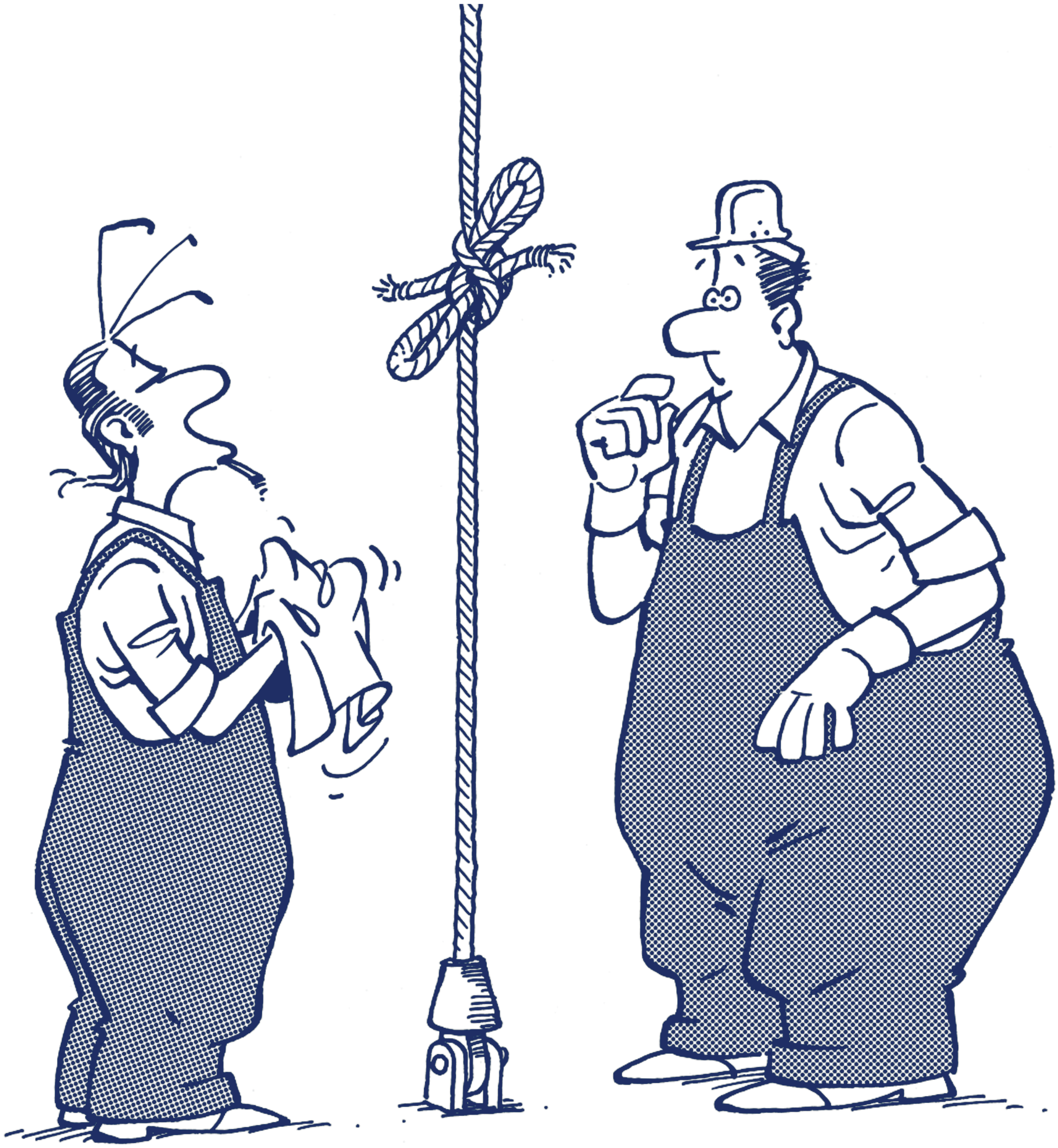
WIRE ROPE
TECHNOLOGY AACHEN



Wire Rope End Connections

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by Dipl.-Ing. Roland Verreet

Content

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1. Introduction

A wire rope is a highly stressed machine element. The load is introduced into the wire rope by means of its end connection. The requirements for the end fitting are demanding: the connection must be able to transfer great static and dynamic forces, and must often need to be able to withstand high temperatures. Also, it must be able to rotate freely in one or two planes around its anchor point, and it must be easily attachable and detachable, particularly for reeving and inspection purposes. The end connection should also be compact, light and, just as importantly, reasonably priced. Unfortunately, there is no end connection that fully meets all these criteria. However, there are a large number of attachments that meet at least some of them.

This brochure describes the various end connections and offers advice on their manufacture, attachment and inspection. We hope it will assist the designers and users of cranes, equipment and architectural structures to select the most appropriate rope end connection for their respective applications.

Should you have any specific problems or queries that have not been dealt with in this brochure, please contact the author of this publication:

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We will do our best to help you.

2. Classification

We differentiate between friction and material closure rope end connections, which comprise metallic spelter sockets as well as resin spelter sockets, and friction and mechanical interlocking closure rope end connections, which comprise non-detachable clamp connections, splice connections as well as the detachable wedge and screwed connections. Fig. 1 shows the classification of rope end connections.

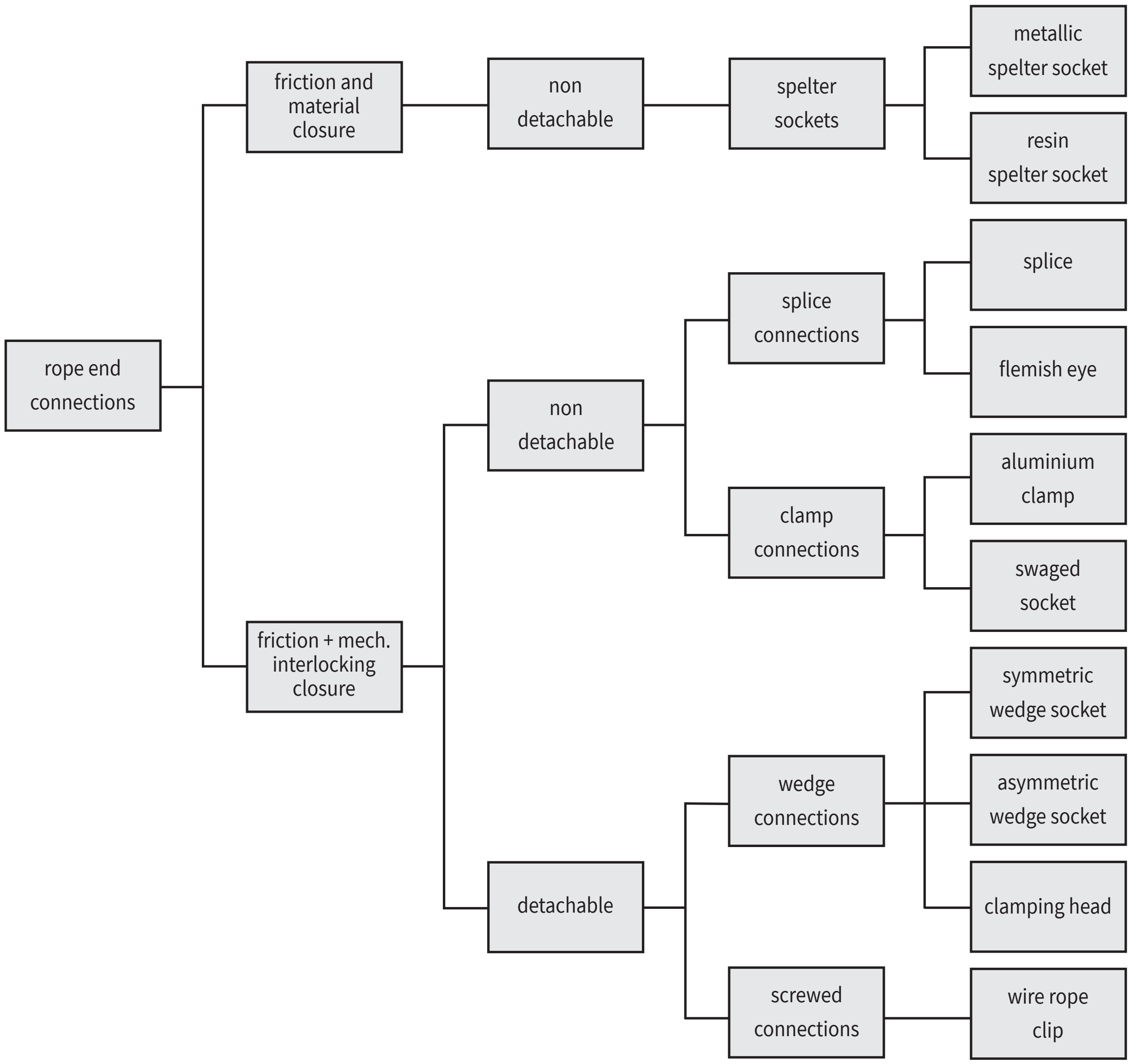

Fig. 1: The classification of rope end connections

3. The wire rope clip

Rope end connections using wire rope clips (Fig. 2) are very popular because they can be fabricated on-site with very little effort and they are also very cheap. Compared with many other end connections they are easily detachable and can be inspected without a problem.

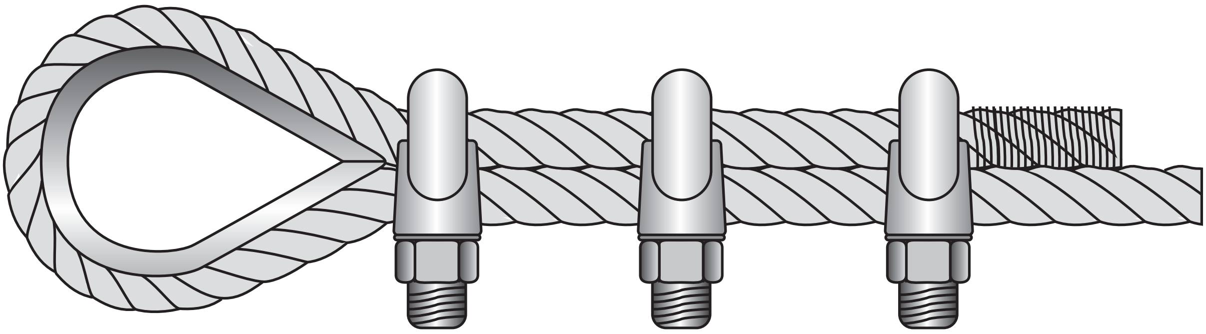

Fig. 2: Rope end connection using wire rope clips

Wire rope clips certified to EN 13411-5 (Fig. 3) must not be used for end connections with lifting devices in hoisting operations. An exception is lifting gear which has been manufactured for a special and single application. Neither must they be employed with mine shaft cables, in reeving systems for iron and steel mill cranes, or for the permanent attachment of ropes in reeving systems designed according to DIN 15020 Part 1.

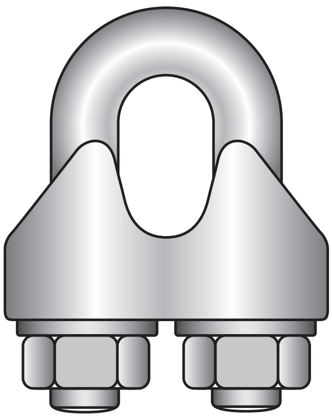

Fig. 3: Wire rope clip certified to EN 13411-5

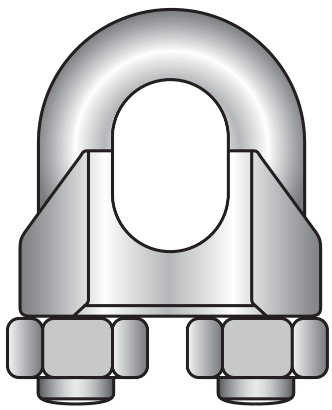

Fig. 4: Wire rope clips certified to DIN 741

3.1. Breaking strength and tension-tension endurance

In a quasi-static pull test, rope end connections with wire rope clips achieve about 90% of the breaking strength of the wire rope used. In a dynamic tension-tension fatigue test they achieve about half the number of tension-tension cycles of metallic spelter sockets.

3.2. Standardisation

Wire rope clips for detachable rope connections are standardised in EN 13411-5. DIN 741, standardising a weaker design using simple nuts (Fig. 4) was withdrawn in 1982. A wire rope clip consists of a clamping jaw which, because of its shape, is also called a 'saddle', a U-bolt and two collar nuts (Fig. 3). The clips are identified according to their greatest permissible nominal rope diameters. For example, a complete rope clip for the rope diameters 20mm to 22mm is identified in the following way: Wire rope clip EN 13411-5 - S 22. The components are identified as follows: Clamp jaw: EN 13411-5 - SB 22, U-bolt: EN 13411-5 - SA 22 and Collar nuts: EN 13411-5 - SC M 16

3.3. Operating mechanism

The clips press the 'live' rope line onto the 'dead' one, thereby allowing a transfer of load between the two ropes' lines by friction closure as well as by form closure (indentation).

At each clip about the same amount of force is transferred from the 'live' onto the 'dead' line. If, for example, five rope clips are used at every single clip, about 10% of the traction force is transferred. So, at first the 'live' line is subjected to 100% of the traction force. At each of the rope clips it transfers 10% of that force to the 'dead' rope line. At the thimble, the rope force will have been reduced to exactly 50% (Fig. 5).

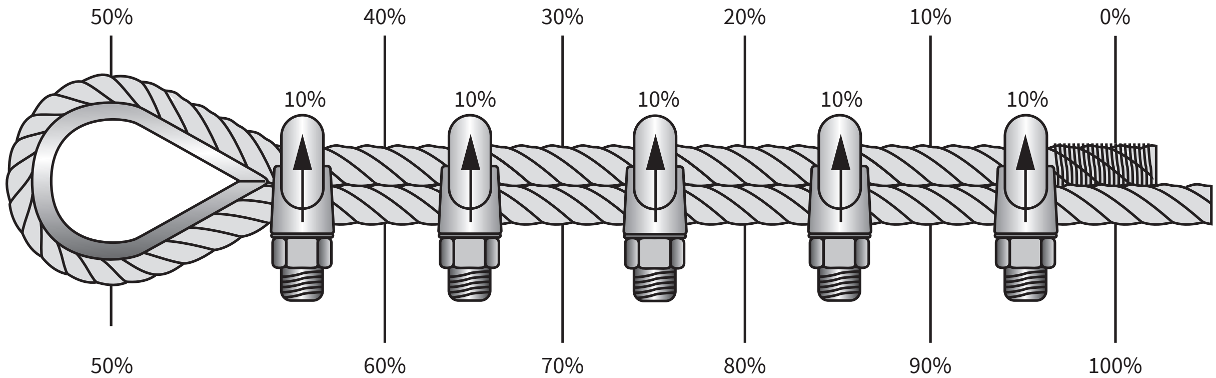

Fig. 5: The gradient of force in a rope end connection with wire rope clips

The ‘dead’ rope line, on the other hand, is completely unloaded at its end. At every rope clip it takes up 10% of the traction force of the ‘live’ line until the traction force amounts to 50% at the thimble.

3.4. Fabrication / Installation

Wire rope clips when used as rope end connections are attached in the following way: First the threads of the U-bolt and the collars of the nuts are lubricated to ensure ‘friction-free’ tightening. The rope end is laid around a thimble and the first clip is threaded on close to the thimble. When attached without a thimble, the distance between the first clip and the apex of the loop should be about three times the diameter of the attachment pin, at least, however, fifteen times the diameter of the rope.

The clamp jaw conforms comparatively well to the rope surface, whereas the round U-bolt exercises an almost spot-like lateral force on the wire rope, reducing its breaking load considerably in the area of contact.

Therefore, it must be ensured that the clamp jaw (the saddle) comes to lie on the ‘live’ line, i.e. the line that bears the greater load, and the clamp strap on the ‘dead’ line, the line with the lesser load.

Obviously, many users of rope clips cannot remember which line to put the saddle on and on which line the U-bolt must be applied: two out of three end connections are carried out incorrectly (Fig. 6).

The place for the saddle is the ‘live’ line – not the ‘dead’ one:
Never saddle a dead horse!

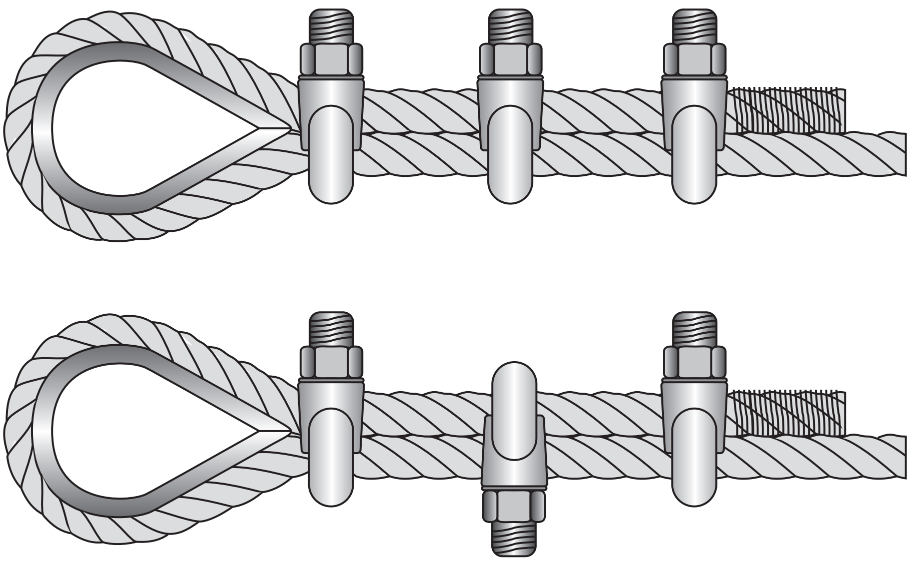

Fig. 6: End connections with rope clips fitted incorrectly

Depending on the rope diameter used, another two to five rope clips are fitted, keeping a distance of at least the width of a clip. A total of three clips is fitted up to a nominal diameter of 6.5mm, four clips up to 19mm, five up to 26mm and six up to 40mm.

After attaching the clips manually, starting with the one furthest away from the thimble, they are tightened using a torque wrench. After tightening the first clip, the one furthest away from the thimble, the rope end connection should, if possible, be slightly loaded before tightening up the other clips.

The required tightening torques are listed in Fig. 7. For larger rope diameters they can be approximated using the following formula:

$$\text{Tightening moment [Nm]} = 0.22 \cdot (\text{rope diameter [mm]})^2$$

Nominal size	Torque [Nm]	Required number of clips [-]
5	2,0	3
6,5	3,5	3
8	6,0	4
10	9,0	4
13	33	4
16	49	4
19	67,7	4
22	107	5
26	147	5
30	212	6
34	296	6
40	363	6

Fig. 7: Tightening torques for wire rope clips (EN 13411-5)

Under the effect of traction forces, the rope diameter reduces over time. Therefore, the tightening torques of the collar nuts must be checked to ensure that they are not only right after the rope has been loaded for the first time, but also occasionally thereafter. If necessary, the collar nuts must be re-tightened.

Fig. 8 shows an end connection which has been fitted incorrectly and has not been tightened with a torque wrench. The rotated thimble clearly indicates that the rope has slipped in its clips.

Fig. 8: Rope end connection with wire rope clips fitted incorrectly

American users recommend the application of one more clip than the specified number. This should grip the ‘dead’ line to the ‘live’ line, but with a little slack (Fig. 9). If this connection slips, the ‘dead’ rope line will straighten, which can easily be recognised (Fig. 10). If, however, the problem is not noticed, the additional clip will take part of the load from the outer clips and may prevent further slipping

3.5. Inspection

When inspecting a rope end connection with wire rope clips, the tightness of the collar nuts are checked by means of a torque wrench. If necessary, the nuts are tightened. Then the free sections of the rope are visually inspected – particularly along the clip zones – in order to detect wire breaks or corrosion. Especially with ropes that are subjected to great load changes, wire breaks might occur in the contact area between the rope lines near the clips. If wire breaks are suspected, the clips must be completely removed and the squeezed rope inspected meticulously.

If the rope cannot be unloaded, and detaching the clips is consequently not possible for that reason, several additional clips should be fitted. Then one or two of the original clips can be removed and the respective sections inspected.

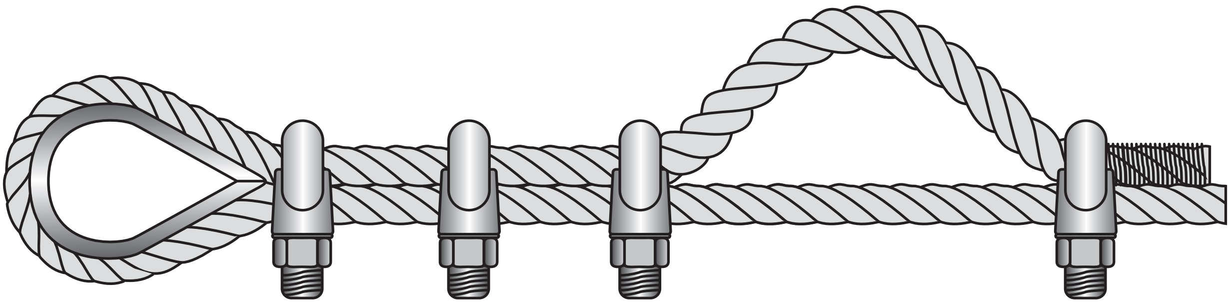

Fig. 9: The ‘dead’ end forms a bow – the wire rope has not slipped

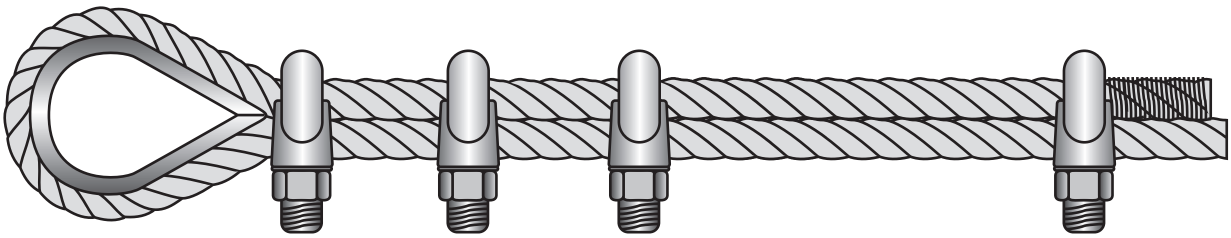

Fig. 10: The ‘dead’ end is straight – the wire rope has slipped

3.6. Special Designs

In mining applications a specially designed wire rope clip is used (Fig. 11), similar to the withdrawn standard DIN 21 260.

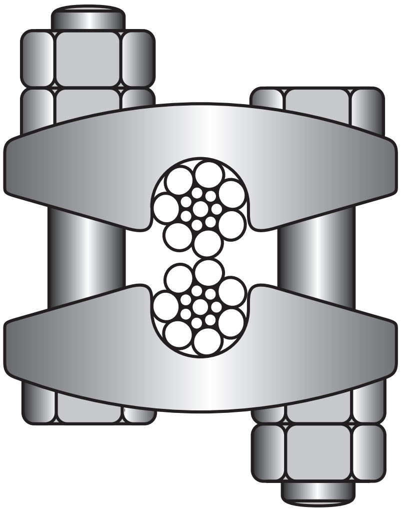

Fig. 11: Round wire rope clip for mining applications

Compared to the standard clip, this one has the advantage that both halves are the same shape and cannot be mixed up during installation. In this case the 'live' as well as the 'dead' line are saddled. Fig. 12 shows the end connection of a hoist rope of a bucket wheel excavator fitted with round wire rope clips.

A new variation of the rope clip, patented in the USA, is the so-called 'Piggy-Back Wedge Socket Clip'. This clip looks like a standard clip except for the fact that it has two clamp jaws instead of one. They are fitted with an extra long U-bolt. Its operation will be explained in connection with the securing of wedge sockets.

Fig. 12: Rope end connection fitted with wire rope clips for mining applications.

4. The asymmetrical wedge socket

The use of asymmetrical wedge sockets (Fig. 13) is highly popular with mobile cranes. They can easily be fitted on site and are as easily removed, which is a great advantage if the reeving is changed frequently.

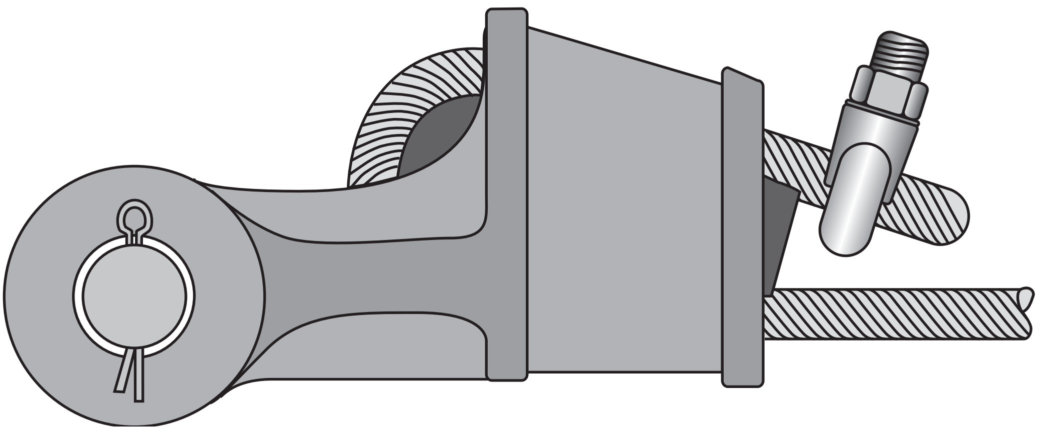

Fig. 13: Asymmetrical wedge socket

4.1. Breaking strength and tension-tension endurance

In a quasi-static pull test, wire ropes in asymmetrical wedge sockets achieve – depending on the design of the sockets – between 80% and 95% of the breaking strength of the rope used. In a tension-tension fatigue test they achieve – on average – about half the tension-tension cycles of metallic spelter sockets.

Usually asymmetrical wedge sockets are reused after the rope has been discarded. Therefore, they must survive tension-tension fatigue tests until rope failure without any damage.

4.2. Standardisation

The minimum requirements for asymmetrical wedge sockets are standardised in EN 13411-6, and a great number of different executions can be found on the market. According to this standard, the clamping lengths between the socket and the wedge must as least be 4,3 x the nominal rope diameter. The wedge angle of the socket must be 14° ± 0,5°, the angle in the bottom of the groove of the wedge itself must be 14° +0°, -2°, in a different execution 15° ± 1°. For the type approval, the asymmetrical wedge socket must be able to endure 75.000 tension- tension- cycles between 15% and 30% of the minimum breaking strength of the rope without any permanent damage.

4.3. Operating mechanism

By means of a wedge, the rope end is jammed into a tapered socket. With increasing load, the wedge is pulled deeper and deeper into the socket and exercises normal clamping force on the rope.

The traction force in the wire rope is transferred by the friction between the rope and the wedge and by the friction between the rope and the socket. Fig. 14 shows a sectional view of an asymmetrical wedge socket.

4.4. Fabrication / Installation

When fitting a wedge socket, the rope end is first fed through the tapered socket, then bent into a loop and fed back out of the socket. After that the rope wedge is placed inside the loop and the protruding rope ends are pulled further out of the socket, so that the wedge is pulled a good way into it.

The ‘dead’ rope end should then poke out from the socket by at least several rope diameters. Immediately at the exit of the wedge socket the tail end should be secured with a wire rope clip. This will prevent the wedge from coming loose and possibly dropping out if the end connections are abruptly unloaded (Fig. 13).

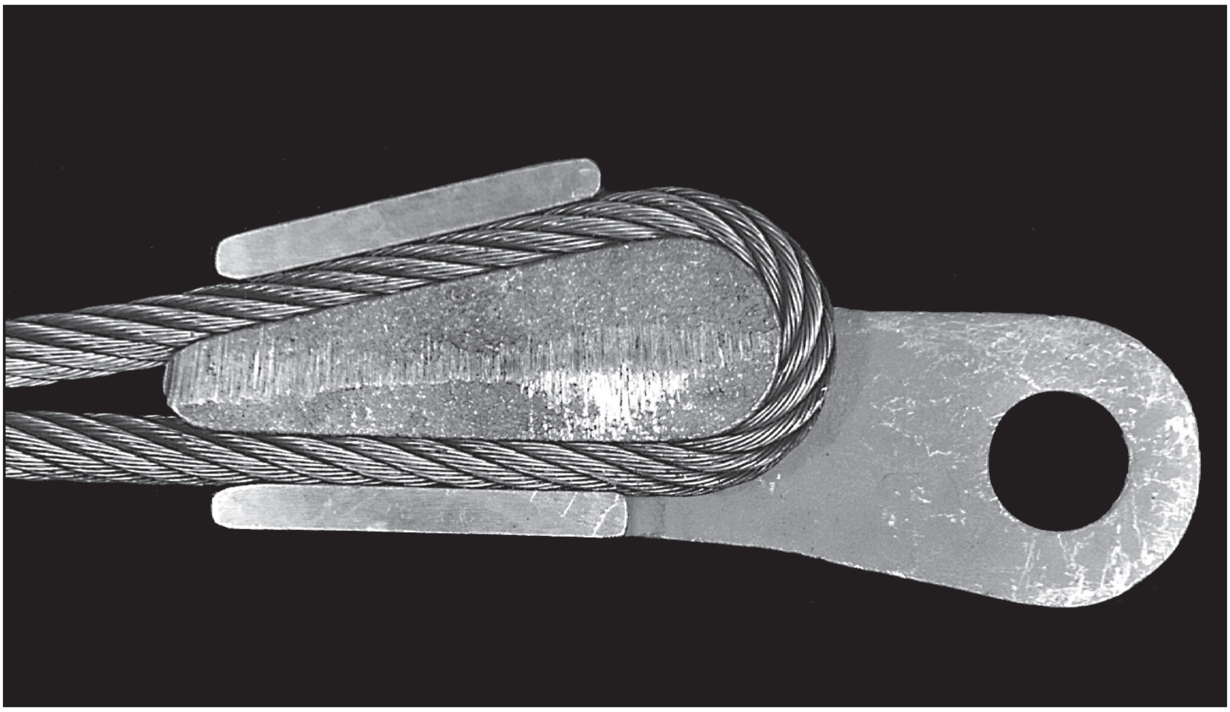

Fig. 14: Sectional view of an asymmetrical wedge socket

The wire rope clip must not be fitted in a way that connects the ‘live’ and the ‘dead’ wire line (Fig. 15). On the one hand, this would considerably reduce the breaking strength of the ‘live’ rope line due to the clamp forces of the clip. On the other hand, the loaded rope line would try to change its length with every change of load. This, however, would be prevented by the unloaded, ‘dead’ rope line. A change of length would only be possible if the ‘dead’ line also changed its length, but it would have to take over some of the load in order to do so. This, however, would lead to a tilting position of the socket every time the rope was loaded, and would, therefore, subject the rope to additional bending stresses at the exit of the socket.

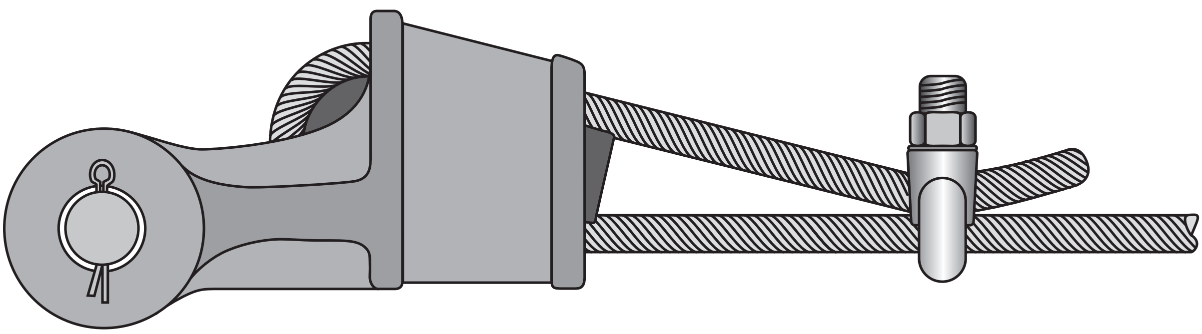

Fig. 15: Incorrect connection between the ‘live’ and the ‘dead’ rope line

Fig. 16 shows a boom hoist rope which was fixed with an asymmetrical wedge socket secured by means of a wire rope clip over both rope lines. The ‘live’ line of the rope is broken at the clamping point. Fig. 17shows the point of break.

As we have seen above, only the ‘dead’ end of the rope must be secured by a wire rope clip. Oddly enough, the thread length of a rope clip is not long enough to clamp a single rope line. Therefore, many fitters, already in doubt as whether to clamp one or two lines, are led to the wrong conclusion that they have to clip both the ‘live’ and the ‘dead’ line.

To remedy the problem of too short a thread, several national regulations demand that the ‘dead’ rope line be clamped together with another short piece of rope (Fig. 18).

A better solution, however, is to let the ‘dead’ end poke out further, and to bend it backwards into a loop (Fig. 19). In this way the ‘dead’ line can be clipped together with its own end at the exit of the socket.

This procedure has several other advantages: bending the line round the very small radius of the wedge generates a permanent deformation within the wire rope. This kink-like, plastic deformation makes it rather difficult to push the rope end through a hook block. If the rope end connection is likely to be opened regularly in order to change the reeving (e.g. when re-reeving a mobile crane from a two-part to a four part line), the ‘dead’ rope end should, if possible, poke out about one metre from the socket. The end of that rope length can be bent backwards and fixed with the clip at the exit of the socket.

The result of this is that the kink-like deformation will occur about one metre away from the rope end. In this position it does not cause any obstruction during re-reeving, allowing the undeformed rope end to be fed into the hook block until the deformation stops it from being pushed any further. Then, using the rope end already poking out from the other side of the hook block, the deformation can be pulled through.

If the asymmetrical wedge socket is installed correctly, the live rope line enters the socket straight (Fig. 20). The straining line of the pulling force goes straight through the fastening pin. Therefore, when the connection is loaded, it will not tilt and bend the ‘live’ line at its exit.

If installed incorrectly, however, the straining line of the pulling force will be offset; therefore, whenever the connection is loaded, it will tilt in order to align the straining line with the fastening pin, thereby severely bending the ‘live’ line at the clamp’s exit (Fig. 21).

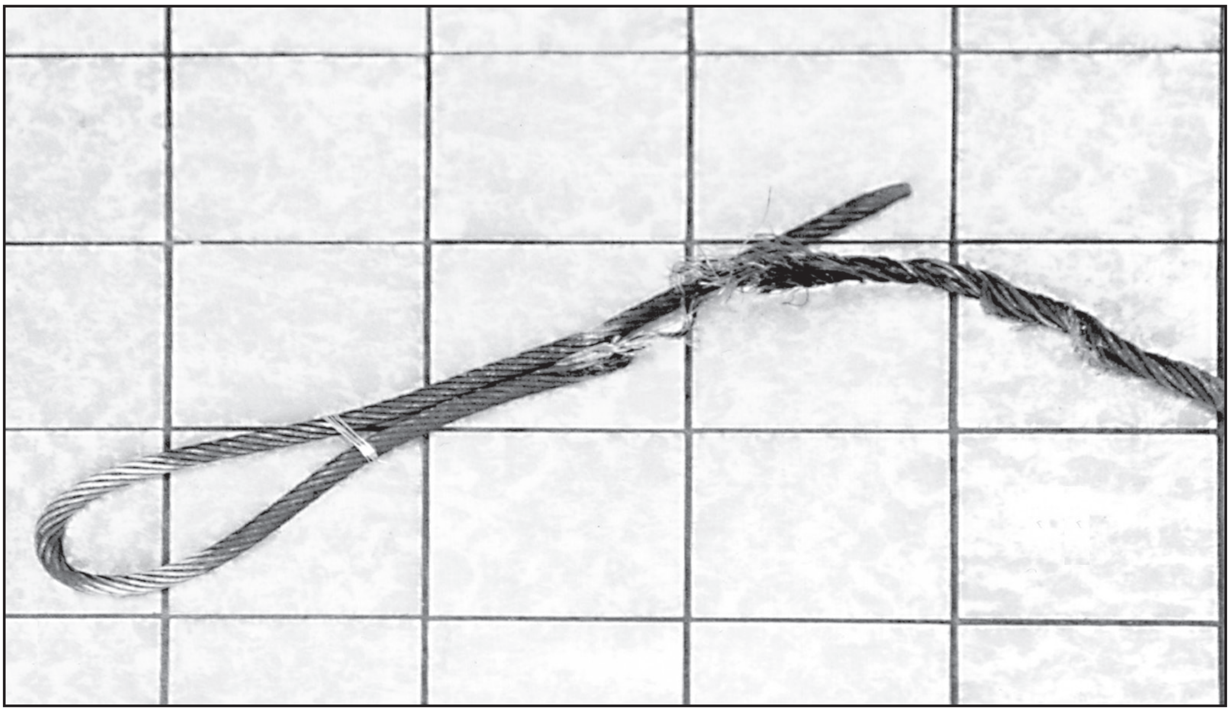

Fig. 16: Rope break in the ‘live’ line at the clamping point

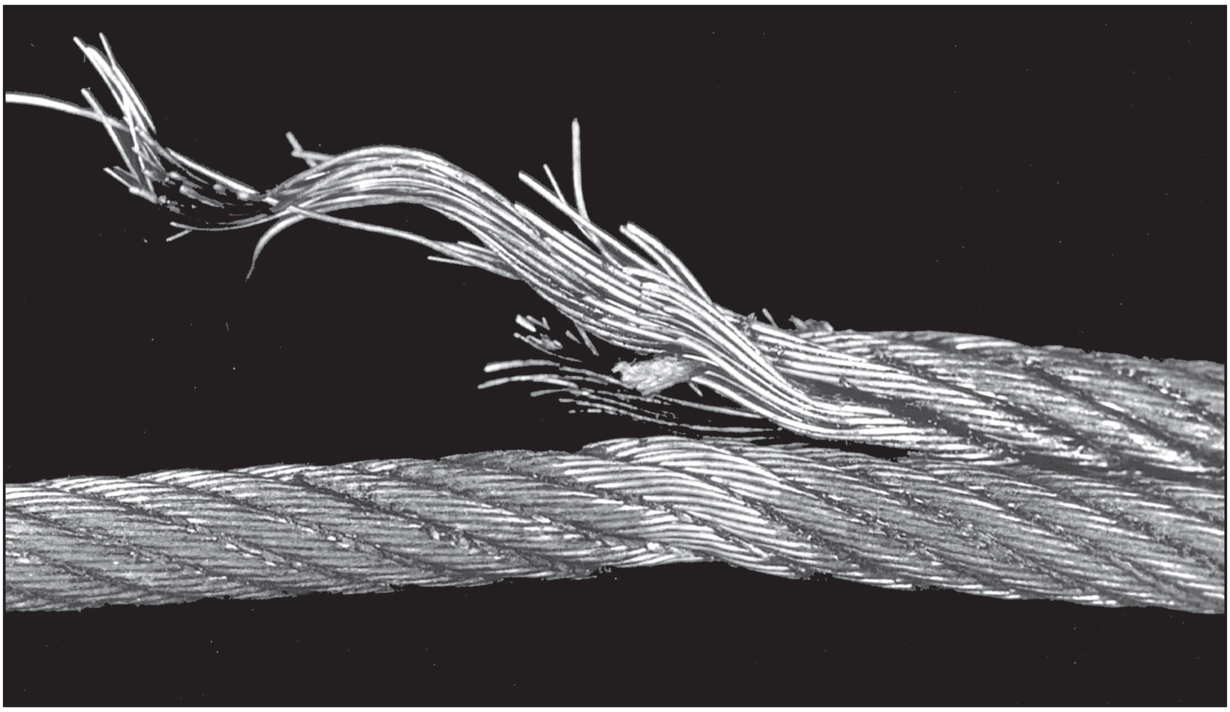

Fig. 17: Rope break at the clamping point (detail)

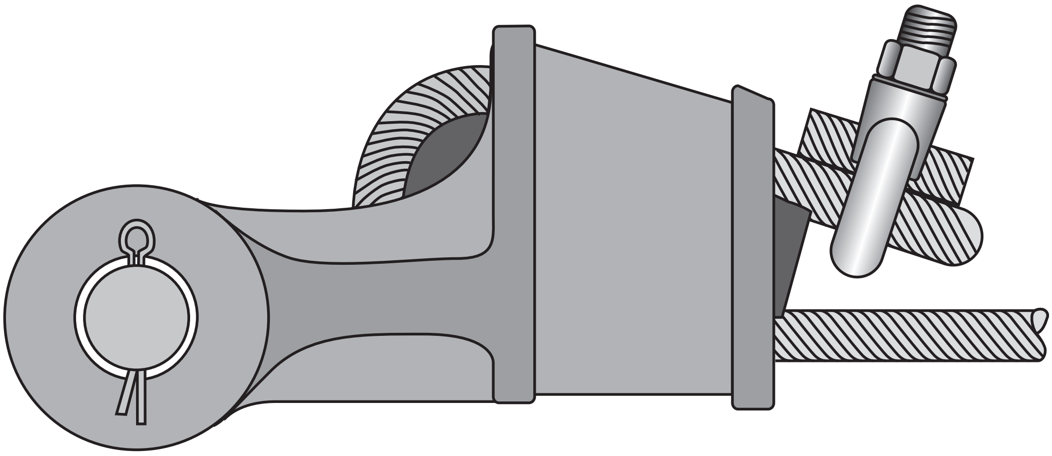

Fig. 18: Clamping the ‘dead’ rope line with another piece of rope

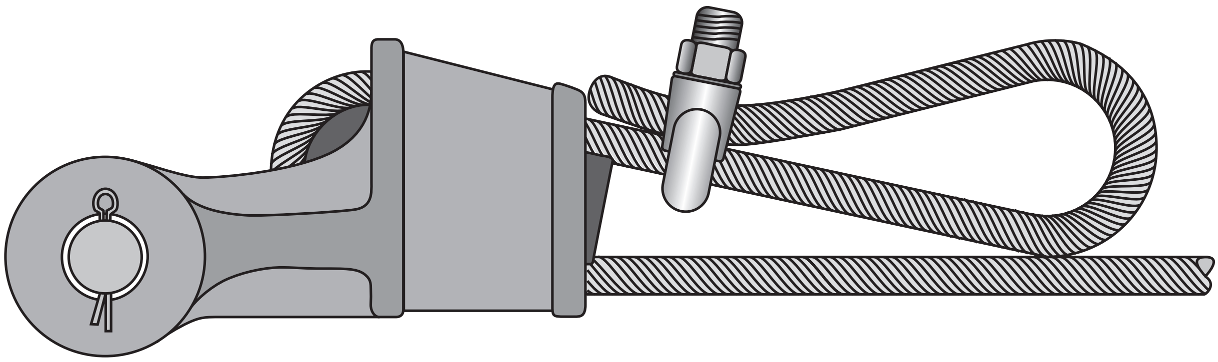

Fig. 19: Recommended clipping of the ‘dead’ line

This leads to a reduction in breaking strength of the end connection. Also, the additional pressure at the exit, in connection with the frequent bending round a very small radius, will generate premature fatigue of the rope wires in that zone, so that the end connection may fail prematurely even under smaller tensile loads.

Due to the enormous amount of bending around the laid-in wedge, often the rope construction opens at the outside of the curve so that the steel core of the wire rope can be seen. Under normal circumstances this is not critical. If wire breaks can be found in those sections, they would probably have occurred during installation. Unfortunately, time and again, a fitter will try to drive the wire rope, along with the wedge, into the socket by means of a series of hammer blows. During this ‘procedure’ the wires on the rope’s surface are damaged.

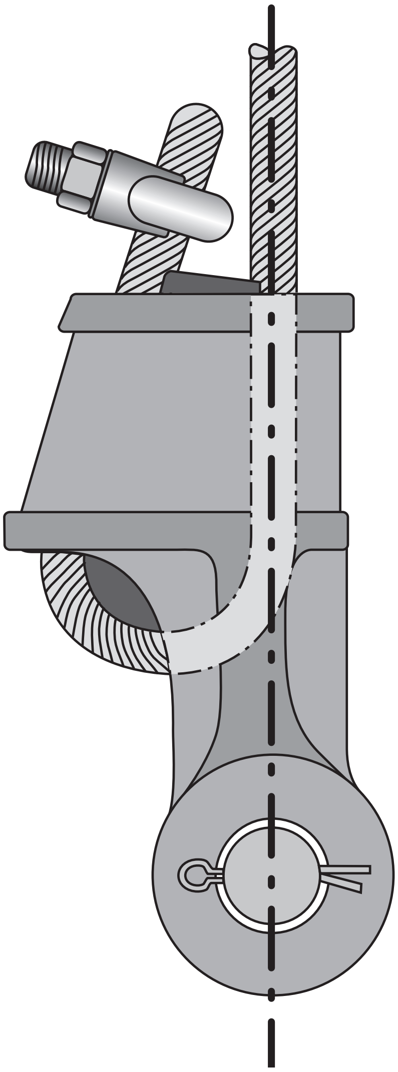

Fig. 20: Correct installation of a wedge socket

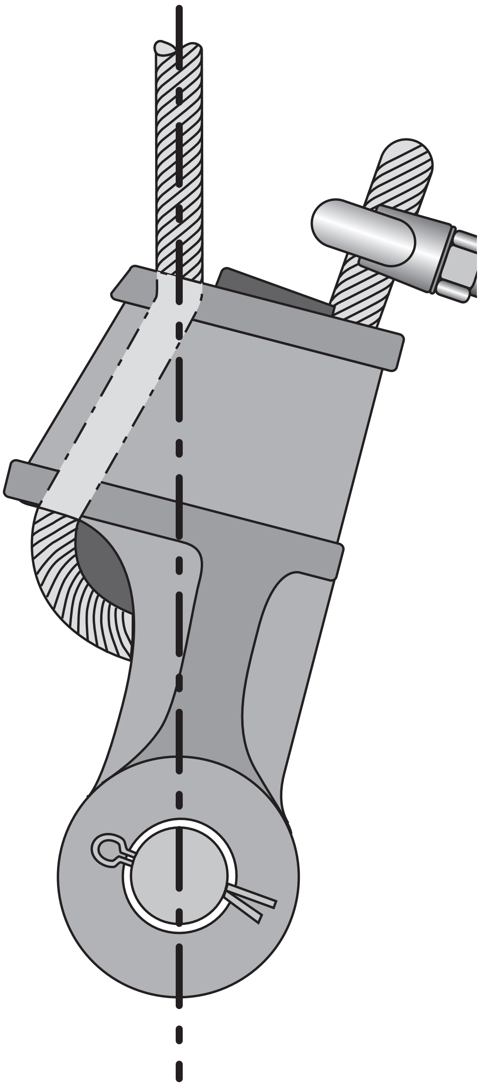

Fig. 21: Incorrect installation of a wedge socket

4.5. Inspection

When inspecting an asymmetrical wedge socket, one should first make sure that the right sizes of wedge and socket for the rope diameter are being used. If the socket is too big, or the wedge is too small, the wedge will be pulled too far out of the socket when under load. Therefore, it is very helpful, particularly if the wedge sockets are being frequently reused, to mark the parts, prior to their first use, with paint or chasing tools.

Furthermore, one should check whether the wedge socket has been fitted correctly and that the ‘live’ line is not bent when under load. The rope should be examined for wire breaks in the area of the wedge socket, and if necessary the wedge socket should be completely dismantled.

After discarding the rope, the wedge socket should be examined very carefully for physical damage and potential cracks, before it is reused.

4.6. Special designs

he number of special designs of asymmetrical wedge sockets is enormous. The types vary depending on material, manufacturing processes (cast and welded designs), geometry (wedge angles ranging between 14° and 30°) and the method by which the ‘dead’ rope line is secured. Fig. 22 shows two extremely large wedge sockets used to attach the hoist ropes of a dragline in Australia.

Fig. 22: Head-high wedge sockets on a dragline

In the USA, one manufacturer offers a patented wire rope clip which clamps the ‘dead’ rope line tightly at the exit of the wedge socket, whilst loosely holding the ‘live’ rope line. This so-called ‘Piggy-Back’ wire rope clip looks like a standard rope clip, except for the fact that it has not only one, but two clamping jaws (saddles). These are fitted with an extra long U-bolt (Fig. 23).

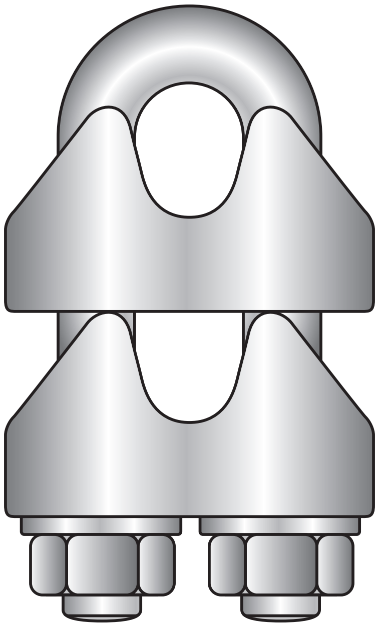

Fig. 23: ‘Piggy-Back’ wedge socket clip

Another design of the asymmetrical wedge socket attaches the ‘dead’ rope line to the body of the rope socket (Fig. 24).

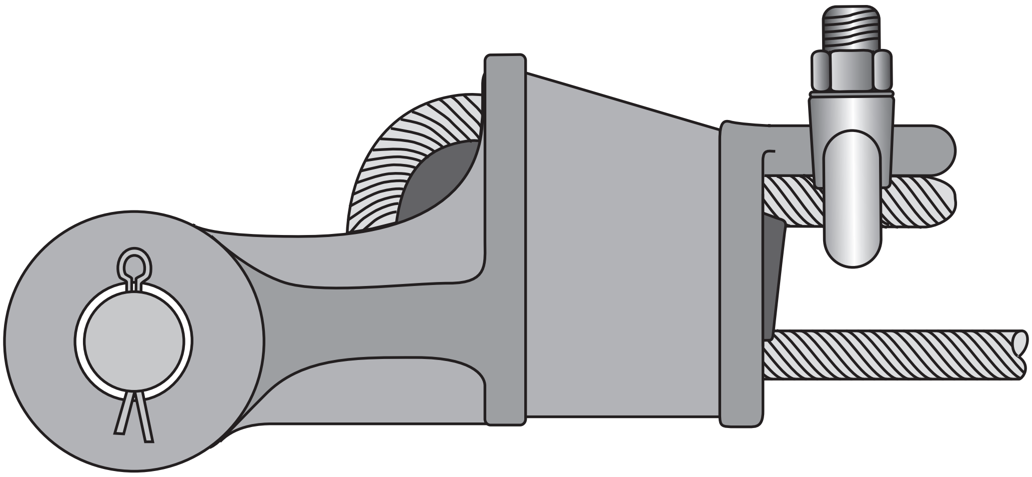

Fig. 24: Attachment of the ‘dead’ rope line to the body of the socket

A new and promising end connection – patented in the USA – is the wedge socket with an extended wedge to which the 'dead' rope end is attached (Fig. 25).

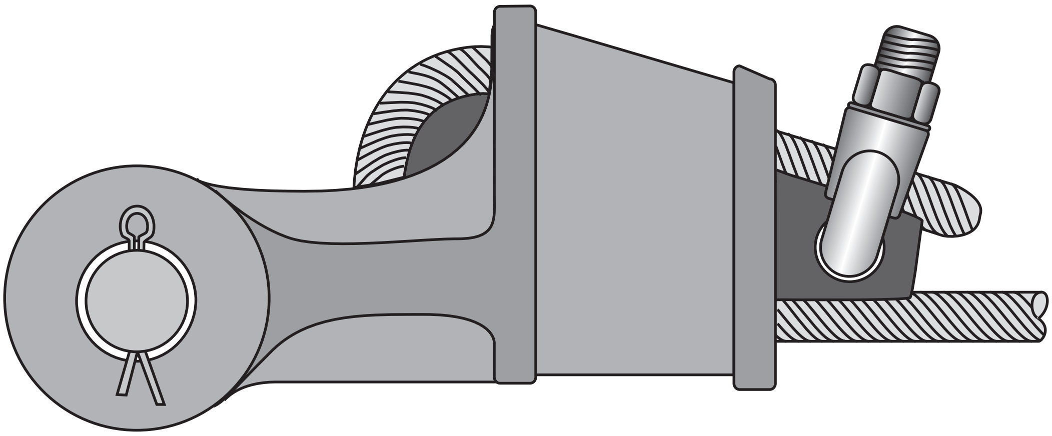

Fig. 25: Attachment of the 'dead' rope line to the wedge

When rotation-resistant ropes are used, it is often recommended that a swivel be fitted between the rope end connection and the point of attachment to the crane. However, the lifting height of the device will be reduced by the fitting of the swivel. Here the use of an asymmetrical wedge socket with a built in swivel is recommended (Fig. 26).

This end connection reduces the lifting height only marginally and has the added advantage that the swivel will always automatically align itself with the wire rope.

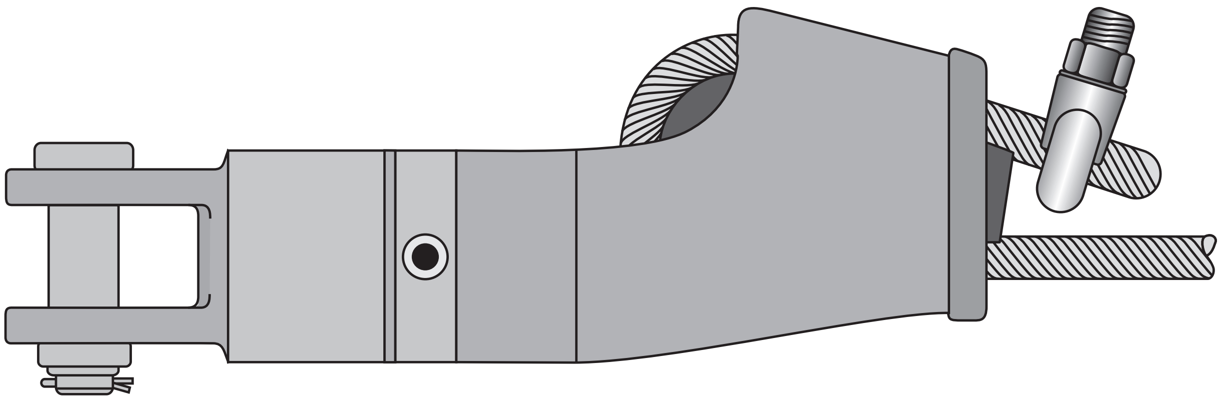

Fig. 26: Wedge socket with built-in swivel

5. The symmetrical wedge socket

The symmetrical wedge socket (Fig. 27) is used as an end connection for elevator ropes. It can be easily attached and just as easily removed, which is a great advantage when manually adjusting the length of elevator ropes.

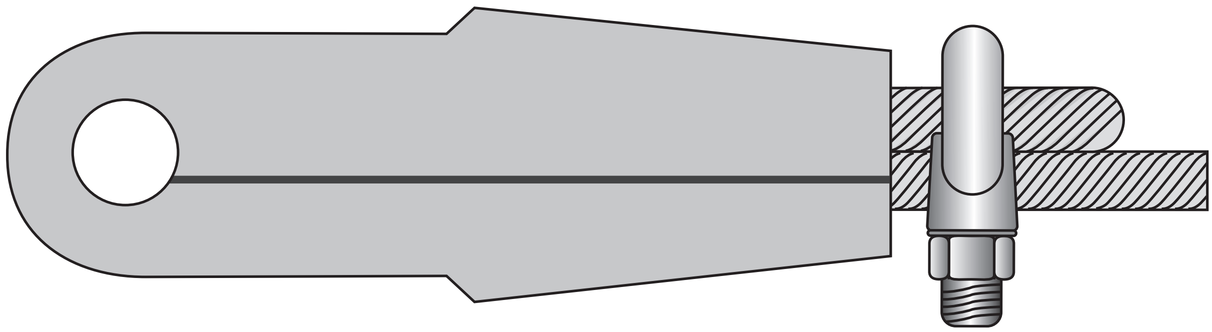

Fig. 27: Symmetrical wedge socket in accordance with EN 13411-7

5.1. Breaking strength and tension- tension endurance

In a quasi-static pull test, wire ropes in symmetrical wedge sockets achieve between 80% and 85% of the breaking strength of the wire rope used. In a tension-tension fatigue test they achieve – on average – about half the number of tension-tension cycles of metallic spelter sockets. After discarding the rope, symmetrical wedge sockets are normally reused. Therefore they must survive tension-tension fatigue tests until rope failure, without any damage.

5.2. Standardisation

Symmetrical wedge sockets are standardised in EN 13411-7. According to this standard, the angles of the socket and the wedge must be identical. The clamping length must be 7,3x the nominal rope diameter. For the type approval, the asymmetrical wedge socket must be able to endure 75.000 tension- tension- cycles between 15% and 30% of the minimum breaking strength of the rope without any permanent damage.

5.3. Operating mechanism

For the functioning of the symmetrical wedge sockets, section 3.3 applies accordingly. In contrast to a correctly installed asymmetrical wedge socket, the loading line of the force applied to the symmetrical wedge socket will always be offset from the centre of the fastening pin. For this reason, the end connection will always assume a slightly tilted position when under load. This, however, is of minor importance with elevator ropes which are always used with high design factors and only small changes in line pull.

5.4. Fabrication / Installation

The installation of symmetrical wedge sockets is carried out in the same way as described in section 4.4. for asymmetrical ones. Yet, due to the symmetry of the socket, there is no danger of fitting it incorrectly. After the wedge has been pulled into the socket, it is secured against falling out by means of a split-pin. In contrast to the procedure for asymmetrical wedge sockets, the rope clip must be attached in a way that connects the ‘live’ line with the ‘dead’ one.

5.5. Inspection

The inspection of a symmetrical wedge socket is carried out in a similar way to that of asymmetrical ones (see section 4.5).

5.6. Special designs

There are no known special designs of symmetrical wedge sockets.

6. The splice

The splice is the oldest end connection for ropes. Fibre ropes have been spliced for thousands of years. Wilhelm August Julius Albert, the inventor of the wire rope, was also the first person to manufacture splices as end connections for wire ropes. Nowadays, however, the splice is being replaced with other types of end connections. On steel mill cranes and other applications where some other types of end connections are not permitted because of high temperatures, the splice is still of great importance.

A splice around a thimble is called a thimble splice (Fig. 28). A splice which simply forms a loop without a thimble is called a loop splice.

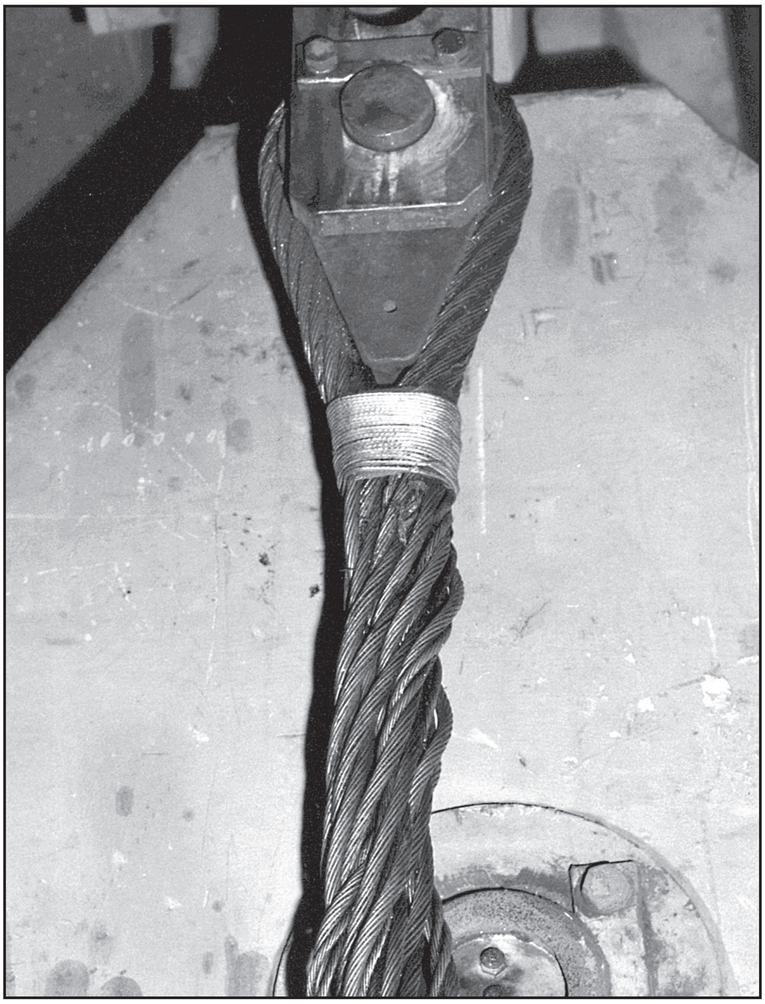

Fig. 28: Thimble splice

6.1. Breaking strength, tension-tension endurance and working temperatures

In a quasi-static pull test, splice end connections in accordance with DIN 3089 Part 1, transfer about 85% of the breaking strength of the wire rope used. If round thimbles are employed, this figure will be reduced to about 50% of the breaking strength of the rope. In a tension-tension fatigue test, splice end connections achieve well below half the number of tension-tension cycles of metallic spelter sockets.

The working temperatures of splice end connections on wire ropes with fibre cores, are between -60°C and +100°C. Splice end connections on wire ropes with steel cores may be used at temperatures of between -60°C and +400°C. At temperatures of between +250°C and +400°C, the lifting capacity of the wire ropes must be reduced to 75%.

6.2. Standardisation

A spliced rope end connection for slings is standardised in EN 13411-2 for 6 and 8 strand ropes.

6.3. Operating mechanism

The splice's grip is caused solely by the friction closure between the strands of the wire rope and the spliced strand ends. Here, of course, it is a great advantage that when the wire rope is strained by a load, it tries to reduce its diameter, and in doing so exerts a contracting pressure on the spliced strands.

If, however, the wire rope is frequently strained in use by high loads (more than 15% of the minimum breaking strength) and afterwards completely or almost completely unloaded, then there is a danger that the splice will loosen and that the spliced strand ends will work themselves out of the splice.

For this reason DIN 3089 categorically prohibits splices as end connections for ropes with these loading characteristics, e.g. for hoist ropes on cranes with small 'dead' loads.

6.4. Fabrication / Installation

The production of a splice is described in great detail in DIN 3089 Part 1. Eight-strand ropes are spliced slightly differently to six-strand ropes, and ropes with a steel core differently to ropes with a fibre core. A splice can be executed both in the direction of lay, as well as against it.

In the following, the most important steps in the production of a splice are described for a loop splice on a six-strand wire rope with a fibre core.

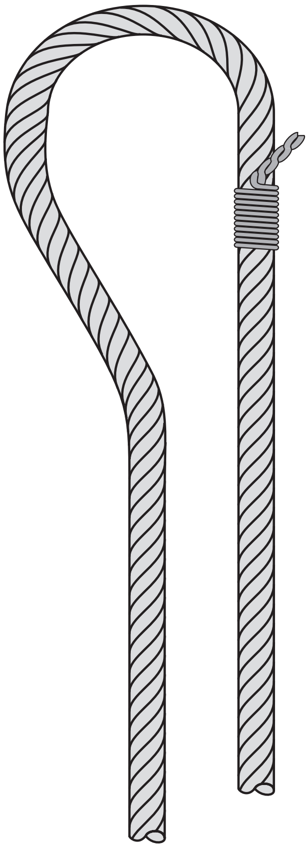

Fig. 29: Seizing at the loop end

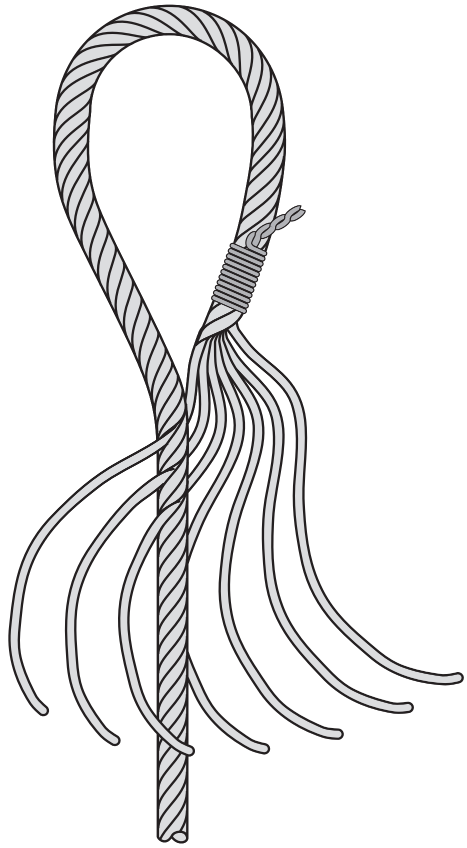

Fig. 30: Inserted strands

First the rope to be spliced is formed into a loop with a certain surplus length and is served at the designated loop end. The two pieces of rope are then connected by a second serving (Fig. 29). Then the single strands of the loose end are unlayed up to the serving and inserted between the strands of the ‘live’ line (Fig. 30) according to the specifications of the standard.

In order to obtain a gap between the strands, a marlin spike – preferably a flat one – is usually used (Fig. 31). This is pushed between the strands and then twisted so that it lifts the strands and provides the necessary space to insert the strand ends.

Fig. 32 and Fig. 33 show a splice on an eight-strand wire rope with a marlin spike inserted.

When splicing larger diameter wire ropes, physical strength is often insufficient to lift the outer strands. In these cases, hydraulic marlin spikes are used. In order to make lifting the strands easier, sometimes the ropes are mechanically unlayed in the splice zone. After the strands have been inserted, the ropes are closed again. Fig. 34 shows splicers working with a device which can turn the rope end by motor.

Fig. 31: Hammering in the marlin spike in

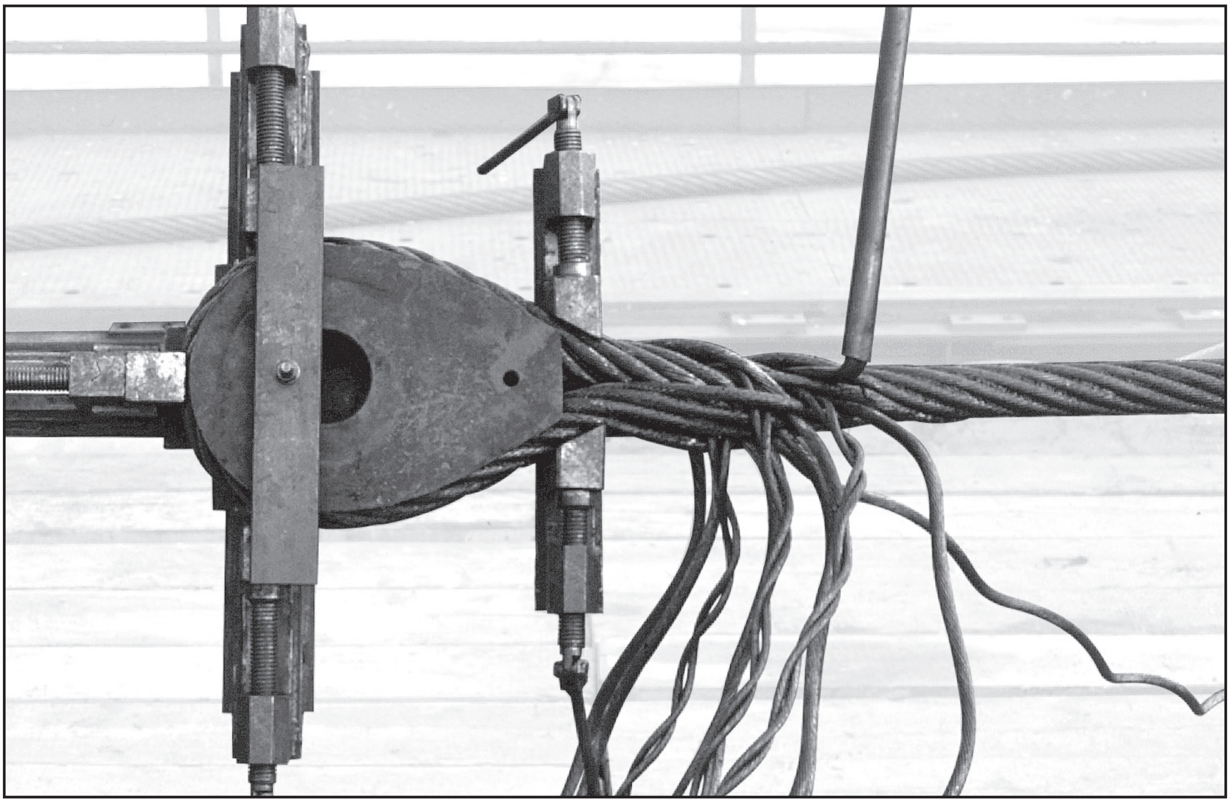

Fig. 32: Splice on an eight-strand wire rope with a steel core

Fig. 33: Splice on an eight-strand wire rope with a steel core (detail)

When every strand has been put through, pulled tight and hammered home once, one tuck has been completed. When splicing ropes with a fibre core, after the fourth tuck the bare fibre core is cut off.

Now, between every two outer strands of the ‘live’ rope, one inserted strand must poke out.

With regular lay ropes, another five roundstitches are completed in the same way. With Langs lay ropes or regular lay ropes which are mainly subjected to tension-tension forces, another seven roundstitches must be completed.

After that, one last so-called half roundstitch is made using every second strand only, to create a transition between the distinctly thicker splice zone and the unspliced rope length.

All the protruding strand ends are then cut off leaving a projecting end of approximately one strand diameter. In order to reduce the danger of injury all strand ends are wrapped with hemp, plastic or wire. Finally, the seizing which was put on initially, is removed.

Fig. 34: Splicers at work

6.5. Inspection

It is relatively easy to inspect a splice visually. A splice must be discarded when wire breaks occur or the strands in the area around the splice have slipped out by the length of one roundstitch, or if they are heavily corroded. Several users recommend that the splice be lightly sprayed with paint once it is completed, so that any strand slippage can be easily recognised. If slippage does occur, the unsprayed sections will be visible where once they were hidden.

To assess the condition of a splice it may be necessary to remove any plastic tapes, seizing wires or seizing strands from the splice zone.

6.6. Special designs

There is a great number of non-standardised special designs of the splice as an end connection. However, they will not be covered in any further detail in this brochure.

7. The aluminium clamp

The aluminium clamp is probably the most wide-spread end connection in Europe (Fig. 35). In the USA this end connection is called a 'mechanical splice'.

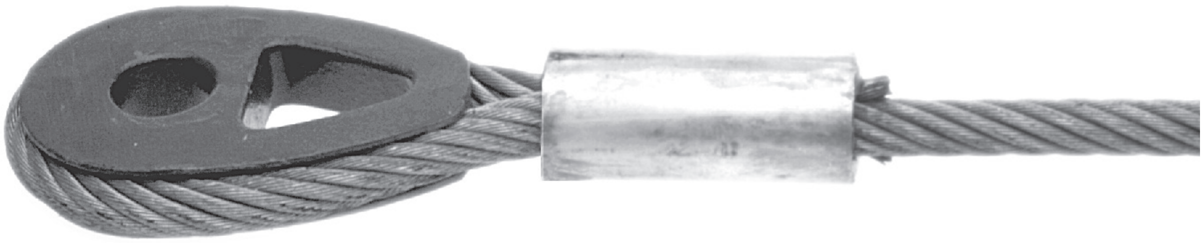

Fig. 35: Aluminium clamps are probably the most wide-spread end connection in Europe

7.1. Breaking strength, tension-tension endurance and working temperatures

In a quasi-static pull test, aluminium clamps achieve - depending on their design – between 80% and 100% of the breaking strength of the wire rope used. In a tension-tension fatigue test they achieve – on average – about 60% of the number of tension-tension cycles of metallic spelter sockets.

Aluminium clamps on wire ropes with fibre cores may be used at temperatures of between -60°C and +100°C. The permissible working temperatures of aluminium clamps on wire ropes with steel cores are from -60°C to +150°C.

7.2. Standardisation

Aluminium wrought alloy clamps are standardised in EN 13411-3.

7.3. Operating mechanism

The clamps firmly press the 'live' rope line onto the 'dead' one and in doing so allow a transfer of force between the two rope lines by friction closure as well as by form closure. The mechanical interlocking is caused by the two ropes both indenting each other, as well as the two ropes indenting the aluminium sleeve.

7.4. Fabrication / Installation

The sleeves required for the fabrication of aluminium clamp end connections are standardised in EN 13411-3.

First the desired clamp shape must be selected. Clamp types are differentiated between cylindrical form A, cylindrical-rounded form B and cylindrical-conical form C (Fig. 36).

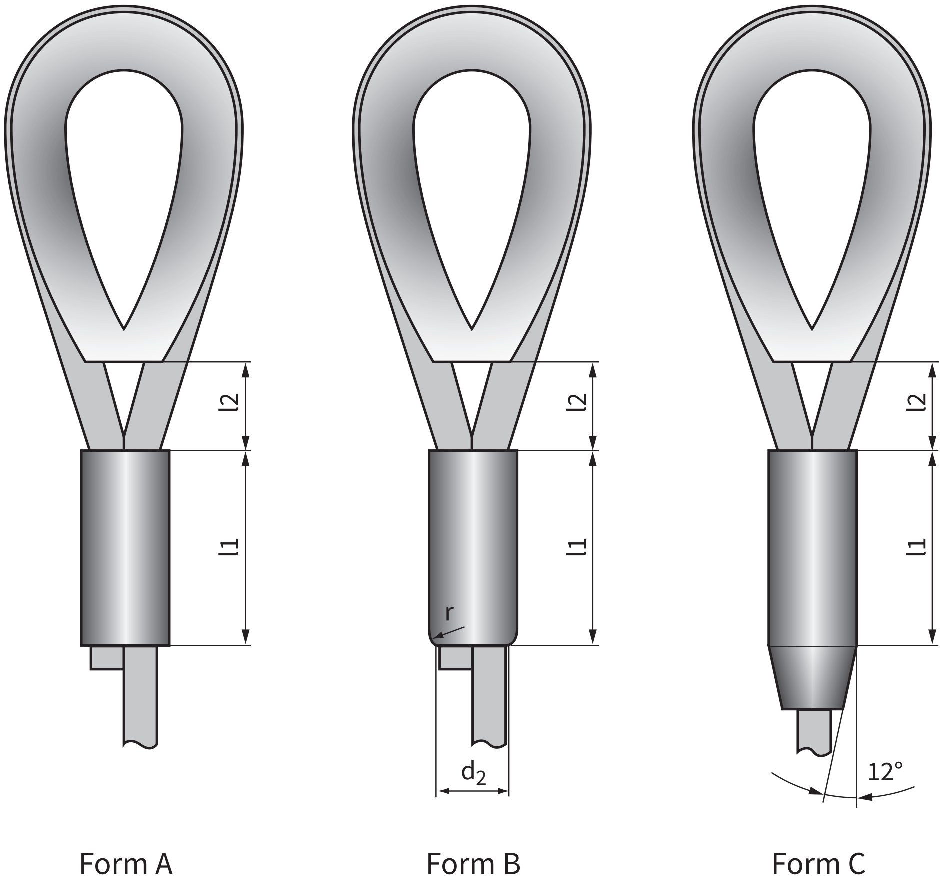

Fig. 36: Clamp shapes

Types A and B are fabricated from the same clamp slugs (Fig. 37). Type C is produced from the same sized slugs but with a flat cone-point and a window (Fig. 38). Type C is intended to make it easier to pull the rope ends out from under a load. The sharp rope ends poking out from clamp types A and B present a risk of injury. Type C eliminates this danger by completely enclosing the 'dead' rope end.

The correct clamp size must be selected in accordance with the nominal diameter, the fill factor and the design of the wire rope. For nominal rope diameters from 7mm to 14mm, the clamp-size number increases in steps of one, for diameters from 16mm to 28mm in steps of two, and for diameters from 32mm to 60mm in steps of four.

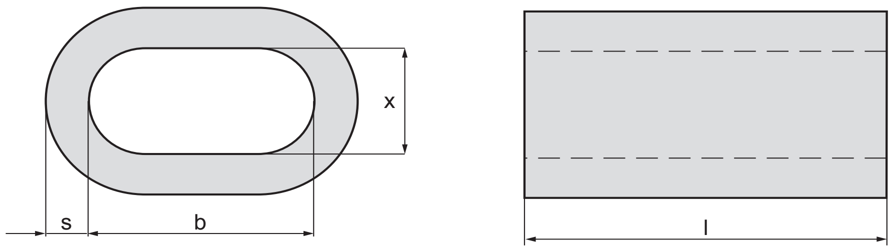

Fig. 37: Slug for clamps A and B

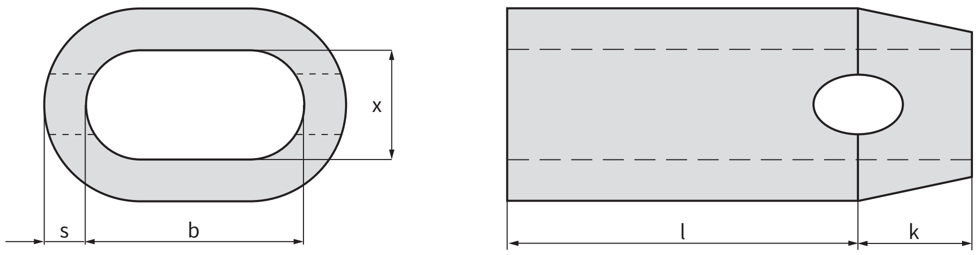

Fig. 38: Slug for clamp C

There are four distinct cases for choosing the clamp size (Fig. 39):

Case X: For single-layer round-strand ropes with a fibre core, and for cable-laid ropes with fill factors of at least 0,36 or a c- value of at least 0,283. For these ropes a clamp-size number is selected corresponding with the nominal rope diameter. For example, a rope with a nominal diameter of 22mm is pressed with a No. 22 clamp.

Case Y1: For single-layer round-strand ropes with steel cores and also for multi-layer round-strand ropes, with a fill factor of up to 0,62 or a c- value of 0,487. For these ropes the clamp size is chosen one number higher than the corresponding nominal rope diameter. As from 14mm to 28mm these numbers increase in steps of two, a rope with a nominal diameter of 22mm would be pressed with a No. 24 clamp.

Case Y2: For single-layer round-strand ropes with a steel core and also for multi-layer round-strand ropes, with fill factors between 0,62 and 0,78 or c-values between 0,487 and 0,613. For these ropes the clamp is chosen two numbers higher than the corresponding nominal rope diameter. As from 32mm to 60mm these numbers increase in steps of four, a rope with a nominal diameter of 44mm would be pressed with a No. 52 clamp.

Case Z: For open spiral ropes with a fill factor of at least 0,78 or a c- value of at least 0,613. For these ropes the clamp is also chosen two numbers higher than the nominal diameter of the wire rope.

Here two clamps must be fitted with a distance of twice the rope diameter. For example, a rope with a nominal diameter of 22mm would be pressed with two No. 26 clamps.

Rope diameter			Clamp number (acc. to EN 13411-3)			
nominal	actual rope dia.		Case X Single layer round strand ropes with fibre core and cable laid ropes	Case Y1 Single layer round strand ropes with steel core and multi-layer round strand ropes	Case Y2 Single layer round strand ropes with steel core and multi-layer round strand ropes	Case Z spiral strands 2 clamps
d [mm]	from [mm]	to [mm]	c ≥ 0,283	c ≤ 0,487	0,487 < c < 0,613	c ≤ 0,613
2,5	2,5	2,7	2,5	3	—	—
3	2,8	3,2	3,	3,5	—	—
3,5	3,3	3,7	3,5	4	—	—
4	3,8	4,3	4	4,5	—	5
4,5	4,4	4,8	4,5	5	—	6
5	4,9	5,4	5	6	—	6,5
6	5,5	5,9	6	6,5	—	7
	6,0	6,4			7	
6,5	6,5	6,9	6,5	7	8	8
7	7,0	7,4	7	8	9	9
8	7,5	7,9	8	9	9	10
	8,0	8,4			10	
9	8,5	8,9	9	10	10	11
	9,0	9,5			11	
10	9,6	9,9	10	11	11	12
	10,0	10,5			12	
11	10,6	10,9	11	12	12	13
	11,0	11,6			13	
12	11,7	11,9	12	13	13	14
	12,0	12,6			14	
13	12,7	12,9	13	14	14	16
	13,0	13,7			16	
14	13,8	13,9	14	16	16	18
	14,0	14,7			18	
16	14,8	15,9	16	18	18	20
	16,0	16,8			20	
18	16,9	17,9	18	20	20	22
	18,0	18,9			22	
20	19,0	19,9	20	22	22	24
	20,0	21,0			24	
22	21,1	21,9	22	24	24	26
	22,0	23,1			26	
24	23,2	23,9	24	26	26	28
	24,0	25,2			28	
26	25,3	25,9	26	28	28	30
	26,0	27,3			30	
28	27,4	27,9	28	30	30	32
	28,0	29,4			32	
30	29,5	29,9	30	32	32	34
	30,0	31,5			34	
32	31,6	31,9	32	34	34	36
	32,0	33,6			36	

Fig. 39: Clamp-size numbers according to EN 13411-3 (The c- value is defined as the fill factor of the rope, multiplied byt π/4.)

For various special wire ropes, such as ropes with an intermediate plastic layer, and for rope designs with a high fibre content in their strands, different clamp-size numbers could be required from those expected based on to their fill factors.

When cutting wire ropes to length, it must be ensured that the rope sections which later lie inside the clamp are not damaged and that the lay length is not changed in this section. When the rope is cut to length and fused, it must be ensured that the annealing length is not greater than one rope diameter. In addition, the rope ends must not be quenched. Ropes using type C clamps (cylindrical-conical), where the rope end is enclosed by the clamp, must not be cut and fused.

If the seizing of the wire rope is clamped as well, it must consist of wires or strands of a low tensile strength only, and the seizing wire may have a maximum diameter of only 1/20th of the rope's diameter.

The wire rope is threaded through the clamp, shaped into a loop or laid round a thimble and then fed back through the clamp. A loop which is half a loop length wide (Fig. 40) must be the length of three attachment pin diameters, and in any case not less than fifteen rope diameters.

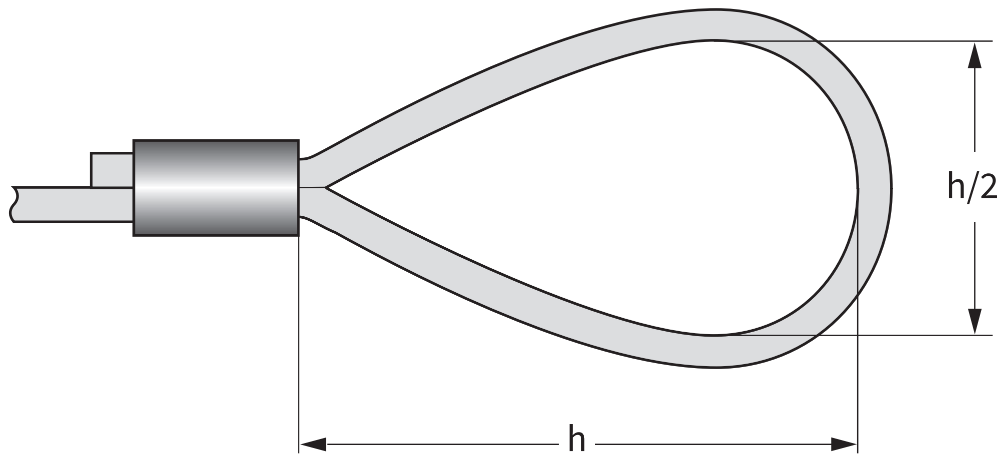

Fig. 40: Dimensions of the loop

When pressed with a thimble, the distance between the clamp and the thimble should be two rope diameters after pressing. With clamps of types A and B, the rope end must project from the clamp. With type C it must end with the cylindrical part of the clamp and be visible in the clamp's window.

Before being transported to the press, wire ropes are often prepared on a work-bench. In order to prevent the clamp from slipping during transportation, it can be fixed temporarily on the rope lines either by means of a hammer, a vice or some hydraulic device. Great care must be taken to ensure that the sides of the clamp are not dented because if they were they might collapse during the pressing procedure (Fig. 41 and Fig. 42).

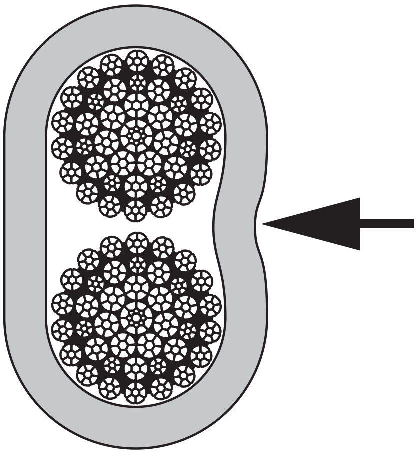

Fig. 41: Incorrect attachment of the clamp

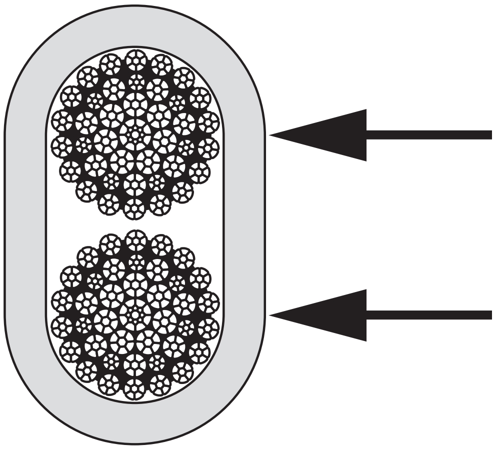

Fig. 42: Correct attachment of the clamp

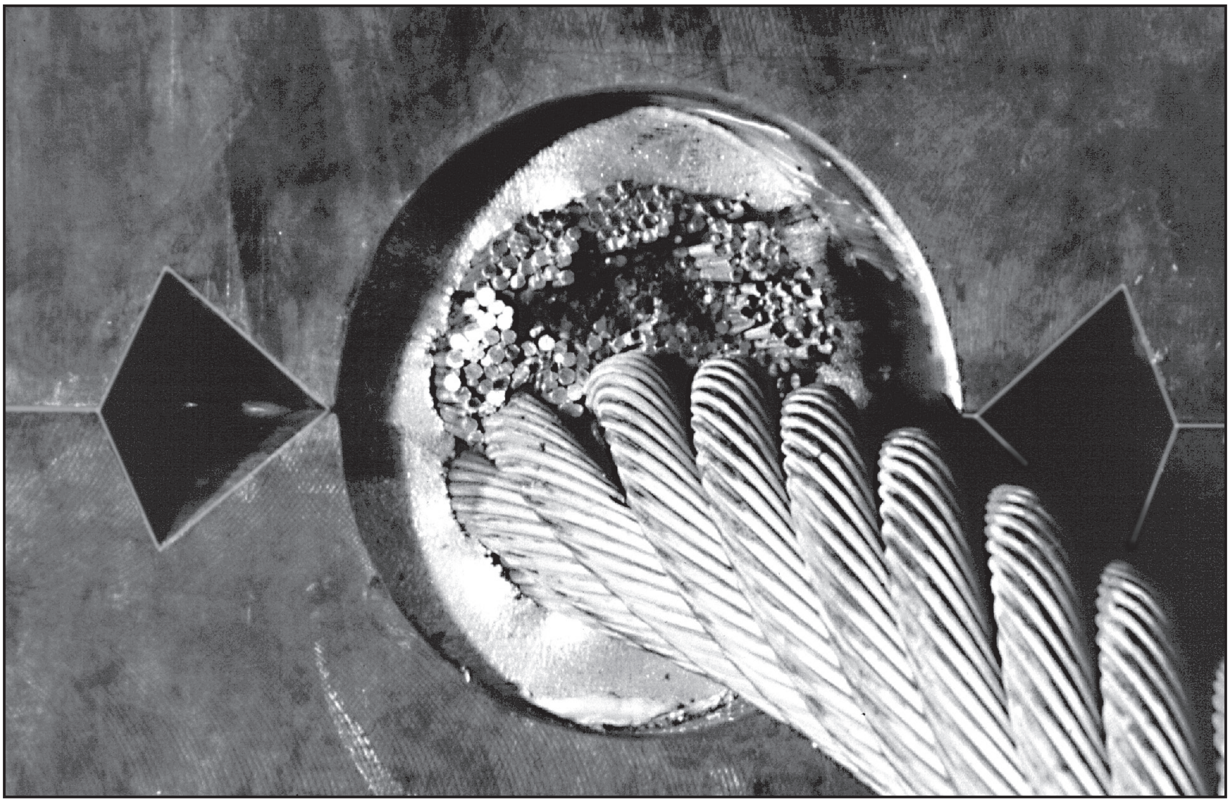

Fig. 43: Pressing of the aluminium clamp

Before pressing, the contact zones and the interior surfaces of the die must be cleaned. In addition, the interior surfaces must also be greased so that the aluminium clamp can flow unhindered during the pressing. Next, the prepared, unpressed clamp is laid into the die, aligned exactly in the direction of the pressing and is finally pressed in one go until the contact zones of the die halves meet (Fig. 43). After pressing, any seams left on the clamp should be filed off in order to avoid injuries.

Along an arc of 120° around the circumference, the pressed clamp must have the diameter specified in EN 13411-3. This diameter corresponds to twice the clamp No. in mm (Fig. 44).

Ferrule size number	External pressed size d_1			Parallel length		
	nominal [mm]	tolerance [mm]	d_2 min. [mm]	l_1* [mm]	l_2* [mm]	r * [mm]
2,5	5	+0,2 / 0	—	12	3,75	—
3	6	+0,2 / 0	—	14	4,5	—
3,5	7	+0,2 / 0	—	16	5,25	—
4	8	+0,2 / 0	—	18	6	—
4,5	9	+0,2 / 0	8	20	6,75	4,5
5	10	+0,2 / 0	9	23	7,5	5
6	12	+0,4 / 0	11	27	9	6
6,5	13	+0,4 / 0	12	29	9,75	6,5
7	14	+0,4 / 0	13	32	10,5	7
8	16	+0,4 / 0	14,5	36	12	8
9	18	+0,4 / 0	16,5	40	13,5	9
10	20	+0,5 / 0	18	45	15	10
11	22	+0,5 / 0	20	50	16,5	11
12	24	+0,5 / 0	22	54	18	12
13	26	+0,5 / 0	24	59	19,5	13
14	28	+0,7 / 0	25	63	21	14
16	32	+0,7 / 0	29	72	24	16
18	36	+0,9 / 0	32	81	27	18
20	40	+0,9 / 0	36	90	30	20
22	44	+0,9 / 0	39	99	33	22
24	48	+1,1 / 0	43	108	36	24
26	52	+1,1 / 0	46	117	39	26
28	56	+1,1 / 0	50	126	42	28
30	60	+1,4 / 0	53	135	45	30
32	64	+1,4 / 0	56	144	48	32
34	68	+1,4 / 0	59	153	51	34
36	72	+1,6 / 0	63	162	54	36
38	76	+1,6 / 0	66	171	57	38
40	80	+1,6 / 0	69	180	60	40
44	88	+1,9 / 0	75	198	66	44
48	96	+1,9 / 0	81	216	72	48
52	104	+2,1 / 0	87	234	78	52
56	112	+2,3 / 0	93	252	84	56
60	120	+2,4 / 0	99	270	90	60

Fig. 44: Final dimensions of aluminium pressings in accordance with EN 13411-3 (* approximate dimensions)

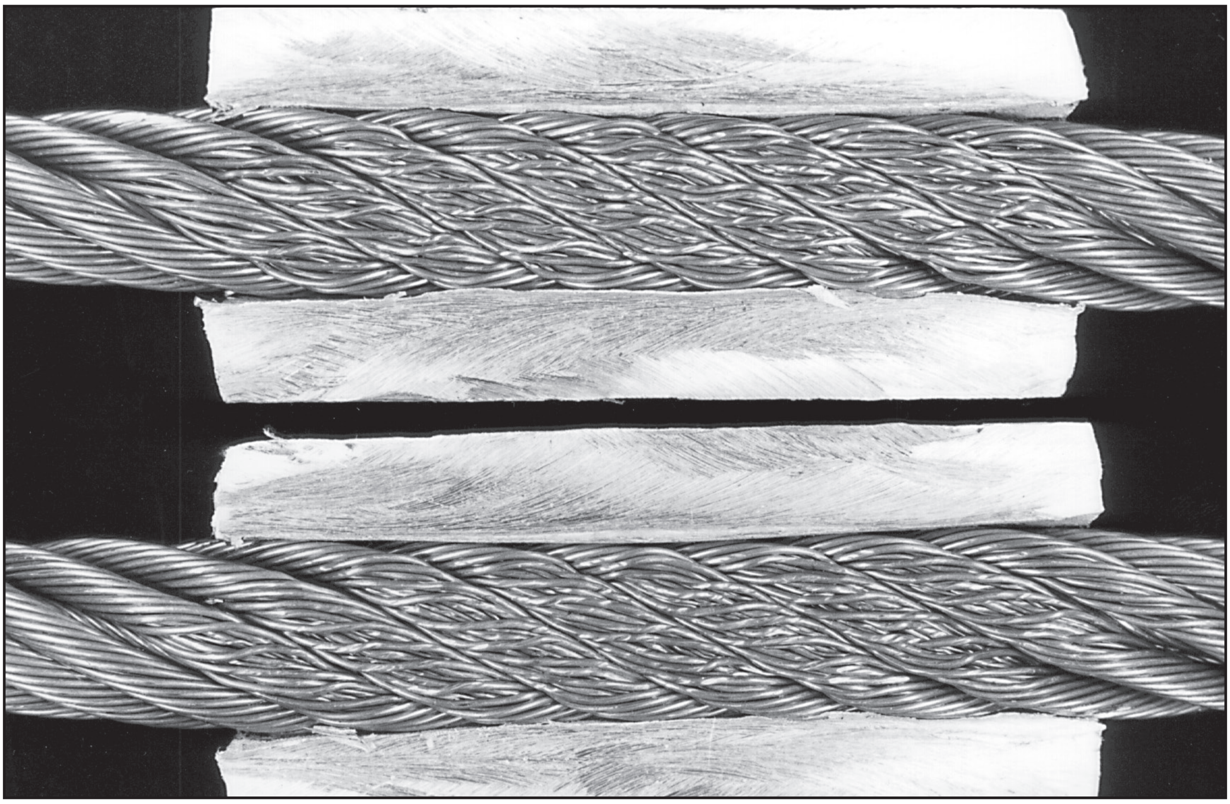

Fig. 45: The contact zones of regular lay ropes made visible by cutting the clamp in half

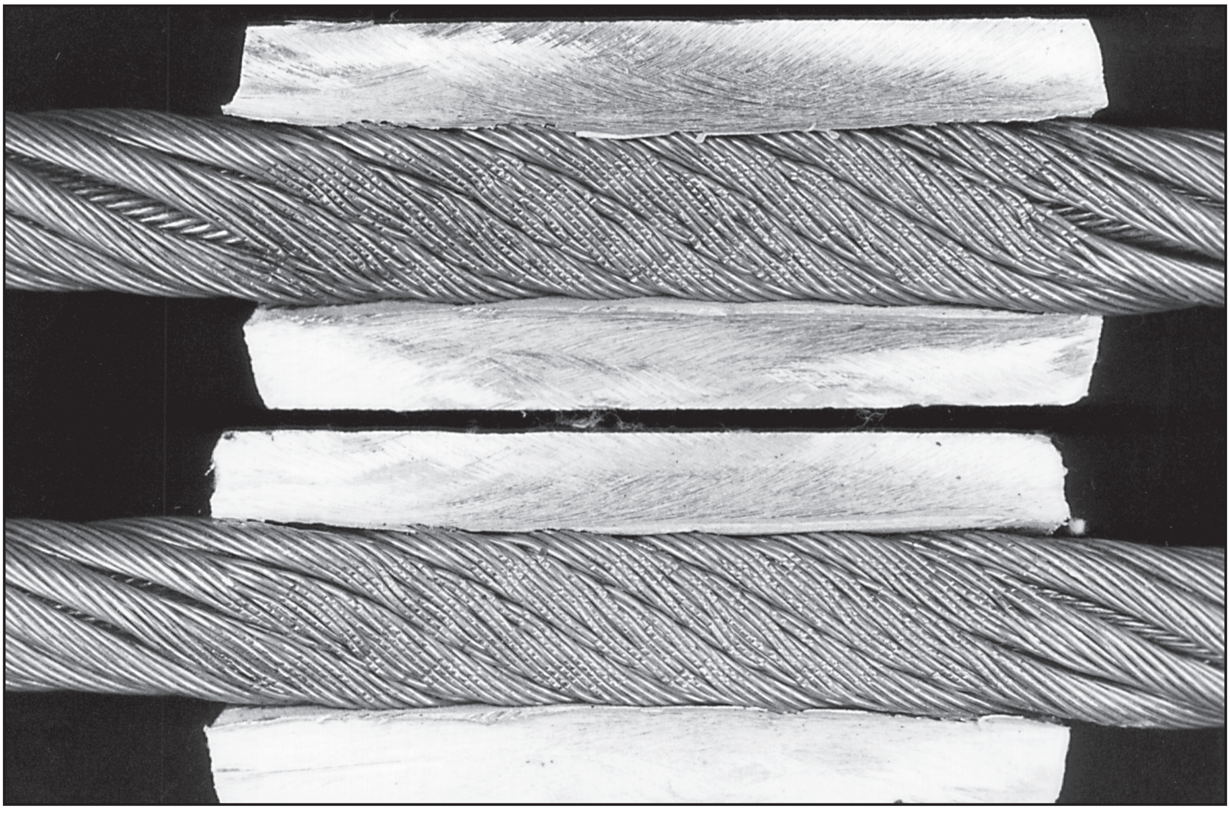

Fig. 46: The contact zones of Langs lay ropes made visible by cutting the clamp in half

Before pressing, the length of the cylindrical part of the clamp is 3.5 times the amount of the clamp-size number in mm, after pressing it is 4.5 times that amount. The clamp must bear the presser's initials (two letters) and the DIN logo.

In the area of the clamping zone, the 'live' and the 'dead' rope line are heavily pressed against each other. When pressing regular lay ropes, the outer wires, which have approximately the same direction as the rope's axis, will arrange themselves in a parallel order (Fig. 45).

When pressing Langs lay ropes, however, the outer wires of the neighbouring rope lines cross over so that they can nick each other (Fig. 46). However, tests have shown that this does not lead to great differences in the breaking strengths between aluminium pressings of regular lay ropes and Langs lay ropes.
Along the clamping zone, regular lay ropes are slightly superior to Langs lay ropes in tension-tension fatigue tests. However, this does not influence the choice of lay for running ropes as these are usually discarded because of wire breaks along the working zone, and not because of damage at the end connections.

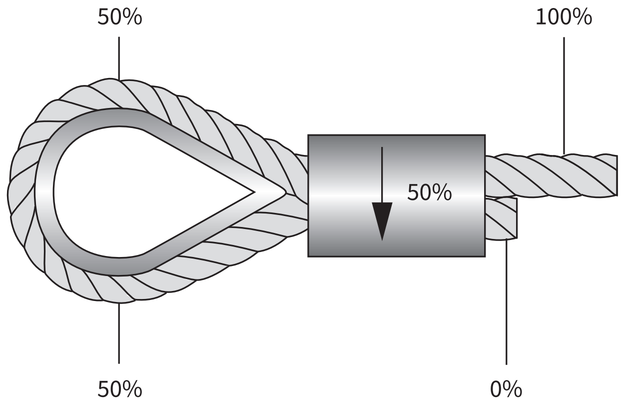

Fig. 47: Force transfer in aluminium clamps

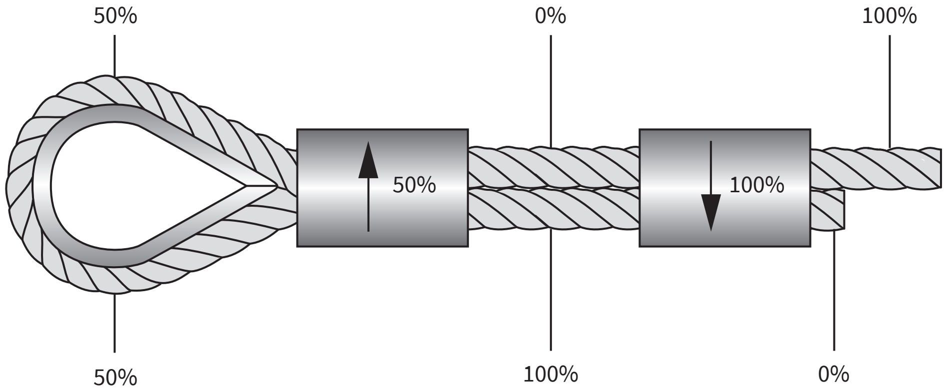

Fig. 48: Flow of force in an aluminium pressing when two clamps are used

Occasionally, rope end connections of the X and Y types are found with two aluminium clamps (remember that two aluminium clamps are a must with type Z). The second clamp is meant to increase safety. Yet, in reality, it makes the end connections unsafe.

In the clamp zone, the ‘live’ rope line usually transfers 50% of the line pull to the ‘dead’ line (Fig. 47). If a second clamp is fitted in the immediate vicinity of the first, it might happen that – due to uncontrollable movement in the section between the clamps during the pressing procedure – the ‘live’ load line is slightly longer than the ‘dead’ one. The flow of the force runs along this short zone of the ‘dead’ line.

As a consequence, one of the clamps must now transfer not only 50%, but 100% of the line pull (Fig. 48). When the line pull is high, the clamp cannot withstand these stresses. For these reasons a rope end connection with two aluminium clamps is not permitted in cases X and Y.

For case Z, which only applies to spiral rope, i.e. for relatively stiff strands, the danger of differences in rope length between the clamps does not exist.

Fig. 49: Incorrect connection of two ropes

Fig. 49 shows the lengthening of a sling by using an aluminium clamp. Here, too, the clamp must transfer 100% of the line pull. This kind of rope lengthening is not permitted.

7.5. Inspection

When inspecting the clamp and the loop for the first time, their dimensions must be checked to ensure they meet the specifications. Later, the end connection must be inspected for wire breaks as well as for cracks and physical damage in the area around the aluminium clamp (Fig. 50).

Fig. 50: Physical damage to the aluminium clamp

Since the introduction of force into the end connection occurs off-centre, the clamp will adopt a slightly tilted position, which strains the clamp near the exit point of the 'live' line. Therefore, cracks and wire breaks may occur at this point. At the other end of the clamp, the two projecting rope lines will try to change their angle and widen the clamp. This might lead to cracks in the clamp, especially if it was attached too close to the thimble, or if the loop was too short. Cracks in the conical part of type C clamps do not affect the breaking strength of the end connection.

During every inspection it must be checked whether the position of the 'dead' rope line has changed. When employed in a marine environment, the clamp should also be checked for corrosion damage. Fig. 51 shows a corroded aluminium clamp.

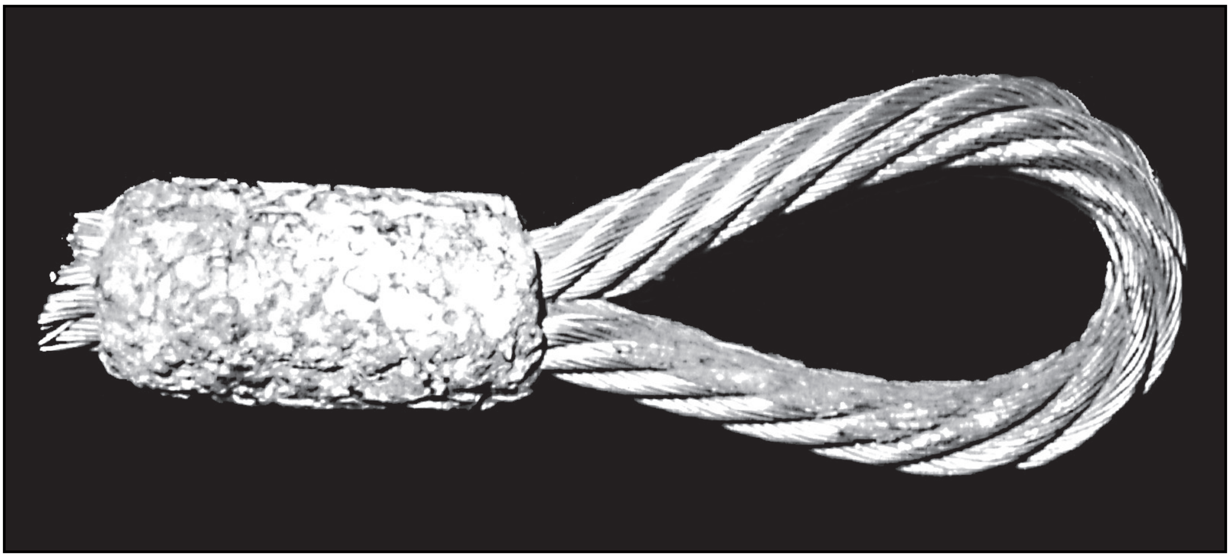

Fig. 51: Corroded aluminium clamp

7.6. Special designs

Various suppliers offer special designs, but the number is too great to cover here.

8. The Flemish Eye

The Flemish Eye is a comparatively new end connection. It consists of a combination of a splice and a pressing. It is mainly used in steel mills, where ropes are exposed to higher temperatures, and serves as a replacement for the thimble splice.

8.1. Breaking strength, tension-tension endurance and working temperatures

In a quasi-static pull test, rope end connections with Flemish Eyes transfer between 80% and 100% of the breaking strength of the wire rope used. In a tension-tension fatigue test they achieve – on average – about 70% of the tension-tension cycles of metallic spelter sockets.

Rope end connections with Flemish Eyes may be used at temperatures of between -60°C and +400°C. At temperatures between +250°C and +400°C the lifting capacity of the wire ropes must be reduced to 75%.

8.2. Standardisation

The Flemish Eye with steel clamps is standardised for single-layer round-strand ropes with a steel core in EN 13411-3. Different types of Flemish Eyes are denoted as follows: Flemish Eyes without a thimble (Type PF), and Flemish Eyes with a thimble (Types PFKF and PFKV) (see Fig. 52).

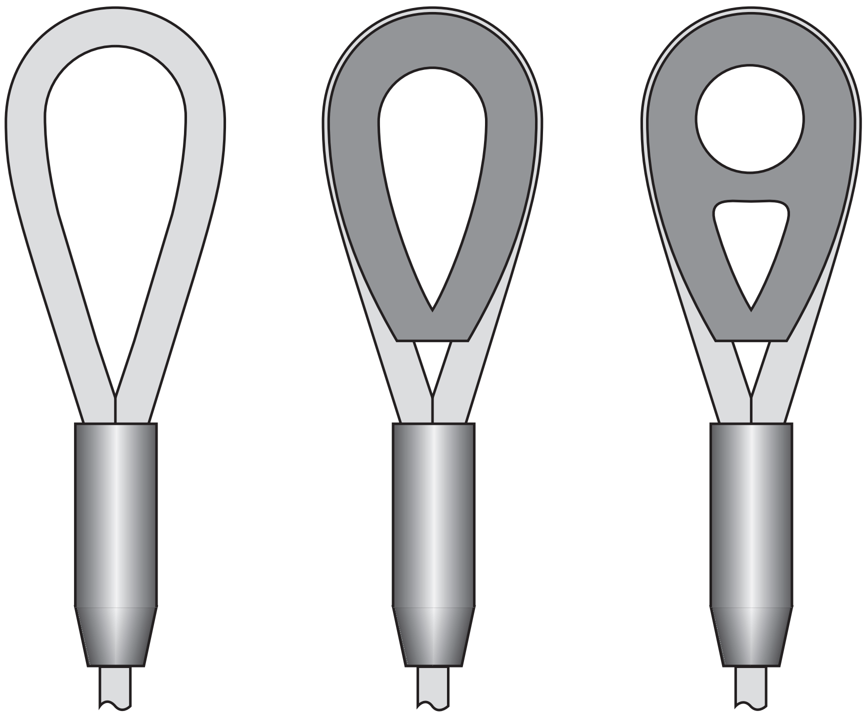

Fig. 52: Various designs of the Flemish Eye

8.3. Operating mechanism

Even without pressing, in a quasi-static pull test a Flemish Eye transfers as much as 70% of the breaking strength of the wire rope used. This result is achieved just by the friction closure between the rope's elements. A further improvement of that result is achieved by friction closure and form closure when the steel clamp is pressed on.

8.4. Fabrication / Installation

First it must be decided whether or not the steel core of the rope should be pressed along with the outer strands. If so, then a clamp of type A – EN 13411-3 – must be used. If not, a clamp of type B should be fitted. Both types are available in cylindrical and in cylindrical-conical form. The latter design is supposed to prevent the clamp from getting caught when being pulled from under a load. Its disadvantage is that it makes inspection more difficult.

First, the as yet unworked rope is pulled through the steel clamp selected. Then the outer strands of the rope are unlayed and separated into the required lengths (Fig. 53 B). Here the rope length must be chosen in a way that the loop length for a Flemish Eye without a thimble (Type PF) amounts to three times the size of the attachment pin diameter, and in any case to at least twenty rope diameters (Fig. 54). When fabricating a Flemish Eye with a thimble (Types PFKF or PFKV), the unlayed rope length must amount to at least four lay lengths of the wire rope.

The wire rope's core is bent backwards and formed into a loop. Then the unlayed wire rope halves are closed around the wire rope's core. In this way, for instance, the core of an eight-strand rope is closed from the right and left with only four strands respectively, until the strands from both sides are rejoined at the head of the loop. When the strands are closed further, starting from the head, a complete wire rope is formed in the vicinity of the loop (Fig. 53 C).

After the outer strands of the rope have been closed completely around the rope core (Fig. 53 D), they are all wound further around a piece of the non-unlayed rope beneath the loop. Then the steel clamp is slid over the strand ends and is pressed in several steps in accordance with the specifications. If a steel clamp of type B is used, the steel core within the clamp must be removed before pressing.

In a modification of the procedure, first the steel core is split and wrapped around the core strand, then the outer strands are wound around the loop and pressed with a steel clamp.

The clamp must display the following information: identifying letter F, the breaking strength, the presser's initials (two letters) and the DIN logo.

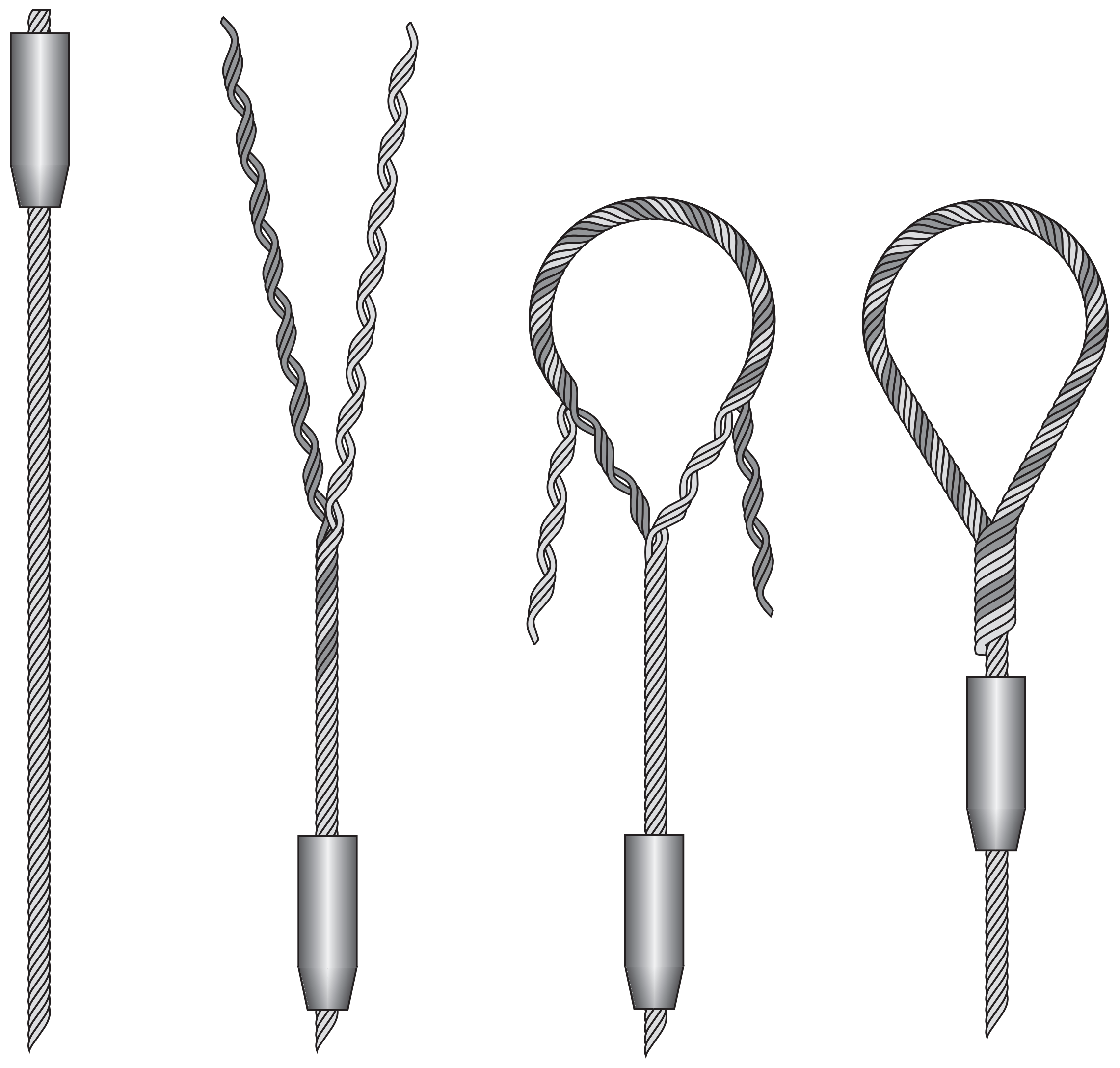

Fig. 53: The fabrication of a Flemish Eye

8.5. Inspection

The inspection of Flemish Eyes fitted with cylindrical-conical clamps is difficult, because any displacement of the strands inside the clamp cannot be detected. With Flemish Eyes of the PFKV type with cylindrical steel clamps, the strand ends project from the clamp, making dislocation of the strands slightly easier to detect. Flemish Eyes must be checked for wire breaks, especially in the area around the clamp.

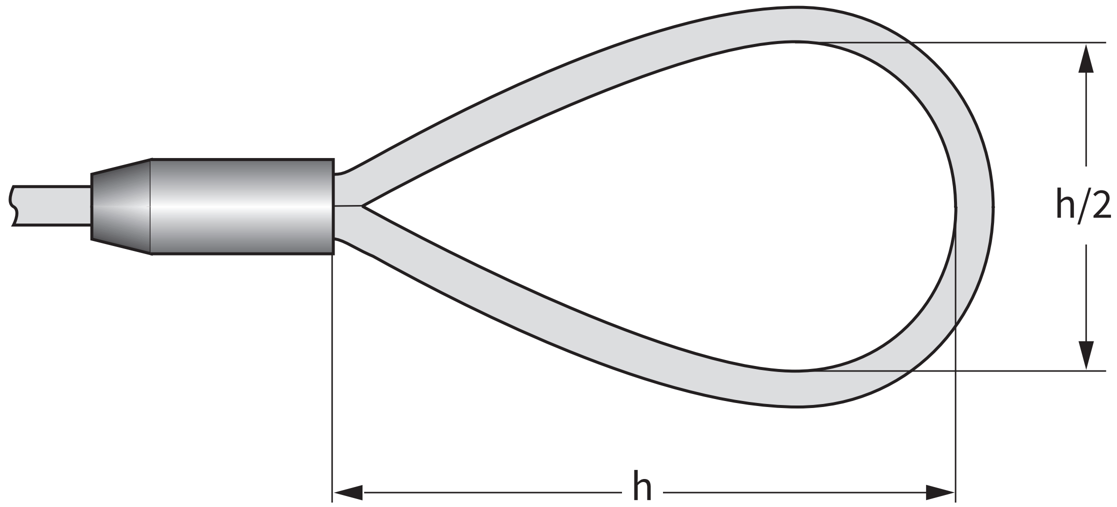

Fig. 54: Dimensions of the loop

8.6. Special designs

Flemish Eyes also achieve satisfactory results when they are fabricated using an aluminium clamp. This variant, which is not suitable for operation in high temperatures, is not covered by any recognised standards.

A Canadian manufacturer offers a variation on the Flemish Eye where the loop is secured by a resin spelter socket instead of a steel clamp. This is achieved by sliding a thin-walled aluminium clamp over the strand ends once they have been closed. It is then plugged with a two-part hardening resin. Of course, this variant is not suitable for operation in high temperatures either, but its advantage is that it can be fabricated manually on any construction site or drilling platform without the aid of a large press. Under quasi-static loading, this variation of the Flemish Eye achieves very high breaking strengths.

9. The swaged socket

A swaged socket, also referred to as a 'swaged terminal', is an end connection characterized by a sleeve which is slid onto the rope end and is attached by either pressing, rolling or hammering it on (Fig. 55). Its advantages are the coaxial introduction of force and ease of fabrication. In Europe the swaged socket is mainly used for ropes with small diameters, such as Bowden strands, aircraft cables or stainless steel shrouds for sailing boats. In the USA, however, the swaged terminal is also very popular as an end connection for suspension ropes and crane hoist ropes.

Fig. 55: Swaged socket

9.1. Breaking strength and tension-tension endurance

In a quasi-static pull test swaged sockets transfer – depending on their design and installation – between 90% and 100% of the breaking strength of the wire rope used. In a tension-tension fatigue test, they achieve – on average – about 75% of the number of cycles of metallic spelter sockets. Rolled-on terminals achieve an even higher number of cycles than metallic spelter sockets.

9.2. Standardisation

Swaged sockets are standardised in EN 13411-8. There is a great variety of designs on the market.

9.3. Operating mechanism

The wire rope is inserted into the bore hole of the bolt. Then the bolt is attached to the rope by either pressing, rolling or hammering. The transfer of force from the wire rope to the bolt (the terminal) is essentially managed by form closure (indentation).

9.4. Fabrication / Installation

There are many designs of swaged sockets on the market. Fig. 56 shows an eye socket, an open socket, a screw terminal and one design incorporating a ball head.

Before the terminal is pressed, hammered or rolled on, it is important to ensure that the bore hole of the sleeve is free from any swarf. If there is any left in the bore hole, the wire rope might not be pushed far enough into the bore hole and the bolt might be pressed in the wrong position. As a rule the wire rope should be pushed into the bore hole by an amount equal to between four to six rope diameters.

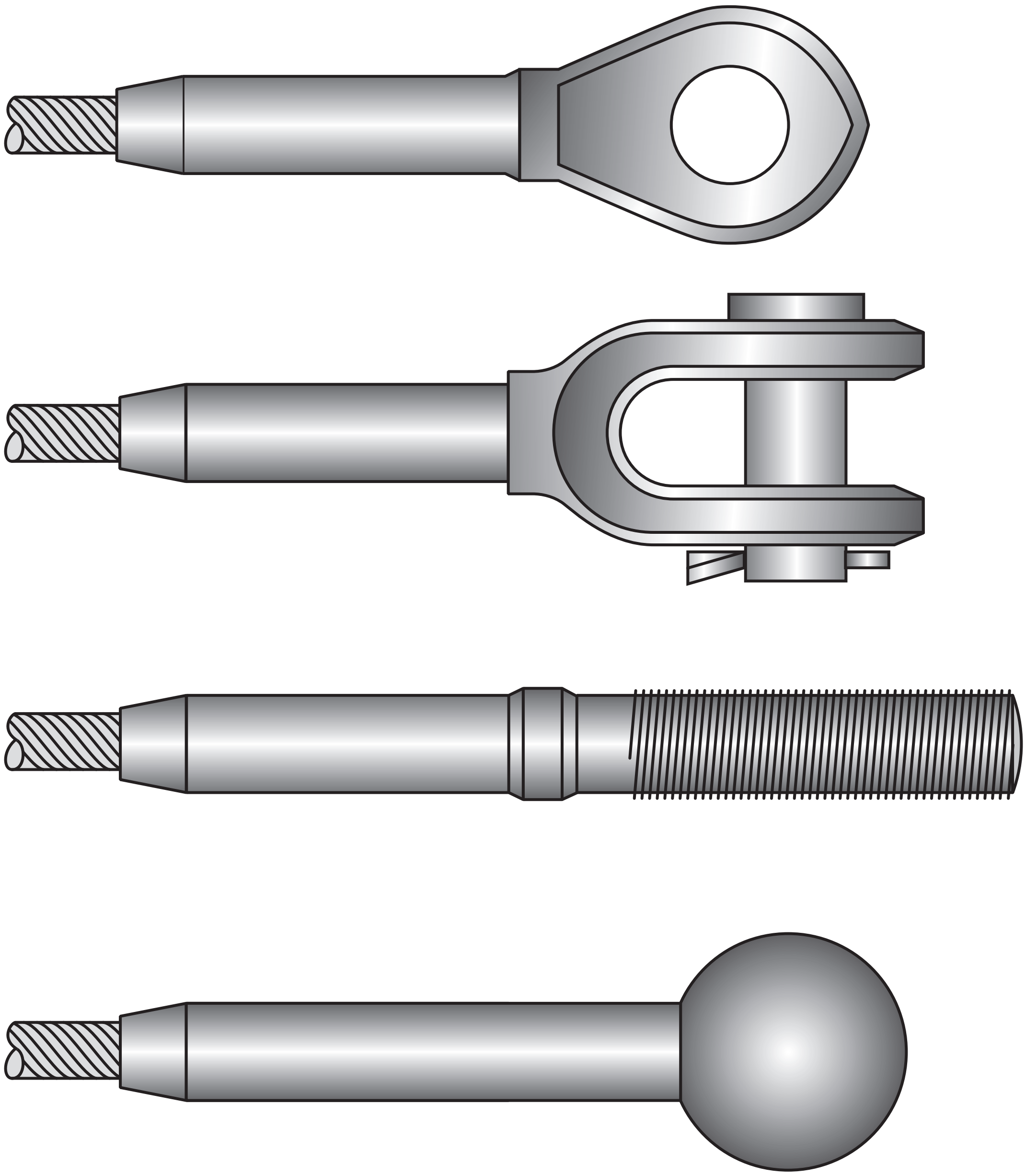

Fig. 56: Designs of swaged sockets

To make sure that the rope is actually pushed far enough into the sleeve, it should first be held alongside the bolt and the required length marked on the rope with a coloured crayon or a felt pen. Then the rope is pushed into the bolt as far as is possible. The crayon mark should then be very close to the exit of the sleeve. Finally, the sleeve is pressed in two planes perpendicular to each other, by using either a stationary knee lever or a hydraulic press (Fig. 57).

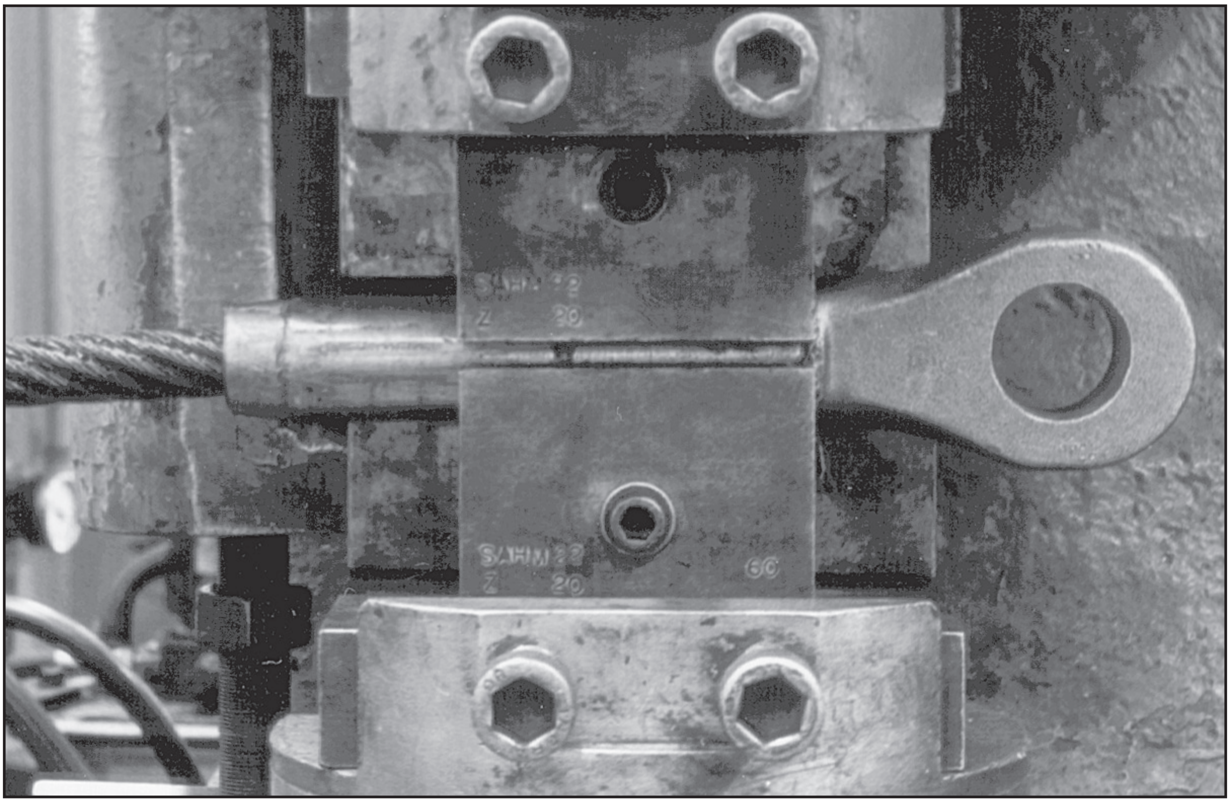

Fig. 57: Pressing procedure

When being pressed in a rotary swager, the sleeve is beaten by two or four stationary hammers at very short intervals (Fig. 58). During this process, the sleeve must be turned once through 90° whilst being moved longitudinally.

Usually the manufacturers of the sleeves will state the permissible rope diameter and the diameter of the sleeve in its pressed and unpressed condition. The bolt diameter is usually reduced by 15% to 20%. Achieving the specified final swaged diameter is an accepted proof of successful pressing.

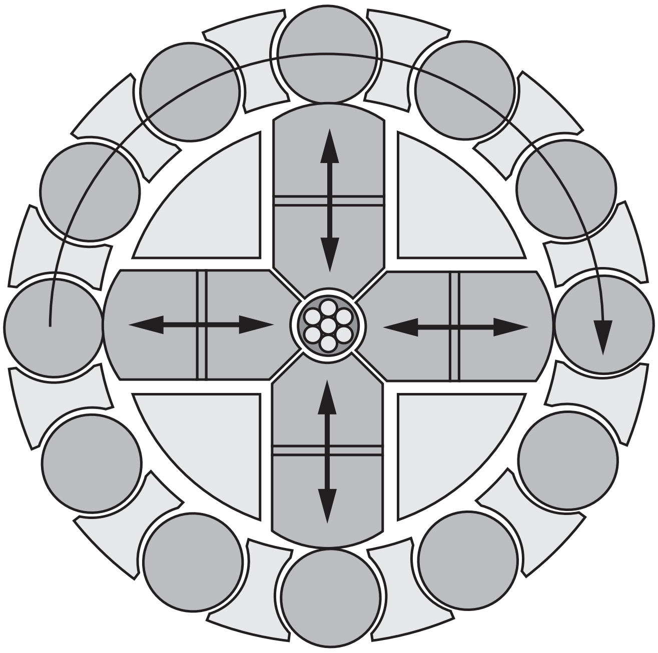

Fig. 58: Cross-sectional view of a rotary swager for attaching swaged sockets

Dipl. Ing. Hemminger, of the University of Stuttgart, has developed the following formula to calculate the minimum diameter of a sleeve after pressing:

$$D_{min} = d \sqrt{\frac{f\,R_{o\,Rope}}{R_{o\,Sleeve}} + 1}$$

In this formula

d	indicates the nominal diameter of the wire rope
f	the fill factor of the wire rope
$R_{o\,Rope}$	the tensile strength of the wire rope
$R_{o\,Sleeve}$	the tensile strength of the sleeve material

According to Hemminger, the bore of the unpressed sleeve for wire ropes with nominal diameters of 0% to +5% should have a maximum diameter of the nominal wire rope diameter plus 10%.

Eight-strand wire ropes with a fibre core should not be pressed with a bolt. With six-strand wire ropes with a fibre core, the core should be removed to an amount equal to its length in the bolt and should be replaced by a piece of outer strand of an equal length.

9.5. Inspection

A swaged socket must be inspected for cracks and physical damage near the point of its attachment. In addition, the wire rope must be inspected for corrosion or wire breaks where it exits from the bolt.

9.6. Roller-swaged sockets

Swaged sockets can also be roller-swaged onto wire ropes. The advantage of this procedure is that the bolt is not pressed along its entire length in one go. On the contrary, the rollers successively press short pieces of the terminal onto the rope (Fig. 59). Therefore, the force required from the swaging machine is relatively low, with the result that these machines can be made compact and transportable (Fig. 60).

With roller swagers, the end connections can be fabricated directly on the construction site or on a drilling platform. This is particularly advantageous in situations where the exact length of rope required is not known before work commences. This is why these types of machines are very popular for producing shroud fastenings in the yacht building industry.

Compactness of machinery is not the only advantage of roller swagers. When the bolt is either pressed or hammered onto the wire rope, the steel from the cylinder is pressed into the valleys between the outer strands of the wire rope, resulting in indentation between the bolt and the rope. When pressed further, there is no space left into which the steel can be forced. Therefore, the resistance increases and the bolt is lengthened.

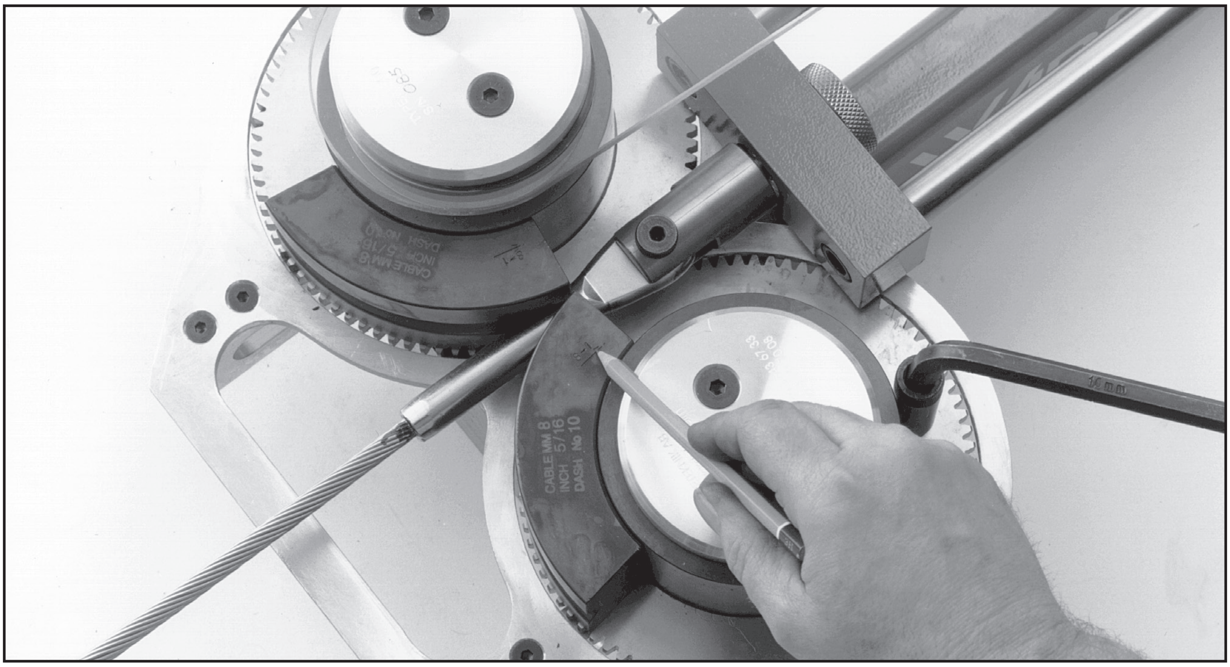

Fig. 59: Successive pressing of short sections of the end connection

Fig. 60: Compact, transportable roller swager

Since the wire rope has been heavily indented with the bolt cylinder, it is forced to follow the lengthening of the bolt. This lengthening is the reason why, in the area around the bolt of a ready swaged socket, the wire rope – even when unloaded – is subjected not only to enormous contact pressure, but also to consistently high pulling forces.

This is not the case in a rolled-on terminal where the bolt is pressed and lengthened little by little. The lengthening of the bolt can take place completely unhindered along the unpressed section of the wire rope. In this way, the socket is pressed without lengthening the rope too much. For this reason, rolled-on swaged sockets achieve a considerably higher number of tension-tension cycles in a tension-tension fatigue test than swaged sockets pressed on conventionally.

There are two different designs of roller swagers on the market: One design presses the terminal by means of two power-driven rollers. Here the sleeve, behaves as dough might do, and tends to bevel around one of the two rollers. The result is a curved end connection which can crack under tensile fatigue stresses.

In a second case, the end connection is pulled hydraulically through a pair of manually operated rollers synchronised by gear wheels (Fig. 59). During the entire pressing procedure, a pulling force is effective in the loading direction of the terminal, which results in a perfectly straight end connection.

9.7. Special designs

There is a great variety of special designs of swaged sockets on the market. In all cases the manufacturer’s instructions should be carefully studied and strictly observed.

10. The metallic spelter socket

The metallic spelter socket is a very reliable and efficient rope end connection. In a pull test it achieves the highest breaking loads, and furthermore, its tension-tension fatigue endurance is excellent. Therefore, it lends itself to all those applications where reductions in breaking strength, caused by the use of end connections, need to be taken into account when selecting the wire rope diameters. It is also used for applications where the end connection is subjected to high tension-tension stresses, as is the case with suspension ropes of crane booms (Fig. 61) or engineering structures (Fig. 62).

Fig. 61: Suspension ropes for lattice boom cranes

10.1. Breaking strength and tension-tension endurance

In a quasi-static pull test, metallic spelter sockets transfer the full breaking strength of the wire rope used. In a tension-tension fatigue test, they achieve the highest number of tension-tension cycles of all rope end connections.

10.2. Standardisation

Metallic spelter sockets as an end connection are standardised in EN 13411-4. The open and closed sockets themselves are standardised in EN 134114 or DIN 83 313.

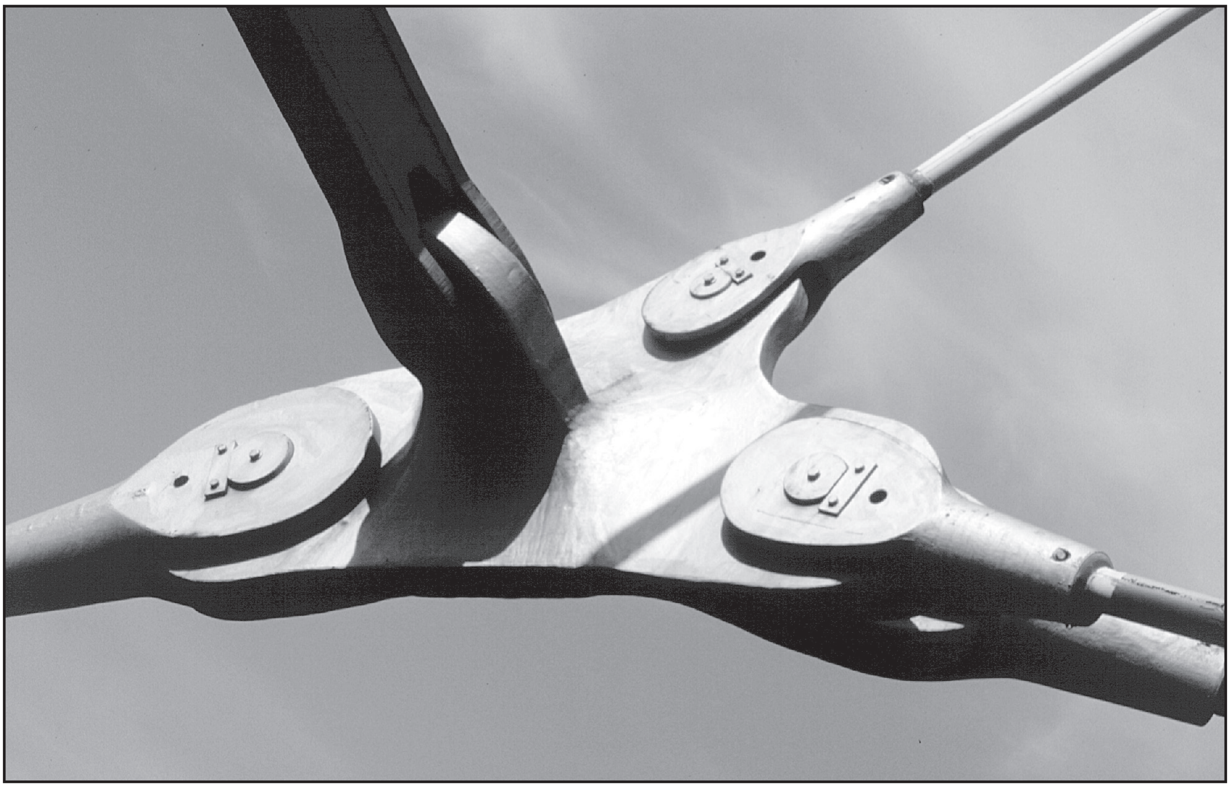

Fig. 62: Suspension ropes on structures

10.3. Operating mechanism

At its end, the wire rope is fanned out like a brush which is then pulled into the conical socket. Once in position a metallic cone is cast securing the brush of the rope into the rope socket. With increasing line pull, the metallic cone is pulled deeper and deeper into the socket, generating increasing transverse clamping forces. The transfer of force between the metallic cone and the rope socket is achieved purely by force closure.

10.4. Fabrication / Installation

10.4.1. Selection of rope socket

Wire rope sockets are available in two types: open and closed sockets.

Fig. 63 shows an open wire rope socket in accordance with DIN 83 313. Open wire rope sockets provide a conical cup to contain the spelter cone, and fastening lugs with holes for a pin.

Open wire rope sockets are hinge-mounted by their fastening pin. They cannot follow a displacement of the rope perpendicular to the plane of rotation.

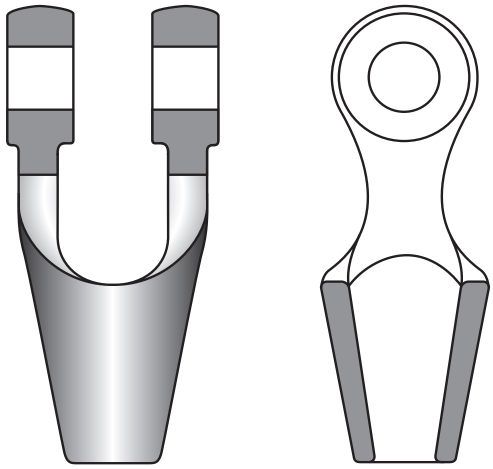

Fig. 63: Open wire rope socket (DIN 83 313)

Fig. 64 shows a closed wire rope socket in accordance with DIN 83 313. Closed wire rope sockets provide a conical cup to contain the spelter cone and a loop for a connecting pin. Closed wire rope sockets are hinge-mounted by their fastening bolts. If the bearing surface of the loop is designed according to Fig. 64, it will be able to follow the displacement of the rope from the perpendicular to the plane of rotation to a limited degree.

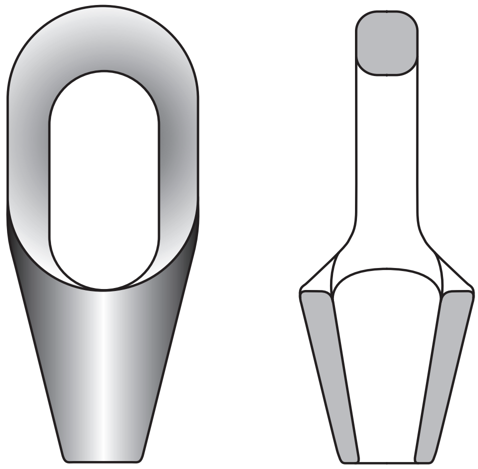

Fig. 64: Closed wire rope socket (DIN 83 313)

Rope sockets are not only used for attaching wire ropes to structural parts. They also serve to connect wire ropes when adjusting the length of a crane's boom suspension ropes. In such a case, there is always one open socket connected to a closed one.

The spelter cone of rope sockets in accordance with DIN 83 313 has a spelter-length five times the nominal wire rope diameter, and an opening ratio of 1:3. This corresponds to an opening angle of 18.4°. There are many other non-standardised spelter sockets on the market. Their advantage is that they are considerably smaller and much lighter than the standardised types.

In accordance with EN 13411-4, the opening angle should be between 9,5° and 18°. For stranded ropes, the length of the spelter cone should be at least 4 times the nominal rope diameter. For ropes with less than 50 wires, the length should be 50 times the outer wire diameter. For spiral strands, the length of the spelter cone should be at least 5 times the nominal rope diameter. For spiral strands with less than 50 wires, the length should be 50 times the outer wire diameter.

The smallest cone diameter should at least be 1.2 times the amount of the nominal rope diameter + 3mm to take into account the tolerance of the wire rope, and in order to enable the wire rope end, including its serving, to be pushed into the socket. The smallest openings of the rope sockets in accordance with DIN 83 313 are often smaller than the greatest permissible nominal rope diameter for these sockets. In these cases the sockets may be bored open at their exits.

10.4.2. The problem of the moment of the rope

Under equal line pull, the moment of a wire rope increases linearly with the rope diameter. Under equal tensile stress of the rope cross section, however, the line pull itself increases by the square of the rope diameter. The consequence is that the moments which wire ropes exercise on their end connections increase by a power of three of the rope diameter. At the same time, the friction forces between the spelter cone and the rope socket only increase linearly with the line pull, i.e. by the square of the rope diameter. What are the consequences?

For example, a wire rope of 10mm diameter and a torque factor of 0.1, when subjected to a line pull of 20 000N, will exercise a moment of 20Nm on its end connection. The friction forces between the spelter cone and the rope socket will prevent the rope from turning in the socket, and transfer the moment onto the rope socket. In turn, the rope socket will transfer the moment onto the structure it is attached to.

When a wire rope of the same design but six times the diameter is loaded with the same percentage of its breaking strength, the line pull will increase by a factor of 36, and will amount to the value of 720 000N. However, the moment of the rope will assume enormous proportions, it will be increased to 4 320Nm. An increase in rope diameter by a factor of 6 will increase the moment of the rope by a factor of 216!

This over-proportional increase of the moment must be not only taken into account when designing the point of attachment, but also when designing the socket itself. The moment trying to rotate the rope within the socket will have increased by a factor of 216. The friction forces between spelter cone and rope socket, which are supposed to prevent the ropes from doing so, however, will only have risen by a factor of 36 (proportionally to the line pull, and proportional to the rope diameter squared). In this case there is the danger that under load the spelter cone will rotate in its socket.

Fig. 65 shows a photo- elastic stress analysis on a rope socket. With the aid of a thin plastic coating, deformations to the rope elements, which are subjected to great line pull and a high moment, are made visible by polarised light. It is evident that the perfectly symmetrical rope socket is deformed and has become asymmetrical.

On the one side the moment increases the deformations caused by the pulling forces, on the other side it reduces them.

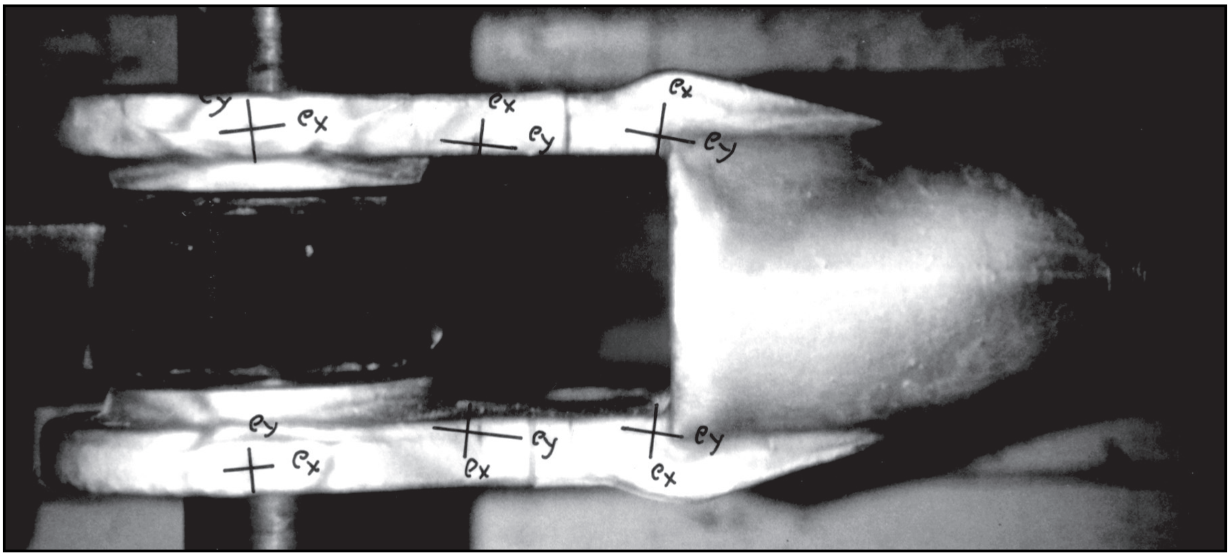

Fig. 65: Photo-elastic test on an open wire socket

In order to prevent the spelter cone from rotating, rope sockets for large diameter ropes are often fabricated with not round, but oval cross sections, for instance. Another solution is to cut grooves inside the socket into which the spelter cone can be indented (Fig. 66a), or tongues which can also indent with the spelter material (Fig. 66b). However, the grooves or tongues must run longitudinally in the socket in order to allow the cone to be drawn into the socket when loaded (setting). Only when the cone can move will it be able to generate the transverse clamping forces required to transfer the line load safely.
Fig. 66c shows a wire rope socket with tongues protruding into the spelter material. These tongues will prevent the cone from setting.

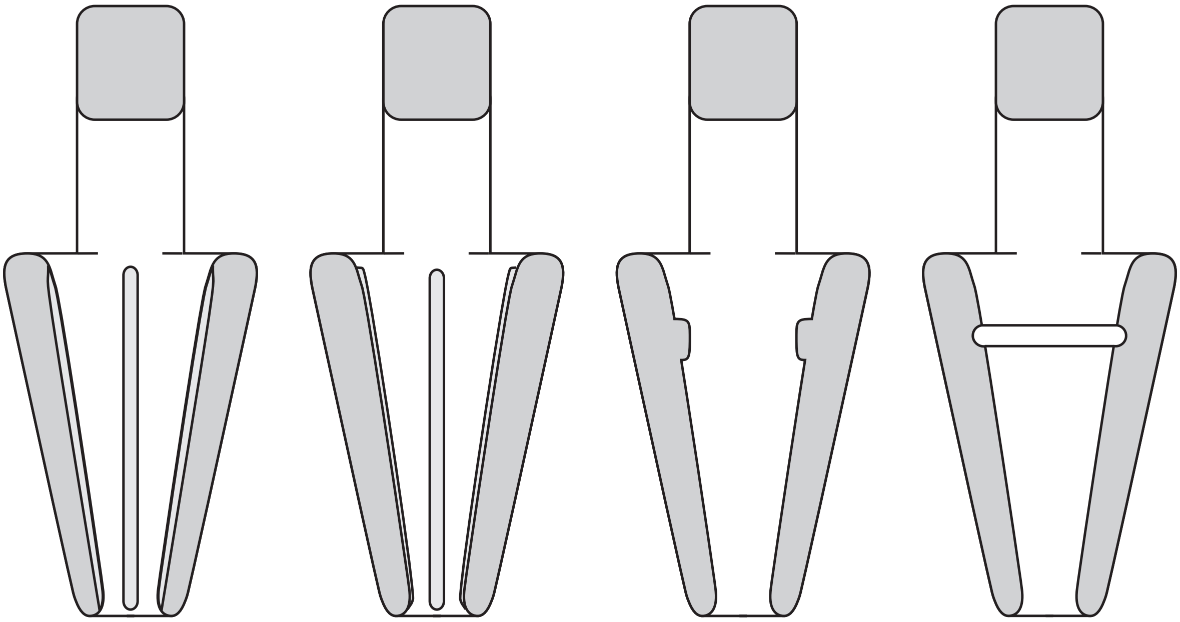

Fig. 66: Designs of rotation preventers

When a socket of that type was tested with a large diameter rope, the cone was at first held by the tongues so that the complete line pull was not transferred via the cone, but via the tongues. The pulling force was increased steadily, and eventually the spelter cone broke between the tongues. The lower part of the cone was released and abruptly pulled tight, whereas all the spelter material above the tongues, shattered with a loud bang.

Fig. 66d shows an American design with a circumferential groove in accordance with US Federal Specification RR-S-5500. This groove does not prevent the cone from rotating. It is supposed to prevent the spelter cone from popping out of its socket in the event that the rope should suddenly be unloaded. In reality, however, it prevents the cone from setting, which means the cone cannot serve its purpose at all.

Some manufacturers have found a solution to the problem that on the one hand they have to fulfill the federal specification, but on the other hand they have to provide a termination which works; they design the grooves so that they shear at 5% or less of the MBL of the rope. Other designs with excessive numbers or overlarge grooves, however, will prevent the cone from setting and the end connection from functionning.

10.4.3. Fabrication of the spelter socket

Before a rope socket is attached, it must first be examined carefully to make sure it is in perfect condition. Fig. 67 shows a possible defect: there is surface damage at one of the lugs. Austenitic manganese steel sockets must be checked by means of a magnet for micro-structural changes caused by the influence of temperature.

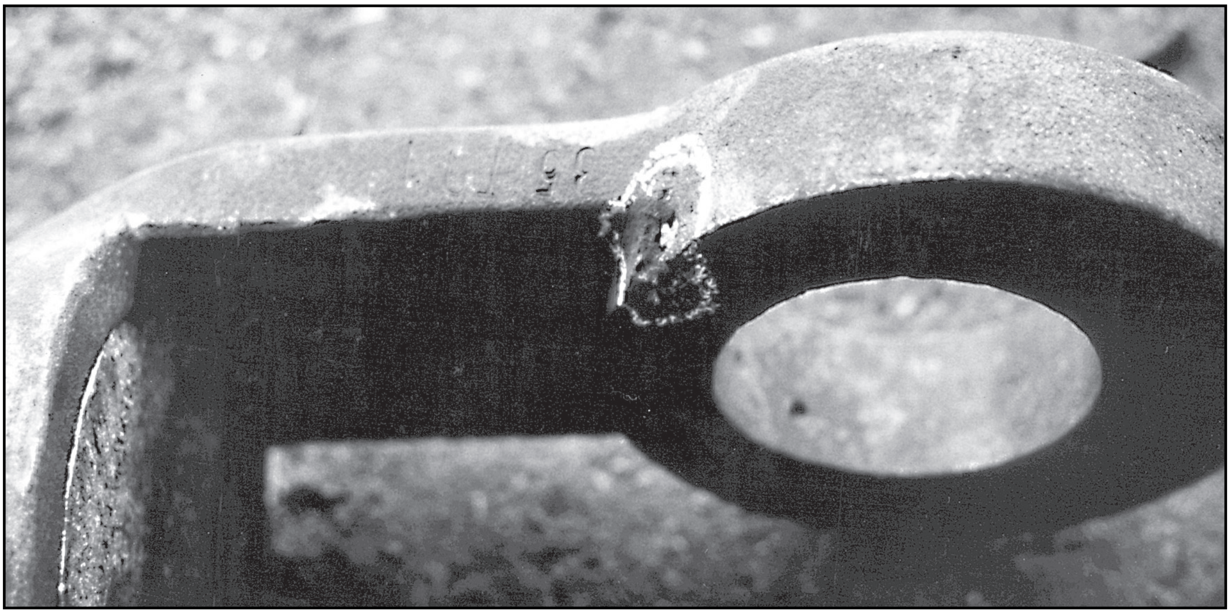

Fig. 67: Casting defect on an open wire rope socket

Before being cut to length, the rope must be served as prescribed, near the point where it will be cut, and at the point where the base of the socket will be. The wire rope should be cut without welding or fusing it. Then rope end is put through the spelter socket. After that, every single strand of the rope is unlayed until a wire brush has been formed (Fig. 68). If the wire rope has a steel core this must also be unlayed; a fibre core, however, should be cut out up to the serving.

If the wire rope has an intermediate plastic layer, the plastic material must be cut out up to the serving, before the steel core is unlayed.

Formerly, it was recommended that the wire ends be bent backwards so that they were shaped like hooks, but this has not proved successful. Using this procedure, the wire volume is doubled in the upper part of the spelter cone, but this does not increase the breaking strength. In fact, the increased wire volume might even prevent the spelter material from penetrating the spelter cup completely.

Next the wire brush is carefully cleaned and degreased with a degreasing agent, e.g. Eskapon S 143. Toxic cleaning agents or those which encourage corrosion must not be used. The bare, ungalvanised rope wires are then treated with a caustic agent (e.g. Tego Roptin™ – a zinc chloride solvent) to roughen their surfaces.

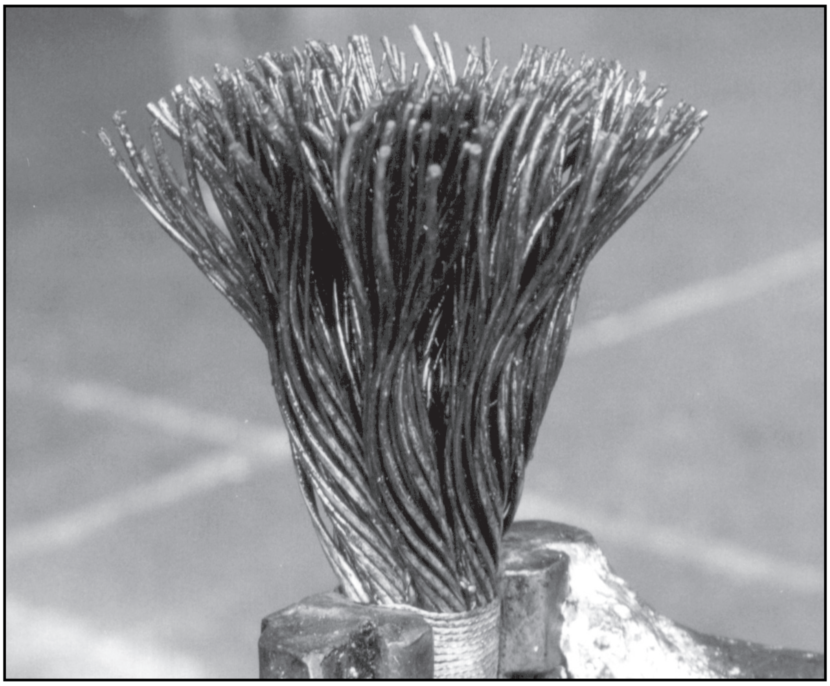

Fig. 68: Broom formed for socketing by unlaying the strands

Hydrochloric acid or soldering fluid must not be used as there is a danger that any residue of the caustic agent might penetrate the wire rope and cause corrosion. The wire brush is then immersed into the caustic agent to a maximum of two thirds of its length before being removed and dried (Fig. 69).

Fig. 69: Drying the rope brush

Then the wire brush is plated with solder in accordance with DIN 1707. The temperature of the solder should be between 280°C and 300°C. Plating in this way is also carried out with galvanised wires which are later cast with Tego™ VG 3. During degreasing and plating, the wire rope brush must always be inverted in order to avoid any fluids trickling down into the rope's interior.

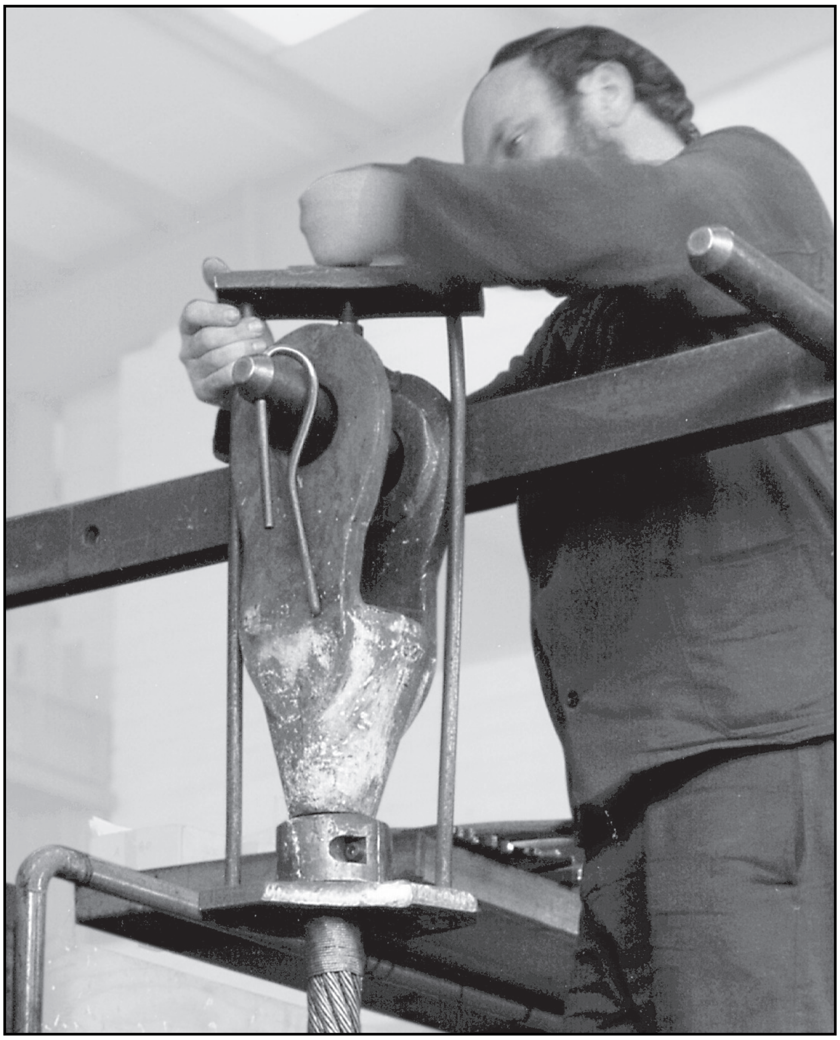

Fig. 70: Adjusting the wire rope socket

Next the wire rope brush is pulled back into the socket and attached to the socket's exit. This has the effect of achieving the correct rope length whilst ensuring that the wire brush cannot move when being cast. Placing a stopper directly beneath the socket will prevent excessive leakage of the spelter material during casting.

It is also advisable to fix the rope socket at a reasonable height so that the wire rope has enough room to drop in a perfectly straight line and can be cast in this position (Fig. 70). Fig. 71 shows a wire rope that was cast with the wire rope offset from the socket.

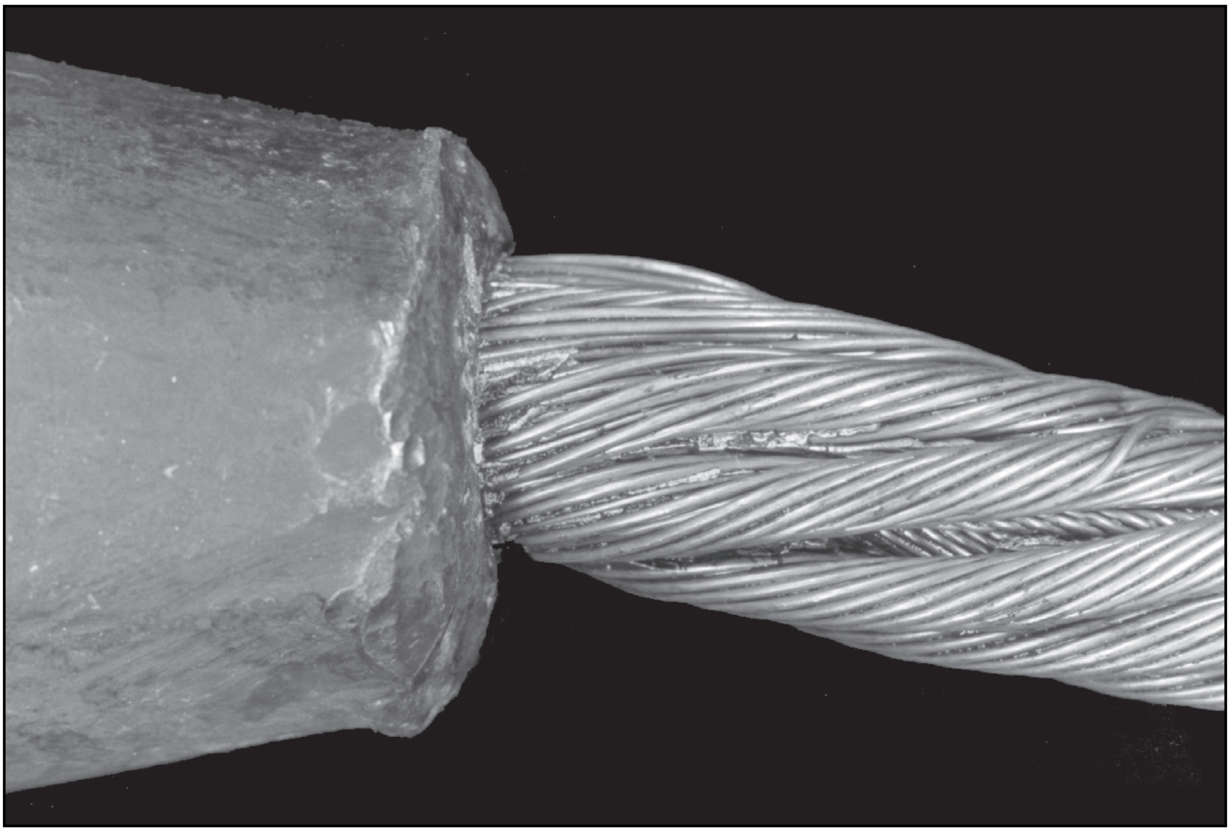

Fig. 71: A wire rope that was not adjusted before casting

%	Tego VG 3	LgPb Sn 10	WM 20	LgSn 80	Hard lead	Bi- Lot	Zinc	Pure zinc	ZnAl-6Cu1	Zinc alloy	Cd-alloy
Pb	77,0	73,5	64,0	2,0	87,0	32,0	max 2,4	-	-	3,0	-
Sn	10,0	10,0	20,0	80,0	13,0	15,0	-	-	-	3,0	0,2
Sb	10,0	15,5	14,0	12,0	-	-	-	-	-	1,6	0,3
Cd	2,0	(0,2)	-	-	-	-	-	-	-	-	65,4
Cu	0,5	1,0	2,0	6,0	-	-	-	-	1,4	-	-
As	0,5	(0,2)	-	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	97,5	99,99	92,6	92,4	34,0
Al	-	-	-	-	-	-	-	-	6,0	-	-
Bi	-	-	-	-	-	53,0	-	-	-	-	-
Melting point [°C]	242	235-370	182-400	183-400	252	96	319-419	419	380	188-406	266-305
Pouring temp. [°C]	320-350	420-450	440-450	440-460	320-350	125	450-480	450-480	420-450	450-480	360-380

Fig. 72: Composition, melting points and temperatures of common spelter materials

Before casting, about 1.5 times the amount of the spelter material required is heated up to the prescribed temperature. The casting temperature of the spelter material depends on its composition.

Fig. 72 provides an overview of the composition in percent of weight, melting points, solidification ranges and casting temperatures of various common spelter materials.

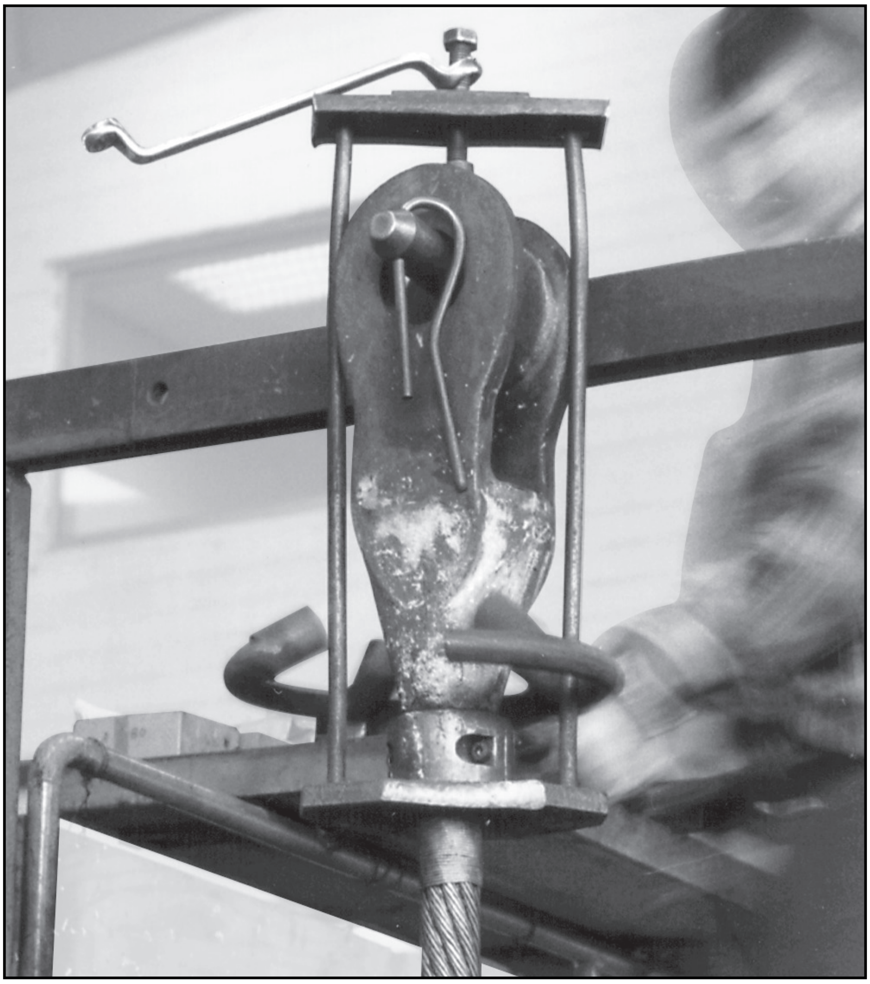

Fig. 73: Preheating the rope socket

During the casting process there is always the danger that the molten spelter material will solidify prematurely in the upper areas of the socket when coming into contact with the cold socket and the cold rope wires. This can prevent the penetration of the spelter material into the lower reaches of the spelter socket and could result in air pockets in the spelter cone. Therefore, prior to casting, the rope socket should be heated up to a temperature approaching that of the melting temperature of the spelter material. This can be achieved by means of controllable burners e.g. ring-shaped gas burners (see Fig. 73).

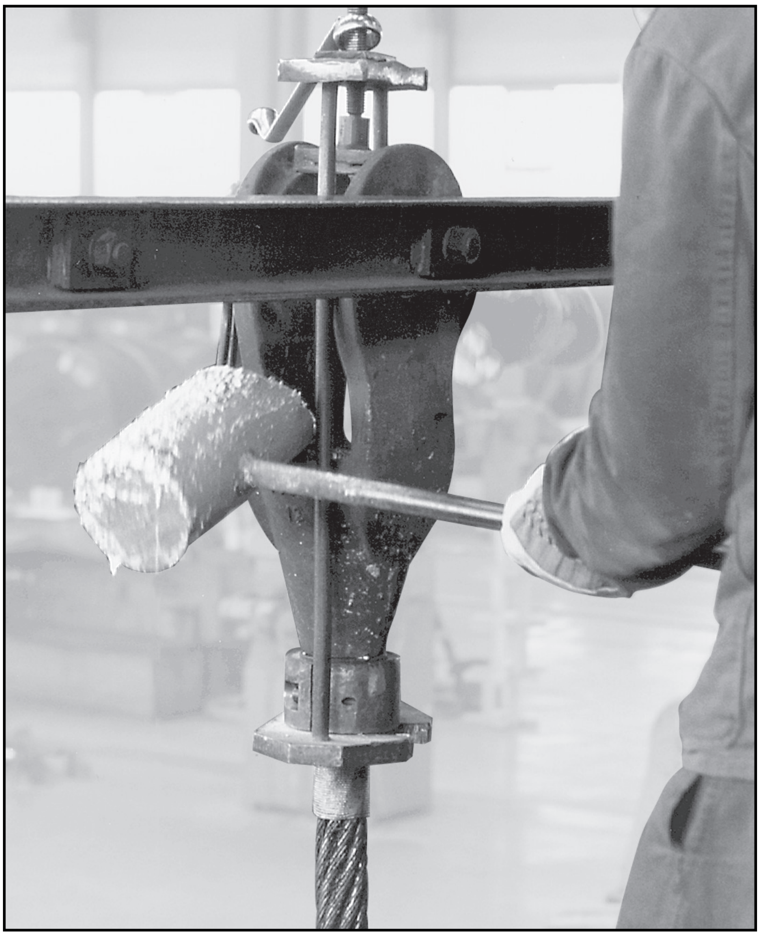

Fig. 74: Slow pouring of the spelter material

The temperature of the socket should be monitored with the aid of thermo-coupling devices or the type of thermo-crayons which change colour depending on the temperatures achieved.

Next the casting process begins. The spelter material must be slowly and steadily poured into the wire rope socket so that no air can be trapped inside (Fig. 74). The oxide skin must be skimmed off.

If the design of the stopper beneath the rope socket permits it, small quantities of the spelter material can seep through the valleys in between the outer strands of the rope. This is a clear sign that the spelter material has actually reached the base of the rope socket.

After casting, the top of the spelter cone should be reheated with a burner to ensure that no cavities are trapped inside it. Then, if necessary, more spelter material can be poured in to fill the socket to its brim in order to create a finish that is flush with the socket. Finally, identifying marks are stamped into the surface of the spelter material using steel stamping tools. In special cases a metal tag bearing the required information can be enclosed in the spelter material.

Once the spelter material has solidified and cooled down, the serving is removed from the socket exit. Then the area where the wire rope leaves the socket must be protected against corrosion. This can be done by painting on or immersing the rope into an anti-rusting agent or relubricant.

10.5. Inspection

During inspection, the rope sockets should be examined for cracks, especially in the vicinity of the loops and the lugs. The area where the rope leaves the socket must be inspected for wire breaks and also for kinks or changes in lay lengths. This is especially the case with boom suspension ropes which are frequently dismantled. Occasionally, wire breaks can be found adjacent to the rope socket or along the first few centimetres inside it. These are caused either by kinking the rope when handling it, or by a lack of spelter material or insufficient and inadequate relubrication. Therefore, these areas must be inspected with particular care.

Normally, after the rope has been discarded, the rope socket will be reused. Before using the socket again, it must be inspected meticulously for any signs of physical damage or cracks.

10.6. Special designs

When rotation-resistant ropes ar e used, it is often recommended that a swivel be fitted between the rope end connection and the point of attachment to the crane. However, the lifting height of the device will be reduced by the fitting of the swivel. Here the use of a spelter socket with a built in swivel is recommended (Fig. 75).

This end connection reduces the lifting height only marginally and has the added advantage that the swivel will always automatically align itself with the wire rope.

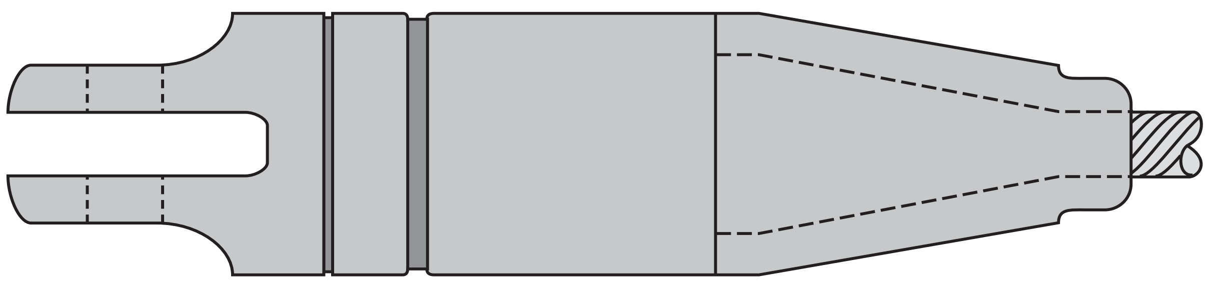

Fig. 75: Spelter socket with built-in swivel

10.7. The pear-shaped socket

Sometimes end connections have to run over sheaves or onto drums. In these cases, the end connections as well as the sheaves and drums must be specially designed. One example is the Demag rope-connector which joins two rope ends using two pear-shaped sockets and a screw-link (Fig. 76). This rope connector can travel over a specially designed sheave with two grooves. The first groove is wide enough to accommodate the socket, the second groove, undercutting the first groove, accommodates the rope.

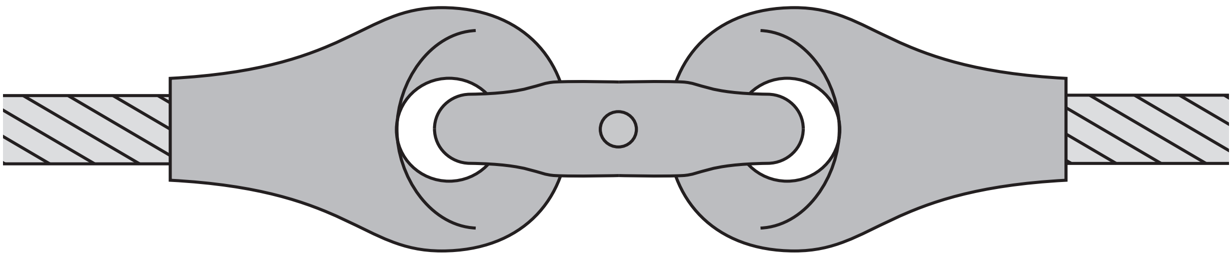

Fig. 76: Rope pear sockets with link

The Demag rope connector is advantageous if a short section of rope fails considerably earlier than the rest of the rope length. In such a case it is not necessary to discard the entire rope length, but only the worn out section. The replacement section can then be screwed onto the undamaged rope length.

Such a rope end connection might conceivably be used in a situation where, due to a high number of bending cycles over relatively small sheaves, and due to abrasion caused by particles from bulk cargo being unloaded, the short length of a grab rope in a two- or four-rope grab can wear out very quickly. In this case only the short rope length inside the grab is replaced and not the whole closing rope.

Fig. 77 shows the connection of wire ropes with the aid of pear-shaped sockets on a wire rope drum.

The rope connection must be of a very short fitting length and it must also be of a special design so that it can follow the curvature of the widened sheave or drum. Fig. 78 shows a pear-shaped socket cut in half with a rope defect at the exit of the pear. It is evident that the spelter length is very short. Nevertheless, these rope end connections are able to transfer the full breaking strength of the rope.

If the permissible casting temperature of the spelter material is exceeded, pear-shaped sockets of austenitic manganese steel will lose their tensile strength due to embrittlement, which is caused by the decomposition of their austenitic micro-structure. In this case they must not be used again.

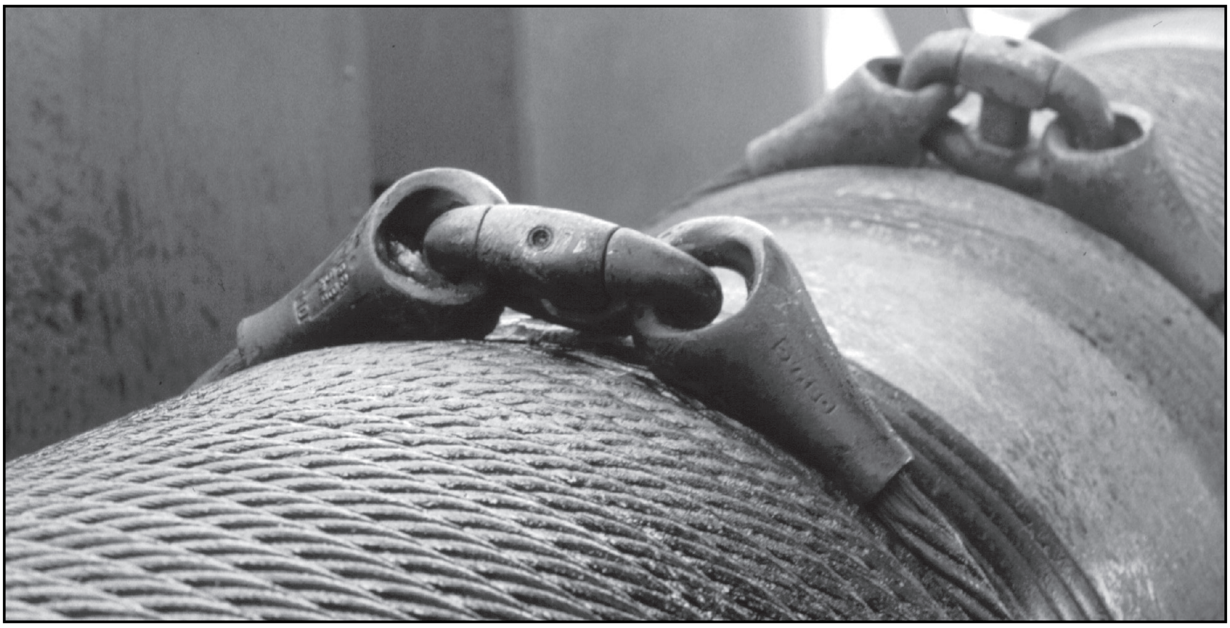

Fig. 77: Pear-shaped sockets with a screw-link on a rope drum

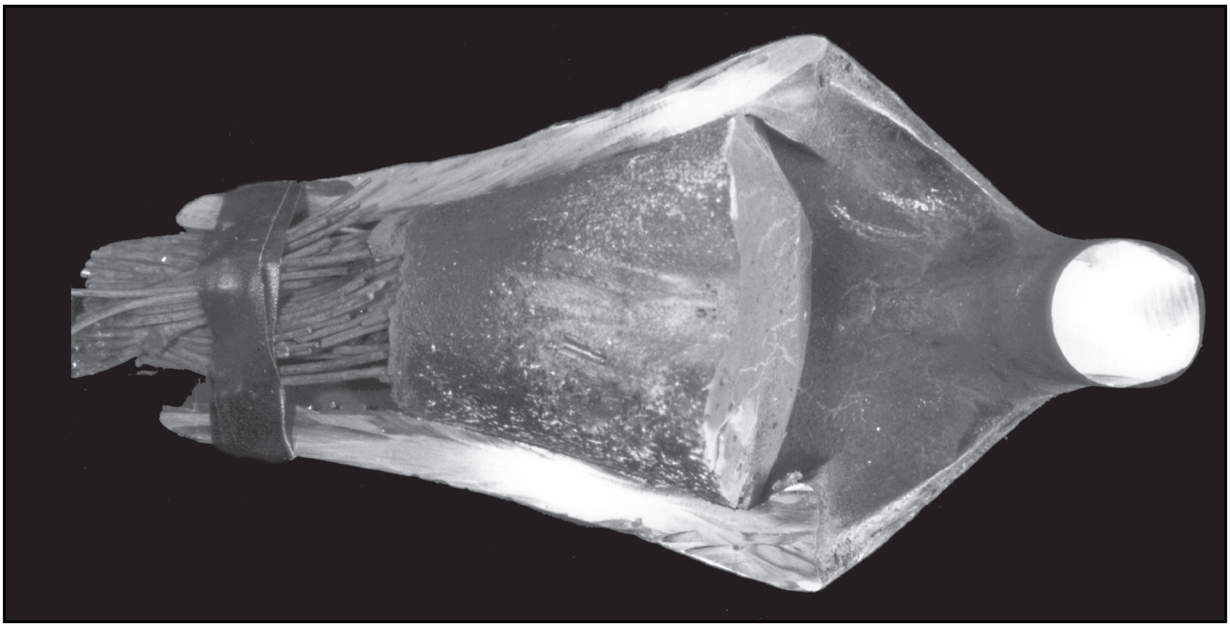

Fig. 78: A pear-shaped socket cut in half showing rope damage

When losing its tensile strength, the metal becomes heavily magnetic. Therefore, the integrity of the pear can be tested by examining it at several points with a permanent magnet. Pears may be reused if a magnet exercises no more than 30% of its normal attraction to unalloyed steel.

At their exit, the pear-shaped sockets display a trumpet-shaped widening. This cavity is filled with spelter material during the casting process.

When running over the U-shaped sheave, the wire rope is heavily bent in this trumpet section. At the same time, the rope is lifted abruptly onto a greater sheave diameter. This generates an additional dynamic loading for this critical rope section. In the course of time this might lead to wire breaks at the exit of the pear.

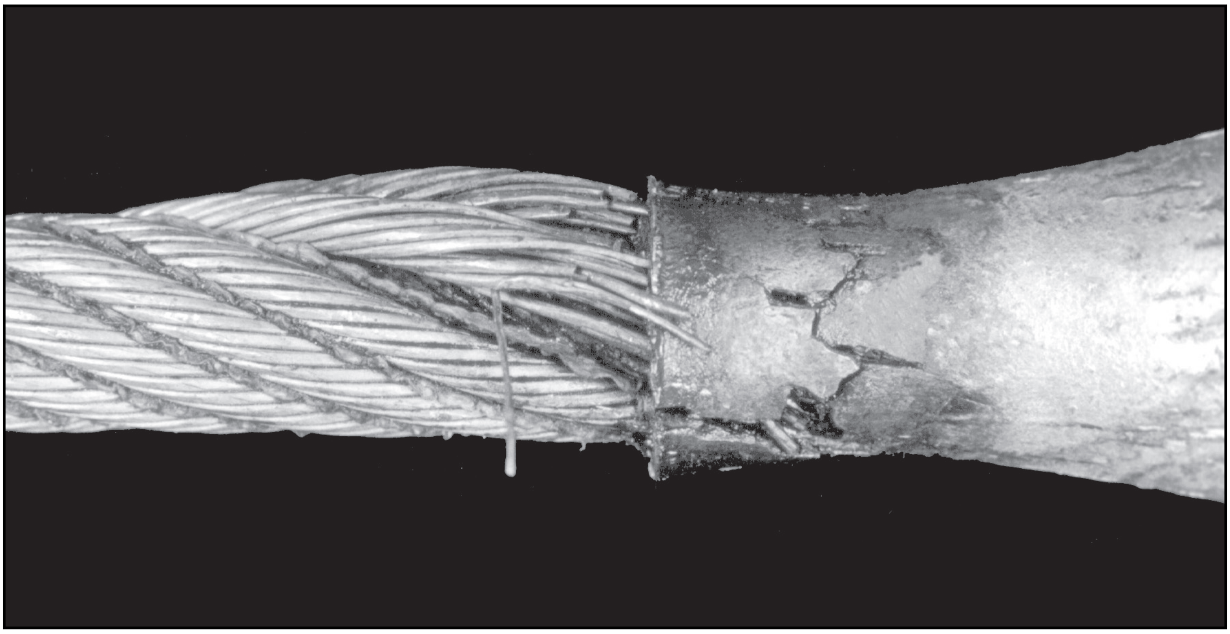

Fig. 79: A pear-shaped socket cut in half showing rope damage

The high pressure on the spelter material in the trumpet shaped cavity during bending of the rope can in no time lead to cracks in the spelter material (Fig. 79) which, as a result of its wedge-shape, is pushed out of the socket in fragments, bit by bit. Near the trumpet-shaped widening the wire rope will, after a certain time, become completely bare and unprotected. In a socket hanging downwards, water can collect where the socket is no longer filled with spelter material.

Before casting, the bare rope zone was lightly etched, after casting, however, it was not relubricated because it was surrounded by spelter material. Therefore, this section will now rapidly fail due to severe corrosion and high mechanical stresses and must therefore be observed carefully. Fig. 80 shows a pear-shaped socket cut open to illustrate a typical failure. Fig. 81 is another example of this.

It has proved advantageous to alter the trumpet shape by boring open the socket. If resin spelter materials are used, wire pear-shaped sockets will usually achieve much better results than when metallic spelter materials are used. Not only do the resins appear to absorb dynamic impacts more readily, they also seem to be more tolerant to the stresses they endure at the exit of the pear.

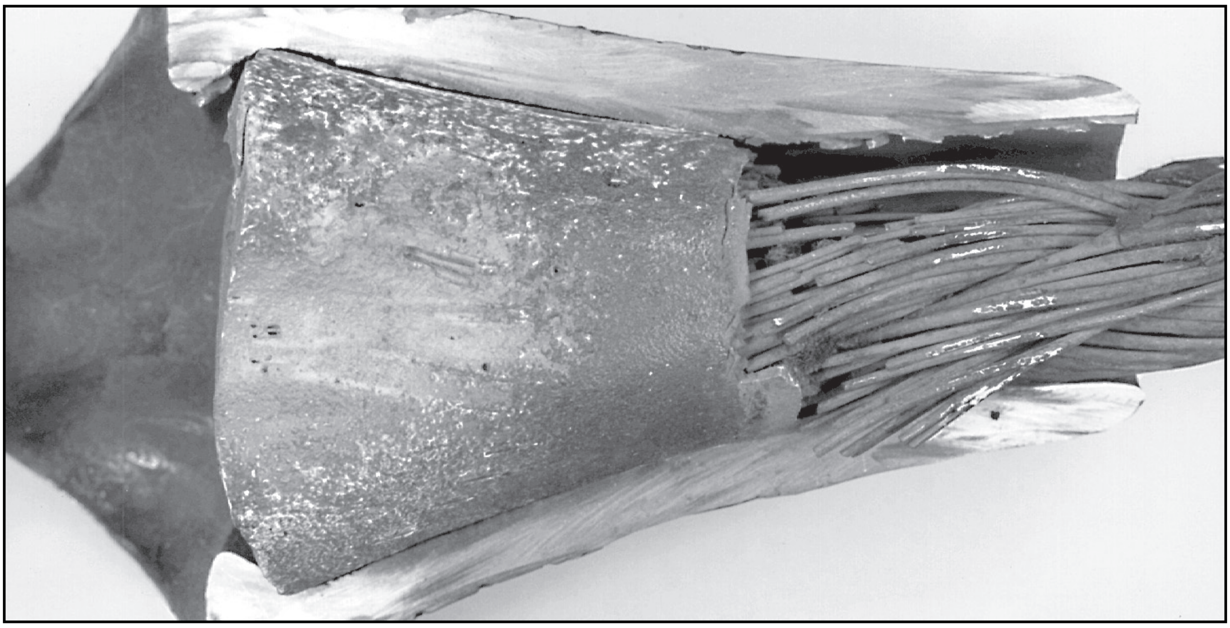

Fig. 80: Corrosion and wire breaks at the pear's exit

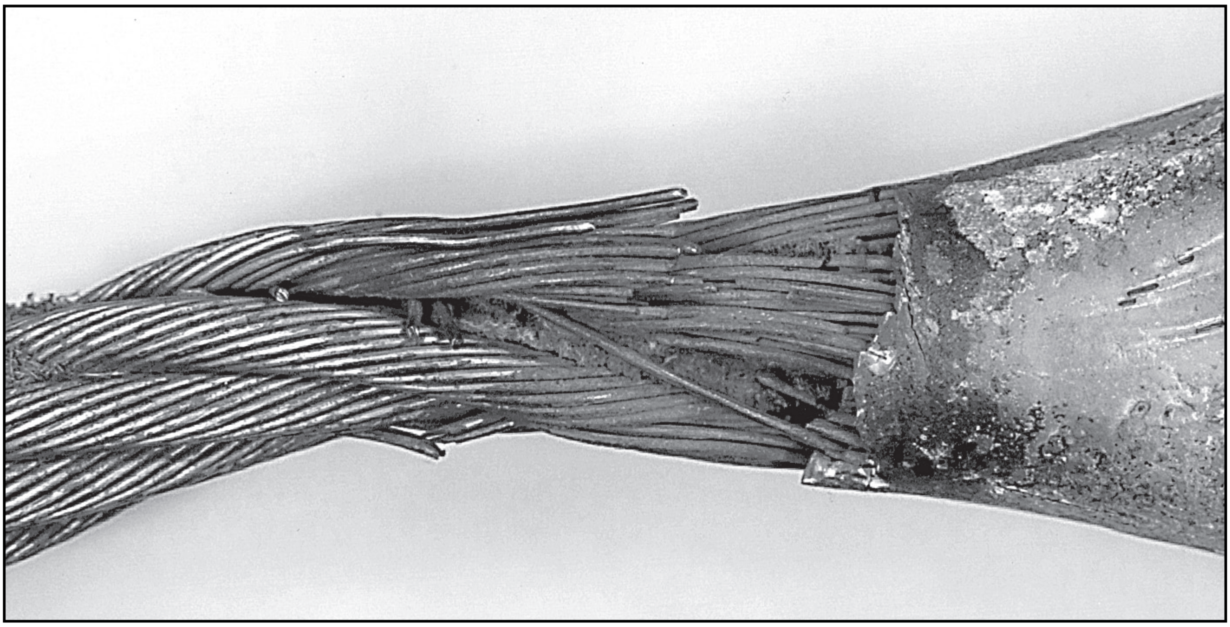

Fig. 81: Corrosion and wire breaks at the pear's exit

Furthermore, if resin spelter materials are used, there is no danger of over-heating the pear-shaped socket during casting.

There is, however, a disadvantage with resin spelter material: after discarding the rope, the resin has to be removed mechanically from the pear, whereas the metallic spelter material only needs to be reheated and liquefied.

11. The resin spelter socket

The resin spelter socket is a very reliable and efficient rope end connection. In a pull test it achieves the highest breaking loads. Furthermore, its tension-tension endurance is excellent. Compared to metallic spelter sockets it has one great advantage: it can be fabricated on-site without any special equipment. Additionally, the finished resin end connection is lighter than the metallic one. The resin spelter socket lends itself to all applications where reductions in breaking strength brought about by the end connections have to be taken into account when selecting the wire rope dimensions. The resin spelter socket is also used in applications where the end connections have to be fitted on-site. Resin has almost entirely replaced metal as a casting material for pear-shaped sockets.
The long-term behaviour of resins – service times of ten years or more – have not been sufficiently tested yet. This is the reason why resin spelter sockets are not more common as end connections for suspension ropes.

11.1. Breaking load, tension-tension endurance and working temperatures

In a quasi-static pull test, resin spelter sockets transfer the full breaking strength of the wire rope used. In a dynamic tension-tension test they achieve the highest number of tension-tension cycles of any wire rope end connection. The manufacturer of Wirelock™ recommends working temperatures below 115°C.

11.2. Standardisation

Resin spelter sockets are not standardised.

11.3. Operating mechanism

At its end the wire rope is fanned out like a brush and plugged conically into a wire rope socket. With increasing line pull, the resin cone is pulled deeper and deeper into the socket, generating increasing clamping forces. The transfer of force from the wire rope to the resin cone is achieved by force closure and material closure. The transfer of force between the resin cone and the rope socket is achieved purely by force closure.

11.4. Fabrication / Installation

The casting material consists of a resin, usually polyester resin or epoxy resin, a hardener and filler material. The hardener is needed to cross-link the resin. During the cross-link reaction, the filler material absorbs part of the heat of reaction and prevents the resin cone from becoming over-heated and subsequently forming cracks.

It also reduces the shrinkage of the spelter cone when it cools down, and it reduces the cost of the spelter material.

The brand Wirelock™, based on a polyester, has proved very successful.

Selecting the rope socket, preparing and degreasing the wire rope brush, as well as hanging up the socket, are carried out in the same way as that described for metallic spelter sockets in section 10.4.3. Cleaning the wire rope brush in an ultrasonic bath is recommended.

Before casting, the required amounts of resin and hardener must be assembled and their expiry date checked. Some components only have a shelf-life of about nine months, and using them after their expiry date can prove highly dangerous. For instance, the spelter might only harden at its surface and could fail later when subjected to a high load.

The required amount of resin is added to the respective amount of hardener and stirred for the prescribed time, typically about two to five minutes. Then the casting process can begin.

The spelter material must be poured into the socket slowly and steadily. Casting should be interrupted several times in order to allow any trapped air bubbles to escape. Depending on the design of the stopper beneath the rope socket, the penetration of small quantities of resin into the valleys between the outer strands of the wire rope usually indicates that the spelter material has actually reached the base of the socket.

Finally, identifying marks are stamped into the surface of the spelter material using steel stamping tools. In special cases a metal tag bearing the required information can be enclosed in the spelter material.

After about thirty minutes, the resin will have hardened and solidified. Now the serving should be removed from the point where the rope leaves the socket. This area must then be carefully relubricated.

This can be done by painting on or immersing the rope into an anti-rusting agent or relubricant. After approximately one and a half hours, resin spelter sockets are usually ready to be loaded.

11.4.1. Resin spelter sockets with pear-shaped sockets

When using metallic spelter materials in pear-shaped sockets, often the spelter material flakes off at the point where the rope leaves the pear (see section 10.7). With increasing service time this leads to wire breaks and corrosion in this area. Due to the higher elasticity of resin, this phenomenon does not occur with resin spelter sockets. In addition, there is no danger of over-heating the austenitic manganese steel pear-shaped sockets, which would lead to a reduction in their tensile strength. For these reasons, resin has almost entirely replaced metal as a casting material for wire pear-shaped sockets.

11.4.2. Reusing the rope socket

When a rope socket comes to be cast again, it is a disadvantage of resin that it can only be removed at great expense. Whereas metallic spelter can be reheated until the metal flows out of the socket, it is not possible to plastify the hardened resin by means of heat. Therefore, the spelter cone must be removed mechanically. Some users of resin spelter sockets have built hydraulic devices which enable them to push the resin cone out of its socket (Fig. 82).

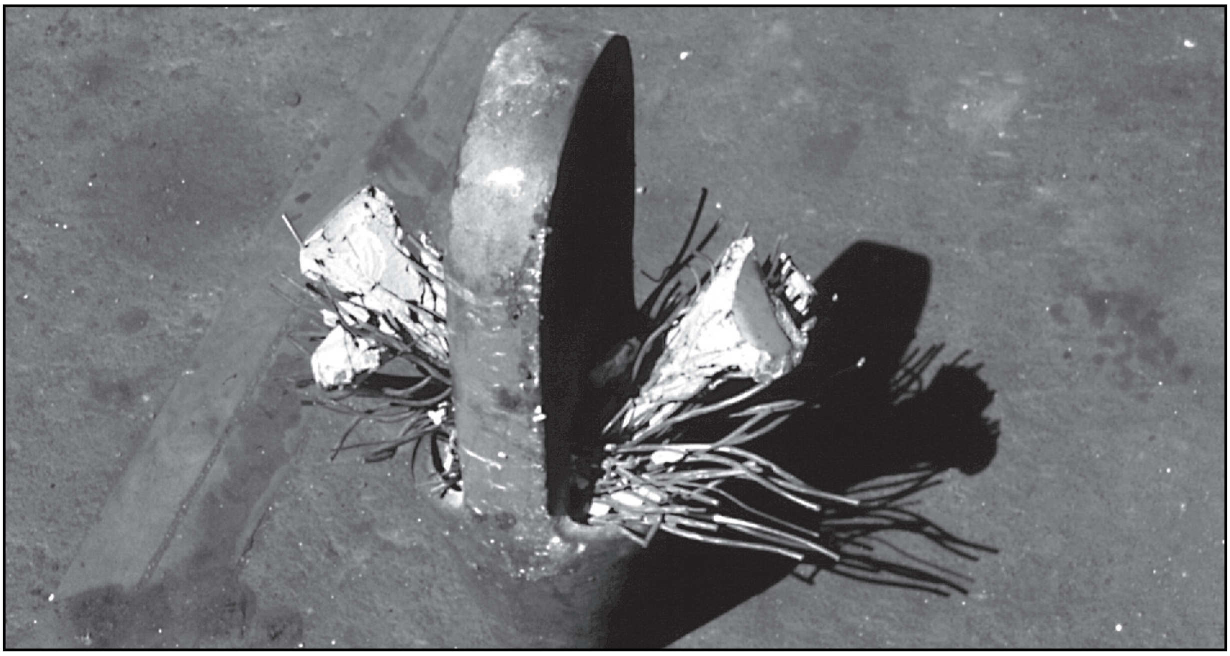

Fig. 82: Resin spelter socket pushed out of its socket mechanically

11.5. Inspection

See section 10.5

11.6. Special designs

See section 10.6

12. Let's talk about prices

Obviously price is an important factor when selecting a rope end connection. For example, an aluminium clamp is good value for small nominal rope diameters, a splice or metallic socket can be many times as expensive. However, with increasing nominal rope diameter, the price differences decrease, and above a certain nominal rope diameter, the metallic spelter socket can even prove to be the cheapest solution.

The statements made in the following should be understood essentially qualitatively. Since these prices may change over time, in different countries with different discounts available and with the end connections selected or wire ropes used, the conclusions drawn are shown as a general guide only.

12.1. The price of end connections for running ropes

The continuous curve in Fig. 83 illustrates the price ratio of an aluminium clamp fitted with a thimble according to EN 13411-1 and of a metallic spelter socket, as a function of the nominal rope diameter. As shown, a spelter socket for a 12mm nominal diameter rope is four times as expensive as a clamp. Although the proportional difference decreases with increasing nominal rope diameter, for a 44mm rope a spelter socket is still twice as expensive as a clamp. This is one of the reasons why, especially for series cranes, the aluminium clamp is preferred to the metallic spelter socket.

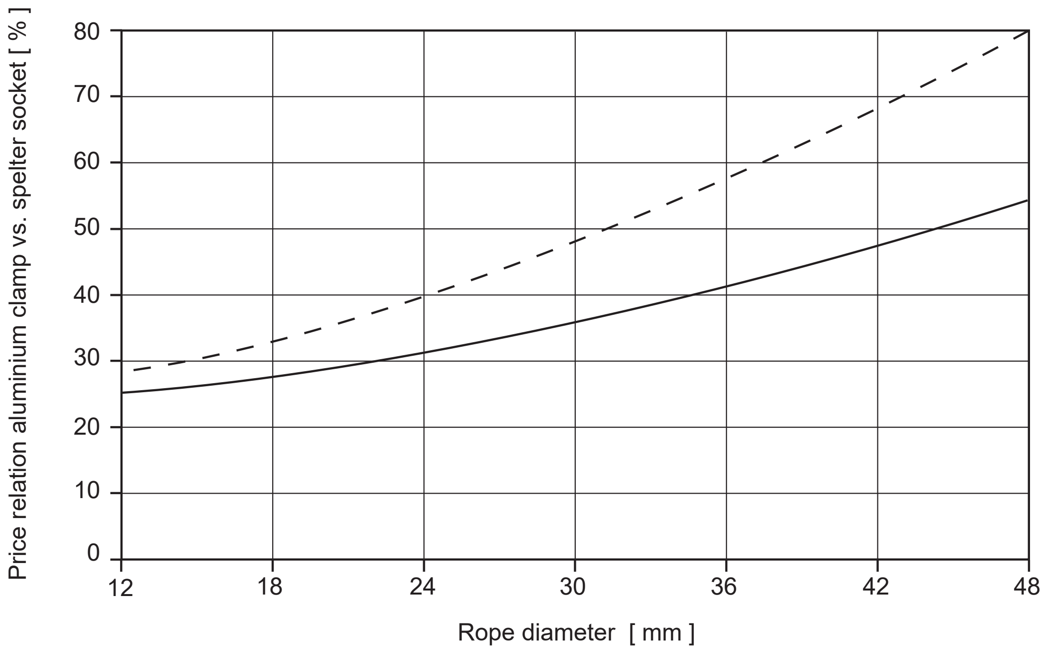

Fig. 83: Price ratio of aluminium clamp against spelter socket with and without regard to increase in rope diameter.

12.2. The price of end connections for suspension ropes

As we have seen from the above, when selecting the end connection for a running rope, no distinction is made with respect to the breaking strength of the different types of end connections available. When selecting the end connection for a static rope, however, the loss of breaking strength caused by the end connection must be taken into account by increasing the rope diameter.

According to DIN 15 018, metallic spelter sockets or bollards will provide 100% of breaking strength. In the case of aluminium clamps, the breaking strength of the rope must be reduced to 90%, with wedge sockets and splices that figure is reduced to only 80%.

If the designer uses aluminium clamps, wedge sockets or splices as end connections, the rope diameter must be increased to compensate for the loss of breaking load caused by the end connection. With increasing rope diameter, the size, weight and price of the end connection will also increase.

The dotted curve in Fig. 83 shows the price ratio of aluminium clamps against metallic spelter sockets, taking into account the increase in size and price of aluminium clamps. The difference in price is no longer that great.

Yet, throughout the entire range of diameters shown, the aluminium clamp is still the cheaper end connection. However, when using aluminium clamps, wedge sockets and splices, the rope diameter must be increased, resulting in a higher rope price. This means that above a certain length of the suspension rope, the higher wire rope price will negate the price advantage of the end connection.

Fig. 84 shows the price ratio of suspension ropes with aluminium clamps and metallic spelter sockets as a function of the rope length. For instance, a suspension rope with a nominal rope diameter of 12mm and a length of five metres, fitted with two aluminium clamps, will cost only 40% of a similar rope fitted with two metallic spelter sockets. When 78 metres long, however, the two suspension ropes cost the same. Above 78 metres, the suspension ropes with metallic spelter sockets are cheaper.

With increasing nominal rope diameters, the price equilibrium will be reached with shorter and shorter rope lengths. For a 48mm rope, the execution with two aluminium clamps is cheaper, but only up to a length of 19 metres. If the rope length for which the suspension ropes with the different end connections are of the same price is plotted against the nominal rope diameter, the relationship is – interestingly enough – a linear one (Fig. 85).

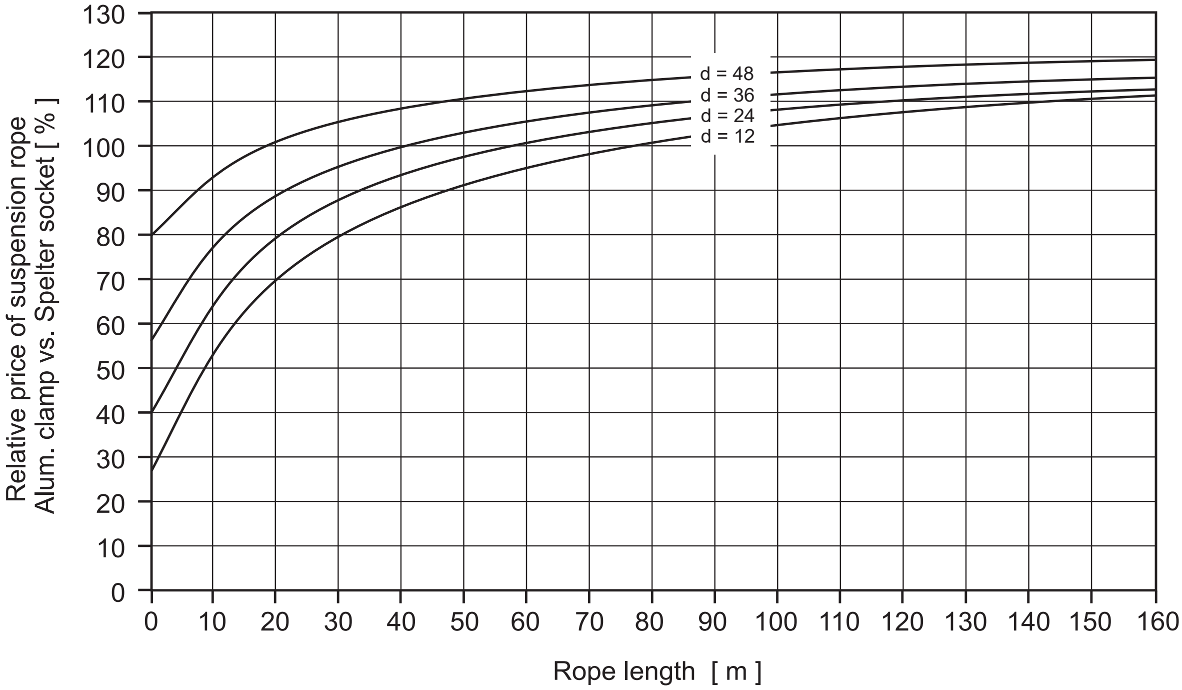

Fig. 84: Price ratio of aluminium clamps against spelter sockets taking into account he increase in nominal rope diameter and in rope price

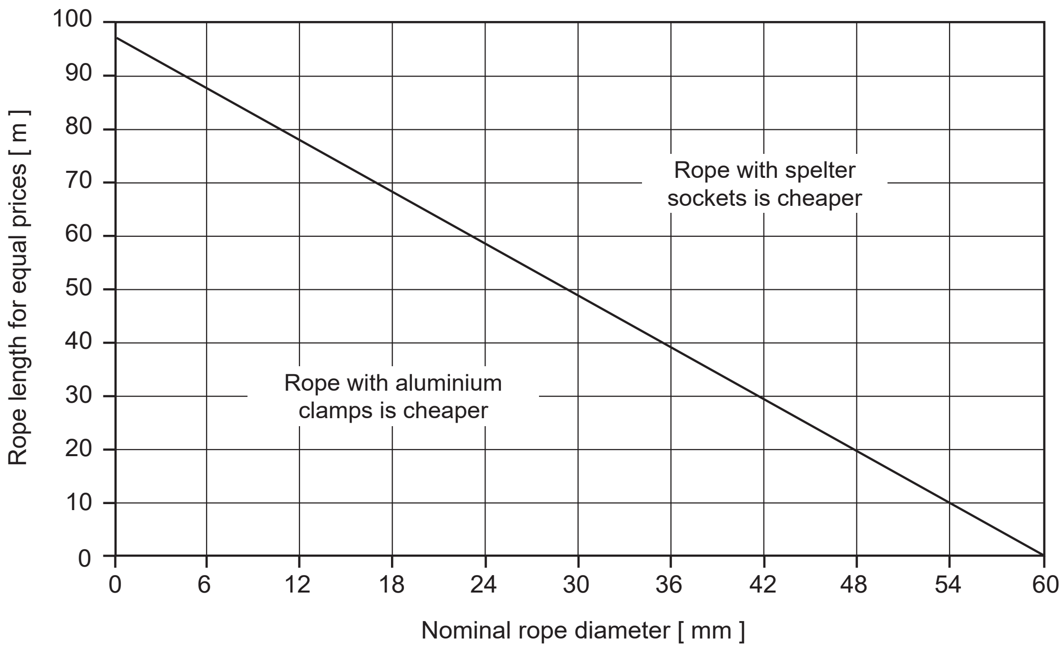

Fig. 85: Rope length for price equilibrium. Above the indicated rope length a suspension rope with metallic spelter sockets is cheaper than one with aluminium clamps

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