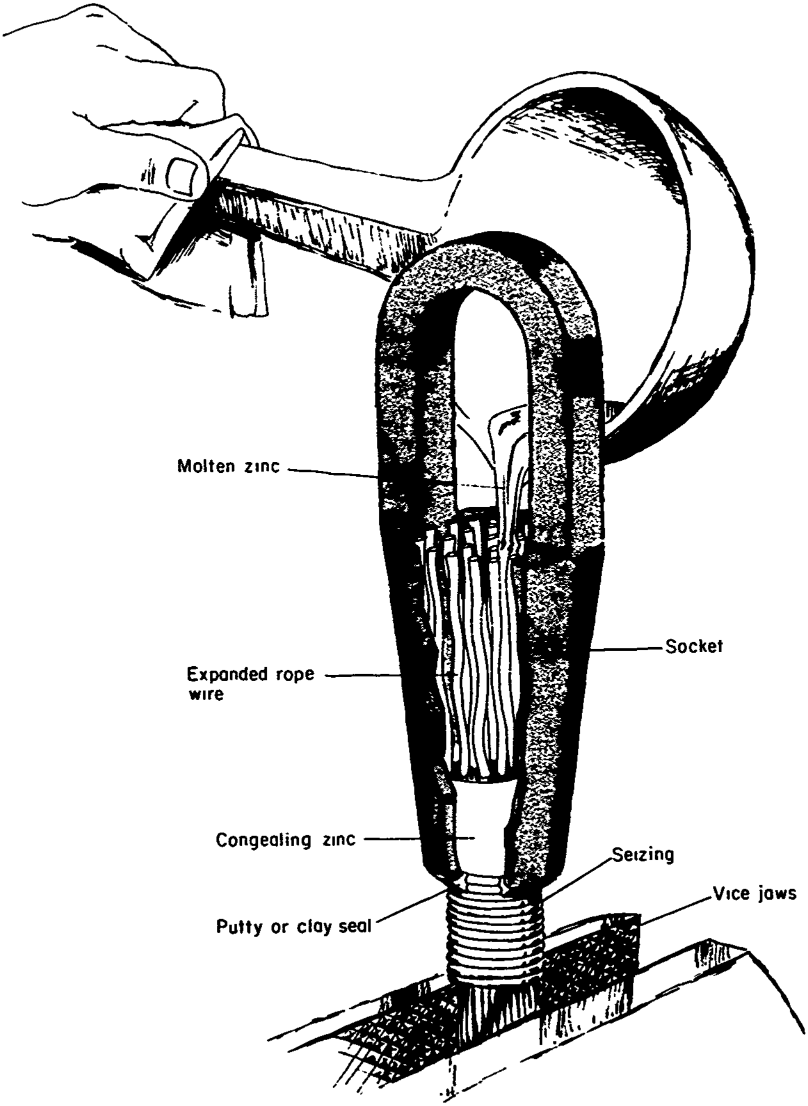


Figure 6-1. Zinc Socket

Properly applied zinc sockets develop maximum rope breaking strength. They are quite susceptible to vibration fatigue at the socket nose, however, and they are fairly difficult and time consuming to apply (see Volume III of this handbook for installation procedures). Zinc sockets are available for all rope diameters, and with either open or closed ends.

In some applications epoxy may be used instead of molten zinc for poured sockets. When this is done (which is still relatively infrequent), a zinc-socket basket is generally used. Epoxy has a higher strength-to-weight ratio than zinc and can be applied without the heat required to melt zinc. Some epoxies, however, are best cured in an air-pressure-reduced chamber or enclosure where entrapped air bubbles within the resin may escape and maximum packing of the epoxy can take place.

6.1.2. Swage Fittings

The principle behind swage fittings is the same as that for poured sockets: encasing the rope in metal provides the gripping power. However, pressure replaces bonding in the gripping process. Swage fittings are available in a variety of forms--eyes, threaded rod ends, clevises, and ferrules. These fittings are manufactured from several different ductile materials that can be swaged or deformed by squeezing the sleeve portion of the fitting onto the rope, as shown in Figure 6-2. Common materials are medium carbon steel and stainless steel.

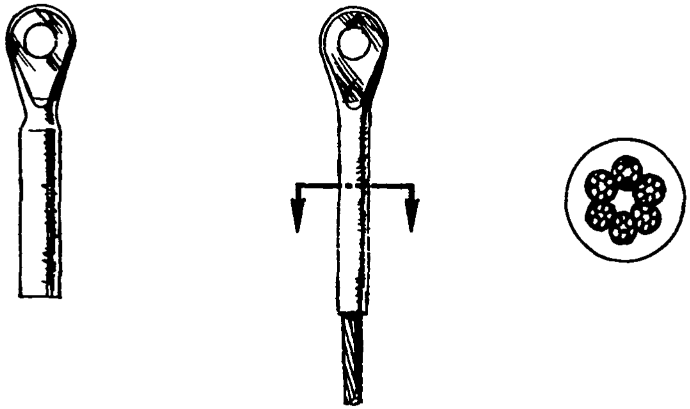


Figure 6-2. Swage Socket

Swaged fittings develop nearly 100 percent efficiency when properly installed. Ropes with swage fittings are not as vulnerable to fatigue damage as zinc sockets at the base of the socket because the rope structure is not interrupted within the socket. If a swaging press is available, swage fittings may be installed in considerably less time and with nearly the same efficiency as zinc sockets.

Swage fittings are made to fit ropes as small as ¼ inch in diameter. They are not commonly used for ropes larger than 2½ inches in diameter, however, since a very large swaging press (in excess of 2000 tons in capacity) is necessary to effectively swage larger fittings.

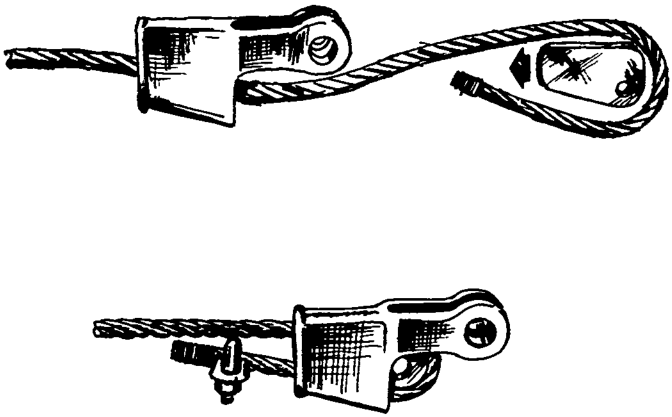
6.1.3. Wedge Sockets

One commonly used type of wedge socket consists of a hollow, trapezoidal housing and a triangular wedge (Figure 6-3(a)). To begin installation the rope is placed into the housing, around the wedge, and back out the nose of the socket. Tension on the rope forces the wedge further into the housing, firmly gripping the rope between wedge and housing. Another similar type of wedge socket is shown in Figure 6-3(b). With this type of termination, the rope is held within the socket by a wedging action of two grooved plates that are compressed about the rope as the tension in the rope is increased. The end of the rope (not shown) is often retained with a clip or clamp to prevent the possibility of rope pull-out. The wedge tips may also have a clip placed about them (as shown in Figure 6-3(b)) to increase wedge-to-rope contact pressure, but care must be taken to prevent crushing or distortion of the rope which could result from excess clip torque. Wedge sockets are simple and quick to install even in the field; and unlike swage fittings, they are reusable. If a clip is applied, it should be applied to the dead end of the rope (as shown in Figure 6-3(a)).

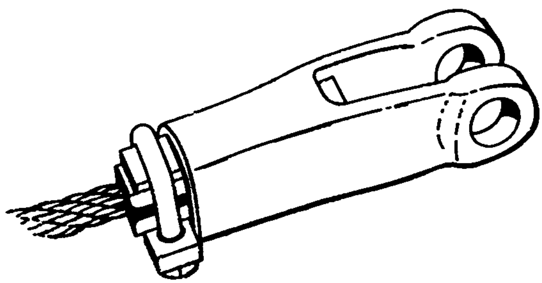
Wedge sockets are relatively resistant to fatigue compared to zinc sockets, but, because their clamping process places uneven stresses on the rope, they distort the rope construction and are normally less efficient. The efficiency of wedge sockets normally varies between 70 and 90 percent, depending on the quality of the socket design and termination procedure. If a wire rope is cut prior to placement in a wedge socket, it should not be flame-cut, because this process welds the strand end together, making it impossible for the strands to shift relative to one another to compensate for the uneven stresses created by the sharp bend of the rope in the socket.

6.1.4. Fiege Fittings

Fiege fittings also operate on a wedging principle, but their axially symmetric configuration causes minimal rope distortion and makes them more efficient than wedge sockets. The fitting consists of a two-piece housing and a plug as shown in Figure 6-4. The plug is inserted in the center of the unlaid end of the rope and the two housing pieces screwed together over it. Tension on the rope forces the plug into the housing and grips the rope more firmly. Fiege fittings come with a wide variety of terminations for different rope uses. They are easier and quicker to install than zinc and swage sockets, and like wedge sockets, are reusable. Their efficiency and fatigue resistance vary with the types used.



(a) Wedge Insert Type



(b) Compression Plate Type

Figure 6-3. Typical Wedge Sockets

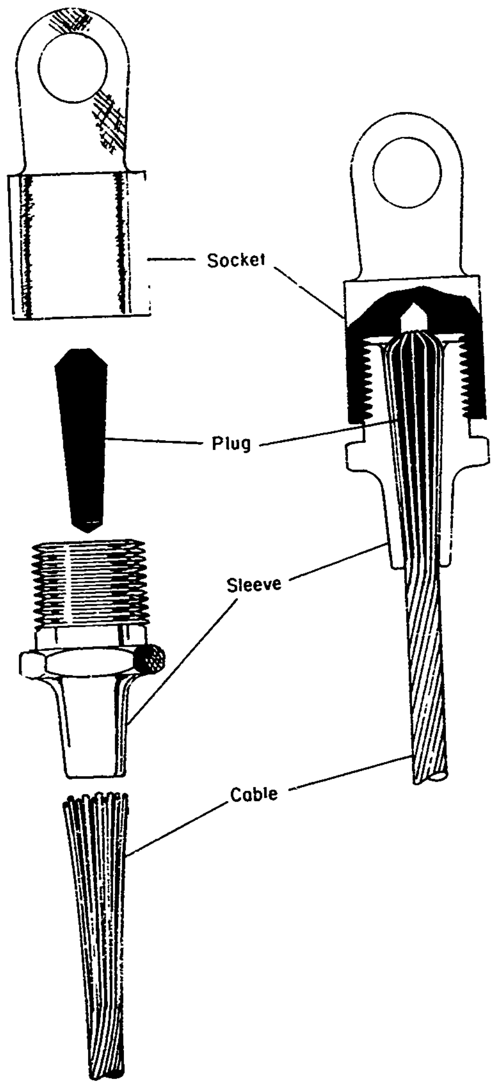


Figure 6-4. Fiege Fitting (for a Cable)

6.1.5. Carpenter Stoppers

Carpenter stoppers are used to grip a rope at a point along its length rather than at the end. Like wedge and fiege fittings, they work on a wedging principle. Schematically, a carpenter stopper consists of a two-sided wedge inside a housing. The rope fits between the two sides of the wedge so that rope tension forces the wedge tightly into the housing. A carpenter stopper may have two movable sides, or one side may be fixed and the other movable. The basic design of a carpenter stopper is shown in Figure 6-5.

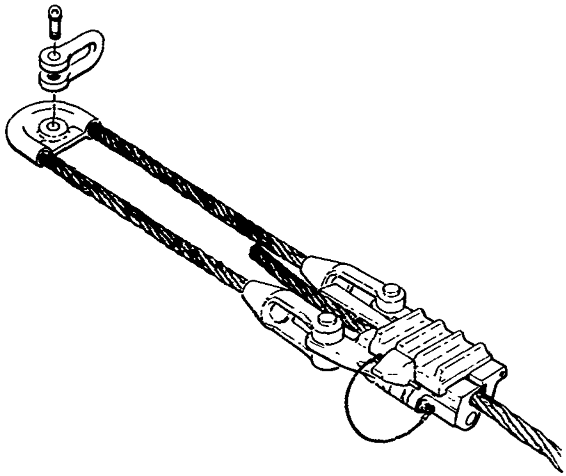


Figure 6-5. Carpenter Stopper

Recently designed Navy carpenter stoppers do not appreciably reduce the rope breaking strength. In fact, the Navy rates them at 100 percent of rope strength. This high efficiency results because they are designed to fit the rope strands so that the rope is not significantly deformed during use.

6.1.6. Cable Grips

Cable grips consist of preformed wire strands which are shaped into interlocking helices (Figure 6-6). They are normally terminated using the eye formed at the middle of the closed cable grips. For installation the half-helical sections of the cable grip are wrapped around the rope end; the inner diameter of the cable being slightly smaller than the rope diameter so that the interlocking strands form a compressive grip. Tension on the termination induces increased radial pressure in the strands and thereby increases the pressure on the rope.

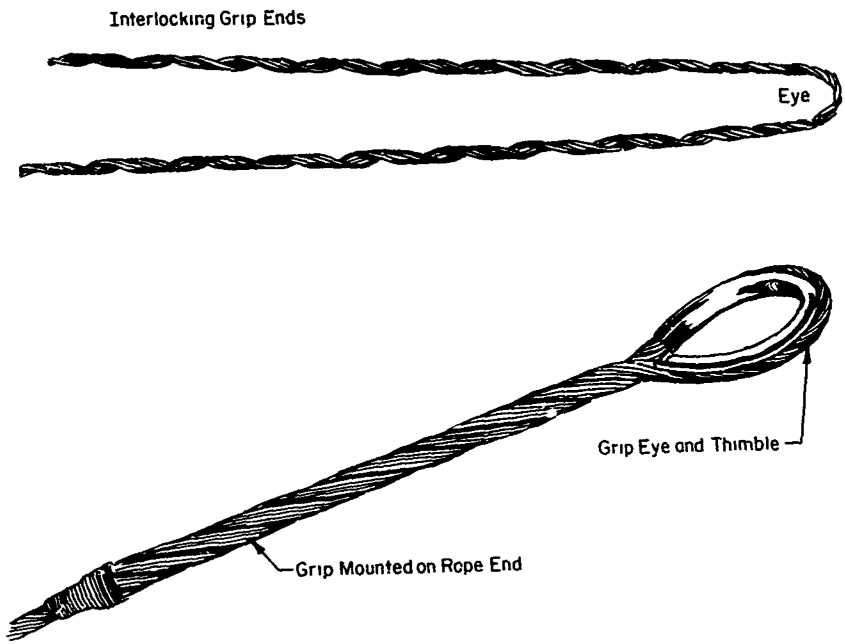


Figure 6-6. Cable Grips

Under certain conditions cable grips can be used as a full-strength rope termination; normally, however, they are used under lower-load, axial-fatigue conditions. The extremely long gripping area distributes the stresses, making this type of termination exceptionally fatigue-resistant. They are easy to apply in the field but they are not reusable. Cable grips come in sizes and materials to accommodate most wire ropes. They are normally designed to match the lay direction of the cable or rope to be terminated.

6.1.7. Thimbles and Clips

Thimbles and clips are not normally recommended for permanent use but they are probably the most commonly used type of temporary in-the-field wire-rope termination. Thimbles are stamped from metal in a teardrop shape so that they fit into the eye loop of a rope. Clips are made either from U-bolts with screw-on crossbars or from two L-shaped bolts which fit together (fist-grip clips) (Figure 6-7). Usually the crossbar is grooved to conform to the rope lay for less rope distortion and greater gripping power. A thimble-and-clip installation is made by folding a section of rope back on itself, inserting a thimble in the loop formed, and holding the termination in place with two or more clips (Figure 6-7).

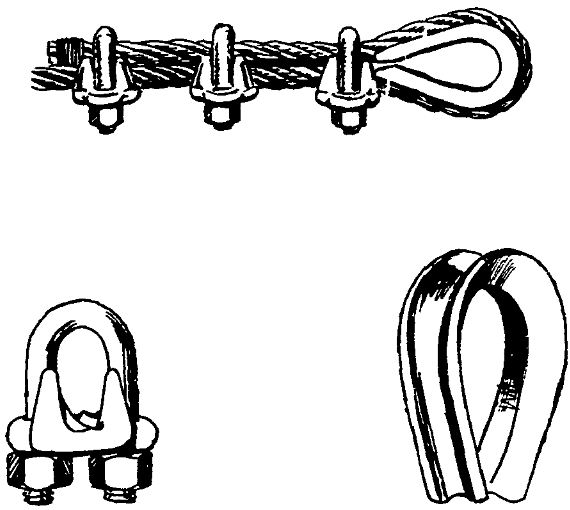


Figure 6-7. Thimbles and Clips

Thimble-and-clip terminations are more fatigue-resistant than standard zinc sockets, but they do not develop maximum rope breaking strengths. Properly applied clips are generally considered to be about 80 percent efficient. The correct number of clips for various rope sizes is given in Volume III of this handbook, Table 5-2. The specific installation instructions which are given in Volume III should be referred to before clips are installed, or the clip manufacturers contacted, so that details such as proper torque values and retorquing are handled properly. All clips distort the rope construction to some degree, so service lives are normally somewhat less than that found with cable grips or fiege fittings. Clips and thimbles are normally reusable.

6.1.8. Clamps

Clamps are essentially long clips and use the same principle to develop holding power. They consist of two half-housings held together by several bolts

(Figure 6-8). They may be used instead of clips in a thimble-and-clip termination.

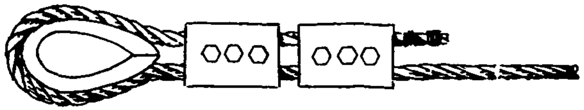


Figure 6-8. Thimble and Clamp

Clamps are used less frequently than clips. The reason is not completely clear, but it evidently is because clamps are somewhat more conducive to rope fatigue damage, and they distort the rope more severely. They are recommended only for temporary rope terminations at relatively low loads. Because of possible rope damage due to distortion, the affected rope end should also be cut off before the rope is reterminated.

6.1.9. Seizings

A seizing is the simplest wire-rope termination. It consists of a soft iron wire wrapping which only prevents a rope from unlaying (a wire rope may also be seized with tape or rope in some situations). Figure 6-9 shows a finished wire-rope seizing.

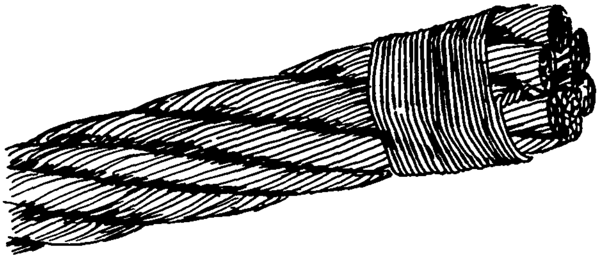


Figure 6-9. Wire-Rope Seizing

6.1.10. Splices

Splices are formed by "braiding" or "weaving" one rope end into another. Splices may be made at the end of a single rope after forming a loop (an eye splice) or between two ropes (endless splicing). There are two common methods of splicing an eye: the "flemish eye splice" and the "hand-tucked eye splice". A flemish eye splice for a six-strand rope is made by separating three strands and the core from the three other strands, then laying them back together to form a loop. Detailed instructions are given in Volume III of this handbook, Section 5.3.3. Mechanical Eye Splices. A hand-tucked eye splice is made by bending the rope into a loop and then tucking the dead end into the live portion of the rope. In both cases, the rope is seized at the base of the splice. Properly constructed splices develop between 80 and 95 percent efficiency with smaller sizes being slightly more efficient than larger sizes, and flemish eye splices being somewhat more efficient than hand-tucked splices.

A mechanical splice is any eye splice in which a sleeve is swaged to the base of the loop. The "splice" may be as simple as swaging the dead rope end to the live part. Correctly swaged mechanical splices develop nearly 100 percent rope efficiency. Thimbles are frequently used with hand and mechanical eye splices.

Endless splices may be of the "long" or "short" type; in either case they are made by marrying the two rope ends. Long splices may develop up to 85 percent efficiency; short splices are less efficient. Long splicing is the best method of joining rope ends that must be reeved over sheaves, as other joining methods usually result in an undesirable increase in the rope diameter at the connection.

6.2. EFFICIENCIES OF WIRE-ROPE ATTACHMENTS

To maintain the necessary degree of safety, the end attachment on any wire-rope installation must be suitable for the operating conditions and properly installed. Where field attachments are made, the work should be done carefully, following attachment instructions explicitly.

In many cases, the attachment efficiency is important because of its influence on the design factor. Efficiency, generally expressed as a percentage, is the ratio of strength developed by the attachment, if tested to destruction, to the actual breaking strength of the rope. The efficiency thus determined is then applied to the catalog breaking strength.

If a rope with a design factor of 5 has an end fitting which is 80 percent efficient, the actual design factor of the system is 4 instead of 5. To maintain a design factor of 5, it is necessary to use a rope at least 25 percent stronger. If 100-percent-efficient end attachments are used, a smaller (less expensive and easier-to-handle) rope can be used.

In some situations attachment efficiency is not of prime importance. For example, on many wire-rope systems, the rope wears and develops wire fatigue breaks as a result of sheave operation at some distance from the rope end. If the rope is left in operation only until losing 20 percent of its original strength, an 80-percent-efficient attachment would not normally impair the overall safety.

Actual efficiencies of various wire-rope attachments vary according to the quality of attachment design and installation practice used. Refer to the text for efficiency limitations of each type attachment. A range of values based on actual tests with end fittings properly installed are shown in Table 6-1 below:

Table 6-1. EFFICIENCIES OF VARIOUS WIRE-ROPE ATTACHMENTS WITH END FITTINGS PROPERLY INSTALLED

Attachment	Efficiency
Zinc Sockets	100%
Swaged Fittings	up to 100%
Wedge Sockets	70% to 90%
Fiege Fittings	up to 85%
Carpenter Stoppers	up to 100%
Cable Grips	up to 100%
Thimble and Clips	up to 80%
Plate Clamp (3-Bolt Type)	up to 80%
Flemish Eye Splice	up to 90%
Spliced Eye and Thimble:	
(for rope) 1/4" and smaller	90%
5/16" - 7/16"	88%
1/2"	86%
5/8"	84%
3/4"	82%
7/8" and larger	80%

Table 6-2 shows a comparison of the approximate dimensions and weights of several fitting types for a 1-inch wire rope.

Table 6-2. COMPARISON OF FITTINGS FOR 1-INCH WIRE ROPE

Type of Socket	Total Length, Inches	Greatest Width	Weight, Pounds
Poured Socket	10	4 1/8	13.3[(a)]
Swage Socket	12 1/8	3 5/8	11.9
Wedge Socket	12 3/4	5 3/4	20
Fiege Fitting	14	4	16.0
Thimble & Clips (4 Clips + Recommended Thimble)	~25	4 1/2	28
Mechanical Eye Splice	10 1/2	4 1/2	5

(a) Including 2.3 pounds zinc.

7. MISCELLANEOUS HARDWARE

Wire rope in Navy rigging systems is normally used in conjunction with various pieces of system hardware, including shackles, hooks, chafing gear, links, H-bitts and swivels. The designs for each specific item of hardware are numerous and varied in intended usage. The following sections provide common usage information and examples for the various types of commonly used rigging systems hardware.

7.1. SHACKLES

A shackle consists of a U-shaped steel bar with parallel eyes at the ends of the U and a pin which slides through the eyes, forming a closed loop. The pin is usually anchored in place with a nut and/or cotter pin; the pin itself can be either of the screw or round type. The U-bar shackle is available in numerous configurations: heart-shaped, twisted, self-enclosed (i.e., an "O"-bar with eyes), V-shaped, with added eye attachments, etc. Some shackle types are shown in Figure 7-1.

Shackles are available which can safely support working loads of up to 130 tons. The shackles themselves may weigh more than 350 pounds. They are normally available in both regular and high strength (alloy) classifications. For specific Navy recommendations regarding shackles, refer to Military Specification (MIL-RR-C-271), (Bibliography Entry No. 75).

7.2. HOOKS

Hooks come in a large variety of styles, from simple hoist hooks to pelican hooks. They can be divided into several major categories:

- Grab, hoist, and slip hooks
- Cargo hooks
- Snap hooks
- Barrel and drum hooks
- Chain hooks
- Pelican hooks
- Choker hooks

Any of the above hook types (except chain and pelican) may terminate in an eye, a clevis, a swivel, a shank, or a choker (these last are identified separately as "choker hooks"). In addition, grab-type hooks can be equipped with a "safety" pin which prevents the load from slipping out the hook opening.

Examples of grab, hoist, and slip hooks ar shown in Figure 7-2. It is important to differentiate between grab hooks and slip hooks, regarding their intended usages--a grab hook will maintain the specific position on a chain to which it is attached, a slip hook will not. Information on other hook types may be found in the Federal Supply Catalog C4000-IL-N (Bibliography Entry No. 23).

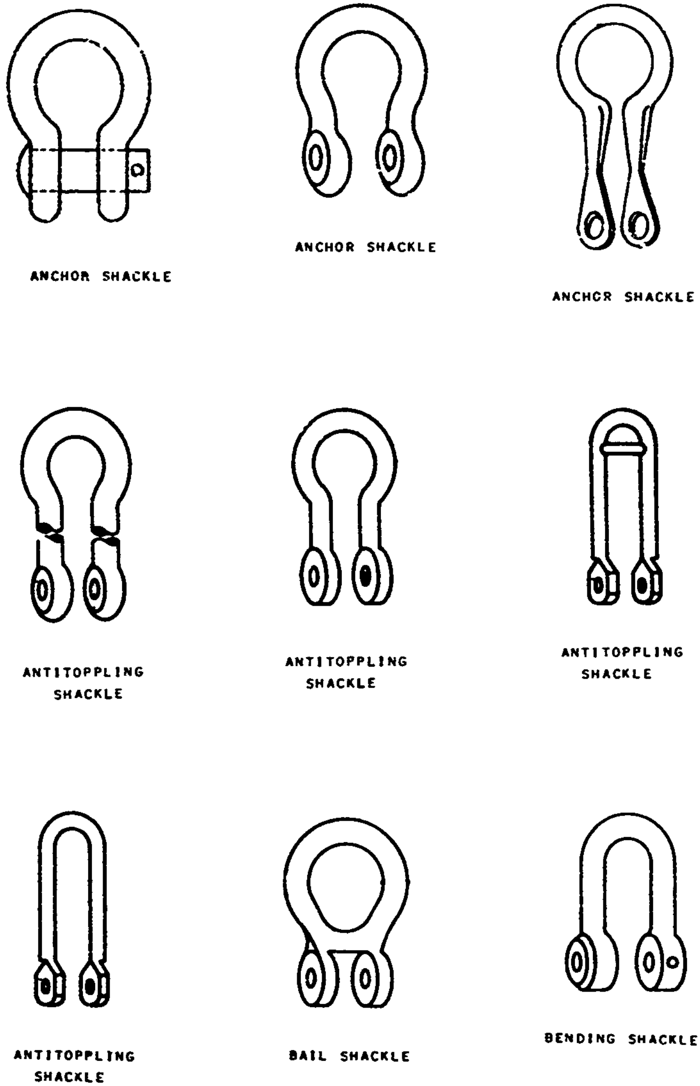


Figure 7-1. Types of Shackles

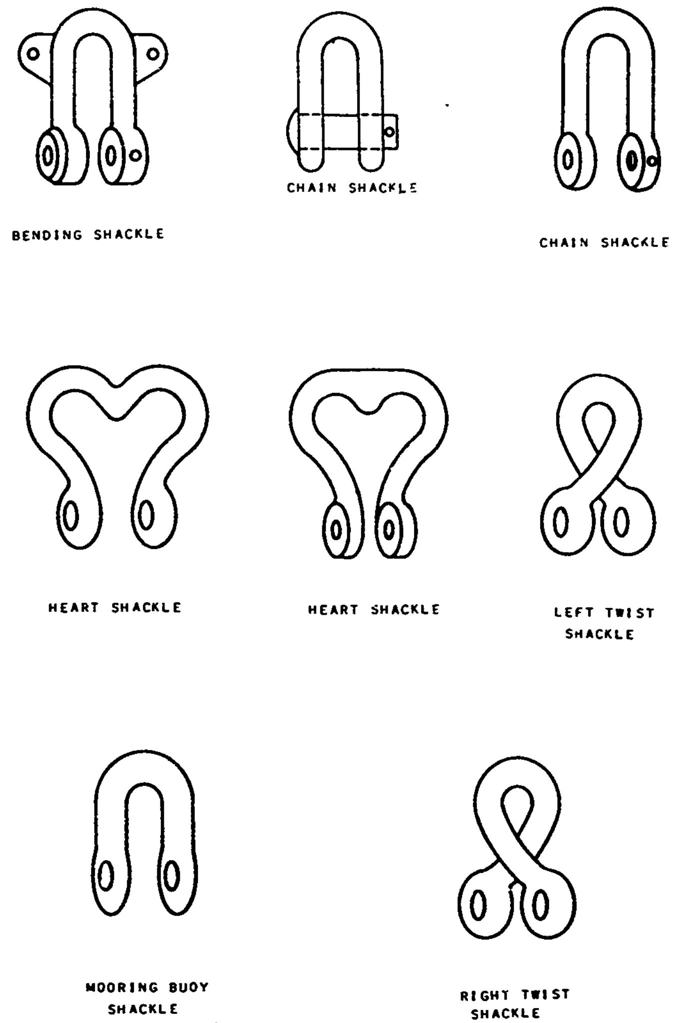


Figure 7-1. (Continued)

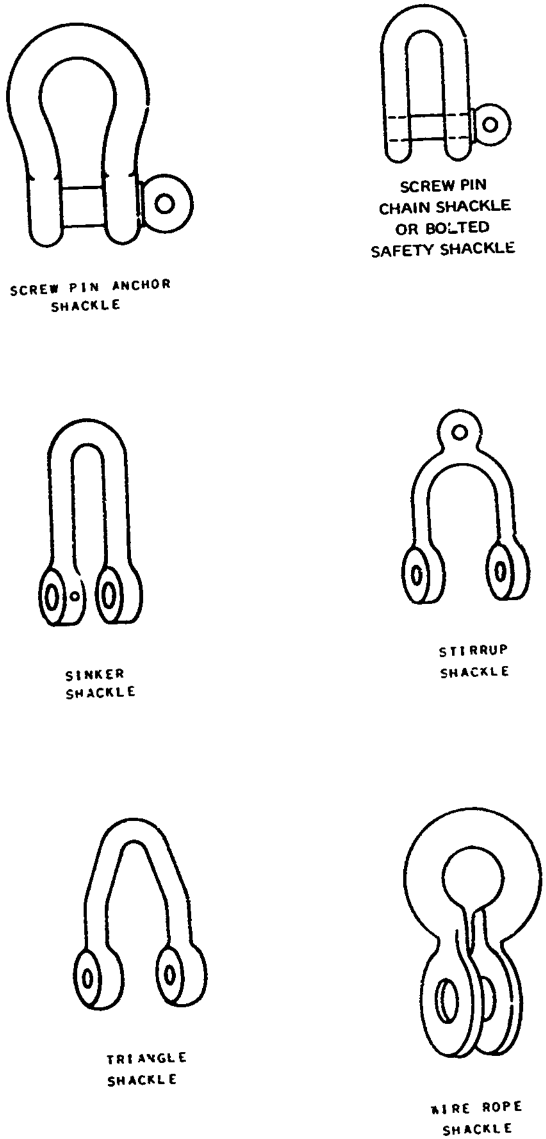
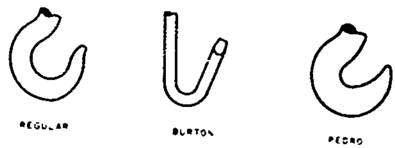


Figure 7-1. (Concluded)

Grab Hooks

Hoist Hooks



Slip Hooks

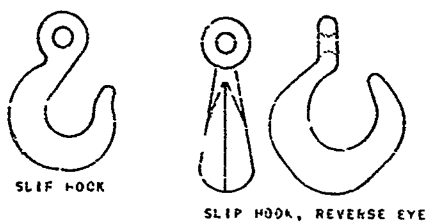


Figure 7-2. Types of Hooks

7.3. CHAFING GEAR

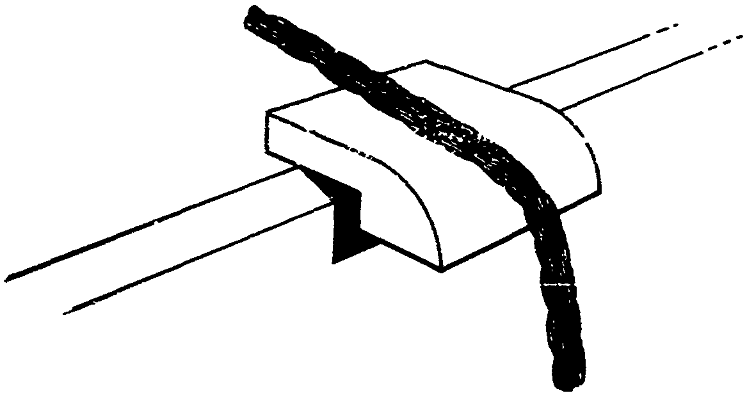
Chafing gear is used in deck operations to prevent rope from being damaged by chafing against sharp edges or abrasive surfaces. The gear can be fashioned from many items found aboard ship or around docks. A typical example of a chafing gear used to help a moving wire rope pass over a narrow edge is shown in Figure 7-3(a). Well-oiled rags, large pieces of old hemp rope and fire hose are other popular types of chafing gear for semi-fixed position ropes (see Figure 7-3(b)).

7.4. LINKS

Links are available in "closed" and "open" styles, and in a wide variety of shapes. Open links include two-pieced arrangements (detachable and connecting links), end- and side-lap links (which are squeezed together to close), swing links (cross-shaped hinged devices which close, forming figure eights), and split-triangular links. Closed links are round, pear-shaped, oval, or rectangular. They may be split by a bar to form two separate compartments (end links).

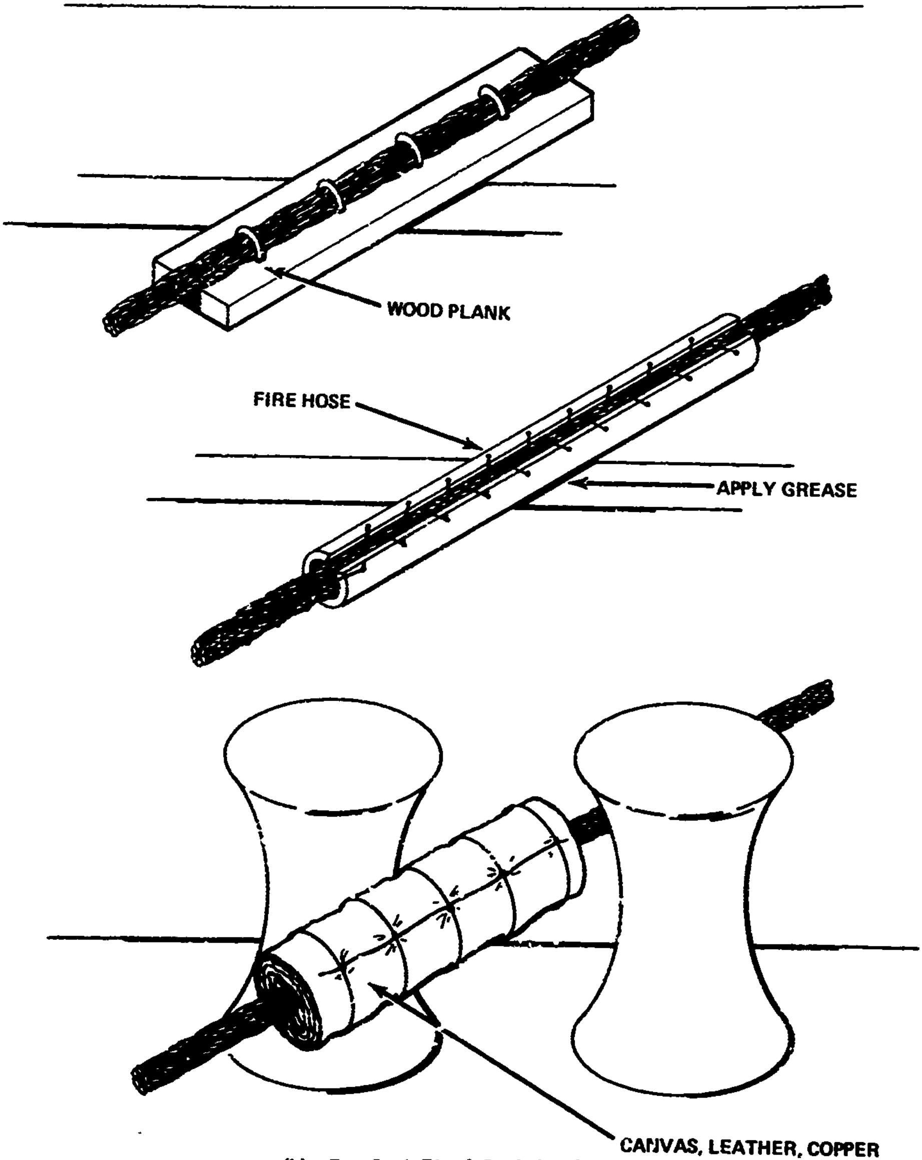
Links can weigh up to 20 pounds, and safely support up to 100 tons.

Figure 7-4 shows a variety of link styles.



(a) For Moving Ropes

Figure 7-3. Chafing Gear



(b) For Semi-Fixed Position Ropes

Figure 7-3. (Concluded)

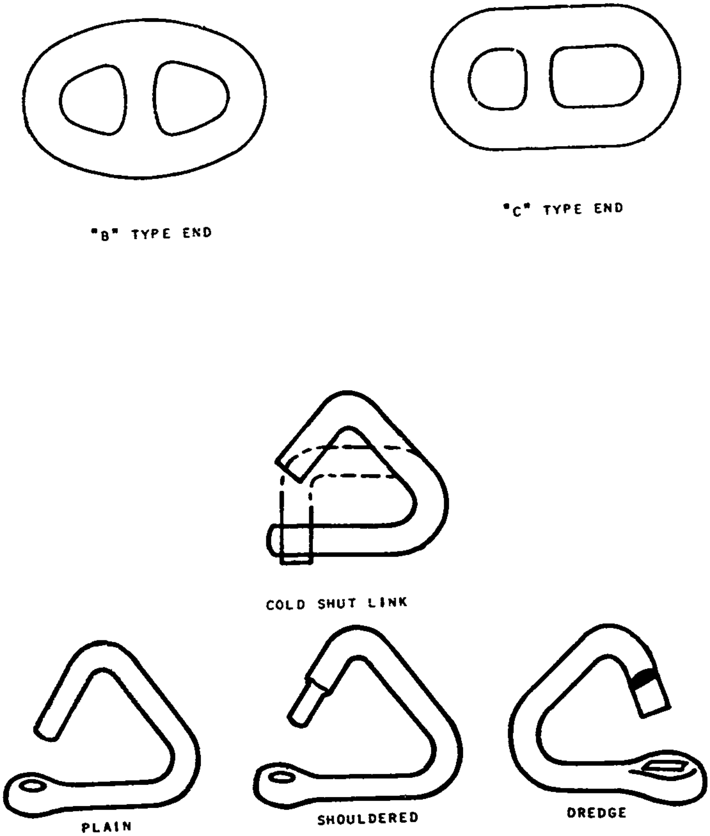


Figure 7-4. Types of Links

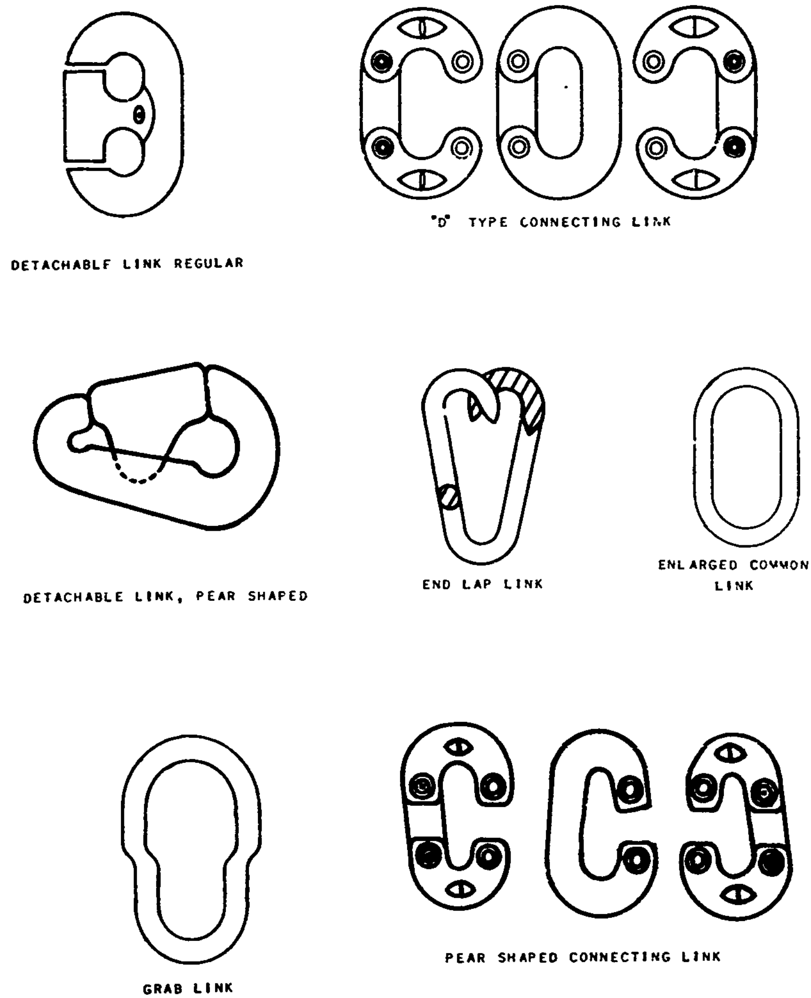


Figure 7-4. (Continued)

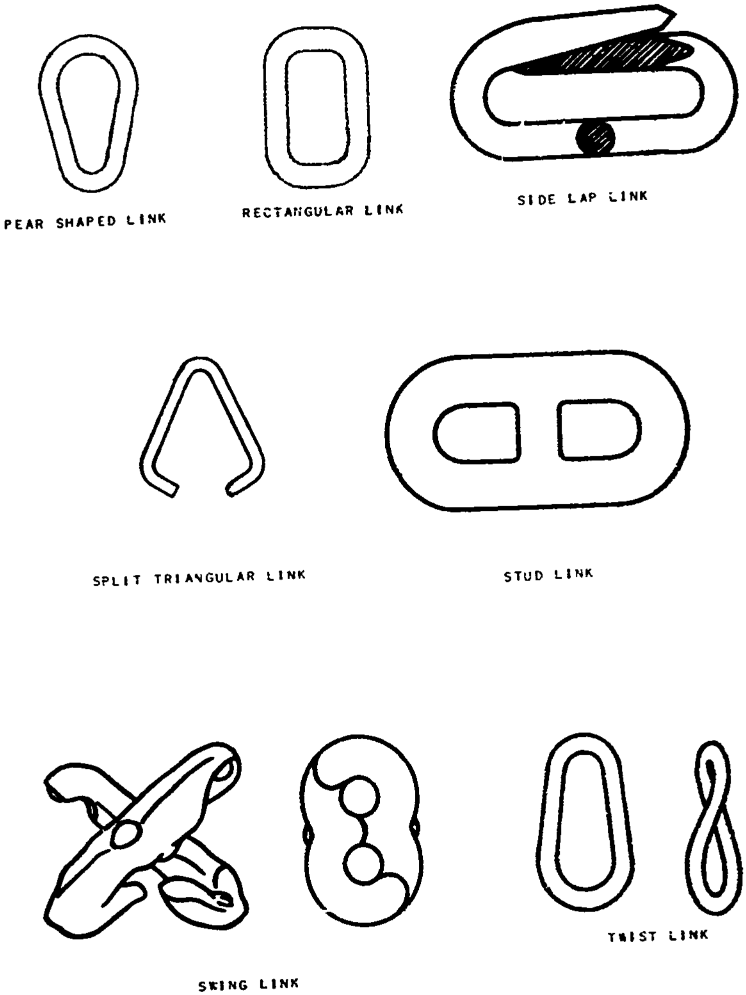


Figure 7-4. (Concluded)

7.5. BITTS AND H-BITTS

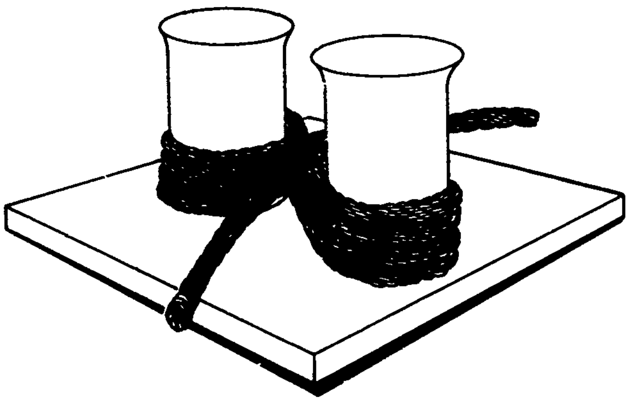
Bitts and H-bitts are used to fasten mooring or towing line to the ship. They are generally not used with chocks. With small ropes the end is wrapped around a bitt in an under-over, figure-eight pattern, as shown in Figure 7-5(a). With large ropes the load is transferred to an H-bitt through a carpenter stopper attached to the H-bitt as shown in Figure 7-5(b).

7.6. SWIVELS

Swivels are used to allow free rotation of the line. There are two types: the ball-and-socket type and the antifriction-bearing type. The ball-and-socket type allows free rotation on an unloaded rope only; on a loaded rope its action is unreliable due to the high friction between the moving parts.

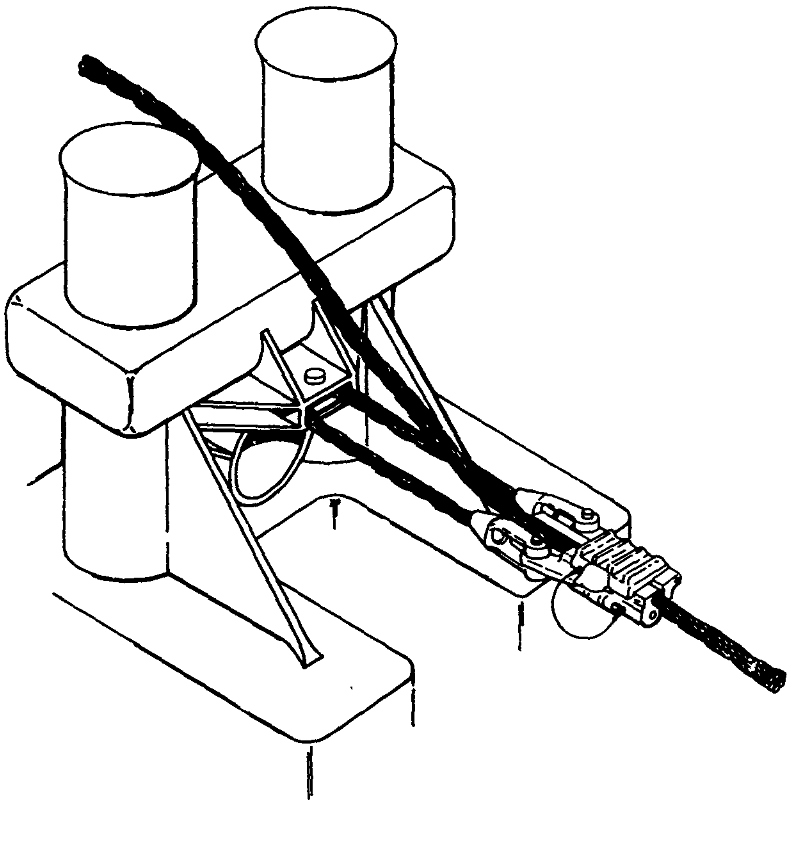
Swivels come with a variety of terminations for different coupling purposes. The antifriction-bearing type may weigh up to 60 pounds and support safe working loads of up to 15 tons; ball-and-socket swivels may weigh up to 50 pounds and support up to 25 tons safely.

Some swivel styles are shown in Figure 7-6.



(a) Bitt for Small Ropes

Figure 7-5. Bitts and H-Bitts



(b) H-Bitt With Carpenter Stopper for Towing With Large Rope

Figure 7-5. (Concluded)

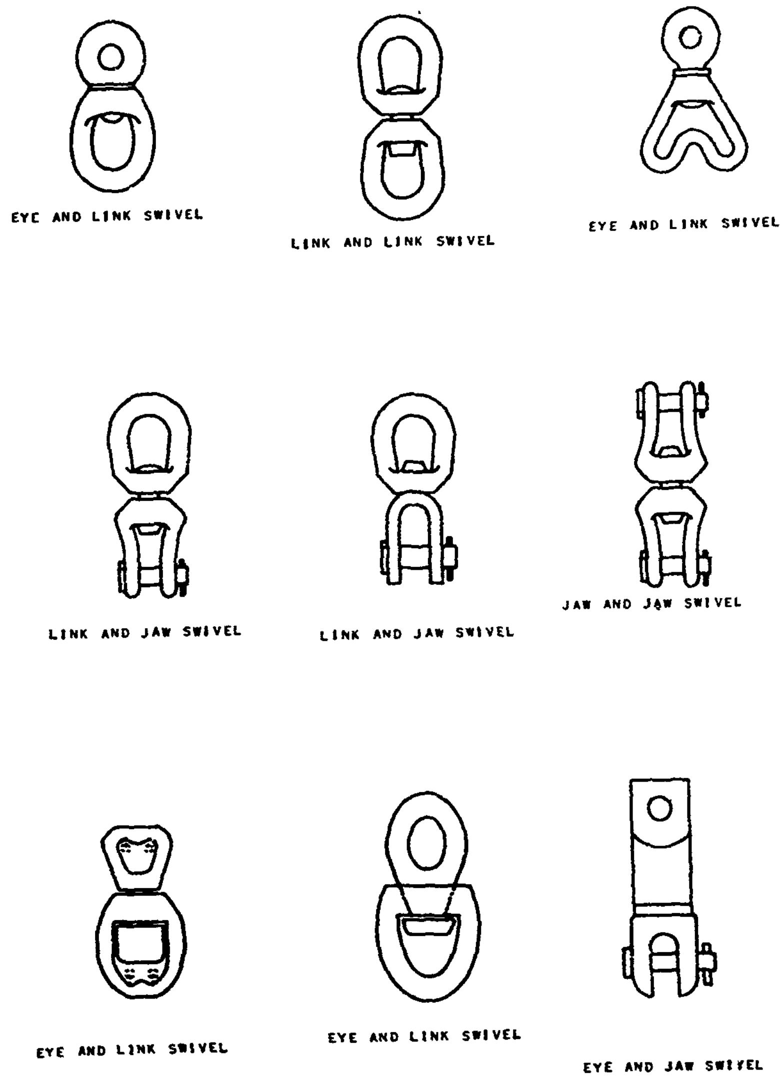


Figure 7-6. Types of Swivels

8. WIRE-ROPE RETIREMENT CRITERIA

As a wire rope is used, its condition is constantly changing due to the nature of its operation. Gradual changes occur as a result of varying loading (tension, torsion, and/or bending), abrasion, vibration, and corrosive influences. More abrupt changes may occur as a result of abuse such as impact, crushing, peening, overstress, or excessive heat; examples of this type of damage include doglegs and kinks, high strands or popped core, birdcage, core crushing or strand nicking. These changes eventually reduce the rope's strength to the point where it must be replaced.

Periodic inspection is necessary to detect the extent and location of rope deterioration so that replacement may be made at the most advantageous time. The frequency and details of inspection methods are unique to each wire-rope installation; generally, however, the intent is to estimate the remaining strength of the rope. A limit is set, a minimum allowable design factor, and the rope is replaced when the rope strength decreases to that limit. It is recommended that, if possible, photographs be taken of the rope and kept with the inspection record; also, a breaking strength test after the rope is removed will ascertain whether the rope is being replaced at the appropriate time.

When rope loading and operating environment is controlled and lubrication is adequate, the remaining rope strength may be estimated fairly accurately by measuring the amount of abrasive wear on the outer wires and the number and location of broken outer wires. However, the effect of corrosion cannot be measured and judgement is the only criterion; therefore, corrosion prevention is quite important. Significant lengthening of rope lay length or reduction of rope diameter are danger signals, but again the actual loss of strength cannot be estimated (unless the diameter reduction can be attributed entirely to wear of the outer wire crowns). Finally, the results of rope abuse must be detected quickly so that a decision may be made, based upon experience and judgement, whether the rope must be replaced immediately or can still be operated safely.

8.1. ABRASION AND BROKEN OUTER WIRES

In most cases, unless corrosion or unusual operating conditions exist, it is the outer wires of the wire-rope strands which are subject to the most wear and bending fatigue; the outer wires, therefore, will generally begin to break or wear through first. For this reason, it is common to consider the ratio of the area of the inside wires of a rope strand to the total metallic wire area. This ratio, expressed as a percentage, is called the rope's "reserve strength". In general, the reserve strength of a wire rope increases with the number of outer wires in the strands. The reserve strength is an indicator of how many broken or worn outer wires can be permitted before rope replacement is necessary. Table 8-1 lists the reserve strength versus the number of outer wires for various strand constructions; these values are approximate, and are applicable to six- and eight-strand ropes. In other words, Table 8-1 presents the percent of initial rope breaking strength that a rope would still have assuming the external layer of wires were completely abraded or broken and the internal wires were not damaged.

Table 8-1. PERCENT RESERVE STRENGTH

Number of Outer Wires	Percent Reserve Strength	Typical Strand Construction
3	0	3-Wire Single Layer
4	5	5-Wire Single Layer
6	17	7-Wire Single Layer
8	27	17-Wire Seale
9	32	19-Wire Seale
10	36	21-Wire Filler Wire
12	43	19-Wire Warrington
14	49	43-Wire Filler Wire Seale
16	54	41-Wire Seale Filler Wire
18	58	46-Wire Warrington Seale

After a rope has been inspected and the wear patterns and number and distribution of broken wires noted, an estimate of remaining strength should be made. If it cannot be decided visually which location along the rope has the worst combination of wear and broken wires, several locations should be checked. The graphs in Figures 8-1a - 8-1k (originally developed by Roebling Wire Rope Company) provide a relatively simple means of estimating remaining strength for several wire-rope constructions in both regular- and Lang-lay. Calculations of remaining metallic area are not required since the interrelated nomographs allow these factors to be determined without computation.

To use these graphs for a particular rope construction, a straight line should first be drawn from the nominal rope diameter (A) through the average wire wear length (B) to line (C) where the percent of wire diameter remaining can be found. (Wear length on Lang- and regular-lay ropes is determined differently--see Section <u>4.1.2. Abrasion and Wear</u> in Volume III for additional information.) Figure 8-1a is marked to serve as an example. As shown, a 1-inch nominal rope diameter is indicated, and measured average length of wear is shown as 0.43 inch. Approximately 81 percent of the wire diameter is found remaining. Then, starting with this same value on (D), a straight line should be drawn across line (E) to the number of broken wires in the worst rope lay (F). Assume for the example under discussion that 12 broken wires were found. With that assumption, the percent rope area intact (65 percent) can then be read from the intersected value on line (E). After the percent rope area intact has been found, it must be adjusted to account for the distribution of broken wires; obviously, if all the broken wires are in one strand, the rope strength is lower than if the broken wires are evenly distributed along the strands. Figure 8-1k can be used for this adjustment. In this case assume that broken wires are found in 4 strands. Then according to Figure 8-1k it can be estimated that 59 percent of the effective rope area is intact.

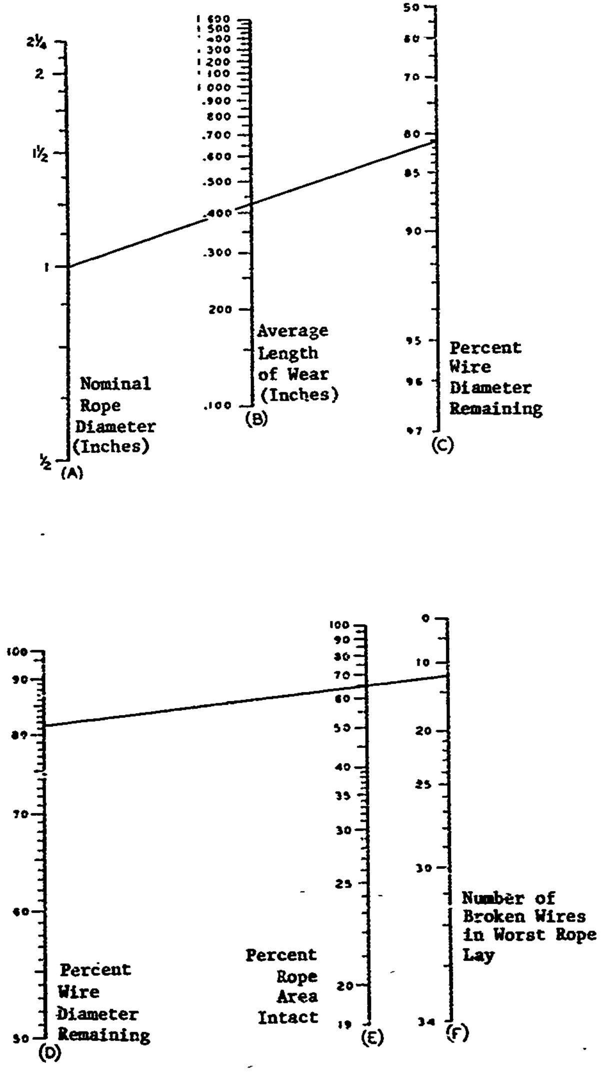


Figure 8-1a. 6 x 7 Coarse Laid Regular-Lay Rope

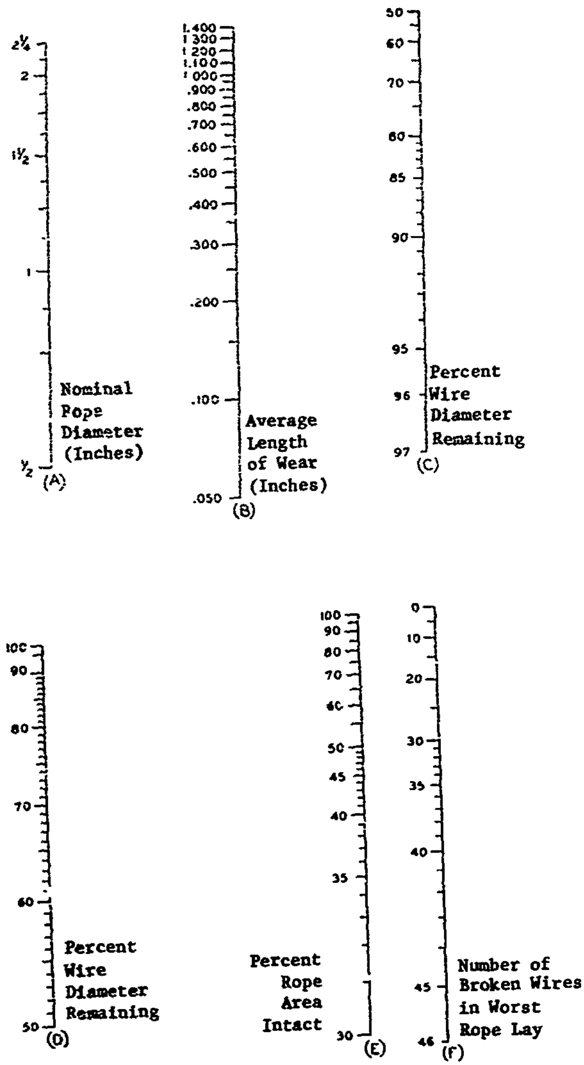


Figure 8-1b. 6 x 17 Filler-Wire Construction, Regular-Lay Rope

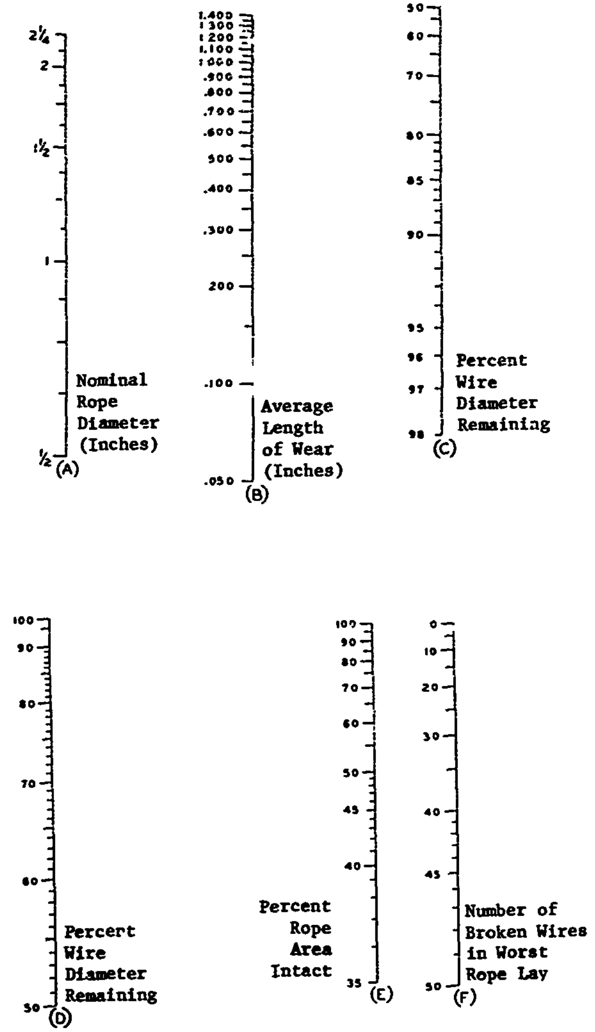


Figure 8-1c. 6 x 19 Seale Construction, Regular-Lay Rope

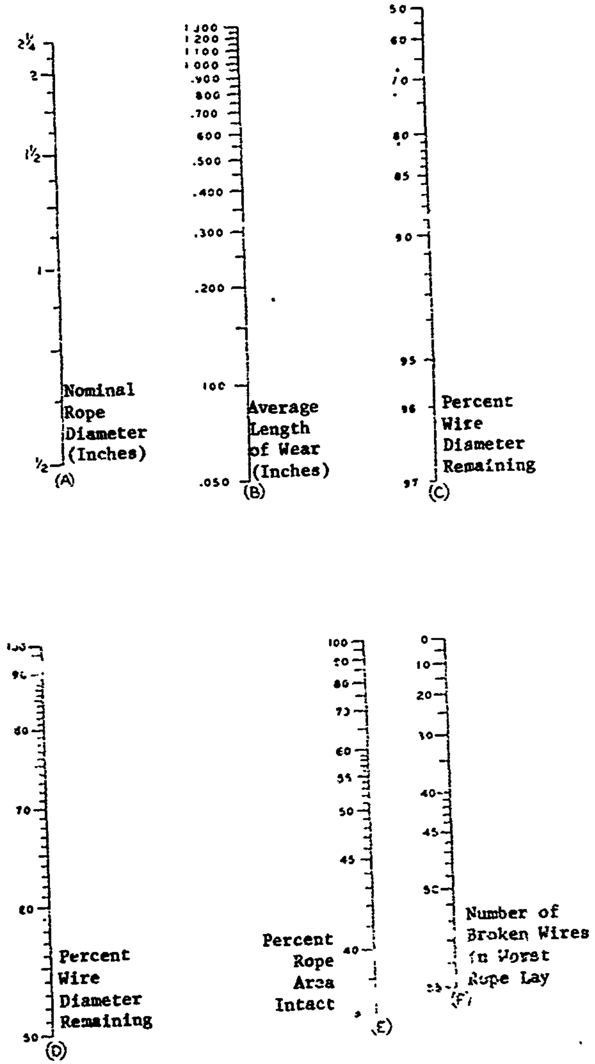


Figure 8-1d. 6 x 21 Filler-Wire Construction, Regular-Lay Rope

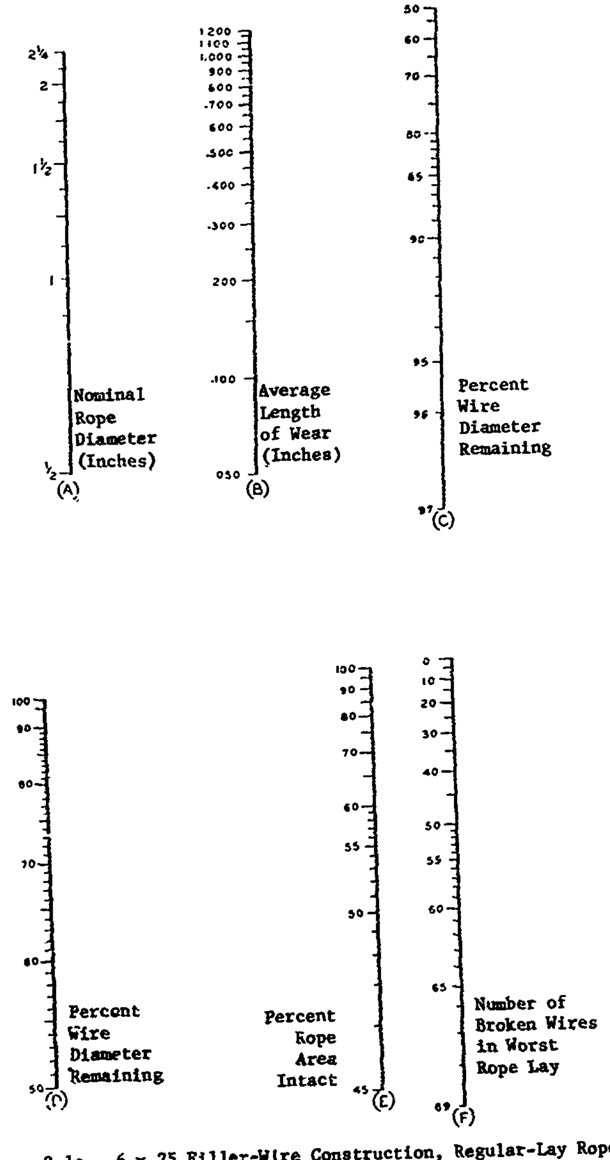


Figure 8-1e. 6 x 25 Filler-Wire Construction, Regular-Lay Rope

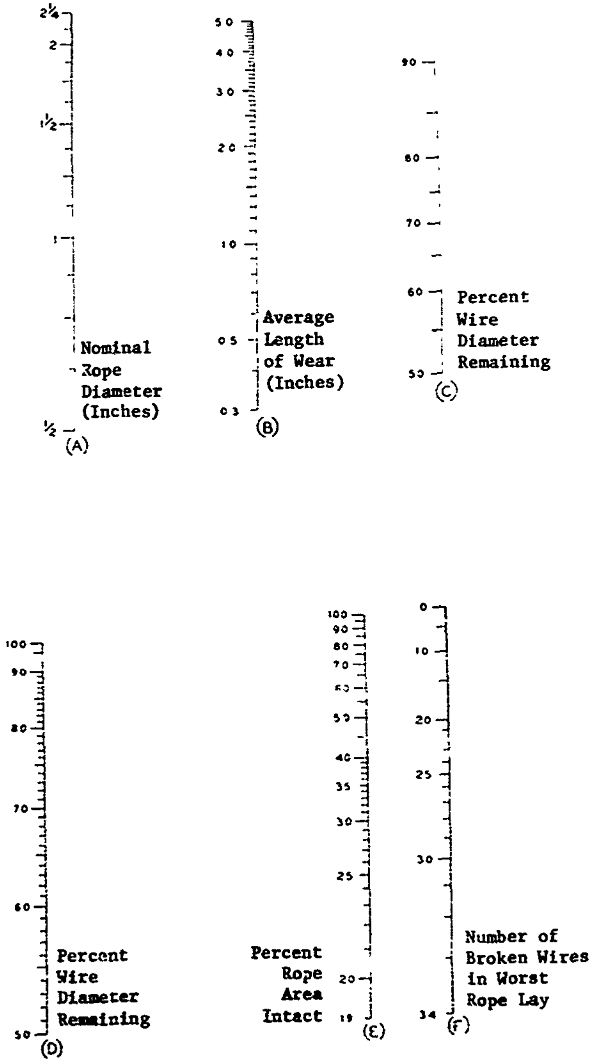


Figure 8-1f. 6 x 7 Coarse Laid Lang-Lay Rope

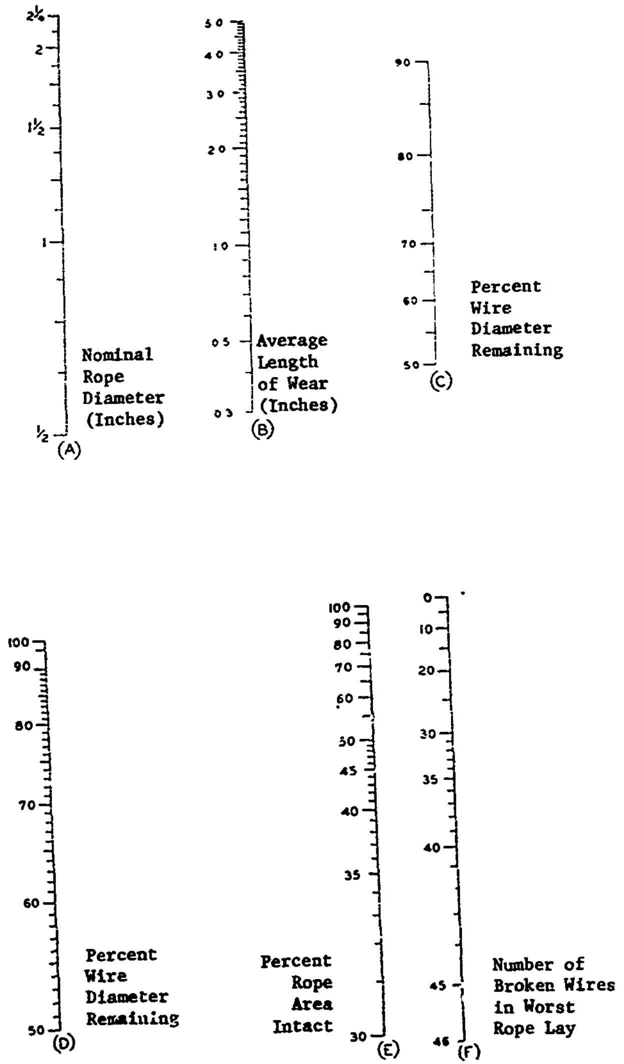


Figure 8-1g. 6 x 17 Filler-Wire Construction, Lang-Lay Rope

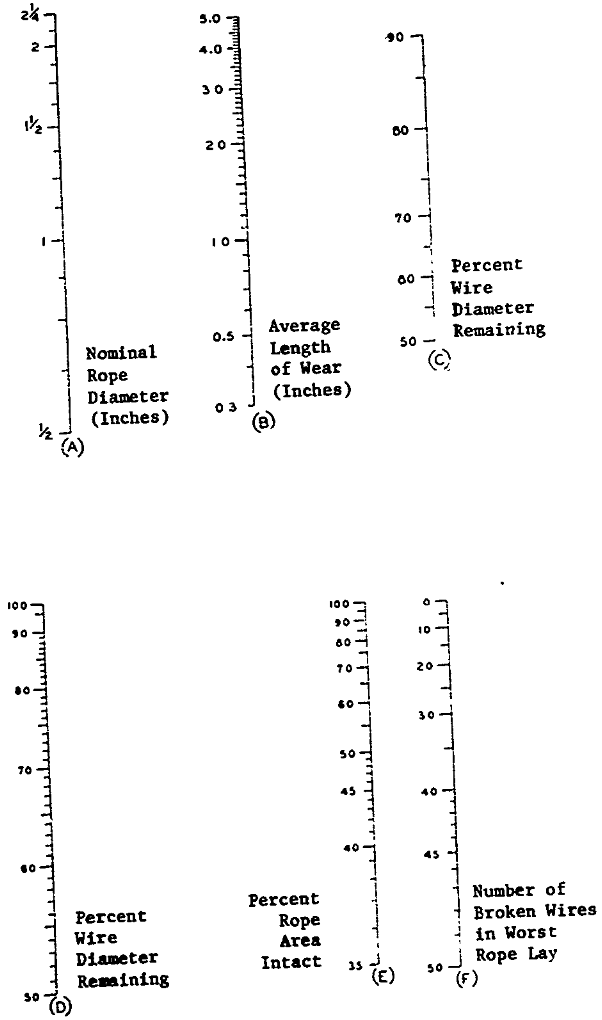


Figure 8-ih. 6 x 19 Seale Construction, Lang-Lay Rope

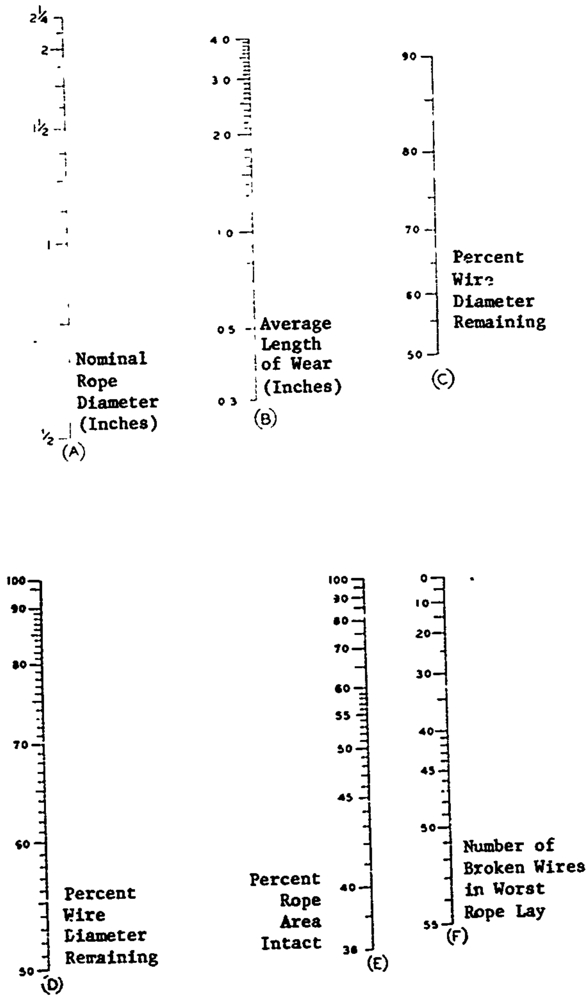


Figure 8-1i. 6 x 21 Filler-Wire Construction, Lang-Lay Rope

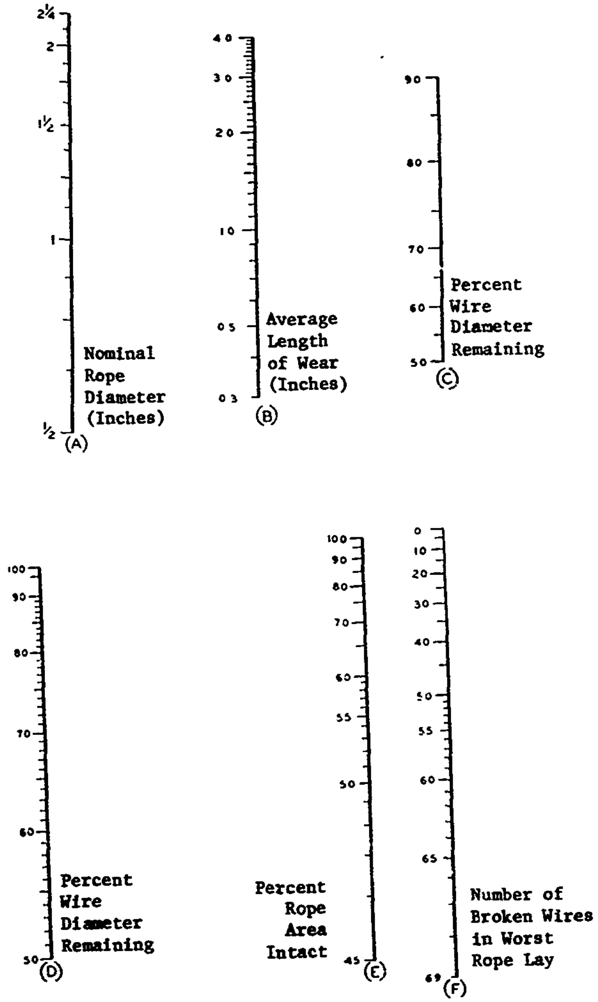


Figure 8-1j. 6 x 25 Filler-Wire Construction, Lang-Lay Rope

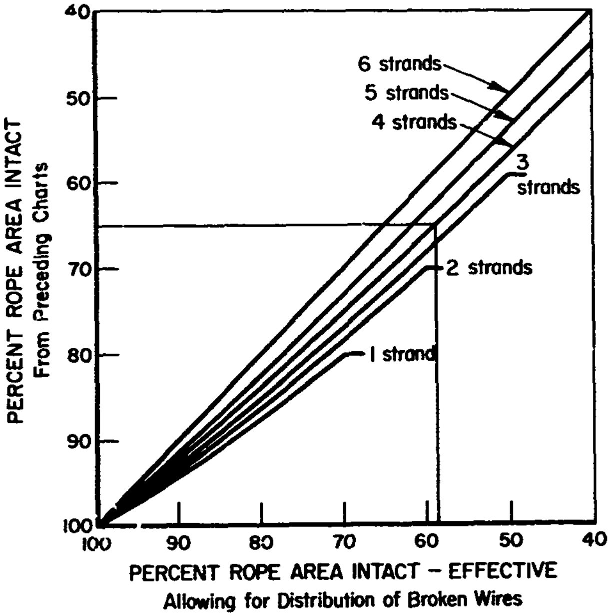


Figure 8-1k. Effective Percent Rope Area Intact

The monographs presented should not be used if calculations are to be made on 6-strand rope constructions containing more wires per strand than those given in Figures 8-1a through 8-1j (e.g., 6 x 36 Seale Filler Wire). In these cases, external wear resulting in the loss of at least 1/3 of the diameter of the outer wires should promote consideration for rope replacement, especially if that wear is accompanied by numerous outer wire breaks.

Assuming no internal wear, corrosion, or rope distortion, the effective percent rope area intact is a good estimate of the percent remaining rope strength. However, this estimate must be used with care and judgement based on experience, and a knowledge of the operating conditions of the rope. For example, these methods are of little value if the broken wires are undetected, as can happen when sheave bending radii are small and internal wire breaks occur. Also, if the rope has an IWRC or WSC, this should be taken into account in the calculations.

8.2. CORROSION

Whenever a wire rope is operated in conditions where corrosion is a potential factor, extra precautions must be taken to prevent the start of corrosion. Bronze or stainless steel ropes may be used since they are less subject to corrosion than carbon-steel ropes under most conditions, but their lower strength, decreased fatigue resistance, and higher cost must also be considered. Galvanized wires are initially more corrosion resistant than bright wires, but the difference diminishes as the rope is used and the zinc coating wears off or is removed by corrosion. Periodic lubrication of steel wires, whether bright or galvanized, is still one of the most effective means of corrosion protection. There is little difference in the corrosion resistance of the various grades of carbon steel commonly used in rope construction. Corrosion reduces metallic area and therefore rope strength. In addition, the wire surfaces are roughened, creating stress raisers and leading to early development of broken wires. Of critical importance, however, is the virtual impossibility of estimating the remaining strength of the rope; a rope showing corrosion generally must be discarded, often well before its full service life has been realized.

When corrosion has just started, the wire surfaces appear discolored. Although only a small amount of steel has been oxidized at this stage, the susceptibility to fatigue cracking of the wires has been greatly increased. As the corrosion progresses, pitting of the wires becomes evident and the gross rope strength diminishes. The rope elasticity and flexibility is reduced and the rust particles act as an abrasive, especially internally, further accelerating metal loss.

Generally, it is the exposed outer surfaces of the rope wires which corrode first. However, corrosion can develop in the rope interior before any evidence can be detected from outside. This is often due to poor lubrication technique; the outside may be protected by a superficial coating, enough to protect the visible wires but insufficient to penetrate the core to replace the loss of original lubricant and to prevent the infiltration of moisture.

The coarser rope constructions are better able to resist corrosion, since the larger diameter wires have less surface area per unit of cross-sectional area.

In addition, the regular-lay construction is marginally more corrosion resistant than the Lang-lay construction due to the shorter exposed length of outer wires.

When all prevention methods have been employed and corrosion of the rope wires still persists, the only way to estimate remaining rope strength is to periodically remove ropes from service and pull them to failure. If all other operational variables remain constant, a pattern should develop indicating rope breaking strength versus time, bending cycles, or other combinations of variables. Then a suitable minimum design factor may be chosen and the ropes removed at that point in their operational history. It must be emphasized, however, that if operational variables change, there can be no confidence that the rope will be removed before its strength is dangerously reduced.

8.3. DIAMETER REDUCTION AND LAY-LENGTH INCREASE

After the rope has been used for 5 to 10 percent of its expected life under normal operating conditions, any significant changes in the rope diameter or the lay length should be investigated thoroughly to determine the cause. These changes may be either localized or include most of the operating portion of the rope. A diameter reduction or an increase in lay length may be due either to external or internal causes.

Corrosion of the exposed wire surfaces will result in pitting and metal loss, reducing the rope diameter. The remaining strength in this case may be estimated from the graphs in Figures 8-1a - 8-1k, but only after the oxidized layer has been removed from the outer surfaces and it is certain that there is no internal corrosion. Abrasive wear to the outer wire surfaces that results in a reduction of the rope diameter may be handled in the same manner, providing that no internal abrasion has occurred. When the rope has been subject to pounding and peening action during its use, the crown wires are flattened and the rope diameter is reduced. However, the wire material is only distorted, not removed, and it is unlikely that an accurate estimate of remaining strength may be made. In addition, pounding and peening may also increase notching between adjacent wires, leading to the development of internal fatigue cracks. Finally, localized external rope damage from abuse, such as cutting or crushing, may reduce the rope diameter and distort the rope structure so that the rope must be removed from service.

Internal corrosion or abrasion causes both a reduction in the rope diameter and a lengthening of the lay. As discussed in the "Corrosion" section earlier, internal corrosion usually results from trapped moisture; sometimes rust flakes may be observed working out between the strands. Internal abrasion can occur when particles of sand or grit penetrate the interior of the rope and gradually wear away at the wire surfaces. Both internal corrosion and abrasion usually occur slowly, so that diameter reduction and lay length increase may be detected and the rope replaced. Overstressing of the rope, however, may be a single event resulting in core compression or failure, and severe cross-wire notching. If not detected immediately by the change in diameter and lay length, the sudden reduction in breaking strength may cause unexpected rope failure during operation. The final cause of sudden diameter reduction and accompanying lengthening of rope lay may be failure of a fiber-rope core. This can be due either to excessive heating and the resulting charring of a fiber core, or drying out because of inadequate lubrication. While not critical to the initial rope strength, core failure means that the outer strands are no longer properly supported; cross-wire notching between adjacent strands will become severe, and the rope shape may be easily crushed or distorted. If core failure is suspected, the rope should be replaced. (In an IWRC rope, even when the wires in the core are broken, there is still some support for the strands.)

Figure 8-2 illustrates the potential (nonrecoverable) elongation behavior of a rope subjected to normal wear during cycling. This behavior results not only in an increase in lay length, but also in a reduction in rope diameter. The first part of the curve shown in Figure 8-2 represents the initial changes due to constructional adjustments of the wires and strands in the rope. The second part of the curve shows essentially no change in rope length during most of its service life. The third part of the curve illustrates the rapid increase in rope elongation which occurs as the rope begins to fail. In some cases this behavior allows detection of incipient rope failure and timely replacement. Not all ropes behave according to this pattern, however. In some cases the increase in elongation starts so near to the time of rope failure that it is not a safe removal criterion. Only experience with individual applications can reveal whether or not this replacement criterion can be safely employed.

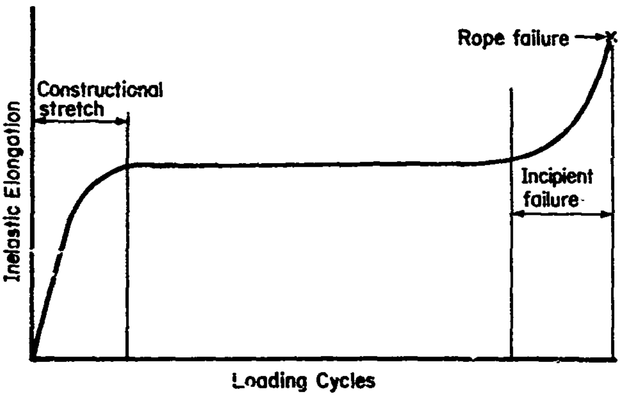


Figure 8-2. An Example of Possible Rope Elongation Versus Loading Cycles

(Note: Some ropes may display lesser or greater amounts of constructional stretch, steady-state elongation, and incipient failure elongation.)

8.4. SERVICE HISTORY

A complete record of the operational history of previously installed ropes in a system can be an invaluable aid in predicting the correct time to replace ropes currently in service. This record should include all the information possible on operating conditions such as loads, lengths cycled, numbers of cycles, and environmental factors. In addition, any abuse the rope may have been subjected to should be recorded, as this may later explain early rope retirement. When operating conditions remain fairly constant and good inspection and record-keeping procedures are adhered to, a reliable estimate of rope life can be made based on past experience and the rope replaced before problems develop.

As mentioned previously, it is useful to complete a tensile test on a section of the rope being removed from service. This tensile specimen should be taken from the operating section showing the worst combination of broken wires, abrasive wear, and corrosion. The results of tests on several ropes from the same system may indicate a trend of remaining rope breaking strength versus time or loading cycles. In this way, the safest and most economical rope life may be obtained.

8.5. OTHER ROPE DAMAGE

There are many other forms of rope damage that may necessitate rope removal. When rope damage or deterioration has been identified, a judgement must be made whether or not to replace the rope. To aid in this decision, the more frequent forms of damage have been grouped according to severity as to whether the rope should be replaced immediately, in the near future, or whether the damaged area should simply be observed for further deterioration. This listing is subjective, but should give an indication of the difficulty in estimating remaining rope strength.

If any of the following forms of damage are detected, the rope should be removed from service immediately:

(a) crushing
(b) kinking
(c) dogleg
(d) birdcaging
(e) popped core.

Unless the condition of damage is found to very minor, detection of the following should also serve as reason for rope removal:

(a) cutting
(b) numerous broken wires
(c) high strands
(d) overloading
(e) excessive heating.

The following forms of rope damage are usually indicative of an operating condition which can be corrected. In this case, a judgement must be made about the rope condition, and the rope removed before confidence in its remaining strength is impaired:

(a) pounding and peening (c) chafing.

(b) scrubbing

Illustrations of various types of rope damage are given in Volume III of this handbook, Section 4.1.4. Other Rope Damage.

9. APPLICATIONS INFORMATION

This section is intended to provide information necessary to select wire rope for many of the specific applications of interest to the Navy. Recommendations are made for rope constructions, materials, and end fittings. Where practical, suggestions are made concerning overall system design, such as recommendations for design factors. This section reflects current design and selection practices; periodic revision and expansion will guarantee the applicability and completeness of the information contained here.

9.1. OCEAN MOORING

Ocean mooring systems commonly involve fixed emplacements or ship anchoring systems - each application has somewhat different wire-rope requirements. Galvanized improved plow steel 3 x 19 or 3 x 46 thermally stabilized wire rope is used frequently for anchor lines because of its resistance to torsion and rotation. Other nonrotating constructions, such as 18 x 7 are also used occasionally, but they tend to unlay when used to suspend an anchor and to kink or birdcage when suddenly relieved of load.

Field experience has shown that the 3 x 46 construction may fail due to bending fatigue with little or no visible warning. Anchor cable failures of this type usually occur at the last overboarding sheave; they may be avoided, or at least delayed if the rope can be periodically adjusted on the reel to force different rope sections to pass over the fatigue-damaging sheave(s). A spring between the rope end and the anchor may also be used beneficially in some situations to dampen shock loadings to the rope.

Level-winding of 3 x 46 rope on the drum must be carefully controlled to minimize cross-wire notching. Inspection must be carried out frequently. Although it is now common practice to replace anchor ropes after six months of service, laboratory tests show little strength reduction due to corrosion in that time. Anchor lines for fixed emplacements (buoys, platforms, etc.) should be prestretched to minimize in-service elongation.

Hot poured zinc socket end fittings are commonly used on anchor lines because of their reliability and high efficiency in seawater--even for long periods of time.

9.2. TOWING HAWSERS

Towing hawsers are generally made from galvanized improved plow steel wire in a 6 x 37 construction with regular lay and a fiber core. The 6 x 37 construction allows good flexibility around stern rollers and small winch drums, while the fiber core provides resistance to shock loadings created by towing impact and surge. If the shock loadings are cushioned in some way, an IWRC rope may be used instead of a fiber-core rope, if greater resistance to crushing is desired.

Spring lines of regular-lay, 6 x 3 x 19 galvanized spring-lay construction are sometimes used for close tows in which the tow boat and towed craft are separated primarily by fenders.

Closed zinc sockets (galvanized) are frequently used on towing hawsers because they display good corrosion resistance and strength retention.

See the "U. S. Navy Towing Manual" for further information.

9.3. ELEVATOR ROPES

There are several different types of elevators in use in the Navy; these include aircraft carrier flight deck elevators, cargo elevators, personnel elevators, and bomb elevators. These types are covered in "Navships Technical Manual 091-830-0002, Chapter 9830".

Aircraft elevators generally use 6 x 30 flattened-strand (Type G) construction with 7 x 7 IWRC, preformed, Lang-lay, uncoated wire rope. This construction is normally selected because of its ability to withstand high shock loads and its durability in high-speed operation.

In order to insure system safety and to achieve maximum rope life, it is necessary to tension-equalize all ropes in a particular elevator systems. In addition, it is advisable to use wire rope from a single production run on a given elevator to avoid uneven constructional stretch and subsequently imbalanced rope tensions. Aircraft elevator cables generally employ poured zinc sockets for holding power and safety.

Cargo, personnel, and bomb elevators are usually fitted with 6 x 37 IWRC construction rope. This flexible construction can be used on smaller sheave and drum diameters than 6 x 30 flattened strand rope while still maintaining an economical and safe rope life. Cargo and personnel elevator ropes generally use threaded cable terminals at the rope ends, while bomb elevators use either special swaged sockets or poured zinc sockets because of their higher efficiency.

Most elevator ropes, with the exception of aircraft carrier elevator ropes, are ordered in regular lay because of superior resistance to crushing, distortion, and rotation. The safety factor in an elevator rope application is chosen based on the projected operational speed of the elevator--the higher the speed the greater the safety factor (for the same desired safe rope life). If the rope fail is long or the loads light, it is sometimes necessary to add in the rope weight when calculating rope service loads.

9.4. AIRCRAFT ARRESTING-GEAR ROPES

These ropes are subjected to such severe service and their safety is so critical that they are covered by a separate Naval specification. Interested readers should contact the Navy Air Engineering Center for detailed information.

9.5. REPLENISHMENT AT SEA

There are many uses of wire rope for replenishment-at-sea systems and equipment. Table 9-1 outlines the current practice. In the cases where high strength is necessary, extra improved plow steel (EIPS) is used, together with poured zinc sockets. For additional information, refer to COMTAC Publication NWP-38, Replenishment at Sea (Bibliography Entry No. 78).

Table 9-1. WIRE ROPE FOR REPLENISHMENT AT SEA

Replenishment at Sea Application	Diameter	Construction[a]
Cargo Drop Reel	3/8"	1
Saddle Whip	1/2"	2
Outhaul Line	1/2"	2
Span Wire (Single Hose)	3/4"	1
Housefall	3/4"	1
Burton (Normal)	3/4"	1
Inhaul	3/4"	1
Topping	3/4"	1
Vangs	3/4"	1
Preventers	3/4" - 1 1/4"	3
Span Wire (Double Hose)	7/8"	1
Highline (Light Station)	7/8"	1
Highline (Heavy Station)	1"	1
Backstay	1 1/8"	4

(a) Construction 1: 6 x 37 Warrington-Seale, IWRC, Improved Plow Steel, Bright, Right Regular Lay (RR-W-410 Type 1, Class 3, Construction 6).

Construction 2: 6 x 37 Warrington-Seale, IWRC, Extra Improved Plow Steel, Bright, Right Regular Lay (RR-W-410 Type 1, Class 3, Construction 6).

Construction 3: 6 x 19 Warrington-Seale, IWRC, Improved Plow Steel, Bright, Regular Lay (RR-W-410 Type 1, Class 2, Construction 5).

Construction 4: 6 x 19 Warrington-Seale, IWRC, Extra Improved Plow Steel, Bright, Regular Lay (RR-W-410 Type 1, Class 2, Construction 5).

9.6. MINESWEEP ROPES

There are several types of wire rope in use for minesweep applications. These include the 7 x 19 Warrington construction for ropes up to ½ inch in diameter, and the 6 x 19 Warrington construction with a 7 x 7 IWRC for ropes between ½ inch and 1 inch in diameter. A 4 x 8 serrated Warrington construction with a wire-strand core (WSC) is also sometimes used in an 8/10-inch-diameter size. Rope of this latter construction is used in pairs, one right- and one left-lay, to assist in cutting mine moorings. The 6 x 19 construction is used in a 1-inch-diameter size for mine-cable clearing guards. Strength, rather than fatigue resistance, is the primary requirement in the selection of most minesweep ropes.

Because minesweep ropes are immersed constantly in seawater, and must be nonmagnetic to avoid detonating mines, a corrosion-resistant steel wire such as AISI 305 stainless steel is normally used. For material compatability (to avoid anodic corrosion) as well as strength, all end terminations (whether poured sockets or eyesplices with thimbles) are also made from corrosion-resistant steel.

For instructions on the use of minesweep ropes, reference is made to NAVSHIPS 0981-002-1000.

9.7. CRANE, HOIST, AND DAVIT ROPES

For all running ropes in these applications, the 6 x 37 class of rope construction is recommended and generally used. It provides good strength combined with maximum flexibility and superior bending-fatigue resistance over sheaves and drums. For most cranes and hoists, IWRC rope is used. For the same design factor, however, greater rope life can be expected at low-load levels with a fiber-core construction, especially in a small sheave application such as that commonly encountered with boat davits.

Crane, hoist, and davit ropes generally use bright, uncoated wires, but should be kept well lubricated for corrosion protection. In the smaller sizes where strength may not be as important as flexibility and corrosion resistance, 6 x 12 galvanized ropes may be used.

Poured zinc sockets or swaged end fittings are commonly used because of their strength and reliability and because of their general familiarity to most people regarding installation requirements. Both types of end fittings can be galvanized for environmental protection in corrosive environments.

In general, the minimum safety factor for cranes and large hoists is 5.0, with the exception of some truck, crawler, and locomotive cranes, where the safety factor may be as low as 4.0. Small electric hoists usually require a somewhat greater safety factor of approximately 7.0.

Table 9-2 shows the recommended and minimum ratios of drum- and/or sheave-to-rope diameters for drums having only a single layer of rope.

Table 9-2. DRUM- AND SHEAVE-TO-ROPE DIAMETER RATIOS, SINGLE-LAYER DRUM HOISTS

Equipment Type	Wire-Rope Classification	Drums and Running Sheaves		Equalizer Sheaves
		Recommended	Minimum	Recommended
Portal, Hammerhead, Tower, and Floating Cranes and Derricks	6 x 37	30	24	24
	6 x 25 Filler Wire	30	24	26
	8 x 19 (Spin Resistant)	30	24	--
	6 x 19 Seale 6 x 21 Filler Wire 6 x 25 (Typu B) Flattened Strand 6 x 30 (Type G) Flattened Strand	36	24	30
	18 x 7, 19 x 7 (Nonrotating)	40	34	--
Overhead, Traveling and Gantry Cranes	6 x 37	24	24	18

For further information on cranes, hoists, and davits, reference is made to the following documents: NAVSHIPS Technical Manual 0901-820-0002, Chapter 9170 (Cranes), Chapter 9780 (Hoists), and Chapter 9820 (Davits); NAVSHIPS Technical Manual 0900-008-9010 (Multiple-Layer Drums).

9.8. STANDING RIGGING

Strength rather than flexibility is generally the primary consideration for standing rigging, so the first choice for this application is 6 x 19 construction rope. Because it is constantly exposed to the elements, standing rigging must be protected; although stainless steel is effective, galvanizing is normally used for reasons of economy. Poured sockets are normally installed in an attempt to maximize available rope strength. On shipboard and land installations where strong electromagnetic radiation is present, eddy currents may be set up in the wires of the rigging, accelerating electrolytic corrosion. Wire ropes may also cause interference around antennas, in which case nonmetallic rigging may be preferable. It is often advantageous to order rigging ropes prestretched to minimize elongation when loaded, especially for fixed guy ropes. A safety factor of at least 3.0 is normally advisable.

9.9. LIFELINES AND SAFETY NETS

Lifelines are generally fabricated from small-diameter (7/16 to 9/16 inch) 6 x 19 filler wire, regular-lay rope with fiber core. For corrosion protection, the wire material is usually chosen to be phosphor bronze or corrosion-resistant steel (especially in missile blast areas). Poured corrosion-resistant sockets and fiege fittings are often used and turnbuckles are commonly installed for adjusting the length of line. Chafing strips are normally recommended at support stanchions, but care should be taken to insure that these strips do not promote internal rope corrosion at support locations. In some instances, lifelines have been experimentally replaced with fiberglass rods.

Safety nets may be made with small-diameter (1/4 to 3/8 inch) 6 x 19 IWRC rope. The wire material may be galvanized improved plow, or stainless steel. Because of the small size, swaged-sleeves are often used as end fittings because the tools for this size fitting are portable.

9.10. AIRCRAFT CONTROL LINES

Control lines are generally small (1/16 - 3/8 inch in diameter) and lightly loaded. The constructions commonly used are 7 x 19 and 7 x 7. Both galvanized carbon steel and stainless steel lines are available, as is plastic-jacketed rope.

Aircraft control lines are commonly subjected to a combination of cold temperatures and bending fatigue, and the characteristics of specific cables should, therefore, be evaluated under these conditions before service. Evaluations of this type are currently covered under Military Specification MIL-W-83420.

9.11. TILLER ROPES

Wire rope for steering systems must be extremely flexible to withstand the repeated bending over numerous small sheaves. A 6 x 6 x 7 (or 6 x 42) fiber-core construction has been used for this application, but it has limited strength and poor abrasion resistance. If the strand and rope-fiber cores are replaced with wire-strand cores and an IWRC, respectively, to give a 7 x 7 x 7 construction, an increase in strength and resistance to crushing is realized, but the bend-over-sheave fatigue resistance decreases at the same time. Current practice is to use a 6 x 37 classification (6 x 43 filler wire with 18 outer wires) because of its good combination of abrasion and crushing resistance as well as extra flexibility. The end fittings are normally poured zinc sockets. Frequent lubrication is required if maximum rope life is to be obtained.

9.12. TRAMWAY - SPAN ROPES

For aerial tramway ropes, such as those used in ship-to-shore transport of supplies, both the 6 x 24 IWRC and the 6 x 25 and 6 x 30 flattened strand ropes may be selected. The flattened strand construction is best for maximizing the life of the rollers which ride on the span rope and support the suspended load. In fixed systems, manufacturers' handbooks generally recommend track strand, either smooth coil, locked smooth coil (half-locked), or locked coil (full-locked). The smooth coil is the strongest of these three, but broken wires will protrude from the rope surface. The half-locked smooth coil uses shaped outer wires and is somewhat weaker, but offers smoother operation and freedom from protruding broken wires. Locked coil has the smoothest outer surface, with all the outer wires being of the same interlocking shape. A minimum design factor of 3.5 is recommended. Span ropes should be prestretched, especially for fixed installations.

9.13. OCEANOGRAPHIC ROPES

In the past, ropes used for oceanographic service have been made primarily in an 18 x 7 "nonrotating" construction to minimize spinning of instrument packages or other payloads. This construction does unlay under load, however, and its strength decreases at the same time, so a safety factor in excess of 10 is often required. In addition, great care must be taken to avoid kinking or other damage to the rope that may occur when the rope goes slack (such as when the payload touches bottom or is released).

In the majority of cases, a 3-strand construction is now recommended. This rope can be manufactured so that it is essentially nonrotating, which, at least in part, eliminates many of the problems discussed above. Because the rope is normally used in seawater, it should be galvanized or plastic-jacketed to avoid corrosion damage. Swaged end fittings can be applied rapidly to small-diameter ropes with little loss in rated rope strength. Poured zinc sockets are recommended for large ropes or critical applications.

9.14. SLINGS, TACKLE, AND PURCHASE ROPES

Sling types are shown in Figure 9-1. Primary considerations are strength and flexibility; 6 x 19 and 6 x 37 construction bright rope (fiber core and IWRC) are commonly used. When selecting a wire rope for sling use, the minimum bend radius for basket slings should be 20 times the rope diameter, with an absolute minimum of 8 times the rope diameter for other sling types. A minimum design factor of 5.0 is recommended, based on the actual rope load. For all but a straight lift, the rope load increases with the angle the rope makes with the vertical (Figure 9-2). Tables 9-3 and 9-4 provide information pertaining to rated capacities of single-part wire-rope slings. This information was taken from Bibliography Reference 79 and represents what is under consideration for OSHA standardization for these sling types.

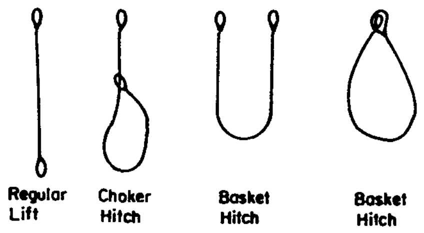


Figure 9-1. Sling Types

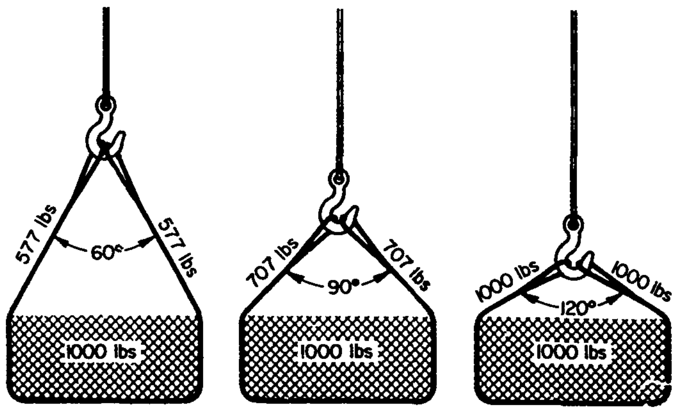


Figure 9-2. Rope Load for Various Leg Angles in a Basket Hitch Supporting a 1000-Pound Load

Table 9-3. RATED CAPACITIES FOR SINGLE-LEG SLINGS 6 x 19 AND 6 x 37 CLASSIFICATION IMPROVED PLOW STEEL GRADE ROPE WITH INDEPENDENT WIRE-ROPE CORE (IWRC)

Rope Diameter, Inches	Rated Capacities, Tons (2,000 pounds)							
	Vertical			Choker			Vertical Basket[d,e]	
	HT[a]	MS[b]	S[c]	HT	MS	S	HT	MS
1/4	0.53	0.56	0.59	0.40	0.42	0.44	1.0	1.1
5/16	0.81	0.87	0.92	0.61	0.65	0.69	1.6	1.7
3/8	1.1	1.2	1.3	0.86	0.93	0.98	2.3	2.5
7/16	1.5	1.7	1.8	1.2	1.3	1.3	3.1	3.4
1/2	2.0	2.2	2.3	1.5	1.6	1.7	3.9	4.4
9/16	2.5	2.7	2.9	1.8	2.1	2.2	4.9	5.5
5/8	3.0	3.4	3.6	2.2	2.5	2.7	6.0	6.8
3/4	4.2	4.9	5.1	3.1	3.6	3.8	9.4	9.7
7/8	5.6	6.6	6.9	4.1	4.9	5.2	11.0	13.0
1	7.2	8.5	9.0	5.4	6.4	6.7	14.0	17.0
1-1/8	9.0	10.0	11.0	6.8	7.8	8.5	18.0	21.0
1-1/4	11.0	13.0	14.0	8.3	9.6	10.0	22.0	26.0
1-3/8	13.0	15.0	17.0	10.0	11.0	12.0	27.0	31.0
1-1/2	16.0	18.0	20.0	12.0	14.0	15.0	32.0	36.0
1-5/8	18.0	21.0	23.0	14.0	16.0	17.0	37.0	42.0
1-3/4	21.0	25.0	27.0	16.0	18.0	20.0	42.0	49.0
2	27.0	32.0	34.0	21.0	24.0	26.0	55.0	64.0

(a) HT = Hand tucked splice (one in which the strands forming the looped end are tucked back into the live portion of the rope).

(b) MS = Mechanical splice (one in which a loop is formed at the end of the rope and a metal sleeve is pressed over the turned back strand ends).

(c) S = Swaged or zinc poured socket (ones in which the sockets are attached to the end of the rope without the formation of a loop).

(d) These values only apply when the D/d ratio for HT slings is 10 or greater, and for MS and S slings are 20 or greater where D = diameter of curvature around which the body of the sling is bent, and d = diameter of rope.

(e) These values are based on both sides being vertical. If they are not vertical, the rated capacity must be reduced. If two basket slings are used, the angle between the slings must also be considered.

Table 9-4. RATED CAPACITIES FOR SINGLE-LEG SLINGS 6 x 19 AND 6 x 37 CLASSIFICATION IMPROVED PLOW STEEL GRADE ROPE WITH FIBER CORE (FC)

Rope Diameter, Inches	Rated Capacities, Tons (2,000 pounds)							
	Vertical			Choker			Vertical Basket[d,e]	
	HT[a]	MS[b]	Z[c]	HT	MS	Z	HT	MS
1/4	0.49	0.51	0.55	0.37	0.38	0.41	0.99	1.0
5/16	0.76	0.79	0.85	0.57	0.59	0.64	1.5	1.6
3/8	1.1	1.1	1.2	0.80	0.85	0.91	2.1	2.2
7/16	1.4	1.5	1.6	1.1	1.1	1.2	2.9	3.0
1/2	1.8	2.0	2.1	1.4	1.5	1.6	3.7	3.9
9/16	2.3	2.5	2.7	1.7	1.9	2.0	4.6	5.0
5/8	2.8	3.1	3.3	2.1	2.3	2.5	5.6	6.2
3/4	3.9	4.4	4.8	2.9	3.3	3.6	7.8	8.8
7/8	5.1	5.9	6.4	3.9	4.5	4.8	10.0	12.0
1	6.7	7.7	8.4	5.0	5.8	6.3	13.0	15.0
1-1/8	8.4	9.5	10.0	6.3	7.1	7.9	17.0	19.0
1-1/4	10.0	12.0	12.0	7.7	8.7	9.7	21.0	23.0
1-3/8	12.0	14.0	15.0	9.3	10.0	12.0	25.0	28.0
1-1/2	15.0	16.0	18.0	11.0	12.0	14.0	29.0	33.0
1-5/8	19.0	19.0	21.0	13.0	14.0	16.0	34.0	38.0
1-3/4	20.0	22.0	24.0	15.0	17.0	19.0	40.0	45.0
2	26.0	29.0	32.0	19.0	22.0	24.0	51.0	58.0

(a) HT = Hand tucked splice and hidden tuck splice.

(b) MS = Mechanical splice.

(c) Z = Zinc poured socket.

(d) These values only apply when the D/d ratio for HT slings is 10 or greater, and for MS and Z slings is 20 or greater where D = diameter of curvature around which the body of the sling is bent, and d = diameter of rope.

(e) These values are based on both sides being vertical. If they are not vertical, the rated capacity must be reduced. If two basket slings are used, the angle between the slings must also be considered.

Cable-laid rope with IWRC is sometimes used in slings where flexibility and kink resistance are important. Braided rope slings are also used for their flexibility, and kink and rotation resistance. Slings are commonly used in critical applications and should be inspected frequently for corrosion, broken wires, crushing, and doglegs.

Wire rope used in salvage work as tackle or purchase ropes are usually 6 x 37 construction with IWRC, galvanized for corrosion protection. These ropes also should be inspected frequently. For further information on this application, the U. S. Navy Salvage Manual should be consulted.

9.15. HAULAGE AND DRAGLINE ROPES

Since abrasive conditions are normally encountered in haulage and dragline work, Lang-lay ropes are generally selected because they have somewhat more abrasion resistance than regular-lay ropes. These ropes may generally be subdivided into hoist ropes (lifting and boom) and draglines. The suggested rope constructions for these categories are shown in Table 9-5. Design factors of at least 5.0 are recommended for long rope life.

Table 9-5. HAULAGE AND DRAGLINE ROPES

Type	Rope Diameter	Suggested Rope Construction
Hoist	3/8 - 1-1/8	6 x 25 Filler Wire. Improved Plow Steel, Regular Lay or Lang Lay, IWRC
	1-1/4 and over	6 x 37 Improved Plow Steel, Regular Lay or Lang Lay, IWRC
Dragline	1/2 - 1-3/8	6 x 21 Filler Wire, Extra Improved Plow Steel, Lang Lay, IWRC
	1-1/2 - 2-1/2	6 x 25 Filler Wire, Extra Improved Plow Steel, Lang Lay, IWRC
	2-5/8 - 3-1/2	6 x 41 Seale Filler Wire, Extra Improved Plow Steel, Lang Lay, IWRC
	2-5/8 - 3-1/2	6 x 49 Seale-Warrington-Seale, Extra Improved Plow Steel, Lang Lay, IWRC
	3-3/4 and over	6 x 55 Seale-Warrington-Seale, Extra Improved Plow Steel, Lang Lay, IWRC

The dragline ropes should be equipped with fixed ends to prevent rotation and should be cleaned and lubricated frequently to extend rope life. Since boom hoist ropes suffer fatigue damage at the end fittings due to shock and vibration loading; the IWRC commonly fails first, leaving the outer strands to support the entire hoist load. For this reason, hoist ropes should be inspected and resocketed regularly.

9.16. TORPEDO RECOVERY ROPES

Torpedo handling ropes may be 6 x 19 or 6 x 37 construction, corrosion-resistant steel. The 6 x 19 rope is used for bridles and pendants because it is reasonably flexible, strong, and inexpensive. When greater flexibility is desired in a pendant, 6 x 37 is chosen. While swaged sockets are occasionally used in this application, poured zinc sockets are preferred.

9.17. AMMI-LIFT DOCK ROPES

At present, 7/8-inch diameter, 3 x 46 ropes of galvanized improved plow steel are used in conjunction with floating lift platforms and large winches, where they act as stabilizer lines. Because these ropes are often submerged in seawater, a heavy coating of grease is usually applied to prevent premature corrosion. When inspecting these ropes, this grease must be stripped off in order to detect damage to the rope (see "NAVFAC P-300, Appendix L" for inspection procedures). Swaged end fittings are normally installed, but zinc sockets are equally effective.

9.18. RADIO ANTENNA LINES

Phosphor bronze wire rope with a black vinyl coating is commonly used for radio antenna lines. A 6 x 19 construction is often used, since flexibility and fatigue resistance over sheaves are not major considerations. A special waterproofing operation is required for the completed system (see NAVSHIPS Technical Manual 0967-177-3020). End terminations may be wire rope clamps, soldered lugs, of fiege fittings.

9.19. MESSENGER-BUOY ROPES

Messenger buoys are mounted in the upper part of a submarine in a compartment open to the sea. Normally the buoy and its rope tether is secured, but the system must release to rise to the surface for signalling: 7/16-inch diameter 6 x 37 regular-lay construction is normally used because of its flexibility and the wire material is usually chosen to be corrosion-resistant steel, Type 304. The end fittings are also corrosion-resistant steel in most cases; one end is made with a poured zinc socket, while the other is manufactured with a special poured zinc bung fitting.

10. TABLES OF USEFUL INFORMATION

Table 10-1. WIRE-ROPE DIAMETER CONVERSION TO METRIC SYSTEM

Fractional Diameter (Inches)	Decimal Equivalent (Inches)	Oversize Tolerance (Inches)	Approximate Metric Diameter (Millimeters)
1/4	0.2500	0.2650	6.5
5/16	0.3125	0.3281	8.0
3/8	0.3750	0.3938	9.5
7/16	0.4375	0.4594	11.0
1/2	0.5000	0.5250	13.0
9/16	0.5625	0.5906	14.5
5/8	0.6250	0.6563	16.0
3/4	0.7500	0.7875	19.0
7/8	0.8750	0.9188	22.0
1	1.0000	1.0500	26.0
1-1/8	1.1250	1.1813	29.0
1-1/4	1.2500	1.3125	32.0
1-3/4	1.3750	1.4438	35.0
1-1/2	1.5000	1.5750	38.0
1-5/8	1.6250	1.7063	42.0
1-3/4	1.7500	1.8375	45.0
1-7/8	1.8750	1.9688	48.0
2	2.0000	2.1000	51.0
2-1/8	2.1250	2.2313	54.0
2-1/4	2.2500	2.3625	57.0
2-3/8	2.3750	2.4938	61.0
2-1/2	2.5000	2.6250	64.0
2-5/8	2.6250	2.7563	67.0
2-3/4	2.7500	2.8875	70.0
2-7/8	2.8750	3.0188	74.0
3	3.0000	3.1500	77.0

Table 10-2. LINEAR MEASURE

1 millimeter	= 0.03937 inches	1 kilometer	= 0.62137 miles
1 centimeter	= 0.3937 inches	1 inch	= 25.4 millimeters
1 decimeter	= 3.937 inches	1 inch	= 2.54 centimeters
1 meter	= 39.37 inches	1 inch	= .254 decimeters
1 meter	= 3.28083 feet	1 inch	= .0254 meters
1 meter	= 1.09361 yards	1 foot	= .3048 meters
1 kilometer	= 3280.83 feet	1 yard	= .9144 meters
1 kilometer	= 1093.61 yards	1 mile	= 1.60935 kilometers

Table 10-3. SQUARE MEASURE

1 square millimeter	= 0.00155 square inches
1 square millimeter	= 1973.5 circular mils
1 square centimeter	= 0.155 square inches
1 square decimeter	= 15.5 square inches
1 square meter	= 1550 square inches
1 square meter	= 10.7639 square feet
1 square meter	= 1.196 square yards
1 square kilometer	= 0.386109 square miles
1 square kilometer	= 247.11 acres
1 square inch	= 645.2 square millimeters
1 squre inch	= 6.452 square centimeters
1 square inch	= 0.06452 square decimeters
1 square foot	= 0.0929 square meters
1 square yard	= 0.836 square meters

Table 10-4. CUBIC MEASURE

1 cubic centimeter	= 0.61 cubic inches
1 cubic decimeter	= 61.0234 cubic inches
1 cubic decimeter	= 0.035314 cubic feet
1 cubic meter	= 35.314 cubic feet
1 cubic meter	= 1.308 cubic yards

Table 10-5. WEIGHT

1 gram	= 15.432 grains
1 gram	= 0.03527 ounce (Avoirdupois)
1 grain	= 0.0648 gram
1 pound	= 0.4536 kilogram
1 metric ton (1000 kilograms)	= 2204.6 pounds
1 metric ton (1000 kilograms)	= 0.9842 gross ton
1 metric ton (1000 kilograms)	= 1.1023 net tons

Table 10-6. CAPACITY

1 liter	= 61.0234 cubic inches
1 liter	= 0.03531 cubic foot
1 liter	= 0.2642 gallon
1 cubic foot	= 28.317 liters
1 gallon	= 3.785 liters

Table 10-7. COMPOUND UNITS

1 gram per square millimeter	= 1.422 pounds per square inch
1 kilogram per square millimeter	= 1422.32 pounds per square inch
1 kilogram per square centimeter	= 14.2232 pounds per square inch
1 kilogram per square meter	= 0.2048 pound per square foot
1 kilogram per square meter	= 1.8433 pounds per square yard
1 kilogram per meter	= 7.2330 foot pounds
1 kilogram per meter	= 0.6720 pound per foot
1 pound per square inch	= 0.07031 kilogram per square centimeter
1 pound per square foot	= 0.0004882 kilogram per square centimeter
1 pound per square foot	= 0.006944 pound per square inch
1 pound per cubic inch	= 27.6798 grams per cubic centimeter
1 pound per cubic inch	= 27679.7 kilograms per cubic meter
1 pound per cubic foot	= 16.0184 kilograms per cubic meter
1 kilogram per cubic meter	= 0.06243 pound per cubic foot
1 foot per second	= 0.30480 meter per second
1 meter per second	= 3.28083 feet per second
1 meter per second	= 2.23693 miles per hour

Table 10-8. SINES AND COSINES

Degrees	Sines							Cosines
	0'	10'	20'	30'	40'	50'	60'	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
Sines	60'	50'	40'	30'	20'	10'	0'	Degrees
	Cosines							

Table 10-8. (Concluded)

Degrees	Cosines 0′	10′	20′	30′	40′	50′	60′	Sines
0	1.00000	1.00000	0.99998	0.99996	0.99993	0.99989	0.99985	89
1	0.99985	0.99979	0.99973	0.99966	0.99958	0.99949	0.99939	88
2	0.99939	0.99929	0.99917	0.99905	0.99892	0.99878	0.99863	87
3	0.99863	0.99847	0.99831	0.99813	0.99795	0.99776	0.99756	86
4	0.99756	0.99736	0.99714	0.99692	0.99668	0.99644	0.99619	85
5	0.99619	0.99594	0.99567	0.99540	0.99511	0.99482	0.99452	84
6	0.99452	0.99421	0.99390	0.99357	0.99324	0.99290	0.99255	83
7	0.99255	0.99219	0.99182	0.99144	0.99106	0.99067	0.99027	82
8	0.99027	0.98985	0.98944	0.98902	0.98858	0.98814	0.98769	81
9	0.98769	0.98723	0.98676	0.98629	0.98580	0.98531	0.98481	80
10	0.98481	0.98430	0.98378	0.98325	0.98272	0.98218	0.98163	79
11	0.98163	0.98107	0.98050	0.97992	0.97934	0.97875	0.97815	78
12	0.97815	0.97754	0.97692	0.97630	0.97566	0.97502	0.97437	77
13	0.97437	0.97371	0.97304	0.97237	0.97169	0.97100	0.97030	76
14	0.97030	0.96959	0.96887	0.96815	0.96742	0.96667	0.96593	75
15	0.96593	0.96517	0.96440	0.96363	0.96285	0.96206	0.96126	74
16	0.96126	0.96046	0.95964	0.95882	0.95799	0.95715	0.95630	73
17	0.95630	0.95545	0.95459	0.95372	0.95284	0.95195	0.95106	72
18	0.95106	0.95015	0.94924	0.94832	0.94740	0.94646	0.94552	71
19	0.94552	0.94457	0.94361	0.94264	0.94167	0.94068	0.93969	70
20	0.93969	0.93869	0.93769	0.93667	0.93565	0.93462	0.93358	69
21	0.93358	0.93253	0.93148	0.93042	0.92935	0.92827	0.92718	68
22	0.92718	0.92609	0.92499	0.92388	0.92276	0.92164	0.92050	67
23	0.92050	0.91936	0.91822	0.91706	0.91590	0.91472	0.91355	66
24	0.91355	0.91236	0.91116	0.90996	0.90875	0.90753	0.90631	65
25	0.90631	0.90507	0.90383	0.90259	0.90133	0.90007	0.89879	64
26	0.89879	0.89752	0.89623	0.89493	0.89363	0.89232	0.89101	63
27	0.89101	0.88968	0.88835	0.88701	0.88566	0.88431	0.88295	62
28	0.88295	0.88158	0.88020	0.87882	0.87743	0.87603	0.87462	61
29	0.87462	0.87321	0.87178	0.87036	0.86892	0.86748	0.86603	60
30	0.86603	0.86457	0.86310	0.86163	0.86015	0.85866	0.85717	59
31	0.85717	0.85567	0.85416	0.85264	0.85112	0.84959	0.84805	58
32	0.84805	0.84650	0.84495	0.84339	0.84182	0.84025	0.83867	57
33	0.83867	0.83708	0.83549	0.83389	0.83228	0.83066	0.82904	56
34	0.82904	0.82741	0.82577	0.82413	0.82248	0.82082	0.81915	55
35	0.81915	0.81748	0.81580	0.81412	0.81242	0.81072	0.80902	54
36	0.80902	0.80730	0.80558	0.80386	0.80212	0.80038	0.79864	53
37	0.79864	0.79688	0.79512	0.79335	0.79158	0.78980	0.78801	52
38	0.78801	0.78622	0.78442	0.78261	0.78079	0.77897	0.77715	51
39	0.77715	0.77531	0.77347	0.77162	0.76977	0.76791	0.76604	50
40	0.76604	0.76417	0.76229	0.76041	0.75851	0.75661	0.75471	49
41	0.75471	0.75280	0.75088	0.74896	0.74703	0.74509	0.74314	48
42	0.74314	0.74120	0.73924	0.73728	0.73531	0.73333	0.73135	47
43	0.73135	0.72937	0.72737	0.72537	0.72337	0.72136	0.71934	46
44	0.71934	0.71732	0.71529	0.71325	0.71121	0.70916	0.70711	45
Cosines	60′	50′	40′	30′	20′	10′	0′ Sines	Degrees

Table 10-9. TANGENTS AND COTANGENTS

Degrees	Tangents 0′	10′	20′	30′	40′	50′	60′	Cotangents
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85
5	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75
15	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70
20	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54674	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60
30	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55
35	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50
40	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
Tangents	Cotangents 60′	50′	40′	30′	20′	10′	0′	Degrees

Table 10-9. (Concluded)

Degrees	Cotangents 0′	10′	20′	30′	40′	50′	60′	Tangents
0	∞	343.77371	171.88540	114.58865	85.93979	68.75009	57.28996	89
1	57.28996	49.10388	42.96408	38.18846	34.36777	31.24158	28.63625	88
2	28.63625	26.43160	24.54176	22.90377	21.47040	20.20555	19.08114	87
3	19.08114	18.07498	17.16934	16.34986	15.60478	14.92442	14.30067	86
4	14.30067	13.72674	13.19688	12.70621	12.25051	11.82617	11.43005	85
5	11.43005	11.05943	10.71191	10.38540	10.07803	9.78817	9.51436	84
6	9.51436	9.25530	9.00983	8.77689	8.55555	8.34496	8.14435	83
7	8.14435	7.95302	7.77035	7.59575	7.42871	7.26873	7.11537	82
8	7.11537	6.96823	6.82694	6.69116	6.56055	6.43484	6.31375	81
9	6.31375	6.19703	6.08444	5.97576	5.87080	5.76937	5.67128	80
10	5.67128	5.57638	5.48451	5.39552	5.30928	5.22566	5.14455	79
11	5.14455	5.06584	4.98940	4.91516	4.84300	4.77286	4.70463	78
12	4.70463	4.63825	4.57363	4.51071	4.44942	4.38969	4.33148	77
13	4.33148	4.27471	4.21933	4.16530	4.11256	4.06107	4.01078	76
14	4.01078	3.96165	3.91364	3.86671	3.82083	3.77595	3.73205	75
15	3.73205	3.68909	3.64705	3.60588	3.56557	3.52609	3.48741	74
16	3.48741	3.44951	3.41236	3.37594	3.34023	3.30521	3.27085	73
17	3.27085	3.23714	3.20406	3.17159	3.13972	3.10842	3.07768	72
18	3.07768	3.04749	3.01783	2.98869	2.96004	2.93189	2.90421	71
19	2.90421	2.87700	2.85023	2.82391	2.79802	2.77254	2.74748	70
20	2.74748	2.72281	2.69853	2.67462	2.65109	2.62791	2.60509	69
21	2.60509	2.58261	2.56046	2.53865	2.51715	2.49597	2.47509	68
22	2.47509	2.45451	2.43422	2.41421	2.39449	2.37504	2.35585	67
23	2.35585	2.33693	2.31826	2.29984	2.28167	2.26374	2.24604	66
24	2.24604	2.22857	2.21132	2.19430	2.17749	2.16090	2.14451	65
25	2.14451	2.12832	2.11233	2.09654	2.08094	2.06553	2.05030	64
26	2.05030	2.03526	2.02039	2.00569	1.99116	1.97680	1.96261	63
27	1.96261	1.94858	1.93470	1.92098	1.90741	1.89400	1.88073	62
28	1.88073	1.86760	1.85462	1.84177	1.82907	1.81649	1.80405	61
29	1.80405	1.79174	1.77955	1.76749	1.75556	1.74375	1.73205	60
30	1.73205	1.72047	1.70901	1.69766	1.68643	1.67530	1.66428	59
31	1.66428	1.65337	1.64256	1.63185	1.62125	1.61074	1.60033	58
32	1.60033	1.59002	1.57981	1.56969	1.55966	1.54972	1.53987	57
33	1.53987	1.53010	1.52043	1.51084	1.50133	1.49190	1.48256	56
34	1.48256	1.47330	1.46411	1.45501	1.44598	1.43703	1.42815	55
35	1.42815	1.41934	1.41061	1.40195	1.39336	1.38484	1.37638	54
36	1.37638	1.36800	1.35968	1.35142	1.34323	1.33511	1.32704	53
37	1.32704	1.31904	1.31110	1.30323	1.29541	1.28764	1.27994	52
38	1.27994	1.27230	1.26471	1.25717	1.24969	1.24227	1.23490	51
39	1.23490	1.22758	1.22031	1.21310	1.20593	1.19882	1.19175	50
40	1.19175	1.18474	1.17777	1.17085	1.16398	1.15715	1.15037	49
41	1.15037	1.14363	1.13694	1.13029	1.12369	1.11713	1.11061	48
42	1.11061	1.10414	1.09770	1.09131	1.08496	1.07864	1.07237	47
43	1.07237	1.06613	1.05994	1.05378	1.04766	1.04158	1.03553	46
44	1.03553	1.02952	1.02355	1.01761	1.01170	1.00583	1.00000	45
Cotangents	Tangents 60′	50′	40′	30′	20′	10′	0′	Degrees

Table 10-10. SECANTS AND COSECANTS

Degrees	Secants 0′	10′	20′	30′	40′	50′	60′	Cosecants
0	1.00000	1.00000	1.00002	1.00004	1.00007	1.00011	1.00015	89
1	1.00015	1.00021	1.00027	1.00034	1.00042	1.00051	1.00061	88
2	1.00061	1.00072	1.00083	1.00095	1.00108	1.00122	1.00137	87
3	1.00137	1.00153	1.00169	1.00187	1.00205	1.00224	1.00244	86
4	1.00244	1.00265	1.00287	1.00309	1.00333	1.00357	1.00382	85
5	1.00382	1.00408	1.00435	1.00463	1.00491	1.00521	1.00551	84
6	1.00551	1.00582	1.00614	1.00647	1.00681	1.00715	1.00751	83
7	1.00751	1.00787	1.00825	1.00863	1.00902	1.00942	1.00983	82
8	1.00983	1.01024	1.01067	1.01111	1.01155	1.01200	1.01247	81
9	1.01247	1.01294	1.01342	1.01391	1.01440	1.01491	1.01543	80
10	1.01543	1.01595	1.01649	1.01703	1.01758	1.01815	1.01872	79
11	1.01872	1.01930	1.01989	1.02049	1.02110	1.02171	1.02234	78
12	1.02234	1.02298	1.02362	1.02428	1.02494	1.02562	1.02630	77
13	1.02630	1.02700	1.02770	1.02842	1.02914	1.02987	1.03061	76
14	1.03061	1.03137	1.03213	1.03290	1.03368	1.03447	1.03528	75
15	1.03528	1.03609	1.03691	1.03774	1.03858	1.03944	1.04030	74
16	1.04030	1.04117	1.04206	1.04295	1.04385	1.04477	1.04569	73
17	1.04569	1.04663	1.04757	1.04853	1.04950	1.05047	1.05146	72
18	1.05146	1.05246	1.05347	1.05449	1.05552	1.05657	1.05762	71
19	1.05762	1.05869	1.05976	1.06085	1.06195	1.06306	1.06418	70
20	1.06418	1.06531	1.06645	1.06761	1.06878	1.06995	1.07115	69
21	1.07115	1.07235	1.07356	1.07479	1.07602	1.07727	1.07853	68
22	1.07853	1.07981	1.08109	1.08239	1.08370	1.08503	1.08636	67
23	1.08636	1.08771	1.08907	1.09044	1.09183	1.09323	1.09464	66
24	1.09464	1.09606	1.09750	1.09895	1.10041	1.10189	1.10338	65
25	1.10338	1.10488	1.10640	1.10793	1.10947	1.11103	1.11260	64
26	1.11260	1.11419	1.11579	1.11740	1.11903	1.12067	1.12233	63
27	1.12233	1.12400	1.12568	1.12738	1.12910	1.13083	1.13257	62
28	1.13257	1.13433	1.13610	1.13789	1.13970	1.14152	1.14335	61
29	1.14335	1.14521	1.14707	1.14896	1.15085	1.15277	1.15470	60
30	1.15470	1.15665	1.15861	1.16059	1.16259	1.16460	1.16663	59
31	1.16663	1.16868	1.17075	1.17283	1.17493	1.17704	1.17918	58
32	1.17918	1.18133	1.18350	1.18569	1.18790	1.19012	1.19236	57
33	1.19236	1.19463	1.19691	1.19920	1.20152	1.20386	1.20622	56
34	1.20622	1.20859	1.21099	1.21341	1.21584	1.21830	1.22077	55
35	1.22077	1.22327	1.22579	1.22833	1.23089	1.23347	1.23607	54
36	1.23607	1.23869	1.24134	1.24400	1.24669	1.24940	1.25214	53
37	1.25214	1.25489	1.25767	1.26047	1.26330	1.26615	1.26902	52
38	1.26902	1.27191	1.27483	1.27778	1.28075	1.28374	1.28676	51
39	1.28676	1.28980	1.29287	1.29597	1.29909	1.30223	1.30541	50
40	1.30541	1.30861	1.31183	1.31509	1.31837	1.32168	1.32501	49
41	1.32501	1.32838	1.33177	1.33519	1.33864	1.34212	1.34563	48
42	1.34563	1.34917	1.35274	1.35634	1.35997	1.36363	1.36733	47
43	1.36733	1.37105	1.37481	1.37860	1.38242	1.38628	1.39016	46
44	1.39016	1.39409	1.39804	1.40203	1.40606	1.41012	1.41421	45
Secants	60′	50′	40′	30′	20′	10′	0′	Degrees
	Cosecants							

Table 10-10. (Concluded)

Degrees	Cosecants 0′	10′	20′	30′	40′	50′	60′	Secants
0	∞	343.77516	171.88831	114.59301	85.94561	68.75736	57.29869	89
1	57.29869	49.11406	42.97571	38.20155	34.38232	31.25758	28.65371	88
2	28.65371	26.45051	24.56212	22.92559	21.49368	20.23028	19.10732	87
3	19.10732	18.10262	17.19843	16.38041	15.63679	14.95788	14.33559	86
4	14.33559	13.76312	13.23472	12.74550	12.29125	11.86837	11.47371	85
5	11.47371	11.10455	10.75849	10.43343	10.12752	9.83912	9.56677	84
6	9.56677	9.30917	9.06515	8.83367	8.61379	8.40466	8.20551	83
7	8.20551	8.01565	7.83443	7.66130	7.49571	7.33719	7.18530	82
8	7.18530	7.03962	6.89979	6.76547	6.63633	6.51208	6.39245	81
9	6.39245	6.27719	6.16607	6.05886	5.95536	5.85539	5.75877	80
10	5.75877	5.66533	5.57493	5.48740	5.40263	5.32049	5.24084	79
11	5.24084	5.16359	5.08863	5.01585	4.94517	4.87649	4.80973	78
12	4.80973	4.74482	4.68167	4.62023	4.56041	4.50216	4.44541	77
13	4.44541	4.39012	4.33622	4.28366	4.23239	4.18238	4.13357	76
14	4.13357	4.08591	4.03938	3.99393	3.94952	3.90613	3.86370	75
15	3.86370	3.82223	3.78166	3.74198	3.70315	3.66515	3.62796	74
16	3.62796	3.59154	3.55587	3.52094	3.48671	3.45317	3.42030	73
17	3.42030	3.38808	3.35649	3.32551	3.29512	3.26531	3.23607	72
18	3.23607	3.20737	3.17920	3.15155	3.12440	3.09774	3.07155	71
19	3.07155	3.04584	3.02057	2.99574	2.97135	2.94737	2.92380	70
20	2.92380	2.90063	2.87785	2.85545	2.83342	2.81175	2.79043	69
21	2.79043	2.76945	2.74881	2.72850	2.70851	2.68884	2.66947	68
22	2.66947	2.65040	2.63162	2.61313	2.59491	2.57698	2.55930	67
23	2.55930	2.54190	2.52474	2.50784	2.49119	2.47477	2.45859	66
24	2.45859	2.44264	2.42692	2.41142	2.39614	2.38107	2.36620	65
25	2.36620	2.35154	2.33708	2.32282	2.30875	2.29487	2.28117	64
26	2.28117	2.26766	2.25432	2.24116	2.22817	2.21535	2.20269	63
27	2.20269	2.19019	2.17786	2.16568	2.15366	2.14178	2.13005	62
28	2.13005	2.11847	2.10704	2.09574	2.08458	2.07356	2.06267	61
29	2.06267	2.05191	2.04128	2.03077	[illegible]	2.01014	2.00000	60
30	2.00000	1.98998	1.98008	1.97029	1.96062	1.95106	1.94160	59
31	1.94160	1.93226	1.92302	1.91388	1.90485	1.89591	1.88709	58
32	1.88708	1.87834	1.86970	1.86116	1.85271	1.84435	1.83608	57
33	1.83608	1.82790	1.81981	1.81180	1.80388	1.79604	1.78829	56
34	1.78829	1.78062	1.77303	1.76552	1.75808	1.75073	1.74345	55
35	1.74345	1.73624	1.72911	1.72205	1.71506	1.70815	1.70130	54
36	1.70130	1.69452	1.68782	1.68117	1.67460	1.66809	1.66164	53
37	1.66164	1.65526	1.64894	1.64268	1.63648	1.63035	1.62427	52
38	1.62427	1.61825	1.61229	1.60639	1.60054	1.59475	1.58902	51
39	1.58902	1.58333	1.57771	1.57213	1.56661	1.56114	1.55572	50
40	1.55572	1.55036	1.54504	1.53977	1.53455	1.52938	1.52425	49
41	1.52425	1.51918	1.51415	1.50916	1.50422	1.49933	1.49448	48
42	1.49448	1.48967	1.48491	1.48019	1.47551	1.47087	1.46628	47
43	1.46628	1.46173	1.45721	1.45274	1.44831	1.44391	1.43956	46
44	1.43956	1.43524	1.43096	1.42672	1.42251	1.41835	1.41421	45
Cosecants	60′	50′	40′	30′ Secants	20′	10′	0′	Degrees

Table 10-11. PHYSICAL AND MECHANICAL PROPERTIES OF WIRE

Diameter, Inches	Area, Square Inches (x 10^3)	Breaking Force (for 100,000 psi Ultimate Strength), Pounds	Weight[(a)], Pounds per 1000 Feet	Feet[(a)] per Pound
0.0010	0.00079	0.079	0.00267	375000
0.0012	0.00113	0.113	0.00384	260000
0.0014	0.00154	0.154	0.00523	191000
0.0016	0.00201	0.201	0.00683	146000
0.0018	0.00254	0.254	0.00864	116000
0.0020	0.00314	0.314	0.0107	93700
0.0022	0.00380	0.380	0.0129	77500
0.0024	0.00452	0.452	0.0154	65100
0.0026	0.00531	0.531	0.0180	55500
0.0028	0.00616	0.616	0.0209	47800
0.0030	0.00707	0.707	0.0240	41700
0.0032	0.00804	0.804	0.0273	36600
0.0034	0.00908	0.908	0.0308	32400
0.0036	0.0102	1.02	0.0346	28900
0.0038	0.0113	1.13	0.0385	26000
0.0040	0.0126	1.26	0.0427	23400
0.0042	0.0138	1.38	0.0470	21200
0.0044	0.0152	1.52	0.0516	19400
0.0046	0.0166	1.66	0.0564	17700
0.0048	0.0181	1.81	0.0614	16300
0.0050	0.0196	1.96	0.0667	15000
0.0055	0.0238	2.38	0.0807	12400
0.0060	0.0283	2.83	0.0960	10410
0.0065	0.0332	3.32	0.113	8820
0.0070	0.0385	3.85	0.131	7650
0.0075	0.0442	4.42	0.150	6660
0.0080	0.0503	5.03	0.171	5860
0.0085	0.0567	5.67	0.193	5190
0.0090	0.0636	6.36	0.216	4630
0.0095	0.0709	7.09	0.241	4150
0.0100	0.0785	7.85	0.267	3750
0.0105	0.0866	8.66	0.294	3400
0.0110	0.0950	9.5	0.323	3100
0.0115	0.104	10.4	0.352	2830
0.0120	0.113	11.3	0.384	2600
0.0125	0.123	12.3	0.417	2400

Table 10-11. (Continued)

Diameter, Inches	Area, Square Inches ($x 10^3$)	Breaking Force (for 100,000 psi Ultimate Strength), Pounds	Weight[a], Pounds per 1000 Feet	Feet[a] per Pound
0.0130	0.133	13.3	0.451	2220
0.0135	0.143	14.3	0.486	2060
0.0140	0.154	15.4	0.523	1910
0.0145	0.165	16.5	0.561	1780
0.0150	0.177	17.7	0.600	1670
0.0155	0.189	18.9	0.641	1560
0.0160	0.201	20.1	0.683	1460
0.0165	0.214	21.4	0.727	1380
0.0170	0.227	22.7	0.771	1300
0.0175	0.241	24.1	0.817	1220
0.0180	0.255	25.5	0.864	1160
0.0185	0.269	26.9	0.913	1090
0.0190	0.284	28.4	0.964	1040
0.0195	0.299	29.9	1.01	986
0.0200	0.314	31.4	1.07	237
0.0205	0.330	33.0	1.12	892
0.0210	0.346	34.6	1.18	850
0.0215	0.363	36.3	1.23	811
0.0220	0.380	38.0	1.29	775
0.0225	0.397	39.7	1.35	742
0.0230	0.415	41.5	1.41	709
0.0235	0.433	43.3	1.47	680
0.0240	0.452	45.2	1.54	651
0.0245	0.471	47.1	1.60	625
0.025	0.491	49.1	1.67	600
0.026	0.531	53.1	1.80	554
0.027	0.573	57.3	1.94	514
0.028	0.616	61.6	2.09	478
0.029	0.661	66.1	2.24	445
0.030	0.707	70.7	2.40	417
0.031	0.755	75.5	2.56	390
0.032	0.804	80.4	2.73	366
0.033	0.855	85.5	2.91	344
0.034	0.908	90.8	3.08	324
0.035	0.962	96.2	3.27	306
0.036	1.02	102	3.46	289

Table 10-11. (Continued)

Diameter, Inches	Area, Square Inches (x 10^3)	Breaking Force (for 100,000 psi Ultimate Strength), Pounds	Weight[a], Pounds per 1000 Feet	Feet[a] per Pound
0.037	1.07	107	3.65	274
0.038	1.13	113	3.85	260
0.039	1.19	119	4.06	246
0.040	1.26	126	4.27	234
0.041	1.32	132	4.48	223
0.042	1.38	138	4.71	212
0.043	1.45	145	4.93	203
0.044	1.52	152	5.16	194
0.045	1.59	159	5.40	185
0.[illegible]	1.66	166	5.64	177
0.[illegible]	1.73	173	5.89	170
0.048	1.81	181	6.15	163
0.049	1.88	189	6.40	156
0.050	1.97	197	6.67	150
0.051	2.04	204	6.94	144
0.052	2.12	212	7.21	139
0.053	2.21	221	7.49	133
0.054	2.29	229	7.78	129
0.055	2.38	238	8.07	124
0.056	2.46	246	8.36	120
0.057	2.55	255	8.67	115
0.058	2.64	264	8.97	111
0.059	2.73	273	9.28	108
0.060	2.83	283	9.60	104
0.061	2.92	292	9.93	101
0.062	3.02	302	10.2	97.5
0.063	3.12	312	10.6	94.4
0.064	3.22	322	10.9	91.5
0.065	3.32	332	11.3	88.7
0.066	3.42	342	11.6	86.1
0.067	3.53	353	12.0	83.5
0.068	3.63	363	12.3	81.1
0.069	3.74	374	12.7	78.7
0.070	3.85	385	13.1	76.5
0.071	3.96	396	13.4	74.4
0.072	4.07	407	13.8	72.3

Table 10-11. (Continued)

Diameter, Inches	Area, Square Inches (x 10^3)	Breaking Force (for 100,000 psi Ultimate Strength), Pounds	Weight[a] Pounds per 1000 Feet	Feet[a] per Pound
0.073	4.18	418	14.2	70.4
0.074	4.30	430	14.6	68.4
0.075	4.42	442	15.0	66.6
0.076	4.54	454	15.4	64.9
0.077	4.66	466	15.8	63.2
0.078	4.78	478	16.2	61.6
0.079	4.90	490	16.6	60.1
0.080	5.03	503	17.1	58.6
0.081	5.15	515	17.5	57.1
0.082	5.28	528	17.9	55.8
0.083	5.41	541	18.4	54.4
0.084	5.54	554	18.8	53.1
0.085	5.67	567	19.3	51.9
0.086	5.81	581	19.7	50.7
0.087	5.94	594	20.2	49.5
0.088	6.08	608	20.6	48.4
0.089	6.22	622	21.1	47.3
0.090	6.36	636	21.6	46.3
0.091	6.50	650	22.1	45.3
0.092	6.65	665	22.6	44.3
0.093	6.79	679	23.1	43.4
0.094	6.94	694	23.6	42.4
0.095	7.09	709	24.1	41.5
0.096	7.24	724	24.6	40.7
0.097	7.39	739	25.1	39.8
0.098	7.54	754	25.6	39.0
0.099	7.70	770	26.1	38.2
0.100	7.85	785	26.7	37.5
0.101	8.01	801	27.2	36.7
0.102	8.17	817	27.7	36.0
0.103	8.33	833	28.3	35.3
0.104	8.49	849	28.8	34.7
0.105	8.66	865	29.4	34.0
0.106	8.82	882	30.0	33.4
0.107	8.99	899	30.5	32.7
0.108	9.16	916	31.1	32.1

Table 10-11. (Continued)

Diameter, Inches	Area, Square Inches (x 10^3)	Breaking Force (for 100,000 psi Ultimate Strength), Pounds	Weight[a] Pounds per 1000 Feet	Feet[a] per Pound
0.109	9.33	933	31.7	31.6
0.110	9.50	950	32.3	31.0
0.111	9.68	967	32.9	30.4
0.112	9.85	985	33.5	29.9
0.113	10.0	1000	34.1	29.4
0.114	10.2	1020	34.7	28.8
0.115	10.4	1040	35.3	28.3
0.116	10.6	1060	35.9	27.9
0.117	10.8	1080	36.5	27.4
0.118	10.9	1090	37.1	26.9
0.119	11.1	1110	37.8	26.5
0.120	11.3	1130	38.4	26.0
0.121	11.5	1150	39.0	25.6
0.122	11.7	1170	39.7	25.2
0.123	11.9	1190	40.3	24.8
0.124	12.1	1210	41.0	24.4
0.125	12.3	1230	41.7	24.0
0.126	12.5	1250	42.3	23.6
0.127	12.7	1270	43.0	23.2
0.128	12.9	1290	43.7	22.9
0.129	13.1	1310	44.4	22.5
0.130	13.3	1330	45.1	22.2
0.131	13.5	1350	45.8	21.8
0.132	13.7	1370	46.5	21.5
0.133	13.9	1390	47.8	21.2
0.134	14.1	1410	47.9	20.9
0.135	14.3	1430	48.6	20.6
0.136	14.5	1450	49.4	20.3
0.137	14.7	1470	50.1	20.0
0.138	15.0	1500	50.8	19.7
0.139	15.2	1520	51.6	19.4
0.140	15.4	1540	52.3	19.1
0.141	15.6	1560	53.1	18.8
0.142	15.8	1580	53.8	18.6
0.143	16.1	1610	54.6	18.3
0.144	16.3	1630	55.4	18.1

Table 10-11. (Concluded)

Diameter, Inches	Area, Square Inches (x 10^3)	Breaking Force (for 100,000 psi Ultimate Strength), Pounds	Weight[a] Pounds per 1000 Feet	Feet[a] per Pound
0.145	16.5	1650	56.1	17.8
0.146	16.7	1670	56.9	17.6
0.147	17.0	1700	57.7	17.3
0.148	17.2	1720	58.5	17.1
0.149	17.4	1740	59.3	16.9
0.150	17.7	1760	60.1	16.6
5/32	19.2	1920	65.2	15.3
11/64	23.2	2320	78.9	12.7
3/16	27.6	2760	93.8	10.7
13/64	32.4	3240	110	9.08
7/32	37.6	3760	128	7.83
15/64	43.1	4310	147	6.82
1/4	49.1	4910	167	5.99
17/64	55.4	5540	188	5.31
9/32	62.1	6210	211	4.74
19/64	69.2	6920	235	4.25
5/16	76.7	7670	261	3.84
21/64	84.6	8460	287	3.48

(a) Weights are calculated for steel wire with a density of 489.6 pounds per cubic foot. For the following materials, multiply by these factors:

	Weight per 1000 Feet	Feet per Pound
Stainless Steel:		
302, 304, 305 (density of 494.2 pounds per cubic foot)	1.009	.991
316 (density of 497.7 pounds per cubic foot)	1.017	.984
Aluminum (density of 168.5 pounds per cubic foot)	.344	2.906
Copper (density of 556.4 pounds per cubic foot)	1.136	.880
Phosphor Bronze (density of 554.7 pounds per cubic foot)	1.133	.883

Table 10-12. WIRE GAUGES

Wire Gauge	Diameter of Rope Wire, Inches	American[a] or Browne & Sharpe (A.W.G., B.+S.)	Birmingham or Stubbs (B.W.G.)	British[b] Standard (S. W. G.)
000000 (6-0)	.462	.5800	--	.464
00000 (5-0)	.431	.5165	.500	.432
0000 (4-0)	.394	.4600	.454	.400
000 (3-0)	.363	.4096	.425	.372
00 (2-0)	.331	.3648	.380	.348
0	.307	.3249	.340	.324
1	.283	.2893	.300	.300
2	.263	.2576	.284	.276
3	.244	.2294	.259	.252
4	.225	.2043	.238	.232
5	.207	.1819	.220	.212
6	.192	.1620	.203	.192
7	.177	.1443	.180	.176
8	.162	.1285	.165	.160
9	.148	.1144	.148	.144
10	.135	.1019	.134	.128
11	.121	.09074	.120	.116
12	.106	.08081	.109	.104
13	.092	.07196	.095	.092
14	.080	.06408	.083	.080
15	.072	.05707	.072	.072
16	.063	.05082	.065	.064
17	.054	.04526	.058	.056
18	.046	.04030	.049	.048
19	.041	.03589	.042	.040
20	.035	.03196	.035	.036
21	.032	.02846	.032	.032
22	.029	.02535	.028	.028
23	.026	.02257	.025	.024
24	.023	.02010	.022	.022
25	.020	.01790	.020	.020
26	.018	.01594	.018	.018
27	.017	.01420	.016	.0164
28	.016	.01264	.014	.0148
29	.015	.01126	.013	.0136
30	.014	.01003	.012	.0124
31	.0132	.008928	.010	.0116
32	.0128	.007950	.009	.0108
33	.0118	.007080	.008	.0100
34	.0104	.006305	.007	.0092

Table 10-12. (Concluded)

Wire Gauge	Diameter of Rope Wire, Inches	American[a] or Browne & Sharpe (A.W.G., B.+S.)	Birmingham or Stubbs (B.W.G.)	British[b] Standard (S. W. G.)
35	.0095	.005615	.005	.0084
36	.0090	.005000	.004	.0076
37	.0085	.004453	--	.0068
38	.0080	.003965	--	.0060
39	.0075	.003531	--	.0052
40	.0070	.003145	--	.0048
41	.0066	.002800	--	.0044
42	.0062	.002494	--	.0040
43	.0060	.002221	--	.0036
44	.0058	.001978	--	.0032
45	.0055	.001761	--	.0028
46	.0052	.001568	--	.0024
47	.0050	.001397	--	.0020
48	.0048	.001244	--	.0016
49	.0046	.001108	--	.0012
50	.0044	.0009863	--	.0010

(a) Commonly used for nonferrous wires.

(b) Do not confuse with Old English or London Wire Gauge, which is not the same.

11. GLOSSARY

A

ABRASION -- Surface loss of metal on the wires of a wire rope.

ACCELERATION -- The time rate of change in the velocity of a moving body. "Acceleration" is usually applied to a positive change; "deceleration is applied to a negative change.

ACCELERATION STRESS -- Additional stress imposed on a wire rope due to increasing velocity of load.

ACTUAL BREAKING STRENGTH (OR LOAD) -- See BREAKING STRENGTH.

AERIAL CONVEYER -- See CABLEWAYS and TRAMWAYS.

AGGREGATE BREAKING STRENGTH (OR LOAD) -- See BREAKING STRENGTH.

ALBERT'S LAY -- See LANG-LAY.

ALTERNATE LAY -- Lay of rope in which the wires of alternate strands are laid in right- and left-hand helices.

ALTERNATE LAY (SPECIAL) -- Lay of rope that has two Lang-lay strands alternating with one regular-lay strand. Also called HERRINGBONE.

ALUMINIZING (OF WIRE) -- Coating of wire with aluminum to increase its corrosion resistance.

AREA (METALLIC) -- Cross-sectional area of all the wires in a wire strand or rope; the aggregate area of all load-carrying wires.

ARMORED ROPE -- See STEEL CLAD ROPE.

B

BACKSTAY -- Guy or guys used to support a boom or mast; section of a suspension-bridge cable leading from towers to anchorage.

BAIL (SOCKET) -- The U-shaped member of a closed socket.

BAIL SHEAVE -- Equalizing sheave on an excavator bucket.

BARREL AND DRUM HOOKS -- Wide, flat hooks used in hoisting barrels and drums

BASKET (SOCKET) -- The conical bore of a socket into which the "broomed-out" end of the rope is inserted and secured with zinc or some other binding material.

BECKET -- A contrivance, such as a looped rope, large hook-and-eye, or grommet; used for fastening loose ropes.

BECKET LINE -- That part of the rope in a multiply reeved system that is dead-ended to one of the blocks.

BECKET LOOP -- (1) The fastening on a sheave block to which the dead end of a fall or rope is made fast; (2) a loop of small strand or rope fastened to the end of a rope to facilitate pulling in and anchoring the rope.

BENDING STRESSES -- The stresses imposed on the wires of a rope during bending over drums or sheaves.

BIGHT -- A curve or loop in a rope.

BIRDCAGE -- Enlargement of a rope due to the springing of the strands away from the core upon sudden release of load. Can also result from dragging a rope over a small diameter sheave under load.

BITT -- A deck fitting around which a rope is temporarily secured.

BLACK ROPE WIRE -- Uncoated (as drawn) wire. Commonly known as BRIGHT WIRE.

BLOCK -- The complete housing, attachments, and sheave or sheaves used with rope in a tackle.

BOOM -- A rigid structure extending from the center of a crane, shovel, or dragline.

BOOM LINES -- The wire ropes supporting the boom or jib on cranes, shovels, and draglines.

BOOM POINT SHEAVE -- The sheave on the end of the boom.

BREAKING STRENGTH (OR LOAD) -- (1) Ultimate or Actual: The load required to pull a wire, strand, or rope to destruction. (2) Aggregate: The sum of the individual breaking loads of all the wires in a strand or rope. (3) Catalog: The minimum breaking load of a rope or strand guaranteed by the manufacturer.

BREAKING STRESS -- The load per unit area induced in a rope at its point of failure.

BRIDGE CABLE -- Galvanized steel wire rope or strand usually used as a main suspension member in a suspension bridge.

BRIDGE -- See SADDLE.

BRIDGE SOCKET -- A steel casting with a basket for securing a rope end and equipped with an adjustable bolt. The closed type has a U-bolt, while the open type has two eyebolts and a pin.

BRIDLE CABLE -- A two-part wire-rope sling attached to a single-part line. The legs of the sling are spread to divide and equalize the load.

BRIGHT WIRE -- Wire made of iron or carbon-steel and not galvanized, aluminized, or otherwise coated.

BRONZE ROPE -- Rope made of phosphor-bronze wire.

BROOMING -- The unlaying and straightening of strands and wires in the end of a wire rope, usually in preparation for socketing.

BROW SHEAVE -- See KNUCKLE SHEAVE.

C

CABLE -- A rope-like assembly of electrical conductors insulated from each other but laid up together, usually by being twisted or stranded around a central core. The assembly is usually heavily insulated with outside wrappings and may contain nonconducting metal wires as strength members.

CABLE-BAND SEIZING -- A band of soft steel attached to a rope to serve as a seizing.

CABLE-GRIP -- A termination which is wrapped about the end of a wire rope using interlocking helical strands; designed so that tensile loads are resisted by induced radial pressures.

CABLE-LAID WIRE ROPE -- A compound-laid rope consisting of several ropes or several layers of strands laid together into one rope, such as 6 x 6 x 7, 6 x 42 (tiller rope), and 6 x 3 x 19 spring-lay mooring line.

CABLEWAY -- A conveyer system in which cars, buckets, or other carrier units are suspended from and run on wire cables strung between elevated supports.

CAPEL -- Term most often applied to a wedge and ringed-strand type rope end connection.

CAPSTAN -- A device for applying tension to a rope by friction between it and the rope.

CARGO HOOK -- Long, narrow hook with a short, inward-directed point and a metal protrusion on the eye or clevis.

CARPENTER STOPPER -- A wedge-type fitting which can be used to grip a rope anywhere along its length.

CENTERLESS STRAND -- A wire strand having no core.

CENTER WIRE -- A round or shaped wire used as the axial member of a strand.

CHAFING GEAR -- Any device or material which prevents a rope from chafing, rubbing, or scrubbing.

CHAIN HOOK (ALSO CALLED "S" HOOK) -- S-shaped steel rod used as a hook.

CHOKER -- A single-leg or endless sling formed into a slipping loop around a load to be moved or lifted. Sometimes called a reeved eye -- one eye being passed through another to form the slipping loop.

CHOKER HOOK -- One of a variety of hooks which are threaded onto a wire rope and allowed to move along its length.

CIRCUMFERENCE (OF A WIRE ROPE) -- Perimeter of the smallest cricle completely circumscribing the wires of a wire rope.

CLAMP (STRAND OR ROPE) -- A fitting for forming a loop at the end of a length of strand or rope, consisting of two grooved steel or heavy cast-iron plates and bolts.

CLAMSHELL BUCKET -- An openable container with two hinged jaws vertically suspended from chains, or more generally ropes, for lifting and transporting loose materials in bulk.

CLEVIS -- A U-shaped assembly with holes in the ends through which a pin is run for attaching ropes and equipment together.

CLIP (STRAND OR ROPE) -- A strand or rope fitting comprised of a malleable iron or forged steel saddle piece (grooved to suit rope lay) and a U-bolt by which the clip is held to two parallel ropes. Primarily used to anchor the dead end of a rope to the live side to form a loop.

CLOSE WINDING (ON A DRUM) -- Process of crowding more than the designed number of turns on a drum layer.

CLOSED SOCKET -- A socket in which the basket and the curved bail are connected.

CLOSING LINE -- The rope on a grab or bucket which closes the jaws of the bucket and serves as a hoisting rope to lift it and its contents.

CLOSER OR CLOSING MACHINE -- A machine in which wire strands are laid over a core to form a completed rope.

COARSE-LAID ROPE -- Term applied to ropes of the 6 x 7 classification, because of their large outer wires.

COIL -- Circular bundle of wire, strand, or rope with wire or strip ties--not fitted on a reel.

COMMON STRAND -- Strand made of galvanized iron wire.

CONSTRUCTION -- Term used to describe the design of a rope, covering the number of strands, number and arrangement of the wires in the strands, direction and type of lay, grade of wire material, and type of core.

CONSTRUCTIONAL STRETCH -- The permanent stretch which occurs in a new rope during initial loading. It results from the permanent deformations of the wires, strands, and core during loading.

CONVEYER ROPE -- Parallel spliced endless rope used to handle ores and materials.

CORDAGE -- Ropes made of vegetable fibers such as jute, hemp, or manilla, or synthetic fibers such as nylon, dacron, or polypropylene.

CORE -- The axial member of a wire rope about which the strands are laid. It may consist of wire strand, wire rope, synthetic or natural fiber, or solid plastic.

CORROSION -- The electrochemical decomposition (rusting or erosion) of the wires of a rope (or of any other metallic object) due to exposure to moisture, acids, alkalies, or other destructive agents.

CORRUGATED (SHEAVES AND DRUMS) -- Term describing the rope-wear marks visible on some extensively used sheaves or drums.

COTTON CENTER -- See FIBER CENTER.

COTTON CORE -- See FIBER CORE.

COUNTERWEIGHT ROPE -- Rope operating counterweights on a vertical hoist.

COVER WIRES -- Outer layer of wires in a wire strand.

CREEP (ON DRUM) -- The small continuing back movement of a hoisting rope on a drum as the rope load is released or reduced.

CROSS-LAY (ROPE OR STRAND) -- A multiple-layer rope or strand in which the lay of at least one of the layers is opposite that of another layer.

CROSSOVER -- For rope wound on a drum, the points at which the upper wraps cross over the crowns of the lower wraps.

CROSS-OVER WEAR -- The type of rope wear which is encountered at the cross-over points for multilayers of rope on a drum.

CROWD ROPE -- A wire rope used to pull the bucket of a power shovel into the material being handled.

CROWN WIRE -- A wire in a wire rope at the point where it would contact a circle circumscribed about the rope cross section.

CROWN WIRE BREAKS -- Wire breaks which occur on the crown wires.

CRUSHING -- Distortion of a wire rope due to pressure perpendicular to the rope axis.

CUTTING -- Severing of rope or strand by shearing.

CUTTING BACK -- Cutting off lengths of rope at terminations periodically in order to redistribute areas of severe wear.

D

DEAD END (OR PART OF A ROPE) -- Portion of an operating rope which carries no load. Often refers to the nonactive part of a rope protruding from a loop termination.

DEAD LOAD -- Constant load on a wire rope, not subject to change due to active forces. See LIVE LOAD.

DEAD WRAPS (ON A DRUM) -- Wraps on a drum which are never paid out during rope operation.

DEFLECTION SHEAVE -- A sheave that changes the direction of a rope. It usually has a wrap angle of less than 90°.

DEPTH (OF A SHEAVE OR DRUM) -- The vertical distance from the sheave groove throat or drum throat to the rim of the flange.

DERRICK -- General term for a fixed crane having a movable boom or jib as on structural erection cranes.

DESIGN FACTOR -- The ratio of unused rope breaking strength to rope load during operation. Standards are often set by statutory bodies for minimum design factors. Also known as FACTOR OF SAFETY.

DIAMETER (OF A ROPE) -- The diameter of the circle which circumscribes the rope cross section.

DOGLEG -- Permanent short bend or kink in a wire rope, caused by rope abuse.

DOUBLE SEALE STRAND -- A single-operation strand consisting of three wire layers in which the outer layer is made of uniformly sized wires, the middle layer of the same number of uniform size but smaller wires, and the inner layer of the same number of uniform size but still smaller wires.

DRUM -- A cylindrical, flanged barrel of cast iron or steel on which rope is wound for storage or operation. It may be smooth or grooved.

DRUM HOOK -- See BARREL AND DRUM HOOKS.

DUCTILITY -- The property of metals that enables them to be mechanically deformed.

E

EFFICIENCY -- (1) Wire Rope: Percentage ratio of the actual breaking strength of a wire rope to its aggregate breaking strength; dependent on rope construction and lay length. (2) Fittings: Percentage ratio of the actual breaking strength of the rope-fitting combination to the actual breaking strength of the rope with which the fitting is being used. Usually means the percentage of the rope's actual breaking load needed to pull the rope out of the fitting or fail the rope at the fitting.

ELASTIC LIMIT -- The tensile stress above which a permanent deformation takes place within a material.

END FITTING -- A device which is attached to the end of a rope, enabling the attachment of the rope to other equipment. Also called TERMINATION.

ENDLESS ROPE -- A rope whose ends are spliced together.

ENDLESS SPLICE -- A splice which connects the ends of a rope to form a loop.

EPOXY SOCKET -- A poured socket in which epoxy is used as the binding material.

EQUAL-LAY STRAND CONSTRUCTION -- A strand construction in which all the wires have an equal lay length and, hence, the contacts between the wires in the strand are linear.

EXTRA-IMPROVED PLOW STEEL -- See GRADES: WIRE ROPE.

EYE SPLICE -- A loop formed in the end of a rope by tucking the strand ends under or around the strands of the live part of the rope. A thimble is often used in the loop.

F

FACTOR OF SAFETY -- See DESIGN FACTOR.

FAIRLEADING -- The assembly of sheaves and rollers in a wire-rope system.

FALL ROPE -- The hoisting rope or ropes used in a single-part or multiply reeved rope tackle system.

FATIGUE (OF WIRE ROPE) -- The process of progressive localized wire damage caused by fluctuating stresses and which culminates in multiple wire failures (or fractures) and subsequent rope failure.

FERRULE -- A plug-like rope termination.

FIBER CENTER -- A sisal, cotton, manila, jute, or synthetic fiber rope used as the central member of a strand.

FIBER CORE -- A sisal, cotton, manila, jute, or synthetic fiber rope used as the axial center of a wire rope.

FID -- A large, tapered pin used to open the strands of a rope when splicing.

FIEGE FITTING -- A wedge-type fitting consisting of a plug which is used to expand the rope diameter, a sleeve which fits over the plugged rope from the live side, and a socket which screws onto the sleeve from the dead side. When rope and fitting are loaded, the fitting is held in place by the wedging action of the plugged rope against the sleeve.

FILLER STRIP -- A long, wedge-shaped metal strip which helps to position the wraps of rope on a drum by filling in the space between the last turn of the first layer and the flange.

FILLER-WIRE STRAND -- A multiple-layer strand in which the outermost layer of wires has twice the number of uniformly sized wires as the layer beneath it, with small FILLER WIRES occupying the interstices between the wire layers.

FILLER WIRES -- Small auxiliary wires in a strand for spacing and positioning of other wires.

FIST-GRIP CLIPS -- See INTEGRAL SADDLE-AND-BOLT CLIPS.

FLAG -- Marker to designate the position or length of a rope.

FLANGE -- A rim on a sheave or drum for containing and/or supporting the rope.

FLAT DRUM -- A drum with an ungrooved face.

FLAT ROPE -- A wire rope made by sewing together a number of alternate right- and left-lay ropes. The sewing material is usually soft annealed iron wire.

FLATTENED-STRAND ROPE -- Rope made with oval or triangularly shaped strands.

FLEET ANGLE -- Angle between the position of the rope on a drum, and a line drawn perpendicular to the axis of the drum through the center of the nearest fixed sheave.

FLEMISH EYE -- A type of eye splice made by separating the rope end into two groups of strands and then rewrapping the strands to form a loop.

FLEXIBILITY -- The ease with which a rope may be bent.

G

GALVANIZED ROPES, STRANDS, AND WIRES -- Ropes, strands, and wires in which the individual wires are coated with zinc.

GRADES: ROPE -- Classification of wire rope according to wire breaking strength per unit area. In order of increasing strength the various rope grades are "iron", "traction", "mild plow steel", "plow steel", "improved plow steel", and "extra-improved plow steel".

GROMMET -- An endless 7-strand wire rope.

GROOVE -- Depression in the periphery of a sheave or drum for positioning and supporting a rope.

GROOVE GAUGE -- A flat, teardrop-shaped metal device for checking sheave or drum grooves for proper size and shape.

GROOVED DRUM -- Drum with grooved surface to accommodate and guide a rope.

GUYS OR GUY LINES -- Strands or ropes, generally galvanized, used to steady and support structures in position. They normally are adjustable in length to allow for stretch.

H

H-BITT -- An H-shaped steel or iron deck fitting around which rope is temporarily secured.

HAND-TUCKED EYE SPLICE -- See EYE SPLICE.

HAWSER -- Wire rope, usually galvanized, used for towing or mooring vessels.

HEAVY LUBRICANT -- Viscous, grease-type lubricant.

HEMP -- A plant fiber used in making ropes and fiber cores.

HERRINGBONE LAY -- See ALTERNATE LAY (SPECIAL).

HIGH STRAND -- An unevenly loaded strand abnormally raised above the rope surface.

HOCKLE -- A loop in a slack wire rope formed by applied torque or twist. Application of tension to a hockled rope will result in permanent deformation (kinking) and may even cause rope failure.

HOLDING LINE -- Wire rope on a clamshell or orange-peel bucket that holds the bucket while the closing line is released to dump the load.

I

IDLER (SHEAVE) -- A sheave or roller used to support or guide a rope.

IMPROVED PLOW STEEL -- See GRADES: WIRE ROPE.

INDEPENDENT WIRE-ROPE CORE (IWRC) -- A wire rope used as the core of a larger wire rope.

INTEGRAL SADDLE-AND-BOLT CLIP -- A clip consisting of two L-shaped bolts fastened together with nuts. Also called FIST-GRIP CLIPS and SAFETY CLIPS.

INTERNALLY LUBRICATED -- Wire rope or strand having all the wires and core coated with lubricant.

IRON ROPE -- See GRADES: WIRE ROPE.

IWRC -- See INDEPENDENT WIRE-ROPE CORE.

K

KINK -- Sharp permanent bend in a wire rope.

KNUCKLE SHEAVE (OR BROW SHEAVE) -- A sheave used at the summit of an inclined haulageway to change the rope direction from the surface down the incline.

L

LAGGING -- (1) External wooden covering on a reel of rope or strand to protect it in handling or in storage. (2) Components attached to the barrel of a drum to increase its diameter.

LANG-LAY ROPE -- Rope in which the direction of lay of the wires in the strands is the same as the direction of lay of the strands in the rope. Sometimes called ALBERT'S LAY.

LAYER -- A group of strands in a rope or a group of wires in a strand spun concentrically around the core in one operation. A center wire is not a layer, but a twisted strand center is a layer.

LAY ANGLE -- The arc tangent of the ratio of the rope circumference to the lay length.

LAY DIRECTION -- The direction of strand or wire helix, i.e., right or left.

LAY LENGTH (PITCH) -- The distance parallel to the axis of a rope (or strand) in which a strand (or wire) makes one complete helical revolution about the core (or center).

LEAD LINE -- That part of the rope tackle leading from the first or last sheave to the winch drum.

LEFT-LAY -- The direction of strand or wire helix corresponding to that of a left-hand screw thread.

LEVEL WIND -- A mechanism to assure even and uniform winding of a rope on a drum.

LIGHT LUBRICANT -- Low-viscosity, oil-type lubricant.

LINE -- A term frequently applied to a wire rope especially if it moves or is used to transmit a force.

LIVE LOAD -- An operating, moving, or changing load on a rope, as opposed to a dead or constant load. See DEAD LOAD.

LIVE (PORTION OF A ROPE) -- The portion of an operating rope which carries the load. Usually applied to a rope that is not cut at the termination, but passes through it, leaving an unloaded (dead) rope section.

LOAD CELL -- An instrument for measuring force or torque.

LOCKED-COIL ROPE -- A single-strand rope with a smooth surface, formed with interlocking shaped wires (FULL-LOCKED-COIL ROPE), or alternate round and shaped wires (HALF-LOCKED-COIL ROPE).

LONG SPLICE -- A splice which joins two ropes end-to-end and which involves about twice the rope length of a short splice.

LOOP SPLICE -- An eye splice without a thimble.

M

MANILA -- A hemp-like rope fiber made from the leaf stalks of the abaca plant.

MARLIN(E)-CLAD ROPE -- Marine trawling rope in which each steel strand is coated with fiber, usually manila yarns.

MARLIN SPIKE -- A pointed metal spike, used to separate strands of rope in splicing.

MECHANICAL SPLICE -- A splice made by swaging a sleeve to a loop or eye splice.

MILD PLOW STEEL -- See GRADES: WIRE ROPE.

MINIMUM BREAKING LOAD -- The minimum load which a new rope is designed to withstand without fracture when pulled to failure in tension.

MOLLY HOGAN -- See FLEMISH EYE.

MONEL -- A nickel-copper alloy sometimes used in special usage cables and wire ropes.

MOORING LINE -- Galvanized wire rope, usually 6 x 12, 6 x 24, or spring-lay construction, for holding ships to a dock.

MULTIPLE-LAYER STRAND -- A strand with two or more wire layers.

MULTIPLE-OPERATION STRAND -- A strand in which at least one wire layer has a different lay length or direction from the other layer(s), and is made in a separate stranding operation.

MULTIPLE-PART REEVING -- Reeving a rope over a block or blocks consisting of several sets of sheaves in parallel.

N

NASH TUCK -- Tucking process used in splicing an eight-strand rope.

NICKING (ALSO CALLED NOTCHING) -- Permanent surface deformation of wires at points of wire-to-wire contact.

NONROTATING WIRE ROPE -- A 19 x 7 (or 18 x 7) wire rope consisting of a 7 x 7 (or 6 x 7 fiber core) left Lang-lay inner rope covered by twelve 7-wire strands right regular lay.

NONSPINNING WIRE ROPE -- See NONROTATING WIRE ROPE.

NOSE (OF A SOCKET) -- The part of the socket from which the live rope protrudes.

NOTCHING -- See NICKING.

O

ONE-OPERATION STRAND (ALSO CALLED SINGLE-OPERATION STRAND) -- A strand in which all the wires are laid in one operation with the same direction and length of lay. A single-layer strand is always a one-operation strand.

OPEN SOCKET -- Wire-rope fitting with two integral lugs through which a pin connection is made to the load or anchorage.

OPEN WINDING (ON A DRUM) -- Process of winding too few turns on a drum in a single layer so that excessive gaps form between wraps.

ORANGE-PEEL BUCKET -- An openable container used in hoisting that consists of more than two segments or jaws.

ORDINARY-LAY ROPE -- See REGULAR-LAY ROPE.

OUTER WIRES -- See COVER WIRES.

OVERWOUND ROPE -- See UNDERWOUND ROPE.

P

PEENING -- Permanent surface deformation of outer wire(s) in a rope.

PELICAN HOOK -- An openable hook in which the point is hinged to the hook body and held close to the body when closed with a lock or loop

PHOSPHOR BRONZE -- A metal alloy containing copper, tin, and some phosphorous, known primarily for its corrosion resistance and nonmagnetic properties.

PITCH -- (1) Length of Lay: The distance parallel to the axis of the rope (or strand) in which a strand (or wire) makes one complete helical revolution about the core (or center). (2) The spacing of grooves on a drum.

PITCH DIAMETER -- The diameter of a sheave or drum as measured across the sheave from centerline to centerline of an appropriately sized rope placed in the sheave groove.

PLAIN OR SINGLE DIRECTION BENDING -- The operation of a rope over drums and sheaves so that it bends in one direction only. Opposite of reverse bending.

PLASTIC CORE -- A round plastic member used as a wire-rope core.

PLOW STEEL -- See GRADES: WIRE ROPE.

PLUG -- A conical steel device which provides the wedging action in a fiege fitting.

POINT SHEAVE -- Boom-head sheave.

POLYPROPYLENE FIBER CORE -- A plastic rope core made of many polypropylene filaments.

POPPED CORE -- A section of core which protrudes between strands to the outer surface of a rope.

POSTFORMING -- A process in which a completed rope is passed through rollers in one or more planes to "set" the rope and reduce elongation under load.

POURED FITTING -- An end-fitting which is attached to the rope by pouring molten zinc, babbit, or epoxy into a cavity around broomed-out rope wires, and allowing the material to solidify.

PREFORMING -- Process in which the strands and wires receive a final helical shape before closing that matches the lay and set of the finished rope.

PRESTRESSING -- Stressing a wire rope or strand before use under such a tension and for such a length of time that the constructional stretch is largely eliminated.

PROOF-LOADING -- Preliminary loading of a rope to its maximum expected range to test the load bearing capability of the rope and associated equipment. Also called PROOF-TESTING.

R

RATED CAPACITY (ROPE OR SLING) -- The maximum load at which a rope or sling is designed to operate.

REEL -- The flanged spool on which a wire rope or strand is wound for storage or shipment.

REEVED EYE -- See CHOKER.

REEVING -- The threading of a wire rope through a block, sheave, or other parts of a wire-rope system.

REGULAR-LAY ROPE -- A rope in which the lay of the wires in the strand is opposite the lay of the strand in the rope.

RESERVE STRENGTH -- The strength of the inner wires in a strand, usually given as a percentage of the aggregate strength of all the wires.

RETRACT ROPE -- The rope used on some shovels to draw back the bucket during digging operations; sometimes used along with a crowd rope.

REVERSE BENDING -- Reeving of a wire rope over two sheaves so that it bends first in one direction and then again in the opposite direction.

RIGHT LAY -- The direction of a strand or wire helix corresponding to that of a right-hand screw thread.

RISER STRIP -- A tapered metallic strip used to raise the rope in the last wrap of a drum layer to the next drum layer.

ROLLERS -- Relatively small-diameter cylinders or wide-faced sheaves for supporting ropes and minimizing friction.

ROUND-STRAND ROPE -- A rope with round strands, as opposed to flattened-strand rope.

S

S-HOOK -- See CHAIN HOOK.

SADDLE -- That part of a U-bolt clip that bears against the live side of the rope. Grooved to fit the external surface of the rope, it is fastened to the U-bolt with nuts. Also called a bridge.

SAFETY CLIP -- See INTEGRAL SADDLE-AND-BOLT CLIP.

SAFETY FACTOR -- See DESIGN FACTOR.

SASH CORD -- Small 6 x 7 wire rope commonly made of iron, bronze, or copper wires.

SCRUBBING -- Displacement of wires from normal position due to relative motion between strands.

SCUFFING -- Rope damage caused by abrasion of a moving rope.

SEALE STRAND CONSTRUCTION -- A strand with uniformly sized wires laid parallel with the same number of uniformly sized but smaller wires in the inner layer(s).

SEALE-WARRINGTON CONSTRUCTION STRAND -- A strand in which the outer layer of alternately large and small wires (WARRINGTON CONSTRUCTION) is parallel laid with inner layers of uniformly sized wires in SEALE CONSTRUCTION. See WARRINGTON STRAND CONSTRUCTION, SEALE STRAND CONSTRUCTION.

SEIZE -- To bind a rope or strand securely with annealed wire. Also, to secure by wire two parallel portions of rope.

SEIZINE -- (1) The annealed wire used to seize a rope. (2) The completed wire wrapping itself.

SEIZING MALLET -- A mallet made of wood, brass, or other soft material with a grooved and notched head, used for applying seizings.

SERVE -- To cover a rope with a tight wrapping of marlin(e) or other fiber cord--as over the ends of the tucks on a splice.

SEWING WIRE -- See FLAT ROPE.

SHACKLE -- An U-shaped fitting with a screwed or cottered pin, used to attach a load to a rope or other lifting equipment.

SHEAVE -- A pulley with a rim, used to support or guide a rope in operation.

SHEAVE GROOVE GAUGE -- A flat, teardrop-shaped device used to check shape and size of sheave grooves.

SHORT SPLICE -- A splice used for attaching two rope ends together. See SPLICING.

SINGLE-LAYER STRAND -- A strand either with no center or a fiber or wire center and one layer of uniformly sized wires.

SINGLE-OPERATION STRAND -- See ONE-OPERATION STRAND.

SINGLE-PART LINE -- A rope in a block and tackle hoisting system which travels over a single sheave from the winch to the hoist.

SISAL -- A rope fiber made from the leaves of the agave plant.

SLEEVE -- A type of swage fitting usually employed in the formation of a loop or eye in the end of a wire rope. See MECHANICAL SPLICE.

SLING -- A wire rope made into a form, with or without fittings (thimbles, rings, links), for handling and lifting loads. Generally made with an eye, bight, or hook at the end for attachment to loads and lifting equipment.

SLING, BRAIDED -- A very flexible sling composed of several individual wire ropes braided together.

SMOOTH-COIL TRACK STRAND -- Strand made entirely of round wires, used as an aerial track strand.

SMOOTH-FACED DRUM -- Drum with an ungrooved, plain surface.

SNAP HOOK -- A hook with a spring-loaded safety closure.

SOCKET -- A forged or cast device (usually steel) into which the end of a rope is placed and fastened to permit the rope to be attached to a load or anchor point.

SOCKETING -- The process of attaching a socket to the end of a wire rope.

SPECIAL ALTERNATE LAY -- See ALTERNATE LAY (SPECIAL).

SPELTER -- Zinc.

SPIN-RESISTANT WIRE ROPE -- An 8 x 19 wire rope usually made with Seale construction right regular-lay strands and a 7 x 7 left Lang-lay independent wire-rope core. This rope is usually considered to be somewhat stronger and crush-resistant than a 19 x 7 nonrotating construction but it does not have equal nonspinning properties.

SPINNING LOSS -- See STRANDING LOSS.

SPIRAL GROOVE -- Groove which follows the path of a helix around the drum, as the thread of a screw.

SPLICING -- Interweaving a rope end into a rope section or another rope end to form a loop termination (EYE SPLICE) or a longer or circular rope (ENDLESS SPLICING).

SPOOLING -- Winding a rope on a reel or drum.

SPRING-LAY ROPE -- Preformed cable-laid rope consisting of six ropes around a fiber core. Each individual rope consists of three galvanized steel strands and three fiber cores laid alternately around a fiber core. Spring-lay rope is often used for mooring.

STARTER STRIP -- A metallic, tapered strip which fills the gap between the flange and the first rope wrap on a drum and properly positions the beginning of the second wrap.

STIRRUP -- The U-bolt or eyebolt attachment on a bridge socket.

STRAND -- A number of wires in one or more layers laid around a center wire or fiber core, with a uniform lay length in each layer. The wires are laid helically and may be round or shaped or a combination of both.

STRAND CENTER -- Generally, a 4- to 7-wire strand used to replace a large single wire as the center of a strand.

STRAND CORE -- A wire strand used as the core of a rope. Sometimes called a WIRE STRAND CORE (WSC).

STRANDING LOSS (ALSO CALLED SPINNING LOSS) -- Ratio of the actual breaking strength of a rope to its aggregate breaking strength.

SUSPENSION BRIDGE CABLE -- See BRIDGE CABLE.

SWAGE FITTING -- A tubular steel or alloy fitting sized to accommodate one or more parts of rope or strand. The fitting is applied by squeezing it onto the rope, usually in a swaging press.

SWAGING -- The pressing process used to apply a swage fitting.

SWIVEL -- A termination or attachment for wire rope which permits rope rotation.

T

TACKLE -- An assemblage of ropes, sheaves, rollers, and fittings arranged for hoisting and/or pulling.

TAGLINE -- A small rope attached to an object being lifted to prevent rotation or to position the object.

TAPERED AND WELDED END -- The end of a wire rope with the wires welded together and tapered down to facilitate reeving through block and sheave systems and into drum anchorages.

TENSILE FAILURE -- Rope, strand, or wire failure caused by axial overload.

TERMINATION -- Any device or process applied to the end of a wire rope.

THIMBLE -- A grooved ring (usually teardrop-shaped) used to fit in a spliced loop in a rope as protection from chafing.

TILLER ROPE -- A very flexible operating rope, made by cable-laying six 6 x 6 or 6 x 7 ropes around a fiber core.

TINNED WIRE -- Wire coated with tin.

TORQUE-BALANCED WIRE ROPE*-- A 3-strand thermally-stabilized regular-lay rope (3 x 7, 3 x 19, or 3 x 46) in which the strand lays are designed to produce a torque in tension equal to that, but opposite in direction from, the torque created under load by the opposing rope lay. To be identified as a torque-balanced rope, some current Navy specifications require that this rope rotate less than 1 degree per foot under 60 percent rated breaking strength loads.

TOWLINE -- A line, cable, or chain used to tow a vessel or vehicle. Also called a towrope or towing hawser.

TRACK ROPE (STRAND) -- The suspended rope or strand on a cableway, skyline, or ropeway which supports the load-carrying carriage.

TRACTION ROPE -- Wire rope that propels the carriages on an aerial conveyor. Also, the hoisting rope on elevators, particularly those with traction drives.

TRACTION STEEL -- See GRADES: WIRE ROPE.

TRAMWAY -- Aerial conveying system for transporting loads.

TREAD DIAMETER -- The diameter of a sheave (or drum) measured between opposite low points of the groove.

TRIANGULAR-STRAND ROPE -- A flattened-strand rope whose wires are approximately triangular in cross section.

TURNBUCKLE -- A metal coupling device consisting of an oblong piece internally threaded at both ends, into each end of which a threaded eye is screwed. The thread direction of the ends of the rods are opposite so that when the eyes are connected to wire ropes and the oblong piece turned, the entire rope-turnbuckle assembly is made longer or shorter.

TUCK -- In splicing, the passage of a strand from a rope into or through another section of rope.

TWISTED WIRE-ROD GRIP -- A fitting consisting of a preformed hollow helix of wire strands which is slipped over the rope end. Tension on the rope induces radial compressive stresses on the rope end. See CABLE-GRIP.

U

U-BOLT CLIP -- A clip consisting of a U-bolt and a saddle or bridge which is fastened to the bolt with nuts.

ULTIMATE BREAKING STRENGTH -- See BREAKING STRENGTH.

*Patented by U. S. Steel Corporation, New Haven, Connecticut.

UNDERWOUND ROPE -- A rope which winds onto the underside of a winding drum or winch--as opposed to an overwound rope which winds onto the top of the drum or winch.

V

VALLEY -- The crevice between strands or between wires in a wire rope.

VALLEY BREAK -- A wire breaking occurring in the valley between two strands.

W

WARRINGTON CONSTRUCTION STRAND -- A strand in which the outer of two adjacent layers of wires is composed of alternating large and small wires. The large wires are placed in the valleys of the inner-layer wires and the small wires are placed on the crowns of the inner-layer wires. The two adjacent layers are laid in a single operation.

WARRINGTON-SEALE CONSTRUCTION STRAND -- A strand in which adjacent layers are laid parallel in one operation, the inner a Warrington construction and the outer a Seale construction.

WEDGE SOCKET -- Wire-rope fitting in which the rope is secured with a wedge.

WHIPPING -- (1) Term given to the vibration set up in an operating rope between the sheave and drum due to sudden acceleration, intermittent variation in speed, obstruction to the free movement of a load, or drum crossover points; dangerous and potentially damaging if the frequency of vibration approximates the natural frequency of the rope system. (2) A fiber-core wrapping on a wire rope (See WRAPPING).

WINCH -- Machine with one or more drums on which to coil wire rope for hauling or hoisting.

WIRE -- Single continuous length of metal drawn from a rod. May be "round" in cross section or "shaped" into ovals, triangles, helices, etc.

WIRE ROPE -- A number of wire strands laid helically about an axial core.

WIRE-STRAND CORE -- See STRAND CORE.

WORKING LOAD -- The load that a rope is designed to carry in a particular service.

WORN SHEAVE GAUGE -- A sheave groove gauge used to check sheave grooves over which a rope has been cycled to a worn condition.

WRAPPING -- Fiber core wrapping on a rope. Also see WHIPPING.

Y

YIELD POINT -- The lowest stress at which strain increases without increase in stress.

Z

ZEBRA LAY -- See ALTERNATE LAY.

ZINC SOCKET -- Wire-rope end fitting having a conical basket into which the broomed end of the rope is secured with zinc. May be either open or closed.

12. BIBLIOGRAPHY

1. Roebling Wire Rope Handbook, The Colorado Fuel and Iron Corporation, Roebling Wire Rope, Trenton, New Jersey (1966). (Out of Print).

2. Wire Rope Handbook and Catalog E, Armco Steel Corporation, Union Wire Rope, Kansas City, Missouri (1972).

3. USS Tiger Brand Wire Rope Engineering Hand Book, United States Steel, Pittsburgh, Pennsylvania (1968).

4. Bethlehem Wire Rope for General Purposes, Catalog 1877, Bethlehem Steel Company, Bethlehem, Pennsylvania (undated).

5. Rigger's Handbook, 10th Edition, Broderick & Bascom Rope Co., St. Louis, Missouri.

6. Care and Use of Wire Rope, First Edition, Vocational Training Courses, Petroleum Industry Series, Issued by The University of Oklahoma Business and Industrial Services and State Board for Vocational Education, Department of Trade and Industrial Education; Validated by The Central Committee on Training, American Petroleum Institute, Division of Production; Validated by the Committee on Research and Education, American Association of Oil Well Drilling Contractors. Order from University Book Exchange, University of Oklahoma, Norman, Oklahoma (1954).

7. Wire Rope Catalogue, WRI Publication 681, Wire Rope Industries of Canada Limited, Lachine, Quebec, Canada (undated).

8. Selection of Wire Rope for Engineering Applications, British Ropes Group, Wire Rope Technical Department, Carr Hill, Doncaster, England (1967).

9. Longer Life From Your Wire Rope, United States Steel, Pittsburgh, Pennsylvania (undated).

10. Wire Rope Handbook, Broderick & Bascom Rope Co., St. Louis, Missouri (1966).

11. Here's How to Keep Your Wire Rope Working, Hazard Wire Rope Division, Bridon American Corporation, West Pittston, Pennsylvania (undated).

12. Illustrated Shipboard Shopping Guide, FSC Group 40, Rope, Cable, Chain and Fittings, NAVSUP Publication 4400, U.S. Navy Fleet Material Support Office, Fleet Documentation Department, Mechanicsburg, Pennsylvania (Effective Date: 1 November 1966). (For use by Government agencies only).

13. Navy Technical Bulletin No. 5: Instructions for the Design and Care of Wire Rope Installations, United States Navy Department, Bureau of Ships, Washington, D. C. (January 1946).

14. Tuffy Tips on Abuses and Correct Uses of Wire Ropes and Slings, Union Wire Rope, Armco Steel Corporation, Middletown, Ohio (1968).

15. _____, "Carpenter Stoppers and Related Wire Rope", Boston Naval Shipyard Test Memorandum, File No. Boston 63566 (1968).

16. _____, "Correct Socketing", Pit and Quarry, pp. 104-105 (June 1967).

17. _____, "Recent Developments in Ferrule Connections for Steel Wire Ropes", Wire (Coburg, Germany), Issue 74, pp. 247-248 (December 1964).

18. Smollinger, Carl W., and Cornish, John B., "Investigation of Variables in the Zinc Socketing of Wire Rope and Strand", Wire, pp. 1677-1679, 1725-1727 (December 1961).

19. Delmonte, John, "Epocast Terminated Wire Cables", Wire, pp. 1092-1093 (September 1959).

20. General Specifications for Ships of the United States Navy, Section 9120-1, Mooring and Towing Fittings, Department of the Navy, Bureau of Ships, pp. 75-76 (FY-66). (Official Use Only).

21. _____, "How to Splice Wire Rope Eyes", Coal Age, p. 172 (October 1967).

22. Proposed Federal Item Identification Guide: Chain and Wire Rope, FIIG A082, Defense Supply Agency, Defense Industrial Supply Center (Philadelphia) (September 1968).

23. Federal Supply Catalog, Identification List, FSC Group 40: Rope, Cable, Chain, and Fittings, C4000-IL-N, Defense Industrial Supply Center, Philadelphia (1 December 1968).

24. _____, "Use and Care of Wire Rope", The Timberman, Vol. 61, p. 77 (1960).

25. _____, "How to Apply Wire Rope Clips", The Timberman, p. 60 (August 1961).

26. Lex, W. I., "Tests on This Wire Rope Fatigue Machine Prove That ... Lubricants Do Penetrate Wire Rope!", Engineering and Mining Journal, Vol. 155, No. 6, pp. 96-98 (1954).

27. Clement, E. J., "Basic Facts About Wire Rope", Mill and Factory, Vol. 58, pp. 97-100 (June 1956).

28. Russell, William C., "How to Select and Care for Wire Rope and Operating Conditions Which Shorten Its Life", National Engineer, pp. 43-46 (November 1956).

29. Reynolds, E. S., "Proper Lubrication of Wire Rope Pays", Pit and Quarry, pp. 112-115 (September 1963).

30. Flowers, A. E., "How to Get More Life From Wire Rope", Coal Age, pp. 76-81 (April 1955).

31. Layton, Charles, "Longer Life for Your Wire Rope", Engineering and Mining Journal, Vol. 157, No. 10, pp. 100-103 (October 1956).

32. Hilsher, J. E., "Wire-Rope Assemblies", Machine Design, pp. 88-96 (August 3, 1961).

33. Leach, Robert P. (Bob), Riggers Bible, Revised Edition 20th Printing, Robert P. Leach, Jr., Springfield, Missouri (1971).

34. Lex, W. I., "How to Inspect Wire Rope", Modern Concrete, pp. 38-39 (July 1965).

35. Schneider, A., and Sztankoczy, E., "Wear and Quality Characteristics of Steel Wires in a Systematically Reversed Pulley Rope With a Low Safety Factor", Wire World International, Vol. 14, pp. 245-257 (November/ December 1972).

36. Berteaux, H. O., "An Engineering Review of the Woods Hole Oceanographic Institution Buoy Program", reprinted from Colloque International Sur L'Exploitation des Oceans, Bordeaux (France), Th. V-G1-09, Theme V, Tome II, pp. 1-14 (March 1971).

37. Silverman, Maxwell, and Frautschy, Jeffery D., "Wire Rope Practices at The Scripps Institution of Oceanography", Wire and Wire Products, Vol. 35, pp. 329-333, 383-384 (March 1960).

38. Chase, Lawrence, "Why Wire Rope Breaks and How to Prevent It", Ocean Industry, pp. 98-100, 102 (May 1969).

39. Richards, C. C., "Steel Wire Ropes for Hoisting Machinery and Lifts", Machinery, pp. 1302-1309 (5 December 1962).

40. Murphy, W. A., "Wire Rope--The Working Arm of Construction Equipment", Paper prepared for presentation at National Farm, Construction and Industrial Machinery Meeting, Milwaukee, Wisconsin, September 14-17, 1964, Society of Automotive Engineers. Inc., New York.

41. Care and Abuse of Wire Rope, Independent Wire Rope Manufacturers Association, Silver Spring, Maryland (undated).

42. Sherwood, Peter W., "Longer Lives for Wire Ropes", The British Steelmaker, Vol. 31, No. 1, pp. 24-25 (January 1965).

43. Meger, A. F., "Wire Rope Maintenance", Mining Congress Journal, pp. 34-37 (July 1960).

44. Kasten, R. O., "Wire Rope Lubrication--Its Relation to Rope Life and Safety", Wire, pp. 1271-1273 (September 1963).

45. Ship Salvage Notes, U.S. Naval School Deep Sea Divers, Washington, D.C. (1964).

46. Wire Rope/Its Engineering, Wire Rope/Its Selection (2 booklets), The Rochester Corporation, Wire Rope Division, Culpeper, Virginia (undated).

47. Bethlehim Wire Rope, Bethlehem Steel Corporation, Bethlehem, Pennsylvania, Catalog 2305-A (undated).

48. Carlson, B. N., "Extending Wire Rope Life", Mining Congress Journal, Vol. 43, No. 7, pp. 60-63 (July 1957).

49. Barden, K. L., and Klaus, F. J., "Making Wire Rope Last Longer", Coal Age, pp. 79-82 (March 1972).

50. _____, "Wire Rope and Fittings", Coal Age, Vol. 68, No. 4, pp. 101-116 (April 1963).

51. _____, "Correct Socketing Prevents Premature Rope Failure", Engineering and Mining Journal, Vol. 168, p. 126 (November 1967).

52. Wireco Wire Rope, Handbook W67, Wire Rope Corporation of America, Inc., St. Joseph, Missouri (1971).

53. _____, "Aluminum Gives Wire Rope a New Twist", Marine Engineering/Log, Vol. 72, pp. 61-63 (March 1967).

54. Grimwood, J. E., "When Do You Change Wire Rope Cables?", Iron and Steel Engineer, pp. 94-97 (June 1958).

55. Kasten, R. O., "Inspection of Wire Rope Boom Supports for Operating Safety", Wire, pp. 1179-1180, 1233-1235 (August 1964).

56. Hoover, Hubert M., "Wire Rope", Geo-Marine Technology, Vol. 1, No. 3, pp. 32-33 (February 1965).

57. Harmon, R. Allen, "Report of Wire Rope Wear Test Project Conducted in USS Niagara Falls (AFS-3)", Prepared for NAVSHIPS by Naval Ship Missile Systems Engineering Station (Port Hueneme, CA), R-4800-3 (December 1967).

58. Lex, W. I., "Operation, Maintenance, and Inspection of Wire Rope", U.S. Coast Guard, Proceedings of the Merchant Marine Council, pp. 91-96 (May 1968).

59. Layton, Charles H., "Proper Maintenance Will Make Our Wire Rope Last Longer", The Oil and Gas Journal, Vol. 66, No. 21, pp. 76-80 (July 29, 1963).

60. Pine, G. I., "It Pays to Know the Ropes", Power, Plant Maintenance and Management Section, pp. 120-123 (June 1958).

61. U.S. Navy Ship Salvage Manual--Volume I: Theory of Strandings and the Use of Beach Gear, NAVSHIPS 0994-000-3010, Office of the Supervisor of Salvage, U.S. Navy, Naval Ship Systems Command, Washington, D.C. (1968).

62.* VDI Guidelines for Lifting and Hauling, VDI 2358 (October 1968). (Published in Germany. English translation is NAVSHIPS Translation 1417).

* Also appears as Reference 3-15 in Volume II.

63. Thompson, J. C., and Logan, R. K., "Wire Cables for Oceanographic Operations", NEL Evaluation Report 1199, U.S. Naval Electronics Laboratory (San Diego, CA) (13 November 1963).

64. Ropeman's Handbook, Second Edition, National Coal Board Production Department in collaboration with the Safety in Mines Research Establishment, Ministry of Power (England). Hazell Watson and Viney Ltd., Aylesbury, Bucks (1960).

65. _____, "Sound Splicing is Key to Long Wire Rope Life", Modern Materials Handling, p. 64 (November 1964).

66. Egawa, T., and Taneda, M., "External Pressure Produced by Multi-Layers of Rope Wound on a Hoisting Drum", Bulletin of JSME, Vol. 1, No. 2, pp. 133-138 (1958).

67. Mobile Cranes, Training Manual 8, National Coal Board, Industrial Training Branch, Waterlow & Sons Limited (London) (1972).

68. Handbook of Ocean and Underwater Engineering, John J. Myers, Editor-in-Chief, McGraw-Hill Book Company, New York (1969), Section Four, pp. 4-32 through 4-42; Section Seven, p. 7-8.

69. Swaging Instructions, ESCO Corporation, Portland, Oregon (March 1, 1968).

70. Naval Ships Technical Manual, NAVSHIPS 0901-270-0001, Chapter 9270: Wire Rope, Department of the Navy, Ship Systems Command (September 1967).

71. Look to Preformed for Solutions to Cable Testing & Research Problems, Preformed Line Products Company, Cleveland, Ohio 44101 (Undated).

72. Steel Wire Handbook, Allan B. Dove, Ed., The Wire Association, Inc., Branford, Connecticut, Vol. 3 (1972), Chapter 3, pp. 77-94 and Chapter 4, pp. 95-117.

73. Casarella, M. J., Chairman, "Workshop on Marine Wire Rope--August 11, 12, 13, 1970", The Catholic University of America, Washington, D.C., sponsored by Office of Naval Research, Naval Ships Command (Supervisor of Salvage), Catholic University of America, Naval Oceanographic Instrumentation Center. AD 721 373*.

74. MacWhyte Wire Rope, Catalog G-17, MacWhyte Wire Rope Company, Kenosha, Wisconsin (1974).

75. Federal Specification RR-C-271B, Chains and Attachments, Welded and Weldless (August 28, 1973).

76. Federal Specification RR-W-410C, Wire Rope and Strand (September 18, 1968).

* May be ordered using this number from National Technical Information Service, Springfield, Virginia 22151.

77. American National Standards Specification, ANSI B30.5, Section 5-2.4 Rope Inspection, Replacement and Maintenance (1969).

78. COMTAC Publication NWP-38, Replenishment at Sea.

79. Salanski, C. W., "What OSHA Expects the Industry to Know About Single-Part Wire Rope Slings", Wire Journal (November,1975).

80. Naval Air Systems Command Technical Document, NAVAIR 51-5BCA-1, Section 17, Terminal (Zinc) Pouring and In-Service Inspection Procedures.

81. Military Specification MIL-G-18458A, Grease, Wire Rope-Exposed Gear (August 7, 1961).

13. ALPHABETICAL INDEX

Page

C

D

Page

Page

S

T