Integrity of Large Steel Wire Ropes

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Abstract

Steel wire rope forms an important part of many machines and structures. The mechanical properties of a steel wire rope result from the individual wires and their arrangement or construction. Unlike most other metallic components, rope wires are stressed alternately in tension, compression, torsion, and shear. The wires and strands are designed to slide in relation to each other, distributing the complicated applied stresses more effectively. Therefore, wire ropes require prudent inspection, maintenance, lubrication, and periodic replacement.

This article provides general information on steel wire ropes, guidance on their care and maintenance and the process of determining the limit of degradation for discard of wire ropes.

1. Introduction

A wire rope consists of many wires twisted to make a complex structure combining axial strength and stiffness with flexibility in bending.

Modern ropes are available in a wide range of constructions. They can have different levels of helical complexity and wires of different diameters in combinations to achieve an acceptable performance in a wide range of applications.

1.1 Description

A wire rope is made up of the basic components illustrated in Figure 1.

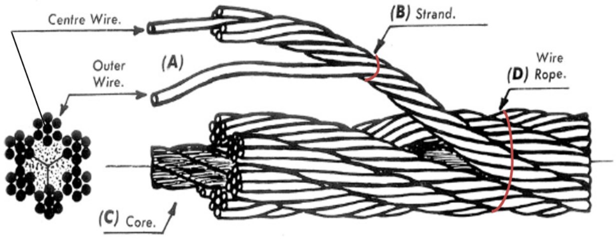


Figure 1 – Composition of Wire Rope

The term "wire ropes" includes strands and wires. Strand is a group of wires laid helically in successive lays over a straight central wire (Figure 1). Wire rope, on the other hand, consists of (typically) six strands laid helically over a central core, which may consist of twisted fibre or a smaller independent wire rope.

The reliable and efficient behaviour of a wire rope and its durability under a given set of working conditions are largely governed by the following constructional features of the rope:

- The size, number and arrangement of the strands in the rope;
- The size, number and arrangement of the wires in the strands;
- The grade of steel in the wire ropes;
- The type of core used;
- The type, direction, and length of rope and strand lays; and
- The method of fabrication used in the manufacture of the rope.

In summary, the properties of a wire rope are derived from its size (rope diameter size), construction (rope components and arrangement), quality (rope tensile strength grade), lay and type of core. Different configurations of the material, wire, and strand structure will provide different benefits for the specific lifting application, including:

- Strength
- Flexibility
- Abrasion resistance
- Crushing resistance
- Fatigue resistance
- Corrosion resistance
- Rotation resistance

1.2 Rope Size

Ropes are referred to by a diameter size. The correct way to measure wire rope is as shown in Figure 2. The true or actual diameter of a wire rope is the diameter of a circumscribed circle that will enclose all the strands.

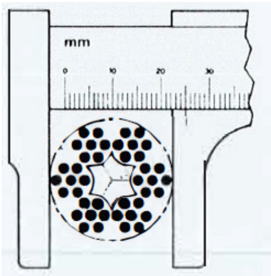


Figure 2 – Correct Method of Measuring Wire Rope Size

1.3 Rope Construction

The construction of a rope for any given application should be suited to the equipment and to the conditions under which it will operate.

In general, having many small size wires and strands produces a flexible rope with good resistance to bending fatigue.

1.3.1 Rope Construction Terms

Figure 3 shows an example of wire rope construction. In this example, each individual wire is arranged around central wire to form a 7-wire strand. Six of these strands are formed around a central core to make a wire rope. The rope is then specified as 6x7 (6/1) - i.e. six strands each of seven wires (six outer strands / one core).

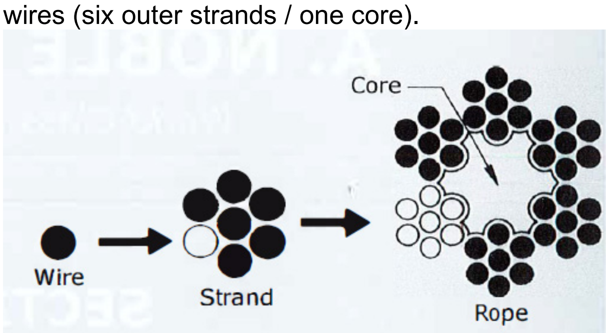


Figure 3 – 6x7 Rope Construction

Various rope construction examples can be found below.

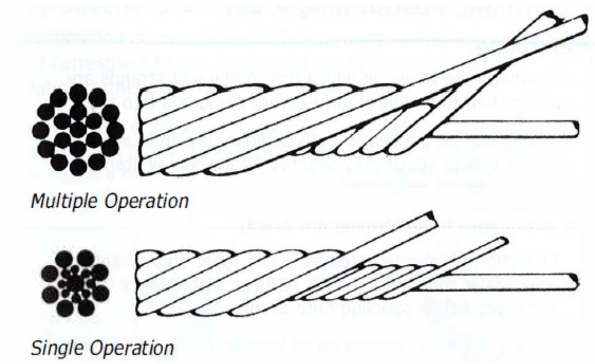


Figure 4 – Various Rope Construction Examples

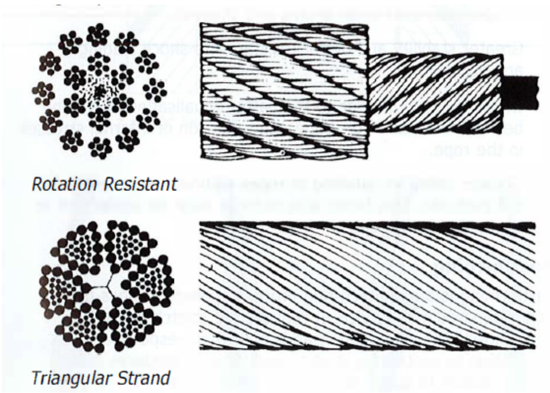


Figure 4 – Various Rope Construction Examples (Cont.)

1.4 Rope Quality

Wire ropes are usually supplied in the following tensile ranges:

Table 1 – Tensile Strength Grades

Rope Grade	Range of Wire Tensile Strength Grades [N/mm^2]
1570	1370 to 1770
1770	1570 to 1960
1960	170 to 2160
2160	1960 to 2160

1.5 Rope Lay

This refers to the way the wires in the strands, and the strands in the rope are formed into the completed rope.

The term “lay” is used in three ways:

1. Strand lay direction – the direction in which the strands are laid (right-hand or left-hand);

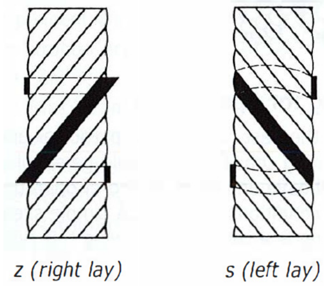


Figure 5 – Right (small z) or Left Lay (small s) Direction of Strands

Lay direction of strands is right (z) or left (s) and correspond to the direction of lay of the outer wires in relation to the longitudinal axis of the strand.

2. Rope lay direction – the manner in which the wires in the strands and the strands in the ropes are laid together to form the finished rope (Ordinary or Regular lay or Lang’s lay)

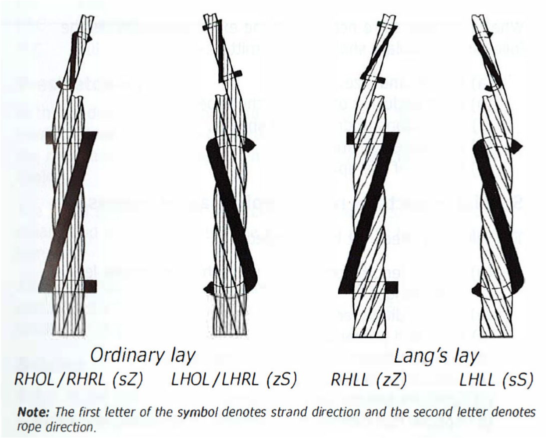


Figure 6 – Ordinary and Lang's Lay for Finished Rope

Lay direction of ropes is right (Z) or left (S) and correspond to the direction of lay of the outer strands in a stranded rope in relation to the longitudinal axis of the rope. Ordinary (or regular) lay is when the strand and rope lay directions are opposite. Lang's lay is when the strand and rope lay directions are the same. The lay direction of ropes can be described as below in Table 2 and is illustrated in Figure 7.

Table 2 – Final Lay Description

Abbreviation	Lay Description**
RHOL/RHRL (sZ)*	Right Hand Ordinary Lay / Right Hand Regular Lay
LHOL/LHRL (zS)*	Left Hand Ordinary Lay / Left Hand Regular Lay
RHLL (zZ)*	Right Hand Lang's Lay
LHLL (sS)*	Left Hand Lang's Lay

**The first letter of the symbol denotes strand direction and the second letter denotes rope direction.*
*** The "right hand" and "left hand" description is dependent on the lay direction of the finished rope.*

Figure 7 – Ordinary and Lang's Lay

3. The length of the pitch of the wires in the strands (strand lay) or the length of the pitch of the strands in the rope (rope lay).

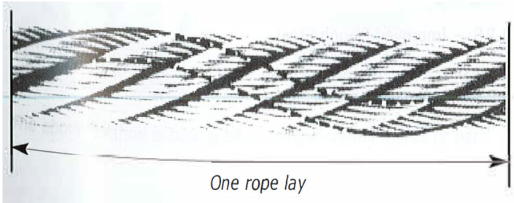


Figure 8 – Ordinary Rope Lay

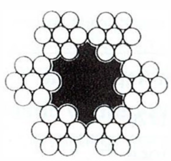
The direction of rope lay does not affect the breaking force of a rope. However, the combination of strand lay and rope lay (Ordinary lay or Lang's lay) will greatly affect the rope characteristics and this factor must be taken into consideration when choosing a rope.

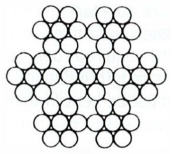
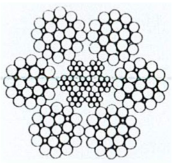
Lang's lay ropes are generally more flexible than ordinary lay ropes and have greater wearing surface per wire than ordinary lay ropes. However, Lang's lay ropes are more susceptible to bending over small diameter sheaves, pinching in undersize sheave grooves, crushing when winding on drums, and failing due to excessive rotation. Left lay rope is often used in applications where rotation of right lay rope would loosen couplings. The rotation of a left lay rope tightens a standard coupling.

1.6 Type of Core

The core of a wire rope runs through the centre of the rope and supports the strands by maintaining their relative position under loading and bending stresses. A number of core types are available (Table 3) and each gives specific properties to the rope.

Table 3 – Core Types and their Key Characteristics

Core Type	Key Characteristics
Fibre Core (FC) in 6x7 rope 	• Traditionally made with sisal but may also use polypropylene. • Has less strength than steel core. • Used for ropes that are not subjected to heavy loading and where flexibility in handling is required. • Inadequate where wire rope is subjected to heavy loading, prolonged to outdoor exposure and crushing on small drums and sheaves. • Used in many overhead crane applications.
Wire Strand Core (WSC) in 6x7 Rope	• Usually of the same construction as the outer strands. • Used chiefly for standing ropes (guys or rigging). • Offer higher tensile strength.

Core Type	Key Characteristics
	• Greater resistance to corrosion failure, owing to the larger wires in the core.
Independent Wire Rope Core (IWRC) in 6x25 FW Rope 	• Recommended core in many instances. • A wire rope usually of 6x7 (6/1)/1x7 (6/1) construction.

1.7 **Strand vs Rope**

For a given cable diameter, there are usually many more wires in a rope than in strand (A group of strands vs a single strand). The smaller wire diameters and the doubly helical wire paths in a rope are responsible for many of the differences between the behaviour of wire rope and strand. Rope is a little more flexible axially than strand but very much more flexible in bending. This bending flexibility is the reason why wire rope is widely used as a tractive element over pulleys and winch drums in mines, cranes, and many other machines.

In most tension structures, such as suspension and cable-stayed bridges, guyed masts, fixed length pendants for draglines, and stacker/reclaimers, strands are used because there is no requirement for a low bending stiffness. The advantages of strand for these applications include greater axial stiffness (greater strength to weight ratio) and improved corrosion resistance due to its larger diameter, closely packed wires, and heavier galvanising. Disadvantages include a larger coiling diameter for delivery, careful packing and attention during transport, and more careful handling, particularly during erection in the field.

For additional information on wire ropes and strands including ordering and installation etc., refer to the Nobles Lifting Equipment Catalogue (See References section of this article)

2. **Causes of Failures**

The types and distribution of wire failures are generally a good indication of the cause of deterioration of a strand. Some typical types of wire failures include tensile, fatigue, corrosion and mechanical.

Whenever tensile failures are detected, the loading on the rope and factor of safety should be checked. Tensile failures can be an indication of an inadequate factor of safety especially if heavy impact loads on the ropes can occur.

Fatigue appears to be a major factor in the failure of ropes. There are not a great deal of test results due to the cost of testing full-size ropes, and available test results show a significant amount of scatter between tests on similar ropes (fatigue of wire ropes will be discussed in more detail in the next section).

On heavy strands, the end terminations are generally made from steel sockets to enable load transmittal between the structure and the cable. The load is carried through the socket forging or casting to the rope by adhesion between the rope wires and the material used in the socket. Typically, the material used in the socket is epoxy resin or zinc metal.

Test results show that even for the same type of end termination, cable fatigue life varies depending on the workmanship of the termination and any secondary effects due to restrained bending and corrosion.

Corrosion failures result from operation in wet, salty, acid, or other chemical conditions which produce various degrees of corrosion and pitting. Every effort should be made to minimise the effects of corrosion by removing the causes, using galvanised rope where suitable and improving lubrication.

Mechanical damage can be seen as nicking or gouging of outer wires and can be due to careless handling, slapping against obstructions, and collisions and impacts. Also, “birdcaging” effects (the springing of wires away from the core or inner strands) can be due to the sudden release of a heavy loading.

Figure 9 – Wire Rope Defect: Bird Caging

3. Failure Strength of Strands

As mentioned previously, fatigue appears to be a major cause of failure in steel strands. Historically, the majority of failures for strands appear to occur near the end terminations and can be attributed to bending fatigue, possibly accentuated by corrosion.

Things that can have a significant effect on the fatigue behaviour of strands include:

- Bending and twisting of the wires due to loading and unloading; and
- Contact stresses between individual wires. Research has shown that contact stresses can govern fatigue life particularly for large diameter cables.

Dynamic effects such as oscillations due to wind on cable-stayed bridges and, digging loads on draglines and reclaimers are a common source of stress fluctuations in wire ropes. These dynamic effects can lead to secondary bending stresses at the end terminations as well as fretting fatigue between individual wires. Wire breakages can occur at the internal wires because the contact stresses at the internal wires can be higher than the stresses at the outer wires.

Figure 9 presents a graph showing the fatigue design specification for wire rope recommended by the American Petroleum Institute (API) compared with some test results for 22mm diameter, 32mm diameter and 36mm diameter wire ropes. As can be seen, there is a wide degree of scatter between test results and the equation recommended by the API can give overstated results for low cycle fatigue.

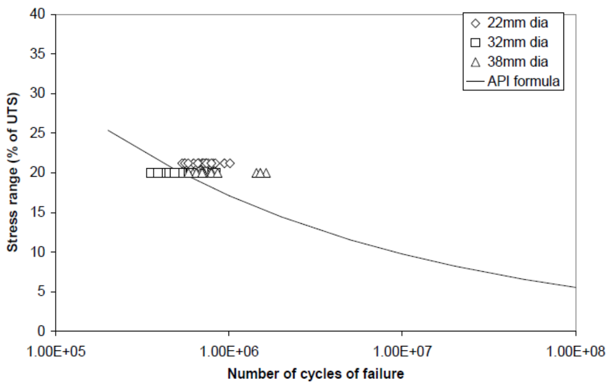


Figure 10 – Example of a Longitudinal Restraint

Based on recent work undertaken on materials handling machines (stacker/reclaimers) – *ASPEC's key service area*, the fluctuating load in the boom pendants due to digging and material on the belt appears to be about five percent of the maximum breaking load and the number of digging cycles over a 25-year period is about 1,000,000. Therefore, we would not expect fatigue of the pendants on these types of machines to be a problem. However, secondary effects due to dynamics from machine movement and wind, poor rope condition, lack of lubrication, and the condition of the end terminations may significantly decrease the rope fatigue life.

4. High Capacity Winch Ropes

In order to provide the higher factors of safety for materials handling machines such as shiploaders to the latest standards, higher capacity rope types have been developed. Wire ropes commonly used now for shiploaders are Turboplast and Paraplast ropes. Depending on the shiploader specification, a shiploader may have luffing, shuttle and telechute ropes (Figure 11).

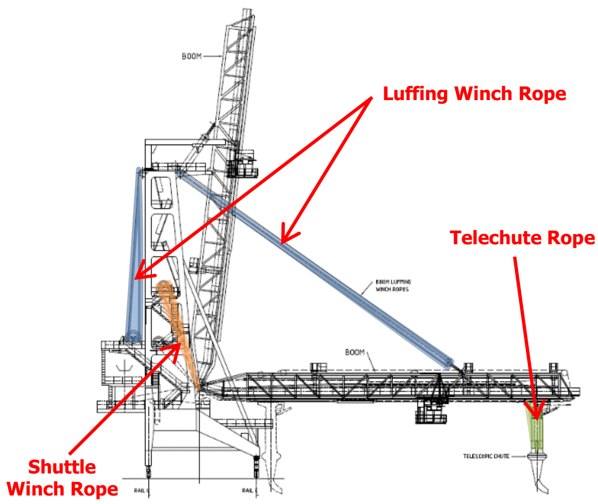


Figure 11 – Example of a Shiploader with Steel Wire Ropes

These ropes support vertical and horizontal movements of the shiploader boom and telechute to load bulk material into ships. As these ropes are exposed to the salty, marine environment, corrosion protection of ropes, especially the core, is critical.

4.1 CASAR Turboplast

CASAR Turboplast rope is an 8-strand rope made of compacted outer strands as shown in Figure 12. Fully lubricated, it is available in both Ordinary Lay and Lang's Lay.

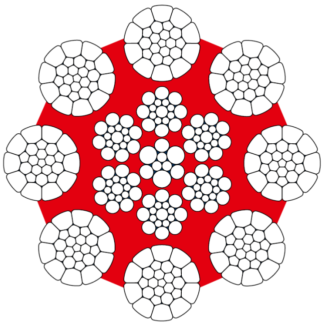


Figure 12 – Example Cross-section of a Turboplast Rope

Turboplast rope has a plastic layer (red) between the steel core and the outer strands, giving the rope a high structural stability, avoiding internal rope destruction and protecting the core against corrosive environment. It also has a high breaking load and a good resistance against crushing. The minimum breaking force ranges from 52.3 kN to 484.67 kN depending on the rope diameter and grade.

4.2 CASAR Paraplast

CASAR Paraplast rope is also an 8-strand rope but in parallel lay construction made of compacted outer strands. Fully lubricated, it is also available in both Ordinary Lay and Lang's Lay. Its plastic layer between the steel core and the outer strands also make it extremely corrosion resistant.

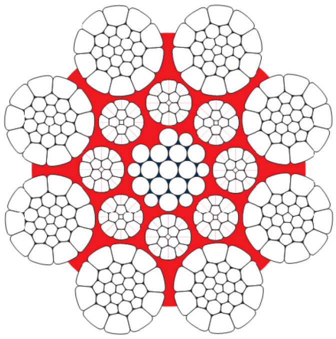


Figure 13 – Example Cross-section of a Paraplast Rope

Paraplast rope has a very fatigue resistant and very high minimum breaking load. The minimum breaking force for Paraplast ropes ranges from 113.4 kN to 484.67 kN depending on the rope diameter and grade.

5. Wire Rope Discard Recommendations

Failures in wire ropes can occur due to internal or external wire breakages or failure at end terminations. Internal wire failures are not common in areas away from the end terminations; however, appropriate testing methods are required to detect these internal defects.

The grounds for discarding wire ropes are varied depending on the application, the degree of risk if the rope breaks in service, the environmental conditions, and the extent of inspection. Some commonly used criteria include:

- A percentage loss of tensile strength and therefore factor of safety. This is generally based on physical tensile testing of the complete rope and may not be appropriate for ropes in service;
- A maximum number of broken or cracked outer wires;
- A maximum percentage of allowable wear on the outer wires; and
- Kinking or "birdcaging" of wires.

As a guide, for a decrease in actual rope diameter greater than 3% for rotation resistant ropes or 10% for non-rotation resistant the rope shall be discarded even if no broken wires are visible.

Section 14 of AS 2759:2004, Section 6 of ISO 4309:2017 and A112 of AS 4324.1:2017 outline rope discard criteria (see references).

It is also important to have the knowledge of the performance of previous ropes used in the same application and factor it in the rope discard process.

6. Care and Maintenance

The remedies needed to control and avoid rope failure can include:

- Use of corrosion-resistant galvanised rope;
- Lubrication of rope, which provides corrosion protection as well as reducing friction (and consequential fretting fatigue) between wires;
- Checking of condition of end terminations, as the type of termination and the workmanship of the termination can have a significant effect on the fatigue strength of the rope system;
- Reducing dynamic effects, as machine digging or wind can cause the ropes to oscillate excessively; and
- Inspections and appropriate testing methods, which are required to detect internal defects such as internal wire failures that commonly occur in areas away from the end terminations. An NDT (Non-Destructive Testing) system as a supplement to visual inspection can also be employed to monitor internal degradation.

6.1 Lubrication

Lubrication is applied during the manufacturing process and should penetrate all the way to the core. This inhibits possible rotting of the fibre core. Lubrication of wire ropes will reduce the resultant friction within the rope as well as the friction between the rope and drum or sheaves. However, pre-lubrication only lasts for a limited time and should be re-applied periodically during service.

6.1.1 Lubrication Types

Field lubricants can be applied by spray, brush, dip, drip or pressure boot. Various types of greases are used for wire rope lubrication. First, there are two types of wire rope lubricants, penetrating and coating. Penetrating lubricants contain a petroleum solvent that carries the lubricant into the core of the wire rope then evaporates, leaving behind a heavy lubricating film to protect and lubricate each strand (Figure 14).

Figure 14 – Foam Penetrating Type Wire Rope

Coating lubricants penetrate slightly, sealing the outside of the cable from moisture and reducing wear and fretting corrosion from contact with external bodies.

Both types of wire rope lubricants are widely used. However, most wire ropes tend to fail from the inside which means the centre core needs to receive sufficient lubricant to maintain the rope's useful life. Hence, it is recommended that penetrating lubricants are used either alone or in conjunction with a coating lubricant.

Wire rope lubricants can be petrolatum, asphaltic, grease, petroleum oils, vegetable oil-based or lanolin based. Where environmental considerations govern, lanolin-based lubricants are commonly used.

6.1.2 Post Lubrication Frequency

Lubricating working wire ropes is a difficult proposition, regardless of the construction and composition. Ropes with fibre cores are somewhat easier to lubricate than those made exclusively from steel materials. For this reason, it is important to carefully consider the issue of field relubrication when selecting rope for an application.

6.1.3 Post Lubrication Compatibility

As lubricant formulations are constantly being modified and improved, it may not be possible to have experience with new formulations in order to compare them with existing in-service lubricants.

The first consideration when changing lubricants is whether the new lubricant and the in-service lubricant are compatible. This issue can impact flushing and change-out decisions as well as result in significant costs. Group V synthetics are often thought to be incompatible with Group I-IV hydrocarbon fluids. This should be addressed first. ASTM D7155 explains how to test fluids for compatibility.

6.2 Inspection

Although wire rope is tough and durable, regular inspection must be carried out for safety and its condition must be monitored and maintained to extend its service life.

The proper frequency and degree of inspection depends largely on the possible risk to personnel and machinery in the event of rope failure.

6.2.1 Non-Destructive Testing

MRT (Magnetic Rope Test) is a non-destructive testing that uses an electromagnetic instrument to examine the rope. It measures the magnetic flux leakage of a magnetized rope.

6.2.2 Inspection Frequency

For initial inspection, ISO4309 recommends that when it is the intention to use electromagnetic means of NDT as an aid to visual examination, the rope should be subject to an initial electromagnetic NDT examination as soon as possible after the rope has been installed. For subsequent inspections testing frequency should be based on expected rope life operating cycles, operating conditions and rope constructions.

AS 4812:2013 recommends that frequencies do not exceed one sixth of the expected rope life, with a limit of between 6 and 30 months depending on the type of rope.

Inspection should be carried out following an incident that could have caused damage to the rope and/or its termination, or if a rope has been brought back into operation after dismantling followed by re-assembly.

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