Chapter 2
Rope Construction and Materials

Wire rope consists of multi-wire strands laid helically around a core (Figure 2-1). The way the wires are laid to form the strands, the way the strands are laid about the core, the core construction, and the materials and coatings used for the components contribute to the overall properties of the rope. The following sections discuss rope properties in regard to construction and materials. They do not cover all the available types of wire rope, but attempt to cover the types applicable to gate-operating devices.

2-1. Classification

a. Designation method. Wire rope classification is designated by the construction of the rope as seen in cross section. The number of strands and the number of wires in each strand are respectively given in its label, for example: 6x19, 6x37, 7x19, 8x61, etc. (Figures 2-2 and 2-3).

b. Strand configuration. Note that the nominal classifications may not reflect the actual construction. For example, the 6x19 classification includes 6x21 Filler Wire, 6x19 Seale, and 6x26 Warrington Seale constructions. The terms Filler Wire, Seale, Warrington, and Warrington Seale refer to the layers and the configurations of the strands (Figures 2-4 and 2-5). Note that for the Seale configuration, the wires in any layer of the strand are of equal diameter. For the Warrington configuration, the wires of the outer layer of the strand are of two different diameters. The Warrington Seale configuration is a blend of the Seale and Warrington configurations. The outer layer has equal diameter wires and the next layer inward has wires of two different diameters. For the Filler Wire configuration, all the main wires of each strand are of equal diameter like the 7-Wire configuration. However, extra wires of a small diameter have been added between the main wires. Compared to the 7-Wire configuration, the more complicated configurations result in strands which are more stable, flexible, and less likely to collapse under load.

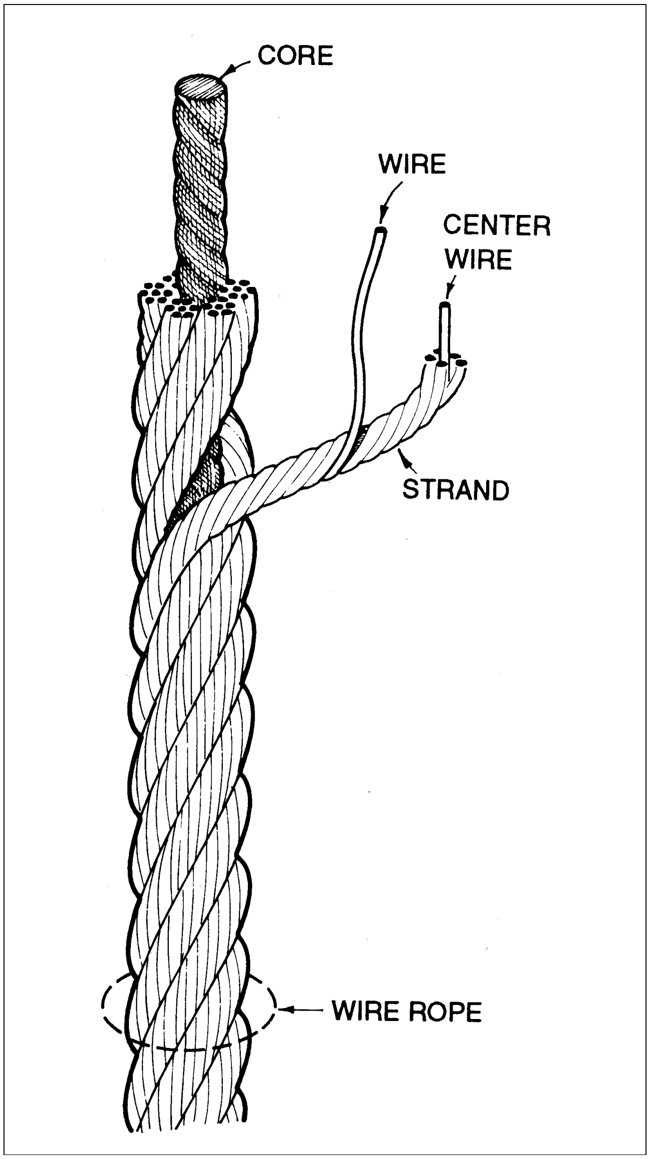

Figure 2-1. The three components of a typical wire rope

c. Rope properties. Important characteristics of wire rope relate to the number and size of the outer wires, and to a lesser extent, the inner wires. A small number of large outer wires results in better resistance to wear and corrosion. A large number of small wires results in better flexibility and resistance to fatigue. Section 4-6, “Service Life” gives data on rope classification versus service life. Figure 2-6 is referred to as the “X-chart” by the wire rope industry. It shows an inverse relationship between abrasion resistance

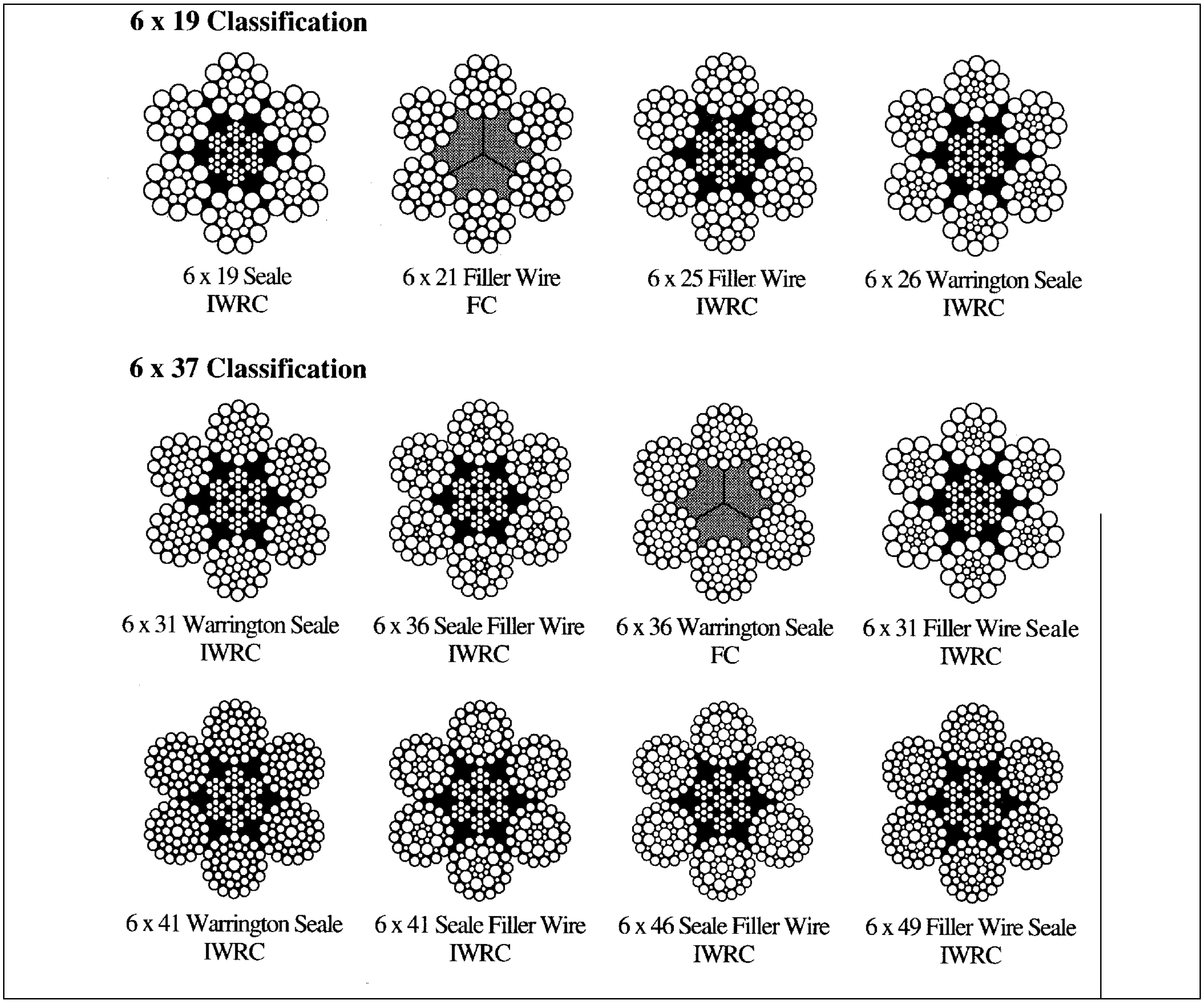

Figure 2-2. Six-strand classes

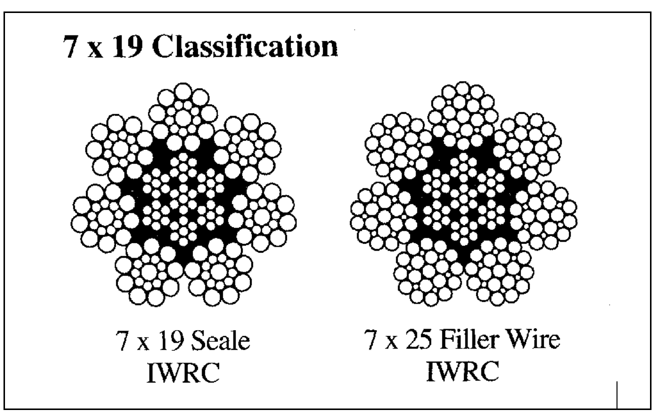

Figure 2-3. Seven-strand classes

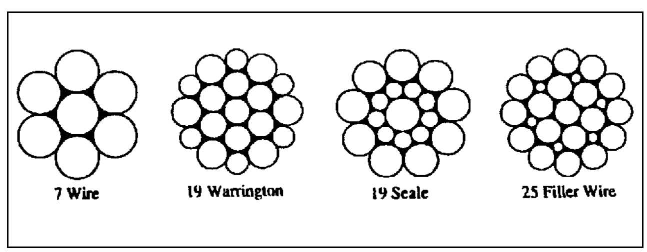

Figure 2-4. Basic strand patterns

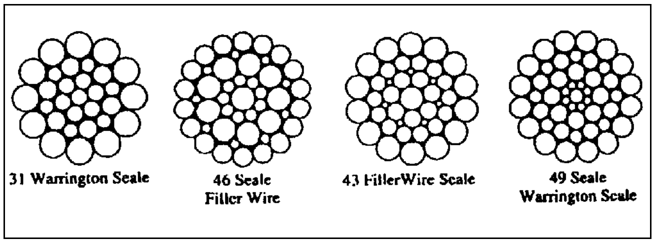

Figure 2-5. Combination strand patterns

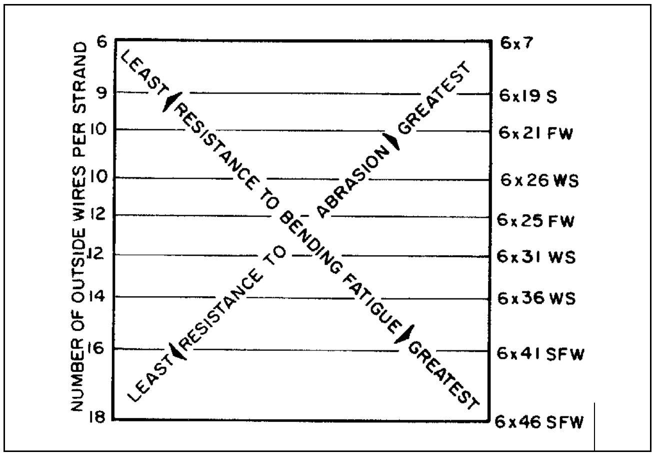

Figure 2-6. The X-chart as referred to by the wire rope industry

and resistance to bending fatigue for some widely used wire rope constructions. For many installations, both wear and fatigue may be a concern, which would require a compromise. Engineering judgment in considering the application is needed to determine the trade-off between fatigue resistance and wear resistance. Strength also varies somewhat with classification and is shown in Appendix C. Note that just as the classification (number of strands x number of wires per strand) is a relative indication of wire size, so is strand configuration. For example, a strand of the Filler Wire configuration will likely have some wires of a much smaller diameter than any of the wires in a strand of the Seale configuration.

d. Classifications for gate-operating devices. It is impossible to present here an all-inclusive list of wire rope classifications suitable for gate-lifting devices. However, 6x37 has long been considered appropriate by most manufacturers for lifting devices. Past guidance for Tainter gate design called for 6x25 type B flattened strand rope. Gate-lifting devices have frequently used 6x37 Fiber Core (FC) and 6x30 Independent Wire Rope Core (IWRC). This does not suggest that any of these classes will be the best engineering choice for any particular device, but they would normally be among the first ones considered in the engineering analysis. Note that in considering the initial selection, it may be wise to keep wires in a manageable size. That can be done by considering both construction and strand configuration. In regards to construction, if a device uses a very small diameter rope, say 16 mm (5/8 in.), initially consider a construction such as 6x7. If a device uses a medium diameter rope, say 32 mm (1-1/4 in.), initially consider a construction such as 6x19. If a device uses a large diameter rope, say 64 mm (2-1/2 in.), initially consider a construction such as 6x37. In this way, a small rope would have relatively large wires and large rope would have relatively small wires. The wires tend to be relatively constant in size through a large range of rope size. The characteristics of the wires in regards to abrasion and corrosion would be similar. In regards to strand configuration, note that strands with a Warrington Seale configuration have relatively small inner wires. This configuration may be appropriate for a large rope, say 52 mm (2 in.). However, strands with a Seale configuration, have relatively large inner wires which may be more appropriate for a small rope, say 26 mm (1 in.). Again, but to a lesser extent, the wires tend to be relatively constant in size through a range of rope size. Finally, note that the Filler Wire strand configuration is not applicable for rope for gate-lifting devices. This is because its filler wires are so relatively small, that even in very large ropes, their absolute size is too small. The small wires are unsatisfactory because of corrosion concerns.

2-2. Lay

a. Designation method. The lay of a wire rope is designated by direction and type (Figure 2-7). Direction is right or left according to how the strands have been laid around the core. The lay type is either regular or lang, depending on whether the wires in the strands are laid in the opposite direction of the strands or the same direction as the strands.

b. Right versus left lay. Right lay rope is standard. If lay direction is not designated, right lay is

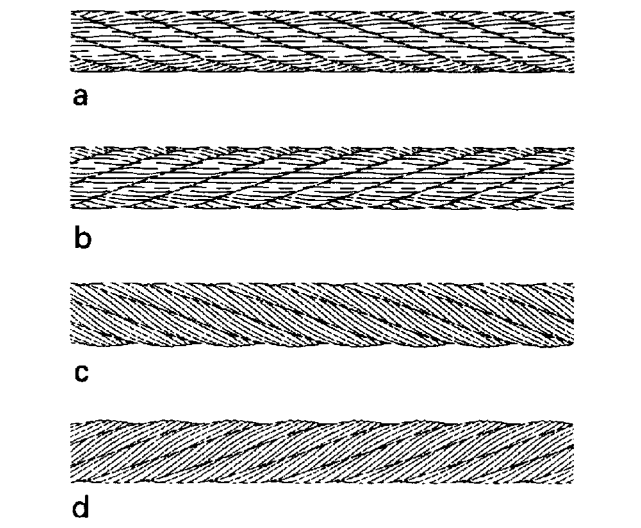

Figure 2-7. Direction and type of lay: (a) right regular lay, (b) left regular lay, (c) right lang lay, and (d) left lang lay

drum. If the correct lay is not used in this case, the rope will not wind smoothly against its previous wrap.

c. Regular lay versus lang lay. The wires in regular lay wire rope appear to line up with the axis of the rope. In contrast, the wires in lang lay wire rope appear to form an angle with the axis of the rope. Regular lay wire rope is used for the widest range of applications. It has a somewhat better resistance to crushing than lang lay wire rope and does not rotate as severely under load when used in an application where either end of the rope is not fixed. Lang lay wire rope has two important advantages. It has better resistance to both fatigue and abrasive wear. Lang lay rope has a longer exposed length of exterior wires. Bending of lang lay rope results in less axial bending of the outer wire, but greater torsional flexure. Overall, lang lay wire rope displays a 15 to 20 percent superiority in service life over regular lay when bending is the principal factor affecting service life. Also, because of the longer exposed length of the exterior wires, the ropes are exposed to less pressure which decreases the rate of abrasive wear on wires, drums, and sheaves (Figures 2-8 through 2-10). There is no difference in breaking strength between lang and regular lay rope.

d. Rope lay in Corps applications. Most of the wire rope used for Corps gate-operating devices is of

Figure 2-8. The difference in wear characteristics of lang lay and regular lay ropes

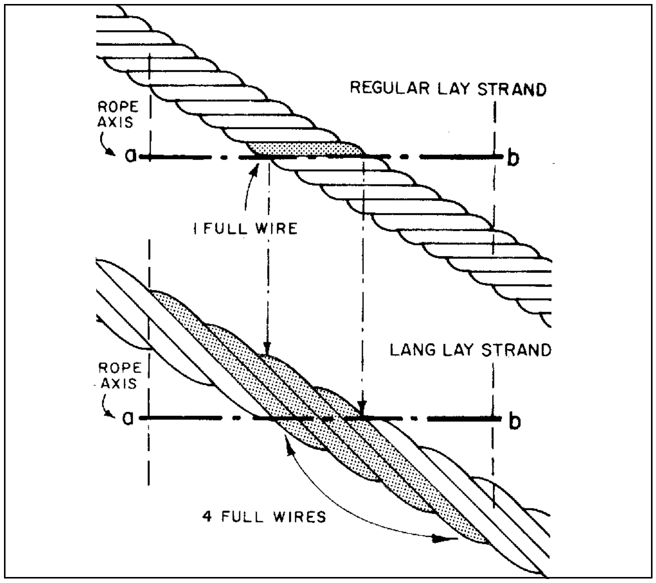

Figure 2-9. Wire direction of lang versus regular lay rope

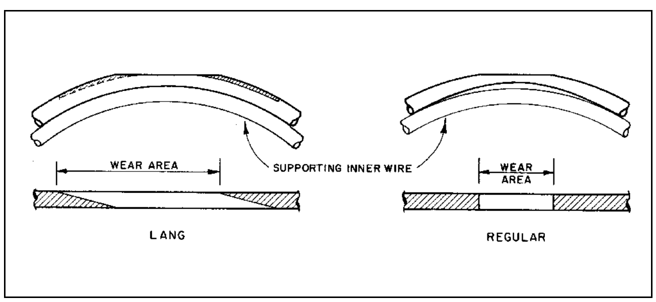

Figure 2-10. Bearing/wear areas of lang lay versus regular lay rope

the regular lay type. However, many installations would be better served with lang lay ropes. A lang lay replacement should be considered for any regular lay wire rope which has failed due to wear or fatigue.

Lang lay wire rope is potentially more prone to kinking and underlaying or opening up. Therefore, a rope tensioning device such as a turnbuckle may be appropriate on gates where lang lay ropes are used.

2-3. Special Shaping of Ropes/Strands

a. General. Manufacturers vary rope from the standard round wire and round strand configurations to enhance some of its properties. The variations covered in this section are (1) compacted strand wire rope, (2) swaged (compacted) wire rope, and (3) flattened strand (triangular) wire rope (Figures 2-11 through 2-13). Manufacturers should be consulted when specifying specially shaped rope to verify that all the characteristics of the special shape are consistent with the needs of the application.

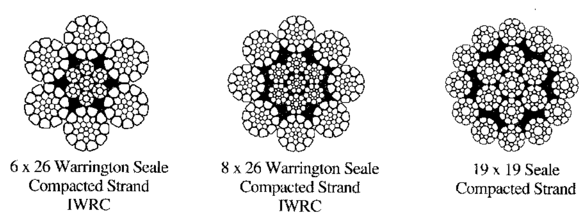

Figure 2-11. Compacted strand wire rope cross sections

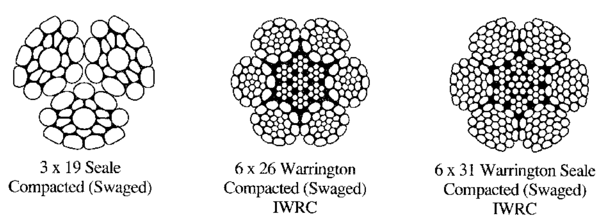

Figure 2-12. Compacted wire rope cross sections

b. Compacted strand wire rope. Compacted strand wire rope is manufactured from strands which have been reduced in diameter by one of several swaging processes. The outer surfaces of the outer strand wires are flattened and the internal wires are no longer round. Compared to a standard wire rope of the same diameter, a rope of the compacted strand configuration has a greater cross-sectional area of metal. This results in higher strength and less resistance to fatigue. It has a smoother surface which makes it more abrasion resistant, but it is less corrosion resistant for two reasons. First, its smoother surface is less able to hold lubrication. Second, the swaging process used to form the strands is not compatible with stainless steel, which is the material of choice for corrosion resistance.

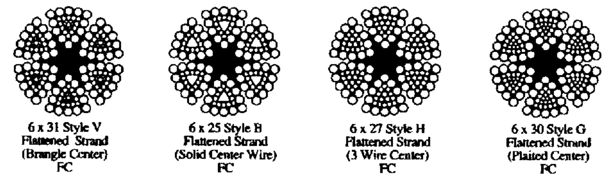

Figure 2-13. Flattened strand wire rope cross sections

c. Swaged (compacted) wire rope. A standard IWRC wire rope is used to form compacted wire rope. Its entire cross section is reduced in diameter, usually by rotary swaging. Compared to a standard wire rope of the same diameter, it has a greater cross-sectional area of metal and flatter wires on the outer surface. The smooth outer surface provides good wear resistance. It is also stronger and more resistant to crushing, but fatigue life is reduced by the compacting process. Like compacted strand rope, it is less corrosion resistant for the same reasons.

d. Flattened (triangular) strand wire rope. Flattened strand wire rope features strands which are triangular in shape. The center of the strands consist of either a triangular-shaped wire or of wires laid in a triangular configuration. Compared to a standard wire rope of the same diameter, it has a greater cross-sectional area of metal and an increased bearing surface. Strength, abrasion resistance, and resistance to crushing are enhanced with the flattened strand configuration. Fatigue resistance is unaffected. Flattened strand wire rope can be obtained with either FC or IWRC and is usually furnished in lang lay. This variation is compatible with stainless steel, which makes it the most useful of the special shapes for gate-operating devices.

2-4. Flat Rope

A number of older Corps installations use flat wire rope for gate-operating devices. Flat rope is always layered over its drum and has generally provided satisfactory service. However, it is expensive to manufacture and requires a long lead time. Expertise in fabricating flat rope is no longer available. When flat rope is retired, it is normally replaced with round rope, along with modifications to the hoisting equipment. See Section 5-3, “Availability/Cost.”

2-5. Wire Materials

a. Steels.

(1) Carbon steels. The grades of carbon steel wire rope are Traction Steel (TS), Plow Steel (PS), Improved Plow Steel (IPS), Extra Improved Plow Steel (EIPS), and Extra Extra Improved Plow Steel (EEIPS). Of these, only EIPS and EEIPS are normally specified for gate-operating devices. TS is normally used for elevators. PS and IPS ropes are nearly obsolete and are seldom stocked or fabricated by manufacturers. EIPS is much stronger than TS and has similar toughness. EIPS carbon steel rope is stronger than the stainless steels and has better resistance to abrasive wear.

(2) Stainless steels. Of the stainless steels available, only types 302 and 304 have been used regularly on gate-operating devices. Any other stainless steels would be experimental. A 10 to 15 percent loss of strength is typical compared to the IPS and better carbon steels. Stainless steels are not as resistant to abrasive wear and are susceptible to galling when layered over sheaves. Since they are not magnetic, inspection by the electromagnetic (non-destructive) method is not possible. The stainless steels are many times more corrosion resistant than the carbon. However, it is important to note that the stainless steels have a different galvanic potential than the carbon steels. When using stainless steel rope, it is possible to set up a galvanic corrosion cell in which carbon steel sockets, rope fittings, or other equipment rapidly corrode. See Sections 3-2, “Materials/Coatings and 7-6, “Cathodic Protection.”

b. Brass/bronze/monel. The non-ferrous metals are more corrosion resistant in salt water than the steels but are susceptible to rapid abrasion. They would rarely be applicable for Corps of Engineers gate-operating devices.

c. Kevlar. At Corps installations where the water has proven to be very corrosive to the submerged portions of wire ropes, Kevlar replacement ropes have given satisfactory results. Kevlar's properties are very different from steel for abrasion resistance, crushing resistance, and elasticity. Kevlar wires are very susceptible to abrasion damage and they must be protected with a jacket, usually of a polyethylene material. The jacket reduces the usable cross section of the rope, but a jacketed Kevlar rope has about the same breaking strength as a stainless steel rope of the same diameter. This strength makes it possible to attain normal factors of safety with Kevlar replacement ropes. Because of the jacket, inspection is difficult compared to bare metal wire rope. However, a change in appearance does occur prior to failure. Kevlar rope, when used with multiple layered type drums soon crushes from a round shape to an almost square shape, but does not lose its integrity. Kevlar rope stretches about two times as much as steel under a full load. Therefore, it stores more energy and a rope breakage will release more energy. A higher degree of personnel protection should be considered where Kevlar rope is used. (See Appendix F for information on Kevlar rope.)

2-6. Core Materials

a. General. As previously stated, wire rope consists of multi-wire strands laid helically around a central core. The core contributes very significantly to the overall properties of the rope. There are two types of cores, Fiber Core (FC) and Independent Wire Rope Core (IWRC).

b. Fiber core (FC). The core in FC wire rope provides no real strength for either crushing or tension. The fiber tends to dampen out vibration, an advantage for some applications, such as elevators. FC is more flexible than IWRC, but flattens under load, inhibiting the free internal adjustment of the wires, which increases stresses. In the past it was thought that its core had a significant lubricant holding ability. That is not presently considered a real advantage. FC wire rope is not well suited for gate-lifting devices.

c. Independent wire rope core (IWRC). The advantages of IWRC are its strength in tension and its resistance to crushing. Its only disadvantage is decreased flexibility. Since bending around drums and sheaves at high loads is required for most gate-operating devices, IWRC wire rope is generally preferred for these applications.

2-7. Coating/Filling/Plating

a. General. In general, galvanized carbon steel rope is the only plated, filled, or coated metal rope suitable for gate-operating devices at Corps installations. The plastic-filled and plastic-coated ropes have certain disadvantages in regards to corrosion and inspection.

b. Plastic-filled. Plastic-filling helps prevent abrasion as the individual wires move relative to each other. However, concentrated corrosion cells will form at the exposed wires in a wet environment making plastic-filled rope unsatisfactory for gate-operating devices.

c. Plastic-coated. Plastic-coated rope is difficult to inspect. Also, the coating soon wears off making it similar to a plastic-filled rope.

d. Galvanized steel. Galvanized carbon steel rope can be manufactured in several ways. It can be weaved from either galvanized rope wire or from drawn galvanized rope wire. Galvanized rope wire is zinc-coated to the finished diameter by either the hot dip process or by the electro-deposition process. Since the diameter of the steel wire is reduced, and the zinc has little strength, a wire rope galvanized in this manner has about a 10 percent reduction in strength compared to one of bare steel. Drawn galvanized rope wire is zinc-coated, by either the hot dip process or by the electro-deposition process, before its last drawing operation. A wire rope galvanized in this manner has the same strength as one of bare steel. It is also possible to zinc-coat a rope after weaving. A rope galvanized in this manner would have no reduction in strength compared to one of bare steel. Either of the last two galvanizing methods would be preferable to the first for gate-operating devices. Galvanized carbon steel rope is generally very corrosion resistant compared to bare carbon steel rope, at least until the zinc coating disappears. Rate of zinc loss can be very high in industrial areas because of airborne pollution. Galvanized rope is much lower in cost than stainless steel (See Section 5-3, "Availability/Cost"). It is also stronger than stainless steel if manufactured from drawn galvanized rope wire. In addition, it is less susceptible to damage from nicks and does not have the galling problems of stainless steel.

2-8. Manufacturing

This section presents information on various rope manufacturing processes.

a. Stress relief. Newly woven wire rope is normally run through molten lead to relieve stresses in the wires resulting from the various drawing, preforming, and swaging processes. If not stress relieved, the fatigue life of the rope is shortened.

b. Pre-stretching. Wire rope normally stretches more rapidly when new than it does as it ages. Pre-stretching is an operation which takes most of the initial stretching out of the rope. It can be accomplished economically if performed in conjunction with socketing. Pre-stretching is recommended for installations with multi-rope drums, where the ropes need adjustment for equal tension. If pre-stretching is not performed, the ropes may tend to stretch unequally in use and may need to be periodically re-adjusted. See Sections 6-3, "Installation" and 4-7, "Rope Length/ Stretch." The normally accepted procedure for pre-stretching wire rope is as follows. The rope is subjected to three cycles of tensile loading to 40 percent of its nominal strength. The 40 percent loads are held for 5 minutes with 5 percent loads between cycles. There is no standard yet established for dynamic pre-stretching, but there may be in the future. This has been performed by tensioning a rope at 20 percent of its nominal strength while operating over pulleys. This process appears to be difficult to specify, but it may be an option to consider.

c. Weaving. The whole weaving process is somewhat of an art as far as wire shaping, preforming, determining the exact wire sizes and spool rotation, and performing welding methods. Including weaving criteria in specifications may be very difficult.

d. Blending wires. Manufacturers occasionally mix stronger wires in with weaker wires (in the same rope) in order to meet minimum acceptance strength requirements. This is common and usually does not present a problem to the buyer. Although the resulting blend meets the required strength criteria, the stronger wires may be less fatigue resistant than the weaker ones and may potentially cause the rope to degrade faster if its prime failure mode is fatigue. If the wire properties are more uniform, that is, if they are of the same strength and meet a minimum ductility requirement, the potential of a fatigue failure may be postponed, increasing service life. Standard procedures for strength testing rope wires for ductility (torsion) are included in Appendix C. Note that the cost of a rope may increase if the wires are required to have both a minimum strength and a minimum ductility.

e. Preforming. Almost all wire rope sold in the United States have preformed wires. Preforming methods differ with different manufacturers. Preforming is normally performed, even if not specified by the buyer. It should be included as a requirement in the rope specifications. Wire rope without preformed wires has tendency to unravel, especially if any individual wires break. Rope with preformed wires has greater flexibility, and it spools more uniformly on a drum. Preforming also provides a better distribution of the load to every wire which improves fatigue resistance and flexibility.