

# CASAR<sup>®</sup>

## SPECIAL WIRE ROPES



### The Inspection of Steel Wire Ropes

# The Inspection of Steel Wire Ropes

by Dipl.- Ing. Roland Verreet

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### Why must wire ropes be inspected?

A steel wire rope is a commodity with a limited lifespan. Many properties will change during its service period. For instance, the breaking strength will increase slightly at the beginning of its service life but may rapidly decrease after reaching this maximum.

The initial increase of the breaking strength is a consequence of settling in effects (within the rope) which lead to a more homogeneous load distribution amongst the wires in the rope. The subsequent decrease in breaking strength can be explained by increasing loss of metallic cross-sectional area caused by abrasion and corrosion, by the occurrence of wire breaks and by structural changes to the rope.

With a chain, which represents a series connection of load bearing elements, the failure of a single element results in the total failure of the whole lifting device. In contrast to this, the load bearing elements of a wire rope are in a parallel arrangement. Therefore, even after a many wire breaks, a steel wire rope can still be operated safely (Fig. 1).

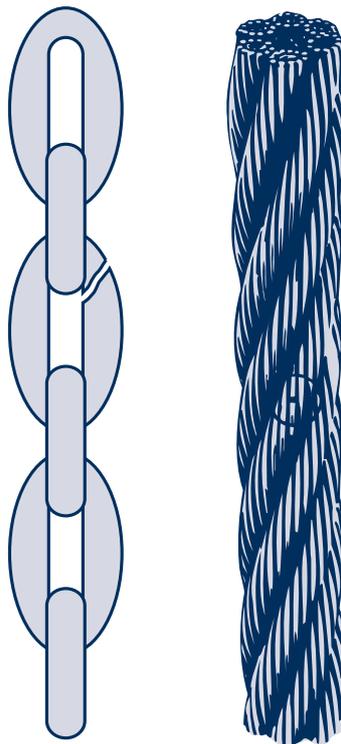


Fig.1: The failure of one element

As a rule the number of wire breaks will increase steadily. Fig. 2 illustrates the typical development of wire breaks with an increasing number of cycles. Monitoring this natural course of increase is one of the objectives of wire rope inspection in order to

make sure that the rope can be discarded before it has reached the state of being operationally unsafe.

Another aim of inspection is to detect abnormal damage to the rope which is usually caused by external influences. This makes it possible to discard the rope in good time and recognising weak areas in the reeving system. Once these have been identified, measures can be taken to prevent such damage from occurring again.

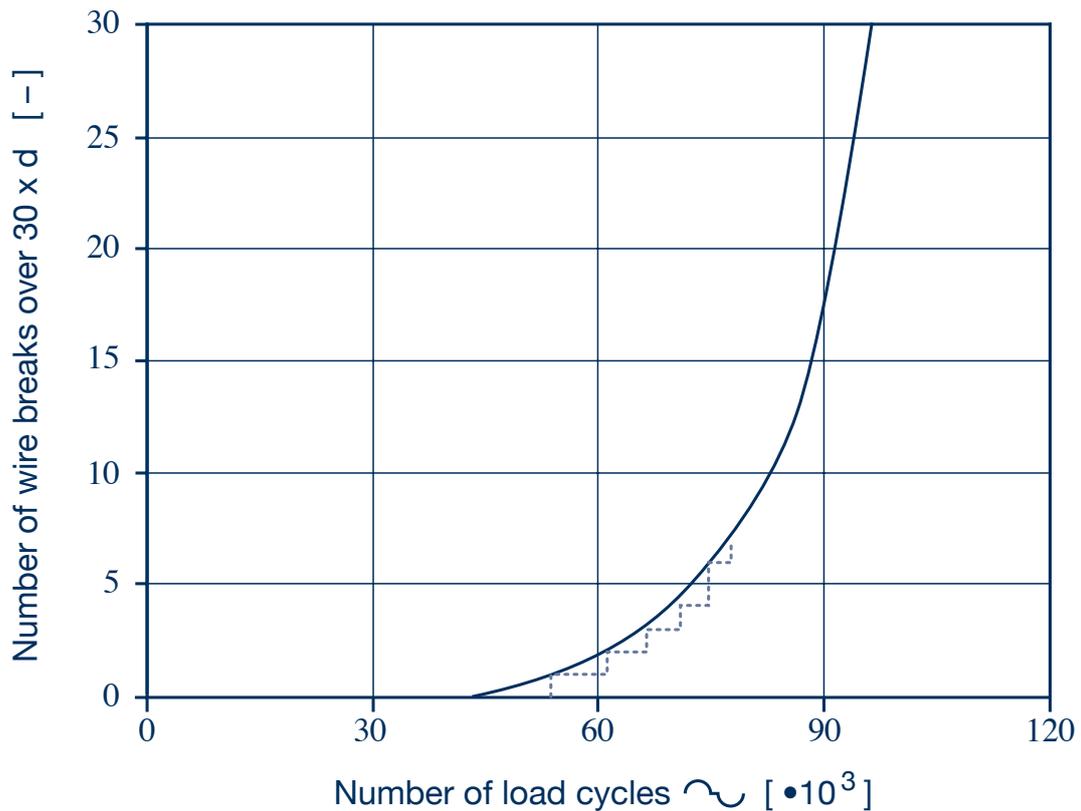


Fig. 2: Typical development of wire breaks in a steel wire rope

### When must wire ropes be inspected?

DIN 15 020, Sheet 2, Point 3.4 - “Monitoring” - recommends daily visual inspection of wire ropes and rope end connections for potential damage.

In addition, at regular intervals, wire ropes must be inspected by qualified personnel as to their operational safety. According to DIN 15 020 the intervals must allow for “any damage to be recognised in good time”. Therefore the intervals need to be shortened - compared to the rest of the service life - during the first weeks after the installation of a new wire rope and also after the first wire breaks have occurred.

After abnormal loading or in the case of presumed non-visible damage, the intervals must be reduced, if necessary, to hours. The rope must also be inspected before starting up machinery again after lying idle for an extended period. The same applies to lifting systems that have been dismantled for a change of location before any operation at the new site. This also applies whenever an accident or any damage has occurred in connection with the reeving system.

According to DIN 15 020, sheaves, rope drums and compensation sheaves “must be examined if the need arises and whenever a new rope is installed. Such examinations should be conducted at least once a year.”

Regular inspections of the reeving system contribute to safety and cover the operator in two ways: first, the risk of accidents is reduced. Secondly, should equipment damage occur, detailed documentation of regular monitoring would demonstrate that the operator has not been carelessness or negligent.

### **Overview of discard criteria**

According to DIN 15 020 a steel wire rope must be discarded if one or more of the following criteria are satisfied:

#### **1. Wire breaks**

A wire rope must be discarded if the permissible number of wire breaks, according to DIN 15 020, has been reached or exceeded. The same applies to clusters of broken wires or to one or more broken strands.

#### **2. Reduction of diameter**

A wire rope must be discarded if, due to structural changes, its diameter has been reduced over extended areas by 15% or more compared to the nominal diameter.

#### **3. Corrosion**

A wire rope must be discarded if its breaking strength or its endurance has been reduced considerably by corrosion. In this case the rope must be discarded if the reduction in diameter is more than 10% of the nominal value, irrespective of any wire breaks.

#### **4. Abrasion**

A wire rope must be discarded if its static breaking strength or its endurance has been reduced considerably by metallic abrasion. In this case the rope must be discarded if the reduction in diameter is more than 10% of the nominal value, even if no wire breaks can be found.

## 5. Rope deformation

### a) Formation of corkscrews

A wire rope must be discarded if the corkscrew formation in the worst affected area has reached a wave height of  $\frac{1}{3}$  of the rope diameter (Fig. 3).



Fig. 3: Formation of a corkscrew

### b) Formation of birdcages

When birdcages occur (Fig. 4) the wire rope must be discarded.

### c) Loop formations

A wire rope must be discarded if wire loop formations (Fig. 5) have considerably changed the rope structure.

### d) Loose wires

A wire rope must be discarded if corrosion or abrasion have generated loose wires. With regard to other causes the consequential damage must be considered when deciding whether the rope must be discarded.

### e) Knot formations

A wire rope must be discarded if severe knot formation causes local thickening in the rope.

### f) Local reduction in diameter

A wire rope must be discarded if severe local reductions in diameter occur (Fig. 6).

### g) Curl-shaped deformations

Wire ropes with permanent deformations caused by being pulled over edges must be discarded.

### h) Kinks

Wire ropes with kinks (resulting from loops that have been pulled tight; Fig. 7) must be discarded.

### i) Buckles

Wire ropes with buckles created by external influences must be discarded.

j) Heat effects

Wire ropes that were exposed to excessive heat must be discarded.



Fig. 4: Birdcages

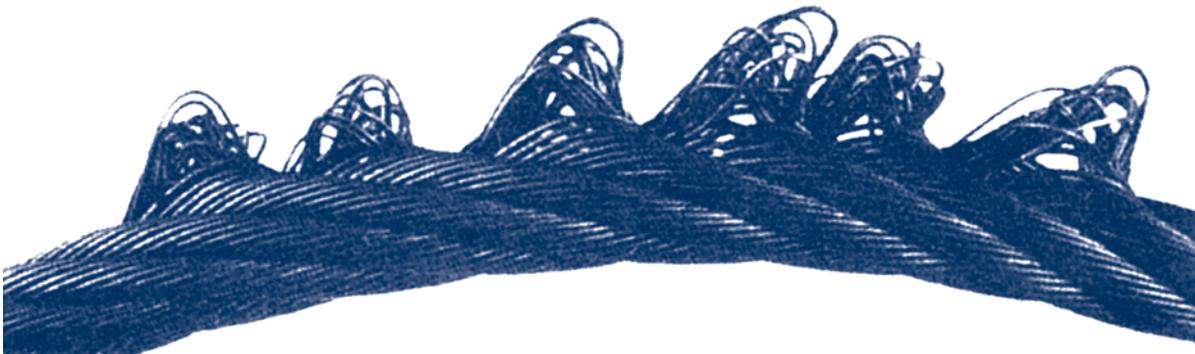


Fig. 5: Wire loops

**Where must wire ropes be inspected?**

Generally speaking the whole rope length must be visually inspected. It goes without saying that critical zones require extra attention. Critical zones are:

- a) Those rope zones which are exposed to the highest number of cycles. Here increased abrasion and wire breaks must be expected.
- b) Loading points. If a lifting system picks up or puts down its load predominantly in one position, all parts of the rope that are in contact with sheaves or running on drums are subject to high stresses.
- c) Rope end connections. At the rope end connections the rope's elasticity is negatively affected; the rope geometry is completely fixed. Very often the end connection exerts additional pressures on the wire rope. The transition zones are often subject to additional tension caused by rope oscillations. Frequently moisture will settle in the end connections. Therefore wire breaks and corrosion must be expected here.



Fig. 6: Local reduction in diameter



Fig. 7: Kink

d) Rope zones on compensation sheaves. In contrast to an opinion voiced in DIN 15 020 which accepts smaller diameters for compensation sheaves than for all other sheaves in the reeving system, some rope zones on compensation sheaves are stressed by a high numbers of cycles, in some cases very high, caused by swinging loads or by uneven spooling on two rope drums (see Case study IV, p. 49). Very often moisture will settle between the rope and the compensating sheave and thus locally generate increased corrosion.

e) Rope zones on rope drums. Loading points and crossovers on rope drums are subject to increased wear and must therefore be examined with special care for abrasion, wire breaks and structural changes. In the case of multi-layer spooling the lower layers might come loose and foul with the incoming rope parts. It is also possible that outer layers are pulled into the loose lower ones. Contact points with the drum flanges and riser zones (from one layer to the next) must be inspected particularly well because they can be subject to severe wear. Please note that Casar have developed special rope constructions specifically to deal with the damage that normally occurs on drums.

f) Sheaves. If possible, sheaves must be inspected as to the proper of their bearings. The sheave groove diameter, which should measure about 6 % to 8 % above the nominal rope diameter, must be checked by means of sheave groove gauges (see p. 27). If the rope groove is too small, the resulting structural changes to the rope will lead to a considerable decrease of the rope's service life. If the rope groove is too wide, this will also cut the rope's service life significantly because the rope will not have sufficient support. The remaining wall thickness of the sheaves should be measured and any potential imprints at the sides should be noted. Sheaves with negative imprints of the rope's surface in their grooves should be replaced or re-machined. Please note that Casar has a special brochure which discusses sheaves with negative imprints in more detail.

g) Rope zones exposed to aggressive agents or heat. Chemicals or heat can considerably reduce the breaking strength of wire ropes. Long-term temperatures of about 200 degrees Celsius do not pose a risk for the wire material (Fig. 8). However, temperatures of only 50 degrees Celsius can result in the complete loss of the rope lubricant and consequently in a noticeable deterioration of the rope's working conditions.

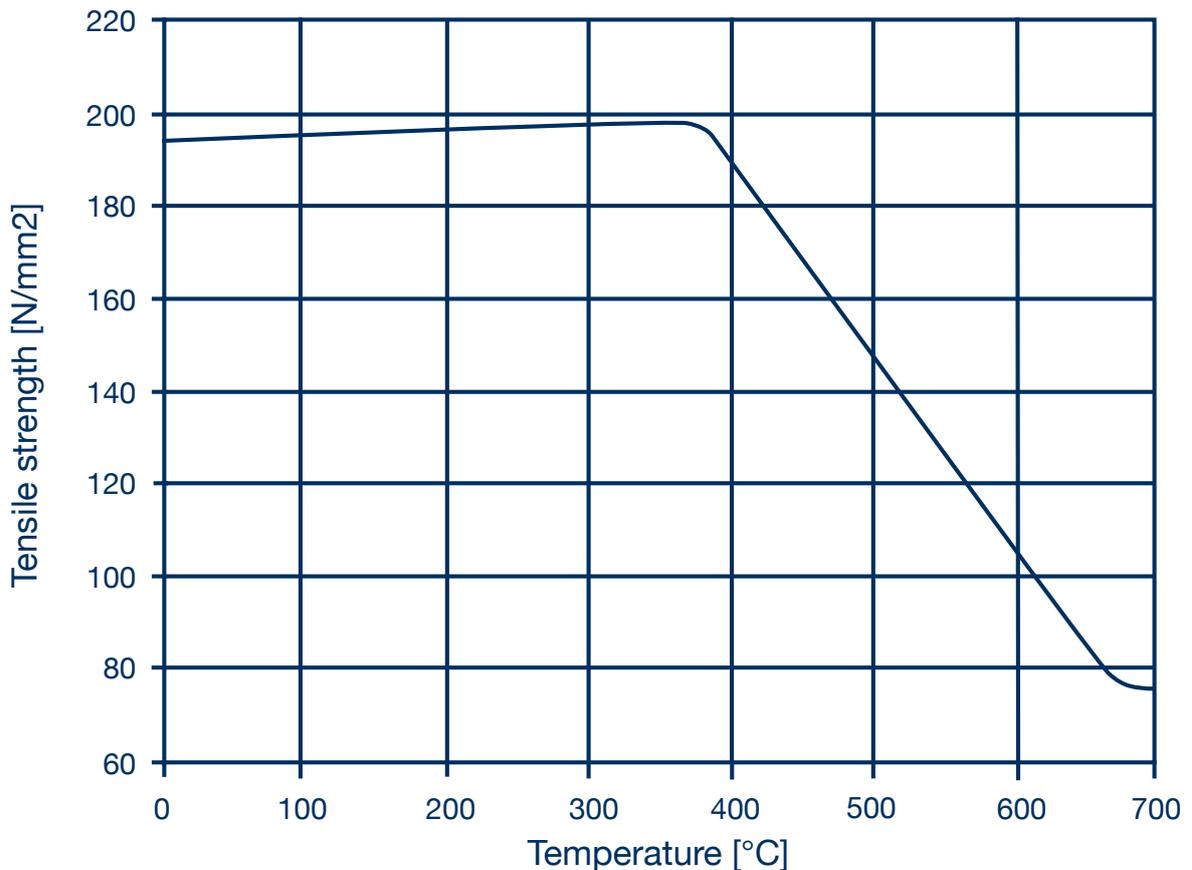


Fig. 8: The effect of temperature on the tensile strength of the wire

Number of load bearing wires in the outer strands of the wire rope  n	Number of visible wire breaks until the discard criteria are reached							
	Groups of mechanism 1Em, 1Dm, 1Cm, 1Bm, 1Am				Groups of mechanism 2m, 3m, 4m, 5m			
	Regular lay		Lang's lay		Regular lay		Lang's lay	
	Over a length of		Over a length of		Over a length of		Over a length of	
	6 d	30 d	6 d	30 d	6 d	30 d	6 d	30 d
to 50	2	4	1	2	4	8	2	4
51 to 75	3	6	2	3	6	12	3	6
76 to 100	4	8	2	4	8	16	4	8
101 to 120	5	10	2	5	10	19	5	10
121 to 140	6	11	3	6	11	22	6	11
141 to 160	6	13	3	6	13	26	6	13
161 to 180	7	14	4	7	14	29	7	14
181 to 200	8	16	4	8	16	32	8	16
201 to 220	9	18	4	9	18	35	9	18
221 to 240	10	19	5	10	19	38	10	19
241 to 260	10	21	5	10	21	42	10	21
261 to 280	11	22	6	11	22	45	11	22
281 to 300	12	24	6	12	24	48	12	24
over 300	$0,04 \cdot n$	$0,08 \cdot n$	$0,02 \cdot n$	$0,04 \cdot n$	$0,08 \cdot n$	$0,16 \cdot n$	$0,04 \cdot n$	$0,08 \cdot n$

Fig. 9: Discard number of wire breaks according to DIN 15 020

### The discard number of wire breaks according to DIN 15 020

The discard number of wire breaks represents the most important criterion for discarding wire ropes. The discard number of wire breaks is defined as the greatest number of outer wire breaks along a length of 6 times the rope diameter or 30 times the rope diameter. If they are accessible (i.e. clearly identifiable) the number of internal wire breaks also need to be considered.

A length of 6 times the rope diameter ( $6 \times d$ ) is equivalent to about 1 lay length, a length of 30 times the rope diameter ( $30 \times d$ ) corresponds to 5 lay lengths.

The discard number of wire breaks is presented in DIN 15 020, Sheet 2, page 3 as a function of the number of load bearing wires in the outer strands of the wire rope and the group of mechanism of the reeving system (Fig. 9).

The table states different discard numbers of wire breaks for regular lay and Lang's lay ropes. On average the discard number of wire breaks for regular lay ropes is twice as high as the one for Lang's lay ropes. The discard number of wire breaks increases with an increasing number of load bearing wires and with decreasing load in the groups of mechanism. Consequently, in the groups 2m, 3m, 4m and 5m twice as many discard numbers of wire breaks are permitted compared to the highly stressed groups 1Em to 1Am.

Stating the discard number of wire breaks for a length of  $6 \times$  rope diameter (about 1 lay length) and for a length of  $30 \times$  rope diameter (about 5 lay lengths) takes into consideration the potential occurrence of local damage or clusters of wire breaks. Even if the discard number of wire breaks has not been reached over a length of  $30 \times$  rope diameter the rope may not be safe for operation due to local damage. It must then be discarded because it has reached the discard number of wire breaks for  $6 \times$  rope diameter.

Fig. 10 shows a rope which must be discarded because of local damage. Here the discard number of wire breaks for  $30 \times$  rope diameter has not been reached but the discard number for  $6 \times d$  has.

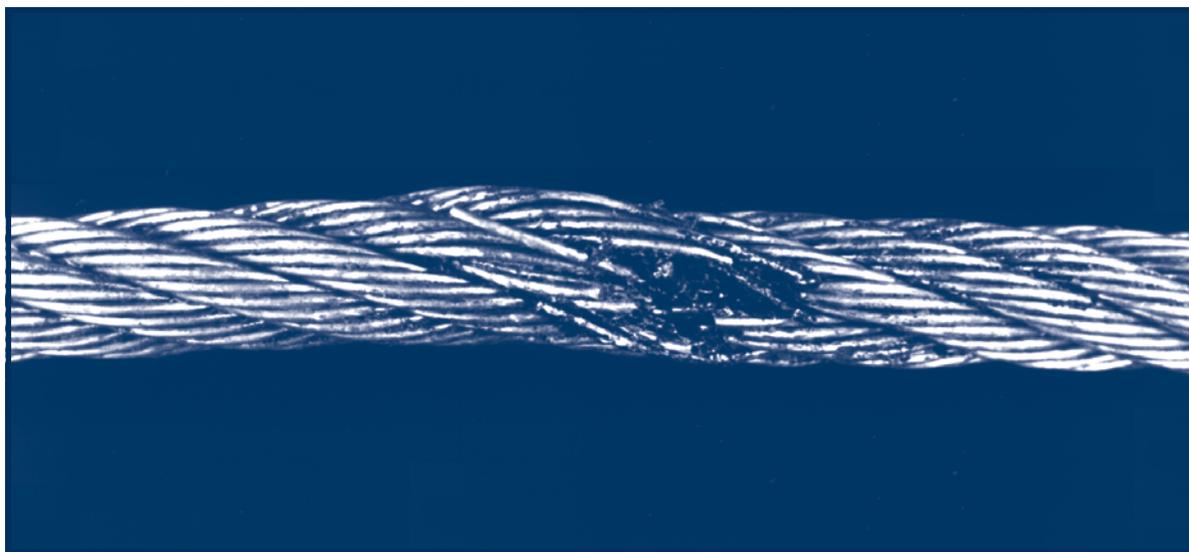


Fig. 10: The discard criteria for  $6 \times d$  has been reached.

### **The discard number of wire breaks according to DIN 3088**

The discard number of wire breaks for slings is laid down in DIN 3088. This standard differentiates between stranded ropes and cable-laid ropes. Fig. 11 shows the discard number of wire breaks for slings according to DIN 3088.

Rope design	Number of visible wire breaks when the discard criteria are reached (over a length of)		
	3d	6d	30d
Stranded rope	4	6	16
Cable-laid rope	10	15	40

Fig. 11: The discard number of wire breaks according to DIN 3088

### How must a wire rope be inspected?

The following tools should be available when a rope inspection is to be carried out in a professional manner :

- wide-jaw vernier callipers for measuring the rope diameter
- a measuring tape, a steel rule or a lay length gauge
- a piece of white chalk and a piece of black wax crayon
- a continuous role of paper strips
- a screw driver or Marlin spike
- a measuring magnifying glass with a thread counter
- two sets of sheave groove gauges
- a cloth
- cleaning solvent
- a scraper
- a notepad or an inspection form
- the records of all previous inspections
- a ball point pen or something similar
- a list of all the discard criteria

### Assessing the number of wire breaks

Assessing the number of wire breaks can take place by external visual inspection or by NDT-testing. During these procedures the whole rope length, if possible, must first be examined to find the rope zone with the highest number of wire breaks.

This zone can be determined by visual and tactile inspection, by spooling the rope through your hand (only if the rope can be run slowly enough). When applying the last method extreme care is necessary as protruding wires from the rope construction can cause severe injuries. In many cases the inspector will run a piece of wood along the rope which is then kicked back by the protruding wire break ends. Another useful technique is to hold a ring of cotton waste around the slow moving rope - any protruding broken wires will snag the cotton and thereby highlight the damaged area.

At the most damaged rope zones, lengths of 30 x rope diameter are measured by means of the measuring tape and marked with chalk. If clusters of wire breaks are detected or there is local damage of the rope, a length of 6 x rope diameter (approx. 1 lay length) which includes the damage, should also be marked. Not all wire breaks along these marked lengths can be determined by visual and tactile examination of the rope along its circumference. In order to assist the visual inspection it is often necessary to clean the rope surface with a solvent-soaked cloth and to get rid of any lubricant or dirt in the valleys between the strands by means of a scraper.

When assessing the number of wire breaks, the tactile examination of the rope is as important as the visual inspection. Quite often the ends of the wire breaks do not protrude from the rope construction, especially with well pre-formed ropes. Another reason is that frequently the narrow gap between the wire break ends is filled with lubricant and is therefore difficult to detect, even if the rope was cleaned. Anyone with clean hands after a rope inspection has not worked thoroughly enough!

The number of wire breaks detected is recorded and compared with the permissible number of wire breaks according to DIN 15 020 and DIN 3088, respectively. If it exceeds these, the wire rope must be discarded.

### **Predicting the point of discard**

Wire ropes are not discarded at fixed dates or after certain working hours but when they reach the discard criteria defined in the relevant standards. When changing a rope you normally need several assistants and sometimes specialised equipment. Understandably, the operator of a crane would not like to be surprised by the untimely news that his wire ropes need to be discarded immediately. On the contrary, he would like to plan the change of rope well in advance. For him it is quite helpful that the development of the wire breaks up to their discard number can be expressed fairly well by an exponential function. Such a function would present the development of wire breaks until the discard criteria are reached in terms of the number of cycles or of the working time. An exponential function can be plotted as a straight line on double-logarithmic graph paper.

When assessing the discard date or the discard number of cycles the procedure is as follows: after every rope inspection the assessed number of wire breaks on a

rope length of  $30 \times d$  is plotted on the double-logarithmic graph paper against the respective working hours, number of load cycles or number of bending cycles. The resulting sequence of points is approximated by a straight line. The point of intersection of this straight line with a parallel line corresponding to the discard number of wire breaks indicates the discard point when projected to the horizontal axis.

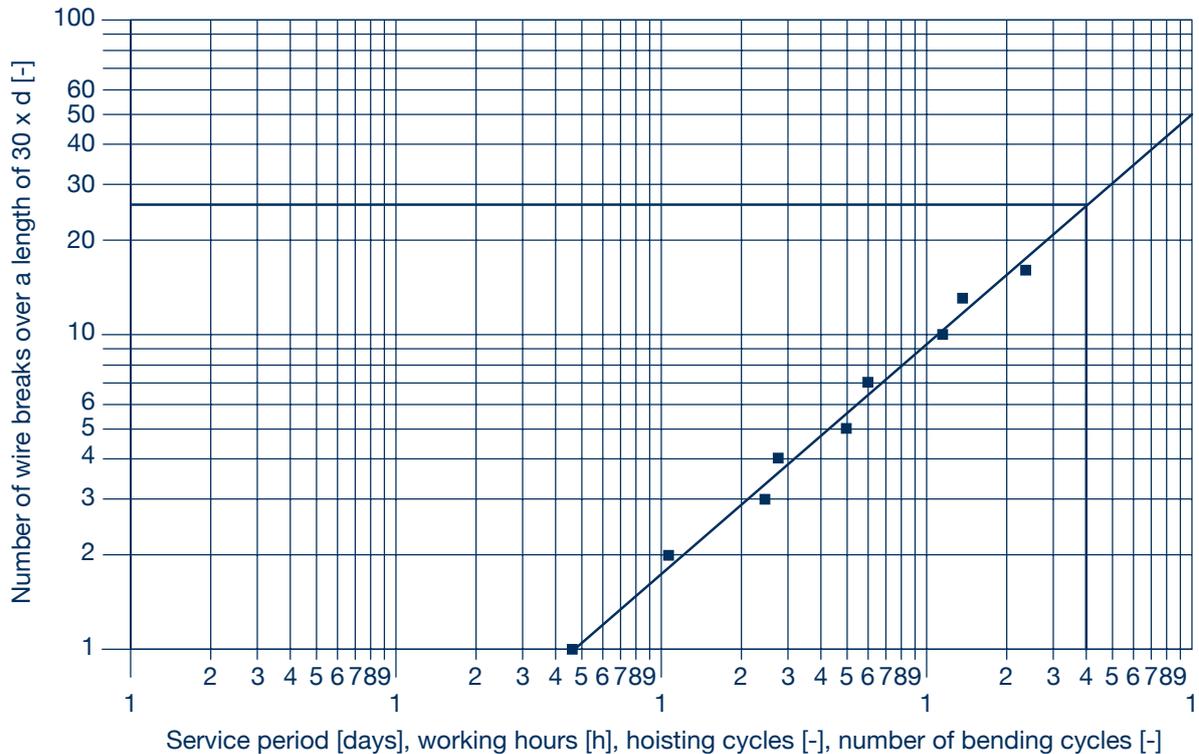


Fig. 12: Predicting the discard date or discard number of cycles

Fig. 12 illustrates a double-logarithmic graph with nine assessed values of wire breaks which were plotted against the corresponding number of bending cycles. The approximating straight line intersects the line indicating the discard number of wire breaks, 26, at a bending cycle number of 40,000. After about 25,000 bending cycles or an approximate 60 % of the service life the operator can predict the discard date of his wire rope with comparatively high certainty.

### Wire breaks not visible from outside

When inspecting a wire rope we must accept the disadvantage that - strictly speaking - only the outer wires of the outer strands can be inspected visually. The inner wires of the outer strands remain hidden, as does the steel core which consequently cannot be inspected visually either. So what is the percentage of the rope that is visible and can actually be inspected visually and how much of it remains hidden?

According to DIN 3064, in a 6 x 36 wire rope design with a fibre core, the outer wires which are accessible to visual inspection have a share of almost exactly 50 % of the metallic cross-sectional area of the rope (Fig. 13). The other 50 % of the metallic cross-sectional area cannot be inspected visually.

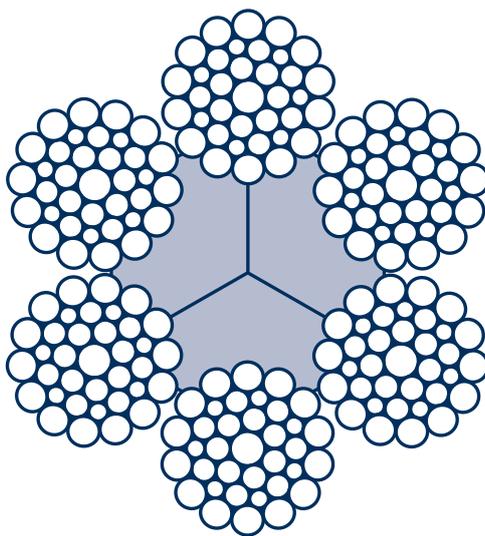


Fig. 13: 6 x 36 wire rope with a fibre core

However, the outer wires of the outer strands are not visible along the underside of the strands for a zone of approximately  $120^\circ$  of the strand's circumference. That means that only  $2/3$  of the 50 % of the metallic cross-sectional area is accessible to visual inspection, i.e. about  $1/3$  of the metallic cross-sectional area of the whole rope.

For the same rope with a steel core, the metallic cross-sectional area accessible to visual inspection remains unchanged, whereas the metallic cross-sectional area not accessible to visual inspection becomes greater. Therefore, the share which the outer wires have in the total metallic cross-sectional area is reduced to under 44 %. Consequently, the actual part accessible to visual inspection is only about  $2/3$  of 44 %, i.e. less than 30 % of the total metallic cross-sectional area.

The steel cores of 8-stranded ropes and multi-stranded rotation-resistant [or rotation-free / non-spin] ropes have an even greater share of the metallic cross-sectional area of the ropes. In these cases the percentage of the metallic cross-sectional area accessible to visual inspection is even lower. The inspector of such wire ropes must live with the unsatisfactory and sometimes even dangerous situation that he can examine only a relatively small part of the metallic cross-sectional area by means of visual inspection.

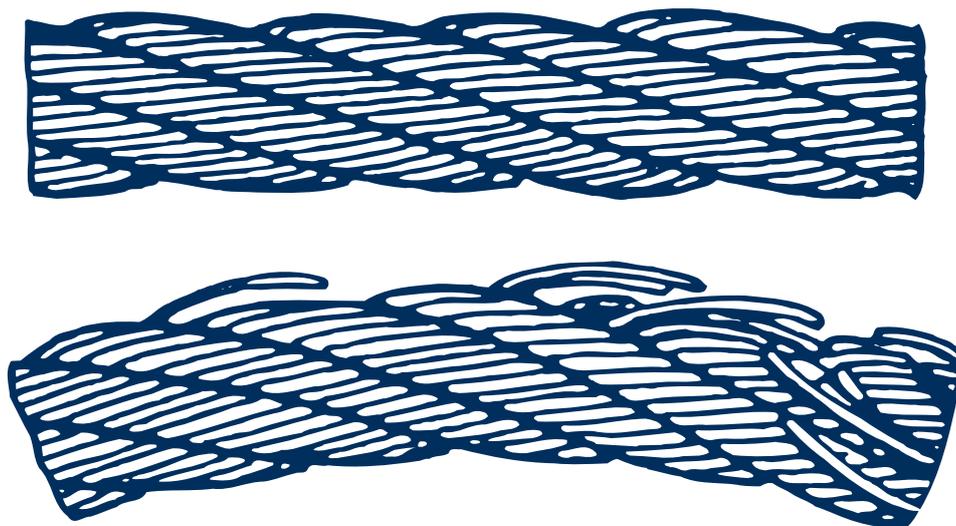


Fig. 14: Detecting wire breaks by bending the rope

Wire breaks of outer wires which do not occur at the crowns of the strands but at the contact points of two neighbouring wires or even on the underside of the strands are very difficult to detect. With thin ropes, which can be completely unloaded, such wire breaks can be made visible by extreme bending of the rope (Fig. 14).

In Fig. 15 a rope is shown which seemed to be free of wire breaks. However, unloading and subsequent bending of the rope brought to light the significant number of wire breaks which had developed at the underside of the strands where they contacted the steel core. The long free wire ends clearly indicate that the wire breaks did not occur at the rope's surface.

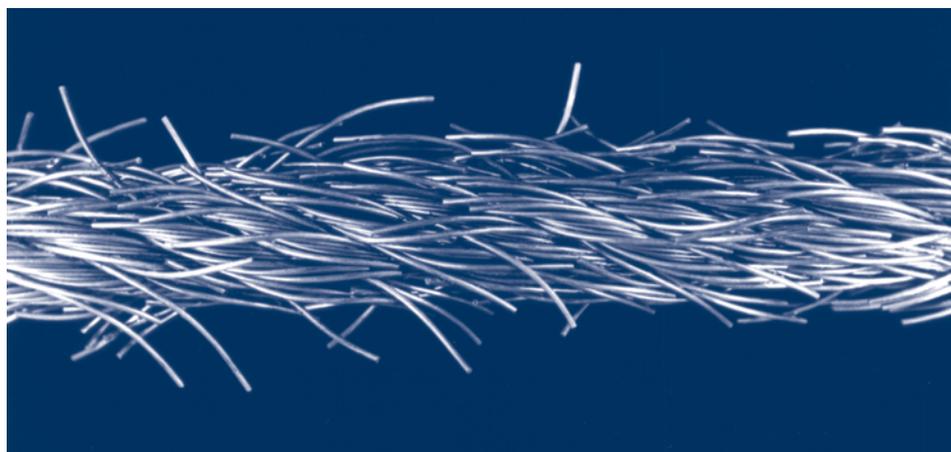


Fig. 15: Wire break ends made visible by bending the rope

Some publications recommend to lift the outer strands of the rope with the help of Marlin spikes in order to assess the state of the steel core and the underside of the outer wires (Fig. 16).

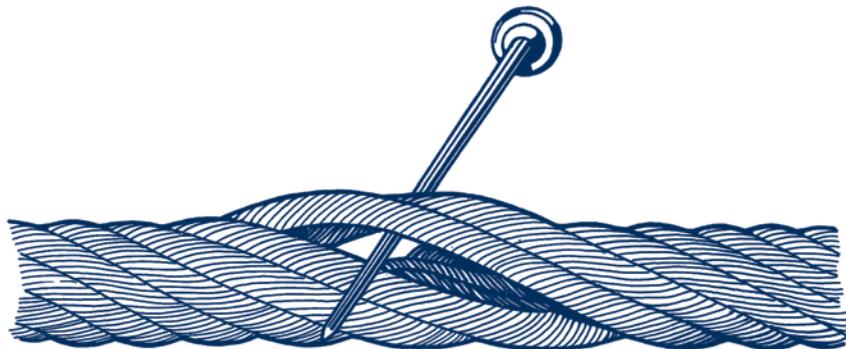


Fig. 16: Opening a wire rope with a Marlin spike

As this procedure quite often causes damage to the rope construction in the zone inspected, it should be carried out by a rope expert only, if at all. A rope tightly closed cannot be opened with this method anyway. Casar wire ropes with internal plastic layers should not be opened up with a spike as this can cause permanent damage to the structure of the rope.

It is also not recommended for the non-expert to untwist a wire rope with the help of two levers attached to it, as is suggested in some professional publications and even by some standards.

### **Assessing cross-sectional area loss caused by external abrasion**

The intention behind assessing the number of wire breaks is to assess the rope's loss of breaking strength. For some rope applications, e.g. in mining, not only the loss of breaking strength caused by broken wires is taken into account but also the weakening of the outer wires caused by the loss of metallic cross-sectional area as a result of abrasion. These damage factors also need to be considered in assessing the overall condition of the ropes.

To determine the effect of abrasion, the width of the wear ellipse on the wire surface is measured with a strong, measuring magnifying glass. From the ratio of ellipse width to wire diameter the loss of breaking strength of the single wire can be found by means of a pre-determined graph (Fig. 17). If broken wires can be removed from the rope construction, the height of the wire in the centre of the wear ellipse can be measured and the remaining cross-sectional area can also be determined (Fig. 18).

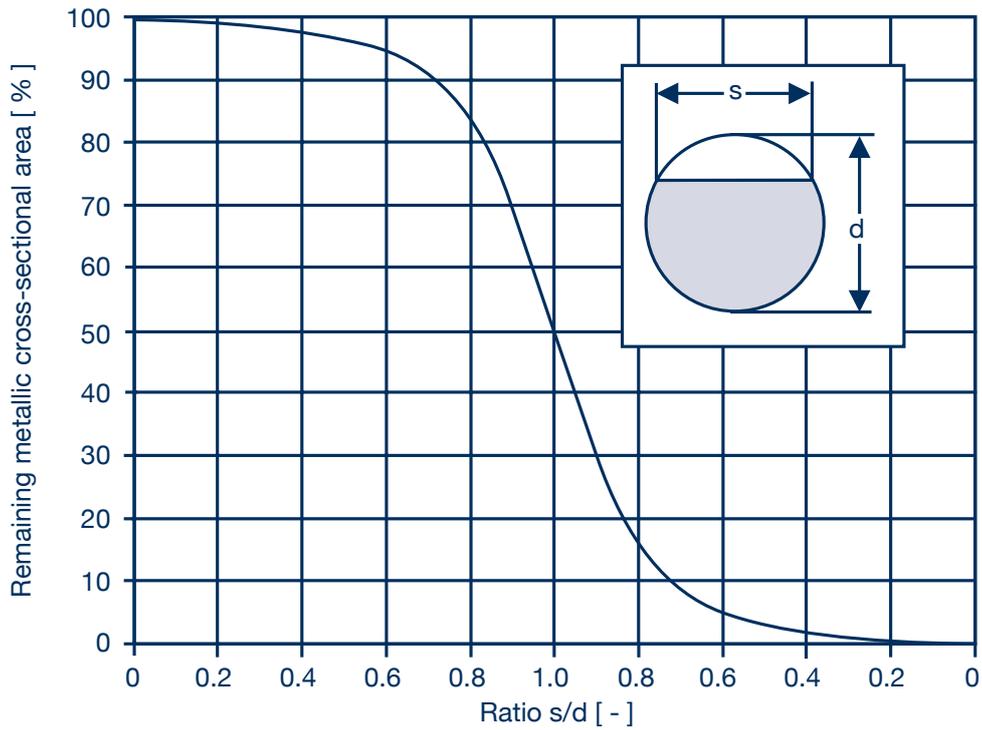


Fig. 17: Determining the remaining metallic cross-sectional area as a result of wear

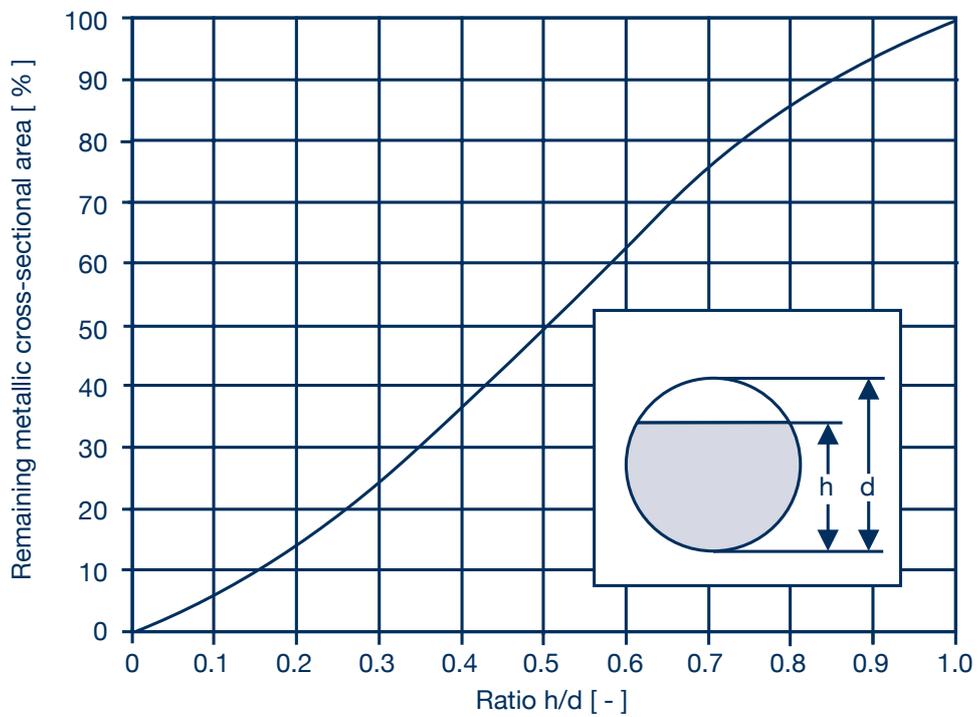


Fig.: 18: Determining the remaining metallic cross-sectional area as a result of wear

The procedure according to Fig. 18 is much more exact than the one according to Fig. 17 because small measuring errors can affect the result of the technique in Fig. 17 considerably. The following example makes this very clear:

For an outer wire of diameter  $d = 2.0$  mm the wear ellipse width is measured as 1.6 mm. The ratio  $s/d$  is calculated as:

$$S/d = 1.6 / 2.0 = 0.8$$

For the value of 0.8 the remaining wire cross section is 84 % from graph in Fig. 17. So the loss of cross-sectional area of the outer wires is 16 %. If, as an example, the outer wire amounts to 40 % of the total cross-sectional area of the rope, the value determined indicates that the rope has suffered a cross-sectional area loss of  $0.4 \times 16 \% = 6.4 \%$  as a result of abrasion of the outer wires.

The following calculation shows the sensitivity of this result to the measured size of the wear ellipse:

For  $S/d = 1.0$  (i.e. only a 0.4 mm or 25 % increase in the measured wear ellipse), the loss of cross-sectional area of the outer wires is 50 % (instead of 16%). The rope has therefore suffered a cross-sectional area loss of 20 % (instead of 6.4 %).

### **Determining the rope diameter**

The rope diameter should already be measured several times when the brand-new rope is delivered. On the one hand these readings indicate whether the new rope is within the tolerance stipulated by the standards, namely from nominal rope diameter + 0 % up to nominal rope diameter + 5 % (when employing special spooling systems the permissible diameter tolerance of the wire rope may be restricted even further). On the other hand, the mean value of the diameter measured when the rope is brand-new can be used as a comparable value for all following measurements.

By measuring the rope diameter during operation of the rope one can be sure that any abnormal decrease of the rope diameter (for instance due to failure of the steel core) is quickly recognised. Furthermore, the measurements are meant to ensure that the rope is discarded when reaching the maximum loss of diameter prescribed by the relevant standards. According to DIN 15 020, a wire rope must be discarded when the rope diameter has lost 10 % of its nominal value.

Vernier callipers (Fig. 19) are used for the exact measurement of the rope diameter along various rope zones which are of particular interest in the condition assessment of the rope. If possible, the vernier callipers should be equipped with wide jaws. A digital display is also an advantage.

Let us now look at the cross-section of a six-stranded wire rope: measuring the rope thickness over the crowns (Fig. 20) results in a higher value than measuring over



Fig. 19: Digital vernier calliper with wide jaws

the valleys (Fig. 21). The diameter of the wire rope is defined as the diameter of the circumscribing circle.

Wire ropes with an even number of outer strands (4-, 6-, 8-, 10- and multi-stranded ropes) must be measured with traditional vernier callipers from strand crown to strand crown. Even if callipers with wide jaws are used in the “wrong” way, they will still indicate the “right” diameter.

Measuring the diameter of ropes with an uneven number of outer strands (3-, 5-, 7-, and 9-stranded ropes) is more difficult: here a crown on the one side always faces a valley on the other.

Therefore, while measuring the diameter, normal callipers must always be held at an angle to the rope axis so that a crown neighbouring a valley is included. In such cases, callipers with wide jaws are a definite advantage, because they always return the correct rope diameter.

In all these cases, two rope diameters, measured at right angles to each other, should be taken at every measuring point so that any elliptical areas of the rope cross-section can be identified.

The entry in the inspection record could read: “Rope diameter: 20.4/20.5 mm” and it should be stated where along the rope the diameters were measured. Fig. 22 shows an example of an inspection record.

### **Measuring the lay length of a wire rope**

For measuring the rope’s lay length a measuring tape and some chalk must be available. In order to keep the measurement error to a minimum the measurement must

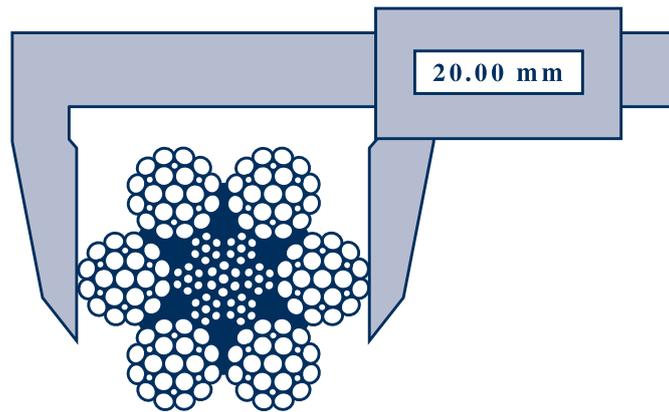


Fig. 20: Correct measurement of the rope diameter

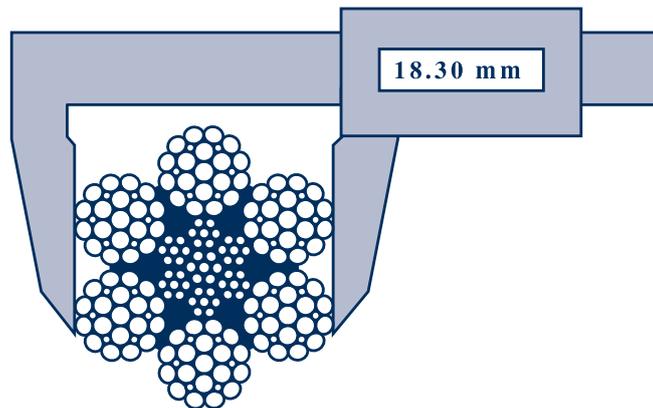


Fig. 21: Wrong measurement of the rope diameter

be taken over three or more lay lengths. After that the length measured is divided by the chosen multiple to give the correct rope length.

Any strand within the rope zone of interest is marked on its crown with a chalk dot (crown zero). Along the rest of the rope length, every crown where the same strand reappears after one revolution around the rope must be marked with a chalk dot. That means, for an 8-stranded rope, the 8th, 16th, 24th and 32nd crown is marked. The zone from the first mark (crown zero) to the last includes exactly four lay lengths. We measure the total length and divide the resulting value by four and obtain the lay length in this zone with a comparatively small measurement error.

Just like the rope diameter, the lay length of the rope must be determined by several measurements and recorded immediately after the new rope has been delivered



and installed. Here, the mean lay length value can serve as a comparable value for all later measurements. In the case where this was not done, the lay length of the brand-new rope can still be measured later on, namely on the unused dead wraps at the fixed point on the drum, taking into account the curvature.

The length of the lay alone does not suffice as an alarm signal for the operator of the rope but clear changes of the lay length indicate that something may be wrong. It should be noted, however, that certain applications where 6 and 8 strand ropes are suspended at great lengths (>500 m) lay length changes can occur which do not necessarily suggest problems with the rope or the reeving system. These changes would be as a result of the geometry of the lifting system and the rope self weight. In such cases the lay length measured on the operating rope may be quite different to the lay length at which the rope was manufactured. Certain standards give guidelines for discard criteria based on percentage changes in the nominal lay length of ropes, particularly in mining applications.

Another possibility to measuring the lay length - and at the same time create a document for the archives - is making a rubbing of the rope surface on a long strip of paper. This print is produced as follows: first the loose end of the wound-up strip is attached to the rope by means of sticky tape. Then the strip is unrolled along the rope length while a wax crayon is simultaneously drawn along the same zone. On the crowns of the strands you will get a clear print of the rope's outer wires. The paper strip is then labelled for later analysis (Fig. 23).

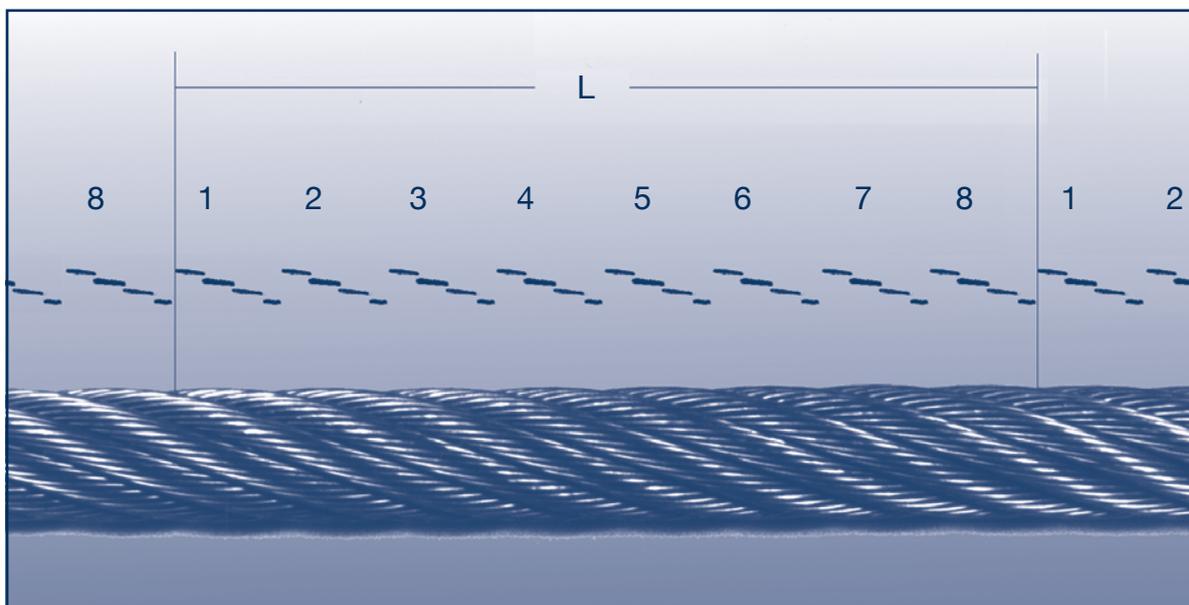


Fig. 23: Measuring the rope lay length

On site, it is possible to assess whether any lay length changes have taken place without measuring the lay lengths directly. Prints on paper strips can be produced of the rope zone being examined (while it is on the drum) and of the dead wraps at the fix point on the drum. Then, on both prints the strand crown “Zero” and, for example, strand crown “Twenty” are clearly marked. After that the paper strips are placed on top of each other and held up to the light. With the “Zero” strand crowns lined up, the distance between the two strand crowns “Twenty” indicates the lengthening (or shortening) of the rope over the twenty strand crowns and hence an immediate indication of the change in lay length. This technique is only applicable to installations where the lay length of the rope is not expected to change significantly due to the geometry of the reeving system.

### **Testing the structural integrity of the wire rope construction**

The structural integrity of the wire rope can be tested by putting a flat-head screwdriver between two adjacent of strands and then, without using too much force, trying to create a gap by turning the screwdriver. If the wire rope does not offer too much resistance to this twisting then we can be sure that slackening in the rope construction has occurred. Note that this practice should not be undertaken with Casar wire ropes with internal plastic layers.

The same procedure can be applied to determine whether the outer wires have become loose within a strand.

Lifting the top layer of strands forcefully with a screwdriver or a Marlin spike (Fig. 16), as is often practised to examine the condition of core rope, should be avoided. It happens often that the rope is irreparably damaged in this way, especially when there is moderate tension on the rope.

### **Examining structural changes**

Usually the initial damage to a rope is expected in the main working zone, i.e. in the areas that are exposed to the highest number of bending cycles or tensile loads. However, rope deformations such as corkscrews, birdcages or kinks can very often be found outside the main working zone because the sheaves can massage out those deformations and transfer them to different parts of the rope. Such deformations can therefore also be expected before the rope drum or before the end connections. It is necessary to examine these areas with equal care.

During the inspection the ropes must be moved in order to examine the zones which are not normally accessible. This can be done by changing the hook height or the position of the boom on a crane.

Indications of abrasion on a structural components (e.g. on a crane) may give valuable hints as to why the reeving system is not working perfectly (Fig. 24). These could also explain why abnormal damage to the rope has occurred.

Disturbances caused by the reeving system present rope discard criteria which are the most difficult to evaluate. If there is any doubt as regards the operational safety of the wire rope, it must be discarded. It is also critical that the problems identified in the reeving system are corrected before a new rope is installed.



Fig. 24: Indications of abrasion on a structural component

### Examining the sheaves and drums

Apart from the wire rope itself, all other parts of the installation that have contact with the rope deserve careful attention. The following statements applying to the rope sheaves but are also valid for the rope drums.

The grooves of the sheaves should be smooth and have a diameter that is slightly greater than the effective diameter of the rope. In DIN 15 020 a groove diameter of at least 1.05 times the nominal rope diameter is recommended. The standards DIN 5881 for the oil industry and DIN 15 061 for lifting devices explicitly state the minimum radii for rope sheaves and rope drums. In some cases they state lower values than recommended in DIN 15 020. The ideal diameter at the bottom of the sheave groove is about 1.06 to 1.08 times the nominal rope diameter.

If the groove is too tight, the wire rope is subject to high loads in the radial direction. This can lead to premature wire breaks and or to changes to the rope's structure (Fig. 25).

If the sheave groove is too wide, the wire rope will lack adequate contact area and support from the flanges. The increased contact pressure at the bottom of the groove and the additional wire tensions caused by the increased rope deformation (i.e. ovality of the rope cross-section) will also contribute to a reduction of the rope's service life.

The grooves are checked by means of sheave groove gauges. These gauges are widely available in different forms but best of all are circular templates produced on a lathe.

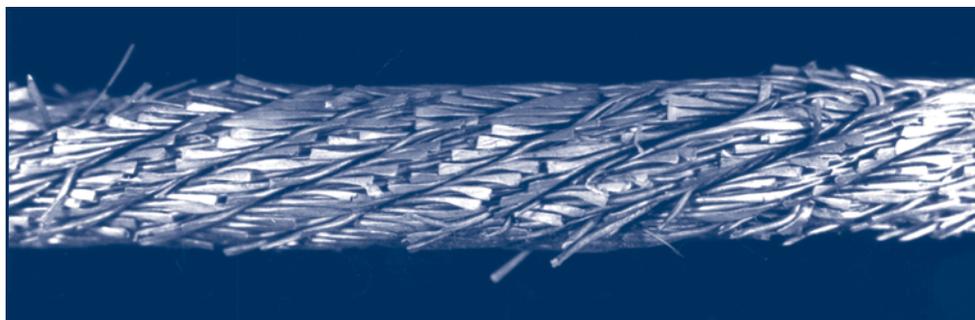


Fig. 25: Wire rope damage from a too tight sheave groove



Fig. 26: Groove gauge of the right size

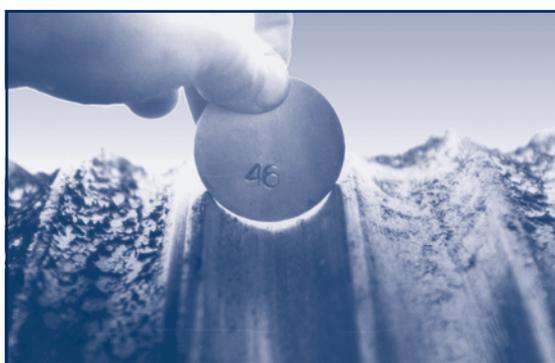


Fig. 27: Groove gauge bigger than the groove

It is advisable to produce separate groove gauges for each reeving system to be tested, with the diameter exactly the desired six percent bigger than the nominal rope diameter. Gauges with slightly smaller and slightly bigger diameters should be available for making comparative measurements.

For checking the groove diameter, one would insert the correct size groove gauge into the sheave groove and also examine the conditions of the contact area (i.e. the quality of the surface finish). If the gauge fits well into the groove's circumference then the groove dimensions are correct (Fig. 26). If the gauge touches the sides of the groove only, the groove is too narrow (Fig. 27). If it lies on a small part of the circumference only, the groove is too wide. In both cases additional gauges must be used to find out the extent of the deviation from the desired value.

Inspection is often made difficult by the cramped conditions of many installations. If it is not possible to check the contact area of the groove gauges from the sides, it is then possible to pull the gauge through the groove and then assess the contact conditions on the basis of the sliding tracks in the rope lubricant. A narrow track in the centre indicates that the groove is bigger than the gauge. A wide track in the whole groove bottom means that the groove and the gauge are of equal size. Two narrow tracks on the flanges suggest that the gauge is bigger than the groove.



Fig. 28: Indentations in a sheave groove

While measuring the groove we simultaneously check the size of the groove and its surface condition. Indentations and other changes of the surface often reduce the

rope's service life considerably. If negative imprints of the rope can be found in the groove bottom (Fig. 28), these may provide optimal contact areas for the current rope but as soon as the rope is changed the new rope will not fit into this pattern of negative imprints and will be destroyed quickly. Sheaves with severe imprints must be changed together with the rope. Alternatively, if remachining of the groove is possible, this must be done before the rope is changed.

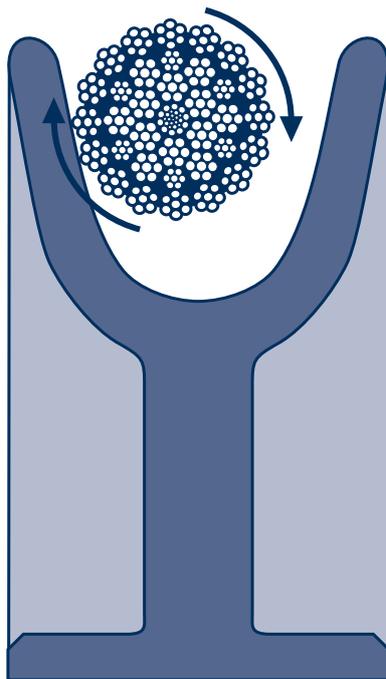


Fig. 29: The rope rolls into the groove bottom

The flanges of the sheaves must also be inspected regularly. Traces of abrasion in the radial direction towards the groove bottom indicate that the rope, when running over the sheave, first contacts the flange and then rolls into the groove bottom (Fig. 29). This has two dangerous implications: the rope might be twisted by the sheave or it might climb out of the sheave altogether.

The reason why the rope first contacts the sheave flanges is because the fleeting angle which the rope makes with the sheave is greater than the recommended value. DIN 15 020 recommends a maximum fleeting angle of  $4^\circ$  for non-rotation-resistant ropes and  $1.5^\circ$  for rotation-resistant (non-spin) ropes.  $4^\circ$  is equivalent to a deflection of about 1 m over 14.3 m, and  $1.5^\circ$  is equivalent to a deflection of 1 m over 38.2 m.

If the sheaves can be turned when the rope is unloaded, they should be tested for smooth running of their bearings and that they run true. This is ideally measured with a clock gauge set up to follow the machined inner flange of the sheave.

When loaded a wire rope elongates and when unloaded it shortens. During these processes the rope zones which are in contact with a sheave or drum can be subject to abrasion. As a rule, this abrasion occurs over the whole rope length, on the circumference of the sheaves and over the windings on the drum. However, in installations with highly repetitive motion, the same rope zones always carry out the same relative motions on identical parts of the drum and sheaves. Therefore, it is necessary to inspect these loading points with special care.

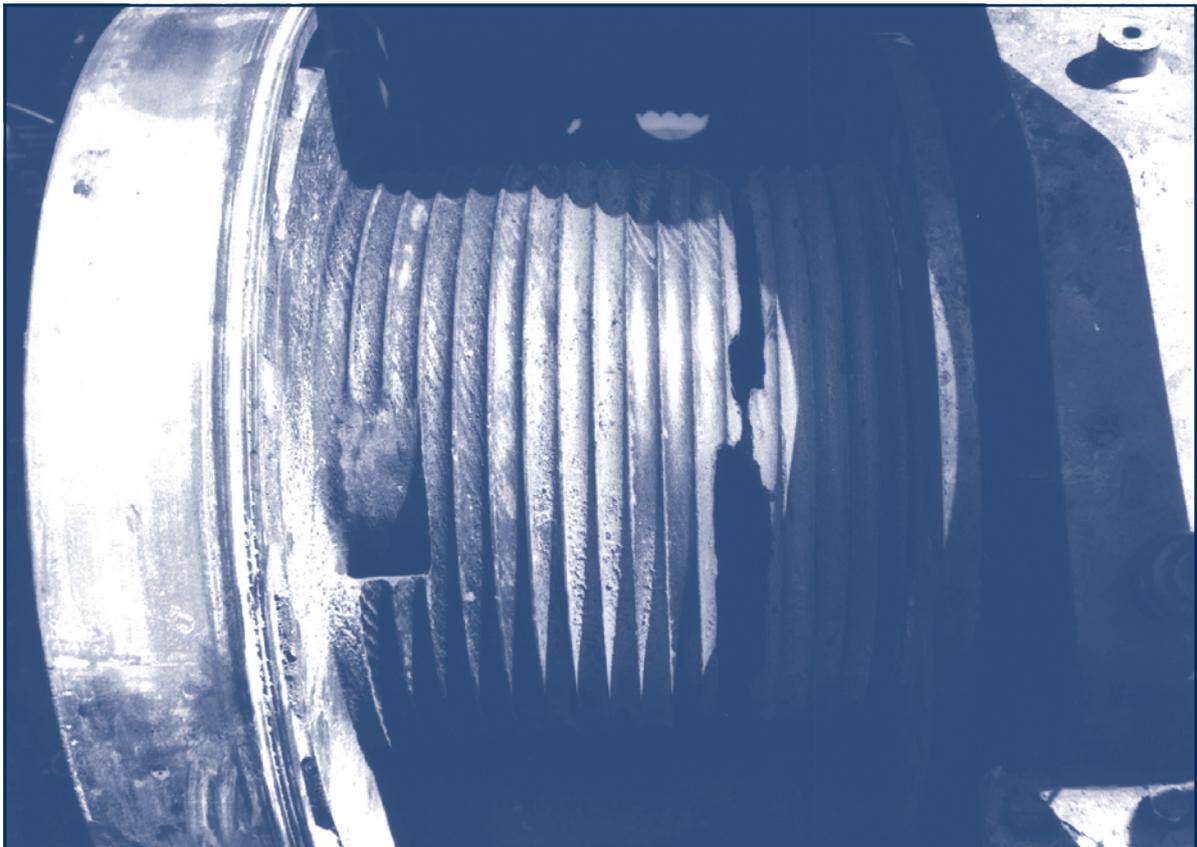


Fig. 30: A drum severely worn at the loading point

Fig. 30 shows the drum of a dragline on which two parallel ropes are wound with a double pitch arrangement. In the zone of the loading point, the drum has virtually been cut in two by the two wire ropes. Newly installed ropes on this drum would experience extremely bad operating conditions and would definitely fail prematurely.

In order to avoid such concentrated stresses on a drum, the loading point should be shifted at regular intervals during the rope's service life. If this is not possible, one can also slightly alter the rope length after certain periods of operation so that the loading point on the drum is shifted.

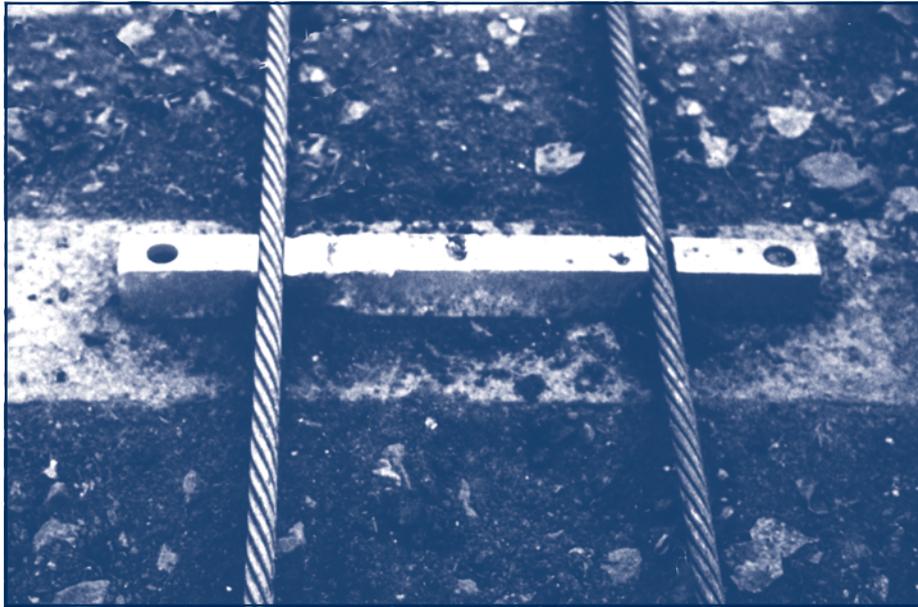


Fig. 31: Heavily worn rope support bars

Horizontal running ropes will always show a certain degree of sagging. In order to avoid abrasion on structural members (e.g. of a crane) or on the ground, wooden boards or plastic sheets are often installed. They should also be examined carefully during an inspection. If these supports are heavily worn (Fig. 31) there is a danger that a new, slightly thicker rope gets stuck in the grooves, is damaged or even breaks.

### **The inspection of rope end connections**

When inspecting a wire rope, the end connections require special attention. Standing ropes, under pulsating stresses, often fail along the transition zone between the elastic wire rope and its inelastic end connections.

Rope clamps, according to DIN 1142, are not permissible for permanent use in reeving systems. During an inspection the clamp bolts should be tightened up. If there is any doubt about the condition of the rope beneath a clamp, it can be replaced with another clamp and can then be inspected. The percentage of wire rope clamps that are attached the wrong way round is alarming. Therefore, their correct arrangement should always be examined during an inspection. The saddle must not be put on the dead, but on the live end. Just remember: Would you saddle a dead horse?

Fig. 32 clearly illustrates the operator's insecurity. Since he did not know which line to put the saddle on, the clamps were fitted alternately right and wrong. The twisted thimble indicates that the rope has slipped within the clamps.



Fig. 32: Rope clamps attached incorrectly

Spliced rope terminations must be examined with respect to wire breaks and slipping of the tucked strands. This is why a splice must not be wrapped up in a permanent manner. Unfortunately, the discard number of wire breaks for splices has not been stipulated yet. Of course, the slipping of one tucked strand is difficult to detect, as the rope inspector doesn't know its original position. Occasionally the rope splice is painted after the first loading. Any slipping of the strands will then be visible, i.e. if non-painted areas appear.

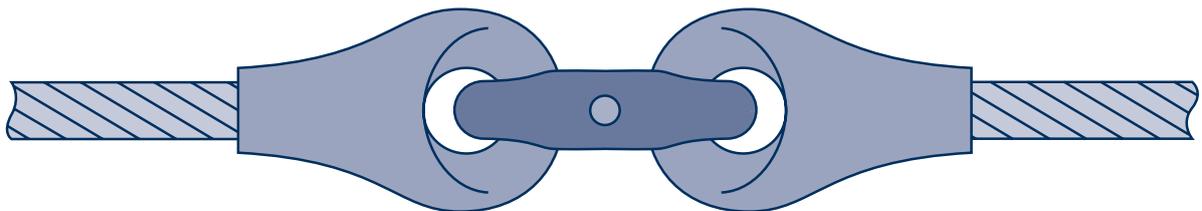


Fig. 33: Pear-shaped sockets with connecting link

Wedge sockets must be inspected with regard to wire breaks along the zone where the rope leaves the socket and along the deflection zone. The bolts of the rope's safety block attached to the dead end must also be tightened up. Asymmetrical wedge sockets are often fitted the wrong way around. Under load this will lead to bending of the rope where it leaves the wedge socket. When inspecting sockets make sure they are arranged in the right way - this takes only a second longer.

With spelter sockets the rope zone adjacent to the throat of the socket is particularly at risk because it may have been treated with acid during the fitting of the end connection in order to roughen the wire surfaces. In the event that this zone was not carefully impregnated with a lubricant afterwards, severe and frequent corrosion is to be expected there.

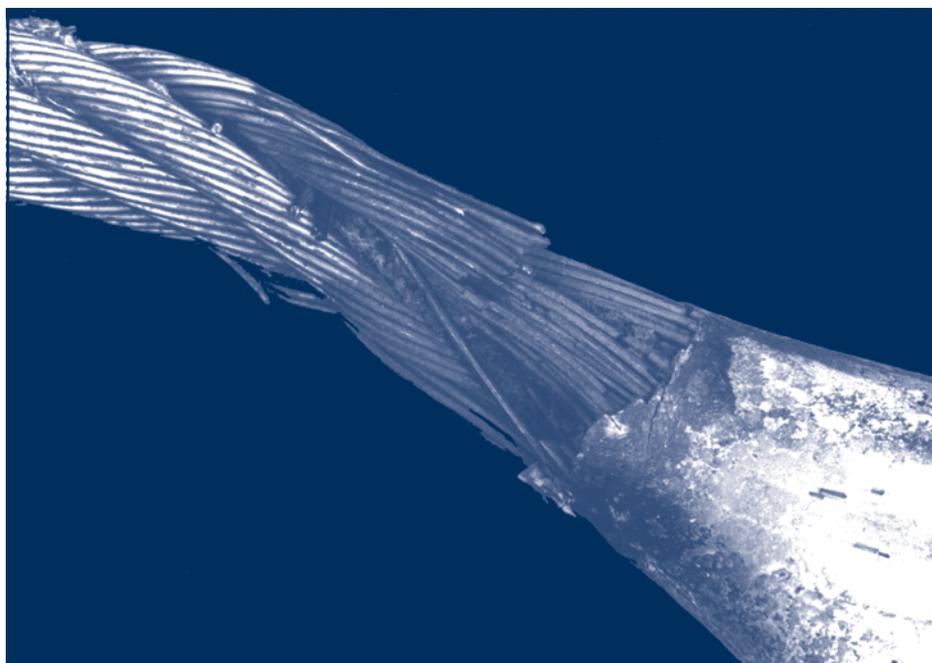


Fig. 34: Damage to a wire rope at the exit point of a pear-shaped spelter socket

In particular this applies to a special design of the spelter socket, the pear-shaped socket (Fig. 33) which usually connects the ropes of a grab with its closing ropes. Here it happens quite often that after a short service period the spelter metal is wedged out of the trumpet-shaped exit zone of the socket (Fig. 34). The wires which were originally covered by the spelter metal lie bare and unprotected. When exposed to rain, there will always be water trapped in the trumpet-shaped exit zone of the socket. With every operation of the pear-shaped socket over the sheave the wire rope is bent right next to its exit from the socket. This leads to very high stresses in the outer strands along this critical zone.

With pressed aluminium or steel sleeves the rope is slightly deflected in the area where it leaves the sleeve when being loaded. Therefore this area should be given special attention during inspections. In case of pulsating loads, cracks can occasionally occur in the sleeves. If this occurs, the end connection must be replaced.

The swaged socket and Flemish eye avoid the problem of eccentric loads so that the rope is not bent at the termination during a change of load. Nevertheless, the wire rope should still be inspected at the exit of the socket.

Shaped steel thimbles, according to DIN 3090 and solid thimbles, according to DIN 3091 must be examined for cracks, damage and changes of their geometry.

### **Assessing the internal condition of wire ropes**

The visual inspection of wire ropes, especially for determining the discard number of wire breaks, is usually limited to the visible rope surface. Strictly speaking, this only includes the outer strand outer wires where these are on the rope surface. The steel core, the internal wires of the outer strands and the zones in which the outer wires lie inside the rope are not directly accessible for visual inspection.

The percentage of outer wires compared with the total metallic cross-sectional area of a wire rope is usually between 36 % and 44 %. This means that only about 40 % of the rope wires are accessible during visual inspection and of these, only really the parts on the outside of the rope. So you might rightly say that the visual inspection of a wire rope covers no more than 20 % of its metallic cross-sectional area, whereas 80 % remains hidden to the inspector.

Visual rope inspection = 20 % evidence + 80 % hope

In order to assess the internal condition of wire ropes, quite often a short zone of the rope is unlaidd with the help of two screwed-on levers until the outer strands are raised from the rope's steel core. This method makes the undersides of the outer strands and the steel core accessible to inspection. If the technique is not carried out by a rope expert and with great care, the rope construction can be severely damaged in the zone being inspected. This area will later be far more prone to various kinds of damage. Therefore, this procedure should only be carried out by skilled experts and only on particular types of rope construction.

Raising the outer strands with the help of a Marlin spike is not recommended either. A well manufactured, tightly closed rope can not be opened without using some force. This can also lead to severe damage in the area being inspected. As in the case above, the inspected zone will be susceptible to various kinds of damage during the subsequent operation of the rope.

There is an alternative and very reliable procedure for assessing the condition within a rope - magnetic non-destructive testing, NDT.

### **Magnetic testing of wire ropes (NDT)**

Usually, after a certain working period, wire ropes clearly indicate their state of deterioration through visible abrasion and or wire breaks on their outer surface. However, there are certain operational instances where a wire rope can predominantly generate wire breaks and loss of metallic cross-sectional area on the inside of the rope. Some rope constructions are also more prone to internal wire failures than others. This depends very much on the design of the rope, the quality of its manufacture and the working conditions.

Ropes which are subjected to fluctuating load and rotation are often susceptible to internal wire breaks due to the excessive strain and fretting of the internal rope elements. Furthermore, when running on plastic or plastic-lined sheaves (which offer much more elastic support than steel sheaves), the pressure between the outer wires and sheave groove can be reduced so much that with some rope designs the first wire breaks do not occur on the outside of the rope's surface but inside the rope.

In all these cases, NDT techniques allow for effective rope inspection, including the internal conditions, without causing any damage to the rope.

Depending on their design, the NDT equipment obtainable on the market allow the display or continuous recording of local rope damage such as wire and strand breaks, soldering or welding spots, pitting, assessment of changes in metallic cross-sectional area caused by corrosion as well as measurement of the loss of metallic cross-sectional area due to abrasion along the whole rope length.

The damage data obtained during a NDT examination can be traced to an exact position along the length of the rope. The rope length is continuously measured by means of a length measuring device (e.g. a wheel with a shaft encoder) during the testing period. In this way damage zones along the rope length can be linked to the corresponding signals on the measurement plot. This information then allows for a more precise visual inspection of those rope zones which showed particular discrepancies.

Recording the data of regular NDT inspections enables the operator to compare each new trace with previous ones. In this way the process of the rope's degradation can be monitored and the future rate of degradation predicted.

The first NDT equipment for wire ropes was developed in the early 1900's. Until recently only a few specially trained experts could use such machines effectively. However, over the last decade these instruments have been improved considerably and are more user-friendly and consistent in their output. Nowadays many more technicians can make effective use of magnetic testing equipment. Computer based data storage and analysis has also made the recording of the NDT history of a particular rope a lot simpler.

NDT instruments are currently being developed which do not only record the data of rope measurements but also - by means of sophisticated computer algorithms - process the data with regard to the amplitude and frequency of the magnetic flux signals and inform the inspector about the extent of the rope deterioration. This aids considerably in the overall condition assessment of wires ropes, particularly in safety critical applications. Casar, in collaboration with the University of Stuttgart have developed and market a range of advanced wire rope NDT machines. The CMRT (Casar Magnetic Rope Tester) is offered in three sizes. The smallest machine, the CMRT 16, tests ropes with a diameter of 4 mm to 16 mm and a maximum metallic cross-section of 130 mm<sup>2</sup>. With the CMRT 40 ropes with a diameter of 16 mm to 45 mm and a metallic cross-section of max. 1000 mm<sup>2</sup> can be tested. The diameter for testing with the CMRT 60 is from 35 mm to 60 mm with metallic cross-section of up to 2400 mm<sup>2</sup>.

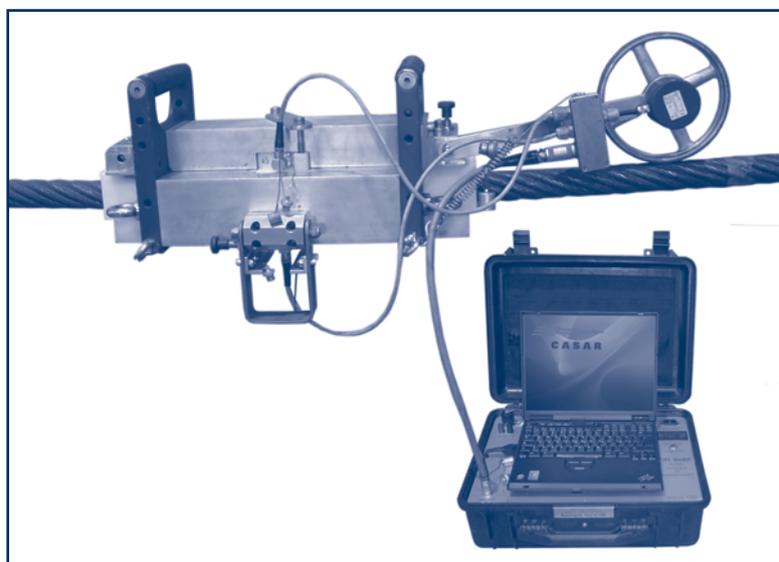


Fig. 35: Wire rope NDT instrument

At present instruments are being developed which, apart from the features mentioned above, can also record the rope diameter and the lay length and will therefore be capable of recognising ovality of the rope's cross section, corkscrews or changes of lay length along the whole rope length.

For magnetically inspecting a wire rope, a hinged measuring head is placed around the rope. Then the whole length of the rope is run through this measuring head. If this is not possible, for instance with the standing rope of an aerial ropeway, the measuring head is pulled along the rope. During this process all the measurement data are transmitted to an amplifier via cable or radio. The results are presented either visually or acoustically, recorded on a magnetic tape or hard disk and simultaneously plotted as a graph (either on paper or on a laptop computer screen). Fig. 35 shows a typical magnetic testing instrument.

The calibration of the test instrument must be carried out with the greatest care. It is common practice to fix pieces of wire to the first few meters of the rope being inspected. These pieces of wire would match the diameters of the thickest and thinnest wires of the particular rope construction. They are attached by means of sticky tape in the valleys between the outer strands. In this way the inspectors can obtain reference values along the first centimetres of their recording which indicate the extent of the signal deflection for broken wires of these diameters.

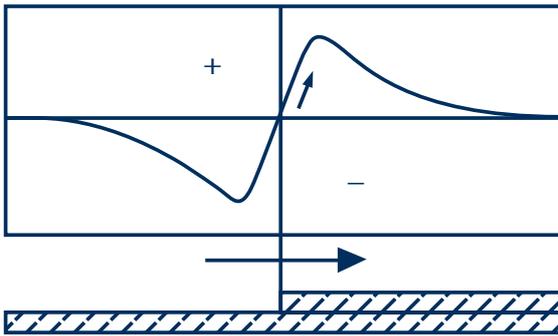


Fig. 36: Beginning of a wire

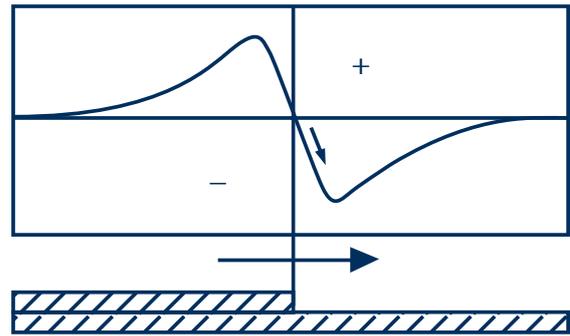


Fig. 37: End of a wire

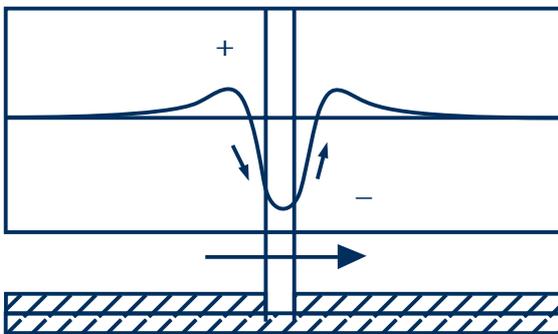


Fig. 38: Wire break

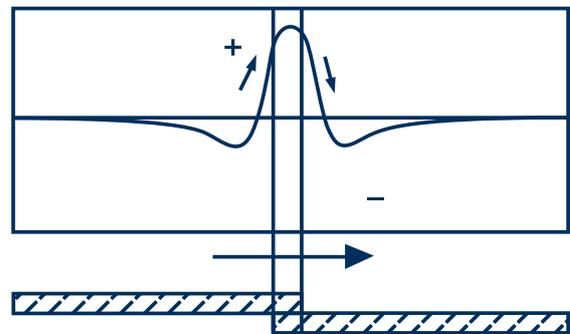


Fig. 39: Overlapping wires

Figs. 36 to 39 show typical theoretical signals of the beginning of a wire, the end of a wire, a composition of these two with the broken ends pulled apart and a wire break with overlapping wire ends. However, it must be noted that such clear signals will not normally be found in practice. Fig. 40 presents a typical graph of a rope zone with wire breaks, Fig. 41 gives a typical NDT recording of a corroded rope zone.

The following two examples are meant to illustrate the problems when interpreting the measured NDT signals:

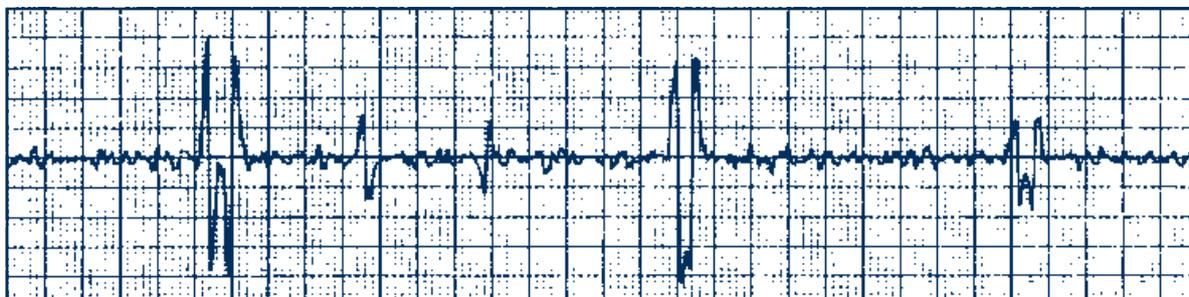


Fig. 40: NDT recording with wire breaks

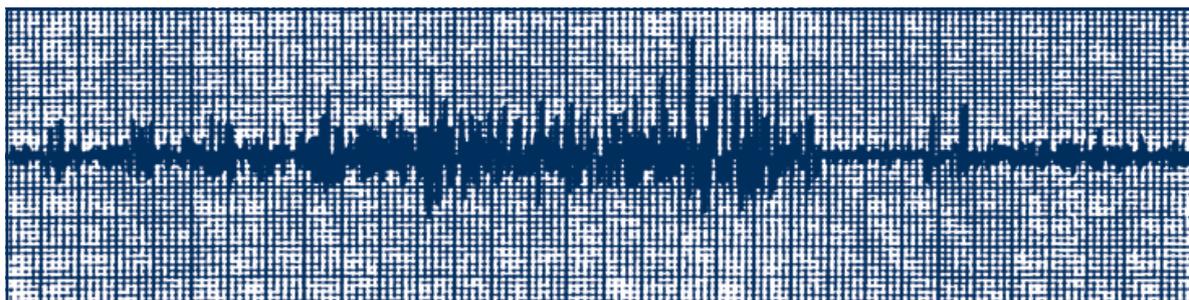


Fig. 41: NDT recording of a corroded rope zone

Fig. 42 shows a 6 x 19 Seale rope with a fibre core according to DIN 3058. Due to the nature of the rope construction, all the 54 outer wires return to the rope surface at very short intervals. Here they suffer a loss of metallic cross-sectional area caused by say abrasion (shown in black).

For every cross-sectional view of the rope, the magnetic test instrument measures the loss of metallic cross-sectional area of the outer wires which are on the outside of the rope at that particular point. This corresponds, for example, to a loss of metallic cross-sectional area of 6 % (see sections marked black in Fig. 42). However, due to the weakening of all 54 wires instead of only 12 wires (see sections marked black in Fig. 43) the effective loss of breaking strength (i.e. cross-sectional area) amounts to nearly 30 %.

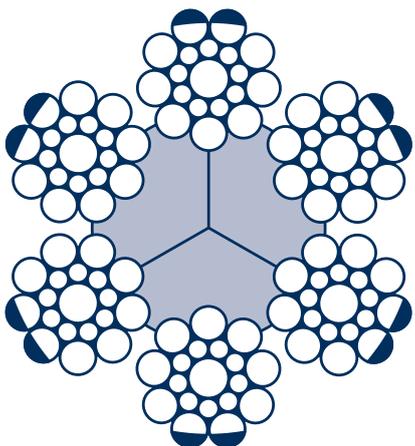


Fig. 42: 6 x 19 Seale rope with a fibre core, apparent loss of metallic cross-sectional area

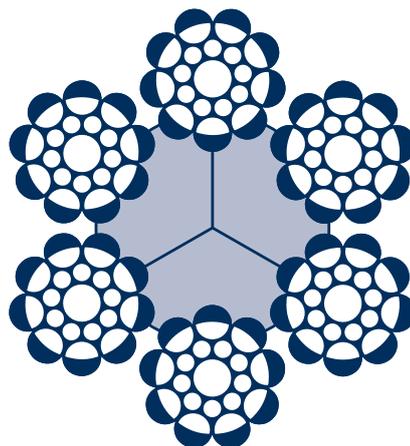


Fig. 43: 6 x 19 Seale rope, effective loss of metallic cross-sectional area

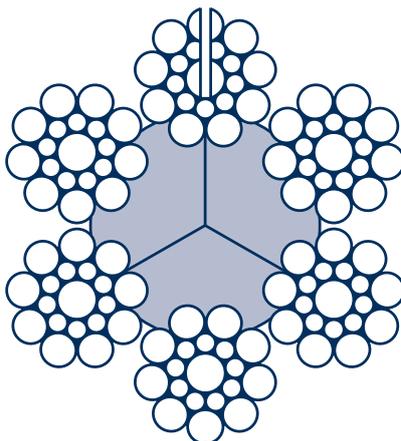


Fig. 44: 6 x 19 rope with a fibre core with a slot cut in one outer strand

Fig. 44 shows the same 6 x 19 Seale rope with fibre core according to DIN 3058. A slot has been cut into the rope along its axis up to slightly over half the diameter of the outer strand. The slot extends over one lay length. When looking at the cross section one would think that only a few wires have been damaged. However, due to their helical shape all 19 wires of the cut outer strand have been severed. The other 5 outer strands also lie in this zone because of their helical arrangement in the rope. Consequently this single slot, one lay length long, cuts through all the rope's elements. Therefore the loss of load bearing metallic cross-sectional area is 100 %. The magnetic test instrument, however, only indicates a loss of metallic cross sectional area of 1 % over the damaged length because its measurement of the metallic cross-sectional area is restricted to one cross-sectional view only.

Magnetic testing procedures cannot and must not completely replace visual inspection of wire ropes. They do, however, deliver additional information about the state of degradation of ropes and must be regarded as a valuable addition to visual inspections.

The discard number of wire breaks, as stipulated in DIN 15 020, only refers to wire breaks visible from the outside of the rope. The assessment of the discard state resulting from internal wire breaks is therefore at the inspector's discretion but he would be well advised to regard the values given in DIN 15 020 as also binding for internal wire breaks. It requires enormous expertise and experience to select the appropriate type of instrument, to handle the NDT equipment professionally and to interpret the data obtained in an effective manner. Several universities, test laboratories and other commercial enterprises offer NDT inspection of wire ropes as a service.

### **Case study I: Internal wire breaks**

The operator of a crane had regularly inspected his hoist rope, 36 x 7, visually according to DIN 3071 and noted his observations. During the last inspection he was pleased to see that after an operating period of several months his rope did not show any outer wire breaks or other symptoms of damage. The following day the rope broke and caused significant damage.

Fig. 45 shows the external state of the rope near the point of failure. One can make out small ellipses of wear on the strand crowns, an indication that the rope had been in service for some time. However, there are no hints as to the poor conditions inside the rope.

Fig. 46 shows the steel core after removing the outer strands. In this layer, all the wires are broken into lengths of 2 centimetres or less. In most cases the breaks can be found at the contact points between the steel core and the outer strands. Fig. 47 shows the most inner layer of strands. Here, too, the wires are broken into lengths of 2 centimetres or less.

This example is by no means exceptional. It simply illustrates the difficulty of having to decide, from only a visual inspection of the outer wires during a rope inspection, on the general state of the whole rope.

Rotation-resistant or non-spin ropes are particularly affected by these problems for two reasons: on the one hand the steel core of these ropes (which is not visible from outside) is proportionally larger than in other ropes which makes inspecting them more difficult. On the other hand the rotational stability of these rope constructions is achieved by closing the outer strands in the opposite direction to the lay of the steel core. Therefore, crossovers of the strand layers are unavoidable and these lead to very high contact stresses between the inner and outer strands. 18 x 7 wire ropes

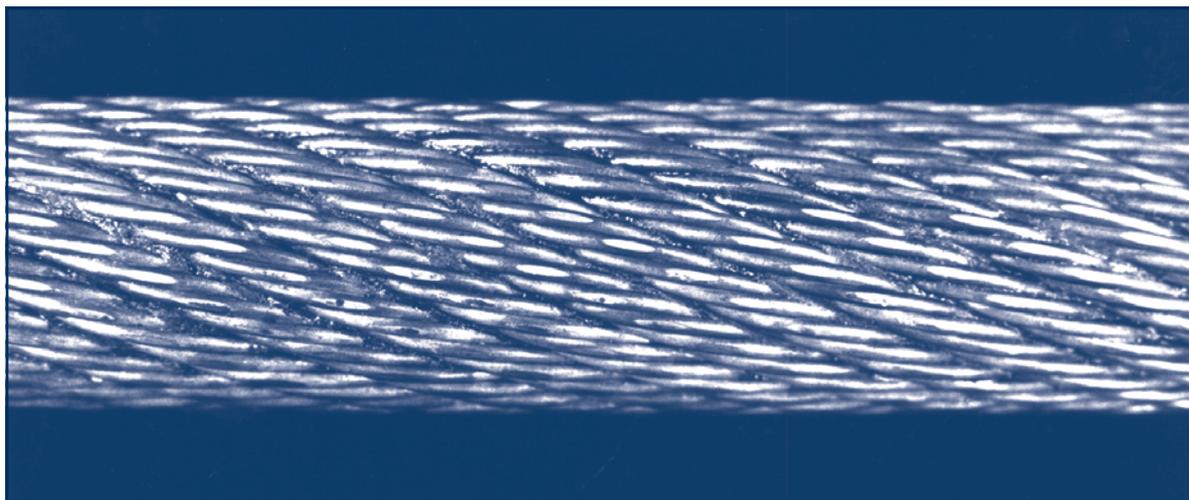


Fig. 45: The external condition of the crane rope (3rd layer)

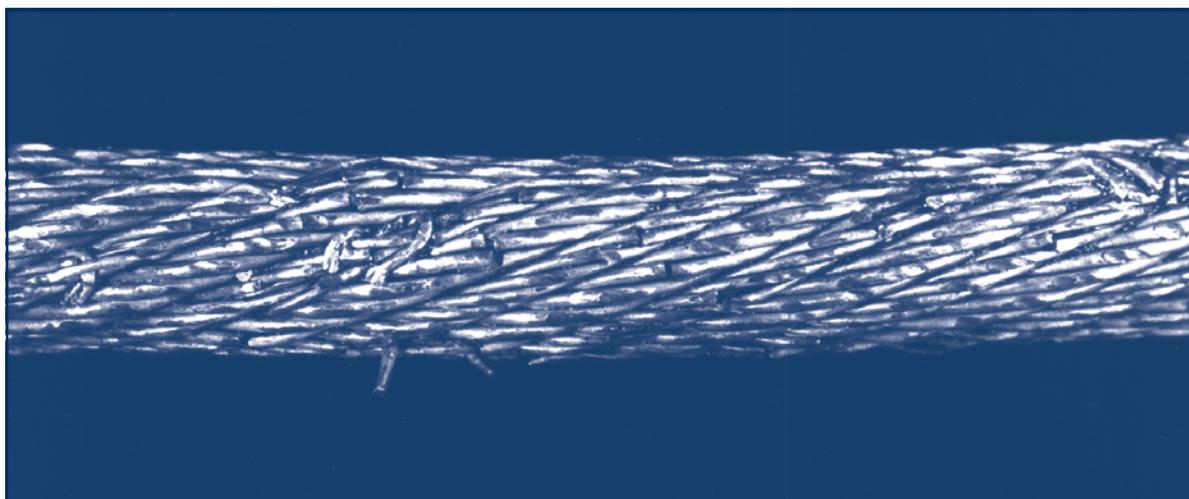


Fig. 46: The internal condition (2nd layer)

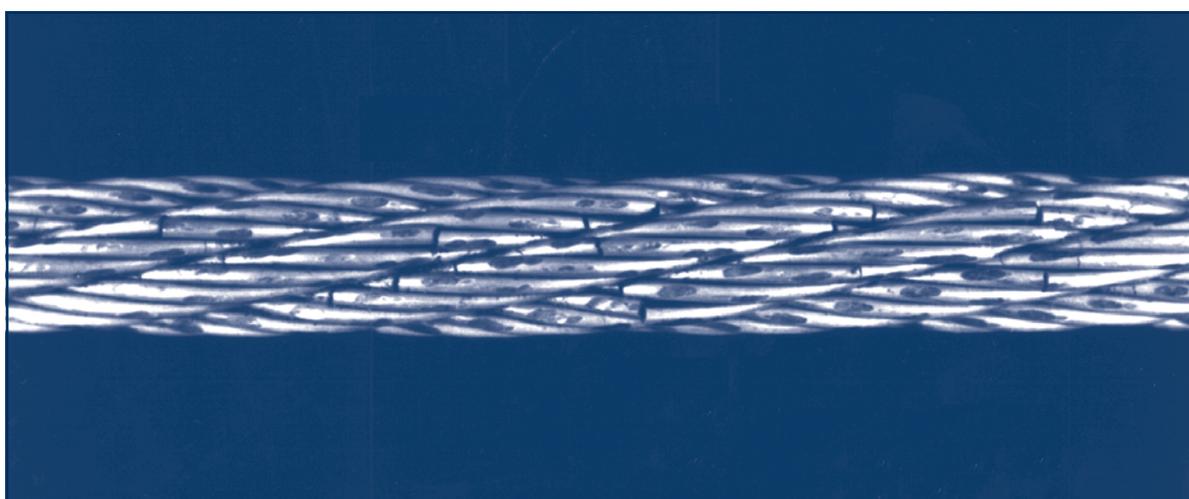


Fig. 47: The internal condition (1st layer)

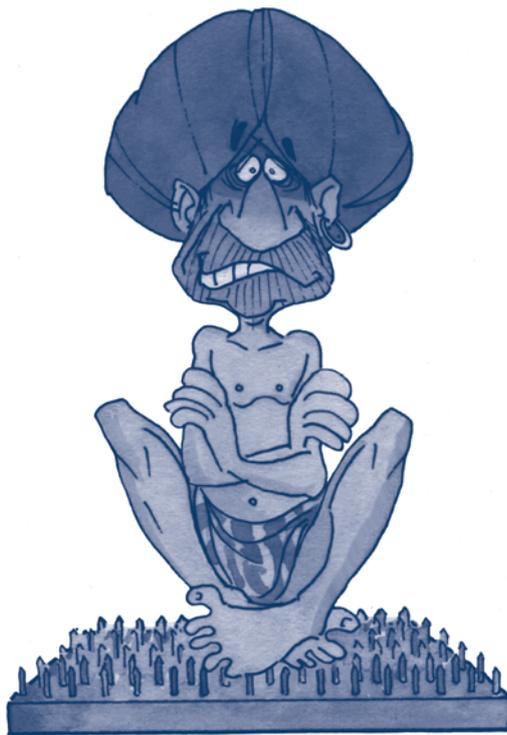


Fig. 48: Contact conditions for a conventional design of the steel core of a rotation resistant rope



Fig. 49: Contact conditions for a special design of the steel core of a rotation resistant rope - in this case the core has been compacted before closing of the outer strands

according to DIN 3069 and their variations as well as 36 x 7 ropes according to DIN 3071 are especially susceptible to the problems described above.

Therefore, when designing rotation-resistant wire ropes one should ensure that the steel cores are manufactured with a parallel lay arrangement without any strand crossovers. In addition, rotation-resistant ropes whose wire rope cores have been compacted (and therefore flattened on their outer surfaces) offer especially favourable conditions at the crossovers between the outer strands and the strands of the steel cores.

Fig. 48 illustrates the contact conditions of conventional rotation-resistant ropes at the crossovers between the outer strands and the steel core. Such ropes are designed to fail internally yet that are still sold by many rope manufacturers.

Fig. 49 shows the contact conditions at the crossovers between the outer strands and the steel core of rotation-resistant ropes with compacted rope cores which have a flattened outer surface. Clearly this is a much more comfortable design!

### **Case study II: Shot blasting**

When inspecting a relatively new rope the inspector detected a surprising number of wire breaks. The wire rope was due to be discarded. The operator had it cleaned to determine the reason why the rope had failed so unexpectedly. Along great lengths, the rope showed equally distributed damage, clearly caused by foreign bodies not much bigger than the diameter of the wires (Fig. 50). In some places metal balls were found which had penetrated the strand construction (Fig. 51).

The reason for the rope's premature failure was quickly discovered: the crane had recently been painted and its structure had been shot blasted with steel balls. Some of these stuck to the lubricant of the wire rope and later on got between the rope and the sheave where they were pushed into the rope surface causing the damage shown.

### **Case study III: The most heavily loaded rope zones**

When inspecting a wire rope the rope zone suffering the highest number of bending cycles should be given greatest attention. For cranes, which constantly carry out the same lifting operations, this zone can be identified relatively easily.

For instance, in case of a four-part overhead crane (Fig. 52, insert) whose hook block always runs through the full lifting height, the most heavily loaded zone with the hook at the lowest point cannot be found, as is often maintained, on the "fastest" fall leading to the drum, but rather on the "slowest" fall leading to the fix point. Fig. 52 shows the distribution of bending cycles for the case in question. The first rope failure caused by fatigue is to be expected on the fall leading to the fix point.

The case is quite different for reeving systems which travel to different points with every lifting action. The distribution of bending cycles may then assume the shape as shown in Fig. 53. The most heavily loaded rope zone can in many cases not be determined.

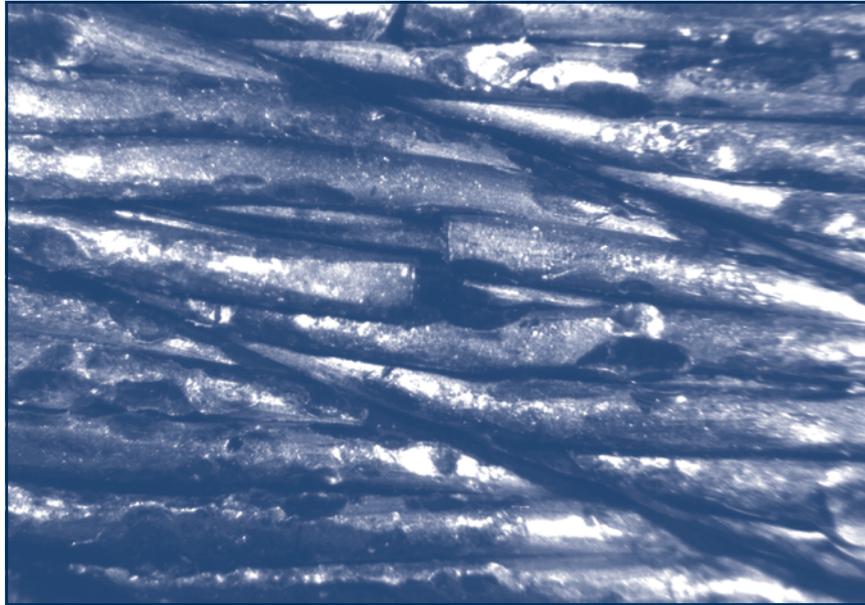


Fig. 50: Damaged wire rope surface

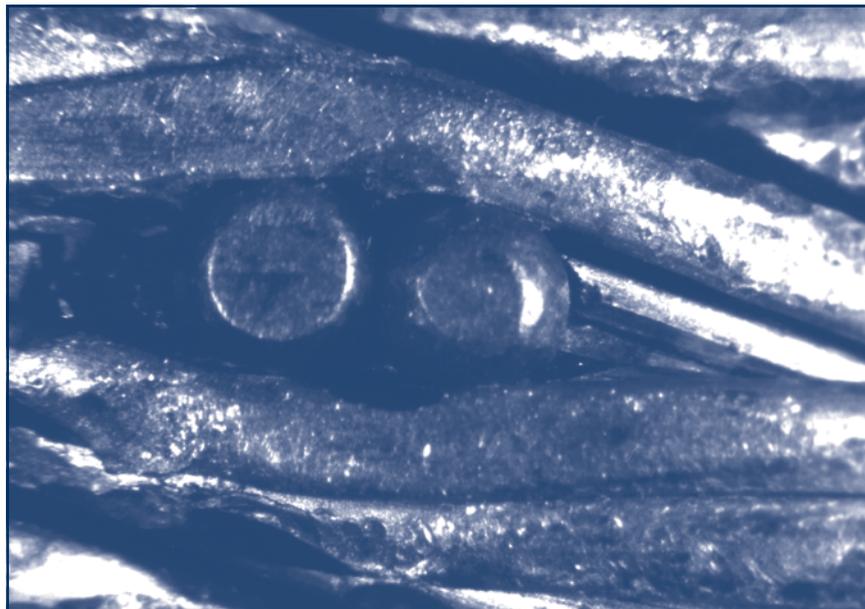


Fig. 51: Steel balls between the rope wires

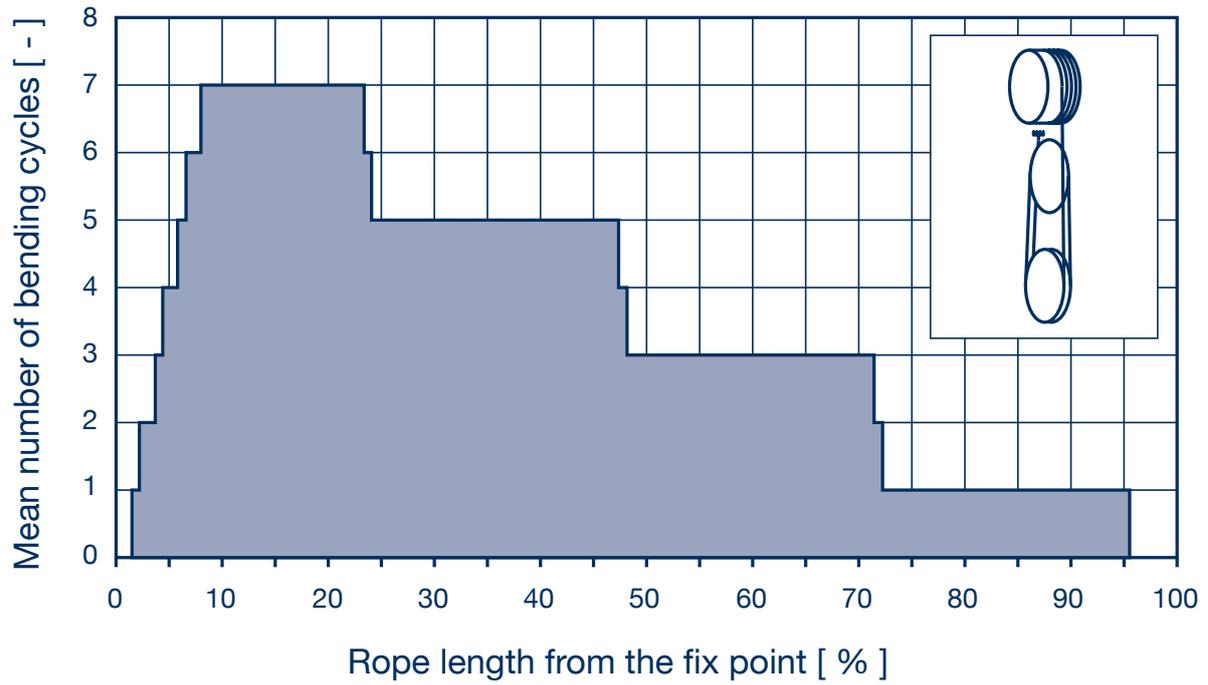


Fig. 52: Mean distribution of bending cycles for four times the same lifting action

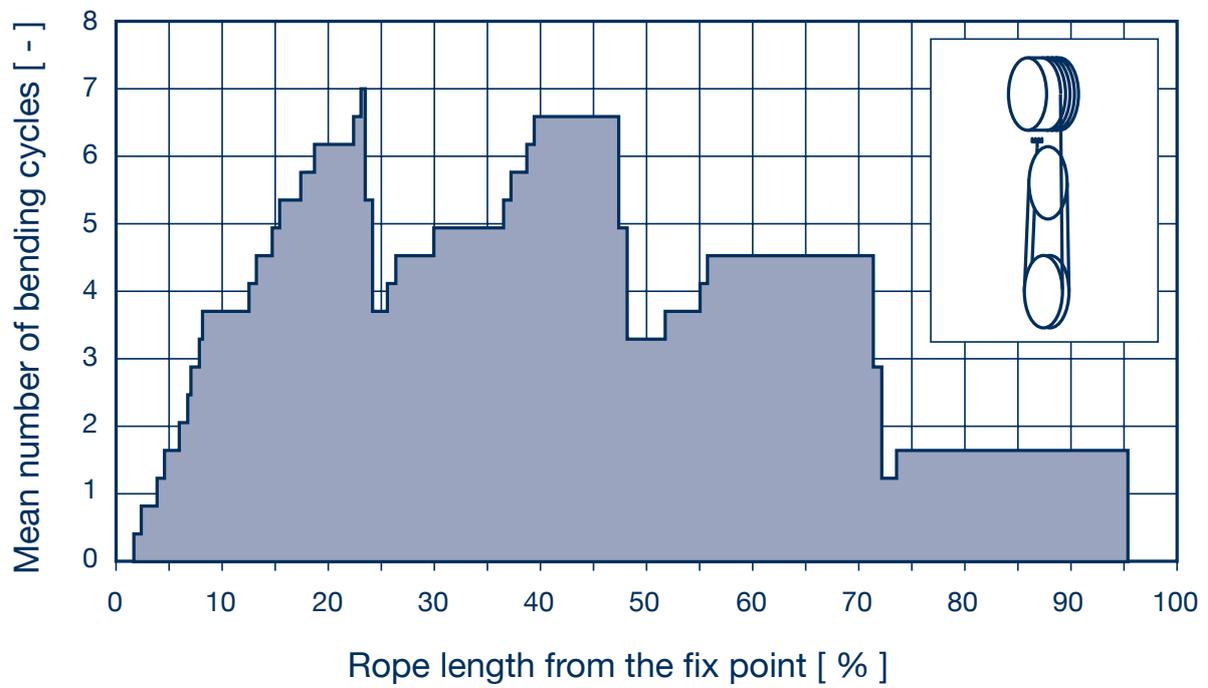


Fig. 53: Mean distribution of bending cycles for four different lifting actions

### Case study IV: The most heavily strained rope zone in lifting systems with multi-layer spooling

Recent investigations which were carried out on two multi-layer drum test stands at the Institute of Materials Handling, University Stuttgart and by Casar Drahtseilwerk Saar GmbH prove that a bending cycle on a multi-layer spooled rope drum damages a wire rope by a factor of 6 to 40 times more when compared to a bending cycle on a rope sheave or on a single-layer spooled rope drum. This is the reason why, despite multiple-reeving (over sheaves) and the associated rope fatigue, a mobile crane reaches the discard state of its hoist rope on the rope drum first.

Fig. 54 shows the distribution of bending cycles for an eight-fall crane hoist lifting its load to the maximum lifting height. The crane is equipped with a single-layer rope drum. The greatest rope fatigue is again expected in the “slowest” rope fall.

Fig. 55 shows the same distribution for a similar crane equipped with a multi-layer drum. Note the rope zone entering the drum is damaged 40 times as much. The consequence is that the most heavily stressed rope zone is no longer in the “slowest” fall but in the “fastest” one and on the rope drum.

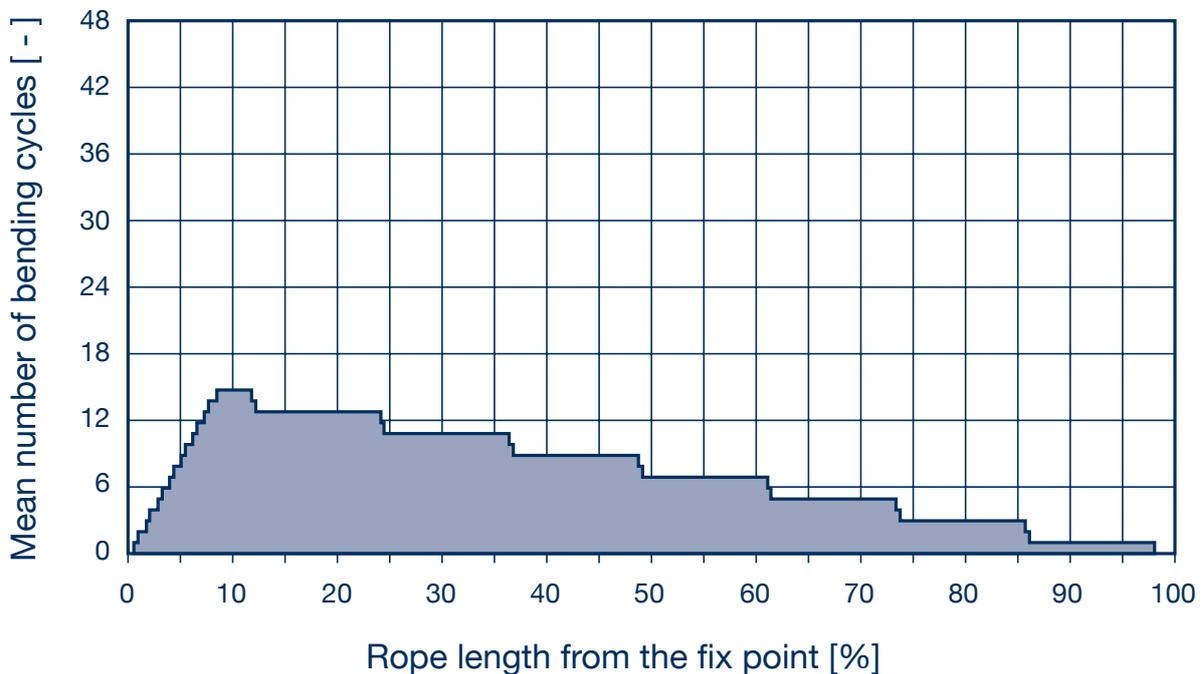


Fig. 54: Distribution of rope damage for a crane with an 8-fall reeving system

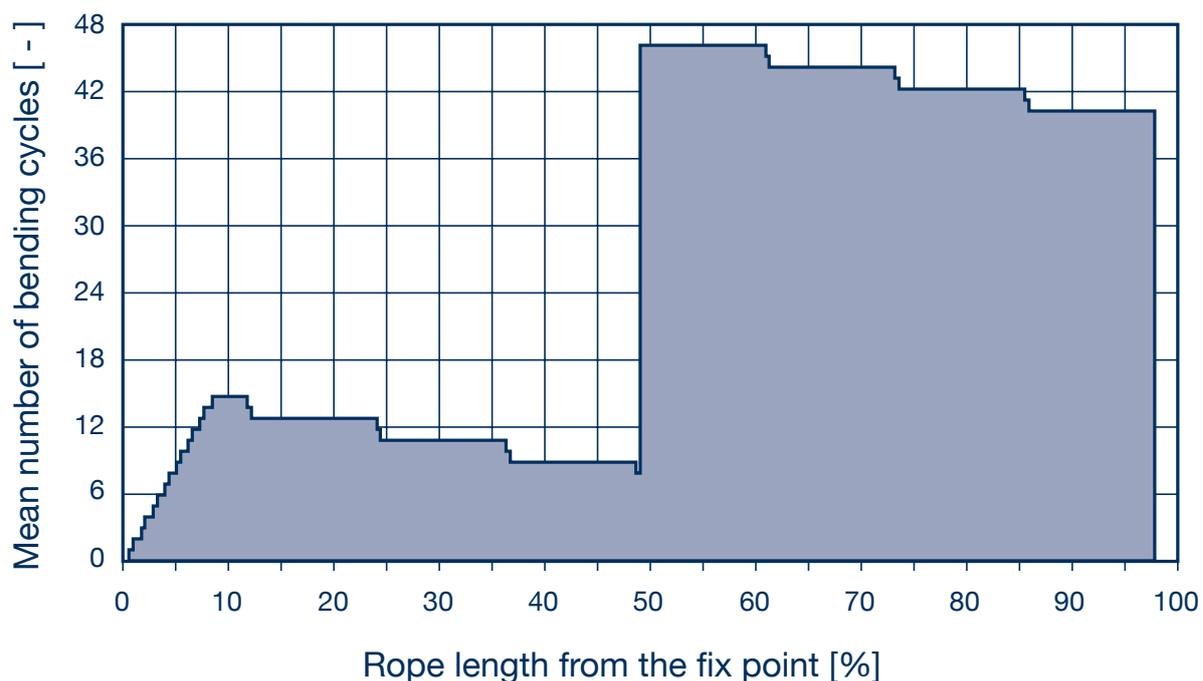


Fig. 55: Distribution of rope damage for a crane with an 8-fall reeving system and multi-layer spooling

### Case study V: Suspension bridge in a theme park

A wire rope expert was asked to inspect the wire ropes of a suspension bridge (Fig. 56) in a theme park. In order to be able to inspect the main rope under the pedestrian crossing in the area of the saddles, the inspector demanded that the wooden beams of the walkway above the saddles be dismantled.

The operators of the bridge tried to convince him that “nothing could happen” in that zone, because there the rope is fixed and can not move. For the inspector, however, this kind of argument was proof enough that the operators had definitely not inspected that part of the rope before. He insisted on dismantling the beams.

Just as well - along the saddle zone the six-stranded wire rope had almost completely been destroyed by corrosion (Fig. 57). Five strands were totally broken, the sixth showed only a few intact wires and would surely have broken a couple of days later. Several visitors probably would have lost their lives in the resulting accident. The moral of the story is:

1. There are no spots “where nothing can happen anyway”.
2. If you are told, “you need not inspect that spot”, you can almost be sure that not a single inspection has taken place there. Therefore that spot must be inspected with special care.

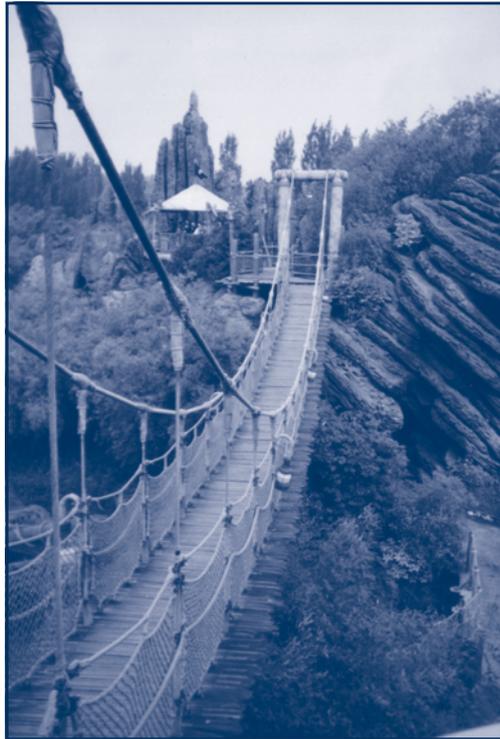


Fig. 56: Suspension bridge in a theme park



Fig. 57: Severe corrosion and rope failure on the saddle point

3. Saddle points are always at risk of being corroded, especially if they are covered. After a rain shower, sun and wind will dry the most of the rope, but not the section at the saddle point.

### Case study VI: Overhead crane with twin-drum system & compensation sheave

An overhead crane with great lifting height requires two rope drums for storing its large rope length. The symmetrical reeving system has a compensating sheave in the middle. Several times per day the crane lifts a load, transports it and puts it down somewhere else. Where is the rope zone with the highest number of bending cycles?

Zone B (Fig. 58) runs over the lower sheave during a lifting operation and back again when the load is lowered. So, during every lifting and lowering procedure it carries out two bending cycles.

Zone A runs over the lower sheave and onto the drum (i.e. 1 1/2 bending cycles). When the load is lowered Zone A leaves the drum and runs over the lower sheave, thus carrying out 3 bending cycles in total with every lifting procedure.

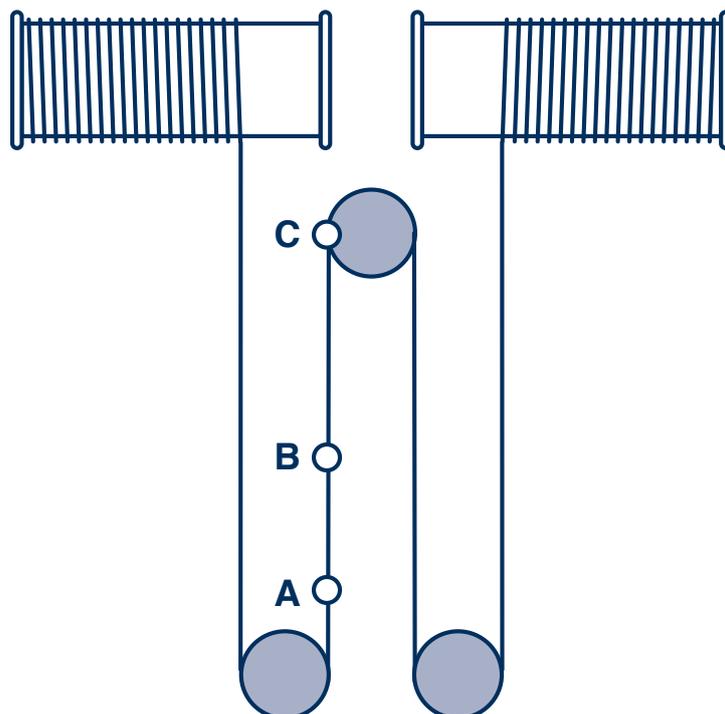


Fig. 58: Overhead crane with twin-drum system and a load compensation sheave

The rope inspector is convinced that Zone A is the most heavily strained rope zone and consequently inspects it with the greatest care. When asked about the middle sheave of the reeving system he replies that “the compensation sheave does not do any work, it simply serves to compensate the force and length between the left and right side of the hoist rope.” Therefore, rope fatigue should not be expected there. Some weeks later the hoist rope broke at Zone C. Why did this happen?

It is true that rope Zone C does not work when the load is being lifted or lowered. However, when the crane is moved sideways, the load swings back and forth under the crane bridge and this constantly generates load and length differences between the two sides of the reeving system. Therefore, during the entire transportation phase the piece of rope in Zone C continuously enters the compensating sheave and leaves it again; as a result it sees many more bending cycles than the piece of rope in Zone A.

But Zone C is particularly critical because the standards for cranes, based on the misunderstanding that the “compensation sheaves do not work (as everybody knows!)” permit a smaller diameter for this very sheave. So, the piece of rope in Zone C not only carries out more bending cycles than the one in Zone A, in most cases these cycles are on a sheave with a smaller diameter.

For cranes operating outside, another problem arises: the piece of rope on the compensating sheave never leaves this sheave completely. After a rain shower, the other rope zones (e.g. Zones A and B) are quickly dried by the sun and wind but Zone C remains wet for a long time. This zone, just like the piece of rope on the saddle of the suspension bridge (see the previous case study) is additionally at risk of developing corrosion.

Very often the rope zone on the compensating sheave is difficult to access because it is located routinely under the crane bridge. Therefore, as a rule, “accidental” detection of the rope damage in Zone C is not usually possible. Manufacturers of cranes with compensating sheaves should draw their clients’ attention to this safety hazard associated with the compensation system.

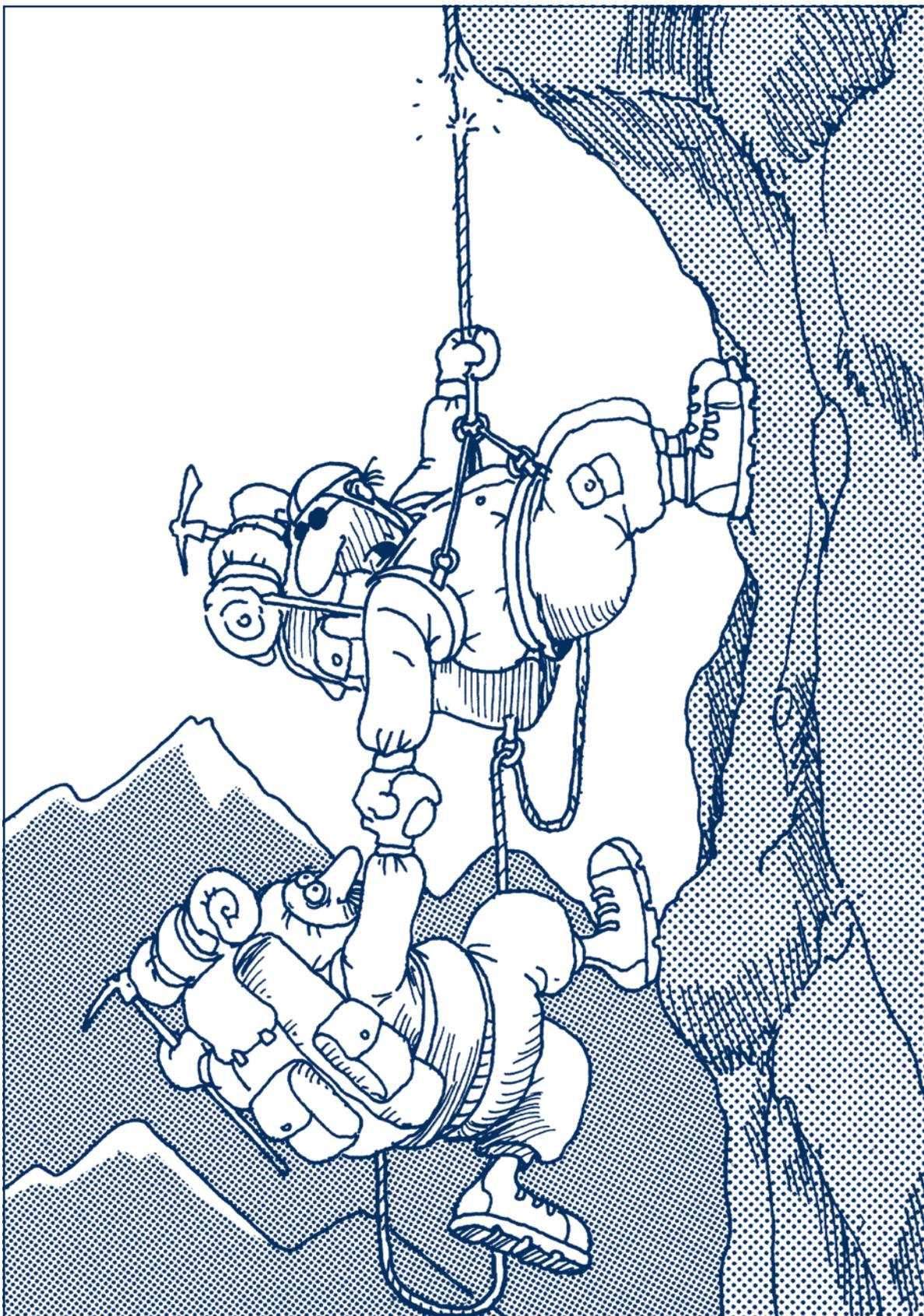
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The author: Dipl. -Ing. Roland Verreet • Wire Rope Technology Aachen  
Gruenenthaler Str. 40a • D-52072 Aachen, Germany

Tel. +49 (241) 173147 • Fax +49 (241) 12982 • Email: R.Verreet@t-online.de

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Have no fear, I am holding you!

	<i>total number of wires</i>	<i>number of load-bearing wires in the outer strands</i>	<i>discard number of wire breaks: 6 x d Regular Lay</i>	<i>discard number of wire breaks: 6 x d Langs Lay</i>	<i>discard number of wire breaks: 30 x d Regular Lay</i>	<i>discard number of wire breaks: 30 x d Langs Lay</i>
<b>STARLIFT</b>	245	112	10	5	19	10
<b>EUROLIFT</b>	280	126	11	6	22	11
<b>POWERPLAST</b>	259	126	11	6	22	11
<b>STARFIT</b>	217	98	8	4	16	8
<b>STRATOPLAST</b>	319	152	13	6	26	13
<b>TURBOPLAST</b>	327	208	18	9	35	18
<b>DUROPLAST</b>	255	136	11	6	22	11
<b>PARAPLAST</b>	322	208	18	9	35	18
<b>SUPERPLAST 8</b>	381	260	21	10	42	21
<b>ULTRAFIT</b>	182	133	11	6	22	11
<b>PARAFIT</b>	298	208	18	9	35	18
<b>STRATOLIFT</b>	303	152	13	6	26	13
<b>TURBOLIFT</b>	311	208	18	9	35	18
<b>SUPERLIFT</b>	307	205	18	9	35	18
<b>ALPHALIFT</b>	303	152	13	6	26	13
<b>UNILIFT</b>	119	56	6	3	12	6
<b>TECHNOLIFT</b>	319	152	13	6	26	13
<b>RAMMBOLIFT</b>	96	96	8	4	16	8
<b>QUADROLIFT</b>	140	140	11	6	22	11

Up to approx. 50 mm rope diameter. Discard number according to DIN 15 020, groups of mechanism 2m to 5m. For groups of mechanism 1Em to 1Am the values in the table must be divided by 2.

	rotation resistant	compacted strands	plastic layer	average fill factor	average weight factor	average spin factor*
<b>STARLIFT</b>	●			0,654	0,90	0,76
<b>EUROLIFT</b>	●	●		0,720	0,87	0,82
<b>POWERPLAST</b>	●	●	●	0,729	0,88	0,81
<b>STARFIT</b>	◐		●	0,720	0,87	0,85
<b>STRATOPLAST</b>			●	0,617	0,89	0,86
<b>TURBOPLAST</b>		●	●	0,665	0,87	0,85
<b>DUROPLAST</b>		●	●	0,651	0,87	0,86
<b>PARAPLAST</b>		●	●	0,702	0,85	0,88
<b>SUPERPLAST 8</b>		●	●	0,686	0,86	0,85
<b>ULTRAFIT</b>			●	0,703	0,88	0,85
<b>PARAFIT</b>		●	●	0,744	0,85	0,87
<b>STRATOLIFT</b>				0,661	0,86	0,86
<b>TURBOLIFT</b>		●		0,734	0,84	0,83
<b>SUPERLIFT</b>		●		0,736	0,87	0,86
<b>ALPHALIFT</b>				0,641	0,86	0,86
<b>UNILIFT</b>				0,643	0,87	0,90
<b>TECHNOLIFT</b>				0,624	0,88	0,81
<b>RAMMBOLIFT</b>	●			0,479	0,92	0,84
<b>QUADROLIFT</b>	◐	●		0,663	0,83	0,87

\* rope diameters up to 40 mm, 1770 N/mm<sup>2</sup> & 1960 N/mm<sup>2</sup>

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