Fatigue

Often when wire rope is removed from service, mechanics report pieces of wire dropping out of a rope when bent by hand. In extreme cases, a retired rope may even be broken in half by bending it back and forth a few times. This phenomena is caused by fatigue. To quickly demonstrate how fatigue works, straighten out a paper clip. With the paper clip firmly pinched between your fingers, and using your thumbnail as the pivot point, bend the wire up and down. You will first notice that the wire becomes easier to bend with each repetition, followed by an increase in the temperature of the wire. Soon after, a fatigue break occurs. Though this is an extreme example, this type of action is exactly what happens inside wire rope. Fatigue occurs when the individual wires lose their ability to bend, and many times is caused by some form of constraint that prevents the rope wires from moving freely and smoothly, and working in conjunction with each other.

All wire ropes are subject to fatigue, though the nature and severity of fatigue varies with each application and machine type. Fatigue may be accelerated by abrasion, nicking and other types of damage such as kinking. When fatigue breaks occur and there is no sign of wear, as shown in **Figure 1**, it is usually caused by bending stresses, or those stresses placed on the rope wires while bending under load over a sheave.

Figure 1: ***Crown Fatigue Breaks***

When wire rope bends around a sheave, the rope's strands and wires must move relative to one another, as shown in **Figure 2**. This movement allows the rope wires to compensate for the difference in traveling distance between the underside and the topside of the rope, the distance being greater along the topside. Rope action (and service) is adversely affected if the wires cannot move properly.

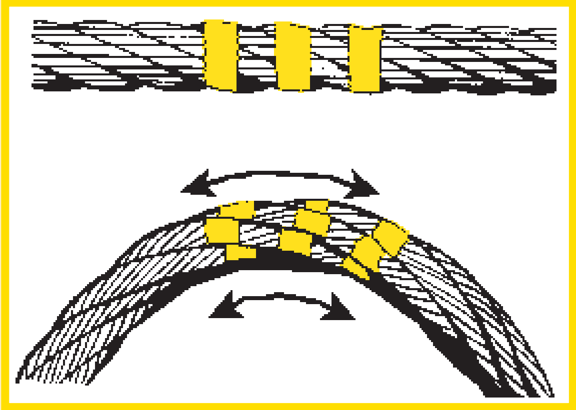

Figure 2: ***When bending over a sheave, the distance rope wires travel is greater on the topside than on the underside, as illustrated.***

Any changes which might take place in the rope, due to the conditions under which it operates, will materially change the bending stress. These conditions include any instance or circumstance that restricts the movement of the wires, such as undersized sheaves, improper sheave maintenance, groove type and lack of lubrication.

Undersized Sheaves

The relationship between sheave diameter and rope diameter is critical in determining a rope's fatigue resistance or relative service life. This relationship is expressed as the **D/d ratio**, where "D" is equal to the diameter of the sheave and "d" represents the

Application	Rope Diameter			
	3/8″	1/2″	5/8″	11/16″
Suspension Ropes (40:1 D/d ratio)	15	20	25	27.5
Compensation Ropes (32: 1 D/d ratio)	12	16	20	22

Table 1: ***Minimum Sheave Diameters***

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diameter of the rope. A minimum D/d ratio has a negative effect on the rope wires' ability to adjust to their ever-changing environment. The smaller the radius over which a rope passes, the greater the fatigue. ASME A17.1-2004 Paragraph 2.24.2.2 Minimum Pitch Diameter references a 40:1 minimum ratio for elevator drive sheaves (suspension ropes), and 32:1 for compensation ropes. This means, in the case of a drive sheave, the sheave diameter must, at a minimum, be 40 times the rope's diameter. Refer

Rated Speed (feet/minute)	No. Rope Strands	Multiplier*
200′ or less	6	42
	8	30
Over 200′	6	46
	8	32

Table 2: **ASME A17.1-2004 Table 2.18.7.4 Multiplier for Determining Governor Sheave Pitch Diameter**

* multiply by the diameter of the rope

to **Tables 1** and **2** for various D/d ratios and multipliers for hoist, compensation and governor ropes. To properly illustrate the effects of sheave diameter on wire rope performance, the wire rope industry developed the **Service Life Curve (Figure 3)**. Following ASME specifications, a 1/2″ diameter rope working with a D/d ratio of 40:1 (20″ sheave) has a relative service life of 40 units. If the same rope works over a sheave with a D/d ratio of 55:1 (27 1/2″ sheave),

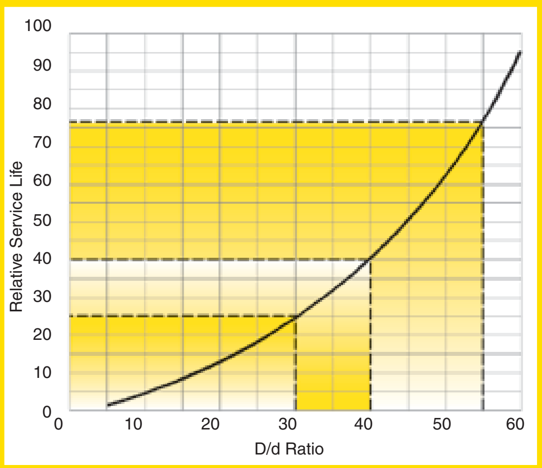

Figure 3: **Service Life Curve**

its service life increases to 76.5 units. In short, the rope's service life can be increased from 40 to 76.5 units — a 91% increase — by operating on a sheave that is only 7 1/2″ larger in diameter. Note the change in service life if an improper D/d ratio is used. With a ratio of 30:1 (15″ sheave), relative service life units drop to 25. Users can anticipate a 37.5% reduction in service life than would have been experienced had ASME specifications been followed.

Improper Sheave Maintenance

Just as critical as using a proper D/d ratio is maintaining the sheaves over which a rope operates. Conditions such as tight or loose grooves, out of round sheaves, misaligned sheaves, and the like all contribute to shortened service life. In each of these examples, sheave conditions interfere with a rope's ability to adjust to its working environment. In combination with normal bending stresses, these conditions accelerate fatigue.

Groove Type

To increase rope traction, the elevator industry designed a series of new groove types, i.e. V-grooves, undercut U-grooves and progressive grooves. (Please refer to Bethlehem Elevator Rope Technical Bulletin 10, *Sheaves and Grooves.*) Improved traction is a result of increased rope pressure. These designs created a trade off—increased traction for decreased service life. The pinching action of these grooves creates excessive stress on the rope wires as the pinching restrains the rope wires from properly moving. A rope operating in such a groove will have a higher occurrence of fatigue breaks than a rope operating in a U-groove, where all other conditions remain constant.

Lack Of Lubrication

It stands to reason that a properly lubricated rope has greater fatigue resistance than a dry rope—properly lubricated rope wires move against and with each other with great ease as the rope passes over a sheave. An improperly lubricated rope, however, will suffer internally, particularly in the area of the core. As the core dries out, becomes hard and no longer supports the strands, the rope strands and wires begin to abrade not only against the core, but against each other as well. Both abrasion and nicking accelerate fatigue. Refer to Bethlehem Elevator Rope Technical Bulletins 2 and 3 for further information.

Modern elevator systems in and of themselves also cause shortened service life. Unlike some of the aforementioned conditions, these designs e.g. multiple sheave and reverse bend configurations, cannot be avoided.

Multiple Sheave Configurations

The greater the bending cycles, the greater the likelihood of fatigue breaks. Therefore, logic dictates that ropes installed on a double wrap configuration will exhibit greater fatigue than those on a single wrap. A 2:1 double wrap utilizes four sheaves, placing greater bending stresses on the rope, thus greater fatigue.

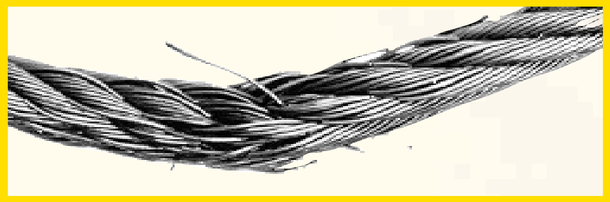

Figure 4: **This 6-strand rope, showing extreme fatigue, operated in a reverse bend configuration. Note the number of crown and valley breaks.**

Reverse Bends

From a wire rope manufacturer's point of view, reverse bends should be avoided, yet they do exist. Because of architectural designs e.g. limited space, elevator OEM's must adapt their elevator systems, usually resulting in machines that are offset from the hoistway. Any reeving arrangement that involves reverse bends (especially where sheaves, or sheaves and drum are spaced closely) causes the rope to operate at a disadvantage and results in greatly reduced rope life (**Figure 4**). A reverse bend develops

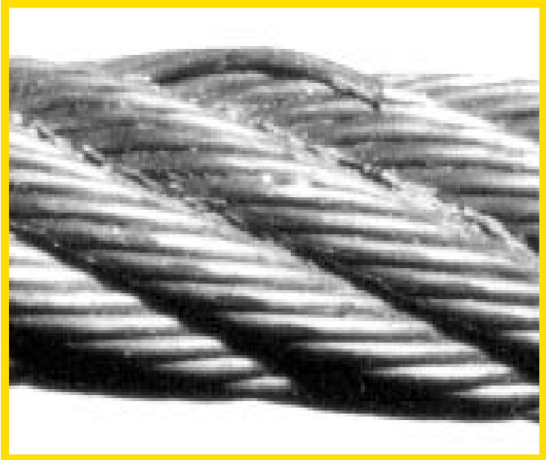

Figure 5: **Valley Fatigue Break**

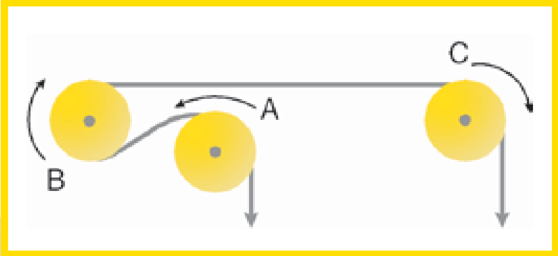

Figure 6: **In a reverse bend configuration, a rope operates in an "S" pattern either horizontally or vertically.**

when the rope bends over a sheave in one direction, then under another in the opposite direction within a short distance, as shown in **Figure 6**. This bending of the rope in reverse directions results in fatigue and the premature breaking of wires. In **Figure 6**, the rope passes over Sheave A. The topside, required to travel a greater distance around the sheave, pulls down while the underside opens up (**reference Figure 2**). The rope then passes under Sheave B, bending in a reverse direction. The topside rope wires, still trying to compensate for the first sheave, are now positioned on the underside and must quickly readjust again—in the opposite direction. This action places extreme pressure upon the rope wires. Actual experience and research shows that the service life of ropes subjected to reverse bends over sheaves is only about one-half of that of ropes bent over a single sheave in one direction.

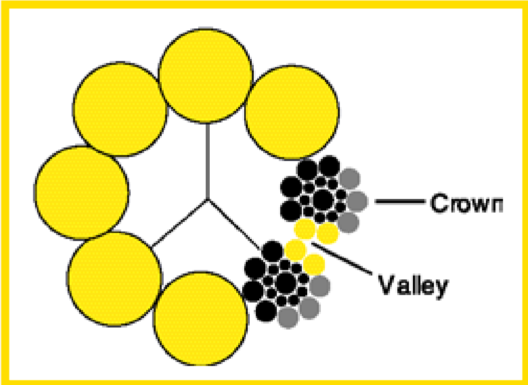

Figure 7: **Crown and Valley Wires**

Fatigue breaks can occur both on the crown (that which contacts the sheave) and in the valleys (**reference Figures 5, 7** and **9**). Crown fatigue breaks typically occur as a result of abrasive wear against the sheave. In most instances, under normal operating conditions, users will first see appreciable surface

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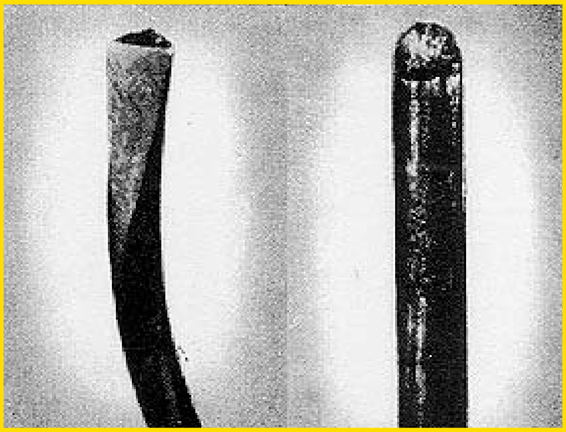

Figure 8: ***Both photos illustrate fatigue breaks. The fatigue break on the left is caused by abrasion, and is normally found on crown wires. To the right is a true fatigue break typically found to be the cause of valley breaks.***

wear, followed by crown fatigue breakage. Though the industry considers these to be true abrasion breaks, they are not. When examined under a microscope, it is clearly evident they are actually fatigue breaks resulting from abrasion, as shown in **Figure 8**. In the event breaks occur on the crown, and little to no surface wear is present, these breaks are true fatigue operating in reverse bend configurations or on sheaves equipped with sheave liners.

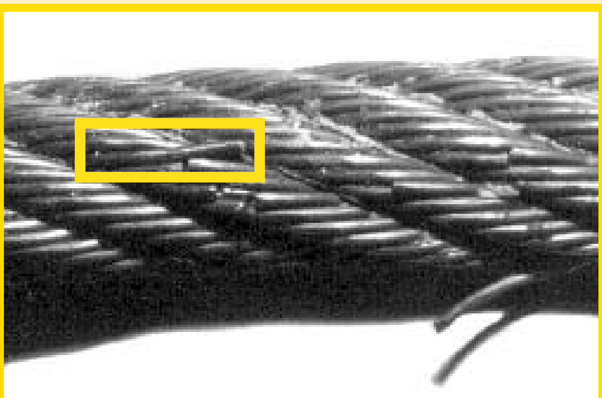

Figure 9: ***A valley break is highlighted above. The break originates in the valley.***

Internal wires are not subjected to the same external forces, but may be subjected to internal forces. These internal forces may be in the form of interstran contact due to a reduction in core support over the life of the rope. Fatigue breaks will occur at these contact points and are identified as valley breaks.

A valley break is defined as a wire break in between two adjoining strands. If a valley break is found, it is almost always due to fatigue and is a strong indication internal rope wires are fatiguing as well. ASME A17.1-2004 Paragraph 8.11.21.3(cc)(1)(e) states "if there is more than one valley break per rope lay the ropes must be removed." If two or more valley breaks exist, the rope is fatiguing internally. Valley breaks are difficult to detect because of their location, poor lighting in the shaft and lubricant on the ropes. While wire breaks protrude in non-preformed ropes, in preformed ropes wire breaks may either lie flat or be slightly raised. With a pocket screwdriver or knife, try to lift the broken wire. If it can be lifted out of place and the break originates in the valley of the strands as shown in **Figure 9**, this is considered a valley break.

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