DDS 613-1

DESIGN DATA SHEET

WIRE ROPE SYSTEMS DESIGN

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362-5101

TABLE OF CONTENTS

TABLE OF CONTENTS
(Cont'd)

TABLE OF CONTENTS
(Cont'd)

TABLE OF CONTENTS
(Cont'd)

TABLE OF CONTENTS
(Cont'd)

LIST OF FIGURES

LIST OF TABLES

RECOMMENDED CHANGES

Ships, training activities, supply points, depots, naval shipyards, and supervisors of shipbuilding are requested to arrange for the maximum practical use and evaluation of NAVSEA design handbooks. All errors, omissions, discrepancies, and suggestions for improvements to NAVSEA technical manuals shall be reported to the Naval Sea Data Support Activity (NSDSA), Naval Ship Weapon Systems Engineering Station (Code 5700), Port Hueneme, CA 93043, on NAVSEA Technical Manual Deficiency/ Evaluation Report, Form NAVSEA 4160/1 (3-82). All feedback comments will be thoroughly investigated and originators will be advised of action resulting therefrom. Copies of Form NAVSEA 4160/1 (3-82) may be requisitioned from the Naval Publications and Forms Center (NPFC), Philadelphia, PA 19120.

1.0 INTRODUCTION

1.1 PURPOSE

This design data sheet is a practical, concise guide written to help engineers design safe and efficient shipboard wire rope systems.

1.2 SCOPE

Good design practices are described for selecting, sizing, and arranging components and equipment to produce integrated wire rope systems. These principles and practices are illustrated by the solution of sample design problems.

Basic information about wire rope nomenclature, construction, materials, and characteristics is given. Also described are wire rope fittings, hardware, and handling equipment such as blocks, drums, fleet angle compensators, and antislack devices.

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 WIRE ROPE CONSTRUCTION

2.1 WIRE ROPE: DESCRIPTION AND NOMENCLATURE

Wire rope is an assembly of components which move and adjust with respect to each other when the wire rope is loaded or flexed. These relative motions tend to distribute and equalize the wire rope load among the components.

Generally, wire rope (as shown in Figure 2-1) consists of the following basic components:

- A center
- Wires laid helically around a center to form the strand
- A core
- Multi-wire strands laid helically around a core

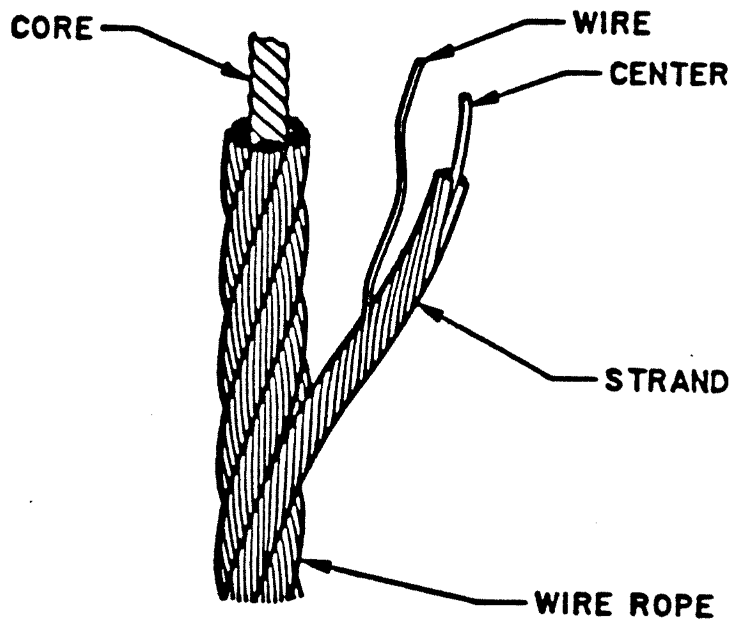


Figure 2-1. Component Parts

Wire rope is identified by its construction, that is, the number of strands, the number and arrangement of the wires in each strand, the wire rope lay, and the type of core. For a given size of wire rope, the wire and core materials and the number of wires and their placement in the strand largely influence the flexibility, stability, resistance to abrasion, crushing, bending fatigue, and breaking strength of the wire rope.

Wire rope construction is designated first by the number of strands and then by the number and arrangement of wires in a strand. For example, a 6 x 7 wire rope has six strands with seven wires per strand. Figure 2-2 shows typical sections of wire rope construction; however, it does not cover all the types of wire rope listed in Federal Specification RR-W-410.

2.2 DIAMETER

The wire rope diameter is defined as the diameter of the circle which will just enclose it. Figure 2-3 shows correct and incorrect ways of measuring wire rope diameter. Because the "true" diameter (A) lies within the circumscribed circle, the larger dimension (B) should always be measured. The actual diameter of new wire rope is usually slightly larger than the nominal diameter. Wire rope diameter tolerance is specified in Federal Specification RR-W-410.

2.3 LAY LENGTH OR PITCH

The lay length or pitch of the wire rope is the distance measured along the wire rope axis in which a strand makes one complete helical turn around the axis of the wire rope (see Figure 2-4). The lay length or pitch of a strand is the distance measured along the strand axis in which one wire makes one complete helical turn around the axis of the strand. The lay length or pitch influences the flexibility and constructional stretch of a wire rope and is specified in Federal Specification RR-W-410.

2.4 WIRE ROPE LAY

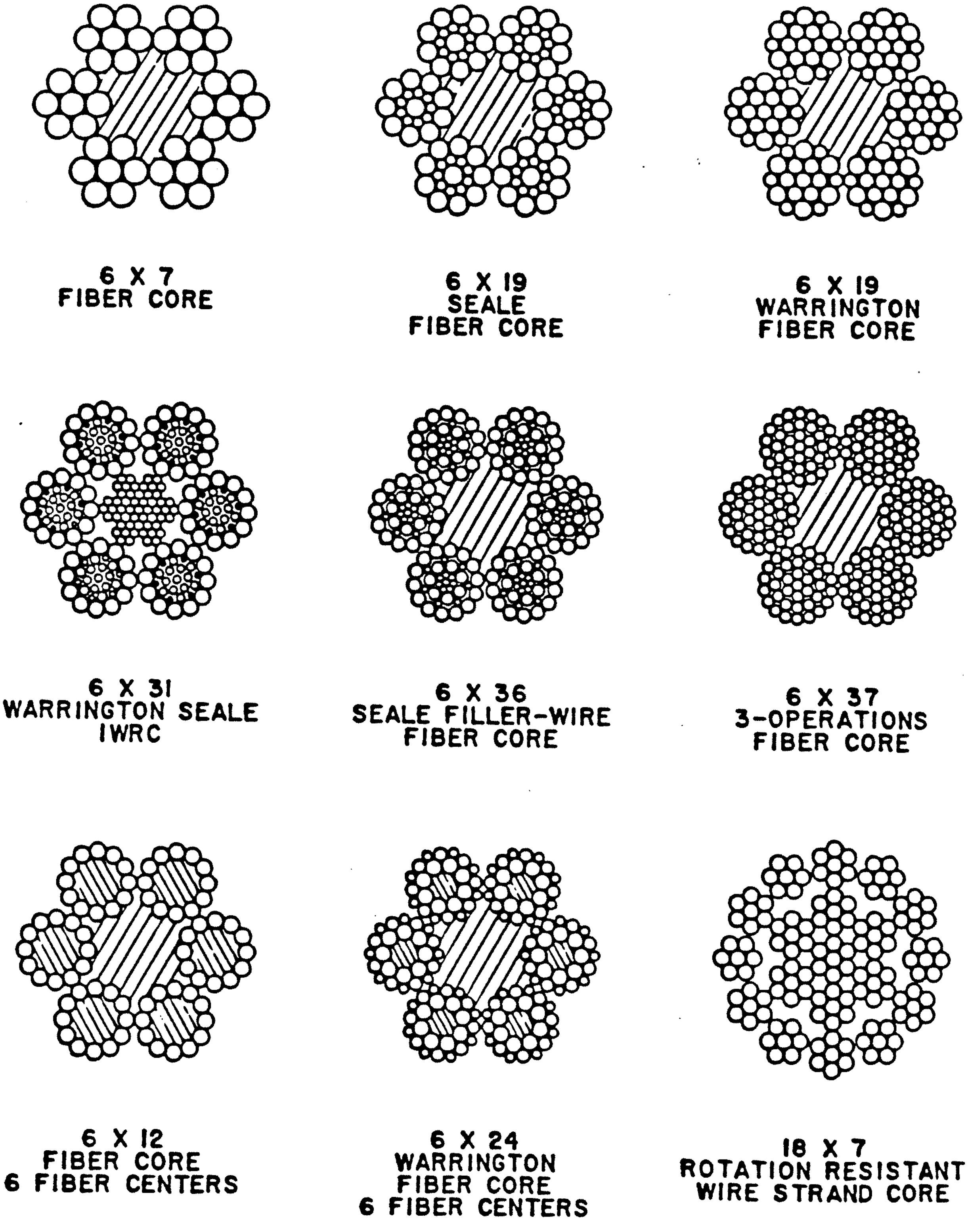
Wire rope lay describes the manner in which the wires in a strand or the strands in a wire rope are helically laid. There are four principal types of wire rope lays: right lay, left lay, regular lay, and lang lay. The most common lay is regular lay, and unless specified otherwise, wire ropes are supplied as right lay regular lay (right regular lay). These types of lays are discussed in the following sections. Figure 2-5 illustrates the types of wire rope lays.

2.4.1 Right Lay

When looking down on a wire rope along its longitudinal axis, the strands of a right-lay wire rope are laid in a clockwise direction.

2.4.2 Left Lay

When looking down on a wire rope along its longitudinal axis, the strands of a left-lay wire rope are laid in a counterclockwise direction.



IWRC-INDEPENDENT WIRE ROPE CORE

Figure 2-2. Examples of Typical Wire Rope Constructions

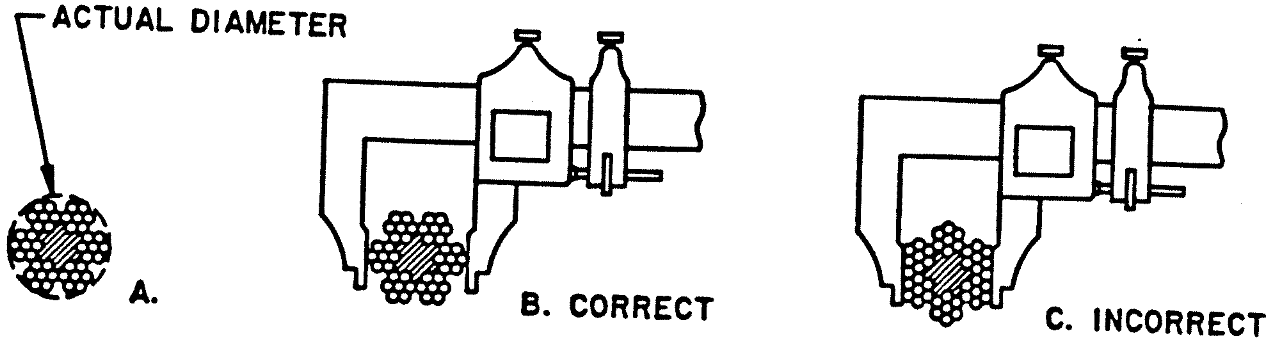


Figure 2-3. How to Measure or Caliper Wire Rope Diameter

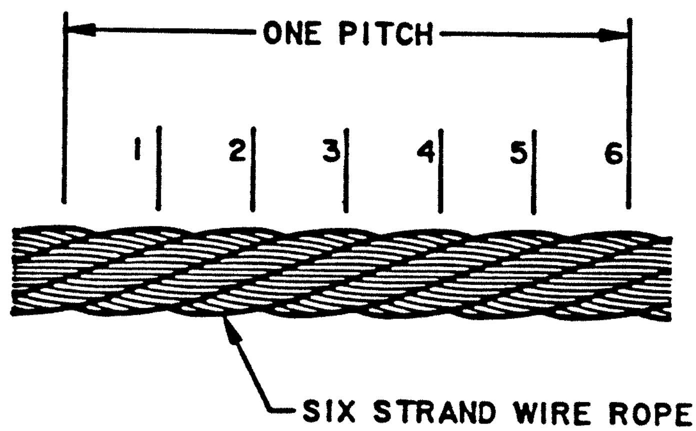


Figure 2-4. Lay Length or Pitch

2.4.3 Regular Lay

In regular-lay wire ropes, the wires in the individual strands are laid in one direction while the strands in the wire rope are laid in the opposite direction. Wire rope may be right regular lay or left regular lay.

In regular-lay construction, the outer wires in the strands run approximately parallel to the longitudinal axis of the wire rope.

2.4.4 Lang Lay

In lang-lay wire ropes, the wires in the individual strands and the strands in the wire rope are laid in the same direction. Wire rope may be right lang lay or left lang lay.

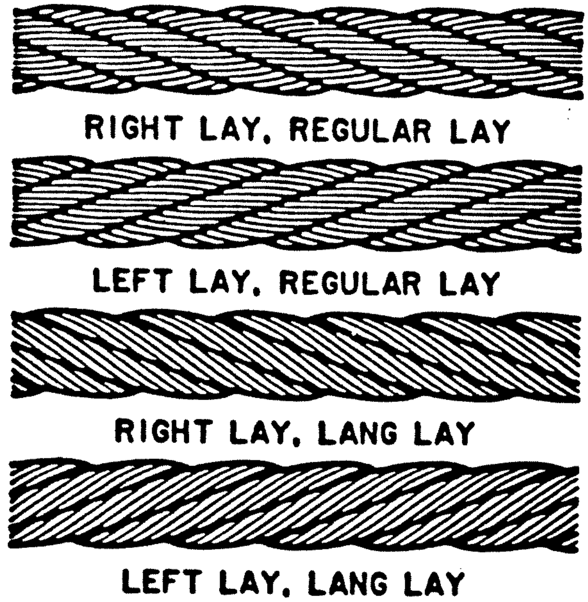


Figure 2-5. Wire Rope Lays

In lang-lay construction, the outer wires in the strands cross the longitudinal axis of the wire rope at an angle. Consequently, in comparison with the outer wires in a regular-lay wire rope, the outer wires of a lang-lay wire rope are exposed for longer length.

The type of lay influences the wire rope's flexibility, stability, resistance to abrasion, crushing, and bending fatigue. These characteristics are discussed in section 6.

2.5 STRAND: DESCRIPTION AND CONSTRUCTION

Generally, a strand consists of a center which supports a specified number of wires laid around it in one or more layers. The center can be either a twisted fibrous material, a single wire, or a wire strand.

When wire rope is manufactured, the strands are either laid in one setup of the stranding machine to form a "single operation" strand or in more than one setup of the stranding machine to form a "multiple operation" strand.

A single-layer strand usually has uniformly sized wires laid in one layer around a fiber or a single-wire center. A single-layer strand is a single-operation strand. Figure 2-6 shows the parts of a single-layer strand.

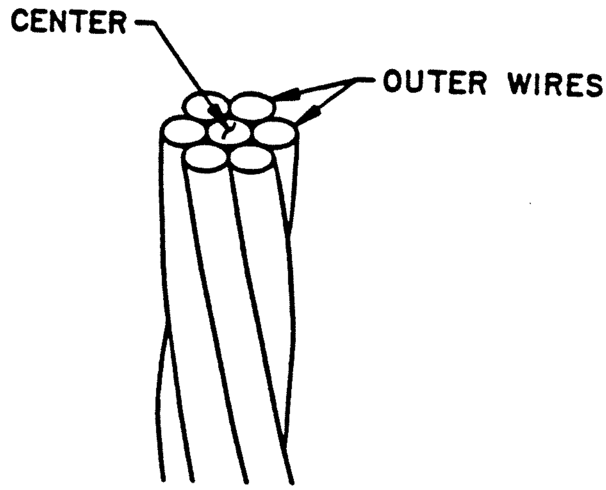


Figure 2-6. Parts of a Single-Layer Strand

Multi-layer strands have two or more layers of wires laid in a single or multiple operation. Most commonly used wire ropes consist of single-operation multi-layer strands.

In a single-operation multi-layer strand, all layers of wire must have the same lay length and lay direction. Therefore, each wire in each layer lies either in the beds formed by the valleys between the wires of the adjacent underlayer or alternatively along the crowns of the underlying wires, and slides and adjusts freely while bending over the drums or the sheaves.

The wires in a single-operation multi-layer strand are arranged in Seale, Warrington, and filler-wire constructions or any combination of the three.

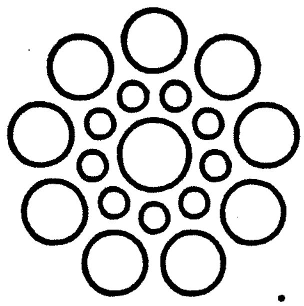
In a multiple-operation multi-layer strand, at least one layer of wires has a different lay length and/or lay direction than the other layers. Consequently, wires with a different lay length or lay direction cross over the crowns of the wires of the adjacent underlayer, which results in local crushing, increased nicking of wires, and increased internal friction during bending over drums or sheaves.

Various single- and multiple-operation multi-layer strand constructions are discussed in the following sections. Their general characteristics are discussed in section 6.

2.5.1 Basic Multi-layer Strand Constructions

2.5.1.1 Seale Construction

The Seale construction strand is a single-operation strand in which two adjacent layers are laid, each layer having the same number of uniformly sized wires. The diameter of the wires in the outer layer is larger than that of the wires in the inner layer so that each wire in the outer layer lies in the beds formed by the valleys between the wires of the inner layer. Seale construction is shown in Figure 2-7.

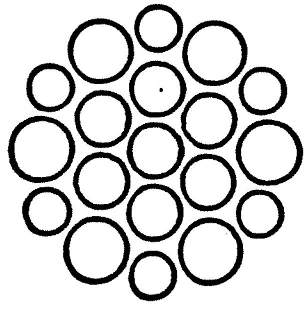


19 WIRE SEALE STRAND

Figure 2-7. Seale Construction

2.5.1.2 Warrington Construction

The Warrington construction strand is a single-operation strand in which two adjacent layers are laid, with two sizes of alternately large and small wires in the outer layer and uniformly sized wires in the inner layer. The large wires of the outer layer lie in the beds formed by the valleys between the wires of the inner layer, and the small wires of the outer layer are supported on the crowns of the wires in the inner layer. The wires in the outer layer are even in total number and add up to twice the number of wires in the inner layer. Warrington construction is shown in Figure 2-8.



19 WIRE WARRINGTON STRAND

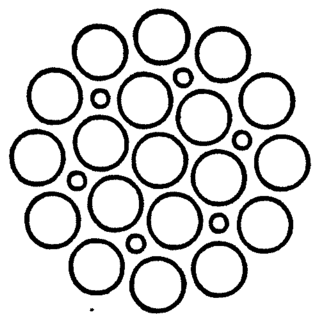
Figure 2-8. Warrington Construction

2.5.1.3 Filler-Wire Construction

The filler-wire construction strand is a single-operation strand in which two adjacent layers are laid, with an even number of uniformly sized wires in the outer layer and one-half that number of uniformly sized wires in the inner layer.

Small "filler wires" fit in the valleys between the wires of the inner layer. The wires of the outer layer rest between the filler wires and the wires of the inner layer.

The primary function of filler wires is to provide bearing support for the outer wires. The filler-wire construction is shown in Figure 2-9.

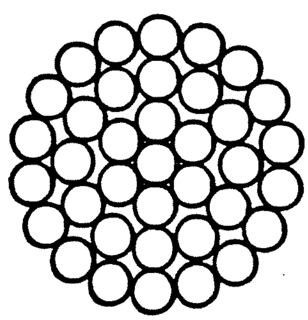


25 WIRE FILLER-WIRE STRAND

Figure 2-9. Filler-Wire Construction

2.5.1.4 One Sized Wire Multiple-Operation Construction

In this construction, each layer is laid in a separate operation with any number of uniformly sized wires in each layer. Usually the number of wires in each succeeding layer is increased by six. The one sized wire multiple-operation construction strand is shown in Figure 2-10.



37 WIRE 3-OPERATIONS STRAND

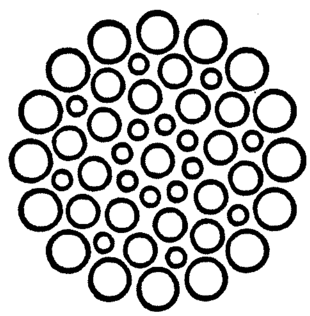
Figure 2-10. One Sized Wire Multiple-Operation Construction

2.5.2 Combined Multi-layer Strand Constructions

Two or more of the foregoing basic multi-layer strand constructions may be combined to form other multi-layer constructions.

2.5.2.1 Combination Strand - Single Operation

Wire sizes would become too large if only Seale, Warrington, or filler-wire constructions were used for fabricating multi-layer single-operation strands with three or more layers of wires. Therefore, wire rope strands with a greater number of wires are constructed as a combination of Seale, Warrington, or filler-wire construction. In the combination strand shown in Figure 2-11, the first two layers are Seale construction, the third layer is Warrington, and the outer layer is a Seale construction of the same size wires. This combination strand construction is called Seale Warrington Seale.



49 WIRE SEALE WARRINGTON SEALE STRAND

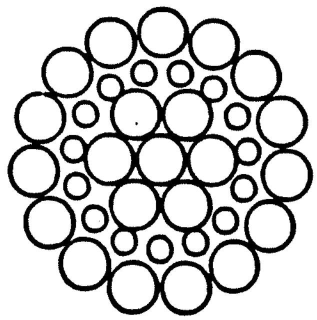
Figure 2-11. Combination Strand

2.5.2.2 Basic Construction - Multiple Operations

In these constructions, a basic multi-layer single-operation strand is covered in one or more additional operations by one or more additional layers having any number of uniformly sized wires in each layer. A Seale (two operations) strand is an example of a multiple-operation basic construction strand. The Seale (two operations) strand is shown in Figure 2-12.

2.5.3 Nonstandard Strand Constructions

In addition to standard strand constructions, several special strand constructions have been developed for specific uses. Some of these constructions are discussed in the following sections.



37 WIRE SEALE (2-OPERATION) STRAND

Figure 2-12. Basic Construction - Multiple Operations

2.5.3.1 Flattened Strand

Flattened strand wire ropes contain six triangularly shaped strands having various numbers of wires per strand as specified in Federal Specification RR-W-410.

The triangular shape of the strands makes the construction more compact. Therefore, compared to a standard round strand wire rope of equal size, a flattened strand wire rope is less flexible, is less resistant to bending fatigue, possesses greater breaking strength, and has greater resistance to crushing.

Flattened strand wire ropes are made in a lang-lay construction which makes them less stable. However, a greater number of contact points (see Figure 2-13) in conjunction with the lang-lay construction results in a greater exposed area of contact with the sheaves and drums and makes a flattened strand wire rope more abrasion resistant than a standard round strand wire rope.

2.5.3.2 Fiber-Centered Strand

In a fiber-centered strand, strand wires are laid around a fiber center. Fiber-centered strand wire ropes in the 6 x 12 and 6 x 24 classes are discussed in this section. These ropes have a fiber core, and right regular lay is standard.

The 6 x 12 class wire ropes are made of galvanized improved plow steel or phosphor bronze. Each strand of a 6 x 12 class wire rope has a single layer of 12 uniformly sized wires laid around a fiber center.

The 6 x 24 class wire ropes are made of galvanized improved plow steel. Each strand of a 6 x 24 class wire rope has two layers of wires laid around a fiber center. Because of its larger metallic area, it is stronger than a 6 x 12 class wire rope of equal size.

The 6 x 12 and 6 x 24 class wire ropes, for a given size, are more flexible and not as strong as wire rope made of all metal strands. The material of these wire ropes has good corrosion resistance and poor resistance to abrasion. Because of the fiber centers and fiber core, 6 x 12 and 6 x 24 class wire ropes have poor resistance to crushing.

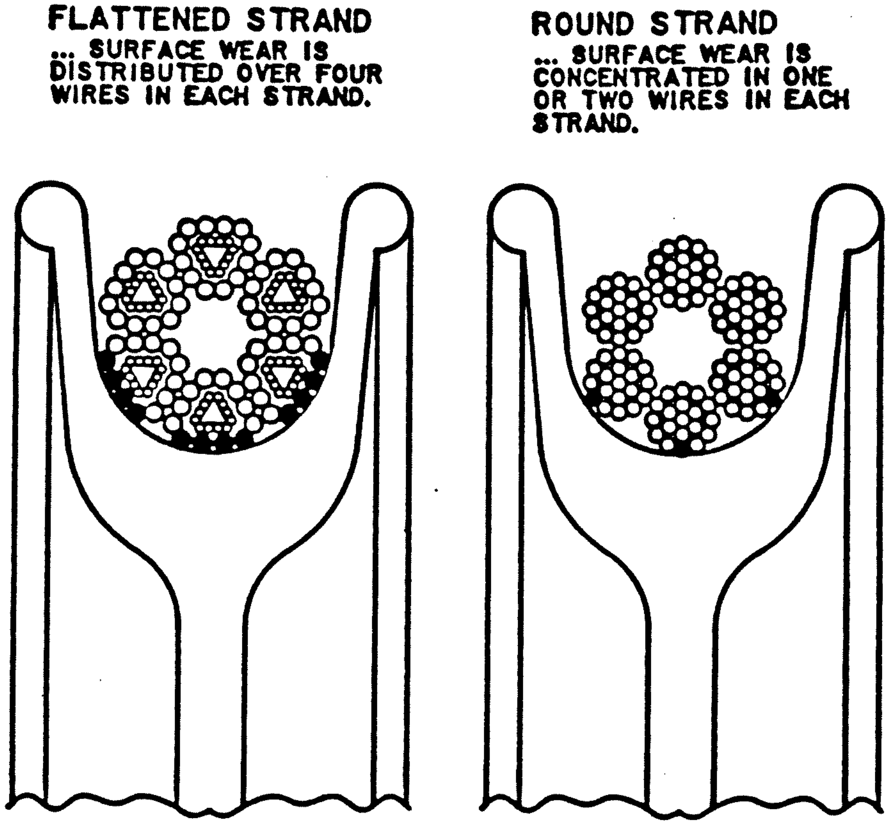


Figure 2-13. Flattened vs. Round Strands

2.6 STRAND CLASSIFICATION

The general characteristics of a wire rope are influenced by the specific construction of the strands. For example, a 6 x 19 class wire rope is made in various constructions and may have 15 to 26 wires in the strands; therefore, wire ropes in this class may have widely varying characteristics. All wire ropes within a class, however, have the same breaking strength and the same weight per foot. The exception is the 6 x 37 class where the breaking strength and the weight per foot of single-operation strand wire ropes are slightly more than the breaking strength and the weight per foot of multiple-operation strand wire ropes.

The strand classifications covered by the various wire rope classes are defined as follows and unless a class is specified within the classification, a different class may be substituted:

Classification	Classes
6 x 19	6 x 15 to 6 x 26
6 x 37	6 x 27 to 6 x 49
6 x 61	6 x 50 to 6 x 74
6 x 91	6 x 75 or more

2.7 CORE TYPES AND FUNCTIONS

Wire rope cores are either fiber or metallic. The core forms the foundation of the wire rope and is the component around which the main wire rope strands are laid. As a wire rope is loaded, the helical lay of the strands causes them to press in toward the wire rope axis. The core supports this bearing pressure and helps to preserve the round shape of the wire rope. The core also maintains the spacing of the strands during bending and tends to minimize rubbing between strands.

A detailed description of the construction and materials of wire rope cores is specified in Federal Specification RR-W-410.

2.7.1 Fiber Cores

Fiber cores for wire ropes are usually made of hard natural fibers (manila and sisal) or polypropylene fiber. Unlike natural fiber cores, polypropylene fiber cores are immune to rot and mildew and are being used more extensively in all types of wire rope applications.

Fiber cores provide no additional strength, yet they do provide maximum flexibility. With a fiber core, the strand-to-core nicking experienced in metallic core wire ropes is also avoided. Fiber core material may crush under high loads; therefore, in wire rope applications where resistance to crushing is important, the fiber core is replaced with a metallic core.

Fiber cores decompose at high temperatures and shall not be used in applications where the temperature of the environment may be expected to exceed 180°F (82°C).

2.7.2 Metallic Cores

Metallic cores are of two types, independent wire rope cores (IWRC) and wire strand cores (WSC). Wires in the metallic cores are usually made of the same material as the wires in the strands of the wire rope.

Metallic cores add to the strength of a wire rope (7-1/2 percent for a six-strand wire rope with a metallic core). Metallic core wire ropes are less elastic and less resistant to shock loads than fiber core wire ropes. Metallic cores increase the wire rope's resistance to crushing and thereby tend to preserve the shape of the wire rope under multi-layer spooling conditions. Metallic core wire ropes, however, experience strand-to-core nicking when the wire rope flexes as it travels over the sheaves and drums.

2.7.2.1 IWRC

IWRC is a small wire rope used as a core in a larger wire rope. Generally the core has the same lay direction as the main wire rope. IWRC may be a wire rope with either a fiber or a wire strand core.

2.7.2.2 WSC

WSC is a single strand used as a core and is usually of the same construction as the main wire rope strands. The WSC gives the smoothest and the most solid support for the outer strands. It is used predominantly in smaller diameter wire ropes where IWRC wires would be too small to use.

2.8 PREFORMING AND PRESTRETCHING

2.8.1 Preforming

Preforming is a process in which individual wires and complete strands are permanently formed into the helical shape they will assume in the finished wire rope. Figure 2-14 shows a strand and a wire in permanent helical form.

The wires and strands in a nonpreformed wire rope have a tendency to straighten out. Holding the wires and strands in place sets up internal stresses in the wire rope. In a preformed wire rope, the wires and strands are "at rest," and when cut, a preformed wire rope will not open up or "broom." Also, after the wire rope has been in service, a wire broken from abrasion tends to lie flat against the wire rope and may not wicker out and become dangerous to handle.

Preforming does not alter the breaking strength of a wire rope, nor does it affect the resistance to crushing. However, when a preformed wire rope is bent around sheaves and drums, the internal friction caused by wire and strand movement during bending is reduced to a minimum, resulting in reduced internal wear (nicking) and longer bending fatigue life. Wire rope rotation in the grooves is also minimized and abrasion is therefore reduced. Preformed wire rope has increased flexibility and stability, is easier to handle, and will spool more uniformly on drums.

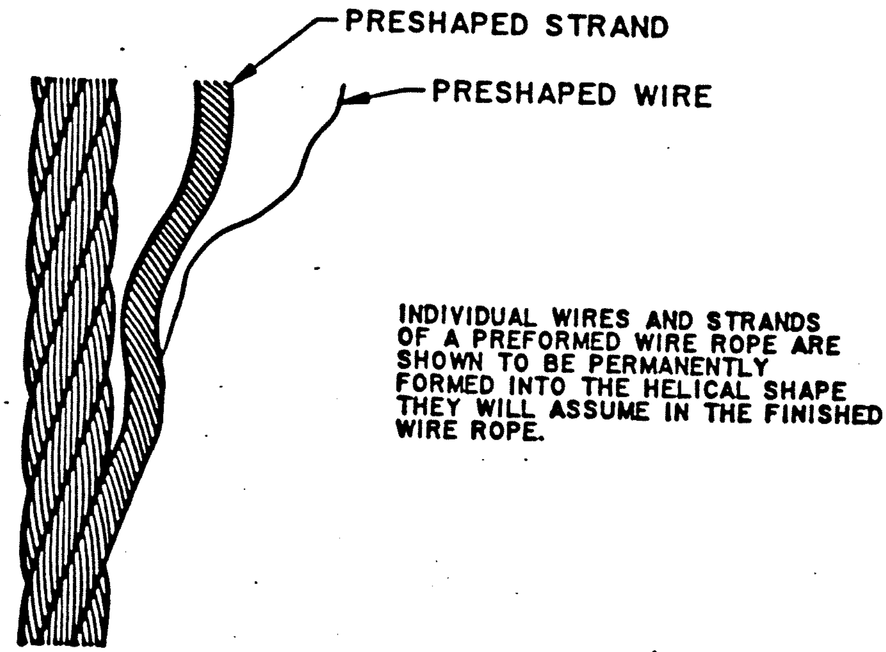


Figure 2-14. Strand and Wire in Permanent Helical Form

2.8.2 Prestretching

Wire rope is prestretched (or prestressed) to remove constructional stretch or elongation and to allow for extremely accurate length control. Prestretching is recommended for stationary metallic core wire ropes where elongation must be limited and specific lengths must be maintained. Prestretching is not recommended for fiber core wire ropes or for wire ropes that will be used in running rigging. Navy experience has shown that prestretched wire ropes may relax appreciably if the wire rope is recoiled, spooled onto a small reel, or not put in service after prestretching. These wire ropes need to be prestretched again before use. The criteria for prestretching a wire rope are discussed in Federal Specification RR-W-410.

2.9 WIRE ROPE APPLICATIONS

In naval installations, the types and uses of wire ropes may be generally grouped as discussed in the following sections.

2.9.1 6 x 12 Classification

Wire ropes in the 6 x 12 class, with a fiber core and a fiber center in each strand, are more flexible and less strong than equal sized wire ropes in either the 6 x 19 or 6 x 37 class. 6 x 12 class wire ropes have good corrosion resistance and have poor resistance to abrasion and crushing. When made of galvanized steel wires, 6 x 12 class wire ropes may be used for ridge ropes, boat ladders, and Jacob's ladders. These wire ropes may also be used where extreme flexibility is required and exposure to moisture is frequent. When made of phosphor bronze wires, 6 x 12 class wire ropes may be used for wheel ropes, or for rigging in applications where either noncorrosive or nonmagnetic properties are required.

2.9.2 6 x 19 Classification

Wire ropes in the 6 x 19 class have good resistance to abrasion and crushing. However, their resistance to bending fatigue and their reserve strength is inferior to 6 x 37 class wire ropes. When made of uncoated carbon steel wires, 6 x 19 class wire ropes are principally used for hoisting in applications where additional abrasion and crushing resistance, as on multi-layered drums, is required. This class of wire ropes is particularly useful on derricks and dredges. To obtain the best results, sheaves for this class of wire ropes shall be larger than those for the other more flexible classifications. When made of galvanized steel wires, 6 x 19 class wire ropes are normally used for standing rigging, guy pendants, topping lift pendants, heavy weather pendants, preventers, boat slings, and towing hawsers. When made of phosphor bronze wires, 6 x 19 class wire ropes are normally used for life lines, wheel ropes, rigging, and antennas, where either noncorrosive or nonmagnetic properties are required. When made of corrosion-resistant steel wires, 6 x 19 class wire ropes are used for torpedo handling, safety nets, and life lines installed in blast areas.

2.9.3 6 x 24 Classification

Wire ropes in the 6 x 24 class, with a fiber core and fiber center in each strand, are almost as flexible and stronger than equal sized wire ropes in the 6 x 12 class. Wire ropes in the 6 x 24 class have good corrosion resistance and poor resistance to abrasion and crushing. These wire ropes are specified only in the galvanized steel type. These wire ropes are used primarily in the larger sizes where the strength of a 6 x 12 wire rope of the same size will not be satisfactory and where extreme flexibility is the major consideration. These wire ropes are used for mooring lines.

2.9.4 6 x 37 Classification

Wire ropes in the 6 x 37 class are quite flexible, have good resistance to bending fatigue, and have good reserve strength because over 50 percent of the strength is in the inner wires of the strand protected from abrasion. However, their resistance to abrasion and crushing is inferior to 6 x 19 class wire ropes. When made of uncoated carbon steel wires, 6 x 37 class wire ropes are suitable for topping lifts, span wires, highlines, vangs, inhaul and outhaul lines, elevators, hoisting on cranes, and cranes, and similar machinery where sheaves are of necessity smaller than desirable. It is used where bending conditions are unusually severe. When made of galvanized steel wire, these ropes may be used for steering gear, transmission rope, hawsers, towing hawsers (except on multi-layered drums), bridles, relieving tackles, and slings for general hoisting.

2.9.5 6 x 3 x 19 Classification (Spring Lay)

6 x 3 x 19 class ropes are more flexible and less strong than other wire ropes of the same diameter. These ropes have alternating fiber and galvanized steel wire strands closed around a fiber core. These ropes are used for alongside harbor towing and are considered a substitute for hawsers.

3.0 WIRE ROPE MATERIALS

Most wire ropes in use today are made of cold-drawn carbon steel wires. Where protection against corrosion is a major concern, wire ropes can be manufactured from corrosion-resistant steel (CRES) wires, phosphor bronze wires, or cold-drawn carbon steel wires coated with zinc.

Wire rope cores are either fiber or metallic. Fiber cores are made of hard natural fibers or polypropylene fibers. Wires in the metallic cores are usually made from the same material as the wires in the strands of the wire rope (refer to Federal Specification RR-W-410 for details).

For ready reference, wire rope material characteristics are qualitatively summarized in Table 3-1.

3.1 CARBON STEEL AND GRADES

Improved plow steel and extra-improved plow steel are the two most common carbon steel grades in Navy application. Extra-improved plow steel wire rope has the maximum breaking strength of all wire ropes in Navy usage and is approximately 15 percent stronger than the improved plow steel wire rope.

Carbon steel wire ropes are susceptible to corrosion in a marine atmosphere. However, carbon steel wire ropes with proper lubrication have proven to be very successful as hoisting ropes in a marine atmosphere.

Fiber cores decompose at high temperatures and shall not be used in applications where the temperature of the environment exceeds 180°F. At temperatures above 400°F, metallic core carbon steel wire ropes start to lose strength, and continued exposure to elevated temperatures results in annealing and further reduction in strength.

Carbon steel wire ropes are used for topping lifts, vangs, inhaul and outhaul lines, highlines, span wires, elevators, hoisting on cranes, and similar machinery.

3.1.1 Improved Plow Steel

Improved plow steel wire ropes are available in most construction types and sizes. The wires for improved plow steel wire ropes are available either uncoated or galvanized. Improved plow steel has good resistance to bending fatigue. In comparison with the good resistance of extra-improved plow steel, improved plow steel has fair resistance to abrasion.

Table 3-1

CHARACTERISTICS OF WIRE ROPE MATERIALS

CHARACTERISTICS / MATERIALS	STRENGTH	AVAILABILITY	RESISTANCE TO HEAT	RESISTANCE TO ABRASION	RESISTANCE TO BENDING FATIGUE	RESISTANCE TO CORROSION	
						ABOVE WATER LINE	IMMERSED IN SEAWATER
EIPS UNCOATED	G	G	F	G	F	P	P
IPS UNCOATED	F	G	F	F	G	P	P
EIPS DRAWN-GALVANIZED	G	G	F	G	F	F	G
IPS DRAWN-GALVANIZED	F	G	F	F	G	F	G
EIPS GALVANIZED AT FINISH SIZE	G	G	F	P	P	F	G
IPS GALVANIZED AT FINISH SIZE	F	G	F	P	P	F	G
CRES	F	F	G	P	P	G	P
PHOSPHOR BRONZE	P	P	P	P	P	G	G

EIPS - EXTRA-IMPROVED PLOW STEEL
IPS - IMPROVED PLOW STEEL
CRES - CORROSION-RESISTANT STEEL

G - GOOD
F - FAIR
P - POOR

Phosphor bronze wire ropes in Navy usage are not suitable in applications where the temperature of the environment may be expected to exceed 180°F, and their resistance to abrasion and bending fatigue is poor. However, these wire ropes are nonmagnetic and nonsparking.

Phosphor bronze wire ropes are used for lifelines, wheel ropes, radio antenna lines, and rigging in applications where either noncorrosive or nonmagnetic properties are desired.

3.4 METALLIC COATINGS

Carbon steel wires used in the fabrication of wire ropes are often coated with zinc to retard corrosion. This is because zinc is more corrosion resistant and more anodic than carbon steel. Thus, a carbon steel wire coated with zinc will resist initial corrosive action; when corrosion penetrates the zinc coating, the corrosion process will preferentially remove the zinc coating until a considerable area of steel is exposed.

3.4.1 Galvanized Steel

Galvanizing is the process of coating carbon steel with zinc. Galvanized steel wire ropes are made from carbon steel wires which are either electrogalvanized or hot-dip galvanized. These wire ropes are available in most construction types and sizes. Electrogalvanizing is the process of covering any metal with a coating of zinc by means of an electric current. In hot-dip galvanizing, the zinc is applied by passing the carbon steel wires through a molten zinc bath. Compared with hot-dip galvanizing, the thickness of the zinc coating may be readily controlled in electrogalvanizing, and the coating is smooth and uniform and adheres firmly to the metal. When galvanizing is done as the final step in the wire-making process, the carbon steel wires are called galvanized at finish size. The tensile strength of carbon steel wires galvanized at finish size is approximately 10 percent less than that of uncoated carbon steel wires. When maximum breaking strength is desired in a galvanized steel wire rope, galvanizing precedes the last cold-drawing series of the carbon steel wires, and the carbon steel wires are called drawn-galvanized. The tensile strength of drawn-galvanized steel wire matches the tensile strength of uncoated carbon steel wire. The minimum weight of zinc coating for both cases is specified in Federal Specification RR-W-410.

Compared with CRES wire ropes, galvanized steel wire ropes have less resistance to corrosion in applications above the water line. When immersed in seawater, galvanized steel wire ropes have better corrosion resistance.

The resistance to heat of wire ropes made from galvanized steel wires is comparable to uncoated carbon steel wire ropes.

For the same grade of carbon steel, the resistance to abrasion and bending fatigue of wire ropes made from drawn-galvanized steel wires is comparable to uncoated carbon steel wire ropes, and wire ropes made from carbon steel wires galvanized at finish size are less resistant to abrasion and bending fatigue. Navy experience has shown, however, that the zinc coating for both types of galvanized steel wire ropes flakes off while running over sheaves and drums. Therefore, galvanized steel wire ropes shall be used for standing rigging only.

Galvanized steel wire ropes are used for standing rigging, mooring lines, hawsers, towing hawsers, boat ladders, steering gear, bridles, standing rigging, ridge ropes, transmission ropes, relieving tackles, preventers, slings, Jacob's ladders, guy pendants, topping lift pendants, and heavy weather pendants.

THIS PAGE INTENTIONALLY LEFT BLANK

4.0 FITTINGS AND TERMINATIONS

The wire rope end must be fastened in some manner to perform useful work. A wire rope termination is made by attaching an end fitting to a wire rope or by making a loop (or eye) in the end of a wire rope. The type of termination to be used depends upon the wire rope application.

Poured sockets are more susceptible to bending and vibration fatigue than others, while splices and Fiege-type fittings will not develop the full wire rope strength. Fiege-type fittings do not require any special tools, while swage fittings require a swaging press.

The efficiency of the termination is defined as the ratio of the actual breaking strength of the installed wire rope fitting combination to the actual breaking strength of the wire rope. Wire rope terminations are often evaluated in terms of efficiency because of its influence on the design strength of the wire rope system. Efficiencies of wire rope terminations are specified in the following sections and are tabulated in Table 7-3.

Fittings are manufactured from a variety of materials such as steel, bronze, brass, and corrosion-resistant steel (CRES). The material of the fitting must be compatible with the wire rope material. Only bronze or brass fittings shall be used with phosphor bronze wire rope, CRES and carbon steel fittings shall be used with CRES and carbon steel wire rope.

For specific operations, fittings and terminations are described in the technical manual for that system.

4.1 ZINC SOCKETS

Zinc sockets (also referred to as poured sockets or spelter sockets) are cone-shaped receptacles which have an opening about the size of the wire rope diameter at the small end and a bail or clevis at the large end. These sockets are for permanent attachment to wire ropes. The wire rope is broomed out and all broomed-out wires are cleaned. The wire rope is placed in the socket through the opening at the small end. Wires are distributed evenly around the socket basket and flush with the top. For carbon steel wire ropes, molten zinc is poured into the basket. The poured metal forms a metallurgical bond with the broomed-out wires of the wire rope and enables the zinc sockets to develop 100 percent efficiency.

Zinc sockets have inferior resistance to vibration and bending fatigue.

A typical closed zinc socket is shown in Figure 4-1. Examples of applications that require zinc sockets include boat lifting slings, high-speed target towing, ship's salvage lifting gear, mine-sweeping towing assemblies, standing rigging, and running rigging, unless specific exceptions permit another type of termination.

Wire rope sockets are specified in Federal Specification RR-S-550 and in standard drawings. Only the galvanized type shall be used. The procedure for attaching a wire rope zinc socket is described in NAVSHIPS S9086-UU-STM010/CH613.

4.2 SWAGE FITTINGS

Swage fittings are attached to the wire rope by a cold working process that causes the ductile material of the fitting to flow into the valleys of the wire rope, thereby forming a strong bond. These fittings are for permanent attachment to wire ropes. Swage fittings are used on wire ropes with metallic cores and shall not be used on fiber core wire ropes. Compared to zinc sockets, wire ropes with swage fittings are less vulnerable to vibrational and bending fatigue damage at the base of the fitting. Swage fittings are made for wire ropes with diameters ranging from 1/4 inch through 2-1/2 inches. Individual systems may vary and may require fittings for larger diameter wire ropes. Swage fittings shall be applied per the manufacturer's recommendations.

In Navy usage, swage fittings are approved for making mechanical eye splices. Figure 4-2 shows a swaged termination (mechanical eye splice with a swaging sleeve).

Typical examples of approved applications for swaged terminations are boat-boom rigging, lifelines, tiller ropes, slings, safety nets, shrouds, stays, topping-lift fittings, and wire rope antennas.

4.3 FIEGE-TYPE FITTINGS

Fiege-type fittings operate on a wedging principle. Fiege-type fittings consist of three parts: a sleeve which slips over the end of the wire rope, a plug which is inserted to separate and hold the wire rope strands in the sleeve, and a covering socket. These fittings are for permanent attachment to wire ropes. Tension on the wire rope forces the plug into the sleeve and grips the wire rope more firmly. The axially symmetric configuration of the plug causes minimal wire rope distortion and makes a strong flexible connection. Figure 4-3 shows a Fiege-type fitting. Fiege-type fittings are reusable and are easier and quicker to install than zinc sockets and swage fittings. However, plugs are not reuseable. Fiege-type fittings develop 85 percent efficiency and have good resistance to vibration and bending fatigue.

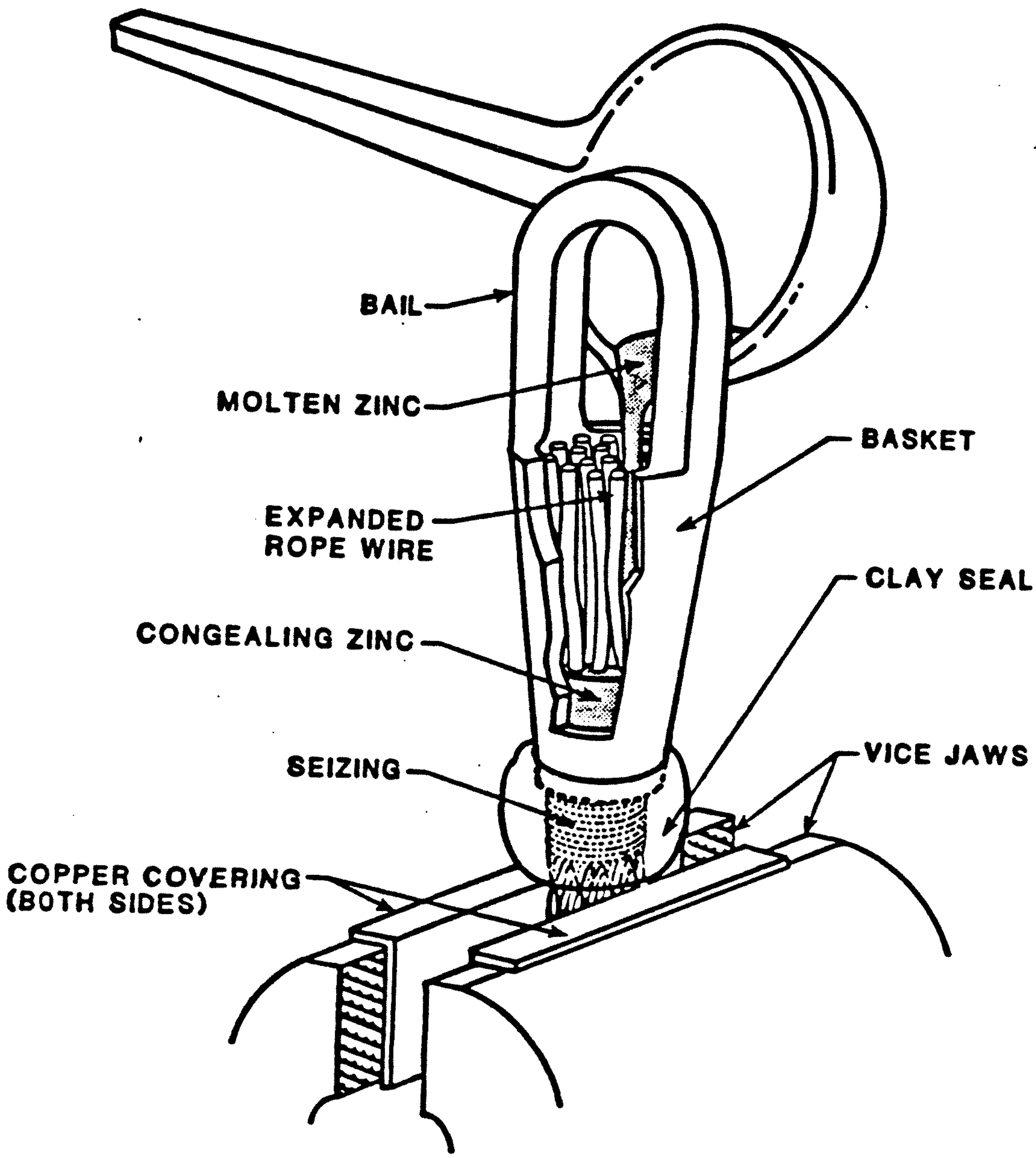


Figure 4-1. Zinc Socket (Closed)

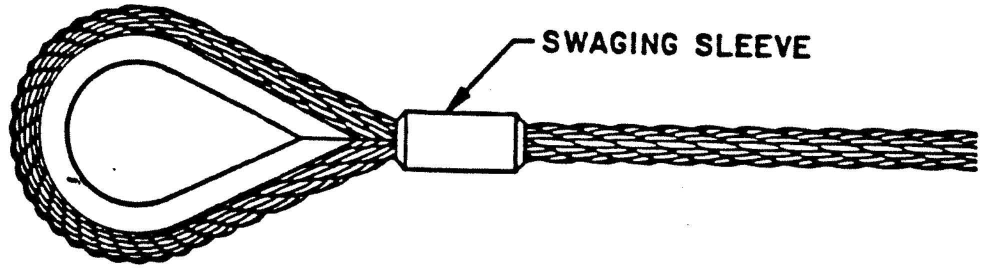


Figure 4-2. Swaged Termination

Different types of Fiege-type fitting plugs, as shown in Figure 4-4, are available for use with various types of wire rope.

Typical examples of approved applications for Fiege-type wire rope fittings are ship's standing rigging, boat booms, lifelines, tiller ropes, and wire rope antennas.

Fiege-type fittings are specified in Military Specification MIL-S-21433.

4.4 THIMBLES

Thimbles are used to form all eye splices except soft eye splices. Thimbles provide a smooth bend in the wire rope and prevent the eye from flattening out of shape, displacing the strands, and reducing the efficiency of the termination. Thimbles also prevent the fittings from wearing through the wire rope.

Thimbles are made from hot rolled or cold rolled steel and are galvanized. They are also used for thimble and clip temporary wire rope terminations.

A wire rope thimble is shown in Figure 4-5. Wire rope thimbles are specified in Federal Specification FF-T-276. Type III thimbles, heavy, are intended for use where full tension of the wire rope may be developed.

4.5 CLIPS

Clips with thimbles are the most commonly used type of temporary wire rope terminations. Clips with thimbles shall not be used for permanent attachment to wire ropes. These terminations are more resistant to vibration and bending fatigue than zinc sockets;

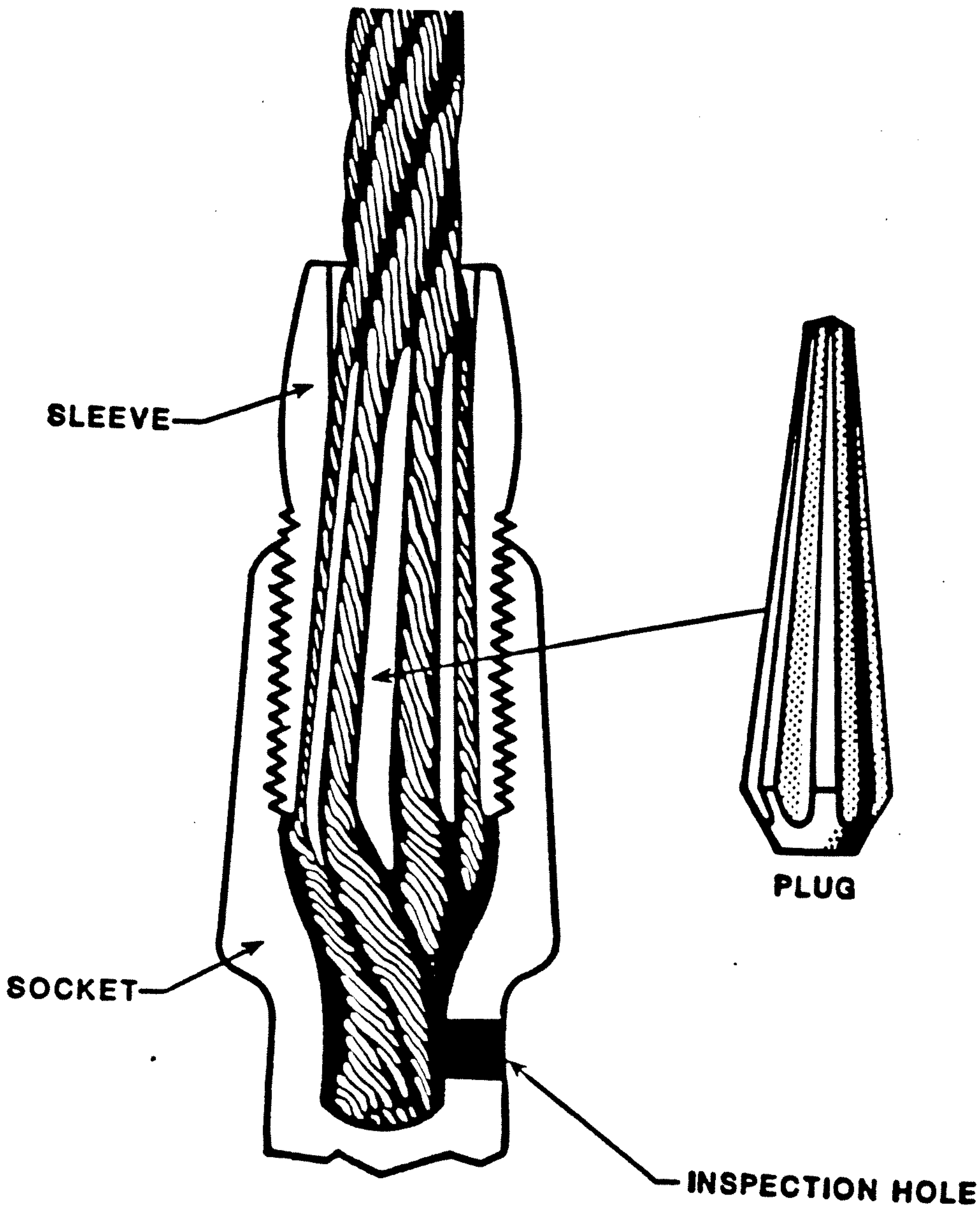
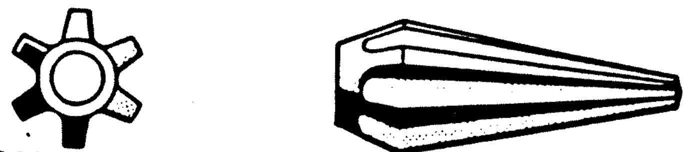
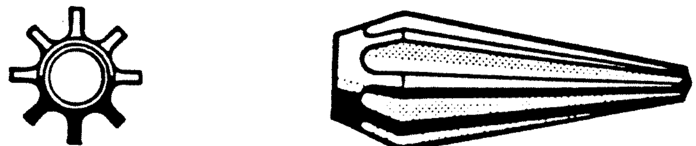


Figure 4-3. Fiege-Type Fitting



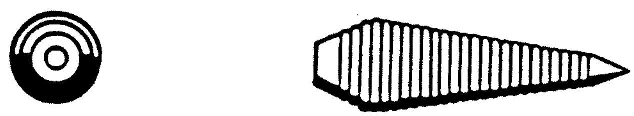
FIBER CORE PLUG, SIX-GROOVE (SOLID)

FOR ALL FIBER CORE WIRE ROPES (EXCEPT 6x42 ROPE), WITH SIX STRANDS. SIZES 5/16 INCH AND SMALLER, HAVE NO GROOVES. CAST BRONZE.



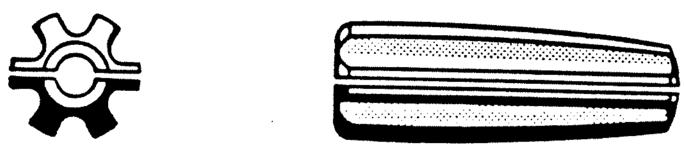
FIBER CORE PLUG, EIGHT-GROOVE (SOLID)

FOR ALL FIBER CORE WIRE ROPES WITH EIGHT STRANDS. SIZES 3/8 INCH AND SMALLER AND FOR ALL INDUSTRIAL-TYPE FITTINGS. DRAWN BRASS OR BRONZE - 1/2 INCH AND SMALLER. STEEL - 9/16 INCH AND LARGER.



METALLIC-CORE PLUG (SOLID)

FOR ALL METALLIC-CORE WIRE ROPES. 6x42 FIBER CORE WIRE ROPE 1/2 INCH AND SMALLER AND FOR ALL INDUSTRIAL-TYPE FITTINGS. DRAWN BRASS OR BRONZE - 1/2 INCH AND SMALLER. STEEL - 9/16 INCH AND LARGER.



METALLIC-CORE PLUG (TWO-PIECES)

FOR ALL METALLIC-CORE WIRE ROPE SIZES 9/16 INCH AND LARGER. CAST BRONZE.

STRAND PLUG (HOLLOW)

FOR ALL STRANDS OF SEVEN OR 19 WIRES 1/4 INCH AND LARGER. (CANNOT BE USED INTERCHANGEABLY - 1x7 REQUIRES LARGER HOLE THAN 1x19). DRAWN BRONZE OR STEEL.

Figure 4-4. Fiege-Type Fitting Plugs

however, the efficiency of a clip-thimble connection is about 80 percent. The correct number of clips and proper tightening torque for various wire rope sizes are given in Table 4-1. Overtightening of clips is detrimental to the wire rope. Clips are reusable. Due to a slight reduction in the wire rope diameter under operating load, clips tend to loosen and should be retightened after one hour of running time. Clip attachments are shown in Figure 4-6. A distance of six rope diameters between clips is suitable.

Wire rope clips are specified in Federal Specification FF-C-450.

4.6 SPLICES

Wire rope is spliced either to fasten the ends of two wire ropes together (long splice) so that the wire rope will run over a sheave or to make a loop (or eye) in the end of a wire rope.

In the design of wire rope installations, long splices are not used, but a brief description is for information purposes. The long splice is used for joining two wire ropes where no increase in the wire diameter is allowed. The long splice develops 80 percent of the full strength of the wire rope.

There are two types of eye splices - hand-tucked eye splices and mechanical eye splices.

4.6.1 Hand-Tucked Thimble Eye Splice

A hand-tucked eye splice is used to form a permanent eye in the end of wire rope. It may be used on regular lay or long lay construction. This type of splice is made by forming a loop in the end of the wire rope, then the dead end is tucked strand-by-strand into the live portion of the wire rope. A thimble is normally used in forming the loop, except when the eye is required to be passed through a block.

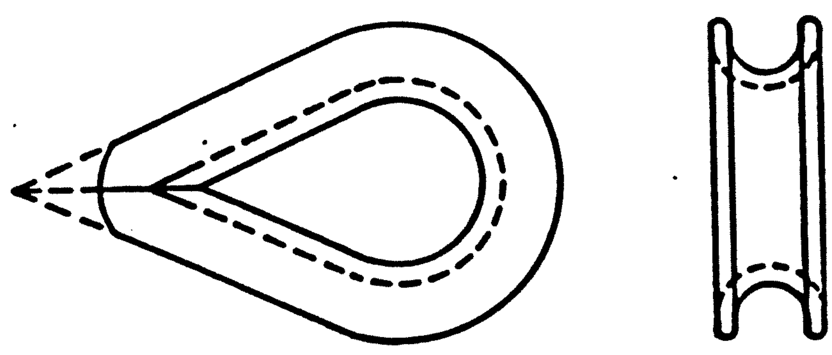


Figure 4-5. Wire Rope Thimble

Table 4-1

MINIMUM NUMBER OF CLIPS REQUIRED

Wire Rope Nominal Diameter (inches)	All IWRC Wire Ropes	6 x 19 and 6 x 37 Fiber Core Wire Ropes	Proper Torque to be Applied to Nuts of Clips ft-lb (dry)
3/8	4	3	45
1/2	4	3	65
5/8	4	3	95
3/4	5	4	130
7/8	5	4	225
1	6	5	225
1-1/8	6	5	225
1-1/4	7	6	360
1-3/8	7	6	360
1-1/2	8	7	360
1-3/4	8	7	590

IWRC - Independent Wire Rope Core

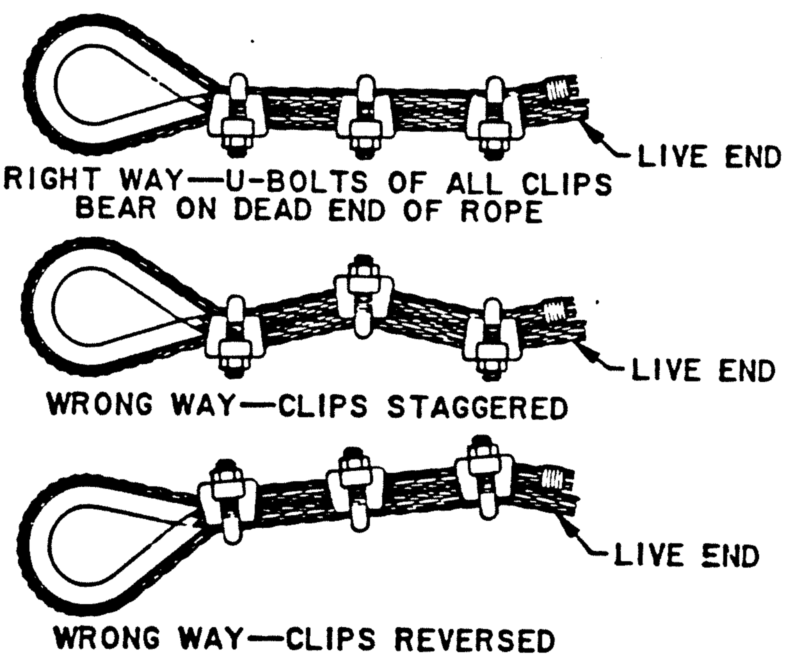


Figure 4-6. Clip Attachments

Standing rigging that has been manually spliced shall be wormed, parceled and served at deck level to prevent injury to personnel. A hand-tucked eye splice with thimble and serving is shown in Figure 4-7.

The efficiency of a hand-tucked thimble eye splice is as follows:

Wire Rope Nominal Diameter (inches)	Efficiency (percent)
1/4 and smaller	95
3/8 to 3/4	88
7/8 and 1	85
1-1/8 to 1-1/2	80
1-5/8 to 2	75
2-1/4 and larger	70

The efficiency of a hand-tucked eye splice without thimble is somewhat less.

4.6.2 Mechanical Eye Splice

A mechanical eye splice is any eye splice in which a metal sleeve is swaged to the base of the loop to hold the dead end of the wire rope in place. The loop may be a Flemished eye or a fold-back eye. The mechanical eye splice with a flemish loop is more dependable than a fold back eye splice. The strength of the splice is not wholly dependent on the sleeve since it has the hand splicing to fall back on should the sleeve fail. Either type of loop can be made into a thimble eye splice or a soft eye splice. A mechanical eye splice is a permanent termination and is not approved on fiber core wire ropes. Mechanical eye splices, with either type of loop, develop 85 percent efficiency.

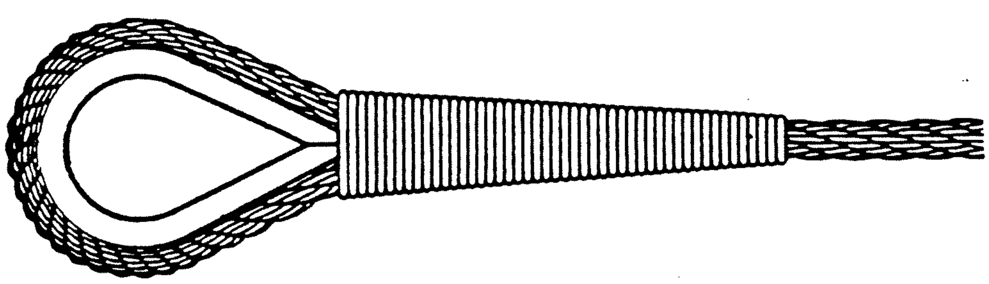


Figure 4-7. Seized Hand-Tucked Thimble Eye Splice

THIS PAGE INTENTIONALLY LEFT BLANK

5.0 MISCELLANEOUS HARDWARE

Wire rope in Navy rigging systems is normally used in conjunction with various pieces of system hardware including shackles, hooks, links, swivels, blocks, and overhauling weights. The safe working load of the rigging hardware must be comparable with the wire rope design load.

For different operations, shackles, hooks, links, swivels, and blocks are specified in the technical manual for that system.

5.1 SHACKLES

A shackle consists of a U-shaped steel forging with parallel eyes at the free ends of the U and a pin which slides through the eyes, forming a closed loop. The two common forms of shackles used in wire rope systems are the anchor shackle and the chain shackle. Shackles are available in regular strength (Grade A) and high strength (Grade B). Each shackle body is permanently marked with the shackle size and the recommended safe working load. The diameter of the steel in the shackle bow section determines the size of the shackle.

Shackles shall have a minimum design safety factor of 5. Shackles for Navy usage are specified in Federal Specification RR-C-271.

5.2 HOOKS

Hoist hooks and safety hoist hooks (with a safety closure device) are intended for use with hoisting devices in cargo handling and other lifting operations.

The minimum design safety factors of hooks are specified in the applicable specifications. Hooks are specified in Federal Specification RR-C-271 and in the military specifications listed in Table 5-1.

5.3 LINKS

Links are used as a means of connection between various pieces of system hardware. Links are available in open and closed styles. A connecting link is an example of an open link and a pear-shaped link is an example of a closed link.

Links shall be designed with a minimum design safety factor of 4 and are specified in Federal Specification RR-C-271.

Table 5-1

TYPES OF HOOKS

Title	Specification
Hooks, Hoist, Regular and Safety	A-A-50469 and A-A-50472
Hook, Cargo (Drop Forged)	MIL-H-20048

5.4 SWIVELS

Swivels are used to permit free rotation between a wire rope and a suspended load. Swivels shall be designed with a minimum design safety factor of 5 and are specified in Federal Specification RR-C-271. These swivels allow free rotation on an unloaded wire rope.

Antifriction (ball or roller) bearing-type swivels have minimal friction between the moving parts of the swivel and, therefore, allow swivel action even when the wire rope is loaded.

5.5 BLOCKS

A block is used for multiplying the pulling force of a wire rope lead line, changing the direction of pull, or both.

Essentially, a block consists of the shell, the sheaves, the center pin, the straps, and the fittings and connections. The block may also have a becket for anchoring the wire rope end. The shell houses the sheaves, acts as a rope guide to keep the wire rope in the sheave groove, and provides strength and rigidity to the block. Heavy-duty load blocks are equipped with cheek plates (or weights). The straps and the side or cheek plates provide bearing support for the sheave center pin and transmit sheave loads to the fittings and connections. A wire rope hook block, with cheek weights, is shown in Figure 5-1.

Snatch blocks are only for temporary use and are normally used when it is necessary to change the direction of the pull on a wire rope. The fittings and connections of a snatch block can swing out of position to permit quick entry of the wire rope into the sheave groove without reeving.

The minimum design safety factors of blocks are given in the applicable specifications (see Table 5-2). Blocks are permanently marked with the recommended safe working load and the size of the wire rope or the outside diameter of the sheave to be used with the block.

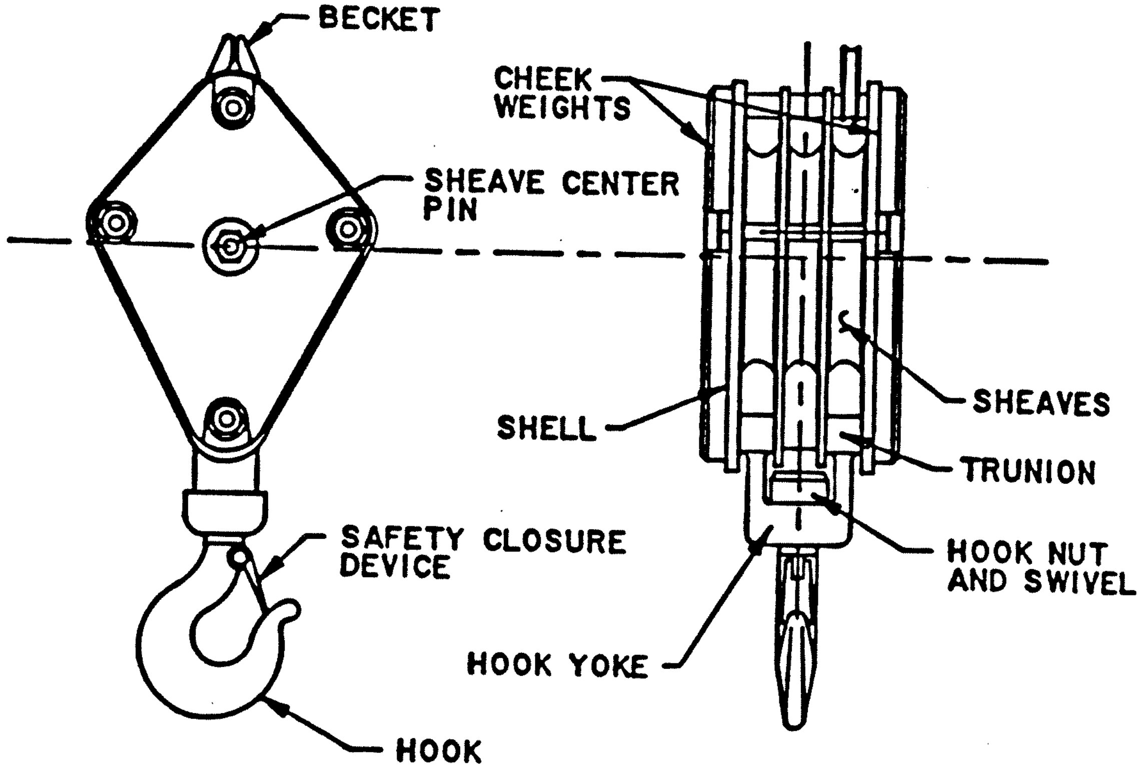


Figure 5-1. Wire Rope Hook Block

5.5.1 Sheaves

Sheaves are rotating machine elements used to support wire ropes and to provide a change in its direction of travel.

The sheave groove diameter and the sheave-throat angle must be chosen to provide the maximum degree of wire rope support, while still allowing the wire rope to leave the sheave without scrubbing against the flanges. A proper fitting sheave groove should support the wire rope over 135 to 150 degrees of the wire rope circumference. A typical cross section of a wire rope sheave rim is shown in Figure 5-2. The tolerances of the groove diameters of a new sheave for various wire rope nominal diameters are given in Table 5-3. Sheave rim dimensions in terms of the wire rope nominal diameter are shown in Table 5-4.

Table 5-2

TYPES OF BLOCKS

Title	Military Specification
Blocks, Tackle, Wire Rope	MIL-B-24141
Blocks, Tackle, Wire Rope, Extra Heavy Duty	MIL-B-23990
Blocks, Tackle, Haul Back, for Wire Rope	MIL-B-12582

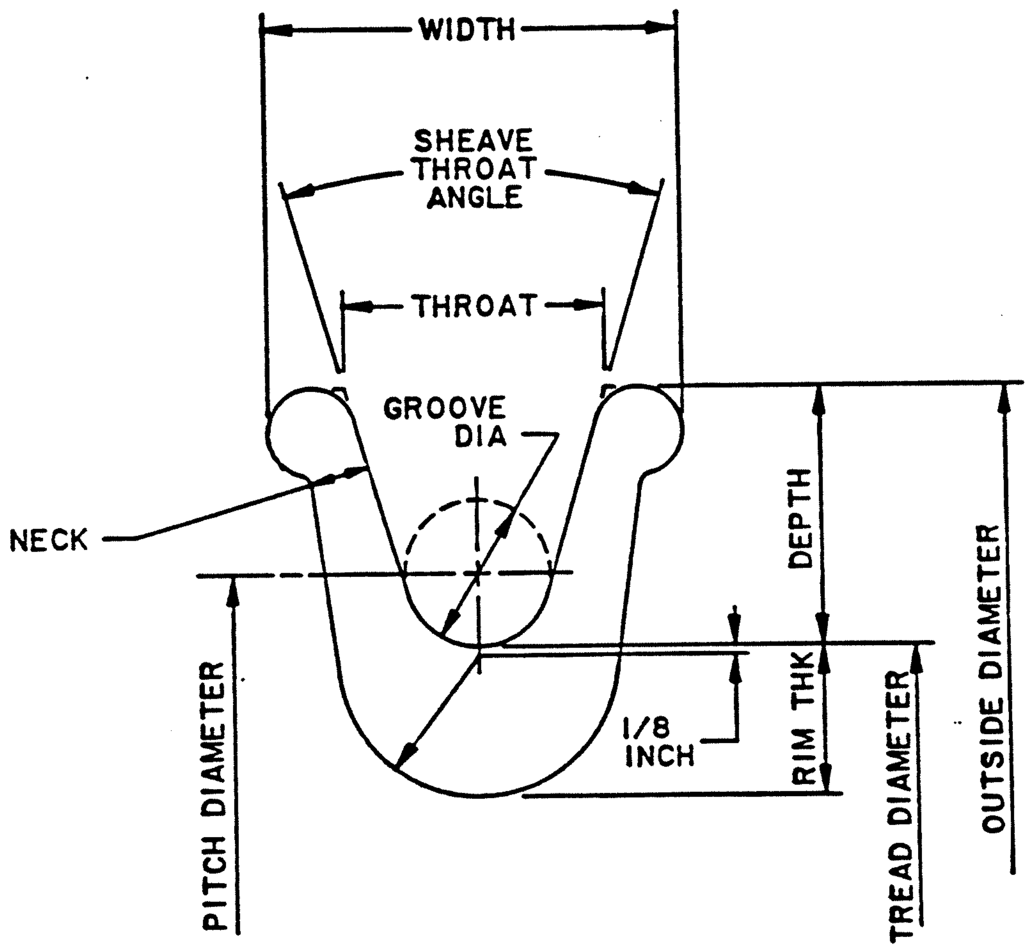


Figure 5-2. Sheave Rim Dimensions

Table 5-3

TOLERANCES OF SHEAVE GROOVE DIAMETERS

Wire Rope Nominal Diameter (inches)	Tolerance of Sheave Groove Diameter (New) (inches)
Up to 5/16	+ 1/64 minimum to + 1/32 maximum
3/8 to 3/4	+ 1/32 minimum to + 1/16 maximum
13/16 to 1-1/8	+ 3/64 minimum to + 3/32 maximum
1-3/16 to 1-1/2	+ 1/16 minimum to + 1/8 maximum
1-9/16 to 2-1/4	+ 3/32 minimum to + 3/16 maximum
2-5/16 and larger	+ 1/8 minimum to + 1/4 maximum

Table 5-4

SHEAVE RIM DIMENSIONS
IN TERMS OF WIRE ROPE NOMINAL DIAMETER d

	Depth	Throat	Rim Thickness	Neck	Groove Diameter
Head sheaves	2d	2d	d	d/2	d plus tolerance of Table 5-3
Other operating sheaves	1-1/2d	1-5/8d	d	d/2	d plus tolerance of Table 5-3

Wire rope sheave grooves shall be hardened to a minimum of Rockwell C35 to provide a hard and smooth bearing surface which wears smooth and lengthens the service life of both the sheave and the wire rope.

Wire rope sheaves are mounted on self- or pressure-lubricated plain journal bearings (bronze bushings), ball bearings, or roller bearings. Sheave bearings support the sheave when it is loaded by the wire rope, reduce sheave friction losses, and guide and align the sheave.

Self-lubricated bushings are recommended for severe service requirements and should not be used for high-speed or continuous operation. Pressure-lubricated bushings are recommended for continuous severe service, while ball or roller bearings are recommended for continuous high-speed operation.

5.5.2 Rollers

Rollers support wire ropes and provide a small change in the direction of travel. Since the use of rollers is detrimental to the service life of the wire rope, rollers should not be used unless unavoidable.

Rollers are plain or grooved cylinders where the length of the arc of contact with the wire rope is less than one lay length of the wire rope. If the rollers are too small, the wire rope will vibrate as each strand passes over it. Experience has shown that for smooth operation, flat rollers should have a diameter of at least nine times the wire rope nominal diameter. Rollers with grooves of the same size and contour as the wire rope, however, should have a diameter of at least six times the wire rope nominal diameter. The roller surface shall be hardened to a minimum of Rockwell C35 to extend the service life of both the roller and the wire rope.

5.6 OVERHAULING WEIGHT

Overhauling weight is the minimum weight of the block or overhaul ball (also referred to as a headache ball) that is required to initiate free fall of the unloaded load block.

The overhauling weight depends upon the size of the wire rope, the number of parts of the wire rope, the type of sheave bearings, the length of the wire rope between the drum and the point sheave λ, and the drum friction.

The required overhauling weight is determined by the following formula:

$$\text{Overhauling weight} = [(\text{Wire Rope Length, } \lambda)(\text{Rope Weight Factor}) + \text{Drum Friction}][\text{Overhaul Factor}] \quad (5\text{-}1)$$

where

Drum Friction = 50 lbs (assumed for all cases)

The wire rope weight factors for 6 x 37 fiber core and independent wire rope core (IWRC) carbon steel wire ropes are listed in Federal Specification RR-W-410. Overhaul factors used in Table 5-5.

Table 5-5

OVERHAUL FACTORS

No. of Parts of Line	Antifriction (Ball or Roller) Bearing Sheaves	Plain Journal Bearing (Bronze Bushing) Sheaves
1	1.03	1.05
2	2.07	2.14
3	3.15	3.28
4	4.25	4.48
5	5.38	5.72
6	6.54	7.03
7	7.73	8.39
8	8.94	9.80
9	10.20	11.30
10	11.50	12.80

THIS PAGE INTENTIONALLY LEFT BLANK

6.0 WIRE ROPE SELECTION

The selection of a wire rope is influenced by many factors. Desirable characteristics of a wire rope include strength, flexibility, stability, reserve strength, and resistance to bending fatigue, abrasion, crushing, and heat. Since no single wire rope possesses a high rating in all of the above categories, the selection of a wire rope is a compromise.

As an example, consider the relationship between resistance to abrasion and bending fatigue. While, for a given size, a wire rope with larger wires in the outer layer of its strands has greater resistance to abrasion, a wire rope with smaller outer wires in its strands has greater resistance to bending fatigue. Therefore, for any particular application, priorities are established based on the most important requirements. A suitable wire rope is selected on a trade-off basis by sacrificing the least essential requirements in favor of the most desirable characteristics.

For ready reference, wire rope characteristics are qualitatively summarized in Table 6-1. Refer to section 3.0 for a detailed discussion of the characteristics of various wire rope materials.

6.1 STRENGTH

Wire rope in service is subjected to various conditions of load. Wire rope should possess adequate breaking strength to sustain the design load, with an allowance for a recommended design safety factor and the efficiency of wire-rope termination.

The breaking strength of a wire rope is determined by the type and grade of the material of the wires making up the wire rope, wire rope diameter, wire rope construction, wire finish, and type of core. The breaking strength of wire ropes listed in Federal Specification RR-W-410 are based on these parameters. Nominal strength refers to the calculated, published strength values of the wire rope, while the acceptance breaking strength is the minimum strength value on which compliance with the specifications is determined, and is 2-1/2 percent lower than the nominal strength. The nominal strength of a wire rope shall be used for design calculations. Design safety factors for designing wire rope systems are discussed in section 7.1.6 and the efficiencies of wire-rope terminations are listed in Table 7-3.

6.2 FLEXIBILITY AND RESISTANCE TO BENDING FATIGUE

When a load is applied to a wire rope, the individual wires stretch and are drawn tightly together. In a bending application,

Table 6-1.

CHARACTERISTICS OF WIRE ROPES

	PARAMETER	STRENGTH	FLEXIBILITY	STABILITY	RESERVE STRENGTH	RESISTANCE TO BENDING FATIGUE	RESISTANCE TO ABRASION	RESISTANCE TO CRUSHING	RESISTANCE TO HEAT
MATERIAL	EXTRA-IMPROVED PLOW STEEL	G	-	-	-	F	G	G	F
	IMPROVED PLOW STEEL	F	-	-	-	G	F	G	F
	CORROSION - RESISTANT STEEL	F	-	-	-	P	P	F	G
	PHOSPHOR BRONZE	P	-	-	-	P	P	P	P
PREFORMED OR NON-PREFORMED	PREFORMED WIRE ROPE	-	G	G	-	G	G	-	-
	NON-PREFORMED WIRE ROPE	-	F	F	-	F	F	-	-
LAY	LANG-LAY WIRE ROPE	-	G	P	-	G	G	F	-
	REGULAR-LAY WIRE ROPE	-	F	G	-	F	F	G	-
CORE	IWRC WIRE ROPE	G	F	G	G	F	-	G	G
	FIBER-CORE WIRE ROPE	F	G	F	F	G	-	F	P
STRAND CONSTRUCTION*	SEALE STRAND	-	P	-	P	P	G	G	-
	WARRINGTON STRAND	-	F	-	F	F	F	F	-
	FILLER-WIRE STRAND	-	G	-	G	G	P	P	-
NUMBER OF OPERATIONS	SINGLE OPERATION STRAND	** G	G	-	-	G	-	G	-
	MULTIPLE OPERATION STRAND	** F	F	-	-	F	-	F	-
NUMBER OF STRANDS	SIX-STRAND WIRE ROPE	G	F	G	-	F	G	G	-
	EIGHT-STRAND WIRE ROPE	F	G	F	-	G	F	F	-

IWRC - INDEPENDENT WIRE ROPE CORE

G - GOOD , F - FAIR , P - POOR

*MOST WIRE ROPES HAVE COMBINATION STRANDS

** ONLY FOR 6X37 CLASS WIRE ROPES

these tightly compressed wires move relative to each other. This movement causes internal abrasion (nicking) and bending fatigue. For satisfactory service life, a wire rope must be both flexible and capable of bending repeatedly under load.

Flexibility and resistance to bending fatigue are the most desirable characteristics in the design of a multiple-sheave wire rope system in which wire rope is spooled in a single layer on a grooved drum.

Greater flexibility is usually accompanied by a greater resistance to bending fatigue. However, in bending applications, where a more flexible fiber core wire rope may flatten and result in early failure, a metallic core wire rope should be selected because it retains its circular cross section, is free to move and adjust internally, and gives a longer service life.

Other factors which influence the flexibility and the resistance to bending fatigue of a wire rope include wire rope materials, preforming of the wires and the strands, wire rope lay, lay length, and wire rope construction.

Carbon steel wire ropes have good resistance to bending fatigue; improved plow steel wire ropes being better than extra-improved plow steel wire ropes. In comparison with carbon steel wire ropes, corrosion-resistant steel (CRES) wire ropes and phosphor bronze wire ropes have poor resistance to bending fatigue.

Preformed wire ropes are more flexible and more resistant to bending fatigue than nonpreformed wire ropes. This is because preformed wire ropes are practically free from internal stresses, which results in minimum internal friction and internal abrasion (nicking) during bending.

In comparison with the outer wires in a regular-lay wire rope, the outer wires of a lang-lay wire rope are exposed for longer length. When a lang-lay wire rope is bent, axial bending of the outer wires is less sharp, and the bending stress is less. Therefore, lang-lay wire ropes are more flexible and more resistant to bending fatigue than regular-lay wire ropes. For wire ropes influenced principally by bending stresses, lang-lay wire ropes have a service life 15 to 20 percent longer than regular-lay wire ropes. Lay length also affects the flexibility of a wire rope. A shorter lay length forms a more flexible wire rope.

Compared to single-operation strand wire ropes, multiple-operation strand wire ropes experience local crushing, increased internal abrasion (nicking), and increased friction during a bending application. Consequently, single-operation strand wire ropes have greater flexibility and greater resistance to bending fatigue than multiple-operation strand wire ropes.

Wire rope constructions differ in their flexibility and resistance to bending fatigue. Generally, a strand containing a large number of small wires in the outer layer has greater flexibility and greater resistance to bending fatigue than an equal sized strand containing a few large outside wires. For example, in 6 x 19 class wire ropes, Seale construction strands contain a few large outside wires, while filler-wire construction strands have a greater number of smaller sized outside wires. Consequently, filler-wire construction wire ropes are more flexible and more resistant to bending fatigue than Seale construction wire ropes.

The X-chart shown in Figure 6-1 illustrates the relationship between the number of outside wires in the strand and the resistance to bending fatigue (and the inverse relationship between the resistance to abrasion and bending fatigue). As can be seen from the X-chart, for a given size, an eight-strand wire rope is more resistant to bending fatigue than a six-strand wire rope. This is because an eight-strand wire rope has smaller strands and a larger core, which makes it more flexible.

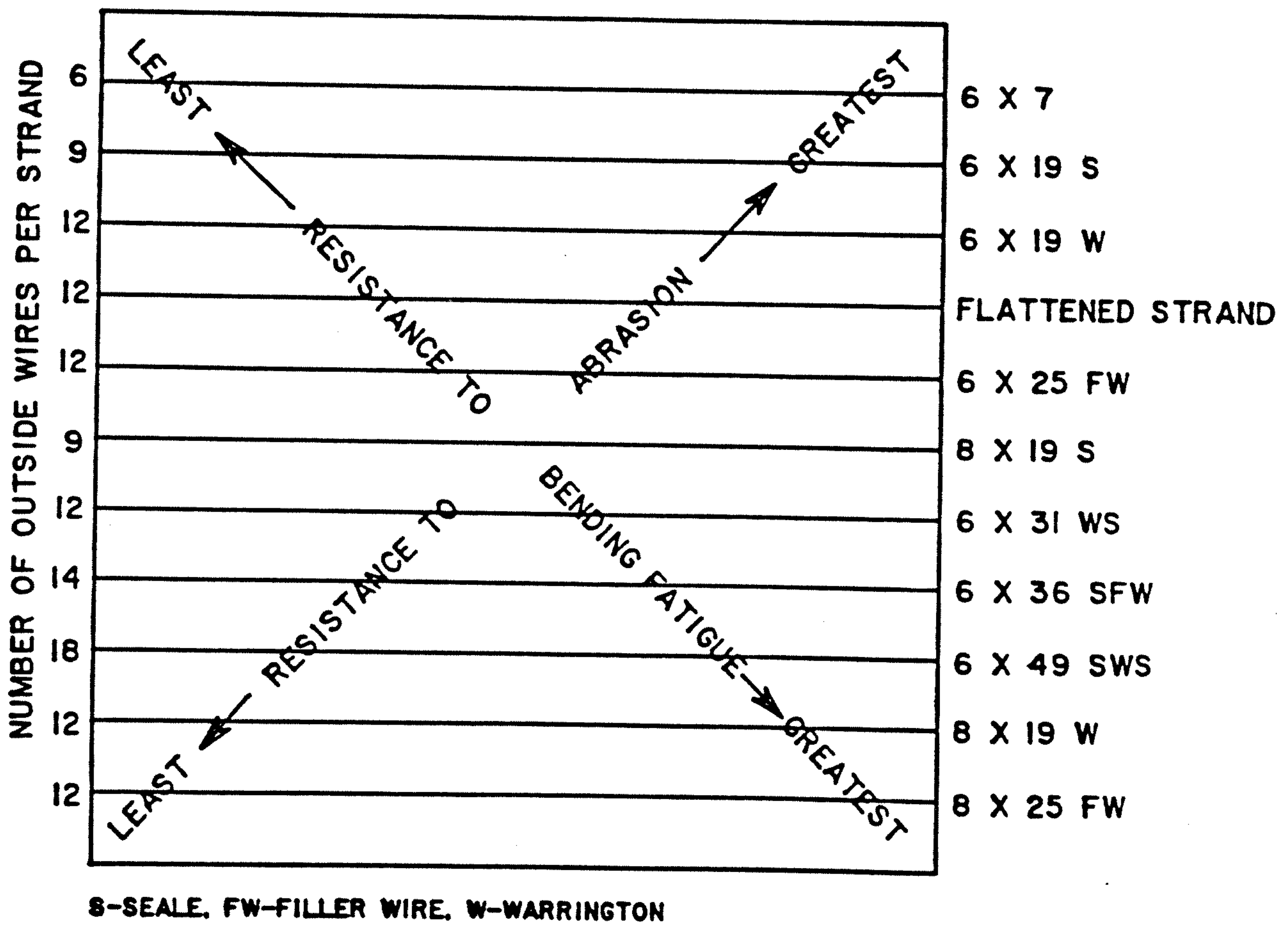


Figure 6-1. X-Chart

In bending applications, the service life of a wire rope is influenced by its construction and by the ratio of sheave/drum tread diameter to the wire rope nominal diameter. Higher sheave-to-rope diameter ratios produce lower bending stresses and improved service life. Figure 6-2 shows a relative service life curve which takes into account only the bending and tensile stresses. For example, wire rope working with a sheave-to-rope diameter ratio, D/d, of 18 has a relative service life of 9 units. If the same wire rope works over a sheave that increases its sheave-to-rope diameter ratio, D/d, to 26, bending stresses are reduced and the relative service life of the wire rope is increased to 19 units, which is an increase of 111 percent.

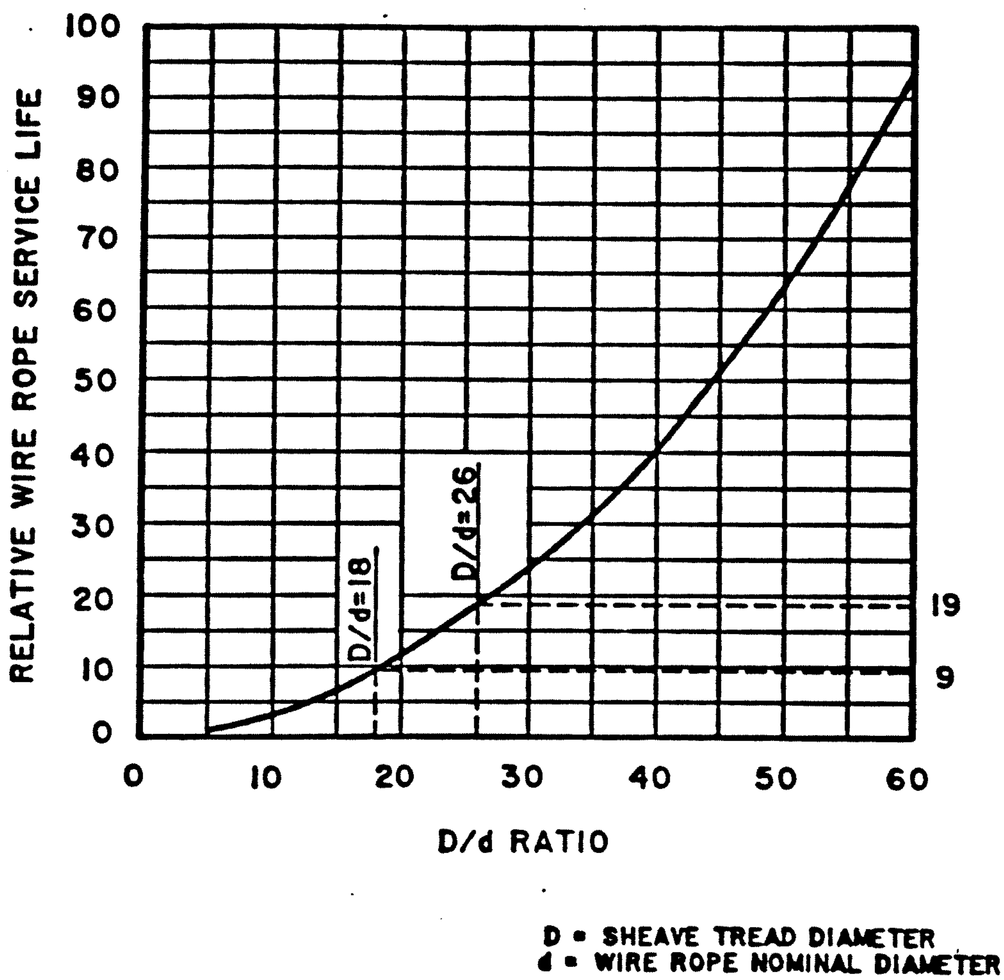


Figure 6-2. Relative Wire Rope Service Life vs D/d Ratio

Very large diameter sheaves, however, become heavy. When the wire rope velocity changes, the inertia of a heavy sheave causes more than normal slip between the sheave and the wire rope and results in more than normal abrasion and surface work hardening of the wire rope. Designers should use the recommended sheave-to-rope diameter ratios listed in Table 7-2. Sheaves and drums with less than the minimum sheave-to-rope diameter ratios listed in Table 7-2 shall not be used.

6.3 STABILITY

The stability of a wire rope can be defined as the resistance to kink, curl, untwist, and tangle. Stability can be a tendency inherent in a wire rope due to its very construction or it could be achieved by reducing the internal stresses set up in a wire rope during the manufacturing process. Stability describes the handling and operating characteristics of a wire rope and is a desirable characteristic in most wire rope applications.

Preformed wire ropes are practically free from internal stresses and are more stable than nonpreformed wire ropes. Wire ropes with metallic cores are more stable than those with fiber cores. Six-strand wire ropes are more stable than eight-strand wire ropes. Because the direction of wire lay in the individual strands is opposite to that of the strands in the wire rope, regular-lay wire ropes are more stable than lang-lay wire ropes. For this reason, to prevent untwisting under load, lang-lay wire ropes shall not be used for single part hoists.

6.4 RESISTANCE TO ABRASION

Abrasion is the loss of metal, due to friction, from the crowns of the outer wires of a wire rope. Abrasion is caused by the rotation (untwisting) and slip of the wire rope while running over sheaves and drums, as well as by dragging the wire rope over stationary objects like chafing gear. Faulty sheave alignment, incorrect groove diameters, inappropriate fleet angles, and improper drum spooling are some of the other causes of abrasion. Resistance to abrasion is the most desirable characteristic in wire rope applications where the wire rope would be dragged across stationary objects. Loss of metal, due to abrasion, reduces the cross-section area and thus the breaking strength of a wire rope. The resistance to abrasion is largely influenced by the hardness of the wire rope material and the construction of the wire rope.

Extra-improved plow steel is the hardest and the most abrasion resistant of all wire rope materials in Navy usage. In comparison with the good resistance of extra-improved plow steel, improved plow steel has fair resistance to abrasion, while CRES and phosphor bronze have poor resistance to abrasion.

Preforming minimizes wire rope rotation and slip when running over sheaves and drums and thus reduces abrasion of the wire rope.

Lang-lay wire ropes have better abrasion resistance than regular-lay wire ropes. Because of the longer exposed length of the outer wires, lang-lay wire ropes exert less contact pressure on the sheaves and drums and can withstand more loss of metal due to abrasion before the outer wires break because of bending.

Seale construction provides maximum resistance to abrasion. For a given size, the outer wires in a Seale construction strand are larger in diameter than the outer wires in a filler-wire construction strand. Therefore, Seale construction develops a larger wear surface resulting in less contact pressure and less abrasion between the wire rope and the sheaves/drums. The X-chart shown in Figure 6-1 illustrates the comparison between the abrasion resistance of various wire rope constructions.

For a given size and construction, the size of the outer wires of a six-strand wire rope is larger than that of an eight-strand wire rope. Consequently, a six-strand wire rope has greater resistance to abrasion than an eight-strand wire rope.

6.5 RESISTANCE TO CRUSHING

Crushing is wire rope distortion caused by high radial pressures. A wire rope tends to distort and flatten if bent over a small sheave, forced to operate under heavy pressures in grooves that do not afford ample support, or spooled on a plain-faced drum under high load. Even when spooling is done in an orderly manner, crossover points on a grooved drum with multiple layers are a cause of crushing and abrasion. Irregular or scrambled spooling causes even greater damage.

Resistance to crushing is the most desirable characteristic in a wire rope system where the wire rope is spooled in a single layer on a plain-faced drum or is spooled in multiple layers on a plain-faced or grooved drum.

Regular-lay wire ropes have a shorter length of exposed outer wires and offer greater resistance to crushing than lang-lay wire ropes. Metallic cores provide greater support for the wire rope strands and therefore metallic core wire ropes are more resistant to crushing than fiber core wire ropes. The coarse rope constructions (with a small number of large wires) are resistant to flattening. Consequently, the crush resistance of wire ropes made with Seale, Warrington, and filler-wire constructions is in descending order. For the same reason, six-strand wire ropes (for a given size and construction) have greater crush resistance than eight-strand wire ropes. Because the wires in a single-operation strand wire rope are cradled among the adjacent wires and are free to slide and adjust, single-operation strand wire ropes are more crush resistant than multiple-operation strand wire ropes. Carbon steel wire ropes, with metallic core, have good resistance to crushing and are more crush resistant than metallic core CRES wire ropes. Phosphor bronze wire ropes have poor resistance to crushing.

6.6 RESERVE STRENGTH

The reserve strength of a wire rope is defined as the combined strength of all the wires it contains, except those in the outside layer of the outer strands. Reserve strength is calculated using actual metallic areas of the individual wires and is expressed as a percentage of the wire rope's nominal strength.

Reserve strength is based on the assumption that the outer wires of the strands are the first to be subjected to damage or abrasion. Therefore, reserve strength is less significant when the wire rope is subjected to internal wear (nicking), corrosion, or distortion.

Maximum reserve strength is desirable in applications where the wire rope could fail due to abrasion of the outer wires of the strands and where dropping the load would be extremely hazardous.

The reserve strength of a wire rope depends upon the number of wires in the outer layer of a strand; for a given size, the greater the number of wires in the outer layer, the greater the reserve strength. For the wire ropes commonly used in hoisting applications, 6 x 37 class wire ropes have superior reserve strength.

6.7 RESISTANCE TO HEAT

The temperature of the environment in which a wire rope operates has a marked effect on its performance. Wire rope lubricants usually have a melting point in the 120° to 140°F temperature range. If the wire rope is to be used at temperatures above this range, special lubricants must be specified. Fiber cores tend to dry out, char, and soften at elevated temperatures. If the temperature of the environment is expected to exceed 180°F, metallic core wire ropes with wire centers in the strands shall be used.

Carbon steel metallic core wire ropes retain their strength up to 400°F. CRES wire ropes operate satisfactorily beyond this temperature range and are specified for use in areas of heat and blast of guns, missiles, or jet engines. Phosphor bronze wire ropes have poor resistance to heat.

7.0 DESIGN OF WIRE ROPE SYSTEMS

7.1 DETERMINATION OF WIRE ROPE SIZE

In Navy usage, the significant loads acting on wire ropes are the static tensile loads, frictional loads, acceleration loads, bending loads, and dynamic loads produced by ship motion. Wire ropes are sized by simultaneously considering the above mentioned loads (design load) acting on the wire rope, efficiencies of the wire rope terminations, and the recommended design safety factors. The following sections provide guidance to determine each of these factors.

7.1.1 Frictional Loads

In multi-part wire-rope reeving systems, the frictional losses in the sheave system become worthy of consideration. These losses occur due to the friction within the sheave bearing assembly, between wire rope and sheaves, and the internal wire rope friction due to bending. The efficiency of a sheave system depends on whether the last sheave (i.e., the sheave at the hauling part) serves to increase the mechanical advantage, in which case it is said to be "floating", or whether it serves as a lead sheave that changes the direction of wire-rope run, in which case it is said to be fixed. In Navy usage, most sheave systems have a fixed last sheave.

The following discussion develops a formula to calculate the efficiency and the lead line load of a wire-rope sheave system in which parallel parts of wire rope are used to support a load. Figure 7-1 shows a multiple sheave system with fairlead sheaves.

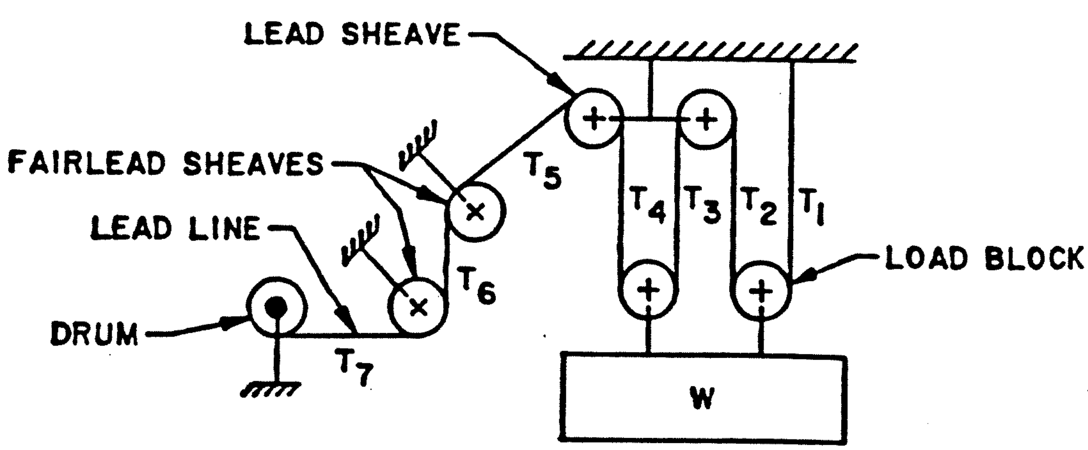


Figure 7-1. Forces in a Multiple Sheave System

P_F = actual pull on lead line

P_o = pull on lead line without friction

T_i = tension in i_{th} part of wire-rope line

W = total suspended load: rated load plus the weight of the load block plus the weight of the parts of wire rope

N = number of parts of wire rope supporting the total suspended load

s = number of rotating sheaves in the system

X = 1 + the friction loss, in percent, in each sheave

h = efficiency of the multiple sheave system

$P_o = \frac{W}{N}$

$T_2 = XT_1;\ T_3 = XT_2 = X^2T_1;\ \ldots;\ T_7 = X^6T_1$

i.e., $T_s + 1 = X^sT_1 = P_F$

$W = T_1 + T_2 + \ldots. + T_N$

$= T_1 + XT_1 + X^2T_1 + \ldots. + X^{(N-1)}T_1$

$W = T_1\ [1 + X + X^2 + \ldots. + X^{(N-1)}]$

$1 + X + X^2 + \ldots. + X^{N-1)}$ is a geometric series.

$$\therefore \quad 1 + X + X^2 + \ldots. + X^{(N-1)} = \frac{(X^N - 1)}{(X - 1)}$$

$$\therefore \quad W = \frac{T_1\ (X^N - 1)}{(X - 1)}$$

and $$\frac{P_F}{W} = \frac{X^s\ T_1\ (X - 1)}{T_1\ (X^N - 1)} = \frac{X^s\ (X - 1)}{(X^N - 1)}$$

$$P_F = \frac{WX^s\ (X - 1)}{(X^N - 1)}$$

$$\eta = \frac{P_o}{P_F} = \frac{W}{N} \frac{(X^N - 1)}{W X^s (X - 1)}$$

$$\eta = \frac{(X^N - 1)}{N X^s (X - 1)} \qquad (7\text{-}1)$$

For plain journal bearings (bronze bushing), the frictional loss is about 4 percent ($X = 1.04$) and for antifriction (ball or roller) bearings the frictional loss is about 2 percent ($X = 1.02$). Where possible antifriction bearing sheaves should be used.

The tensile load in the lead line (lead line load) is given by multiplying the total suspended load, W, by the lead line factor. Lead line factor is given as follows:

$$\text{Lead Line Factor (considering only friction losses)} = \frac{1}{N \eta} \qquad (7\text{-}2)$$

$$\text{Lead Line Load} = W \text{ (Lead Line Factor)} \qquad (7\text{-}3)$$

The efficiencies and the lead line factors, for the reeving cases shown in Figure 7-2, are given in Table 7-1. For these cases, the values in Table 7-1 shall be used for design purposes.

7.1.2 Acceleration Load

The additional load developed in a wire rope due to change of velocity of the static load is known as the acceleration load. For example, starting a load from rest, accelerating a slowly moving load, or suddenly slowing down or stopping a load being lowered under its own weight will generate an acceleration load in the wire rope.

The acceleration load is:

$$F = \frac{W}{g} a_w \qquad (7\text{-}4)$$

where,

F = acceleration load, pounds

W = static load (total suspended load: rated load plus the weight of the load block plus the weight of the parts of the wire rope), pounds

g = acceleration of gravity (32.2 ft/sec^2)

a_w = acceleration of static load, ft/sec^2

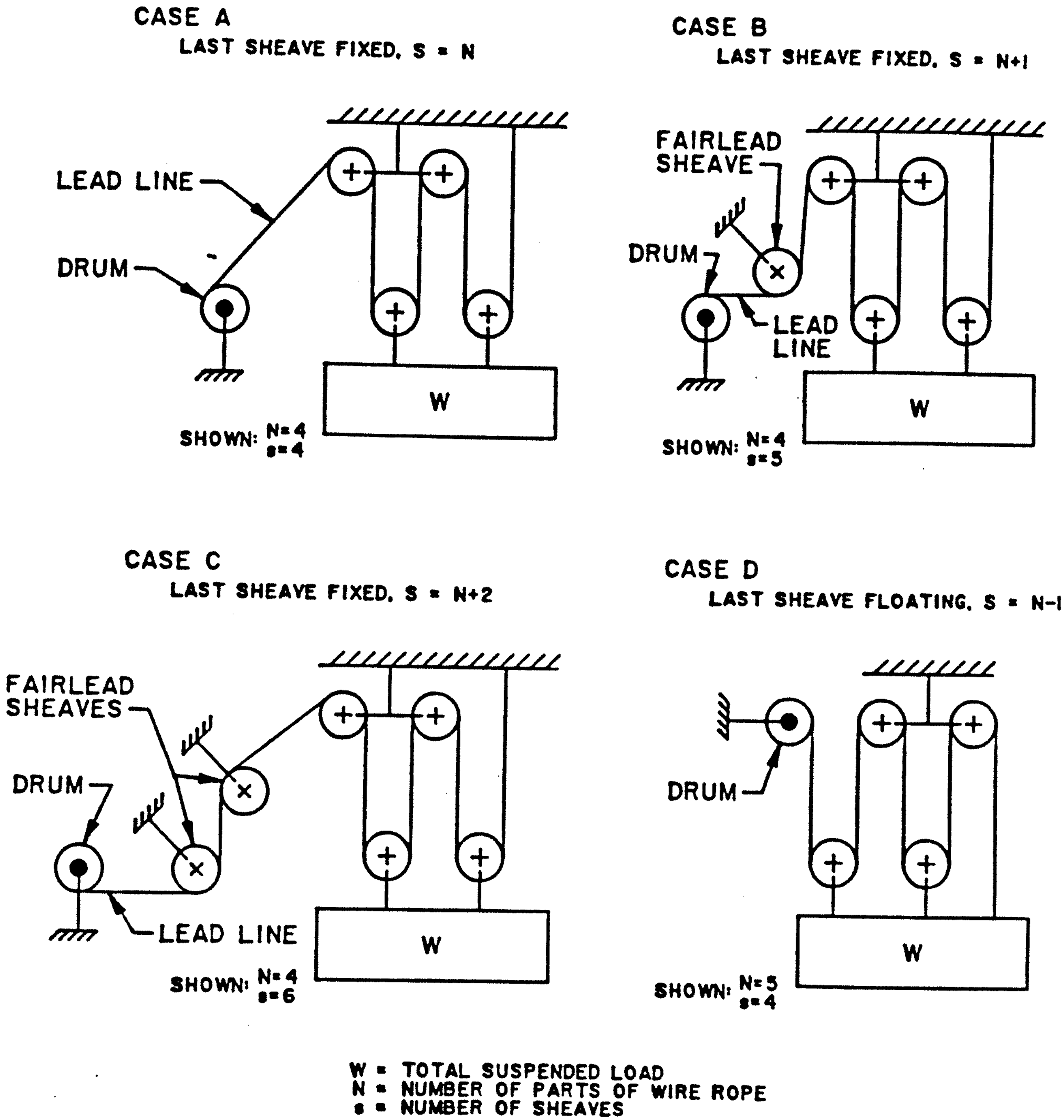


Figure 7-2. Wire Rope Systems

Table 7-1

EFFICIENCY AND LEAD LINE FACTOR

ANTIFRICTION (BALL OR ROLLER) BEARINGS: X = 1.02

N	Efficiency				Lead Line Factor			
	Case A	Case B	Case C	Case D	Case A	Case B	Case C	Case D
2	0.971	0.952	0.933	0.990	0.514	0.525	0.536	0.505
3	0.961	0.942	0.924	0.980	0.346	0.354	0.361	0.340
4	0.952	0.933	0.915	0.971	0.263	0.268	0.273	0.257
5	0.943	0.925	0.907	0.961	0.212	0.216	0.221	0.208
6	0.934	0.916	0.898	0.952	0.178	0.182	0.186	0.175
7	0.925	0.907	0.889	0.943	0.154	0.158	0.161	0.151
8	0.916	0.898	0.880	0.934	0.136	0.139	0.142	0.134
9	0.907	0.889	0.872	0.925	0.122	0.125	0.127	0.120
10	0.898	0.880	0.863	0.916	0.111	0.114	0.116	0.109
11	0.889	0.871	0.854	0.907	0.102	0.104	0.106	0.100
12	0.881	0.864	0.847	0.899	0.095	0.096	0.098	0.093
13	0.873	0.856	0.839	0.890	0.088	0.090	0.092	0.086

PLAIN JOURNAL BEARING (BRONZE BUSHING): X = 1.04

N	Efficiency				Lead Line Factor			
	Case A	Case B	Case C	Case D	Case A	Case B	Case C	Case D
2	0.943	0.907	0.872	0.981	0.530	0.551	0.574	0.510
3	0.925	0.889	0.855	0.962	0.360	0.375	0.390	0.347
4	0.908	0.873	0.839	0.944	0.275	0.286	0.298	0.265
5	0.890	0.856	0.823	0.926	0.225	0.234	0.243	0.216
6	0.874	0.840	0.808	0.909	0.191	0.198	0.206	0.183
7	0.857	0.824	0.793	0.892	0.167	0.173	0.180	0.160
8	0.842	0.809	0.778	0.875	0.148	0.154	0.161	0.143
9	0.826	0.794	0.764	0.859	0.135	0.140	0.145	0.129
10	0.811	0.780	0.750	0.844	0.123	0.128	0.133	0.119
11	0.796	0.766	0.736	0.828	0.114	0.119	0.124	0.110
12	0.782	0.752	0.723	0.813	0.106	0.111	0.115	0.103
13	0.768	0.739	0.710	0.799	0.100	0.104	0.108	0.096

$$\text{The acceleration load factor} = \left(1 + \frac{a_w}{g}\right) \qquad (7\text{-}5)$$

The lead line load shall be multiplied by the acceleration load factor calculated for the maximum acceleration value.

7.1.3 Bending Load

When a wire rope is bent around a sheave or drum, bending loads are induced in the bent part of the wire rope and its strength is decreased. The magnitude of these loads (and the subsequent decrease in the strength of a wire rope) is a function of the wire rope construction, the sheave-to-rope diameter ratio, and the length of wire rope in contact with the sheave. To minimize the magnitude of the bending load it is therefore desirable to use larger sheaves or drums where practicable. Because of bending fatigue, the number of sheaves in the system should be kept to a minimum.

If the length of the wire rope in contact with a sheave or a drum is equal to the lay length of the wire rope, its wires and strands are forced to shift with respect to each other and it undergoes full bending which in turn produces maximum bending load. When more than one rope lay is in contact, more of the wire rope is subject to the same full bending load. When less than one rope lay is in contact with the sheave, the wire rope undergoes less than full bending. In this case, the wire rope loses contact with the sheave before its wires and strands have been forced to shift with respect to each other, and smaller sheave sizes can be used.

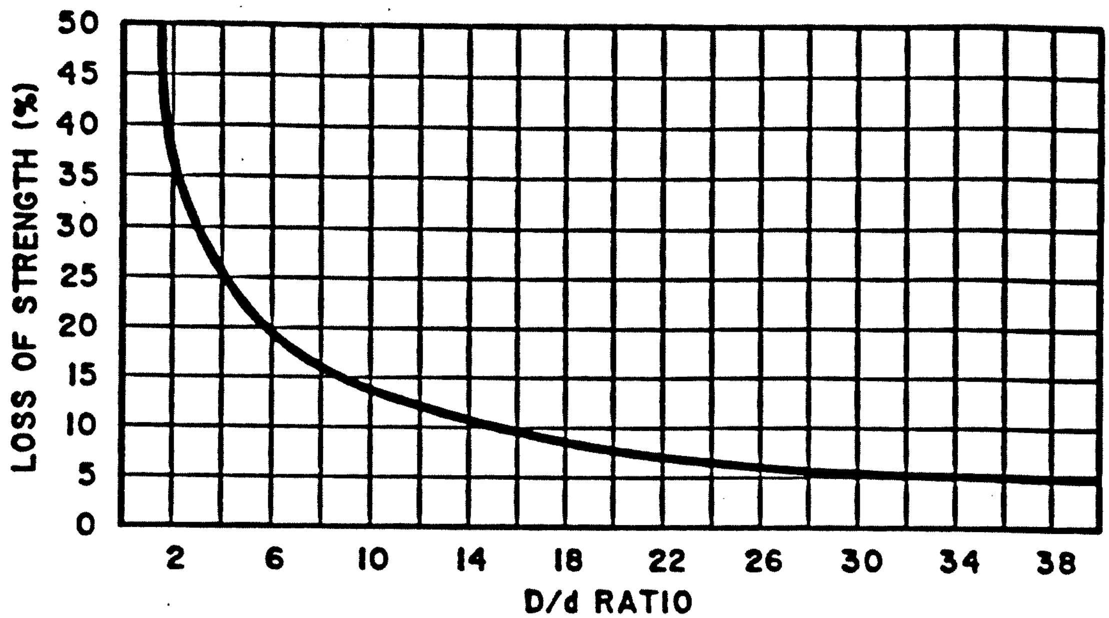
The curve shown in Figure 7-3 shows the percent decrease (loss) in the strength of a wire rope when bent around sheaves and drums for various sheave-to-rope diameter ratios. This curve applies only to 6 x 19 and 6 x 37 class carbon steel wire ropes, irrespective of the type of lay or the type of core.

The decrease in the strength of a wire rope bent around sheaves and drums shall be computed for the smallest diameter sheave (i.e., for the smallest sheave-to-rope diameter ratio) in the wire rope system.

$$\text{The bending load factor} = \frac{100}{(100 - \text{percent loss of strength})} \qquad (7\text{-}6)$$

The lead line load shall be multiplied by the bending load factor.

Appendix A gives the procedure to calculate the bending load for the fiber centered strand wire ropes in the 6 x 12 and 6 x 24 classes.



D = Sheave Tread Diameter
d = Wire Rope Nominal Diameter

Figure 7-3. Decrease in Strength Due to Bending

7.1.3.1 Sheave-to-Rope Diameter Ratio

All wire ropes operating over sheaves and drums are subjected to cyclic bending loads. The magnitude of bending loads is largely dependent on the ratio of the tread diameter of the sheave or drum to the nominal diameter of the wire rope. Too small a sheave or drum can cause permanent set in a loaded wire rope. Also, the magnitude of work lost in bending the wire rope around a sheave or drum and then straightening the wire rope as it leaves the sheave or drum, decreases with an increase in the sheave or drum tread diameter. Consequently, the tread diameter of the sheaves and drums should be as large as practicable. The recommended and the minimum sheave-to-rope diameter ratios for various wire rope constructions are listed in Table 7-2. The designer should use the recommended sheave-to-rope diameter ratios. However, where space limitations do not permit the use of recommended sheave-to-rope diameter ratios, smaller sheaves may be acceptable. Wire rope operation at minimum sheave-to-rope diameter ratios would result in decreased wire rope service life due to bending fatigue. Sheave-to-rope diameter ratios below the minimum value would greatly reduce wire rope service life and may cause permanent set in the wire rope.

Sheave-to-rope diameter ratios below the minimum value shall not be used.

In reeving arrangements where wire rope is subjected to reverse bending, the tread diameter of the sheaves causing the reverse bends should be one-third to one-half greater than the tread diameter of other sheaves.

Table 7-2

SHEAVE-TO-ROPE DIAMETER RATIO

Wire Rope Classification	Recommended Sheave-to-Rope Diameter Ratio D/d	Minimum Sheave-to-Rope Diameter Ratio D/d
6 x 12 (Fiber Centers and Cores)	25	14
6 x 19	29	20
6 x 24 (Fiber Centers and Cores)	22	14
6 x 30 (Flattened Strand)	30	21
6 x 37	22	14
6 x 42 (Tiller Rope)	14	10
8 x 19	21	15
18 x 7 (Rotation Resistant)	34	24

D = Sheave Tread Diameter
d = Wire Rope Nominal Diameter

7.1.4 Ship Motion Loads

Ship motion in a seaway includes roll, pitch, yaw, surge, sway, and heave. These motions induce additional inertial forces on all ship systems and must be included when sizing a wire rope system. The procedure for calculating ship motion loads is given in MIL-STD-1399 Section 301. The lead line load shall be multiplied by the appropriate ship motion load factors.

7.1.5 Efficiency of Wire-Rope Termination

The efficiency of a wire-rope termination influences the design strength of a wire-rope system.

For example, if a wire rope with a design safety factor of 5 has a termination which is 80 percent efficient, the actual design safety factor of the system is 4 instead of 5. To design a system with a design safety factor of 5, a larger diameter wire rope with at least 25 percent more nominal strength will be needed. If 100 percent efficient terminations are used, a smaller diameter wire rope can be used. The efficiencies of various wire-rope terminations are given in Table 7-3.

Since a wire rope drum always has a minimum number of dead wraps, the drum anchor clamp is not subjected to the lead line load. Therefore, the efficiency of the drum anchor clamp shall not be considered in determining the design strength of the wire-rope system.

7.1.6 Design Safety Factors

The wire rope must not only possess enough strength to withstand the design load (total suspended load, frictional load, acceleration load, bending load, and ship motion load), but it should also give a reasonable amount of service before being replaced by a new wire rope. In order to achieve a safe and durable operation, the nominal strength of the wire rope should be more than the calculated design load acting on it. Even though the wire rope is stronger than the calculated design load acting on it, the efficiency of the wire-rope termination would influence the design strength of the wire-rope system and shall be taken into account. For the purpose of determining the wire rope nominal diameter, the design strength of the wire rope system is calculated by multiplying the nominal strength of the wire rope by the efficiency of the wire-rope termination.

The ratio between the design strength of the wire rope system and the calculated design load is defined as the "design safety factor" (or factor of safety).

The selection of the design safety factor for different applications depends upon the extent of fatigue, abrasion, crushing, and corrosion expected in a particular application. Where safety of life is involved, higher design safety factors are used. The minimum design safety factors for different applications are listed in Table 7-4.

7.1.7 Desirable Failure Mode

Systems should be designed so that equipment shafting and bearings, padeyes, supporting structure, etc., will withstand the maximum load that can be developed by the wire rope. The maximum load can be limited by relief valve setting, mechanical or hydraulic springs, or by plastic deformation of collapsible metal elements. Sometimes a weak link, stronger than the maximum operating load but designed to fail at a load below the wire rope breaking strength, is installed in wire rope systems to limit the load that is imposed on the supporting structure.

Table 7-3

EFFICIENCIES OF WIRE-ROPE TERMINATIONS

Type of Termination	Efficiency Percent
Zinc Socket	100
Swage Fitting	85
Fiege-type Fitting	85
Clips	80
Hand-tucked Eye Splice Wire Rope Nominal Diameter (inches)	
1/4 and smaller	95
3/8 to 3/4	88
7/8 and 1	85
1-1/8 to 1-1/2	80
1-5/8 to 2	75
2-1/4 and larger	70
Long Splice	80
Short Splice	60

IWRC - Independent Wire Rope Core

Table 7-4

MINIMUM DESIGN SAFETY FACTORS

Application	Minimum Design Safety Factors
Standing rigging for structures free to rotate at base	3-1/2
Standing rigging for self supporting masts	3
Running rigging, slings	5
Elevator (weapons and cargo) - Multiple suspension	5
Lifting hoists and winches	5

7.1.8 Guys or Stays

Guys or stays are stationary wire ropes that hold a vertical structure in position against overturning forces. Figure 7-4 shows a vertical structure supported by a single guy or stay rope.

For a structure free to rotate about its base, the tensile load, P_G, in a single stay rope is given by the following formula:

$$P_G = \frac{F_H}{\cos \delta}$$

where,

P_G = tensile load in the guy or stay, pounds

F_H = horizontal force acting at the top of the structure, pounds

δ = angle made by the guy or stay with the horizontal, degrees

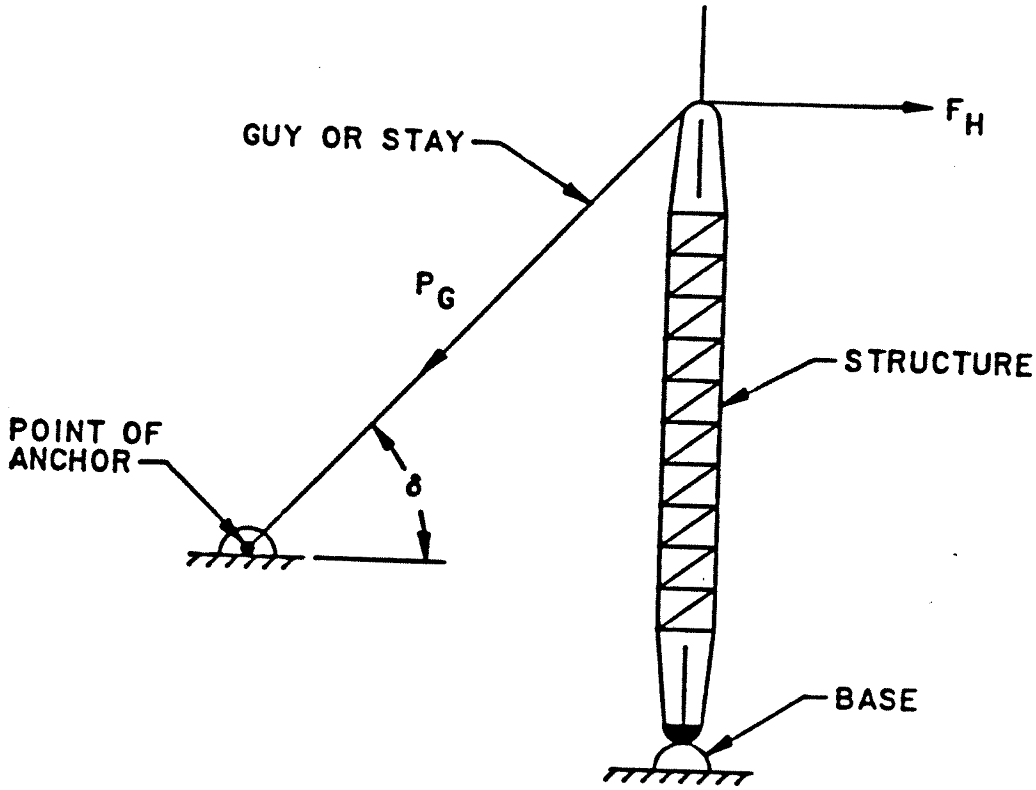


Figure 7-4. Guy or Stay Rope

In uniformly spaced guys or stays the maximum tension, per stay, is given by the following formula:

$$P_G = \frac{F_H A}{\cos \delta} \tag{7-7}$$

where

A = factor given in Table 7-5.

These factors are based on the following assumptions:

- The wire rope size, angle, and the horizontal distance from the structure to the anchor, are the same for all guys or stays.
- When there is no load on the structure, initial tension in the guys or stays is the same, is accurately measured, and is not less than 20 percent of the working tension.

Table 7-5

GUY OR STAY FACTORS

Number of Guys or Stays	Factor A	Number of Guys or Stays	Factor A
3	1.15	12	0.3333
4	1.00	13	0.3084
5	0.8506	14	0.2857
6	0.6667	15	0.2663
7	0.5626	16	0.2500
8	0.5000	17	0.2355
9	0.4476	18	0.2222
10	0.4000	19	0.2104
11	0.3623	20	0.2000

- The structure supported by the guys or stays is free to rotate about its base.
- Stresses in guys or stays from temperature changes are not taken into consideration.

7.2 DRUMS

7.2.1 Introduction

Almost all running wire rope systems utilize a drum to haul the wire rope and to store extra wire rope not in use. A drum consists of the barrel upon which the wire rope is actually spooled, flanges which keep the wire rope from jumping off the drum, and the clamp which anchors the bitter end of the wire rope. Plain-faced (smooth) drums are not recommended because the smooth surface does not guide the wire rope as the first layer is spooled on, which provides a foundation for subsequent layers. Also, the small contact area between the wire rope and the drum barrel results in very high wire-rope-to-drum contact pressures which cause corrugation of the drum barrel and abrasion and crushing of wire rope. Instead, grooved drums are recommended since they support and guide the wire rope which results in reduced contact pressures and even spooling.

A step by step procedure to design a wire rope drum is given below:

- Determine the wire rope design load.

- Determine the wire rope nominal diameter, considering the nominal strength of the wire rope, efficiency of the wire-rope termination, and the recommended design safety factor.

- Determine the minimum drum tread diameter as a multiple of the wire rope nominal diameter.

- Determine the pitch of the drum grooves.

- Determine the length of the drum from the required length of the wire rope, drum tread diameter, drum groove pitch, and layout of the drum.

- Determine the thickness of the drum barrel.

7.2.2 Drum Design

7.2.2.1 Minimum Drum-to-Rope Diameter Ratio

When traveling over a sheave, the wire rope bends while going on the sheave and straightens while coming off the sheave. Whereas when traveling over a drum, the wire rope bends only once, either when going on or leaving the drum. Consequently, in those applications where bending fatigue is the primary factor affecting the service life of the wire rope, the diameter of the drum may be a little smaller than the sheaves in the wire rope system. However, to keep the loss of strength due to bending, and the radial bearing pressures between wire rope and drum within allowable limits, the recommended sheave-to-rope diameter ratios given in Table 7-2 should be used for wire rope drums. Sheave-to-rope diameter ratios below the minimum value shall not be used.

7.2.2.2 Drum Grooves and Types

The grooves on a wire-rope drum can be helical, or counterbalance. Helical grooving forms a wire 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 the grooving. Helical grooving can be either right- or left-hand, similar to right- or left-hand threads. The choice of right- or left-hand grooving depends upon the direction of rotation of the drum and the layout of the wire rope system. When more than one layer of wire rope is spooled on a helically grooved drum, for each wrap on the second layer, the wire rope must make two crossovers. As a result, at each cross-over point the wire rope is slightly raised and is laterally displaced. This periodic displacement of the wire rope at the cross-over tends to produce whipping. Therefore, helically grooved drums are recommended only for single layer spooling of wire rope.

When the wire rope must be spooled in multiple layers, counterbalance grooving (or LeBus grooving) is used. Counterbalance grooving is made so that each wrap of the wire rope spools parallel to the drum flange for a distance less than one-half the circumference around the drum, then follows a short crossover. The crossover is at an angle with the drum flange and displaces the wire rope laterally by one-half of the pitch of grooving. Around the other half of the drum circumference each wrap again spools 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 is equal to the full pitch of the grooving. Since the lateral displacement of each crossover is one-half the displacement of the crossovers encountered with other types of spooling, there is a decreased tendency for the wire rope to whip. Also, in counterbalance grooving, the two crossover areas are on the opposite sides of the drum. Therefore, the raised portion of the spooling also occurs opposite each other and the spooled drum remains essentially balanced and can be operated at relatively high speeds. Spooling is controlled at each drum flange by end fillers and risers of proper design. For the design of counterbalanced grooved drums, follow the manufacturer's recommendations.

7.2.2.3 Drum Groove Contour

As for sheaves, the contour of the drum groove is designed to provide support to the wire rope for nearly one-half of the wire rope circumference. The diameter of the drum grooves is slightly larger than the diameter of the wire rope so that it will not wedge or pinch while going over the drum. The drum groove diameters shall have the same tolerances as the sheave groove diameters listed in Table 5-3. The depth of the drum grooves should be 0.4375 times the wire rope nominal diameter. The cross section of a typical drum groove is shown in Figure 7-5. The grooves should be made smooth in order not to cut or bruise the wires of the wire rope which spools upon it. Drum grooves shall be hardened to Rockwell C35 to provide a hard and smooth bearing surface that lengthens the service life of both the wire rope and the drum.

7.2.2.4 Drum Groove Pitch

At the maximum fleet angle, oncoming wire rope has a tendency to scrub against the wire rope already spooled on the drum. Grooved drums are designed with proper groove spacing or pitch to prevent crowding and scrubbing of the oncoming wire rope against the existing wraps on the drum. Drum groove pitch of 1.125 times the wire rope nominal diameter is recommended for wire rope systems where enough space is available and longer drums can be used.

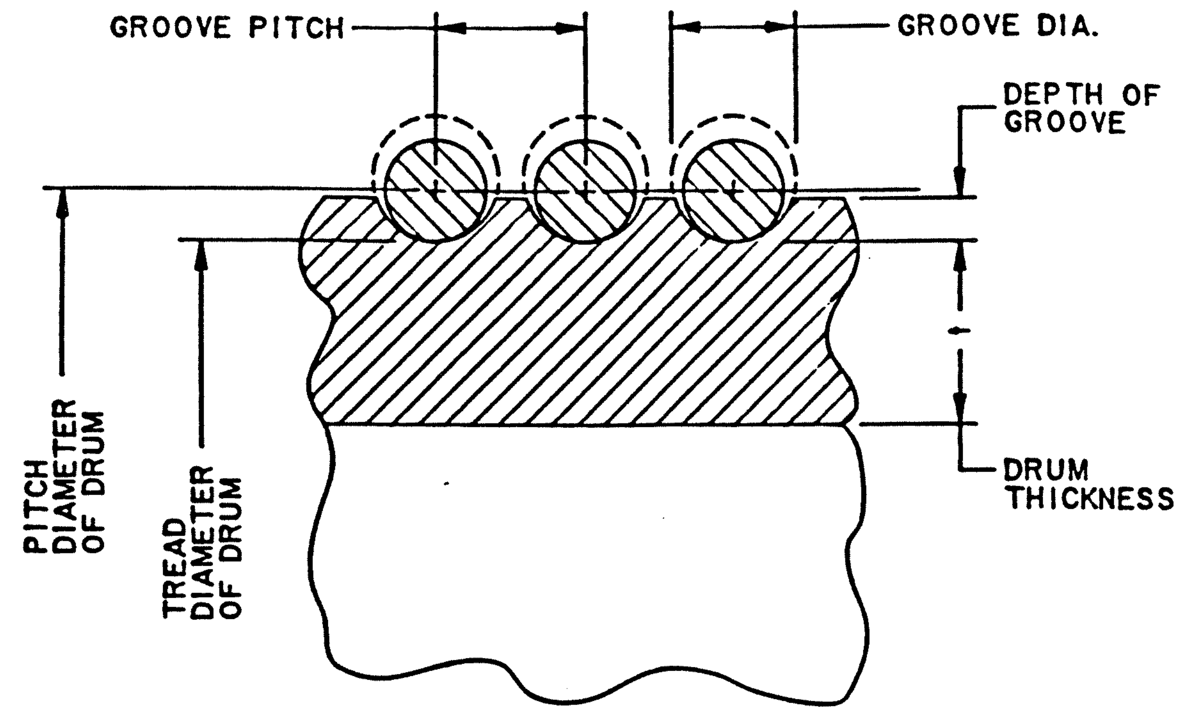


Figure 7-5. Drum Groove Contour

7.2.2.5 Drum Length

The wire-rope drum barrel should have sufficient length to accommodate the live wraps, the dead wraps, the anchor clamp to fasten the bitter end of the wire rope, the clearance between the flange and the anchor clamp, and the clearance between the flange and the end of the drum groove. The length of a single-layered drum barrel is shown in Figure 7-6, and is given by the formula:

$$L_B = a + b + c \qquad (7\text{-}8)$$

where,

L_B = length of the drum barrel, inches

a = 2 (wire rope nominal diameter) + 1/4 inch, but not less than 1-1/4 inch

b = (number of dead wraps + number of live wraps) (drum groove pitch)

c = 2 (wire rope nominal diameter), but not less than 1-1/4 inch

7.2.2.6 Drum Barrel Thickness

Under the wire rope load, the stresses in the drum barrel are bending, compression (radial and tangential) from the wraps on the drum, and torsion. If torsional stresses are negligible, the thickness of the drum barrel is designed for the allowable bending and compression stresses specified in the applicable specification.

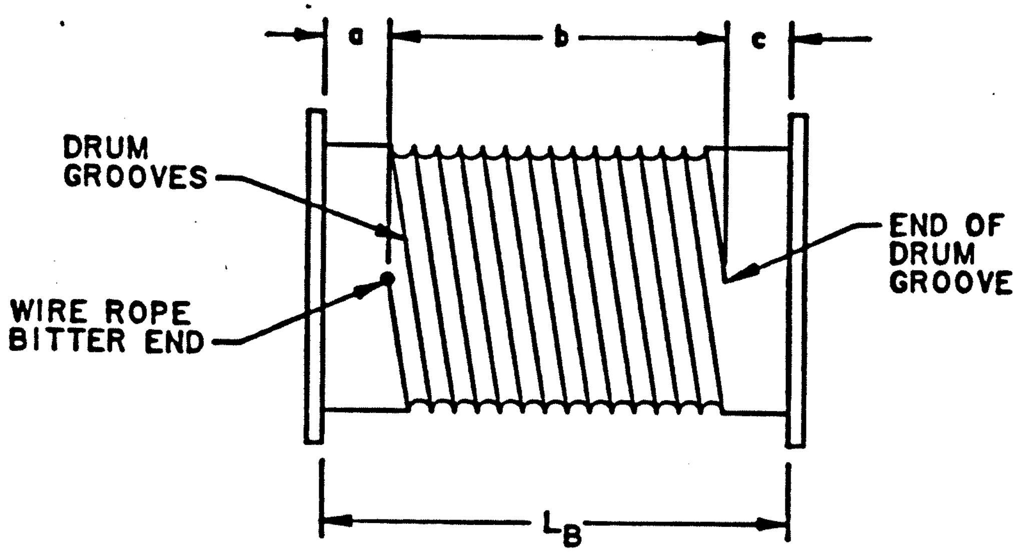


Figure 7-6. Drum Length

The rule of thumb to make the drum barrel the same thickness as the wire rope nominal diameter gives, in general, reasonable values. However, the designer shall refer to the applicable specification and check the torsional, bending, and compression stresses in the drum barrel.

For multi-layered drums, the external pressure exerted on the drum by the wire rope is more than the external pressure for a single layer of wire rope. The external pressure multiplication factors for multiple layers of wire rope spooled on a drum are listed in Table 7-6. As an example, for the same lead line pull for four layers of wire rope on the drum, the external pressure exerted by the wire rope on the drum will be 2.55 times the external pressure exerted by a single layer of the wire rope.

7.2.3 Minimum Number of Wraps

Wire rope bitter ends are generally anchored to drums by means of wire rope clamps or sockets. The lead line pull on the anchor clamp or socket is reduced by leaving a few dead wraps of the wire rope on the drum.

Table 7-6

MULTIPLICATION FACTOR FOR MULTI-LAYER SPOOLING

Number of Layers	1	2	3	4	5	6	7	8
Multiplication Factor	1.0	1.79	2.3	2.55	2.68	2.79	2.82	2.85

It is preferable to have at least three dead wraps remaining on the drum when the rope unwinds during normal operation. However, no less than two dead wraps shall remain on the anchorage of the hoisting drum when the load block is in its extreme low position.

7.2.4 Wire Rope Capacity of LeBus Winch Drum

The total length of wire rope that can be spooled on a winch drum with a LeBus grooved shell is discussed in this section.

The formula for the length of wire rope that can be spooled on the first layer is:

$$L_1 = \frac{\pi Z [D + (d_M)(K_t)]}{12} \tag{7-9}$$

where,

L_1 = length of wire rope on first layer, feet

Z = number of wraps of wire rope on the first layer. Z is determined by counting the number of complete grooves (flange to flange) and subtracting 1/2

D = diameter of drum from bottom of LeBus grooves (tread diameter), inches

d_M = diameter of wire rope (measured), inches

K_t = a spooling factor that varies with spooling tension. For light tensions (as in antislack devices), K_t is approximately 0.25

The formula for the number of layers allowable on a LeBus winch drum is:

$$Y = \frac{D_o - D - 4}{2\ (\sin 60°)} \qquad (7\text{-}10)$$

where,

Y = number of layers of wire rope allowed on a LeBus winch drum (round off to nearest whole number)

D_o = outside diameter of drum flange, inches

The formula for the increase in length of wire rope over the previous wrap on each subsequent layer is:

$$L_i = \frac{2\pi Z\ d_M\ (\sin 60°)}{12} \qquad (7\text{-}11)$$

where,

L_i = length of increase, feet. This formula applies for increases in all additional layers.

The total length of wire rope that can be spooled on the LeBus winch drum is the sum of the lengths in each layer and is given by the formula:

$$L_T = L_1 + L_2 + L_3 + \ldots\ldots + L_A \qquad (7\text{-}12)$$

where,

L_T = total length of wire rope that can be spooled on a LeBus winch drum

L_2 = length of wire rope on second layer, feet
= $L_1 + L_i$

L_3 = length of wire rope on third layer, feet
= $L_2 + L_i$

L_A = length of the wire rope in the last allowable layer, feet
= $L_{(A-1)} + L_i$

7.3 FLEET ANGLES

7.3.1 Sheave Fleet Angles

The sheave fleet angle is the side angle between the plane of rotation of the sheave and the centerline of the wire rope approaching the sheave.

When a wire rope passes over two fixed sheaves, the fleet angle, as shown in Figure 7-7, is given by the following equation:

$$\alpha = \text{arc tan } \left(\frac{h}{L}\right) \quad (7\text{-}13)$$

where,

α = fleet angle

h = distance between the planes of rotation of the sheaves

L = distance between the center line of the sheaves

A large sheave fleet angle causes above normal abrasion of the wire rope and sheave rim wear. Also the bending radius of the wire rope over the sheave rim is usually less than the tread radius of the sheave. Consequently, wire rope bending stresses are increased and wire rope bending fatigue life is reduced.

Experience has proven that the best wire-rope service is obtained when the maximum sheave fleet angle is not more than 1-1/2 degrees. Therefore, sheave fleet angles shall not exceed 1-1/2 degrees.

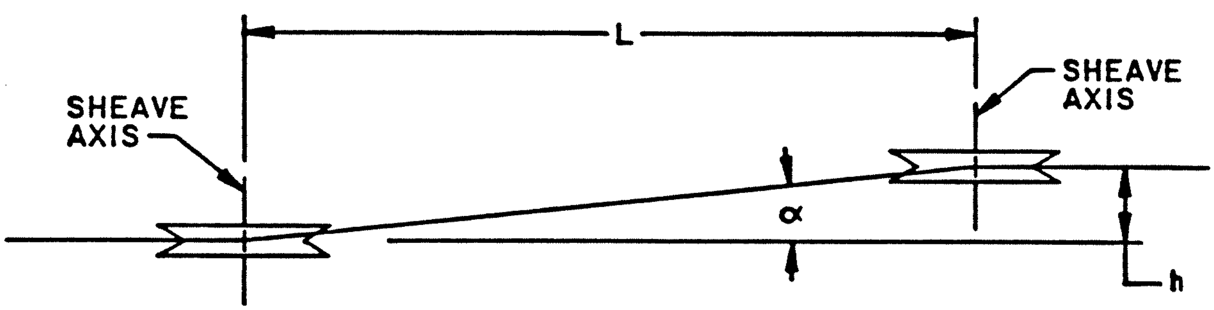


Figure 7-7. Sheave Fleet Angle

7.3.2 Drum Fleet Angles

The drum fleet angle is the angle between the centerline of the wire rope on the drum and a line drawn perpendicular to the axis of the drum through the plane of rotation of the nearest fixed sheave. This angle is maximum when the wire rope is at the extreme end of the live wraps on the drum. Too large or too small drum fleet angles may cause scrubbing between oncoming wire rope and the adjacent wrap, side wear on the drum groove, and spooling problems.

7.3.2.1 Multi-layer Drum Fleet Angle

Figure 7-8, shows the drum fleet angles for systems where the wire rope passes over a lead sheave, then onto a multi-layer wire rope drum. This angle is controlled by the distance between the lead sheave axis and the drum axis, the location of the sheave centerline relative to the drum flanges, and the length of the drum.

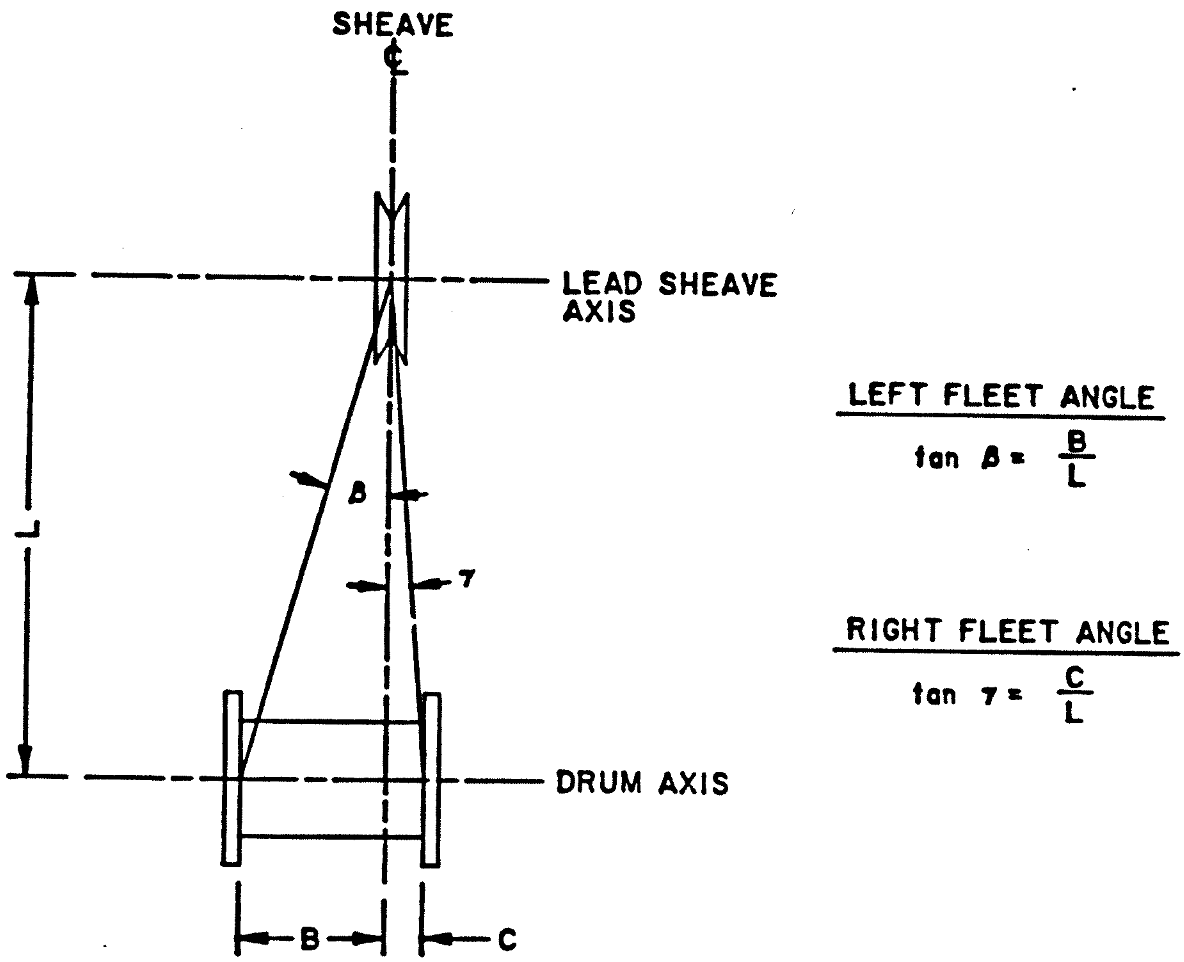


Figure 7-8. Multi-layer Drum Fleet Angles

In a multi-layer wire rope drum system, the magnitude of the fleet angle influences the transition from one layer to the next layer. A large fleet angle causes the wire rope to pull away from the flange too rapidly, thereby leaving gaps in the wire rope layer.

Wire rope on subsequent layers falls into the gaps and causes uneven spooling and crushing of wire rope at crossover points. If the fleet angle is too small, wire rope does not pull away from the flange but tends to pile upon itself, adjacent to the flange, and then drop down with considerable force. The resulting impact is harmful to the wire rope and the equipment.

For multi-layer drums, the best wire-rope service is obtained when the maximum fleet angle is not more than 1-1/2 degrees and the minimum fleet angle is not less than 1/2 degree. The designer shall adhere to these maximum and minimum fleet angle criteria. A fleet angle of 1-1/2 degrees is the equivalent of approximately 38 feet of lead, for each foot of wire rope traverse travel on either side of the centerline of the sheave. Thus, a 3-feet-long drum, with the center of drum in line with the lead sheave, should be located not less than 57 feet from the lead sheave.

7.3.2.2 Single-Layered Drum Fleet Angle

For single-layered grooved drums, spooling is controlled by the drum grooves. Consequently, the maximum allowable fleet angle for a single-layered grooved drum can be slightly more than the maximum allowable value for a multi-layered drum.

When the wire rope is wound on a grooved drum with a uniform helix, calculation of the maximum fleet angle must be modified to take the groove helix angle into account. The helix angle of the drum groove tends to reduce the scrubbing action of the wire rope when it is on one side of the drum flange, and aggravates the scrubbing action of the wire rope when it is on the other side. Consequently, the actual fleet angle is calculated by adding or subtracting the helix angle from the fleet angle calculation shown in Figure 7-8. Figure 7-9 shows the drum groove helix angle, d, and illustrates the effect of groove helix angle on the scrubbing action of the wire rope.

Drum groove helix angle (Figure 7-9) is defined as:

$$\phi = \arctan\left(\frac{P}{\pi D_p}\right) \qquad (7\text{-}14)$$

where,

ϕ = drum groove helix angle

p = drum groove pitch

D_p = pitch diameter of the drum

For the system shown in Figure 7-9:

$$\text{Left Actual Fleet Angle} = \beta + \phi \qquad (7\text{-}15)$$

$$\text{Right Actual Fleet Angle} = \gamma - \phi \qquad (7\text{-}16)$$

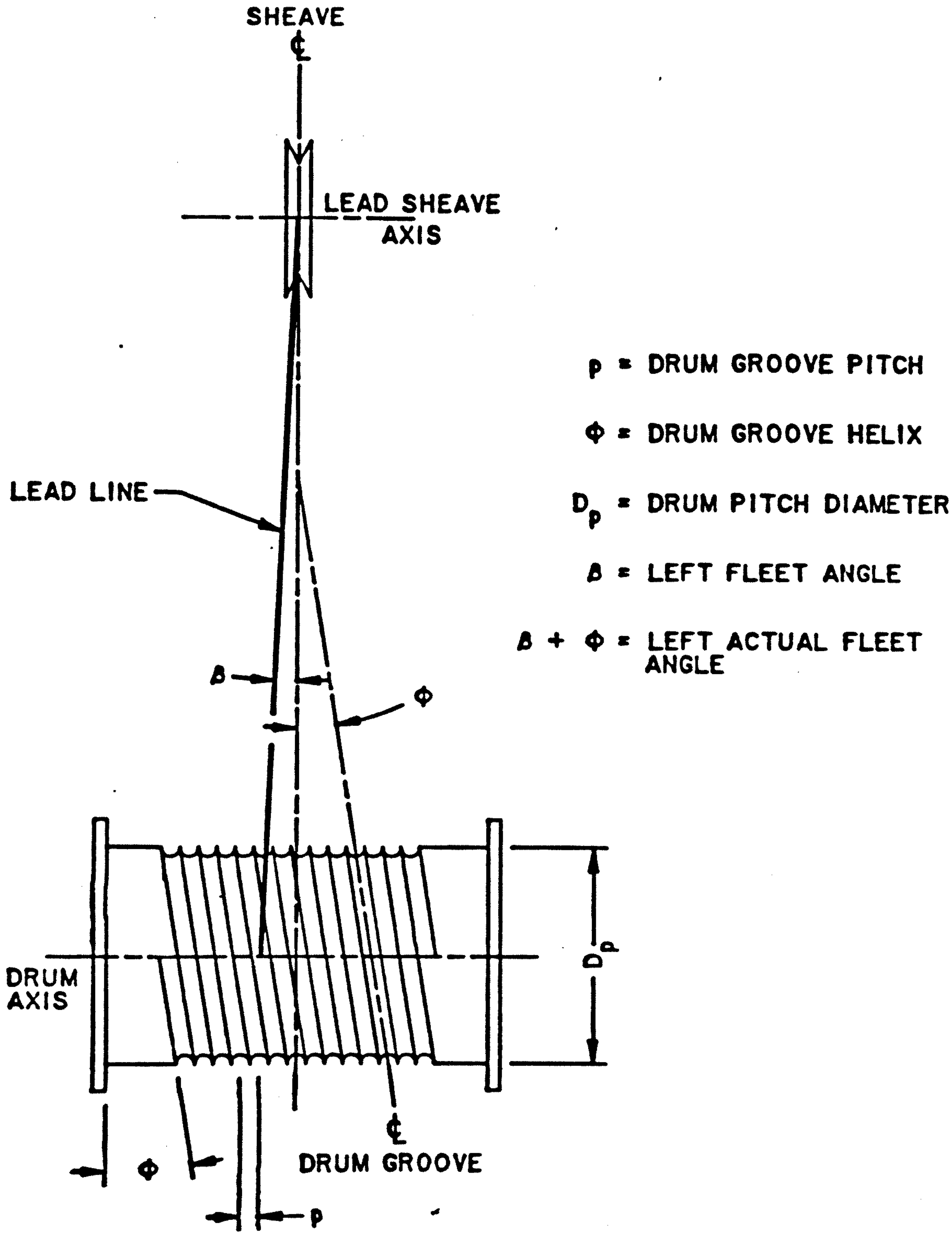


Figure 7-9. Actual Fleet Angles for Helically Grooved Drum

Fleet angle criteria are defined for live wraps only and do not include dead or anchor wraps on the wire rope drum.

A maximum actual fleet angle of 2 degrees shall be used for a single-layered grooved drum. Larger fleet angles may cause side wear on the groove and scrubbing between oncoming rope and the adjacent wrap.

As is the case for multi-layered drums, for single-layered smooth drums, the maximum fleet angle of 1-1/2 degrees and a minimum fleet angle of 1/2 degree shall be used.

7.3.3 Fleet Angle Compensators

When the fleet angles in a wire rope system are larger than the maximum recommended values or when a large amount of wire rope is to be stored on a winch drum, mechanical spooling devices (called fleet angle compensators) can be used. These devices guide the wire rope across the drum so that it does not pile up in one place. The translation of the sheaves or rollers guiding the wire rope can be provided either by a powered threaded shaft or by the tension in the wire rope.

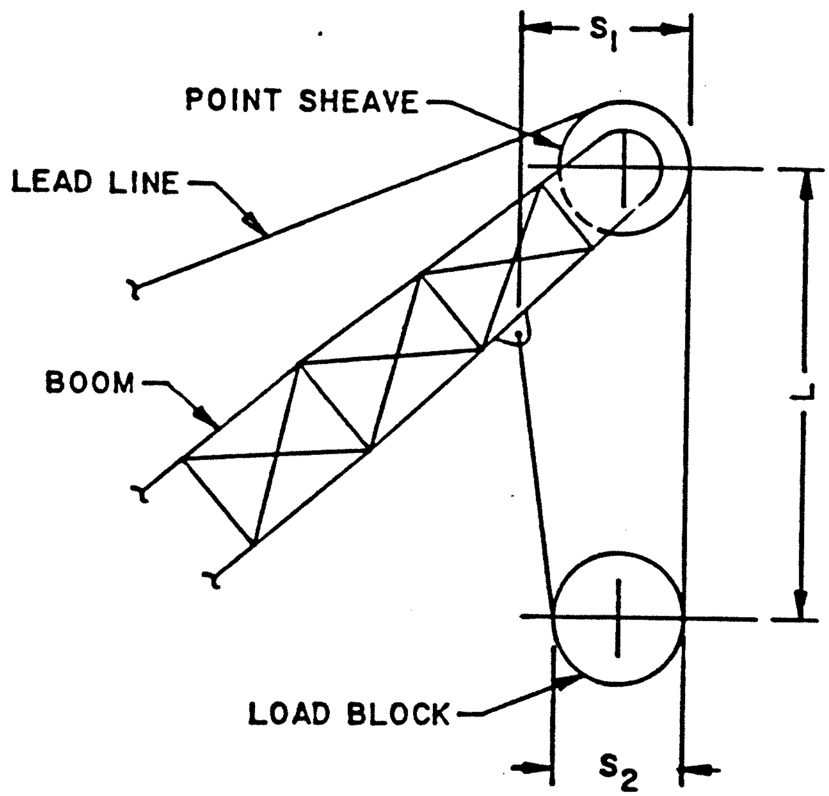


Figure 7-10. Block Stability

7.4 MISCELLANEOUS

7.4.1 Cabling - Block Spinning on Cranes Using Multiple-Part Reeving

Cabling (block spinning or block twisting) is a problem encountered in hoisting cranes. When a load is applied, conventional wire ropes unlay (rotate or twist) slightly and result in cabling. Cabling of a load block is defined as the condition when the block has rotated 90 degrees from its neutral position. The stability of a load block, shown in Figure 7-10, can be predicted. The horizontal angle of block rotation, Δ, is given by the following formula:

$$\Delta = \text{arc sin} \frac{L\ K\ T_F}{S_1\ S_2} \qquad (7\text{-}17)$$

where,

Δ = angle of block rotation, degrees

L = height of falls, feet

K = constant depending upon the number of wire rope parts

T_F = torque factor of wire rope, inch pound per pound

S_1 = effective wire rope spacing at boom point, inches

S_2 = effective wire rope spacing at load block, inches

The values of the constant K, for a number of parts of wire rope, are listed in Table 7-7.

Table 7-7

VALUES OF CONSTANT K

No. of Wire Rope Parts	K
2	48
3	72
4	42
5	63
6	36
7	54

The values of the torque factor T_F, for different wire rope constructions, are given in Table 7-8.

Table 7-8

VALUES OF TORQUE FACTOR T_F

WIRE ROPE CONSTRUCTION: STANDARD ROPES (19 and 37 Wire Strand Class)	Core	T_F INCH POUND PER POUND: Regular Lay	Lang Lay
6 - strand	FC	0.0910 d	0.1550 d
6 - strand	IWRC	0.0849 d	0.1378 d
8 - strand	FC	0.1175 d	0.1706 d
8 - strand	IWRC	0.1047 d	0.1405 d

FC - Fiber core

IWRC - Independent Wire-Rope Core

WSC - Wire Strand Core

d - Wire Rope Nominal Diameter

In a multiple sheave block (Figure 7-11), the effective wire rope spacing depends upon the pitch diameter of the sheaves, the sheave spacing, and the number of wire-rope parts.

The effective wire rope spacing, S (S_1 or S_2), for any number of equally spaced parts of wire rope in a block is given by:

$$S = \sqrt{D_p^2 + H_1^2} \qquad (7\text{-}18)$$

where,

S = effective wire rope spacing, inches

D_p = pitch diameter of sheave, inches

h_1 = number of sheave spacings in terms of h, inches

$$= \frac{N - 0.6667\ h}{3.3333}$$

h = spacing between sheaves, inches

N = number of wire rope parts

The above formula applies only to a stable system and cannot be used once cabling occurs.

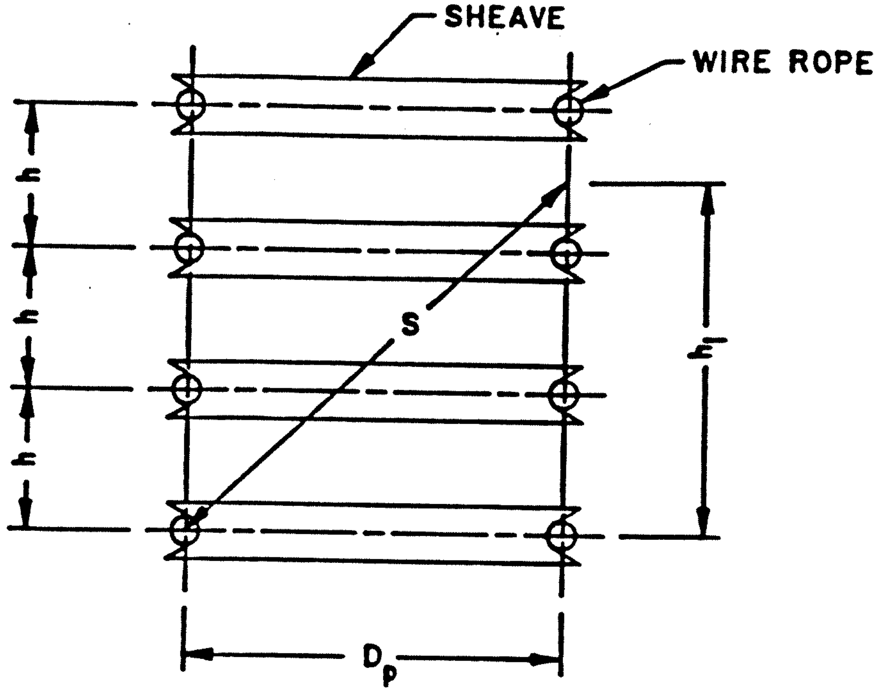


Figure 7-11. Effective Wire Rope Spacing in a Multiple-sheave Block

The following steps tend to reduce cabling:

- Reduce wire rope length. Longer wire rope lengths cause more rotation, due to unlaying, than shorter wire rope lengths.
- Replace fiber core wire rope with an IWRC wire rope. Fiber core wire ropes have a higher torque factor than IWRC wire ropes.
- Eliminate odd-part reeving. Even number of parts is more stable than odd.
- In installations where the wire rope dead end is on the load block, rereeve to the next higher number of parts, and dead end the wire rope on the fixed block. Wire rope rotation is greatest at the wire rope dead end.

- While maintaining the same design safety factor, use a smaller size wire rope.

- Increase the spread between the wire rope falls. Use either larger sheaves, or dead end the wire rope away from the wire rope falls (check the integrity of the structure).

- Restrain the load block with a tag line.

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

7.4.2 Reeving - Anchorage of a Wire Rope on a Plain-faced and Grooved Drum

When wire rope is spooled on a drum, it tends to untwist at the free end when tension is released. At each removal of load, this tendency may result in the wire rope wraps jumping out of the grooves on a grooved drum, and spreading apart on a plain-faced drum. When spooling is resumed, the wire rope may crisscross and overlap on the drum, thereby resulting in abrasion and crushing.

The following rule takes advantage of this tendency and shall be used in determining where to anchor the bitter end and to begin spooling of the wire rope. This rule applies to both regular-lay and lang-lay wire rope.

Visualize yourself behind the drum. The right hand represents the right-lay wire rope and the left hand represents the left-lay wire rope. Note the wire-rope lay. Turn the appropriate hand so that for overwinding the hand goes palm down and for underwinding the hand goes palm up. Extend the index finger and the thumb with the other fingers being closed into a fist. The fist represents the drum and the index finger represents the wire rope, coming onto the drum. The thumb points towards the flange of the drum to which the wire rope bitter end shall be anchored. The above explanation is illustrated in Figure 7-12.

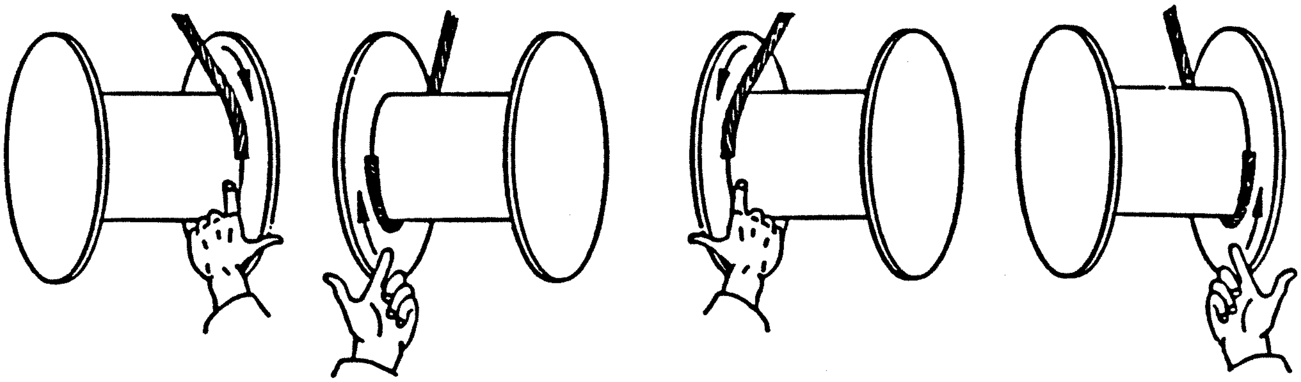


Figure 7-12. Wire Rope Anchorage on Drum

7.4.2.1 Reverse Bends

Reverse bends, if possible, should be avoided. Reverse bending is the condition in which a wire rope is first bent around one sheave in one direction, and later, the same section of rope is passed around another sheave with a bend in the opposite direction.

The service life in reverse bending averages only 40 to 50 percent of that in continuous bending. This indicates that for equal service life, the tread diameter of the sheaves causing the reverse bends should be one-third to one-half greater than the tread diameter of the other sheaves. Figure 7-13 illustrates reverse-bends.

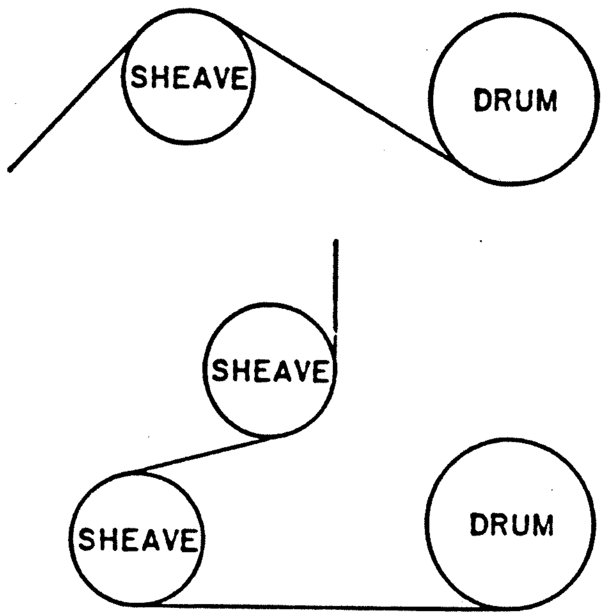


Figure 7-13. Reverse Bends

7.4.3 Antislack Device

An antislack device (ASD) keeps tension on the wire rope in the no-load condition to prevent birdcaging and improve spooling of the wire rope on the drum. The ASD is activated by the operator at times when the wire rope is slack. The ASD usually consists of a powered squeeze sheave which grips the wire rope and maintains tension on it, while being paid out or taken up. The squeeze sheave is always driven in the payout direction through a slip clutch.

When the winch drum pays out, the outer edges of the squeeze sheave grip the wire rope and the clutch slips inside the slip drum. When the winch drum hauls in, the pull of the winch drum causes the clutch to slip inside the slip drum. This permits the squeeze sheave to rotate in the haul-in direction. When the winch drum is not rotating, the squeeze sheave cannot pull the wire rope. Therefore, the clutch slips inside the slip drum and the squeeze sheave does not rotate. The UNREP highline/spanwire air clutch ASD is shown in drawing, NAVSHIPS No. 4684657, and for outhaul winch applications, is shown in drawing, NAVSHIPS No. 4760074.

THIS PAGE INTENTIONALLY LEFT BLANK

8.0 SAMPLE PROBLEM

8.1 HOISTING WIRE ROPE SYSTEM DESIGN

The reeving diagram of a shipboard hoisting crane is shown in Figure 8-1. Design the wire rope system for the given ship motion loads.

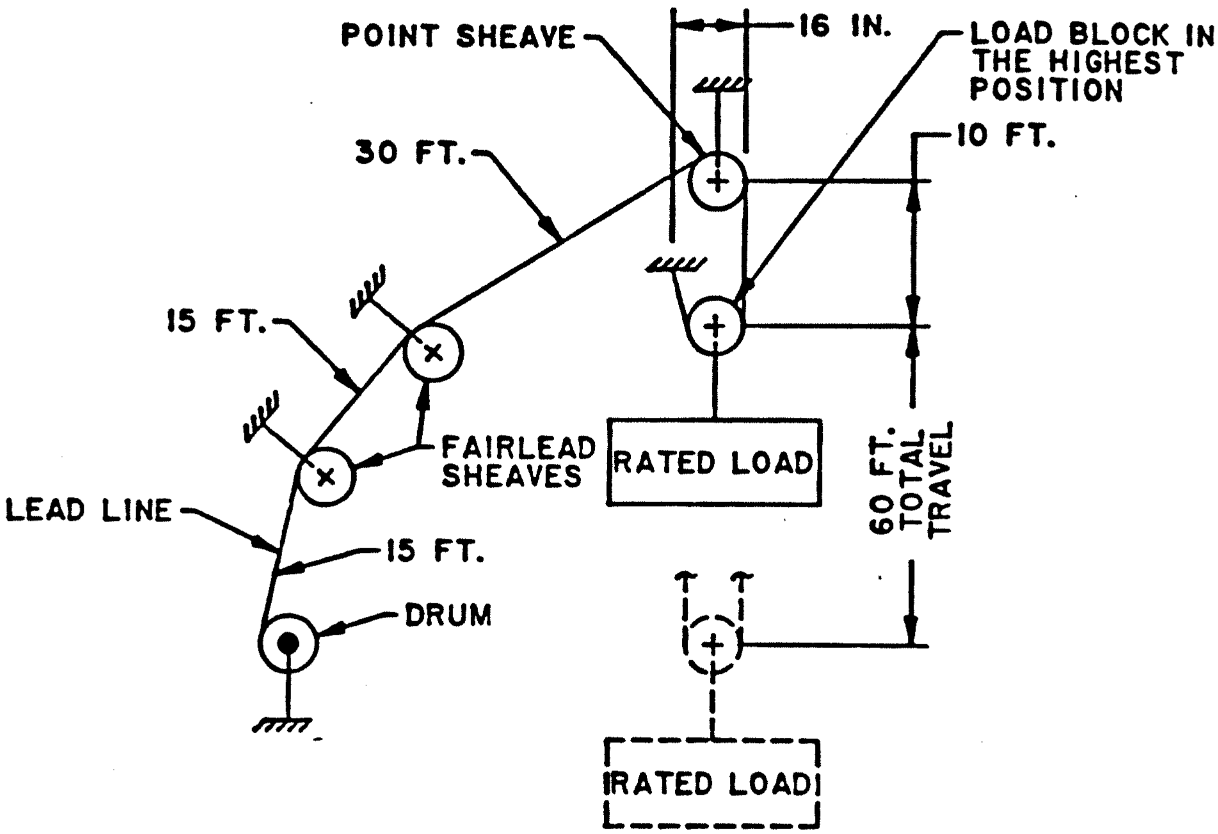


Figure 8-1. Reeving Diagram

Design Data

The design data are as follows:

Rated Load	= 9000 lb
Maximum load acceleration/deceleration	= 5 ft/sec^2
Longitudinal acceleration, Ax	= 0.073 g
Transverse acceleration, Ay	= 0.153 g
Vertical acceleration, Az	= 1.059 g

Sheaves have roller bearings.

8.1.1 Solution

a. Wire Rope Selection

In Navy usage, 6 x 37 class uncoated carbon steel wire ropes are specified for hoisting purposes (Section 2.9.4). For added flexibility and added resistance to bending fatigue and abrasion, a preformed, single-operation strand wire rope would be desirable. Metallic core (IWRC or WSC) wire ropes have added strength. Hence, a preformed single-operation strand 6 x 37 class IWRC right regular lay uncoated carbon steel wire rope would be suitable. The carbon steel grade (IPS or EIPS) will be selected after the target nominal strength of the wire rope has been established.

b. Size of Wire Rope

Wire ropes for running rigging are sized by simultaneously considering the design load acting on the wire rope, efficiencies of wire rope terminations, and the recommended design safety factors.

Zinc sockets (Section 4.1) are approved for running rigging. Zinc sockets have 100 percent (1.0) efficiency (Table 7-3). Also, Table 7-4 gives a minimum design safety factor of 5 for running rigging.

Calculate the various loads on the wire rope.

Frictional Load

Calculate the lead line load in terms of the total suspended load W (Section 7.1.1).

In this example the last sheave is fixed. Also the total number of sheaves s in the sheave system is two (2) more than the number of parts of the wire rope N. Therefore this case is similar to Case C shown in Figure 7-2.

From Table 7-1,

For N = 2, X = 1.02 (Roller Bearings)

Lead line factor (for Case C) = 0.536

Acceleration Load

Use equation (7-5) to calculate the acceleration load factor:

for $a_w = 5\ ft/sec^2$ and $g = 32.2\ ft/sec^2$

$$\frac{a_w}{g} = \frac{5}{32.2} = 0.155$$

$$\therefore \text{Acceleration Load Factor} = (1 + \frac{a_w}{g})$$

$$= 1 + 0.155 = 1.155$$

Therefore, the lead line load, due to acceleration, is multiplied by 1.155.

Ship Motion Load

Since A_x, A_y, and A_z are concurrent accelerations, the resultant acceleration due to the ship motion load is:

$$[A_x^2 + A_y^2 + A_z^2]^{1/2} = [(0.073g)^2 + (0.153g)^2 + (1.059g)^2]^{1/2}$$

$$= 1.072g$$

Therefore, the lead line load, due to ship motion is increased by a factor of 1.072.

Bending Load

Bending load (decrease in wire rope strength due to bending) depends upon the sheave-to-rope diameter ratio. The recommended sheave-to-rope diameter ratio for a 6 X 37 class wire rope (Table 7-2) equals 22. For a sheave-to-rope diameter ratio of 22, the decrease in strength due to bending (Figure 7-3) equals 7 percent. Use equation (7-6) to calculate the bending load factor:

$$\text{Bending Load Factor} = \frac{100}{(100 - 7)} = 1.075$$

Therefore, the lead line load, due to bending, is multiplied by 1.075.

Estimated Nominal Strength of Wire Rope

Rated load = 9,000 lb

Weight of 5 ton capacity load block = 100 lb

Total suspended load (excluding wire rope weight)

= Rated Load + Weight of the Load Block
= 9,000 + 100
= 9,100 lb

The estimated lead line load is calculated by taking into account the frictional load, acceleration load, ship motion load, and the bending load.

Estimated lead line load

$$= (0.536)(1.155)(1.072)(1.075)(9100)$$
$$= 6{,}492 \text{ lb}$$

Estimated nominal strength of wire rope considering the efficiency of termination, and the design safety factor

$$= \frac{(6{,}492)(5)}{(1)}$$

$$= 32{,}460 \text{ lb}$$

Federal Specification RR-W-410 gives the nominal strength of 5/8-inch nominal diameter, single operation strand, 6 x 37 class, uncoated improved plow steel, IWRC, wire rope as 35,800 pounds.

<u>Check</u>

The approximate weight of this wire rope is 0.72 lb/ft (Federal Specification RR-W-410).

Total suspended load = rated load + weight of the load block + weight of the parts of wire rope.

$$= 9{,}000 + 100 + [(70 \text{ ft})(2 \text{ parts})(.72 \text{ lb/ft})]$$
$$= 9{,}201 \text{ lb}$$

Lead line load = (0.536)(1.155)(1.072)(1.075)(9201)
= 6,564 lb

$$\text{Actual design safety factor} = \frac{(35{,}800)(1)}{(6{,}565)} = 5.45 > 5$$

Therefore, the selection of 5/8-inch diameter wire rope is satisfactory.

c. <u>Drum Design</u>

Following the procedure outlined in section 7.2, the wire rope drum is designed for a 5/8-inch nominal diameter wire rope.

<u>Minimum Drum Tread Diameter</u>

Per Table 7-2, the recommended drum tread diameter is 22 times the wire rope nominal diameter d.

Drum tread diameter D = 22 d
= (22)(0.625) in.
= 13.75 in.

Drum Groove Diameter

Per Section 7.2.2.3, the drum groove diameter for a 5/8-inch nominal diameter wire rope (Table 5-3)

$$= \left(\frac{5}{8} + \frac{1}{32}\right) \text{ inch min. to } \left(\frac{5}{8} + \frac{1}{16}\right) \text{ inch max.}$$

$$= \frac{21}{32} \text{ inch min. to } \frac{11}{16} \text{ inch max.}$$

Choose the minimum value of 21/32 inch.

Depth of Groove

Per Section 7.2.2.3,

The depth of drum groove = 0.4375 d
= (0.4375)(0.625) inch
= 0.273 inch

For manufacturing reasons, choose a round figure of 17/64 in.

Drum Groove Pitch

Per Section 7.2.2.4,

Drum groove pitch = 1.125 d = (1.125)(0.625) inch
= 0.703 in.

Per Table 7-6, for a 5/8-inch nominal diameter wire rope, the minimum groove pitch is 21/32 inch (= 0.656 in.).

For manufacturing reasons, choose a round figure of 11/16 inch. (This value is greater than the minimum drum groove pitch of 21/32 inch.)

Drum Length

Design the drum to spool the wire rope in a single layer. The number of parts of wire rope is 2 and the hook lift is 60 feet.

Therefore, the length of wire rope spooled on the drum equals 2 times 60 = 120 ft.
= (120)(12) = 1440 in.

Drum pitch diameter = D + d
= 13.75+ 0.625 = 14.375 in.

$\therefore$ Number of live wraps $\frac{1440}{(\pi)\ (14.375)} = 31.90$

For manufacturing purposes, increase the number to the next higher wrap.

$\therefore$ Design number of live wraps = 32

Per Section 7.2.3, the minimum number of dead wraps on the drum shall be 3.

Per equation (7-8), the length of the drum barrel is given by the equation

$L_B = a + b + c$

where,

a = 2 d + 1/4, but not less than 1-1/4 in.
= (2)(0.625) + 1/4
= 1-1/2 in.

b = (number of dead wraps + number of live wraps) (drum groove pitch)
= (32 + 3) (11/16)
= 24-1/16 in.

c = 2 d + 1/4, but not less than 1-1/4 in.
= 1-1/2 in.

L_B = a + b + c
= 1-1/2 + 24-1/16 + 1-1/2
= 27-1/16 in.

Drum Barrel Thickness

Per Section 7.2.2.6, a drum barrel thickness of 5/8 inch (which is equal to the wire rope nominal diameter) is a reasonable assumption. The designer shall check the torsional, bending, and compression stresses against the allowable stresses given in the specification.

d. Overhauling Weight

The overhauling weight is calculated according to equation (5-1).

Wire rope length λ = 60 ft (Figure 8-1)

Rope weight factor = 0.72 lb/ft (Table 5.5)

Overhaul factor = 2.07 (Table 5-6 for antifriction bearings)

Drum friction = 50 lb (Section 5.6)

.˙. Overhauling Weight = [(Wire Rope Length, λ) (Rope Weight Factor) + Drum Friction] [Overhaul Factor]
= [(60)(0.72) + 50] [2.07]
= 193 lb

Since the weight of the load block is 100 pounds, additional overhauling weight is required.

Required additional overhauling weight = (193-100) lb
= 93 lb

e. Block Twisting

To check the wire rope load block for cabling (block twisting), the horizontal angle of block rotation, W, is given by the equation (7-17).

L = 70 feet (Figure 8-1)

K = 48 (Table 7-8)

T_F = 0.0849 d
= (0.0849)(0.625) (Table 7-9)
= 0.0531 inch pound per pound

S_1 = 16 in. (Figure 8-1)

S_2 = D_p (Figure 7-11)
= D_p + d
= 13.75 + 0.625 in.
= 14.375 in.

$$.˙. \Delta = \text{arc Sin} \frac{L\ K\ T_F}{S_1\ S_2}$$

$$= \text{arc Sin} \frac{(70)\ (48)\ (0.0531)}{(14.375)\ (16)}$$

= arc Sin (0.776)
= 51 degrees

Since the angle of block rotation is less than 90 degrees, cabling will not occur.

8.2 STATIONARY WIRE ROPE SYSTEM DESIGN

Design stationary wire rope stays to hold a vertical structural mast in position.

Design Data

Number of Stays = 6

Spacing of Stays = Uniform

Angle with horizontal = 40 degrees

Horizontal Force acting at the top of the mast = 10,000 lb

Mast is free to rotate at the base.

8.2.1 Solution

a. Wire Rope Selection

In Navy usage, 6 x 19 class galvanized steel wire ropes are specified for standing rigging (Section 2.9.2). Metallic core prestretched wire ropes are recommended since stays must maintain specific lengths.

Hence, a prestretched 6 x 19 class IWRC right regular lay galvanized improved plow steel wire rope would be suitable.

b. Size of Wire Rope

Wire ropes for stationary systems are sized by considering the tension in the wire rope, efficiencies of wire rope terminations, and the recommended design safety factors.

Fiege-type fittings (Section 4.3) are approved for standing rigging. Fiege-type fittings have 85 percent (0.85) efficiency. Also, Table 7-4 gives a minimum design safety factor of 3-1/2 for standing rigging for structures free to rotate at the base.

Calculate the tension in any stationary rope (Section 7.1.8)

Per equation (7-7)

$$P_G + \frac{F_H A}{\cos \delta}$$

where,

F_H = 10,000 lb

δ = 40 degrees

A = 0.6667 (Table 7-5 for 6 stays)

$$\therefore P_G = \frac{(10,000)\ (0.6667)}{\cos 40} = 8703 \text{ lb}$$

<u>Estimated Nominal Strength of Wire Rope</u>

Estimated nominal strength of the wire rope considering the efficiency of the termination and the design safety factor

$$= \frac{(8,703)(3.5)}{(0.85)}$$

$$= 35,836 \text{ lb}$$

Federal Specification RR-W-410 gives the nominal strength of 3/4-inch nominal diameter, 6 x 19 class, galvanized improved plow steel, IWRC, wire rope as 46,000 pounds.

<u>Check</u>:

The design safety factor of the stationary wire rope system

$$= \frac{(46,000)\ (0.85)}{(8703)}$$

$$= 4.49 > 3.5$$

Therefore, the selection of 3/4-inch diameter wire rope is satisfactory.

THIS PAGE INTENTIONALLY LEFT BLANK

9.0 GLOSSARY

A

ABRASION - Frictional surface wear on the outer 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 the increasing or decreasing velocity of a load.

ACCEPTANCE BREAKING STRENGTH - See BREAKING STRENGTH.

ACTUAL BREAKING STRENGTH - See BREAKING STRENGTH.

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

B

BACKSTAY - Standing rigging leading aft, to support a boom or mast.

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

BASKET (OF A SOCKET) - The cone-shaped receptacle of a socket into which the "broomed-out" end of the wire rope is inserted and secured with zinc.

BECKET - The fitting on a block to which the dead end of the fall is attached.

BECKET LINE - The part of the rope in a multiple-reeved system that is dead-ended to the block.

BECKET LOOP - (1) The fastener on a sheave block to which the dead end of a fall or rope is secured. (2) A loop of small rope or strand fastened to the end of a larger wire rope. Its function is to facilitate wire rope installation.

BENDING LOAD - The load induced in the wires of a wire rope during bending over drums or sheaves.

BENDING STRESSES - (1) The stresses induced in the wires of a wire rope during bending over drums or sheaves. (2) The stresses induced in a member due to bending action.

BIGHT - A curve or loop in a rope.

BIRDCAGE - (1) Enlargement of a wire rope due to the springing of the strands away from the core upon sudden release of the load. Can also result from dragging a wire rope, under load, over a small-diameter sheave. (2) Nonuniform spooling of a wire rope on a winch drum.

BITTER END - The free end of a length of a wire rope.

BLACK WIRE - See UNCOATED WIRE.

BLOCK - A term applied to the rope sheave or sheaves enclosed in a housing and fitted with some attachment such as a hook or a shackle.

BLOCK SPINNING OR BLOCK TWISTING - See CABLING.

BOOM - A rigid structure used to support or guide an object to be lifted or swung.

BREAKING STRENGTH (OR BREAKING LOAD) - (1) ULTIMATE or ACTUAL BREAKING STRENGTH: The load at which a tensile failure occurs in the sample of wire rope being tested. The ultimate or actual breaking strength may exceed the nominal strength of the wire rope and must exceed the acceptance breaking strength of the wire rope. (2) ACCEPTANCE BREAKING STRENGTH: The minimum breaking load of a wire rope guaranteed by the manufacturer. The acceptance breaking strength is 2-1/2 percent lower than the published nominal strength. (3) NOMINAL STRENGTH: The nominal strength is the calculated, published strength value of the wire rope accepted by the wire rope industry.

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

BRIGHT WIRE - See UNCOATED WIRE.

BRONZE ROPE - Wire rope made of phosphor bronze wires.

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

BUSHING - A plain journal bearing usually made of bronze.

C

CABLING (OF A LOAD BLOCK) - The condition when the block has rotated 90 degrees from its neutral position. This problem may arise in hoisting cranes. Also called BLOCK SPINNING or BLOCK TWISTING.

CENTER - The axial member of a strand about which the strand wires are laid.

CHAFING GEAR - Any device or material which prevents wire rope damage caused by rubbing or abrading against sharp edges.

CHEEK PLATES - Side plates attached to the shell plates which provide bearing support for the sheave center pin and transmit sheave loads to the fittings and connections of the load block.

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 is threaded onto a wire rope and allowed to move along its length.

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

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

CLIP - A wire rope fitting made of a malleable iron or forged-steel saddle piece (grooved to suit the wire rope lay) and a U-bolt by which the clip is held to two parallel wire ropes. Primarily used to clamp the dead end of the wire rope to the live wire rope after the wire rope is turned back on itself to make a loop termination.

CLOSED SOCKET - A socket comprising a basket and a curved bail.

COARSE LAID ROPE - The term applied to wire ropes of the 6 x 7 construction because of their large outer wires.

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

COLD DRAWING - See WIRE DRAWING.

COMBINATION STRAND - SINGLE OPERATION - A strand which is a combination of Seale, Warrington, or filler-wire construction.

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

CONSTRUCTIONAL STRETCH - The permanent increase in the length of a wire rope which occurs in a new wire rope during initial loading. It results from the seating of the wires in the strand and the strands in the core of the wire rope.

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

CORROSION - The electro-chemical decomposition of the wires of a wire rope (or of any other metallic object) due to exposure to moisture, acids, alkalies, or other agents.

CORRUGATED (SHEAVES AND DRUMS) - Term used to describe the worn grooves of a sheave or drum showing the impression of a wire rope.

COVER WIRES - Outer layer of wires in a wire rope strand. Also called OUTER WIRES.

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

CROSSOVER - For wire rope spooled on a drum, the points at which the wraps of the upper layer cross over the crown wires of the wraps of the lower layer.

CROSSOVER WEAR - The type of wire rope wear which is encountered at the crossover points for multiple layers of wire rope on a drum.

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

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

CRUSHING - Distortion of a wire rope caused by high radial pressures.

CUTTING - Severing of the rope or a strand by shearing.

CUTTING BACK - Periodically cutting off lengths of wire rope at terminations to redistribute areas of abrasion (wear).

D

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

DEAD LOAD - Constant load on a 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.

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 such as on structural erection cranes.

DESIGN SAFETY FACTOR - The ratio of the design strength of the component to the calculated design load. Standards are often set by statutory bodies for minimum design safety factors. Also known as FACTOR OF SAFETY or SAFETY FACTOR.

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

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

DRAWN GALVANIZED - Galvanizing process where galvanizing precedes the last cold-drawing series of the carbon steel wires.

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

DRUM HOOKS - A sling containing a pair of movable hooks; used for hoisting a drum, cask, or barrel by its chines. Also called chine hooks.

DUCTILITY - A property of metals which enables them to be mechanically deformed.

E

EFFICIENCY (OF FITTINGS AND TERMINATIONS) - Percentage ratio of the actual breaking strength of the wire rope-fitting combination to the actual breaking strength of the wire rope.

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, thereby enabling the attachment of the rope to other equipment. Also called TERMINATION.

ENDLESS SPLICE - A long splice made by marrying two ends of wire ropes by replacing alternate strands from one wire rope end with the strands of the wire rope end to which it is being joined.

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

EYE SPLICE (OR LOOP SPLICE) - A permanent loop formed in the end of a wire rope, normally using a thimble to form the loop. This type of splice is made by folding back or flemishing the dead end of the wire rope and completing by (1) hand-tucking the dead end strand by strand and (2) swaging a sleeve to the base of the loop.

F

FACTOR OF SAFETY - See DESIGN SAFETY FACTOR.

FAIRLEAD SHEAVE - A sheave that supports, guides, or changes the direction of a wire rope. It usually has a wrap angle of less than 90 degrees.

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

FALLS - The hoisting rope or ropes used in a multiple- reeved rope tackle system.

FATIGUE - The process of progressive, localized wire damage caused by fluctuating stresses culminating in multiple wire failures (or fractures) and subsequent rope failure.

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

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

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

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

FILLER-WIRE CONSTRUCTION - A multi-layer, single-operation 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 used for spacing and positioning of other wires.

FISHHOOK - A broken end of wire protruding from a wire rope.

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

FLATTENED STRAND WIRE ROPE - Wire rope made with oval- or triangular-shaped strands.

FLEET ANGLE - (1) Drum to sheave: The angle between the center-line of the wire rope on a drum and a line drawn perpendicular to the axis of the drum through the plane of rotation of the nearest fixed sheave. This angle is maximum when the wire rope is at the extreme ends of the live wraps on the drum. (2) Sheave to sheave: The side angle between the plane of rotation of the sheaves and the centerline of the wire rope approaching the sheaves.

FLEET ANGLE COMPENSATOR - A mechanical device used in a wire rope system to guide the wire rope across a drum when the fleet angles are larger than recommended values. This is largely used with multi-layer drums having counterbalance grooving.

FLEMISH EYE - See EYE SPLICE.

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

FORESTAY - Standing rigging leading forward, to support a boom or mast.

G

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

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

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

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

GROOVED DRUM - A drum with a grooved surface to support and guide a wire rope.

GUYS OR GUY ROPES - Wire ropes which are generally galvanized and used as standing rigging to stabilize and support structures in a fixed position. They normally are adjustable in length to allow for stretch.

H

HAWSER - Large-size rope used for towing or mooring marine vessels. If a wire rope, it is usually galvanized.

HEMP - A plant fiber used in making fiber cores.

HOIST BLOCK - See LOAD BLOCK.

I

IMPROVED PLOW STEEL - See GRADES: WIRE ROPE.

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

INTEGRAL SADDLE-AND-BOLT CLIP - A wire rope clip consisting of two identical L-shaped bolts fastened together with nuts. This clip provides bearing surface for both parts of the wire rope. Also called a FIST-GRIP CLIP.

K

KINK - Sharp, permanent bend in a wire rope.

L

LANG-LAY ROPE - Wire rope in which the lay direction of the wires in the strands is the same as the lay direction of the strands in the wire rope.

LAY - Twist or helical form of individual wires or strands in a wire rope.

LAYER - (1) Wire rope: A group of strands in a rope or a group of wires in a strand laid concentrically around the core. A center wire is not a layer, but a twisted strand center is a layer. (2) Drum: A succession of uniformly spooled wraps of wire rope on a drum barrel extending from one flange to the other flange.

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

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

LEAD LINE - The part of the rope leading from the winch drum to the first fixed or floating sheave.

LEFT LAY - The counterclockwise direction of strand or wire helix in a wire rope or strand.

LEVEL WIND - A mechanism used to ensure even and uniform spooling of a wire rope on a drum.

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

LINK - A device used to connect various pieces of system hardware.

LIVE END (OF A ROPE) - 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. See DEAD END.

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

LIVE WRAPS (ON A DRUM) - Wraps on a drum which are paid out during rope operation.

LOAD BLOCK - A block, suspended by the hoisting ropes, to which the payload is attached. Also called TRAVELING BLOCK or HOIST BLOCK.

LONG SPLICE - See ENDLESS SPLICE.

M

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

MECHANICAL SPLICE - Also called MECHANICAL EYE SPLICE. See EYE SPLICE.

MULTI-LAYER STRAND - A strand with two or more layers of wires.

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 through a block or blocks consisting of several sets of sheaves in parallel.

N

NICKING - Permanent surface deformation of wires at points of wire-to-wire contact. Also called NOTCHING.

NOMINAL STRENGTH - See BREAKING STRENGTH.

NONSPINNING WIRE ROPE - See ROTATION-RESISTANT WIRE ROPE.

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

NOTCHING - See NICKING.

O

ONE-OPERATION STRAND - See SINGLE-OPERATION STRAND.

OPEN SOCKET - A socket comprising a basket and a clevis with a pin.

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

OUTER WIRES - See COVER WIRES.

OVERHAULING WEIGHT - Minimum weight of a block or overhaul ball which enables the load block to lower under its own weight.

OVERWOUND ROPE - See UNDERWOUND ROPE.

P

PARCEL - To cover (as a rope) with strips of canvas.

PEENING - Permanent distortion resulting from cold plastic deformation of the outer wire(s) in a wire rope. This distortion is usually caused by pounding against a sheave or machine member, or by heavy operating pressure between wire rope and sheave, wire rope and drum, or wire rope and adjacent wrap of rope.

PELICAN HOOK - A hook used to provide an instantaneous release. It can be opened while under load by knocking away a locking ring that holds it closed.

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

PITCH - (1) Lay length: 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 BEARING - A bushing usually made of bronze.

PLAIN-FACED DRUM - See SMOOTH-FACED DRUM.

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

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

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

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

PREFORMING - Process in which the strands and wires receive a final helical shape (before closing the wire rope) that matches the helical shape they will assume in the wire rope.

PRESTRESSING - See PRESTRETCHING.

PRESTRETCHING - Subjecting a wire rope or strand to tension prior to its intended application and for an extended period of time sufficient to remove most of the constructional stretch. Also called PRESTRESSING.

R

RADIAL BEARING PRESSURE - Contact pressure exerted by a wire rope on a drum barrel or sheave.

RATED CAPACITY - See RATED LOAD.

RATED LOAD - The maximum load which a component or system is approved to lift (excluding the weight of the hook, block, wire rope, etc.). Also called SAFE WORKING LOAD, WORKING LOAD, or RATED CAPACITY.

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

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

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

RESERVE STRENGTH - The combined strength of all the wires of a wire rope, except those in the outside layer of the outer strands, usually given as a percentage of the nominal strength of the wire 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 clockwise direction of a strand or wire helix in a wire rope or strand.

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

RODDLE - See SADDLE.

ROLLERS - Plain or grooved. Cylinders or wide-faced sheaves for supporting or guiding wire ropes where the length of the arc of contact with the wire rope is less than one lay length of the wire rope.

ROTATION-RESISTANT WIRE ROPE - A wire rope consisting of an inner layer of strands laid in one direction and covered by an outer layer of strands laid in the opposite direction. This has the effect of counteracting torque by reducing the tendency of finished wire rope to rotate. Also called NONSPINNING WIRE ROPE.

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

RUNNER - A hoist rope which runs through a single block at the hook assembly so that the block is free to move or "run" in the bight of the line.

RUNNING RIGGING - A wire rope application which involves a wire rope running over sheaves and drums.

S

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

SAFE WORKING LOAD - See RATED LOAD.

SAFETY CLOSURE DEVICE - A device which bridges the throat opening of a hook to prevent dislodgement of a slack or taut wire rope.

SAFETY FACTOR - See DESIGN SAFETY FACTOR.

SCRUBBING - (1) Displacement of wires from their normal position due to relative motion between strands. (2) Rubbing of wire rope against the sheave, drum groove, or adjacent wraps of the wire rope.

SEALE CONSTRUCTION - A single-operation strand in which two adjacent layers are laid, each layer having the same number of uniformly sized wires. The diameter of the wires in the outer layer is larger than that of the wires in the inner layer.

SEALE-WARRINGTON CONSTRUCTION - A single-operation strand in which the outer layer of alternately large and small wires (Warrington construction) is laid with inner layers of uniformly sized wires in Seale construction.

SEIZE - To bind a wire rope or strand end or two parallel portions of rope securely with annealed wire.

SEIZING - (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 seizing such as over the ends of the tucks on a splice.

SHACKLE - A U-shaped fitting with screw, round, or bolt type pins, used to attach a load to a rope or other lifting equipment.

SHEAVE - A pulley with a rim, used to support, guide, or change the direction of a wire rope in operation.

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

SHEAVE THROAT ANGLE - The included angle of a sheave groove valley.

SHROUD - Standing rigging providing athwartship support for a mast.

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

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

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 single-operation strand. Also called ONE-OPERATION STRAND.

SISAL - A 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 to form a mechanical eye splice.

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

SMOOTH-FACED DRUM - Drum with an ungrooved, plain surface. Also called a PLAIN-FACED DRUM.

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

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

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

SPELTER - Zinc.

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

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

SPOOLING - Winding a rope on a reel or drum.

STABILITY - Resistance of a wire rope to kink, curl, untwist, and tangle.

STANDING RIGGING - Wire rope application in a fixed position such as guy or stay ropes.

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

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

STRAND CENTER - A wire strand used as the center of a strand. Generally it is a 7 wire strand.

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

STRAP - (1) A plate which provides bearing support for the sheave center pin and transmits sheave loads to the fittings and connections of the block. (2) A short line or wire rope having an eye in either end.

SWAGE FITTING - A tubular steel or alloy fitting sized to accommodate one or more parts of wire rope or strand. The fitting is applied by squeezing it onto the wire 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 rotation of wire rope.

T

TACKLE - An assembly of ropes and sheaves arranged for lifting, lowering, and pulling.

TAGLINE - A small wire rope used to prevent rotation of a load or to position a load.

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 - See END FITTING.

THIMBLE - A teardrop shaped ring used in an eye splice to provide a smooth bend in the wire rope, prevent the fittings from wearing through the wire rope and to maintain the shape of the eye.

TOP UP - To raise a boom to a working angle by means of its topping lift.

TOPPING LIFT - Wire rope or tackle used to hoist, lower, and support the head of a cargo boom or the outboard end of a sailing boom or boat boom.

TOWLINE - A fiber or wire rope used to tow a vessel or vehicle.

TRAVELING BLOCK - See LOAD BLOCK.

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

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

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

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 is 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.

U

ULTIMATE BREAKING STRENGTH - See BREAKING STRENGTH.

UNCOATED WIRE - Wire that is not coated with zinc. Also called BRIGHT or BLACK WIRE.

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.

UNLAY - To untwist and separate the strands of a wire rope or the wires of a strand.

V

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

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

VANG - Wire rope or tackle secured to the end of a cargo boom, used to swing the boom and hold it in a desired position.

W

WARRINGTON CONSTRUCTION - 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 of wires, and the small wires are placed on the crowns of the inner layer of wires. The two adjacent layers are laid in a single operation.

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

WHIP - A hoist rope which terminates at the hook assembly.

WHIPPING - 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. Can be dangerous and potentially damaging if the frequency of vibration approximates the natural frequency of the rope system.

WINCH - Machine with one or more drums on which to spool wire rope for 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 DRAWING - Reducing the cross section of a wire or rod by pulling it through a die. Also called COLD DRAWING.

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

WIRE STRAND CORE (WSC) - See STRAND CORE.

WORKING LOAD - See RATED LOAD.

WORM - A wire rope in which the wires in a strand or the strands in a wire rope are hellically laid.

WRAP - Coil of wire rope on a reel or drum.

Z

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.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A

BENDING LOAD IN WIRE ROPES

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A

BENDING LOAD IN WIRE ROPES

Bending Load in Wire Ropes

For wire ropes in full bending, the tensile load in an individual wire in a strand due to bending of the wire rope is given by the following formula:

$$P_i = \frac{\pi d_W^4 \; E G}{16 R r_W [2 G (1 + Sin^2\theta) + E \cos^2\theta]} \qquad (A-1)$$

where,

P_i = tensile load, in pounds, in an individual wire in a strand due to bending of the wire rope. The value of p multiplied by the number of wires in the wire rope gives the total tensile load in pounds in the wire rope due to bending.

d_W = diameter of a single wire, inches

E = modulus of elasticity (28.5×10^6 psi for steel)

G = modulus of rigidity (11×10^6 psi for steel)

R = mean radius of curvature, inches = $\frac{D + d}{2}$

D = tread diameter of sheave or drum, inches

d = nominal diameter of the wire rope, inches

r_W = radius from the center of the strand to the center of the wire in question. When r_W = o, then substitute r_s which is defined as the radius from the center of a wire rope to the center wire of a strand. When the wire rope in question has a strand center, the center strand shall be treated as if it were an outer strand.

θ = angle between the perpendicular to the axis of the wire rope and the tangent to the center line of the wire.

By the use of equation (A-1), a value K_B has been determined so that, for various sizes and types of wire ropes in Navy usage, tensile load in rope due to bending is given by the formula

$$P_B = \frac{2\ K_B}{D + d}$$

where,

P_B = tensile load in wire rope due to bending, pounds

D = tread diameter of sheave or drum, inches

d = nominal diameter of wire rope, inches

The average values of $2K_B$ for 6 x 12, and 6 x 24 class wire ropes are given in Table A-1.

While the individual calculated values of $2K_B$ may vary considerably from the average values given in Table A-1, the resulting error in the overall load in the hoisting rope will be negligible.

TABLE A-1

NUMERICAL VALUES OF $2K_B$

Wire Rope Nominal Diameter (inches)	$2K_B$
	6 x 12, 6 x 24
7/16	2,500
1/2	3,700
9/16	5,300
5/8	7,200
3/4	12,700
7/8	20,000
1	30,000
1-1/8	43,000
1-1/4	60,000
1-3/8	80,000
1-1/2	104,000
1-3/4	163,000
2	248,000