Appendix D

Wire Rope

1.0 General

Data included in this appendix and the section on “Slings, Chains, and Accessories” include general information and specific requirements about the design and construction characteristics of commonly used wire rope and accessories.

1.1 General. Wire rope design and construction characteristics shown in this appendix are for reference only. Manufacturer’s specification data may differ from these and must be used in determining safe working loads and proper application.

1.2 Materials. Wire rope may be manufactured from many grades and types of steel and alloys. They may be constructed from nonferrous materials or coated wires. Some of the more common grades with the differing designations are as follows:

a. Improved plow steel—monitor steel—purple grade—Level 3 steel[1]

b. Extra improved plow steel—monitor AA grade—purple plus—Level 4 steel[1, 2]

1.3 Terminology. Cross section AA.
General view.

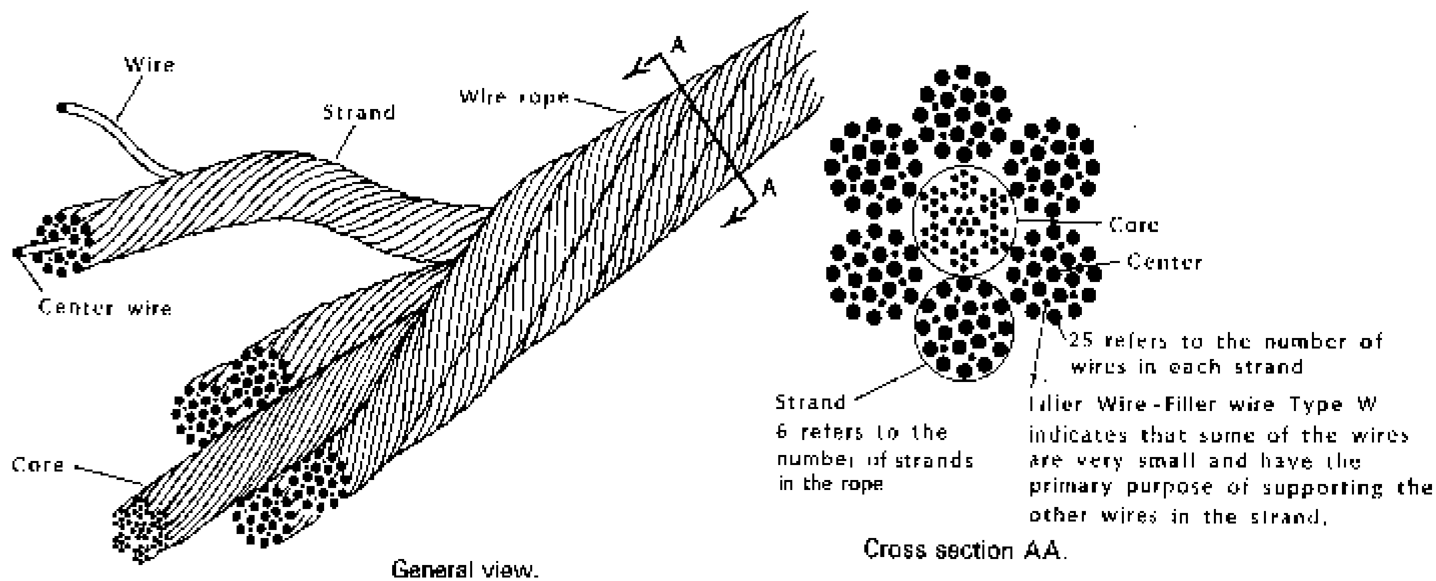
1.3.1 Wire Rope. Figure D-1 shows the general terminology, structure, and cross-sectional views of wire rope.

1.3.2 Cores for Wire Rope. The core is the central member about which the main strands are laid. The principal function of the core is to provide a bearing for the strand. This foundation maintains the proper lateral position of the strands and permits their relative longitudinal motion in adjusting the distribution of stress. Figure D-2 shows the three common types of cores used in wire rope.

1.3.3 Wire Rope Lays. The lay direction of a wire rope is the direction in which the strands rotate around the rope, as seen receding from the observer and viewed from above. The lay direction of outer wires of a single strand is determined in the same manner. Figure D-3 shows the various lay combinations.

[1] These two major grade classifications and corresponding rope breaking strengths may vary with different manufacturer’s and date of manufacturing.

[2] Application of these high strengths should be under the direction of manufacturer or a professional engineer.



General and cross sectional views showing general structure and terminology of wire ropes. Wire rope shown is a class 6×19, of the 6×25 filler wire type W construction. The rope is made up of six 25-wire strands. The strands are each laid 12-6-6-1; that is 12 outer wires, six filler wires, six inner wires, one center wire.

Figure D-1.—General terminology, structure, and cross-sectional views of wire rope.

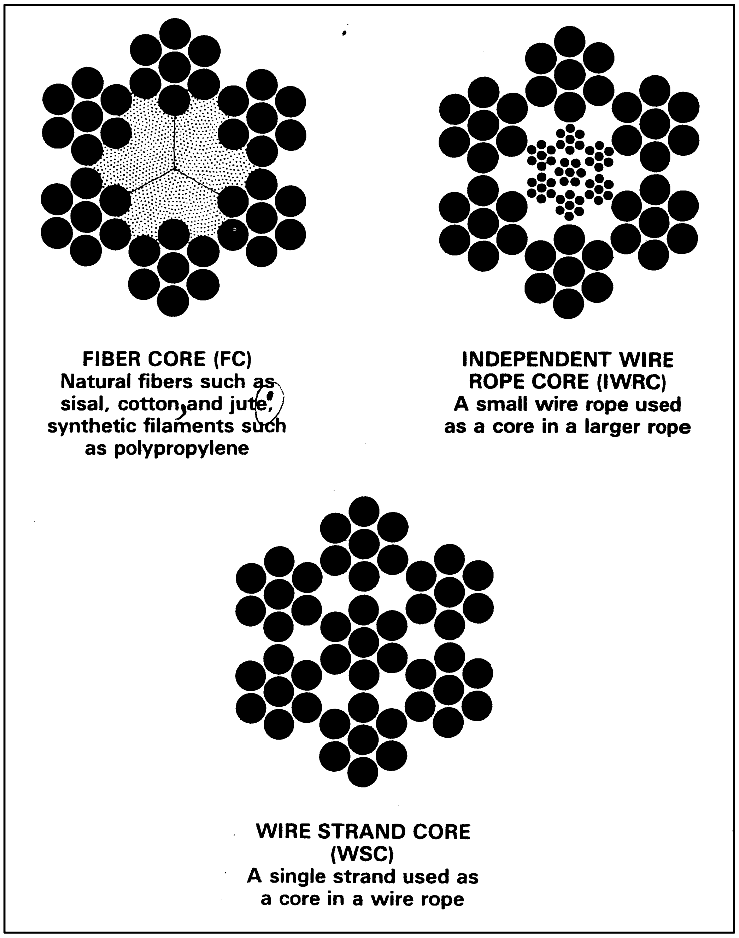


Figure D-2.—Three common types of cores used in wire rope.

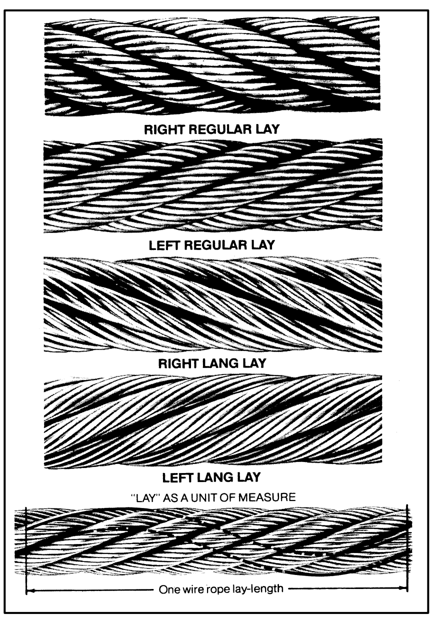


Figure D-3.—Various combinations of wire rope lays.

The lay as a unit of measure is the length a single strand extends in making one complete turn around the rope. Lay length is measured in a straight line parallel to the centerline of the rope; not by following the path of the strand.

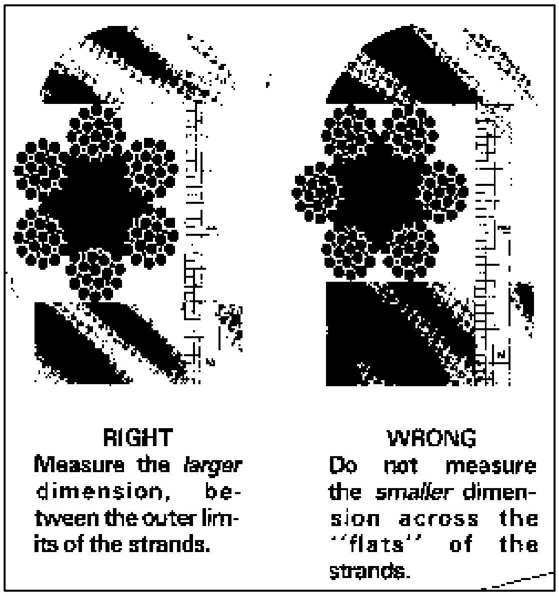


Figure D-4.—Right and wrong way to measure rope diameter.

1.3.4 Rope Diameter. Figure D-4 shows the right and wrong way to measure rope diameter.

1.3.5 Rope Class. Wire rope is designed by class: 6x7 (6 strands, 7 wires); 6x19 (6 strands, 19 main wires per strand); 6x37 (6 strands, nominally 37 wires per strand). When "nominally" is used, the number of wires per strand may vary significantly (i.e., 6x19 nominal may have from 9 to 26 wires per strand).

2.0 Wire Rope End Connectors (fittings, end attachments, terminals)

2.1 General. Choosing proper end connectors (fittings) to be used with wire rope is second in importance only to selecting the rope itself. Connectors are subjected to the same loads as the wire rope used and must be properly designed and built to withstand the stresses imposed on them.

2.2 Wire Rope Clip Connectors. Wire rope clip connectors may use the U-bolt type or the twin base clip ("First" grip, double saddle) type. Use only new clips in making wire rope clip connectors.

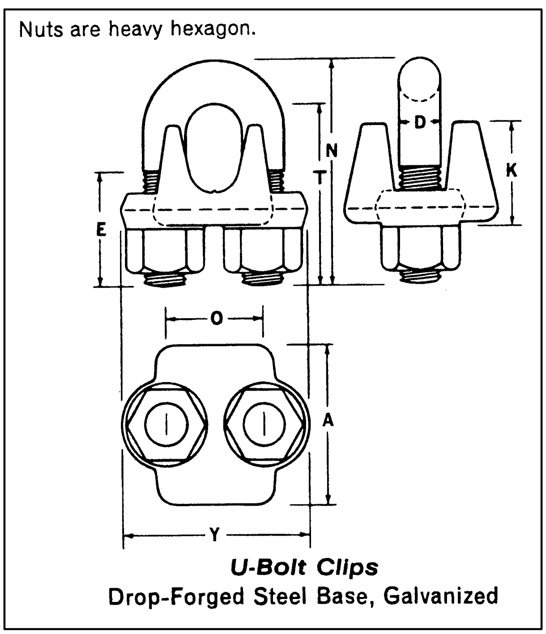


Figure D-5.—U-bolt clip construction details.

2.2.1 U-bolt Type Clip. U-bolt clips shall be constructed of drop-forged steel bases protected by an application of a galvanized zinc coating (see figure D-5). Approximate dimensions and construction details are shown in table D-1.

Table D-1.—Dimensions for U-bolt clips

Rope diameter (inches)	Dimensions (inches)								Approximate weight (pounds)
	A	D	E	K	N	O	T	Y	
1/8	13/16	7/32	7/16	25/64	15/16	16/32	23/32	16/16	.05
3/16	15/16	1/4	8/16	1/2	1-7/32	19/32	31/32	1-5/32	.08
1/4	1-3/16	5/18	5/8	21/32	1-11/32	3/4	1-1/32	1-7/16	.17
5/16	1-5/16	3/8	3/4	23/32	1-11/16	7/8	1-5/16	1-11/16	.30
3/8	1-5/8	7/16	13/16	28/32	1-15/16	1	1-1/2	1-15/16	.41
7/16	1-13/16	1/2	1-1/16	1-1/84	2-3/8	1-3/16	1-7/8	2-8/32	.65
1/2	1-29/32	1/2	1-1/16	1-1/8	2-3/8	1-3/16	1-7/8	2-9/32	.75
9/16	2-1/16	9/16	1-7/16	1-7/32	2-13/16	1-5/16	2-1/4	2-31/64	1.00
5/8	2-1/16	9/16	1-7/16	1-11/32	2-13/16	1-5/16	2-1/4	2-1/2	1.00
3/4	2-1/4	5/8	1-9/16	1-25/84	3-3/8	1-1/2	2-3/4	2-27/32	1.40
7/8	2-11/16	3/4	1-13/16	1-5/8	3-7/8	1-3/4	3-1/8	3-11/32	2.40
1	2-5/8	3/4	2-1/8	1-49/84	4-1/4	1-7/8	3-1/2	3-15/32	2.50
1-1/8	2-13/16	3/4	2-1/4	1-28/32	4-5/8	2	3-7/8	3-18/32	3.00
1-1/4	3-1/8	7/8	2-1/2	2-11/64	5-1/8	2-5/16	4-1/4	4-1/8	4.50
1-3/8	3-1/8	7/8	2-11/16	2-5/16	5-1/2	2-3/8	4-5/8	4-3/16	5.20
1-1/2	3-17/32	7/8	2-13/16	2-23/32	5-13/16	2-19/32	4-15/16	4-5/16	5.90
1-5/8	3-5/8	1	2-7/8	2-21/32	6-5/16	2-3/4	5-5/16	4-3/4	7.30
1-3/4	3-13/16	1-1/8	3-3/16	2-58/64	6-7/8	3-1/16	5-3/4	5-9/32	9.80
2	4-7/16	1-1/4	3-5/8	3-9/32	7-11/16	3-3/8	6-7/16	5-7/8	13.40
2-1/4	4-9/16	1-1/4	4	3-15/16	8-3/8	3-7/8	7-1/8	6-3/8	15.70
2-1/2	4-11/16	1-1/4	4-3/8	4-7/16	8-15/16	4-1/8	7-11/16	6-5/8	17.90
2-3/4	5	1-1/4	4-1/2	4-7/8	9-8/16	4-3/8	8-5/16	6-7/8	22.00
3	5-5/16	1-1/2	5-1/32	5-11/32	10-11/16	4-3/4	9-2/16	7-5/8	30.50

There is only one correct way to attach U-bolt clips to wire rope ends. The base of the clip bears on the live end of the rope; the "U" of the bolt bears on the dead end with a thimble installed in the eye (see figure D-6).

The approximate number of clips and their spacing distance is shown in table D-2 and figure D-7. Consult the clip manufacturer for exact number of clips required and spacing dimensions.

2.2.2 Twin Base Clips. Twin base clips must be constructed of drop forged steel bases protected by an application of zinc coating (galvanized). Approximate dimension and construction details are shown in table D-3. Number of clips and their spacings are the same as shown for U-bolt clips.

Twin-base clips are installed as shown in figure D-8. Because of their special design, there is no top or bottom, and they cannot be installed incorrectly.

Additional information on installation of wire rope clips is in the *Rigging Manual.*

2.2.3 Joining Wire Ropes. Figure D-9 shows an acceptable method for joining wire ropes using a combination of clips and thimbles.

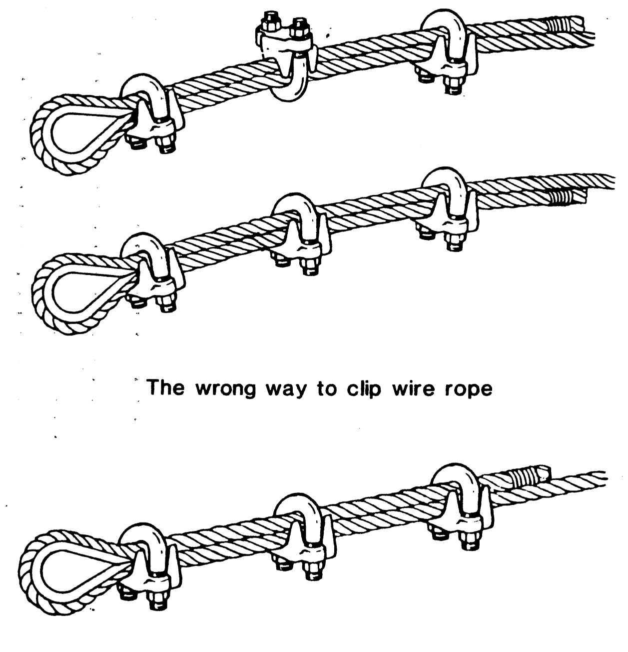


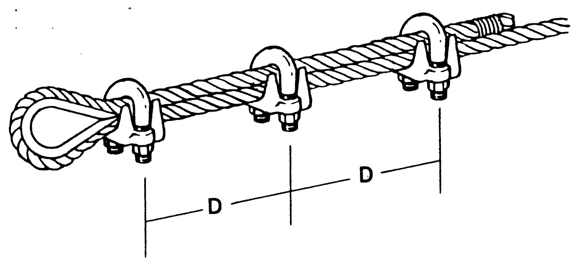
Figure D-6.—Right and wrong way to clip wire rope.

Table D-2.—Dimensions of twin-base clips

Rope diameter (inches)	Dimensions (inches)								Approximate weight (pounds)
	A	B	D	d	J	K	L	N approx	
1/4	15/16	1-1/4	1/4	3/8	1-1/4	21/64	1/2	1-5/8	.21
5/16	1-1/16	1-11/32	5/16	3/8	1-16/32	7/16	5/8	1-15/16	.26
3/8	1-1/16	1-37/64	3/8	7/16	1-13/16	31/64	3/4	2-3/8	.38
7/16	1-1/4	1-7/8	7/16	1/2	2-11/64	9/16	1	2-3/4	.60
1/2	1-1/4	1-7/8	1/2	1/2	2-11/64	9/16	1	2-3/4	.60
9/16	1-1/2	2-8/32	8/16	5/8	2-11/16	11/16	1-1/4	3-1/2	1.08
5/8	1-1/2	2-8/32	5/8	5/8	2-11/16	11/16	1-1/4	3-1/2	1.08
3/4	1-3/4	2-27/64	3/4	5/8	2-3/4	55/64	1-1/2	3-3/8	1.34
7/8	2-1/8	2-61/64	7/8	3/4	3-5/16	31/32	1-3/4	4-1/8	2.20
1	2-1/4	3-1/16	1	3/4	3-23/32	1-3/16	2	4-5/8	2.68
1-1/8	2-5/16	3-3/16	1-1/8	3/4	4-3/32	1-8/32	2-1/4	5	2.96
1-1/4	2-1/2	3-8/16	1-1/4	7/8	4-1/4	1-11/32	2-1/2	5-1/4	4.03
1-3/8	3	4-1/8	1-3/8	1	5-9/16	1-9/16	2-3/4	7	6.58
1-1/2	3	4-1/8	1-1/2	1	5-9/16	1-9/16	3	7	6.58

Diameter of Rope Inches	No. Clips for Each Rope End*
3/16	3
1/4	3
5/16	3
3/8	3
7/16	3
1/2	3
5/8	3
3/4	3
7/8	4
1	4
1-1/8	5
1-1/4	5
1-3/8	6
1-1/2	6
1-5/8	6
1-3/4	6
2	6

Number of Clips



D=6 times rope diameter
Clip Spacing

Figure D-7.—Spacing dimensions for clips.

Table D-3.—Approximate design safety factors for wire rope

Type of service	Approximate safety factors
a. Mobile cranes	
Running ropes	3.5
Standing or pendant lines	3.0
b. Overhead and gantry cranes	5.0
c. Overhead hoists (underslung)	5.0
d. Portal, tower, pillar cranes	
Running ropes	3.5
Standing ropes	3.0
e. Hammer head tower cranes	5.0
f. Power passenger and freight elevators	7-12
g. Rope guided workmen hoist	
Hoist ropes	8.9
Guide ropes	7.0
h. Personnel hoists	8-11
i. Derricks	
Guy	3.0
Hoist	3.5
j. Slings	5.0
k. Material hoists	7.0

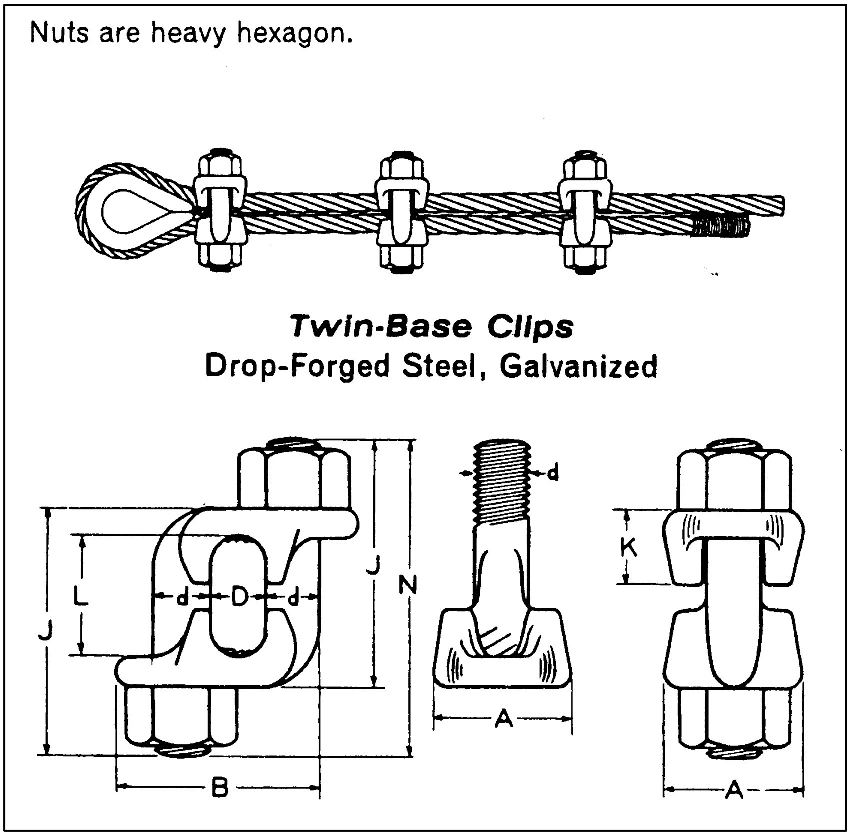


Figure D-8.—Twin-base clip installation.

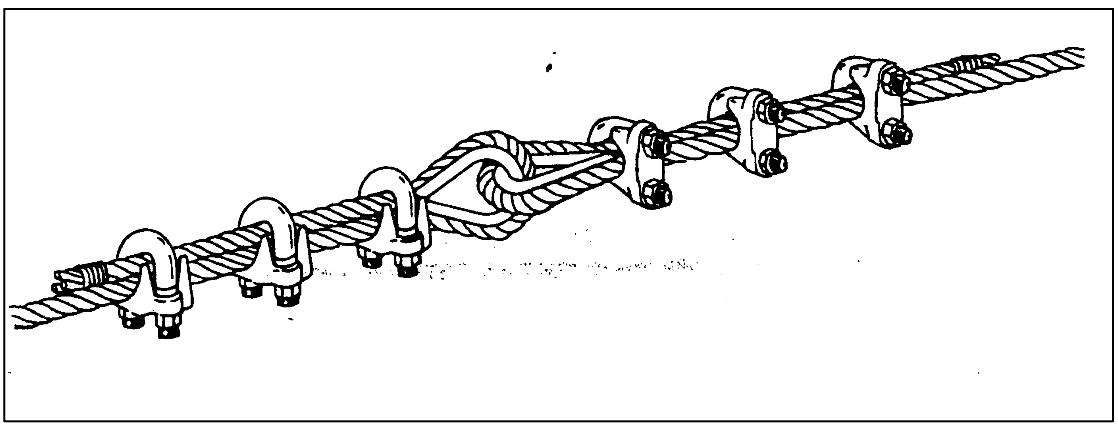


Figure D-9.—Wire ropes joined with clips and thimbles.

2.3 Wedge Socket. The construction industry uses wedge sockets extensively because they attach easily to a wire rope. In applying the socket, the live rope should lead out of the socket in a straight line. Figure D-10 shows a wedge socket. Figure D-11 shows two recommended methods of attaching the socket to the wire rope.

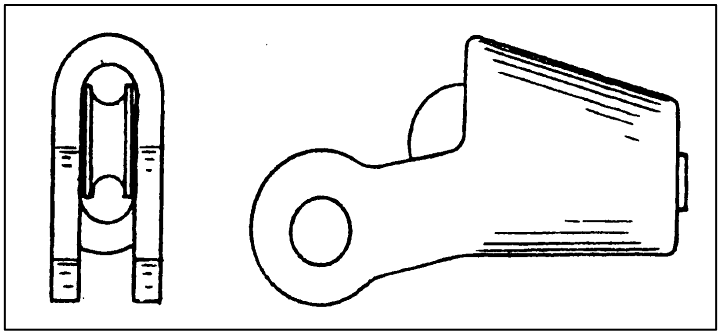
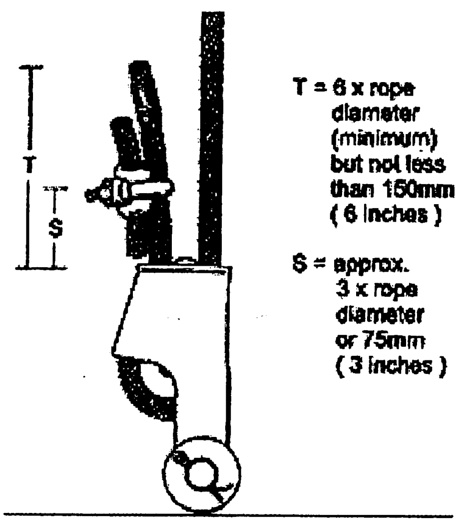


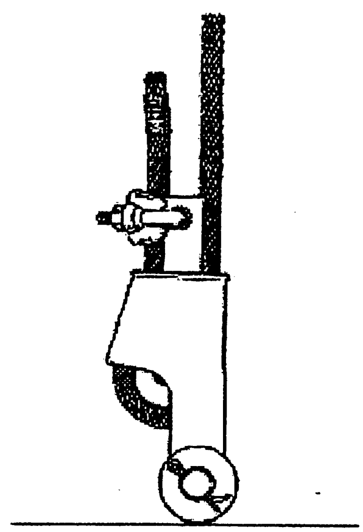
Figure D-10.—Wedge socket.

Method Using a Small Piece Clipped to the Dead End



A small piece of rope is cut and clipped to the dead end. This method is good for regular rope and approved by ASME B30.5. Distance "S" should be approximately 3X rope diameter or 3 inches, whichever is less.

The extended wedge method



In the extended wedge method, the wedge has an extension that accommodates a clip. Once the nuts are torqued, loading of the socket automatically results in proper seating.

Figure D-11.—Two recommended methods of attaching the socket to the wire rope.

Regularly inspect the integrity of the wire rope at the point of exit at the dead-end side. High-velocity spin of wire rope when loading and unloading causes the rope to flip-flop, fatigue, and finally break off. When the wire rope has delivered each one-fifth of service life, remove the portion through the wedge and move the wedge up the rope to a new location.

2.4 Handmade Spliced Eyes. Spliced eyes are frequently used as wire rope end attachments (see figure D-12). They must incorporate rope thimbles to maintain rope strength and reduce wear. Because of the many forms of eye splices and the varying efficiencies, do not use these types of attachments in slings or hoisting operations.

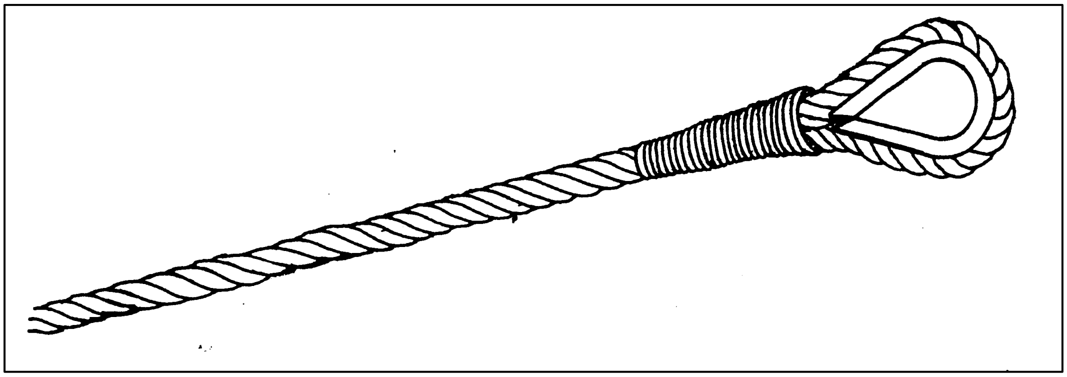


Figure D-12.—Example of a handmade spliced eye.

2.5 Manufactured Eye Splices. Manufactured eye splices, such as flemish eye, flemish eye plus serving, and flemish eye plus pressed metal sleeve are the most efficient attachments and should be considered for all hoisting operations. The zinc and swagged sockets are an excellent attachment for use in permanent nonmovable-type installation such as pendant lines and guy wires. They, like the manufactured eyes, must be constructed by well-trained, qualified personnel to ensure reliability.

2.6 Average Efficiency of Well-Made End Connectors on Terminals

a. Standard open and closed sockets. Attached with pure molten zinc:	100 percent
b. Flemish eye and pressed metal sleeve or swaged sockets on IWRC rope:	100 percent
c. Mechanically spliced eyes:	90 percent
d. Handmade eye splices:	80-90 percent
e. U-bolt clips (drop forged, new):	70-80 percent
f. Cast steel wedge sockets:	70 percent

Note: Percentages relate to rope breaking strength (i.e., a swaged socket has the same strength (100 percent) of the wire rope.

3.0 Common Safety Factors and Maximum (Safe) Working Loads

3.1 Safety Factors. The total stress in a wire rope, in service, is composed of several separate elements. These are reduced to a single tensile load value. When this value exceeds the breaking strength of the wire rope, a failure occurs.

The factor to provide a margin of safety between the applied tensile forces and the breaking strength of the rope is defined as the factor of safety.

Minimum safety factors for wire rope used in different types of service are contained in national standards (i.e., ANSI 17.1 safety code for elevators and escalators, ANSI/ASME B30.5 Mobile and Locomotive Cranes).

Table D-3 shows a partial compilation of approximate design safety factors. Refer to appropriate standards for precise requirements.

3.2 Maximum (Safe) Working Load. Calculate the maximum safe working load of wire rope, dividing the manufacturers' supplied breaking strength by the safety factor.

> ***Example:*** Calculate the maximum safe working load of a single-leg sling made from a 1/2-inch-diameter, 6X19 class wire rope constructed of improved plow steel (purple grade) material with poured zinc fittings and an independent wire rope core (IWRC).
>
> (1) Obtain the breaking strength of the wire rope from the 6X19 class table shown under paragraph 2.4.1 of this appendix (11.5 tons or 23,000 pounds).
>
> (2) Find the appropriate safety factor (5) for slings from table D-3 or from subsection 17.4 of the text.
>
> (3) Divide the breaking strength (23,000 pounds) by the safety factor (5) to obtain the maximum (safe) working load (4,600 pounds).

$$\text{Max (safe) working load} = \frac{23{,}000 \text{ pounds}}{5} = 4{,}600 \text{ pounds} \quad (1)$$

Conversely, to determine the actual safety factor under any condition of loading, multiply the rope breaking strength by the number of parts of line under load and divide this product by the actual working load.

> ***Example:*** Using a 1/2-inch-diameter, 6X19 class wire rope with the breaking strength shown, in a two-part line hoisting operation with a maximum load including weight of blocks, hooks, etc., of 9,200 pounds, calculate the actual safety factor.

$$\frac{23{,}000 \text{ pounds X } 2}{9{,}200 \text{ pounds}} = \frac{46{,}000 \text{ pounds}}{9{,}200 \text{ pounds}} = 5 \text{ safety factor}$$

Note: Consult the table of required safety factors or specify safety factor requirements contained in national standards to determine what type of service this specific hoisting system can be used for. In any service requiring a safety factor of 5 or less, the system would be satisfactory. In any system requiring a safety factor greater than 5, the system would be unsatisfactory.

Exercise caution in using this simplified method of calculation as some dynamic forces may need to be included in the maximum loading figure. Also, other factors such as sheave diameters, friction losses, hot environments, etc., may require higher safety factors.

4.0 Inspection and Retirement of Wire Rope

Eventually, all wire ropes deteriorate to the point that they are no longer safe for use. The frequency of inspections, the extent of the inspection, and the criteria for condemning wire ropes vary greatly for each type of service. Inspection frequencies and rope retirement criteria are usually found in specific national standards. If no standards exist for the type of service anticipated, the rope or equipment manufacturer or a professional engineer must develop the criteria. In no case shall the rope retirement criteria allow rope to be continued in any hoisting or load carrying service when one or more of the following deficiencies exist:

(a) Ropes are not of proper size, grade, or construction for the particular performance or function.

(b) In running ropes, six randomly distributed broken wires in one rope lay, or three broken wires in one strand in one rope lay. (A rope lay is the length along the rope in which one strand makes a complete revolution around the rope.)

(c) In pendants or standing ropes, evidence of more than one broken wire in one lay.

(d) Abrasion, scrubbing, or peening causing loss of more than one-third of the original diameter of the outside wires.

(e) Evidence of severe corrosion.

(f) Severe kinking, crushing, or other damage resulting in distortion of the rope structure.

(g) Evidence of any heat damage from a torch or arc caused by contact with electrical wires.

(h) Reduction from nominal rope diameter of more than 3/64 inch for diameters up to and including 3/4 inch; 1/16 inch for diameters 7/8 to 1-1/8 inches; and 3/32 inch for diameters 1-1/4 inch to 1-1/2 inches. Marked reduction in diameter indicates deterioration of the core, resulting in lack of proper support for the load carrying strands. Excessive rope stretch or elongation may also indicate internal deterioration.

(i) Evidence of “bird caging” or other distortion resulting in some members of the rope structure carrying more load than others.

(j) Noticeable rusting or development of broken wires in the vicinity of attachments.

See separate appendix on “Slings” for retirement criteria for wire rope used in slings.