

Deep Mined Coal

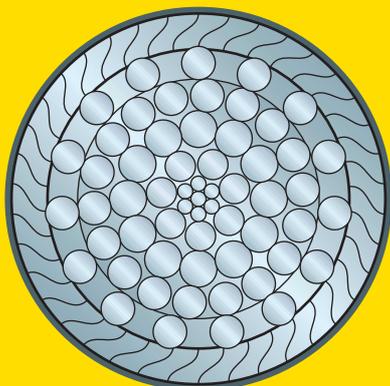
Industry

Advisory

Committee

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**Guidance on the
selection,
installation,
maintenance and
use of steel wire
ropes in vertical
mine shafts**



Members of the DMCIAC working group on steel wire ropes for haulage and vertical shafts at mines

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This guidance was prepared, in consultation with the Health and Safety Executive (HSE), by a working group representative of all sides of the mining industry. The guidance represents what members of the working group consider to be good practice. It has been agreed by the Deep Mined Coal Industry Advisory Committee, the Mining Association of the United Kingdom and the Health and Safety Commission.

Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

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INTRODUCTION

1 This guidance covers winding ropes, balance ropes, guide ropes and rubbing ropes.

2 The failure of a steel wire rope while in service is potentially disastrous, particularly when being used as part of a winding system transporting a large number of people in a vertical shaft. Even when not transporting people, a rope failure gives rise to significant risks to people working near the shaft. Any rope failure could cause damage to winding equipment and the shaft itself putting it out of action. Apart from giving rise to very hazardous recovery operations, the loss of one means of egress presents additional risk to everyone below ground.

Who should read this document

3 This guidance is aimed primarily at owners, managers, members of the management structure and any other person who manufactures, selects, installs, inspects, examines or maintains shaft ropes used in vertical winding systems. Other non-mining employers who use similar ropes may also find some of this guidance useful and the HSC guidance on haulage ropes,¹ for example, the parts on capping, storage and handling of steel wire ropes.

4 This guidance deals mainly with the selection, installation and maintenance of steel wire ropes used in vertical mine shafts. It is split into an introductory section which gives a broad outline of good practice; and four technical annexes covering winding, balance and guide ropes as follows:

Technical Annex 1 - Types of shaft rope including selection process;

Technical Annex 2 - Rope storage, handling and installation;

Technical Annex 3 - The serving and capping of shaft ropes;

Technical Annex 4 - Maintenance procedures, deterioration and discard criteria for shaft ropes.

5 The general advice in this document should also be applied to lift ropes where appropriate, further specific advice on lifts in mine shafts is included at Appendix 8.

Rope selection

6 Regulation 13 of the Mines (Shafts and Winding) Regulations 1993 ('the 1993 Regulations')² requires mine owners to specify the type of rope used in any winding apparatus. Before selecting a rope, owners will need to take advice from people who have the necessary knowledge, experience or expertise. Rope manufacturers can provide assistance in matching a rope to a particular duty and can undertake any calculations that might be necessary. A collaborative approach can often enable problems to be anticipated and avoided or minimised.

7 Wire ropes used in vertical mine shafts have to be both strong enough to do the work required and be matched as closely as possible to the conditions in

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which they will have to operate. There are a number of factors to consider when selecting a wire rope for a shaft winding system:

- depth of shaft;
- type of winding system in use;
- duty of winding system;
- shaft environment;
- frequency of use;
- the factor of safety of the rope. (Note - paragraphs 126 to 129 of the Approved Code of Practice (ACOP) to the 1993 Regulations³ contain details of the minimum factor of safety and maximum specified life of shaft ropes.)

It is then possible to determine:

- rope size - diameter;
- rope construction - locked coil or stranded (round strand, triangular strand or multi-strand); number, size and shape of wires (the fewer the number of wires, the greater the resistance to wear and corrosion; the greater the number of wires the more flexible the rope); the tensile strength of the wires (details of wire tensile strengths are given in Technical Annex 1);
- type and direction of lay - Lang's or ordinary lay; right or left-hand lay;
- surface finish of the wires - ungalvanised (bright) for conditions known to be dry and non-corrosive or galvanised (zinc coated) for conditions known to be wet or possibly corrosive;
- breaking force - to achieve appropriate factor of safety.

Technical Annex 1 contains detailed guidance on rope selection.

8 Paragraph 130 of the ACOP to the 1993 Regulations³ provides further information for extending the specified life of an in-service rope and for increasing the specified life of a new rope.

Winding ropes

9 The main items to be considered in choosing a winding rope are:

- the type of rope - locked coil or stranded (round strand, triangular strand or multi-strand); for stranded ropes, the shape and construction of the strand - the fewer the number of wires the greater the resistance to wear and corrosion; or the greater the number of wires the more flexible the rope
- direction of lay - right or left-hand; type of lay - Lang's or ordinary;

-
- the shape and tensile strength grades of wires - details of wire tensile strengths are given in Technical Annex 1;
 - the surface finish of the wires - ungalvanised (bright) for conditions known to be dry and non-corrosive or galvanised (zinc coated) for conditions known to be wet or possibly corrosive.

Balance ropes

10 Balance ropes are ropes which are used between the undersides of shaft conveyances to balance the weight of the winding ropes on each side of the winding drum or friction-winding sheave.

11 Balance ropes should:

- be flexible enough to allow the suspended loop to form without undue stress on the rope;
- resist rotation to reduce the chance of the suspended loop becoming twisted or tangled;
- have a similar weight per metre to the winding rope(s) it has to balance;
- have a breaking strength of at least six times the maximum suspended weight of the rope, to meet the requirements of paragraph 126 of the ACOP to the 1993 Regulations.³

12 Either multi-strand or flat ropes should be selected as balance ropes, as these are the only two types which are both sufficiently flexible and resist rotation. The multi-strand rope is used exclusively in the UK.

13 A multi-strand balance rope usually comprises an assembly of two or more layers of strands laid helically around a centre. The direction of lay of the outer strands is opposite (ie contra) to that of the underlying strands. Some multi-strand rope constructions display little or no tendency to rotate or, if guided, transmit little or no torque. Such ropes are known as low rotation ropes.

Guide and rubbing ropes

14 Guide and rubbing ropes guide and constrain the conveyances (which include counterweights where used) to prevent collisions between moving conveyances and between conveyances and the shaft wall and shaft furnishings.

15 Since guide and rubbing ropes are stationary ropes hanging in the shaft and do not bend around pulleys they do not have to be as flexible as other ropes. They should be of half-locked coil construction as these have a smooth rope surface, increased strength, excellent locking properties and, as they are made of large wires, will withstand the wear of conveyance shoes or slippers.

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16 Guide and rubbing ropes are normally at least 29 mm and 35 mm in diameter respectively, and when new should have a factor of safety of at least five, to meet the requirements of paragraph 102 of the ACOP to the 1993 Regulations.³ A new European Standard prEN 12385 - 7 *Steel wire ropes - safety - Part 7: Locked coil ropes for mine hoists* is currently being prepared. It includes requirements for guide and rubbing ropes as well as hoist ropes.

Storage of ropes used in shafts

17 If a rope is stored prior to installation, precautions should be taken to prevent external or internal corrosion. Ropes should be stored in a dry, cool, well-ventilated building out of direct sunlight and where the temperature remains substantially steady and does not rise much above 16°C. Further guidance on rope storage and handling can be found in Technical Annex 2.

Installation

18 Prior to installing any rope in a winding system, the potential hazards of the installation process should be identified and an assessment of risks carried out. Write down the significant findings of any risk assessment and take account of them when determining the installation procedure. After determining the installation procedure method statements can be drawn up detailing:

- what work is to be done;
- how it is to be done;
- what steps are to be taken to avoid, control or mitigate risks.

20 Whatever the method of work care should be taken to prevent rope damage during installation.

20 More detail relating to the installation of ropes in winding systems may be found in Technical Annex 2.

Capping and recapping

21 It is essential to use cappings to properly terminate the wire ropes used in winding systems, and provision should be made for them to be recapped at regular intervals after they have been taken into use. Procedures for capping wire ropes properly are given in Technical Annex 3.

Types of capping

22 Resin, white metal or wedge-type cappings are the main types available. HSE strongly recommends resin or white metal capping on ropes used in winding systems.

23 Of the two, resin capping is slightly stronger than white metal capping, less hazardous to install and quality control over the installation process is easier. For these reasons, resin cappings are now used almost exclusively in UK mines.

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Intervals between capping

24 Because of their safety critical duties, winding rope cappings have to be changed periodically. Paragraph 194 of the ACOP to the 1993 Regulations³ sets out the appropriate intervals for the capping of winding ropes for different types of winding systems.

25 Balance rope cappings can remain in service for the statutory life of the rope, which varies dependent upon whether the rope is fitted to a drum winder or a friction winder. The maximum interval that a rope is allowed to remain in service is specified in paragraph 129 of the ACOP to the 1993 Regulations.³ However, if the service life of any balance rope is extended beyond the life specified in the ACOP then recapping should be considered.

26 Guide ropes and rubbing ropes should be lifted and recapped as stated in paragraph 203 of the ACOP to the 1993 Regulations.³

Appointment of competent people to carry out capping

27 The capping and recapping of any wire rope used in a winding system should only be carried out by, or under the supervision of, a competent person appointed by the manager.

Inspection, examination and testing

28 Regulation 11 of the Management and Administration of Safety and Health at Mines Regulations 1993 (MASHAM)⁴ requires that wire ropes used in winding systems be included in the manager's scheme for the systematic inspection, examination and testing of plant and equipment. Regulation 17 of the 1993 Regulations² and the corresponding ACOP³ paragraphs 185 to 203 contain further detailed information. The purpose of inspecting and examining wire ropes is to:

- check that a rope remains safe to use;
- check the general condition of the rope, and in particular to identify the nature and severity of any damage, deformation or deterioration to the rope so it can be properly repaired or replaced; and
- identify and prevent, where possible, the causes of such damage etc.

29 Details on the types of damage, deformation and deterioration that might be found during inspection or examination are given in Technical Annex 4.

30 Criteria to help determine when to discard worn-out, damaged or defective ropes are also detailed in Technical Annex 4.

People carrying out rope inspections

31 Managers should only appoint trained and competent people to inspect, examine, test and maintain ropes used in winding systems as required by regulation 17 of the 1993 Regulations.²

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Routine external inspection

32 All wire ropes used in winding systems which carry people should be inspected daily. Reference should also be made to paragraph 188 of the ACOP to the 1993 Regulations.³

Periodic thorough examination

33 Winding and balance ropes used in winding systems should be subjected to a periodic thorough examination at least every 30 days. The examination procedure should be appropriate to the specimen report form shown at Appendix 2.

34 Paragraph 202 of the ACOP³ specifies that guide and rubbing ropes should be examined at regular intervals. For heavily used winding systems the examination should be made at least every 90 days. For winding systems with lighter duties in non-corrosive conditions the interval may be extended as appropriate but should not exceed six months. The factors considered during any examination and assessment procedure are shown in the specimen report forms in Appendix 5.

Thorough examination of rope removed during recapping

35 Paragraph 195 of the ACOP to regulation 17 of the 1993 Regulations³ gives details of the two thorough examinations of the length of rope removed during the recapping of a winding rope. The specimen report forms contained in Appendices 3 and 4 detail the factors considered during these thorough examinations.

Non-destructive testing of wire ropes

36 Non-destructive testing (NDT) can help locate defects in ropes. NDT is particularly useful for wire ropes used in shafts, where visual internal examination is not possible. NDT should be carried out when a rope is first installed, and then periodically throughout its statutory life. The provision of such condition monitored data is an essential requirement of any application to HSE to extend the life of a rope beyond its statutory limit. Reference should be made to paragraph 130 of the ACOP to the 1993 Regulations.³

37 Using NDT on balance ropes and guide ropes will give an earlier indication of deterioration than visual inspection. The ultrasonic testing of guide ropes in the area of the suspension gland has proved to be a reliable means of detecting deterioration in that area of the rope that is most likely to first suffer from fatigue.

38 The NDT of ropes requires specialist skills and equipment and should only be carried out by competent people using proven equipment in accordance with recognised codes of practice. More details on NDT can be found in Technical Annex 4.

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Maintenance ***Rope maintenance***

39 The main elements of rope maintenance are:

- lubrication;
- other preventative maintenance;
- repair or renewal (including recapping).

40 The degree, nature and extent of maintenance will depend on a number of factors including:

- statutory requirements;
- the duty required of the rope;
- condition of the rope;
- type of rope;
- manufacturer's recommendations;
- the shaft environment.

41 Rope maintenance or repair should only be carried out by people competent to do so.

42 Engineers need to ensure that they assess the risks associated with periodic maintenance work and for other repetitive jobs and draw up method statements. There should be no need to draw up a new method statement each time such work is carried out unless circumstances change, in which case the risks will need to be reassessed. A review of the method statement following completion of the work is recommended. The statement should be modified to incorporate any improvements to working practices identified through experience of performing the work.

Lubrication

43 The main benefits of effective lubrication are:

- (a) to allow free movement between strands or layers of wires which helps to reduce internal wear; and
- (b) to prevent or reduce the ingress of mine water or other potentially corrosive or abrasive materials,

and, therefore, to potentially increase rope life.

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44 Technical Annex 4 details the various types of lubricant available, the methods of application and the potential benefits of lubrication.

Other preventative maintenance

45 The purpose of other preventative maintenance is to avoid problems with shaft ropes during use of the winding system. Engineers should ensure that the manager's planned preventative maintenance scheme includes an appropriate regime of systematic and periodic maintenance. In particular, it should address:

- shaft ropes;
- winding engines; and
- other ancillary equipment and fittings.

46 Appendices 2 and 5 contain two sample report forms that detail the items that need to be checked, maintained and subsequently reported on with respect to shaft ropes.

Repair and renewal

47 Defects found during inspection, examination, testing or in use, will need to be dealt with promptly.

48 If the nature, extent and severity of a defect is sufficient to prejudice the continued safe running of the winding system then it should be stopped and prevented from running until a repair is completed or the rope has been replaced.

49 For minor defects the person making the inspection or examination will have to judge whether or not there is a need to take immediate action. Normal wear or corrosion is unlikely to warrant immediate action unless the rope is approaching its discard limits.

50 A single broken wire, which does not give rise to immediate concern, should be repaired promptly and subsequently monitored regularly to check for any further deterioration.

51 In addition to the normal rope inspections carried out at the mine, the person examining the shaft should determine whether or not there are any matters which might adversely affect the condition of the ropes. Particular situations to look for include:

- rope fouling or rubbing on obstructions;
- areas where localised deterioration may take place ie fan drifts, rope entry holes through headgear casings, wet areas;
- presence of corrosive or abrasive substances; and
- any other defects that need correction.

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52 As required by paragraph 187 of the ACOP to the 1993 Regulations,³ where problems are identified, they should be recorded and reported so that appropriate action can be taken.

Keeping records

53 It is important to keep proper records of shaft rope inspections, examinations, testing, maintenance and repairs. Appendices 1, 2, 3, 4, 5 and 7 are examples of sample report forms and can be freely copied. The forms outline the areas which should be looked at during inspection, examination or testing.

54 Conventional reporting procedures by the use of appropriate record books or electronic data storage can be used for keeping records provided that the same basic information shown on the sample report forms is included.

55 Whatever form of record is used, the important criteria is that any person who might need the recorded information has ready access to it.

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TECHNICAL ANNEX 1 - TYPES OF SHAFT ROPE INCLUDING SELECTION PROCESS

INTRODUCTION TO SHAFT ROPES

1 A wire shaft rope consists of many individual wires laid into a number of strands which are, in



Figure 1:
Components of a rope

Figure 2:
Components of a rope

turn, laid round a centre core (Figure 1), or of many individual wires laid around a centre core to form a rope having one straight strand, (Figure 2). The type and size of wire used, the number of wires in the strands, the type of core, and the rope construction determine the characteristics and strength of a wire rope of any given diameter and hence the uses for which it is suitable.

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2 Wires for shaft ropes generally have a tensile strength more than four times that of mild steel. The increased strength is obtained during manufacture, mainly by drawing the wire several times through small tapered holes in metal blocks or dies, the holes being always slightly smaller than the wire to be drawn through them. This treatment steadily decreases the diameter of the wire and increases its length, elongating the grains of which the steel is composed into longer, fibre-like structures increasing the tensile strength of the steel and hence the wire.

3 Tensile strength is measured in Newtons per square millimetre (N/mm²). Hanging a 1 kg weight on a wire would create just under 10 Newtons (10 N) of tension in that wire. If the wire had a cross-sectional area of 1 mm² then the tensile force in that wire would be just under 10 N/mm².

4 However, wires may fail by the repeated application of relatively small loads, below those that would be required to induce tensile failure. This characteristic is called 'fatigue failure'.

WIRE SHAPES

5 Wire shapes used in the manufacture of shaft ropes are as follows:

■ **round** - ie circular in cross-section (Figure 3);

■ **half-lock** - ie rail-shaped, with the sides curved to take a round wire on each side (Figure 4);

■ **triangular** - ie triangular in cross-section, as used for the centre wire of some triangular strands (Figure 5);

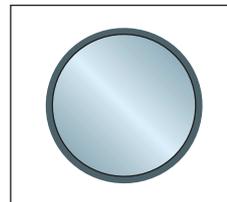


Figure 3: Round

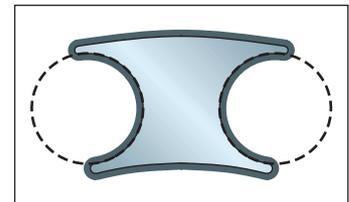


Figure 4: Half-lock

■ **full-lock** - ie Z-shaped or shaped like an inclined bullhead rail which will fit snugly against, or lock into, another wire of the same shape (Figure 6).

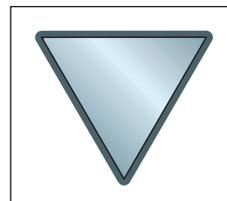


Figure 5: Triangular

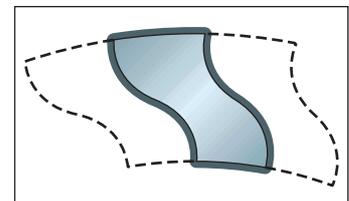


Figure 6: Full-lock

STRAND CONSTRUCTION

6 A strand is formed by laying up or spinning one or more layers of wires around a strand centre (Figure 7). The strand centre is either a single wire or a built-up-centre of a group of wires. The types and shapes of strands are as follows:

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- **round** (Figures 7a and 7b);
- **triangular** (Figures 7c and 7d);

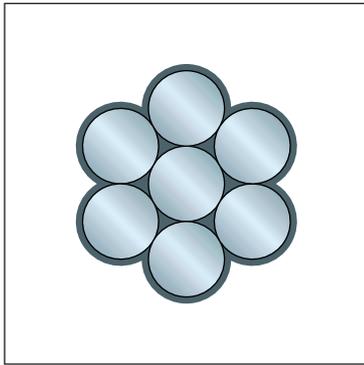


Figure 7a: 6/1 round

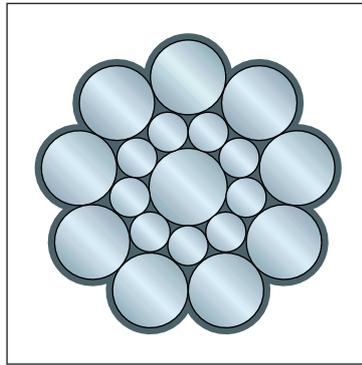


Figure 7b: 9/9/1 round

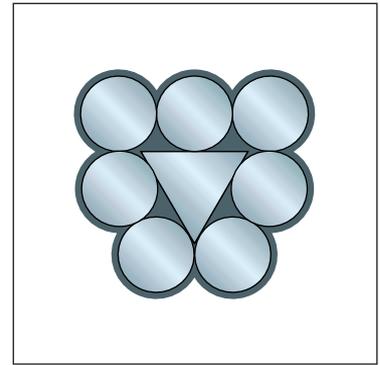


Figure 7c: 7/Δ triangular

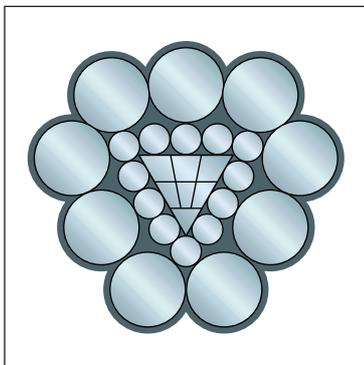


Figure 7d: 9/12/BUC triangular

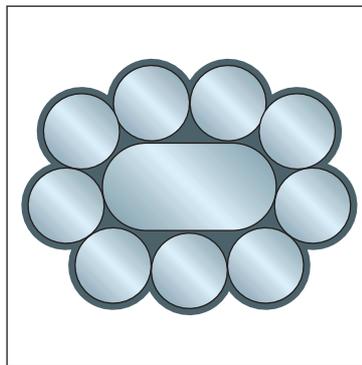


Figure 7e: 9/1 oval

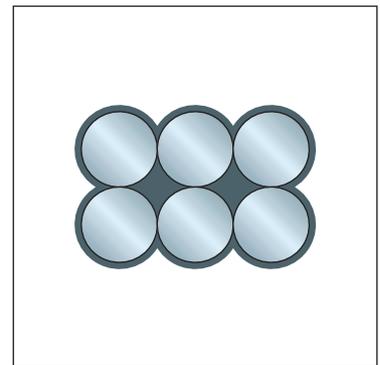


Figure 7f: 6/nil flat/ribbon

- **oval** (Figure 7e);
- **flat or ribbon**, (Figure 7f).

7 Apart from the flat (ribbon) strand, which has no centre, all other types have a centre to support the outer wires. Figure 8 show the types in general use - those shown in Figures 8b, 8c and 8d are known as built-up-centres (BUC).

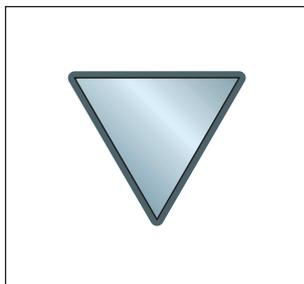


Figure 8a: Triangular

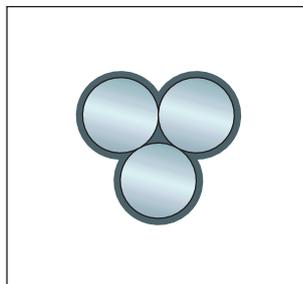


Figure 8b: Round

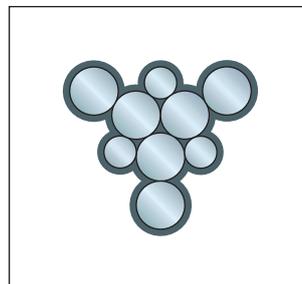


Figure 8c: 3X2+3F

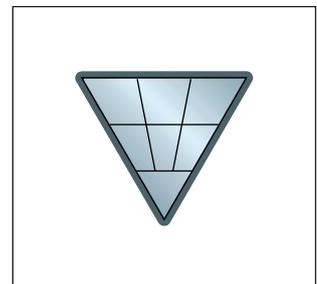


Figure 8d: K6/1 triangular

8 A simple method of describing the construction of a strand is to quote its type (shape) and the number of wires in each layer, starting from the outside. In Figure 7a the strand is 'round 6/1'; in Figure 7d it is 'triangular 9/12/BUC'; in Figure 7f it is 'flat 6/nil'. Paragraphs 26 and 27 of this Technical Annex provide further advice on the subject of rope designations.

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Round strands 9 Round strands may be:

- **single lay** - consisting only of one layer of wires around a centre wire (Figure 7a);
- **equal (parallel) lay** - consisting of at least two layers of wires, all of which are laid in one operation (in the same direction) around a centre wire (Figure 7b). There are a number of constructions which fall under this category, namely Seale, Warrington, Filler, Warrington Seale, etc;
- **cross lay** - a strand in which the wires are laid in the same direction. The wires of superimposed wire layers cross over one another and make point contact, eg 37(18/12/6/1) (Figure 9);

- **compound lay** - a strand which contains a minimum of three layers of wires, where a minimum of one layer is laid in a separate operation, but in the same direction as the others, over an equal (parallel) lay centre. A typical example is 35(16/6 and 6/6/1).

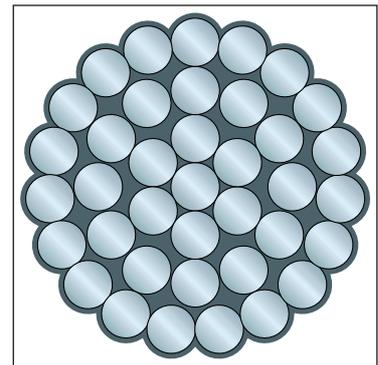


Figure 9: 37(18/12/6/1) strand

10 In any shape of strand of a given size, the more wires there are the smaller those wires will be and the more flexible will be the strand. However, from the point of view of safety, there is a limit to obtaining flexibility in this way.

11 When the outer wires of a strand are less than 2 mm in diameter they may be insufficiently sturdy to stand up to the normal degree of wear and corrosion that occur in mine shaft applications.

Triangular strands 12 Triangular strands (Figures 7c and 7d) have roughly triangular cross-section consisting of one or two layers of round wires laid around a triangular strand centre (Figures 8a to 8d).

Oval strands 13 Oval strands have a basically oval cross-section consisting of one or two layers of wires laid around an oval strand centre (Figure 10).

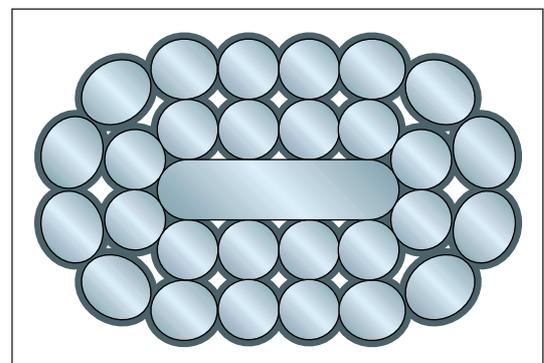


Figure 10: 28(16/12/ribbon) strand

Flat or ribbon strands 14 Flat strands normally comprise six or eight wires laid up side by side (Figure 7f), and are used mainly in ropes for shaft duties where their non-rotating properties and flexibility are very important - eg balance ropes and ropes for shaft sinking purposes.

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ROPE CONSTRUCTION

15 The main types of ropes used in shafts are:

- **full locked coil** (Figure 11a);
- **half locked coil** (Figure 11b);
- **multi-strand** (Figure 11c);
- **round strand** (Figure 11d);
- **triangular strand** (Figure 11e);
- **flat** (Figure 11f).

16 The full and half locked coil types are spiral, single-strand ropes containing shaped and round wires.

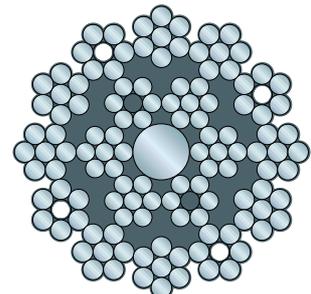
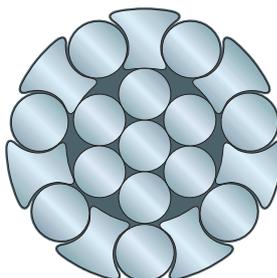
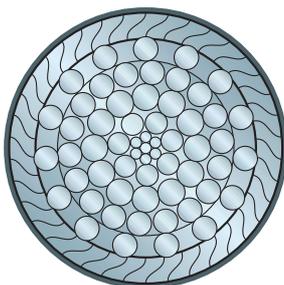
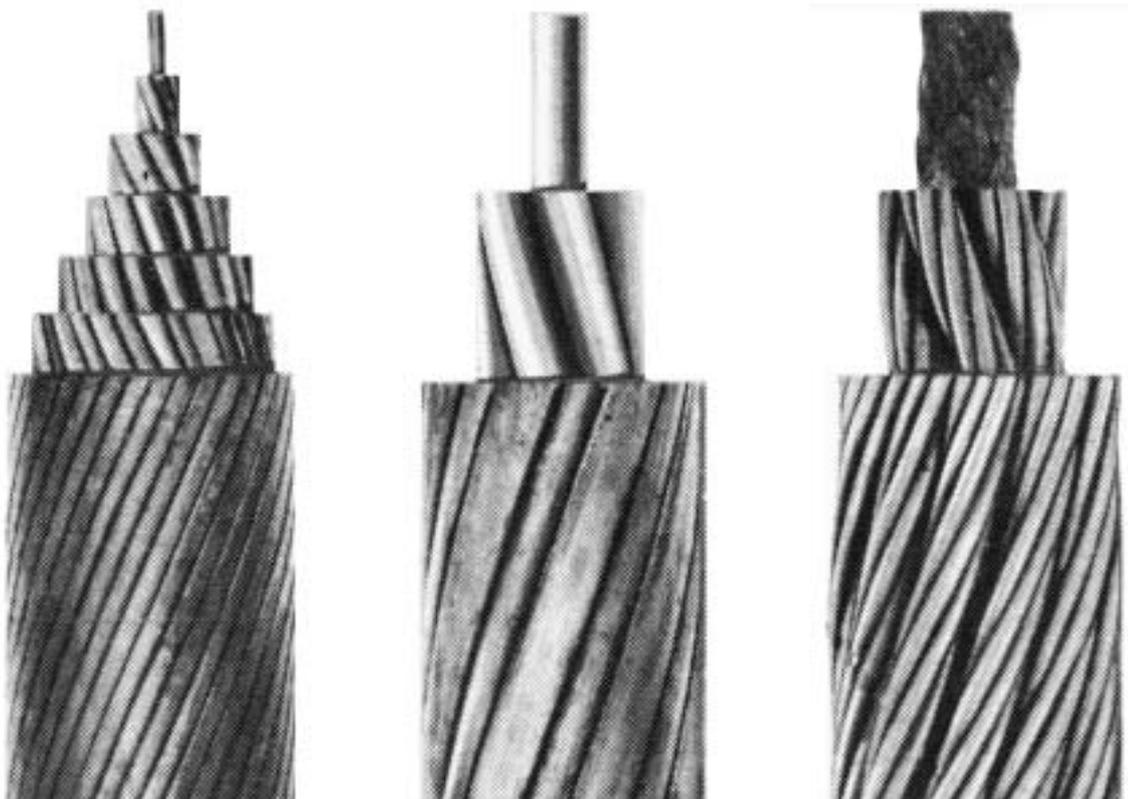


Figure 11a: Full locked coil rope

Figure 11b: Half locked coil rope

Figure 11c: Multi-strand rope

Lay 17 The multi-strand, round strand and triangular strand types have strands that twist around a core like screw threads. If they twist in the same direction as a right-hand thread then the rope is in right-hand lay (Figures 12a and 12c); if they twist in the opposite direction it is in left-hand lay (Figures 12b and 12d). The individual wires also twist around the strands. If they twist in the same direction as the strands, then the rope is in Lang's lay (Figure 13a), and if they twist in the opposite direction to that of the strands, then the rope is in ordinary lay (Figure 13b).

18 If the direction is not specified, the manufacturer will always supply right-hand lay as standard. The best lay for normal purposes is Lang's right-hand lay; engineers should only specify other lays when there is a special reason for doing so.

19 The length of lay (or pitch) of a stranded rope is the distance, measured along the rope, between the crown (highest point) of one strand and the next

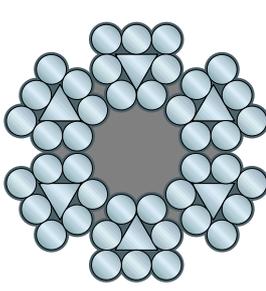
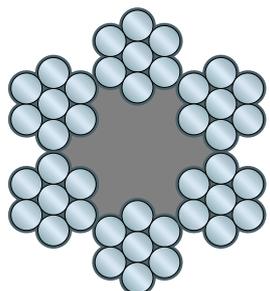
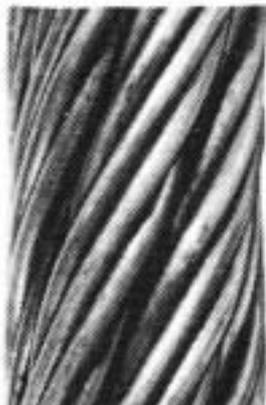
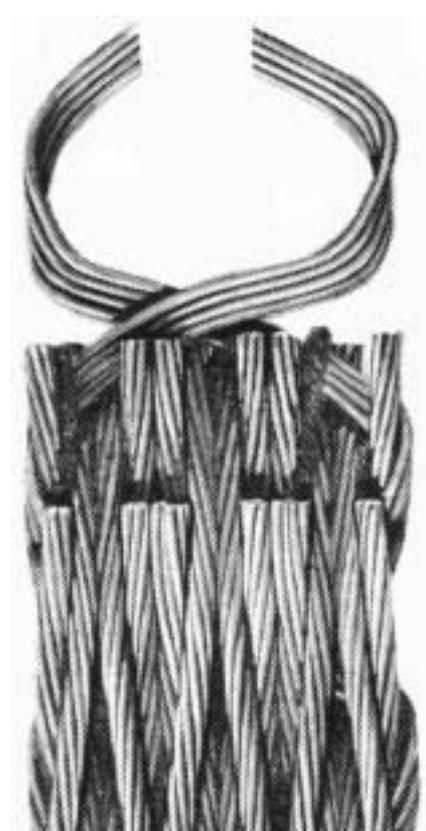
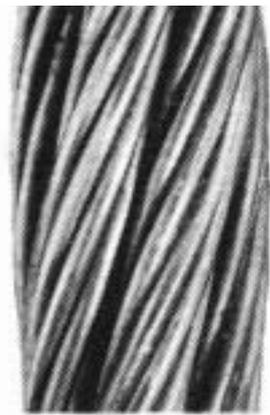
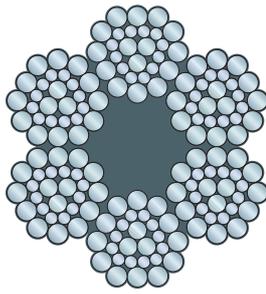
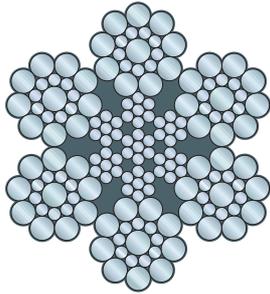


Figure 11d: Round strand rope

Figure 11e: Triangular strand rope

Figure 11f: Flat rope

Figure 12a:
Lang's right hand

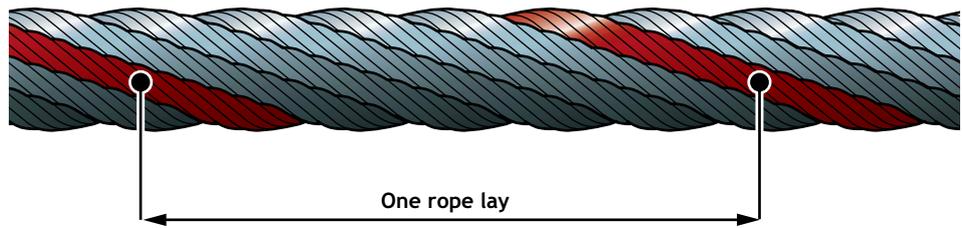


Figure 12b:
Lang's left hand

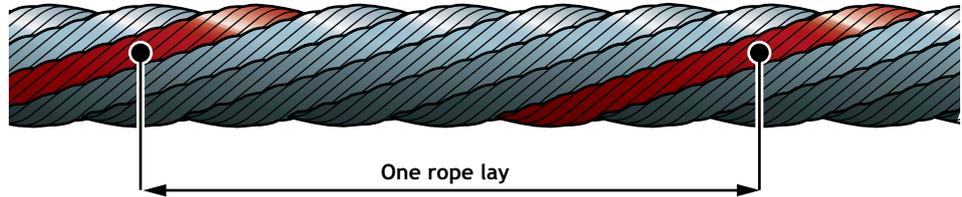


Figure 12c:
Ordinary right hand

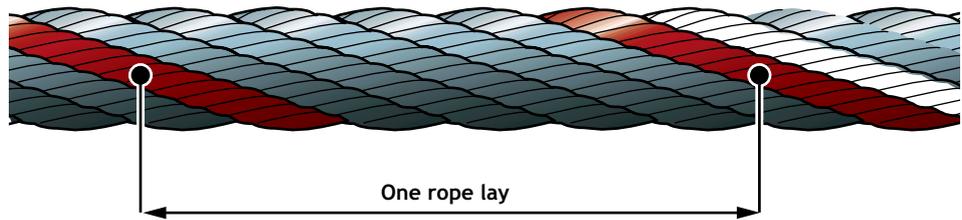
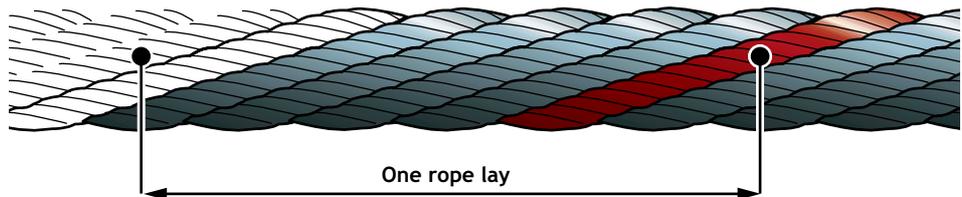


Figure 12d:
Ordinary left hand



crown of that strand along the rope. In Figure 12 one strand has been shaded and the distance between the two crowns, representing the length of lay, is marked.

Cores

20 The core of a stranded rope is designed to support the strands and is usually:

- a fibre rope (fibre core or FC);
- a wire strand (wire strand core or WSC); or
- a small wire rope (independent wire rope core or IWRC).

21 A rope with a fibre core, which may be of natural or synthetic fibres, is flexible and suitable for all conditions except those in which the rope is subjected to severe crushing (working under high load and on very small pulleys and drums, coiling on top of itself in numerous layers on a drum, etc.).

22 A rope with a wire strand core is more resistant to crushing but less flexible.

23 A rope with an independent wire rope core (Figure 11d - top) is resistant to crushing but is more flexible than a wire strand core rope. The reference section at the back of this book contains more information on relevant standards.

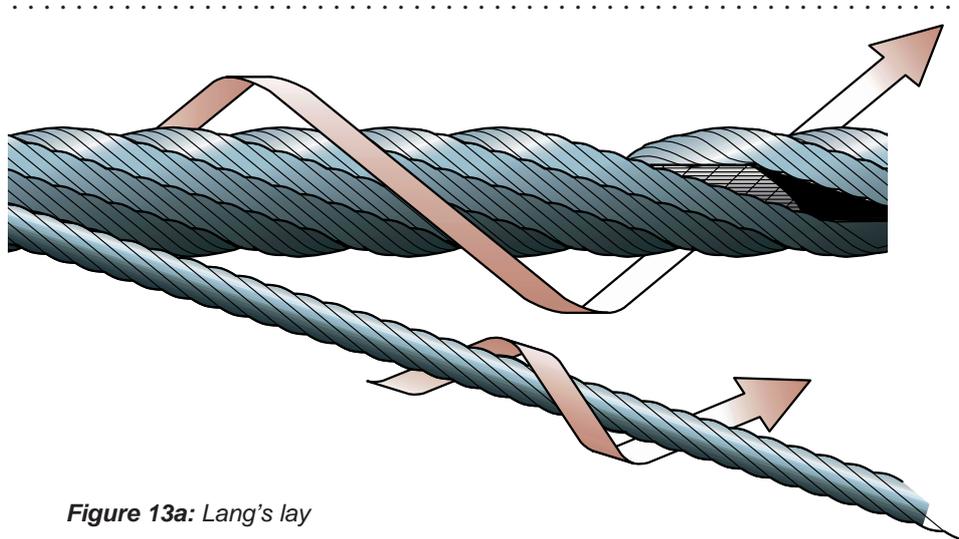


Figure 13a: Lang's lay

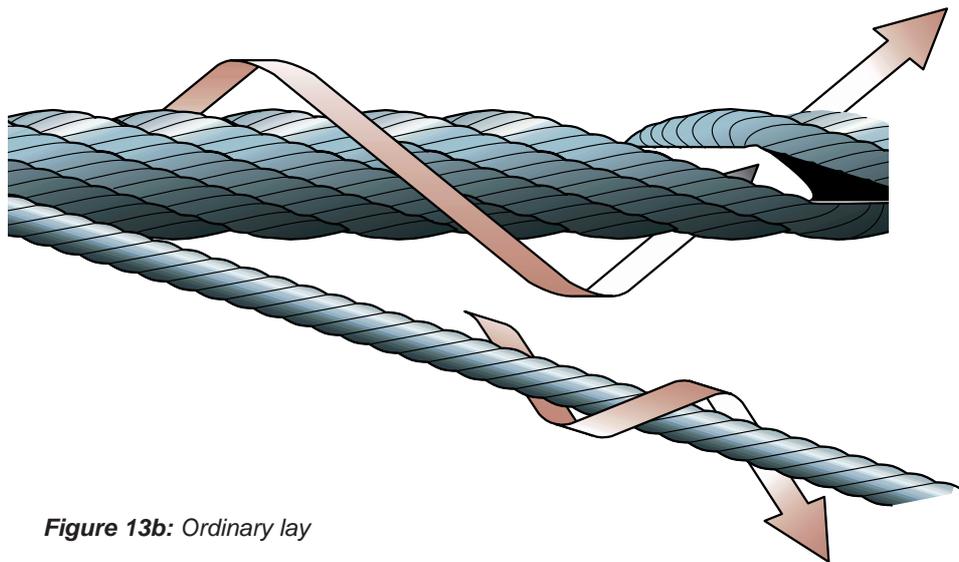


Figure 13b: Ordinary lay

24 Synthetic fibres such as polypropylene (fibre film core or FFC) may be used as a main core of a steel wire shaft rope. Such cores have several advantages in that they are:

- easier to manufacture;
- rot-proof;
- they hold lubrication better than a rope with a steel core.

25 When using ropes with synthetic fibre cores extreme care should be taken when capping with white metal, as the core has a relatively low melting point (eg 130°C for polypropylene) and there is therefore a danger that the part of the core close to the capping could be adversely affected by heat during the capping process.

Rope designation

26 The standard method of denoting the construction of a rope is to quote its type, number of strands, number of wires per strand, construction of strand, direction and type of lay and the type of rope core. For example, the rope shown at Figure 11d (top) is 'Round strand, 6x19(9/9/1) RH Lang's IWRC'

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meaning that it is a round strand rope having six strands, each having a total of 19 wires (6x19) consisting of nine wires, over nine wires over one wire (9/9/1), with an independent wire rope core, laid up in right-hand Lang's lay. The rope in Figure 11e (bottom) is 'triangular strand, 6x8_(7/V) RH Lang's FMC' meaning that it is a triangular strand rope with six strands, each having a total of eight wires consisting of seven wires over one triangular wire laid up in right-hand Lang's lay over a fibre main core.

27 A European Standard - prEN 12385-2 - *Steel wire ropes - Safety. Part 2: Definitions, designation and classification* which is currently being prepared, will present a more detailed means of describing a rope and will eventually supersede existing means of describing ropes. It will also incorporate new rope technology.

Rope specifications

28 To reduce corrosion and friction between wires, the various specifications for ropes (see References section at the back of this book) require that the wires and any natural fibre core must be thoroughly lubricated during manufacture. The amount and type of lubricant should be appropriate to the rope duty.

29 The specifications quote the breaking strengths of each of the different sizes (diameters) of rope available. There are a number of different specifications relating to the various intended uses of the rope.

Single layer round strand ropes

30 Single layer round strand ropes normally consist of six or eight strands laid around a main core. The strands are either of single lay construction (ie only one layer of wires laid around a centre wire (Figure 11d, bottom), or of equal (parallel) lay construction (Figure 11d, top), or of cross lay or compound construction.

31 The construction of the strands can range from comparatively inflexible wire arrangements having only six outer wires per strand to the more flexible arrangements having as many as 14 or 16 outer wires per strand.

32 Approximately 55% of the cross-section of a fibre core single layer round strand rope is steel. It will have a tendency to twist (rotate) about its own centreline when the load (tension) on it changes.

33 Single layer round strand ropes are relatively easy to examine in service as about half the length of each outer wire lies on the surface.

Single layer triangular strand ropes

34 Single layer triangular strand ropes have six almost-triangular strands laid around a main core. The strands can be either single lay construction (Figure 11e, bottom), or compound lay construction, (Figure 11e, top). As the strands are triangular and have almost flat sides, they fit together more closely than round strands and give a more compact rope.

35 In a fibre core single layer triangular strand rope about 62% of the cross-section is steel (when the main core is fibre). For this reason triangular strand ropes are about 10 per cent stronger than round strand ropes of the same size and tensile strength material. They stand up better to wear as they are of more

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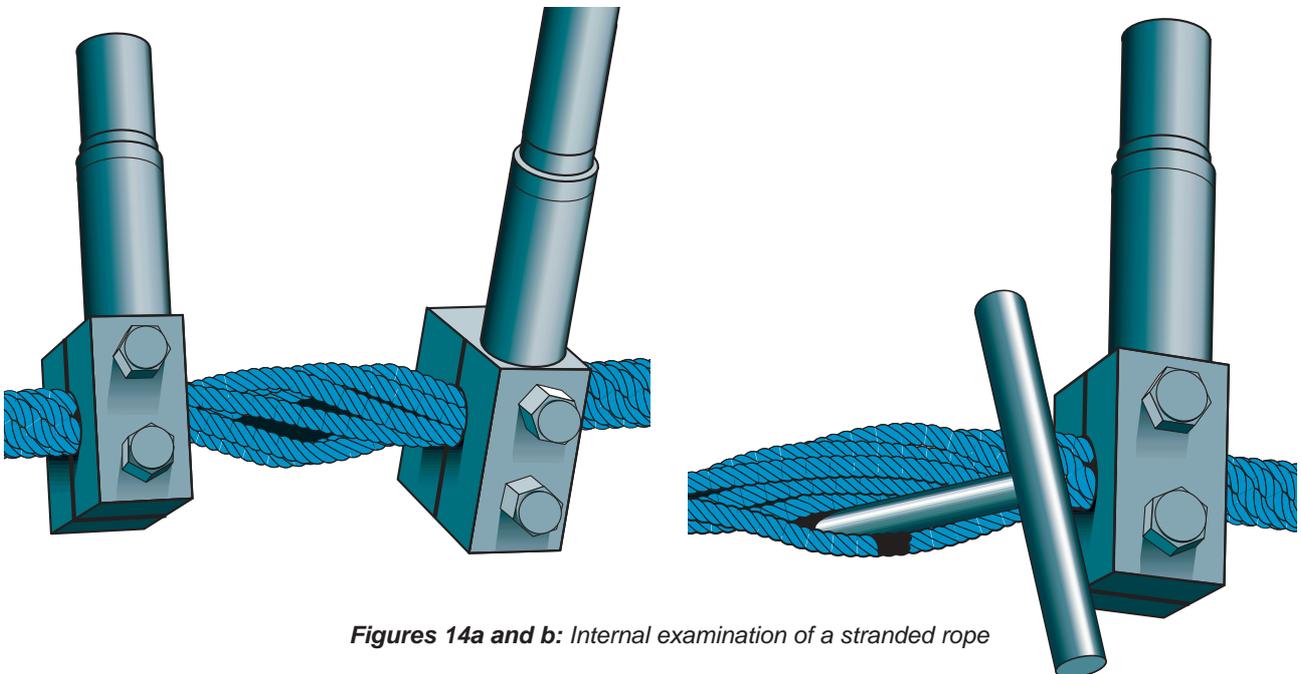
smoothly circular shape, and they resist crushing better as the strands have a greater bearing area.

36 Single layer triangular strand ropes are slightly more difficult to examine in service as a smaller proportion of total length of wire in the rope can be examined at the surface of the rope.

Multi-strand ropes

37 Multi-strand ropes generally consist of an assembly of two or more layers of strands laid helically around a central core, the direction of lay of the outer strands being opposite (ie contra lay) to that of the underlying layer of strands. Depending upon the number of strands the amount of resistance to rotation will vary.

38 This type of rope is not easy to examine visually as only about half the length of the outer wires of one layer of strands can be seen and there may be several layers of inner strands whose wires cannot be seen at all unless the rope is



Figures 14a and b: Internal examination of a stranded rope

carefully opened up (Figures 14a and 14b). It is a fairly flexible type of rope, with the degree of flexibility depending on the number and shape of the strands.

39 Rotation resistant and low rotation multi-strand ropes are suitable for conditions where rope twist must be minimised but where flexibility is required (as for balance ropes).

40 There is no British Standard or NCB Specification for multi-strand ropes for mine shaft purposes, but BS EN 12385-1:2002⁵ and BS 302-6:1987⁶ cover these ropes for general engineering purposes. Multi-strand ropes for mine hoists will be included in the future European Standard prEN 12385-6 - *Steel wire ropes - Safety - Part 6: Stranded ropes for mine hoists*.

Flat ropes

41 A flat rope (Figure 11f) is made up of several ropes called 'strands' or 'ropelets' laid side by side. The ropelets are normally stitched together with one

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or two flat or slightly twisted stitching strands of soft wire so as to hold the rope together and equalise the load between the separate ropelets.

42 This type of rope has a high percentage of the wire surface present on the rope exterior so that it is easy to examine, but it is also more vulnerable to corrosion attack than an equivalent round rope, which will have much less of its wire surface area exposed. For this reason and because, being handmade, they are very expensive, these ropes are now virtually obsolete in the UK.

43 Flat ropes will be included in the future European Standard prEN 12385-6 - *Steel wire ropes - Safety - Part 6: Stranded ropes for mine hoists*.

Full locked coil ropes

44 A full locked coil rope (Figure 11a) consists of a strand containing as many wires as are necessary to give the required rope strength. Its main core is a single central wire as would be present in any round strand. The outermost layer is always composed of full-lock wires (see also Figure 6); these lock together and give a very smooth circular shape to the rope, thus minimising external wear. To make the rope rotation resistant the outermost layer or 'cover' is always laid in the opposite direction to the underlying layers.

45 The locking action of the full lock wires is designed to reduce the possibility of a broken wire unravelling from the rope and, at the same time, restrict the ingress of moisture to the internal wires.

46 The number of underlying layers is dependent on the rope size and can comprise layers of round wires and/or layers of half locked and round wires. The centre of the rope is normally a sealed centre comprising a number of round wires of equal lay. To improve the rotational resistant characteristics the manufacturer can change the direction of selected layers of the inner wires.

47 Locked coil ropes should have no more layers of shaped wires than are necessary, for these close fitting wires leave little space for lubricant.

48 Locked coil winding ropes have many advantages:

- size for size they are of greater strength than stranded ropes in the same tensile grade;
- the smooth external surface gives greater resistance to wear by abrasion;
- they have rotation resistant properties;
- the elastic and permanent stretch is less than that of stranded ropes;
- they can operate under higher radial pressures than any other type of rope;
- broken outer wires can be readily repaired.

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49 Locked coil ropes are less flexible than other types of rope. To ensure long service the rope should not be bent sharply and should work on drums and pulleys whose diameters are not less than those shown in Table 1.

50 For these reasons this type of rope is particularly suitable as a winding rope in cases where large loads have to be raised and where rope twist cannot be tolerated.

Rope type	Rope size	Drum/Pulley ratio
Locked coil ropes	less than 26 mm	80
	26-44 mm	100
	more than 44 mm	120
Stranded ropes	All sizes	80

Table 1: Minimum drum and pulley/rope diameter ratios for winding ropes

51 Locked coil ropes have some disadvantages:

- (a) Only one layer of wires, representing between 18% and 40% of the total length of all wire in the rope (depending upon the rope size and construction) is visible, and it is therefore impossible to visually examine the wires of the underlying layers.
- (b) During service, locked coil ropes, generally over 45 mm diameter, may develop a wavy or spiral form instead of remaining straight (Figure 15).



Figure 15:
Wavy or spiral form

The reason for this is that the larger ropes are built up of more layers of wires, and are more complex than smaller ropes. As such they are more readily affected by any deficiency in manufacturing techniques or operating conditions. See further advice on this subject in Technical Annex 4 under '**Distortion in ropes**'. Modern friction winding installations, designed to raise heavy loads, are of the multi-rope type employing several small locked coil ropes in parallel rather than one large rope. This is better for service and smaller ropes can work on smaller driving sheaves.

- (c) There is no British Standard for locked coil ropes, but NCB Specification No 186: 1970⁷ applies. It should be noted however, that full locked coil hoist ropes will be included in the future European Standard prEN 12385 -7 *Steel wire ropes - Safety. Part 7: Locked coil ropes for mine hoists.*

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Half-locked coil ropes

52 Half-locked coil ropes (for guide and rubbing ropes) also consist of one straight strand (Figure 11b) and contain very large section wires to give the best possible wear characteristics. Used as guide ropes they offer a smooth wearing surface to the conveyance shoe or rubbing plate. The locking action of the outer wires is designed to ensure that any broken wires which develop are held in position in the rope so as not to interfere with the free running of a conveyance.

53 There is no British Standard for half-locked coil ropes but NCB Specification No 388/1970⁸ applies. It should be noted however that half-locked coil guide and rubbing ropes using wires of tensile strength grade 780 to 1270 N/mm². will be included in the future European Standard prEN 12385-7 *Steel wire ropes - Safety: Part 7: Locked coil ropes for mining hoists*.

54 Table 2 lists the advantages and disadvantages of most of the rope types.

PREFORMING

55 Most types of stranded ropes are preformed to some degree during manufacture to give the strands and wires the form they will take up in the completed rope. This process produces a rope which does not tend to unravel or to form itself into loops or kinks when it is slack or free of load. It will however still twist when loaded.

SURFACE FINISHING (GALVANISING)

56 Many steel wire ropes are coated with zinc in a process known as 'galvanising'. A zinc coating protects the steel, partly by acting as a physical barrier between the steel and any corrosive substance, and partly because the coating is attacked rather than the steel. Galvanised ropes should therefore be specified for ropes which will have to work under conditions which are known to be corrosive.

57 Ropes can be supplied in one of three finishes:

- galvanised, Type A (a heavy coating of zinc);
- galvanised, Type Z (a lighter coating of zinc);
- ungalvanised (or bright).

Standards relating to galvanised steel wire ropes are contained in the Reference section at the back of this book.

58 When selecting stranded ropes for use, mines should specify Types A or Z.

59 For locked coil ropes mines should always specify Type Z, as it is relatively easy to damage the thick coating of soft zinc of Type A galvanised ropes, encouraging looseness of lay, and therefore rope distortion.

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Rope type	Advantages	Disadvantages	Recommended uses
Round strand	<p>Easy to examine visually</p> <p>Fairly wide flexibility range</p>	<p>Tendency to twist as load changes</p> <p>Relatively vulnerable to external wear</p>	<p>Small drum hoist on rope guides</p> <p>Large drum hoist on fixed guides</p> <p>Friction hoist up to 1000m depth</p>
Triangular strand	<p>Fairly easy to examine visually</p> <p>Stronger than round strand rope of equivalent size with wires of the same tensile strength</p>	<p>Tendency to twist as load changes</p> <p>Less flexible than round strand rope</p>	<p>Small drum hoist on rope guides</p> <p>Large drum hoist on fixed guides</p> <p>Friction hoist up to 1000m depth</p>
Multi-strand	<p>Rotation resistant</p> <p>Relatively flexible</p>	<p>Difficult to visually examine rope interior</p>	<p>Drum hoists on rope or fixed guides</p> <p>Friction hoists</p> <p>Balance ropes</p>
Flat	<p>Rotation resistant</p> <p>Very flexible in one direction</p> <p>Visual examination easy</p>	<p>Relatively vulnerable to corrosion</p> <p>Very expensive</p>	<p>Balance ropes</p>
Full locked coil	<p>Rotation resistant</p> <p>Resistant to external wear</p> <p>Stronger than other rope types of equivalent size with wires of the same tensile strength</p> <p>Can operate under higher radial pressures than other types</p>	<p>Relatively inflexible</p> <p>Interior impossible to visually examine</p> <p>Larger diameter ropes can sometimes distort</p>	<p>Drum hoists on rope or fixed guides</p> <p>Friction hoists to a depth of 2000m</p> <p>Kibble hoists</p>
Half locked coil	<p>Resistant to external wear</p> <p>Any breaks in outer wires are held in lock</p>	<p>Relatively inflexible</p>	<p>Guide ropes and rubbing ropes</p>

Table 2: Rope characteristics

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60 Locked coil ropes can be supplied:

- with all layers of wire galvanised, for use in corrosive environments;
- with the outer two or three layers galvanised where corrosion is less likely;
- ungalvanised for use in environments where corrosion is unlikely.

61 It is no less important to keep galvanised ropes well-lubricated during storage and service than for ungalvanised ropes.

ROPE SELECTION

Winding ropes

62 The main things to consider when choosing a winding rope are:

- size - the diameter of rope required to give the necessary breaking strength;
- type - locked coil or stranded (round strand, triangular strand or multi-strand);
- rotational properties;
- strand construction - fewer wires for resistance to wear and corrosion; more wires for greater flexibility;
- direction and type of lay:
 - stranded ropes - left or right-hand; Lang's or ordinary;
 - full locked coil ropes - right-hand or left-hand;
- for locked coil ropes, the tensile strength grade may vary from 1570 N/mm² to 1960 N/mm² for round wires, and from 1180 N/mm² to 1570 N/mm² for shaped wires (see NCB Specification 186/1970⁷ which will be superseded by prEN 12385 Part 7 - *Steel wire ropes - Locked coil ropes for mine hoists*). For stranded ropes the tensile strength grades are up to 1960 N/mm²);
- the surface finish - ungalvanised for conditions known to be dry and non-corrosive, but galvanised for conditions known to be corrosive or possibly corrosive.

63 Table 3 gives some guidance on the first five items above but mine engineers should discuss their requirements with rope manufacturers, who have wide experience of the type of rope best suited to particular working conditions.

64 Engineers will need to calculate the loads to be carried and select a size (diameter) of rope that will have a breaking strength which will give a factor of safety not less than those specified in paragraphs 102 and 126 of the ACOP to the 1993 Regulations.³ The factor of safety is the number of times the breaking strength of the rope is greater than the maximum suspended load to be carried

by the most heavily loaded part of the rope; usually, the part just below the headframe pulley or sheave when the fully loaded conveyance is at pit bottom.

65 For example, for a drum-winder, an engineer may have calculated that the maximum suspended load at the most heavily loaded part of a particular rope is 10 tonnes. Paragraph 126(b) of the ACOP³ calls for a minimum static factor of safety of 6.5, so the engineer would specify a rope with a breaking strength of at least 10x6.5, 65 tonnes. The maximum suspended load is the same as the maximum static load and is the load in the rope while it is at rest. When the rope is travelling in the shaft there may be sudden shocks due to both winding characteristics and changes in speed, which may increase the load to about 1.5 times the static value. The bending of the rope around pulleys, sheaves or drums will add further to the load in the wires and secondary bending. A generous static factor of safety is used to take care of these extra loadings, which are not usually included in the calculations, and to allow for normal loss of rope strength during service due to deterioration.

66 Where the design and duty of the system is in accordance with recognised good practice, selection of ropes based on the static factors of safety should normally result in the winding ropes achieving their specified maximum life.

Rope service requirements	Rope design characteristics
Strength	Depends on rope construction and diameter, tensile strength of wires and type of core
Resistance to rotation	Consider use of: <ul style="list-style-type: none"> ■ locked coil ropes ■ multi-strand constructions ■ ordinary lay rather than Lang's lay ■ IWRC rather than fibre core
Resistance to corrosion	Consider use of: <ul style="list-style-type: none"> ■ galvanised ropes ■ outer wires as large as possible
Resistance to bending fatigue	Consider use of: <ul style="list-style-type: none"> ■ locked coil ropes - see Table 1 for advice ■ Lang's lay, round strand, equal lay constructions ■ independent wire rope cores (IWRC) ■ triangular strand constructions
Resistance to crushing	Consider use of: <ul style="list-style-type: none"> ■ locked coil ropes ■ triangular strand ropes ■ equal lay constructions ■ independent wire rope cores (IWRC)

Table 3: Factors to consider when selecting winding ropes

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Where there are adverse design, operating or environmental factors, or where ropes do not normally achieve their recognised specified life, engineers may need to take account of dynamic loads and impose dynamic factors of safety.

67 In both drum-winding and friction-winding installations the maximum suspended load to be carried by the rope or complete set of ropes is the sum of:

- the weight of one conveyance (cage or skip) when loaded with the normal heaviest load;
- the weight of all attachments above and below it (chains, adjusting links, detaching hook, capping of winding ropes and of any balance ropes and balance rope attachments, etc);
- the weight of suspended winding ropes between the headframe pulley or sheave and the conveyance when the conveyance is at pit bottom;
- the weight of any balance ropes hanging below the particular conveyance under consideration when that conveyance is at pit bottom;

(Note - where the balance rope is heavier than the winding rope(s), the maximum suspended weight of the balance rope and winding rope is when the conveyance is at the shaft top.)

- half the weight of any sheaves running in the loops of any balance ropes below the conveyance.

68 With drum winders or single-rope friction winders the total of the above items will give the maximum suspended load on the single rope involved. In the case of a multi-rope friction winder the total of the above items will give the maximum suspended load on the complete set of ropes, and must therefore be divided by the number of ropes in the set in order to get the maximum load on each rope.

69 While the minimum static factor of safety of a drum winder is a specified figure, the factor of safety of a friction winder is affected by the degree of bending in the rope as it passes over the winding sheave, the depth of wind (and hence the frequency of winding) and any reverse bending resulting from the presence of deflecting pulleys. The values for the minimum factor of safety for both of these winding systems is given in paragraph 126 of the ACOP to the 1993 Regulations.³

Balance ropes

70 Balance ropes serve to balance the weight of the winding ropes on each side of the drum, or of the ropes on each side of the friction-winding sheave. Each end of the balance rope is attached to the bottom of one of the two conveyances and, consequently, the rope hangs to form a U-shaped loop in the shaft sump. The rope must be sufficiently flexible to bend enough under its own weight to fit within the distance between the suspension points on the two conveyances. The ratio of

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the distance between balance rope suspension points to the rope diameter should be not less than 25:1, and so a flexible rope is required that has a similar weight per metre to the winding rope(s) it has to balance.

71 Paragraph 126(a) of the ACOP to the 1993 Regulations³ states that the breaking strength of any balance rope must be at least six times its maximum suspended weight.

72 Balance ropes should resist rotation to reduce the danger of the loop in the shaft sump becoming twisted or tangled. The two types of rope that combine rotation resistance with flexibility are the multi-strand rope (Figures 11c and 16) and the flat rope (Figure 11f). The less expensive multi-strand rope is widely used.

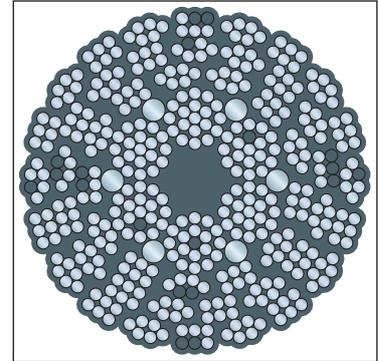


Figure 16: 20x6 superflex

73 'Superflex' multi-strand ropes are susceptible to damage and wear and therefore adequate protection should be provided at all times to prevent the rope from striking the shaft wall or the shaft furnishings.

74 A flat rope has the advantage that it can be bent even more sharply, and is also easier to examine because a high percentage of the wire surface is visible. It is, though, expensive and more vulnerable to corrosion attack than an equivalent round rope, and for these reasons flat balance ropes are not used in the UK.

75 Where balance ropes are to operate in corrosive conditions, they should be manufactured from galvanised wire.

Guide and rubbing ropes

76 Paragraphs 101 to 103 of the ACOP to the 1993 Regulations³ require the use of guide ropes or rigid guides in shafts. Since guide ropes and rubbing ropes are stationary ropes hanging in the shaft and not bending round pulleys, they do not need to be as flexible as other ropes. Therefore they are made of large wires to withstand the wear of conveyance shoes or slippers.

77 Rubbing ropes hang between the conveyances to prevent the conveyances from colliding as they pass. They are also made of large wires to withstand rubbing and nipping between the conveyances. Guide and rubbing ropes are of half-locked coil construction (Figure 11b) since this gives a smooth rope surface, increased strength and excellent locking properties. Round rod guide ropes are now virtually obsolete and are not recommended.

78 Guide and rubbing ropes are normally at least 29 and 35 mm in diameter respectively. Rubbing ropes should be the same diameter or larger than the guide ropes. The rope size will depend on such factors as the depth of the shaft, the applied tension and the safety factor. The nominal tension is usually of the order of 3 tonne + 0.5 tonne/100m of rope length. The tension on each

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rope in the shaft should vary slightly, between about 10% either side of the average tension, so that the ropes in the system will not all sway or oscillate with the same frequency.

79 The breaking strength of the rope when new, at the headgear capping, should not be less than 5 times the load at that point in the rope with the greatest tension.

80 There is currently no British or EU standard for the half locked coil types most commonly used for guide ropes and rubbing ropes, and for the time being guide and rubbing rope constructions should be in accordance with NCB Specification 388/1970.⁸ However, when completed the new European Standard prEN12385-7 - *Safety - Part 7: Locked coil ropes for mine hoists* will cover half lock ropes and should then be followed.

81 Galvanised ropes should be used when the conditions are at all corrosive; even if the zinc coating is removed from the rope exterior by wear, it will remain in the interior to resist internal corrosion.

82 Only ropes designed for the purpose should be used. Old winding ropes are unsuitable for use as guide or rubbing ropes and may be dangerous; their small outer wires could rapidly become worn through and the broken wire ends foul the conveyance.

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TECHNICAL ANNEX 2 - ROPE STORAGE, HANDLING AND INSTALLATION

ROPE STORAGE

- 1 When storing ropes it is essential to take precautions against external and internal corrosion. Reels of new rope for use in shafts should be sheltered from the weather and any fumes, in a dry, cool, well-ventilated building out of direct sunlight.
- 2 A steady temperature will avoid condensation, and if the temperature stays at or below 16°C the lubricant will not thin and run out of the rope. At 21°C most lubricants are twice as fluid as at 16°C, and at 27°C they are about three times as fluid.
- 3 The reel should stand on timbers rather than on a concrete floor and should be rotated from time to time to prevent lubricant draining to the bottom. If the rope remains in store for a considerable time it should be inspected at intervals and fresh lubricant applied when necessary.

UNREELING AND HANDLING ROPES

- 4 People should always handle rope reels with care, and in particular they should never be dropped from a lorry or truck when unloading them. To lift a reel, thread a suitable bar through the central hole and attach suitable slings that do not crush the sides of the reel.

INSTALLATION AND OPERATION OF ROPES

**Hazard identification,
risk assessment and
method statements**

- 5 Prior to installing any rope in a shaft, a competent person, such as the mine mechanical engineer, will need to identify the hazards associated with rope installation, assess the risks and prepare a method statement for each operation. The method statement will give a step-by-step procedure for installing the new rope(s) and the safety precautions to be taken by all people involved.
- 6 Whether or not they would otherwise have been involved, shaftsmen, or other people who inspect ropes during service, should be present during rope installation so that they are aware of the visual characteristics of the new rope as a baseline for subsequent visual inspections.

WINDING ROPE INSTALLATION

- 7 During installation the rope reel should be mounted on a horizontal shaft that is also mounted on bearings in a suitable fabricated steel frame. The shaft should be fitted with an effective brake, both to keep its rotation under control and to maintain tension in the rope as it is led off the reel and onto the winding system.
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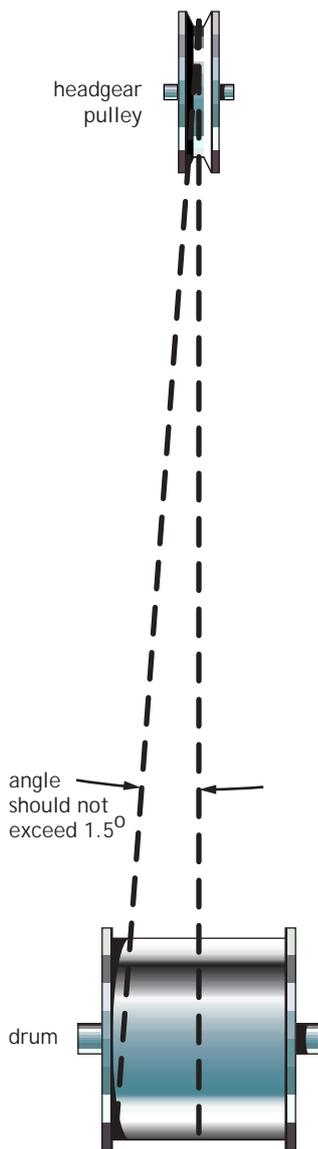


Figure 17: Maximum angle of deviation

Polyurethane inserts

8 The installation procedure should be such that adequate tension is applied to the coils of rope on the winding engine drum. This is particularly important in the case of multi-layered drums, to ensure that the lower layers fully support the layers above.

9 The two ends of the rope must remain securely served throughout the operation until ready for fitting to the conveyance or drum, otherwise the ends may 'spring' or become unlaidd giving rise to the potential for rope damage.

10 The rope manufacturer should be informed of any damage to the rope during installation.

HEADGEAR PULLEY GROOVES

11 Before installing a new rope it is very important to check that the groove in the headgear pulley or sheave is the correct size for that rope, and that the fleet angle (the maximum angle of deviation of the rope from the axis of the pulley groove (see Figure 17) does not exceed 1.5°.

12 For steel and cast iron pulleys the groove radius should be slightly larger than the new rope radius within a range of:

- 5 to 10% - for locked coil ropes;
- 7.5 to 10% - for stranded ropes.

13 After installation the groove radius for both types of rope should be maintained within the range of 7.5 to 10% greater than the actual rope radius. A groove which is too small or tight will pinch the rope and may cause rope distortion or wire breakages.

14 For a stranded rope it is particularly important that the groove is not too large. While the shape of a locked coil rope may alter only slightly in an overlarge groove, a stranded rope will deform and become oval in cross-section, increasing the stress in the rope. Engineers should ensure that regular checking of the groove radius is carried out as part of routine maintenance procedures.

15 Where polyurethane inserts are installed on headgear pulleys or friction winder deflection sheaves, the groove radius should be maintained within the range of 12 to 20% of the actual rope radius. A more specific value within that range is dependent on the grade and hardness of the polyurethane, and advice on the matter should be sought from the supplier of the inserts and the rope manufacturers.

WINDING DRUM GROOVES

16 It is also prudent to check the size of the winding drum grooves against the rope size before a new rope is installed, although it is unusual for a drum to wear

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sufficiently to require machining. The inserts of friction winder drums should be maintained so as to support approximately 120° of the circumference of the rope.

REFERENCE SAMPLES

17 When installing a winding rope, a 2m length should be securely served at each end and then cut off, well lubricated externally, and then labelled. The sample should be kept throughout the life of the winding rope so that ropemen can use it as a reference sample.

18 If the manufacturer supplies a rope that is already cut and capped to the correct length, the mine should ask the manufacturer for a short length of the new rope to act as a reference sample. This sample would be in addition to the sample of new rope which must be sent to an appropriate test centre, at the time of delivery, to check compliance with specification.

TORQUE AND TWIST IN WINDING ROPES

19 All winding ropes generate some measure of turning torque when subjected to their design load. Some stranded ropes are designed as non-rotational ropes and normally achieve minimum torque levels in service. Locked coil winding ropes however can generate torque in either direction depending primarily on the diameter of the rope, the altitude of the outer locked coil wires and the construction of the inner layers.

20 Research has shown that locked coil ropes up to 22 mm diameter can generate torque that causes the outer wires to untwist. For rope sizes between 22 and 40 mm diameter, the rope is generally balanced, and those ropes greater than 40 mm diameter tend to tighten their outer covers. Further detailed advice on this subject may be obtained from rope manufacturers.

21 Winding ropes at most installations will also twist and store energy after being put into service, due to the action of repeatedly passing over headgear pulleys and driving drums. If such twist is not monitored and corrected then problems with both the rope and the conveyances may result.

22 It is important to assess the amount of twist energy stored in winding ropes, and to devise procedures, based on an assessment of risks, for safely releasing it. Mine engineers should ensure that periodic checks for stored twist energy are carried out during the life of a winding rope. The interval between successive checks will depend on previous experience and/or on the advice of the rope's manufacturer.

23 If a rope tends to twist the conveyance or its attachments and displace the rope guides, it may be necessary to release or apply twist to the rope before finally attaching it to the conveyance. However, no more turns than are necessary

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should be released (usually not more than one or two turns) otherwise the rope will become loosely laid up and the loose wires may deteriorate in fatigue as a result of being subjected to accentuated secondary bending.

24 The uncontrolled use of a swivel for releasing twist in winding ropes is not good practice. If too many turns are released from a triangular-strand rope, each triangular strand may turn into the rope raising one of its edges above the surface of the rope accentuating external wear along that edge (Figure 18).

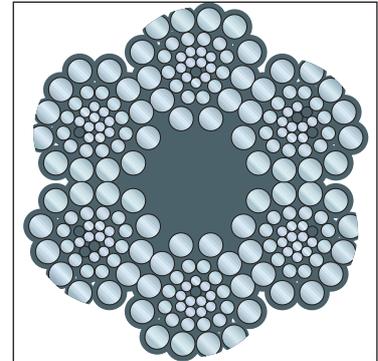


Figure 18: 6x25(12/12/BUC) worn

25 A Lang's lay rope should never be permitted to hang freely as it will tend to uncoil.

26 If rope twist is a problem at a particular shaft, then one of the rotation resistant types of rope, either a multi-strand rope or a locked coil rope, should be used; the preformed type is non-rotating or 'dead' only while it is unloaded.

27 When installing a locked coil or a rotation resistant rope it is better if the rope is allowed to hang freely to the pit bottom, to allow the controlled release of any stored twist. If necessary, one turn or part of a turn may be put in, but always in a direction to tighten the cover, before final connection to the conveyance. However, any stored twist in either a round or a triangular strand rope must only be removed at the shaft top.

PRE-STRETCHING AND PRE-STRESSING BY THE MANUFACTURER

28 The operational performance of shaft ropes may be enhanced by subjecting them to some prestretching by the manufacturer before delivery. This is achieved on both steel and fibre cored ropes by tensioning them to a relatively low level and then measuring the length under an agreed tension that is representative of the working conditions.

29 It is possible to achieve further improvement to the operational performance of winding ropes and balance ropes by subjecting them to prestressing through repeated loading before delivery. A cyclic tensile load that varies between 5% and 20% of the nominal breaking load of the rope is applied for a sufficient period to remove the maximum amount of permanent stretch from the rope. The rope is then measured to the required final length while under a mean load that is representative of the working conditions.

CORRECT COILING OF STRANDED ROPES ON DRUM WINDERS

30 If a stranded rope is secured incorrectly to a smooth-surfaced winding drum it may coil badly, forming open or widely spaced coils instead of closely

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packed coils. The correct way to fit a rope to a drum is to look at the drum in a direction towards the shaft in which the winder operates:

- (a) a right-hand lay underlap rope should have its dead end secured at the right-hand flange of the drum;
- (b) a right-hand lay overlap rope should have its dead end secured at the left-hand flange of the drum.

31 There is a simple method of remembering how to fit a right-hand lay rope to a drum. Looking at the drum in a direction towards the shaft in which the winding rope operates:

- (a) for an underlap rope, extend the right hand towards the under side of the drum, with the palm facing the drum (ie facing upwards) and with the index finger pointing towards the shaft. The thumb will then be near to the right-hand flange of the drum where the dead end of the underlap rope should be (Figure 19a);

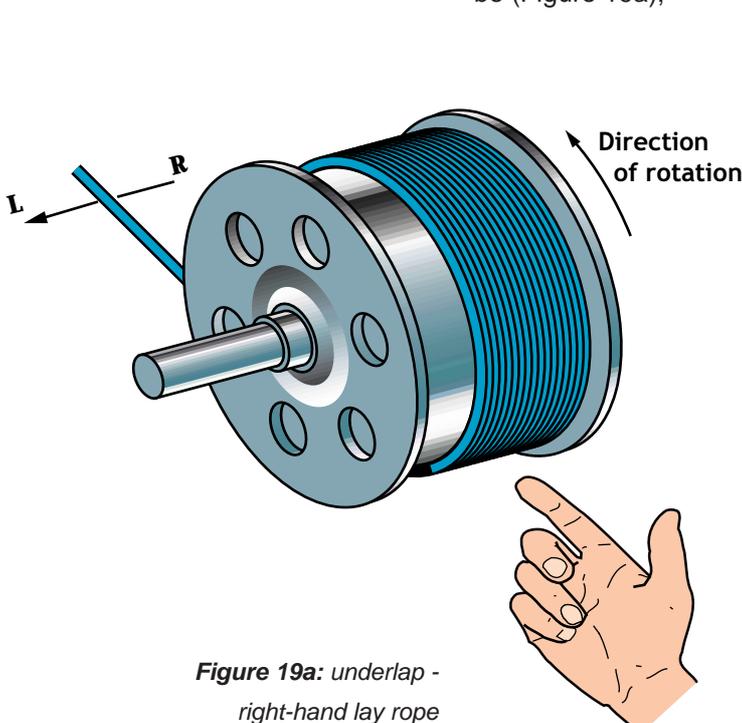


Figure 19a: underlap - right-hand lay rope

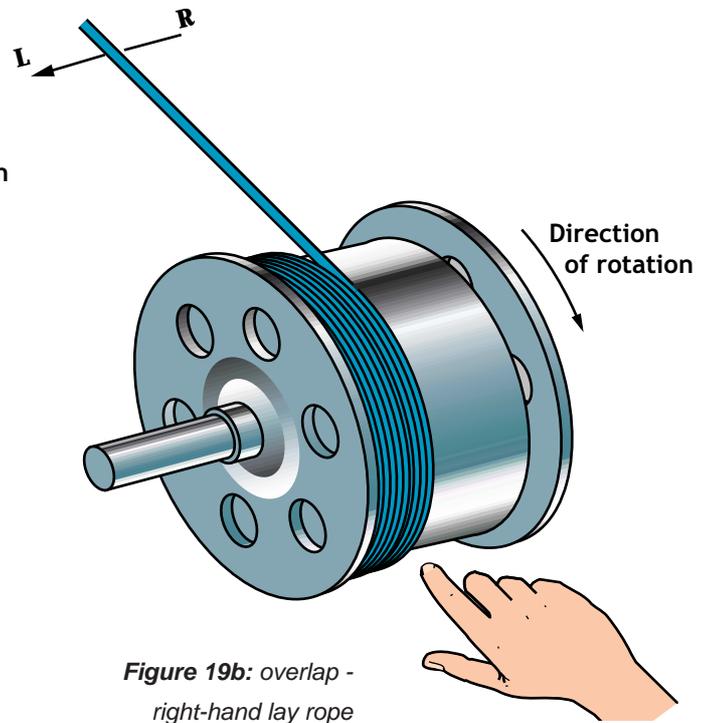


Figure 19b: overlap - right-hand lay rope

- (b) for an overlap rope, extend the right hand towards the top side of the drum, again with the palm facing the drum (ie facing downwards) and again with the index finger pointing towards the shaft. The thumb will then be nearest the left-hand flange of the drum where the dead end of the overlap rope should be fixed (Figure 19b).

32 For left-hand lay ropes, use the left hand instead of the right. A left-hand lay underlap rope should have its dead end at the left-hand flange, and an overlap rope at the right-hand flange.

ROPE TENSIONS IN FRICTION-WINDER ROPES

33 Multi-rope friction-winding installations in the UK operate with the winding ropes directly connected to the suspension gear of the conveyances and not through any form of automatic rope tension compensating gear.

34 In order to keep rope tensions approximately equal, it is necessary to keep the rope tread diameters on the drum as nearly as possible the same. The deeper

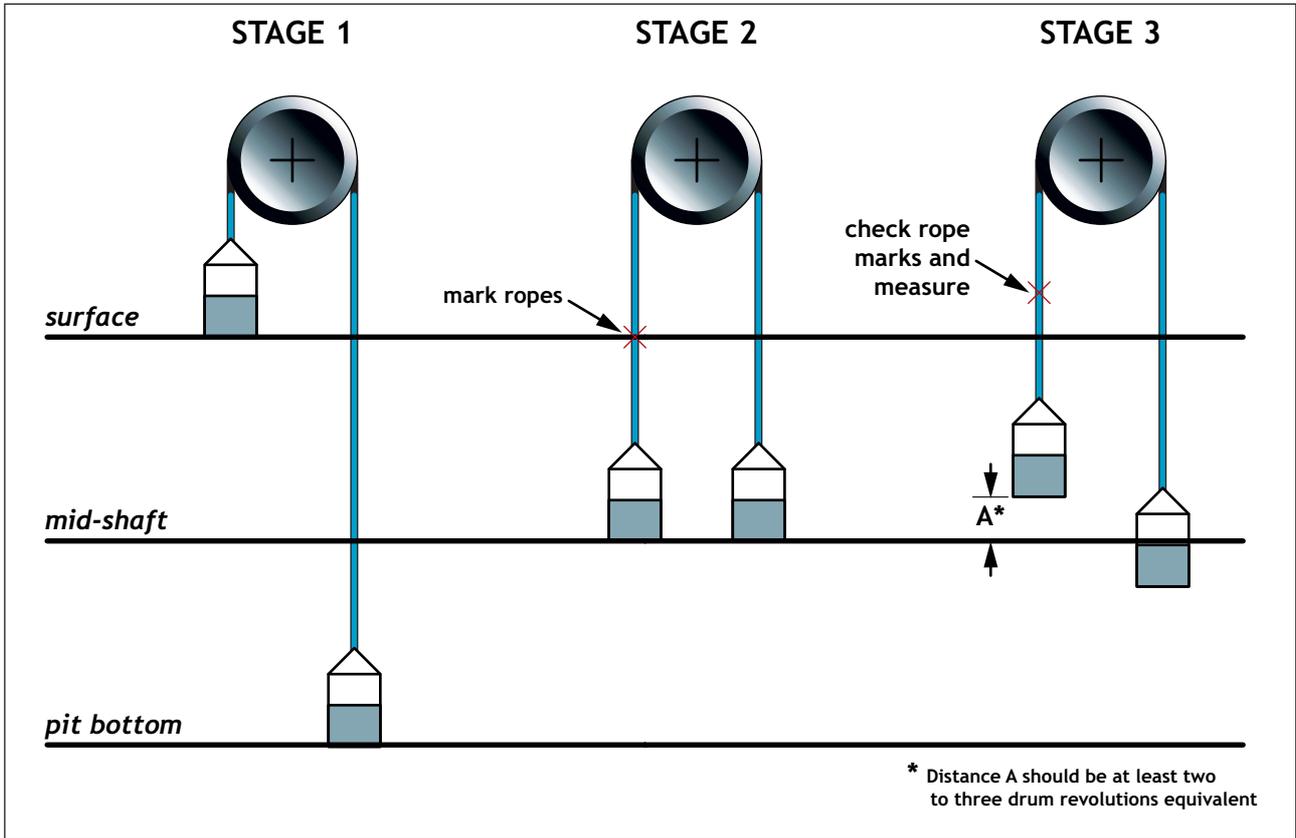


Figure 20: Rope tensions

the shaft, the more important this is. Large differences in rope tensions can cause distortion or broken wires in one or more of the winding ropes. Most tower-mounted friction winders have groove machining equipment installed, and the grooves can be kept in good order by regular checking and trimming as required.

35 In recent years conveyor belting inserts used in the rope treads of friction winder drive drums have provided an improved service life to that of timber inserts and reduce the need for regular trimming of the rope treads.

36 When installing new ropes, engineers should ensure that matched sets of ropes are used to reduce differential stretch to a minimum. Provided care is taken to establish the correct rope tread diameters, when the ropes are installed, the extent of differential tread wear should be small, and it is often possible to avoid re-trimming grooves during the life of a set of ropes. However, it is necessary to keep the grooves clear of deposit from the rope. The preferred method of checking the differences in rope tread diameters and rope tensions on multi-rope friction winders (Figure 20) is to measure the relative rope travel as follows:

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- (a) Wind the conveyance from the surface to approximately mid-shaft at a steady speed of about 3 to 4.5 m/s (10 to 15 ft/s), bringing the conveyance to rest very gradually without any sudden brake application.
 - (b) With the conveyance at mid-shaft, mark the ropes at some convenient place, say ground level in the case of tower winders. The marks can be made by pencil on a chalk background and should be in a horizontal line; this is usually achieved by using a straight edge and spirit level, but if site conditions permit it is advantageous to have permanent straight edge supports available.
 - (c) Having marked the ropes, the conveyance is then wound steadily up the shaft for 2 to 3 drum revolutions, until the rope marks are at some convenient level such as, in the case of tower winders, near the drum or deflecting sheaves. The winder is again brought to rest very gradually and without any sudden brake application. A straight edge should again be mounted accurately in a horizontal position, so that measurements can easily be taken of each mark relative to the straight edge to determine differential rope movement.

37 Any differential movement can be corrected by trimming, in small increments, the groove or grooves that give the largest rope travel; but if the grooves are dirty it is advisable to trim them clean first. Following each trimming the conveyance should be wound through the shaft to bed in the grooves, then a further check should be made of the measurements following the procedure outlined above. The point at which trimming becomes necessary is largely determined by experience, but Table 4 gives guidance on the limits for differential rope movement. Engineers should ensure that grooves are trimmed when or before reaching these limits.

Ropes where trouble has been experienced	Maximum allowable discrepancy between ropes
First 12 months	6 mm
Subsequent life	3 mm
Ropes where trouble has not been experienced	Maximum allowable discrepancy between ropes
First 12 months	10 mm
Subsequent life	6 mm

Note: A new rope will generally tolerate more inaccuracies than one that has been in service for some time.

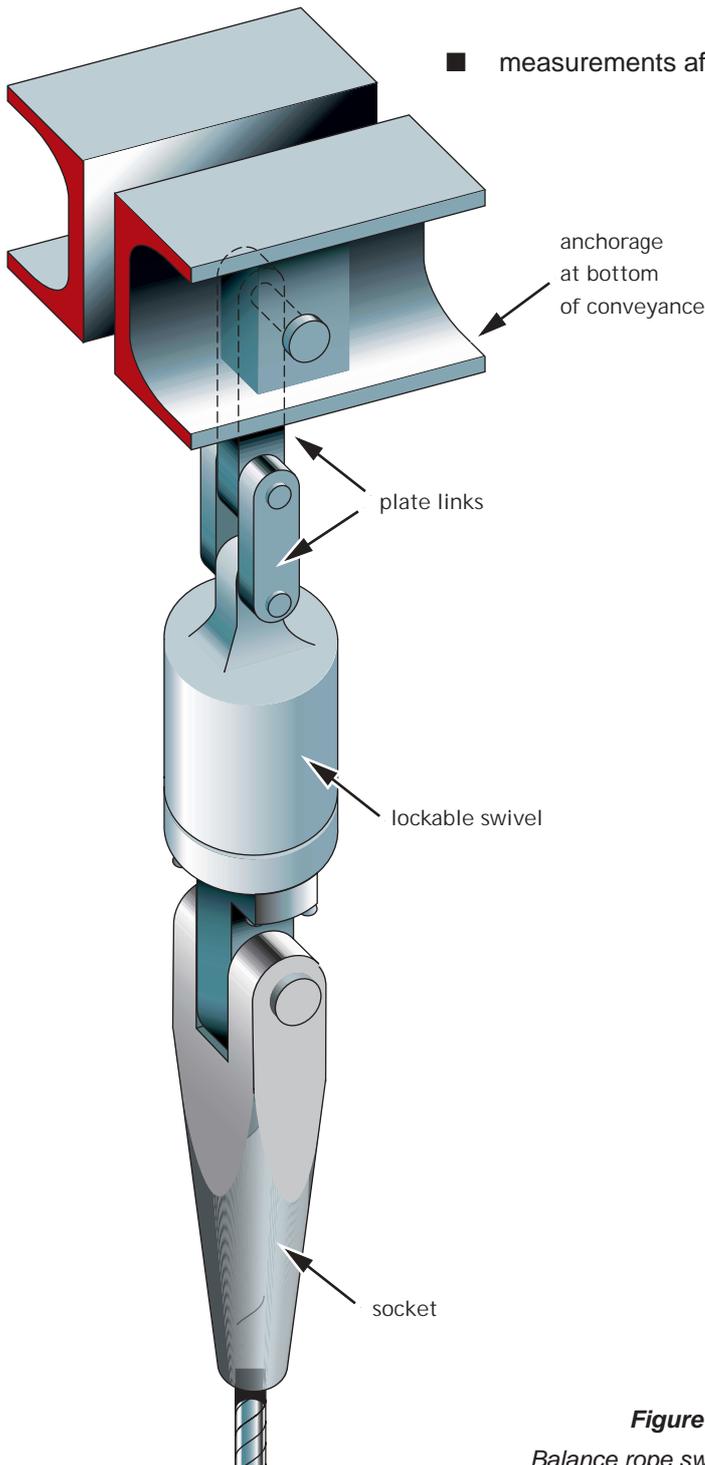
Table 4: Tread maintenance guidance - limits on differential rope movement

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38 Equalisation of the groove tread diameters by this method can reduce discrepancies in rope travel to within 1 mm of rope travel over a distance of 2 to 3 drum revolutions.

39 In order to assist in making a detailed assessment of this method of equalising rope tensions and tread diameters, a record should be kept of the following:

- the actual measurements and the date of checking;
- the date of trimming of each groove;
- measurements after trimming.



40 While other methods have been described in other guidance this method has been proved, over a considerable period on many friction winder installations, to be simple, practical and reliable.

INSTALLATION AND OPERATION OF BALANCE ROPES

41 In addition to the general requirements for shaft ropes given in paragraphs 5 and 6, the same care must be taken as that with winding ropes to ensure that the rope does not go slack as it is led off the reel and that both ends of the rope remain securely served until they have been properly capped and fitted to the conveyances.

42 Multi-strand balance ropes are attached to the underside of the shaft conveyance by means of a swivel (Figure 21) to reduce the possibility of the rope twisting and subsequently becoming knotted at the loop (Figure 71). In all cases, mines will need to use a positive means of preventing the loop from twisting around itself. Four systems have given satisfactory service:

(a) **The baulk system** (where there is sufficient space) - a timber baulk is threaded through the loop. The baulk is designed to break or lift if the rope loop lifts too far. The positioning of the baulk should allow for the loop to rise and fall during normal operations and also permit the

Figure 21:
Balance rope swivel

necessary maintenance operations to be carried out without the need to disconnect the balance rope.

- (b) **The open box system** (Figure 22) - the loop of a balance rope is surrounded by a wooden retaining box (a steel structure would damage the wires). If twin balance ropes are used, a partition is usually fitted to separate the two loops. The size and position of the box should be such that it does not interfere with the movement of the rope. Although the rope striking against timber will cause only light wear or polishing on the outside of the rope, it can accelerate internal wear by causing nicking between the strands as they are driven hard together at each impact.

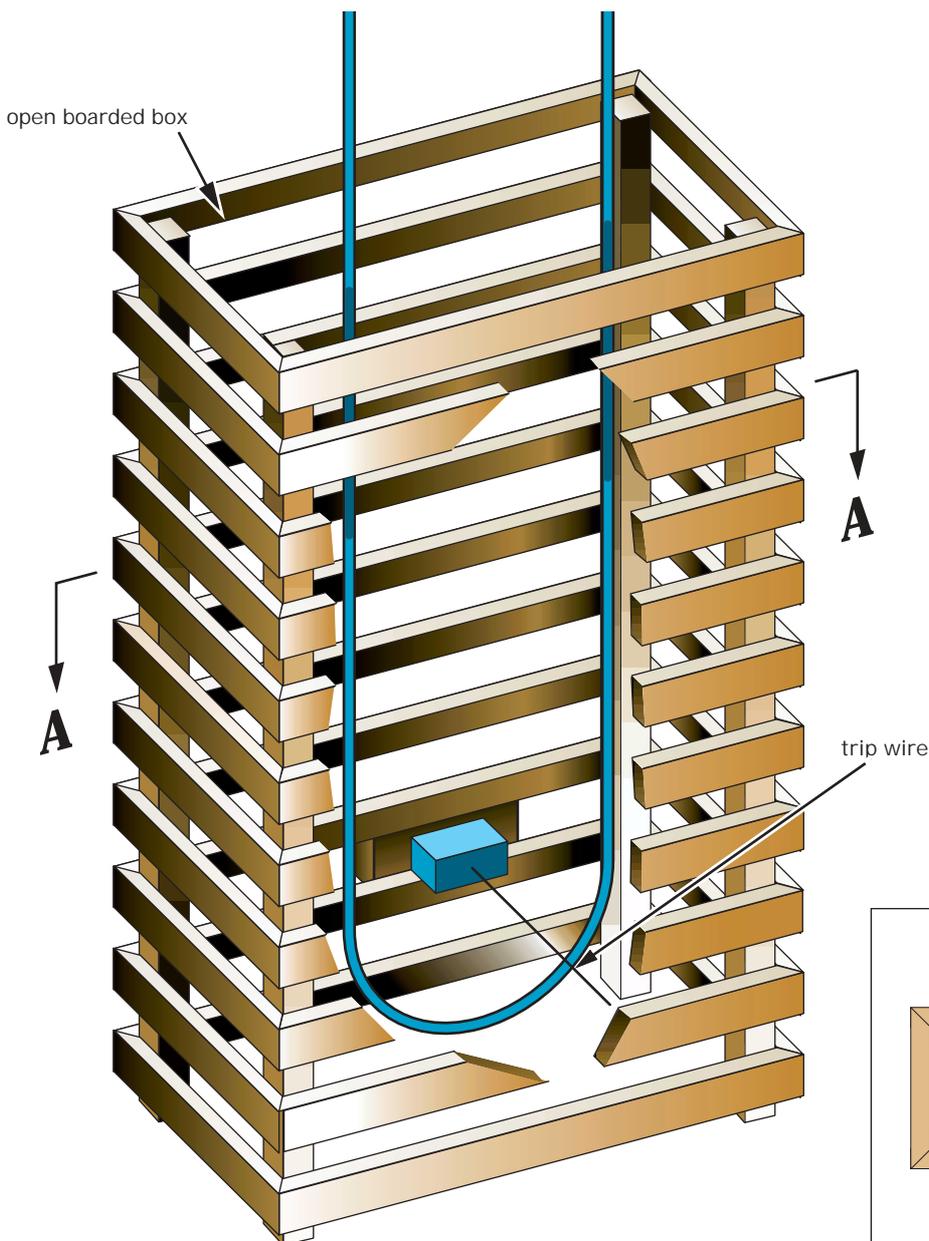
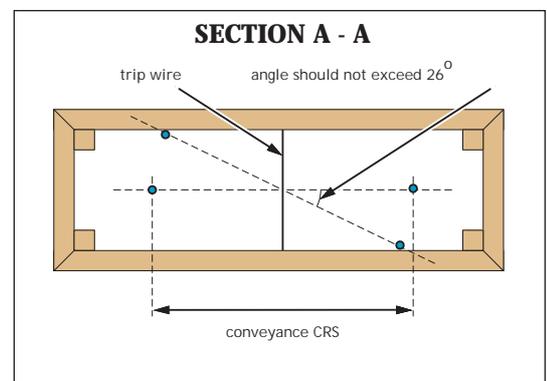


Figure 22: Open box system



- (c) **The restricting frame system** - an alternative to the open box, it consists of a number of suitably spaced substantial wooden frames braced together to control the rope(s) above the loop.

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(d) **The guide hole system** - controls each leg of the rope rather than the loop itself. In this case, a wood-lined slot is used to control the two sides of the rope and prevent twisting or, alternatively, holes are cut in the sump platforms to control the rope in all directions. The slots or holes should be lined with chamfered timbers to allow for both directions of rope travel. They should be large enough to prevent localised wear on the rope and to reduce the chance of fallen debris becoming wedged, and obstructing the passage of the rope.

43 The above systems should be constructed robustly and designed to ensure that the rope cannot strike or rub on anything other than timber.

44 Paragraph 99 of the ACOP to the 1993 Regulations³ requires the provision of rising loop protection. A type of monitor that has proved to be effective is a trip wire through the loop of the balance rope (Figure 22). The wire should be protected from damage and inadvertent operation from falling debris by a light structural beam. The electrical switch to which the wire is connected is of a type that operates in the event of an overtensioned or a broken trip wire.

45 The monitor is connected to the winding engine safety circuit and operates if the rope loop contacts the trip wire. The position of the monitor above the normal highest position of the balance rope loop may be between 1 and 1.5 m but is best finalised by observation, test and experience.

46 Further guidance on balance rope loop monitoring may be found in *Safe manriding in mines report*,⁹ Part 2A, pages 16 and 17 and Part 2B pages 59-61.

47 Balance ropes must not come into contact with debris, water or other obstructions. Where rates of spillage are high (eg skip shafts) mechanised means to remove the spillage and automatic monitoring of the spillage level should be provided.

INSTALLATION AND ATTACHMENT OF GUIDE AND RUBBING ROPES

48 When installing or removing guide or rubbing ropes, the following issues are particularly relevant to the assessment of risk and the method of carrying out the work as described in paragraphs 5 and 6.

(a) Constrain the rope to minimise the chance of sudden twisting. If the free end of a guide or rubbing rope is not properly controlled throughout removal or installation then it may suddenly twist and create a major hazard. The procedures should ensure that people are positioned to minimise the risk to them should the rope move unexpectedly.

(b) Avoid acute rope bending. Guide and balance ropes are constructed of large wear-resisting wires and a permanent bend in a rope is liable to suffer rapid and concentrated wear.

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- (c) The rope should be installed in a smooth, controlled manner to prevent shock loading.

49 Normally ropes are attached at the headframe by means of a resin or white metal capping or wedge-type suspension gland. These attachments are normally above the supporting structure where there is usually adequate space for lifting, rotating and recapping the ropes. The capping of guide and rubbing ropes should be in accordance with the instructions given in Technical Annex 3.

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TECHNICAL ANNEX 3 - THE SERVING AND CAPPING OF SHAFT ROPES

INTRODUCTION

- 1 There are a number of different ways to terminate the ends of shaft ropes. Terminations are safety critical and require strict adherence to correct procedures to quality assure the process and to ensure a satisfactory end product.
- 2 This Technical Annex provides significant guidance on those procedures, but mines will also need to refer to the appropriate manufacturer's instructions.
- 3 Serving and capping operations should only be carried out by trained and experienced people, or under their close supervision.
- 4 The white metal and resin socket techniques described in this Technical Annex are also relevant to the termination of underground haulage ropes. The HSC guidance on haulage ropes¹ directs readers to this document for guidance on those techniques.
- 5 The term 'capping' that appears within this Technical Annex has the meaning as defined in *Safe manriding in mines report Part 1A*,⁹ as follows - 'The attachment fitted at the end of a steel wire rope by means of which the rope is coupled to any conveyance or apparatus'.

HAZARDS FROM INADEQUATE CAPPING PROCEDURES

- 6 It is essential that all personnel associated with the capping operation are aware of the potential hazards from improper capping procedures.
- 7 The most obvious hazard that can arise is the release of a load due to failure of the capping which may lead to serious injury or death of anyone being conveyed through the shaft or those in the vicinity of the winding equipment.
- 8 Premature failure of the capping can be caused by the following:
 - (a) incorrect choice and specification of socket/gland;
 - (b) incorrect preparation of brush and socket/gland;
 - (c) incorrect positioning of the brush and alignment of socket/gland and rope;
 - (d) incorrect capping procedure.
- 9 Capping materials present hazards in themselves, and should be included in the overall assessment of risks, as required by the provisions of the Control

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of Substances Hazardous to Health Regulations 2002 (COSHH).¹⁰ Work should be organised to minimise workers' exposure to potentially harmful substances, including vapour and fume.

ROPE SERVING

Serving and clamping

10 Whenever any type of shaft rope is cut, it is essential to take effective precautions in order to prevent any loosening of the wires during the cutting and capping operations. To do this the rope must be securely served before cutting off the old capping, or excess length of new rope, and, where appropriate, clamped on both sides of the proposed cutting point **X** in (Figure 23a). Tinned annealed serving wire of the size shown in Table 5 should be used. On no account should copper wire be used as it is liable to cause corrosion.

Serving

11 A serving is a wrapping of wire laid tightly around a rope to prevent its wires from unlaying or moving and slackening when the rope is cut between two adjacent servings. A serving would be insufficient, particularly on a larger rope, if it consists only of a few turns of wire, string or insulating tape wrapped around the rope in the form of open or partly overlapping coils.

12 The correct size and type of serving has to be applied tightly to the rope, under proper tension, and in neatly laid parallel coils that are in hard contact with one another, otherwise they could move sideways and become slack.

13 Serving wire must be soft to readily take a permanent bend, so that it fits closely to the shape of the rope; otherwise the rope will move and accommodate itself to the shape of the serving. A good serving on a six-strand rope will appear somewhat six-sided.

Size of serving wire

14 Table 5 gives the recommended sizes of serving wire for ropes of 13 mm diameter and greater:

Rope diameter (mm)	Size of serving wire (mm)
13 to 22	1.3
22 to 38	1.6
Larger than 38	1.8

Table 5: Recommended sizes of serving wire

15 Full locked coil and half-locked coil ropes should only be served using single serving wire. A stranded wire serving must never be used to serve those types of rope as it may collapse and flatten in places, and consequently become slack allowing the rope to loosen.

Length of serving

16 The length of rope to be served is critical to ensure that the wires in the rope remain tightly laid. The length of the serving depends on the size and type of the rope. Details of the minimum length of serving required are given in paragraphs 29 to 31.

Serving tools

17 The tools essential for proper serving are:

- a vice or other means of holding the rope;
- serving machines or serving mallets (Figures 24 and 25). The head of the mallets should be shaped to enable them to sit on the rope and should be made of brass or other soft material, which will not score the rope. The handles of the type shown in Figure 25a should be long enough to take a reel of wire or strand;



Figure 24: Serving machine

- a reel, which can be mounted on the handles of the mallets on which sufficient wire can be wound to complete a serving is also shown in Figure 25a;
- pliers and wire-cutters, for twisting wire ends together and cutting them short;
- a small soft-headed hammer, for tapping the coils of a serving into contact with one another.

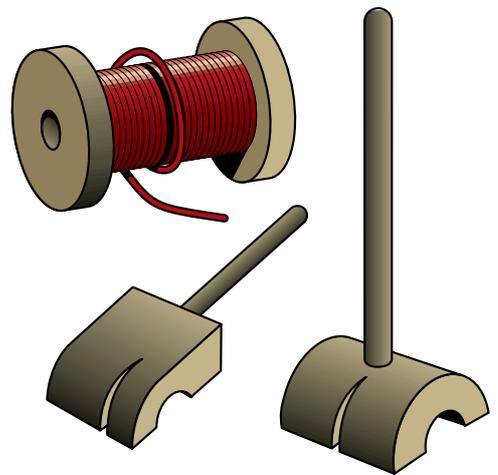


Figure 25a: Serving tools

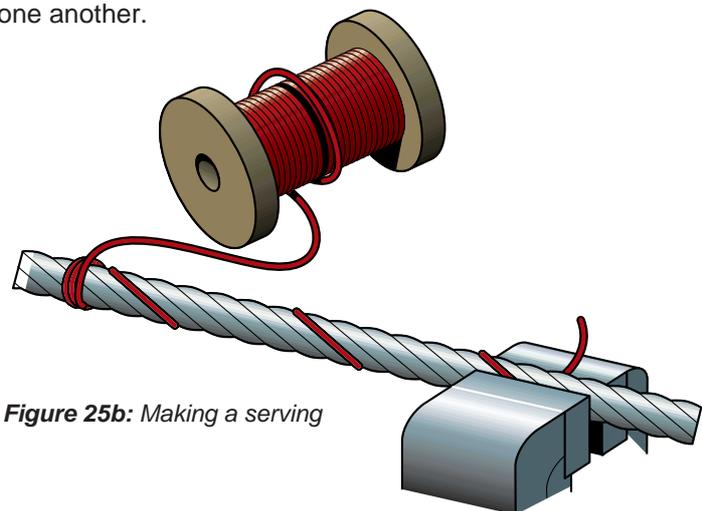


Figure 25b: Making a serving

The ordinary or buried wire serving

18 This is the type of serving used in conditions where soldering is not permitted for stranded ropes; for example, below ground in a mine where a potentially explosive atmosphere may be present.

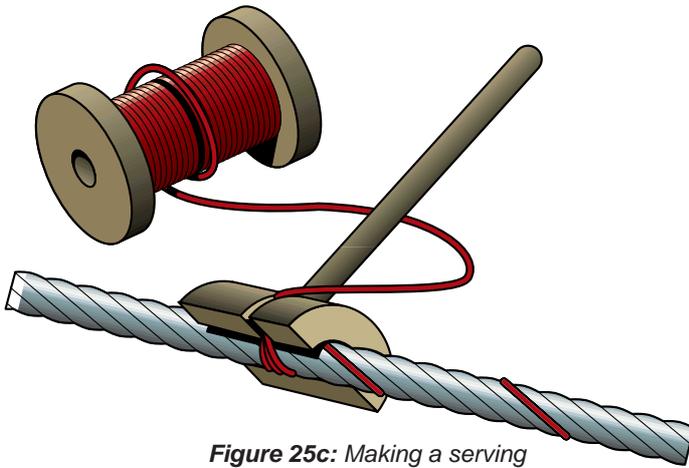


Figure 25c: Making a serving

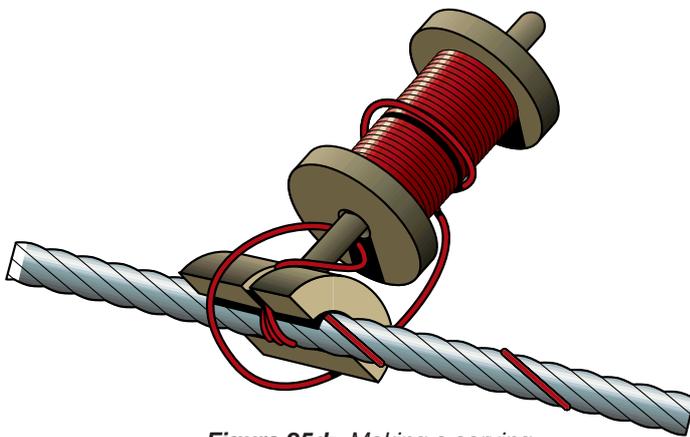


Figure 25d: Making a serving

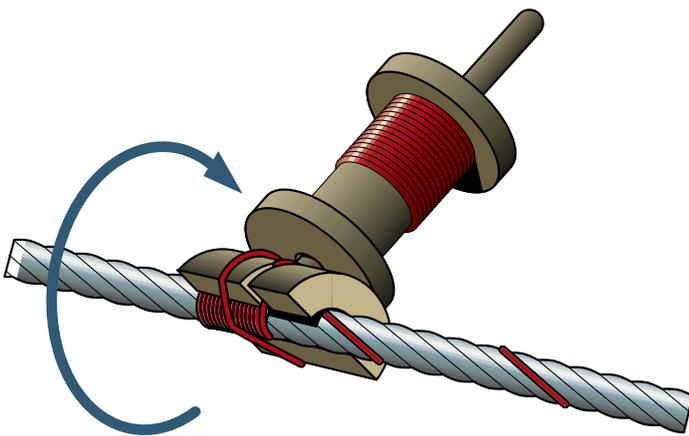


Figure 25e: Making a serving

19 The first part of the serving wire is laid along the length of rope to be served, and the remaining wire is then wound tightly over it in coils so that the two ends of the serving wire finish at the same place. They can be twisted together and cut off short to complete the serving.

20 To make such a serving, the free end of the serving wire is paid out for about 0.5 m and its end clamped in a vice together with the rope (Figure 25b). Next, the paid-out wire is laid from the vice along the rope to the far end of the rope length to be served. The wire should be laid in the 'valley' between two strands such that it spirals around the rope. This part of the wire is known as the 'buried wire'.

21 The paid-out wire should be bent to lay at right-angles to the rope and turned twice around it, so that it lays on top of the buried wire to form the beginning of the serving (Figure 25b). The serving mallet is then placed on the rope, on top of these two turns (Figure 25c), and the wire leading from these turns passed over the top edge of the mallet and round the back of the handle (Figure 25c). The wire is passed over the top edge of the mallet again, under the rope, up over the other edge of the mallet and the reel placed on the handle of the serving mallet (Figure 25d), and the reel turned to take up the slack wire. The mallet is then rotated round the rope in the same direction as the serving (Figure 25e). The drag or friction of the wire passing round the mallet handle will ensure that the serving is applied tightly to the rope, under proper tension.

22 It is essential to control the turning of the reel on the handle so as to pay out wire only at the rate at which it is needed; slack wire will mean slack serving. Each turn of serving wire should be tight to the rope and should be in hard contact with one another. A method of guiding the wire into close packed

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coils is to cut a guide-groove for the wire in the head of the mallet (Figure 25a). If the turns are not in hard contact it will be necessary to tap them more closely together with a soft-headed hammer.

23 When serving is complete, the wire from the final coil and that from the buried wire should be twisted together, pulled tight and twisted further to keep them tight. The ends should then be trimmed to leave about four twists, (Figure 25f). Finally, the twisted end should be tapped down with a hammer so that it lays neatly against the rope in a valley between two strands.

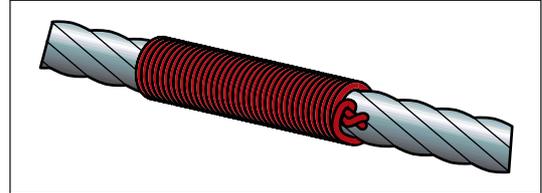


Figure 25f: Completed serving

The soldered or wiped serving

24 This is the preferred serving where soldering is permitted. With this method wire is served directly on to the rope, without any buried wire being present, so that the two ends of the serving wire lie at opposite ends of the serving. The type of serving machine used is shown in Figure 24.

25 To apply a wiped serving, the starting end of the wire is reeved from the bobbin of the serving machine and fastened to a nearby object or lashed to the rope with yarn or tape so that the fastened end is close to the left-hand. The serving machine is passed around the rope until the wire holds it in position where the cut is to be made.

26 For a right-hand lay rope the serving is then applied by raising the handle of the machine upwards and towards the body, passing it over the rope and down away from the body, moving to the right. For a left-hand lay rope the starting end of the wire is fastened such that it is close to the right-hand and the same method is applied but the machine moves to the left. Adopting the appropriate method to suit the lay of the rope will ensure that the serving applied is coiled in the opposite direction to the rope lay. This procedure ensures that if the rope tends to unlay then it will tighten the serving.

27 When the serving is about 150 mm long its surface should be thoroughly cleaned in preparation for soldering. Coraline flux or powdered rosin is then applied. Baker's fluid or killed spirit should never be used as a flux because they can penetrate between the turns of the serving and corrode the rope. The coils of wire are then soldered along one side of the rope using tinman's solder; the hot soldering iron being passed several times across the surface of the serving so that the solder flows into the gaps between the turns of serving wire.

28 The length of rope to be served depends on the object of the serving and on the size and type of the rope. A stranded rope exerts only a moderate bursting force on a serving. A large locked coil rope will exert a considerable pressure on the serving, and should the serving burst, the rope will unlay itself violently over a long length.

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29 For stranded ropes apply two or more short servings at least 6 x rope diameter (d) in length to secure the rope end.

30 In the case of locked coil ropes, more stringent precautions are necessary than with other rope types. With locked coil ropes, the length AD (Figure 23a) is a continuous length of serving at least 26 x rope diameter (d), plus the length of the socket basket and the length BC needed for cutting the rope at point X. The serving length AB (Figure 23a) on the part of the rope to be discarded should be at least 6d in length.

31 On the part to be retained, the serving CD (Figure 23a) should have an overall length of not less than 20d, plus the length of the socket basket. A further length of serving, at least 20d in length, should be applied lower down the rope about 3.6 m from the first serving. Then, as an extra safeguard, six clamps should be fitted between these two lengths of serving (D to E in Figure 23a). Each served length must be of the soldered type but need not necessarily be composed of one continuous length of wire.

CAPPING WITH RESIN OR MOLTEN WHITE METAL

32 This part of the guidance should be applied to the capping of steel wire ropes using sockets (or glands) specified in the Reference section at the back of this book whether they are capped at the mine or rope manufacturer's works.

33 The statutory requirements for capping ropes on winding and haulage apparatus are governed by the 1993 Regulations² and the Coal and Other Mines (Shafts, Outlets and Roads) Regulations 1960¹¹ respectively. In particular, regulation 17 of the 1993 Regulations and ACOP^{2,3} make provision for:

- the capping of ropes used in winding apparatus;
- the appointment of competent people; and
- the writing of reports by such people.

The remainder of this Annex provides further guidance on rope capping.

34 Resin and white metal are excellent capping mediums, are the most widely used, and work on the principle of gripping the wires individually in a single cone of resin or white metal within a conical socket. When properly made and in BS or NCB standard sockets, this type of capping is at least as strong as the rope. The progressive operations for capping as illustrated in Figure 23, are detailed below, and should be strictly observed to ensure that a reliable capping is obtained.

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CUTTING THE ROPE AND FORMING THE BRUSH

35 The six clamps referred to in paragraph 31, should be the half-clamp, two-bolt type with a machined bore, with a 3 mm gap between the half clamps when tightened on the rope. Set the clamps on the rope alternately at right angles to one another, the clamp nearest the old capping being used as a marker clamp, if required, with the bolts in the required direction of the pin in the new socket.

36 Before cutting the rope, set temporary clamps at **B** and **C** (Figure 23a) immediately on either side of the cutting point **X**.

Cutting **37** Cut the rope at **X** by any suitable method which does not disturb the wires. With percussive or shearing methods special care is required to avoid any disturbance to the serving or to the wires in the rope. Flame cutting equipment must not be used as the heat may damage the rope and the serving.

38 After cutting the rope, remove the temporary clamp at **C** and thread the new socket (to NCB Specification 465/1965¹² for a winding rope) over the end of the rope, pushing it along the serving as far as the marker clamp **D** (Figure 23b). Before threading the socket onto the rope, make sure that the inside of the socket basket is clean and dry and that there are no rough places on the radius in the socket mouth. Apply another clamp over the serving at **F** so that the length **XF** (Figure 23b) is equal to the length of the basket less about 2 x rope diameter (d). The value of about 2d is recommended so that sufficient length of served rope will be inserted into the mouth of the socket to ensure that the point at which the wires begin to separate to form the brush will be well embedded in the capping medium, rather than being in hard contact with the small end of the conical bore of the socket.

Preparing the brush **39** Remove the part of the long serving between **X** and **F** (Figure 23b). With large locked coil ropes care should be taken with this operation, as the rope wires will tend to open with some force, and a clamp at **F** is essential on all shaft ropes to ensure that the rope does not loosen beyond this point. Open the rope over the length **XF**.

40 Separate all the wires but do not straighten them, and take great care to avoid bending or twisting any wire too sharply at **F** (Figure 23c), otherwise deformed wires may break in fatigue during service. If there is a fibre core it must be cut at **F** and removed.

41 When opening the brush on locked coil ropes it is particularly important to ensure that there are no bends or twists in the outer full lock wires, because these may dramatically reduce both the fatigue life of those wires and therefore the life of the capping as a whole.

42 Investigations into brushing standards on locked coil ropes across the industry identified that there was only one correct method by which the outer layer wires could be opened out. This method depends on whether the cross-

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section of each outer full-lock wire appeared, when viewed from the end of the rope about to be brushed, as a distorted 'S' or as a distorted 'Z'. After pulling out the first outer layer wire from the rope, which is quite difficult, the rest of the outer layer must be opened out progressively in either a clockwise or anticlockwise direction according to whether the wires appear as 'S's or 'Z's respectively. It is important to remember that when the outer full-lock wire appears as a 'S' then the wires must be unlaidd in a clockwise direction; and when it appears as a 'Z' then it must be opened in an anticlockwise direction. This and the remainder of the resin capping procedures is explained and illustrated in more detail in the video *Capping locked coil winding ropes with resin*,¹³ which should be used in conjunction with this guidance.

43 There is no exception to this rule, the wires must all be opened out progressively in the same direction around the circumference. Any change in this order immediately introduces bends and spoils the symmetry of the brush. The reason for this rule is that, if followed, the wire being opened out at any moment is always totally free from its neighbours and can be lifted out from the rope from exactly the same point relative to the root of the brush or the first turn of the serving wire.

44 If the rule is broken by trying to progress round the circumference in the wrong direction then the toe of the full lock wire being opened out will be trapped under the heel of its neighbour preventing it from bending at the correct position. If the wrong direction of opening is continued then the point at which each wire bends gradually gets further and further from the root of the brush, or the first turn of the serving, whichever is taken as the reference point. This will result in the bend positions occurring in a helical pattern round the brush.



Figure 26: *Bends in helical pattern*

At intervals the person opening the brush will pull out a wire with a little more force and this will generate a step in the helical pattern as the next wire bends back at the original starting point (Figure 26).

45 The irregularity in opening out the outer layer wires, which is produced by opening out the wires in the wrong direction, is perhaps the major factor that causes a brush to form asymmetrically about the original axis of the rope from which the brush is being made. This feature then leads to misalignment of the rope inside the socket mouth with the axis of the socket. Opening the wires by progressing in the wrong direction round the circumference is also harder to do



Figure 27: *Narrow angle and smooth transition*

than opening them in the correct direction and the extra difficulty tends to result in the wires being bent at sharper angles, sometimes introducing twists into the wires, which can have dramatic effects on capping life.

46 The presence of sharp bends or twists in individual wires influences the fatigue life of a capping, so when making a brush such features must be avoided. The transition from rope to brush should be as smooth as possible. The smoothness of the transition is determined by the angle through which the outer layer wires are opened out; a small angle optimises fatigue life, while opening the wires to a wider angle facilitates easier degreasing of the wires in the second and inner layers.

47 For a maximum service life a narrow angle and smooth transition are required (Figure 27). The small amount of lubricant left on the inner wires very close to the root of the brush will not have a major effect on the strength of the capping. The shape of the brush at this point is the more important factor. However, the inner layer wires should be thoroughly degreased for the rest of the length of the brush.



Figure 28: *Control over shape of brush*



Figure 29: *Outer full-lock wires retaining original helical form*

48 While the opening out of the outer layer wires at the root of the brush is the factor that influences the life of a capping more than anything else, the overall shape of the brush and especially its symmetry about the rope axis can have a detrimental effect if not properly controlled (Figure 28). When the outer full-lock wires are opened out they should be left with as much of their original helical form as practical (Figure 29). Attempts to straighten these wires and to make them lie parallel with the axis of the rope increases the possibility that one or more of them will twist over as they are being straightened and it can introduce unnecessary bends, often quite sharp, close to the root of the brush (Figure 30). With the

wires retaining as much of their original helical shape as possible, the brush usually forms into either a ‘tulip’ or ‘daffodil’ shape depending on lay direction of the outer layer and the construction of the rope. The actual shape adopted is not a problem as long as the shape remains symmetrical about the axis of the rope.



Figure 30: *Unnecessary bends*



Figure 31:
Assymmetric shape

49 If the overall shape of the brush is asymmetric, which is usually caused by the irregular opening out of the full-lock wires at the root of the brush, then, as the brush is drawn back into the socket it will be forced over towards one side, possibly affecting the centring of the rope in the socket mouth (Figure 31). In most cases even if the centring is not affected, the length of rope which is inside the socket mouth will be forced out of alignment with the axis of the socket (Figure 32) and it will emerge from the socket at a slight angle to the axis of the socket.

50 Tests made on a small number of discarded cappings from coal mines have shown that such misalignment of the rope inside the socket mouth introduces additional stresses into the wires on one side of the rope and, if tested up to the breaking load of the rope, failure will usually occur inside the socket neck under the first turn of the serving at the root of the brush at a load which can be 5-10% below the actual breaking load of the rope.



Figure 32: *Forced out of alignment*

51 Under fatigue loading conditions the extra bending stresses generated by the misalignment will severely reduce the fatigue life of the capping, perhaps halving the potential fatigue life obtainable under the same test conditions with a well made capping.

52 In a locked coil rope the outer layer wires contribute about 30% of the total strength of the rope so it is important that individually these wires should be separated from each other and as fully enveloped by the resin or white metal as possible. Examinations of discarded cappings revealed that there have been some cones where the outer layer wires had been opened out in groups of two, three, and even four or five wires, which lay parallel and touching each other for almost the full length of the cone (Figure 33). Such poor separation could have a detrimental effect on the pull out strength of these wires from the cone. Although the capping medium will grip each group as a whole this grip will be less than the sum of the gripping forces which would have been applied if the wires had been separated.



Figure 33: *Grouping of outer layer wires*

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53 If a rope is held in the horizontal position while making the brush then the wires on the top of the rope tend to be opened out at a greater angle to those underneath it, because it is easier to prize a wire upwards than downwards with the rope in this position. When the end of the rope is placed in a frame at an angle of about 45° to the horizontal then the wires on both the top and underside of the rope tend to be opened out in a more symmetrical manner. This brushing position has now been adopted at many mines and is demonstrated in the video referred to in paragraph 42.¹³

54 Where necessary, rearrange the wires in the main part of a brush to make it as symmetrical as possible before it is finally drawn into the socket. This could give a useful increase in the fatigue life by alleviating or reducing misalignment of the rope inside the socket mouth.

55 To ensure that the white metal or resin securely grips the wires, thoroughly clean each wire of all traces of lubricant or dirt with a water-soluble degreasing fluid or a non-flammable organic solvent. Paraffin must not be used. During this operation keep the brush in a downward position (Figure 34) to make sure no degreasing fluid enters the unopened part of the rope as this may affect its internal lubricant. The brush should remain in a downward position until all the wires are completely dry.



Figure 34: *Cleaning the brush*



Figure 35: *Single serving wire*

56 By means of a single turn of serving wire placed around the brush near its top end (Figures 23d and 35) or, in the case of a large rope, two or three single or double-turn servings spaced along the length of the brush where required; draw the cleaned wires of the brush slightly together just enough to prevent appreciable lengths of the outermost wires from touching the inner surface of the socket when the socket is pulled onto the brush. This will ensure that the wires are effectively embedded in the resin or white metal.

57 The temporary clamp at F (Figure 23d) can now be removed. Before the socket is pulled into position it should be rotated on the rope until orientated similarly to the marker clamp at D (Figure 23d). It can then be drawn carefully over the prepared brush by any means which provide a direct axial pull. Figure 36 shows a suitable method. The socket is then pulled onto the brush so that the ends of the wires are approximately 5 mm above the top of the socket basket at S (Figure 23e); this leaves a length of about 2d of the

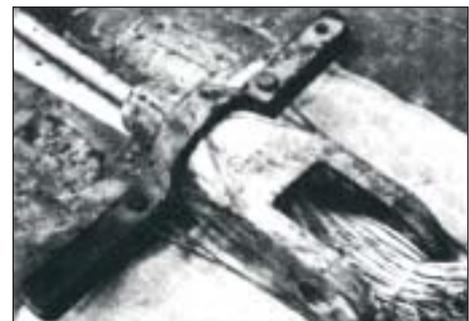


Figure 36: *Socket pulled into place*

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serving contained within the mouth of the socket. The 5 mm protrusion of the wires above the top of the socket basket will allow easier detection of any movement of the wires relative to the resin or white metal during the pouring operation and use of the rope. However, care is needed to ensure that the wire ends do not foul the mating unit which will be subsequently connected to the pin of the socket.

FORMING A RESIN CAPPING

58 The following guidance has been prepared in conjunction with the video previously mentioned in paragraph 42.¹³ The video shows in great detail the forgoing procedure for preparing the brush and the procedure for making a resin capping that follows. It is strongly recommended that the video is made available to people involved in rope capping operations for both training and reference purposes.

59 The only resins used should be polyester-based proprietary resin systems that include an inorganic filler and a curing agent. Resin systems need to have a minimum ultimate compressive strength of 90 N/mm² and a minimum ultimate shear strength of 15 N/mm².

HEALTH AND SAFETY REQUIREMENTS DURING RESIN CAPPING

60 Risk assessments under the COSHH Regulations¹⁰ and the Management of Health and Safety Regulations¹⁴ will define the appropriate working procedures for safe use of resin systems for rope capping. The advice given in this section serves only as a general guide.

61 Information on the hazards of any resin capping system can be found in the supplier's health and safety datasheet.

62 A resin capping kit contains a polyester-based resin which is classified as a flammable substance. The resin component contains styrene, the vapours of which can be irritating to the eyes and respiratory system, and if inhaled in high concentrations may cause symptoms associated with solvent intoxication, including drowsiness. The maximum exposure level (MEL) for styrene is specified in EH40 produced in accordance with the provisions of the COSHH Regulations.¹⁰

63 It is essential to use resin capping kits only in well-ventilated areas, using working procedures that minimise personal exposure to vapours. Most of the vapours are given off from the mixing vessel rather than from the resin inside the socket. To reduce the vapour level when working in a closed or relatively confined space, the mixing vessel should be removed from the work area after pouring. Where work is carried out on a frequent or regular basis, air monitoring may be necessary to ensure that styrene levels are as low as possible.

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64 Uncured resin is an irritant and contact with eyes and skin should be avoided, for instance by careful mixing and pouring of the resin. Those mixing and working with the resin should wear appropriate gloves, goggles and other protective equipment to minimise the possibility of direct contact. Those handling the powder component should do so in a manner that minimises the chance of dust being raised into the air. They should wear dust masks for additional protection.

65 Polyester resin is a flammable substance and should be used away from sources of ignition. Particular attention needs to be paid to the storage of resin capping kits.

Material **66** Resin kits contain the exact proportions of ingredients required to achieve full strength, and for this reason packages should never be sub-divided. The ingredients should be mixed and used in accordance with the manufacturer's instructions. The kit should only be opened immediately before mixing.

67 The only resin system currently in use in UK mines is the Wirelock system. Wirelock resin kits are marked 'wire rope capping' and are available in four sizes to produce after setting the following volumes:

- 500 cc - green container
- 1000 cc - yellow container
- 1700 cc - blue container
- 3400 cc - red container

68 The kits are pre-measured and consist of two containers; one with liquid resin and one with filler/catalyst powder. The two containers are packed in an outer plastic container, which is used for mixing, together with a stirrer, silicone release agent and plasticine.

69 The kits have a shelf life of 18 months. Expiry dates are marked clearly on the containers. Date expired kits should not be used.

70 The expiry date applies only when the kit has been stored in suitable conditions. To ensure that the kits are not adversely affected by storage, they should be stored in a dry place at a temperature between 10°C and 25°C and away from any source of direct heat.

PREPARATION, CLEANING AND POSITIONING OF THE ROPE AND SOCKET - ADDITIONAL GUIDANCE FOR RESIN CAPPING

71 The preparation, cleaning and positioning of the rope, socket and brush should be carried out in accordance with the procedures described previously. Additional guidance is given overleaf.

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72 The served length of rope inside the socket or gland should be as shown in Table 6 below, where d is the rope diameter:

Socket/gland type	Served length
British Coal Specification 465:1965- Winding, balance and haulage rope sockets	2 x d
British Coal Specification 461:1965- Haulage rope sockets	1 x d
British Coal Specification 353:1966- Haulage rope sockets	2 x d
Balance rope sockets to BCC MECH/CIRC(81)82	1 x d
Guide/rubbing rope suspension glands having a ratio of tapered length to rope diameter of 6:1 and above	1 x d
Safety block on wedge type capping	0.5 x d

Table 6: Served rope lengths for socket/gland types

73 Use a tinned or galvanised annealed mild steel or soft iron single serving wire (not a strand) of the size shown in Table 5. Exceptionally, when using sockets to BCC Specification 353 and 461 for haulage ropes a serving wire of 1 mm diameter should be used due to the restricted clearance in the socket neck.

74 Before the socket is threaded on to the rope, the inside of the socket should be very lightly smeared with some of the silicone release agent supplied with the kit. This will reduce the tendency of the resin to bond to the socket basket. When the socket is pulled over the brush it is important to minimise any rotation which could cause the wires to scrape off the silicone release agent from the socket basket. This could produce a build-up of silicone release agent on the wires which would reduce the grip of the resin on these wires. It should be noted that it is not necessary to use the whole tube of silicone release agent supplied with the kit.

75 The wires of the brush should be distributed as evenly as practicable within the socket basket. Special precautions are necessary when capping half-lock guide ropes with resin. Stress cracking of the resin cone can occur at the curing stage if the outer wires are allowed to press heavily against the bore of the socket/gland at the wide end of the basket. To prevent this a space of approximately one wire diameter should be maintained so far as practicable between the wall of the socket and any wire at the end of the socket.

76 Resin leakage may cause voids in the cone and lead to unsupported wires (Figures 37(a) and 37(b)). It is therefore imperative that no leaks



Figure 37a: General view



Figure 37b: Close up

occur. Where a centralising device is used, of the type used for white metal sockets (Figure 38), then all joint faces of the device, together with any other points necessary to contain the resin, should be sealed with plasticine prior to pouring, taking care not to force the plasticine into the neck of the socket.

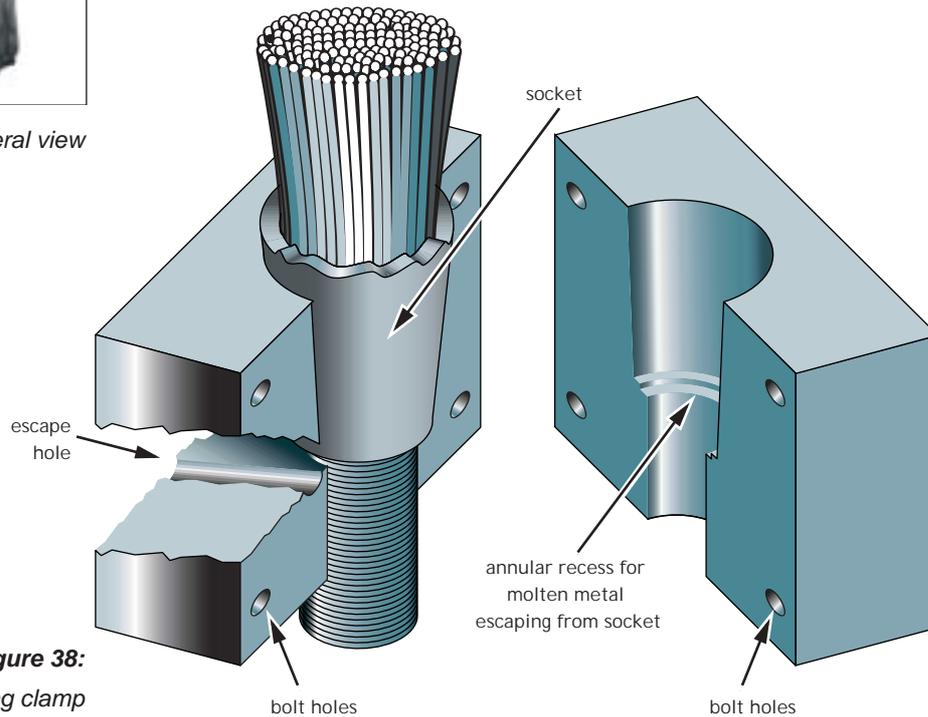


Figure 38:
Rope centring clamp

77 The preferred sealing method for resin sockets is the use of a vertical kingpost and then a rubber 'O' ring and plasticine to seal the base of the socket (figure 39). With stranded ropes, the resin may run down the gaps between the strands under the serving, and therefore these gaps should be sealed after the strands have been separated but before they have been opened to form the brush, by pushing small plugs of plasticine into the served portion, or by laying plasticine on the rope prior to serving.

78 The rope end should be carefully positioned so that it is exactly vertical for a distance of at least 36 times the rope diameter directly below the socket. The best way to achieve this is to clamp the rope to a vertical kingpost (Figure 39). Before pouring, the socket should be checked with a spirit level to make sure that it is level. If a rope and its socket are not exactly aligned, bending stresses will be produced in the rope at the mouth of the socket; these could induce premature fatigue failure of the wires in this region.

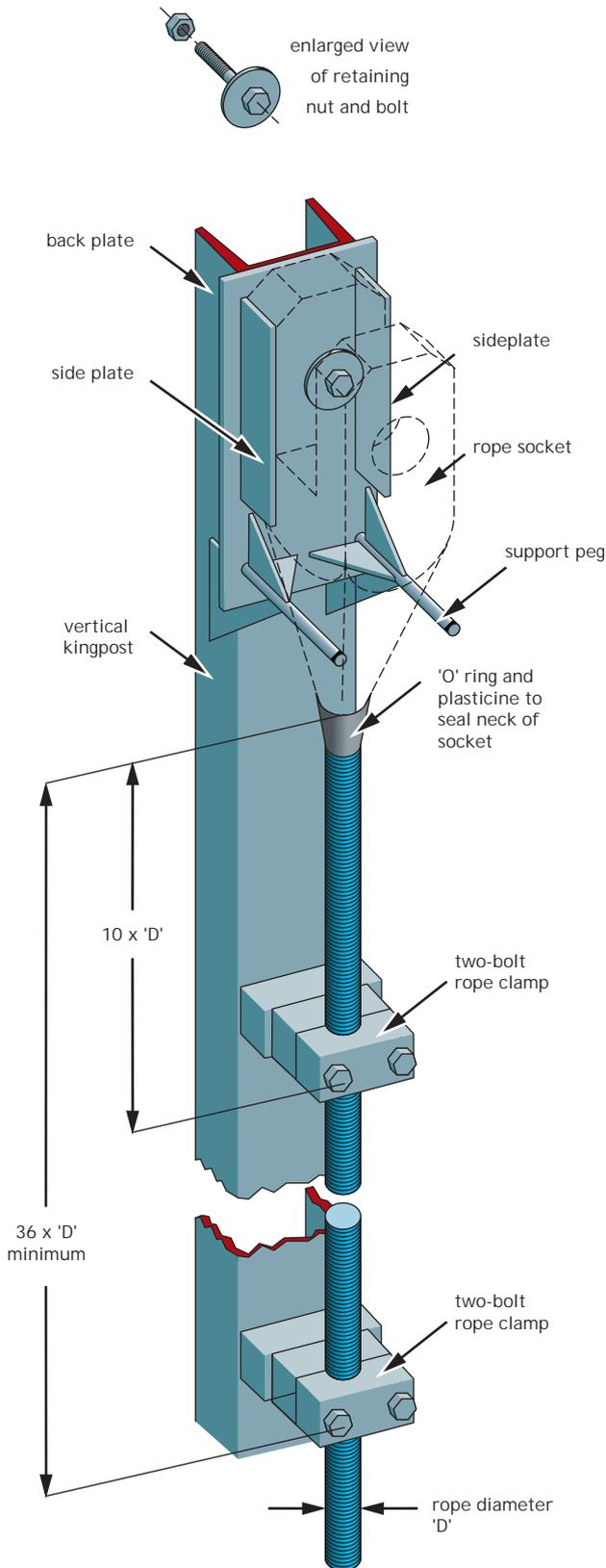


Figure 39:
Vertical kingpost

resin through the brush to the socket mouth. The booster packs should be stored in a dry place at a temperature between 10°C and 25°C and away from any source of direct heat.

(b) **Preheating the socket** - if the socket temperature is below 8°C it should be gradually warmed to a uniform temperature of between 10°C and

TEMPERATURES

79 Resin kits are formulated for mixing and pouring at temperatures of around 18°C to give a gelling time of approximately 15 to 20 minutes and cure one hour after gelling. At ambient temperatures higher than 18°C the mix will gel more quickly and at ambient temperatures lower than 18°C it will gel more slowly. Gelling is the term given to the change in condition of resin from liquid to a semi-solid, jelly-like composition. This is followed by a curing stage in which there is a considerable rise in the temperature of the mix due to the exothermic chemical reaction. Curing is complete when the resin has completed its exotherm, cooled and reached its full strength.

80 Because the socket is a large heat sink, it is the socket temperature rather than ambient air temperature which determines the gelling time. Therefore the socket temperature should be checked immediately before mixing, using a suitable thermocouple type thermometer.

81 At socket temperatures below approximately 8°C there is an appreciable increase in the gelling time. Two alternative methods are therefore recommended to maintain convenient gelling times at these lower temperatures:

(a) **Booster packs** - these accelerate the chemical reactions involved in the gelling process and may be added to the kit at the mixing stage. At socket temperatures between +8°C and +5°C one booster pack should be added to the kit. Below +5°C but above -3°C (minus 3°C) two booster packs should be added to the kit.

Booster packs are sized and colour coded to match the resin kits. Only booster packs of the appropriate size should be used. Booster packs should not be used with preheated sockets as the combined effect would cause a rapid gel time which could prevent penetration of the

15°C, measured at the socket bore before the resin is poured in. This is the only method that should be used if the socket temperature is below -3°C (minus 3°C). It is usually possible to achieve temperatures in the 10°C to 15°C range by storing the socket in a suitably warm environment for several hours before capping. The temperature should be maintained during the brushing operation, but no part of the socket should be heated above the upper (15°C) temperature limit, as this can accelerate the gelling too much.

82 After removal from storage and prior to mixing, it is essential that the resin kit is maintained within the storage temperature range of 10°C to 25°C. For example, the kit should not be placed in direct sunlight, near hot radiators, or left outside in cold weather.

MIXING

83 Those mixing the resin should inspect the powder before use; it should be off-white and free flowing. If the powder is discoloured (especially brown) or lumpy, it should not be used and returned to the manufacturer for investigation. The liquid resin should be free flowing and pour easily from the can. An identical spare kit should be available in case either the powder or liquid resin quality is suspect.

84 Mix all of the liquid resin with all of the powder, gradually adding the powder and stirring briskly until a uniform bluish-green colour is obtained. The colour is an important indicator that the mixed kit conforms with the manufacturer's specification and can be used. If the mixed kit remains a pale straw colour, the kit should not be used and returned to the manufacturer for investigation.

85 Sufficient resin mix should be prepared to enable the socket to be completely filled at one pouring. It is possible to combine various kit sizes to achieve the required volume, eg 2700 cc = 1 x 1000 cc plus 1 x 1700 cc etc. In such cases, all the liquid resin should be poured into the mixing vessel first, followed by all the powder, so that the total mix can be prepared in one operation. The 500 cc kit should only be used individually, as it is specially formulated for smaller ropes and sockets.

86 It is essential that the mixing takes place as quickly as possible and that no unmixed solids remain in the mixing vessel. Complete mixing normally takes about two minutes. A suitable stirrer is included in each kit, but mechanical mixing may be used for larger volumes, say 3400 cc and above. For mechanical mixing, experience has shown that a simple triangular mixer made from 10 mm diameter rod is suitable (Figure 40).

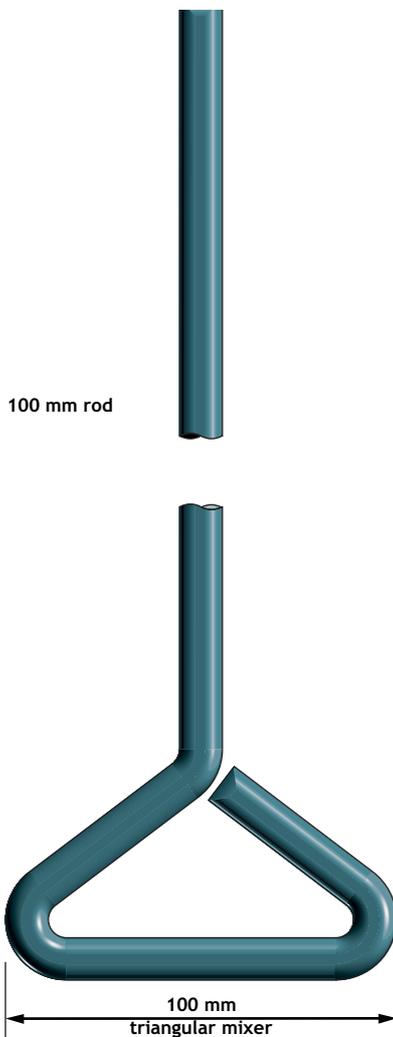


Figure 40: Triangular mixer

87 Where a booster pack is used, it should be added to the powder before mixing with the liquid resin.

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POURING

88 Once the resin is mixed it should be poured immediately into the socket. This will ensure good penetration through the brush and down to the socket neck. It will also ensure that the gelling stage occurs in the socket and not in the mixing vessel.

89 No more than two cappings should be poured from one mix.

90 The mixture should be poured at a fairly slow and steady rate in one position, to avoid air entrapment, and continue until the socket is full. Immediately after pouring the mixture in, the socket should be puddled for a few seconds with a length of clean stiff wire to help free any entrapped air, and confirm that the resin in the socket has not started to gel.

91 If the resin settles, the socket should be topped-up using the original mix. Before topping-up, the mix should be re-stirred for a short period.

92 Any leakage of resin can be critical and must be stopped immediately, otherwise it may result in cavities being formed near the root of the brush. Gelling of the resin tends to start at the wider end of the socket, owing to the greater amount of resin present and therefore slightly higher temperatures during the exothermic reaction. If leakage is occurring at this time near the root of the brush, it may not be accompanied by a drop in the level of resin at the wider end of the socket and may be difficult to correct because of the gelling resin above it. Leaks may occur not only from the neck of the socket but also from the served section of rope below the capping. Always keep available some plasticine to seal any leaks detected during pouring and in the early stages of gelling.

93 If there is not sufficient resin to fill the socket using the original mix then the capping must be discarded and completely remade.

Curing

94 Movement of the rope or socket during gelling and curing can seriously reduce the efficiency of the capping. The resin should therefore be allowed to gel and cure before disturbing the rope and socket.

95 To determine whether or not curing is complete, a sharp implement, such as a screwdriver blade, is drawn over the surface of the resin at the large end of the cone. This should leave only a shallow light coloured scratch mark on the surface. It is quite normal, particularly on small sockets, to have a very thin tacky layer on the surface of the resin after curing. The scratch test can be carried out through this layer.

96 The final colour after curing is a function of the peak exotherm temperature reached during the cure; the hotter the cure the more sandy-brown it becomes, and the cooler the cure the more bluish-green it remains. The resin will tend to go sandy-brown in larger sockets and in the mixing vessel. In smaller sockets when the mass of the socket compared with that of the resin is relatively large, the resin

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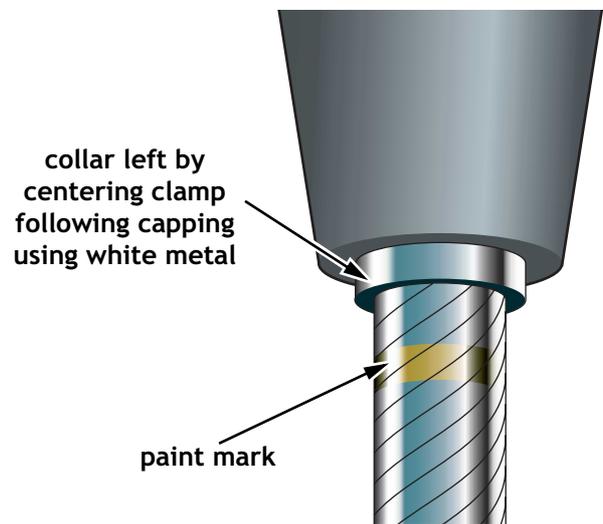
does not reach high temperatures during exotherm, due to the heat sink effect of the metal. The resin cone may therefore tend to remain a bluish-green colour.

97 Following a satisfactory scratch test, allow a minimum of one hour before the service load is applied to the rope.

Inspection **98** After removing the seals and any collar of excess resin or plasticine around the mouth of the socket, an experienced person should inspect the capping and the serving adjacent to the socket, to ensure that it has been satisfactorily carried out.

99 Checks should be carried out to confirm that:

- (a) the socket and the rope axis are aligned;
- (b) the annulus between the rope and the small end of the socket is even and filled with resin;
- (c) the socket is filled with resin;
- (d) the ends of the brush wires protrude by a few millimetres beyond the end of the resin cone.



Marking **100** A well-defined paint mark should be made around the rope, about 12 mm wide and about 50 mm from the socket (Figure 41). This will indicate any broken wire which might occur at the socket neck, as it makes it easy to detect any movement of an individual wire.

Figure 41: Marking

Re-lubrication **101** The rope adjacent to the narrow end of the socket should be re-lubricated, taking care to seal the neck of the socket. Any remaining servings and clamps should also be removed and the rope lubricated in those areas.

Handling **102** If the socket moves inadvertently back along the rope during handling, it should be moved clear of the resin cone. The cone can then be examined to check that it is undamaged. If the cone is damaged or any wire misplaced, the rope should be recapped.

103 When capping haulage ropes, to prevent the socket moving back along the rope, a clamp should be fitted on the rope immediately adjacent to the socket. The clamp should be removed at intervals to inspect the rope for corrosion and fatigue damage.

Disposal of resin residue **104** Mixed materials should be allowed to cure and then be disposed of as normal rubbish together with the used cans. The empty resin cans should not be resealed.

Other safety precautions **105** Cured resin is not affected by oils or greases and is unlikely to be affected by any chemical action likely to be encountered during service in a mine environment. However, special care should be taken to ensure that substances containing strong caustic or acid solutions, such as paint remover, do not come into contact with the cured resin as these will act as a solvent and may reduce the integrity of the capping.

Reporting **106** Immediately following completion of the capping, information should be provided on the sample form shown at Appendix 1.

Application of service loading **107** When the service load is applied to the rope the resin cone will pull into the socket (bed-in) by a few millimetres.

Resin kit sizes **108** A schedule of the rope sizes covered by resin kits for various socket types is shown in Tables 7 to 11 below:

Rope diameter	One rope	16-24 mm	25-32 mm	33-40 mm	41-48 mm	49-53 mm	54-64 mm
	Two ropes	-	-	25-30 mm	31-35 mm	36-40 mm	41-48 mm
Resin kit volume		500 cc	1000 cc	1700 cc	2700 cc (ie 1000 cc + 1700 cc)	3400 cc	5100 cc (ie 1700 cc + 3400 cc)

Table 7: Resin kits for NCB Specification 465:1965¹² Sockets for winding, balance and haulage purposes

Rope diameter	One rope	21-44 mm	45-54 mm	55-67 mm	68-75 mm
	Two ropes	21-32 mm	33-38 mm	39-48 mm	49-54 mm
Resin kit volume		1000 cc	1700 cc	2700 cc (ie 1000 cc + 1700 cc)	3400 cc

Table 8: Resin kits for balance rope sockets to MECH/CIRC(81)82¹⁵

Rope diameter	One rope	29-32 mm	33-38 mm	39-48 mm	49-51 mm
	Two ropes	-	-	29-35 mm	36-38 mm
Resin kit volume		1000 cc	1700 cc	2700 cc (ie 1000 cc + 1700 cc)	3400 cc

Table 9: Resin kits for guide rope suspension glands

Rope diameter	<i>One rope</i>	8-24 mm	25-41 mm	-
	<i>Two ropes</i>	-	25-32 mm	33-41 mm
Resin kit volume		500 cc	1000 cc	1700 cc

Table 10: Resin kits for BCC Specification 461:1965 Haulage rope sockets

Rope diameter	<i>One rope</i>	13-24 mm	25-35 mm	-	-
	<i>Two ropes</i>	-	-	23-32 mm	33-35 mm
Resin kit volume		500 cc	1000 cc	1700 cc	2700 cc (ie 1000 cc + 1700 cc)

Table 11: Resin kits for BCC Specification 353:1966 Haulage rope sockets¹⁶

Notes:

- (a) *The above tables are based on the cone volume of the socket plus 150 cc (neglecting the volume of the rope).*
- (b) *The 500 cc kit is intended for winding and haulage ropes up to 24 mm diameter. It should not be added to any of the larger kits to increase the total volume. When a number of very small ropes need capping no more than two should be poured from one kit.*
- (c) *Currently there is no national specification for guide or rubbing rope suspension glands. The volumes shown in Table 9 above are based upon those of typical commercially available glands.*

CAPPING WITH WHITE METAL

109 After cutting the rope to length and preparing the brush in accordance with the procedures described previously, a special rope-centring clamp is fitted to align the socket accurately with the rope (Figure 38). When fitted, it should leave an annular space at the base of the socket in which to pour the white metal. The clamp should incorporate a drain hole, which acts as a tell-tale during pouring to indicate that the required penetration of white metal has occurred.

110 As with resin capping, the rope should be exactly vertical for a distance of at least 36 times the rope diameter directly below the socket, and the socket should be level. It is beneficial for the rope to be clamped to a kingpost (Figure 39) (as shown in the resin capping video¹³).

111 To prevent the metal chilling during pouring, the socket is preheated to the correct temperature (see Table 12) by fitting a suitable furnace around it, or by means of blowtorches or other suitable heating nozzles. Oxyacetylene flame cutters must not be used for heating the socket.

Socket material	Preheating temperature
Mild steel	100°C
1.5% manganese steel and other approved steels to BS 2772-2:1989 ¹⁷	100°C-205°C

Table 12: Preheating temperatures for sockets

112 Heating steel sockets to the upper end of the temperature range will lead to better penetration of the white metal into the socket. When using heating nozzles, operators should take care to apply the heat evenly to all parts of the socket. Under no circumstances must flame be allowed to play on any part of the rope. The socket temperature can be readily checked by applying suitable thermocrayons or a contact type pyrometer to various parts of the socket.

113 While the preheating operation is being carried out on the socket, the white metal (to BS 643:1970 - White metal ingots for capping steel wire ropes¹⁸) should be prepared and heated to the correct pouring temperature of 350°C±14°C. A predetermined weight of white metal in excess of that required to fill the socket should be broken up, placed in a clean pot and heated in a furnace until molten; flame should not be allowed to play on the metal itself. New ingots must be used for winding rope capping.

114 When using ropes with synthetic fibre cores, operators will need to take extreme care when capping with white metal, as polypropylene, for example, melts at about 130°C. Therefore, the part of the core close to the capping might be adversely affected by heat during the capping process.

115 The wires within the socket should be treated with a non-acid flux or finely powdered rosin, which must be dusted among all the wires within the heated socket immediately before pouring the white metal.

116 When the molten metal reaches a temperature slightly in excess of the pouring temperature, it is stirred thoroughly right to the bottom of the pot, and any dross skimmed from the surface. Ensure that the stirring and skimming implements are clean and dry. The pot should have a vertical baffle close to the pouring lip and extending to within 25 mm of the bottom. This allows only clean metal to be poured.

117 Once the metal has been stirred and skimmed, and is at the correct pouring temperature, it is poured into the socket in a continuous stream until it reaches the top of the basket. The pouring should be done slightly off-centre to allow for venting and for any gas to escape. At the start of the operation white metal should run from the tell-tale hole in the centring clamp. The metal should be allowed to run for two or three seconds before the hole is plugged using a suitable stopper.

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118 If a depression or 'pipe' occurs in the centre of the white metal during the early stages of cooling it should be topped up with a small amount of white metal. When the basket is full, the socket should be left to cool naturally and undisturbed for at least one hour.

119 A report covering the above details should be prepared for each completed white metal capping in a similar format to that for resin cappings as shown at Appendix 1.

Dismantling the clamps and servings

120 After the completed socket has cooled, the rope-centring clamp and two-bolt clamps are removed and the socket neck is examined to make sure that the white metal has penetrated around the whole of the rope circumference and that the socket is full. If the remaining metal in the pot after pouring, together with any spillage, is weighed, the weight of the metal in the capping can be determined.

121 The socket should be allowed to cool to air temperature before use. If there is insufficient time for natural cooling, a stream of cold air may be directed onto the socket, but this should only be done after the white metal has completely solidified. In no circumstances should the socket be immersed in water for cooling.

122 All the servings should now be removed, the long serving up to the point where it enters the mouth of the socket. This is to facilitate subsequent examinations of the rope near the socket mouth.

123 As for resin cappings, a well-defined paint mark should be made around the rope about 12 mm wide positioned approximately 50 mm from the socket (Figure 41), to provide for easy identification of any broken wire at the socket neck.

124 When the capping has reached air temperature the length of rope next to the socket must be re-lubricated. The capping is then ready for use.

Possible faults in procedure

125 The white metal used must be of the correct composition (BS 643:1970¹⁸), and heated to the correct temperature (350°C±14°C), otherwise it may fail to penetrate to the narrow end of the conical part of the socket and, therefore, to the narrow end of the brush of separated wires. Conversely, the temperature of the white metal should not exceed that specified, otherwise the heat may adversely affect the wires of the brush. An open socket (one with two lugs rather than a bowed end) facilitates the pouring of the white metal.

126 The socket must be of the correct size; for winding ropes it must conform to NCB Specification 465/1965.¹² If the socket is too short, the length of each wire embedded in the white metal will be insufficient to ensure that the wire is securely gripped at loads up to its breaking strength. A length of embedded wire equal to about 40 times its diameter will ensure proper grip and leave a margin for safety, provided that the wire has been properly cleaned. On the other hand, the socket must not be too long otherwise the taper of the conical



Figure 42: Fractured wires

part will not be steep enough or wide enough to allow the molten white metal to reach the narrow end of the socket before solidifying. The taper should be 1 in 7 or steeper (8° or more).

127 If the wires at the narrow end of the socket are loose and unsupported, they will bend and twist as the rope moves, increasing the likelihood of fatigue failure (Figure 42). In order to ensure that the wires at the narrow end of the brush are properly embedded in white metal, the procedure stipulates that the narrow end of the brush should not lie right at the narrow end of the conical part of the socket, but should lie further inside at a wider part of the socket. Therefore, when fitting sockets to NCB Specification 465/1965,¹² a length of seized rope about twice the rope diameter should lie within the socket mouth.

RECOVERY OF A SOCKET

128 The white metal cone should be removed from the socket by pressing out. Should this prove difficult the socket may be warmed; provided that the critical temperature for preheating, given in Table 12, is not exceeded. Examination of the extracted cone will provide useful information on the quality of capping procedures.

WEDGE CAPPING

129 Wedge cappings work on the principle of gripping the rope between interlocking tapered wedges (with grooves to suit the rope diameter), which are enclosed in limbs encircled by heavy bands (Figure 43a). After initial bedding down, the rope should not move in the wedges and, because of their interlocking action, the wedges cannot move independently of each other. The wedges and the rope must, however, be able to move as a unit, so that if the load on the capping is sufficient to cause movement of this unit, the force on the wedges will be increased and consequently the grip exerted upon the rope will be greater. A safety block is fitted to act as a rope movement indicator and to assist movement of the wedges should this become necessary.

130 The capping can be used with stranded or locked coil ropes. While the following guidance relates to its use on a locked coil rope, it applies equally to its use on a stranded rope.



Figure 43a: Wedge capping

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131 Capping wedges are stamped with the rope type and size for which they are designed, and also with the capping identification number. Wedges should be fitted only to a capping having the same identification number. Check that all component parts, ie limbs, bands and wedges, bear the same capping number (Figure 43a). Cappings should NEVER be used with a size or type of rope different from that stamped upon the wedges. The number of bands will vary with the design and manufacturers of the capping.

132 Under no circumstances should liners be used in the grooves or at the backs of the wedges.

Serving and clamping

133 Check the length of rope to be gripped by the wedges for uniformity of diameter and compliance with the capping rope groove tolerances.

134 The rope must be securely served and clamped on both sides of the proposed cutting position in the same way as for resin and white metal capping; the length CD (Figure 23a) for locked coil ropes should be at least equal to 20 x rope diameter (d) plus the length of the safety block.

Cutting

135 Cut the rope in the same way as for resin and white metal capping.

Fitting the safety block

136 Thread the safety block, which should be clean and dry, over the rope end so that the larger end of the conical bore is towards the rope end. Fit a temporary clamp over the serving so that its top edge is the length of the safety block less one-half the rope diameter from the rope end and remove the serving wire at the rope end down to the top of this clamp. The procedure is now similar to that for making a resin or white metal capping:

- (a) Separate the wires at the rope end to form a small brush, cutting out the fibre core, if present, close to the serving. Avoid undue bending of the wires over the edge of the clamp (Figure 43b).
- (b) Thoroughly clean all the wires in the brush with a water-soluble degreasing fluid, with the rope brush pointing downwards, so that no degreasing fluid enters the unopened part of the rope. Remove the temporary clamp close to the brush.
- (c) Pull the safety block into position over the rope brush so that a length of serving equal to one half the rope diameter is projecting into the bore of the block. The wire ends should be flush with the top of the block.
- (d) Clamp the rope, with the safety block in place, vertically with the large end of the block uppermost. Ensure that the axes of the rope and safety block are in line for at least 36 x rope diameter (d).

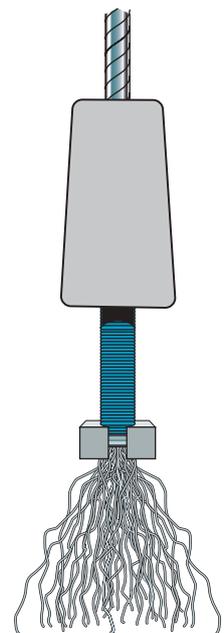


Figure 43b: Fitting the safety block

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- (e) Seal the bottom of the safety block with a tight serving of heat resistant yarn, to prevent the escape of molten white metal.
 - (f) Heat the outside of the block with a blowtorch, gradually and evenly all round the outer faces. Heating of the block is essential to ensure the free flow of molten metal, undue heating may impair the strength of the rope wires. Avoid undue local heating and particularly avoid heating the rope outside the block. Monitor the temperature of the block with thermal crayons or any other suitable method. When the block is at the correct temperature (see Table 12), before pouring the white metal, a non-acid flux or finely powdered rosin should be dusted among the wires in the core of the block.
 - (g) Fill the block with molten, clean white metal, poured at a temperature of $350^{\circ}\text{C}\pm 14^{\circ}\text{C}$. Pouring should be continuous, uniform and slightly off-centre until the white metal completely fills the block. If the surface of the white metal sinks in the centre, pour in a little more white metal.
 - (h) The white metal used should have been previously melted from new ingots of the composition laid down in BS 643: 1970.¹⁸ The pouring pot should be of sufficient capacity to hold the full amount of white metal to fill the bore of the safety block. The pot should have a minimum capacity level mark for the quantity of molten white metal required for the block, and should incorporate a baffle plate to ensure that only clean, bright fluid metal is poured into the prepared, heated safety block. Using a suitable thermometer, confirm the temperature of the white metal immediately before pouring.
 - (i) Leave the rope and block undisturbed and allow it to cool gradually until the white metal has set and the block has reached air temperature.
 - (j) Remove the heat resistant yarn and the serving from below the safety block and check that the white metal has fully penetrated the block.
 - (k) Check the length of rope to be gripped by the wedges for uniformity of diameter and compliance with the capping rope groove tolerances.

Fitting the capping

137 Prior to assembly, remove any protective paint, grease or backing strips from capping limbs and wedges. Using only emery cloth, remove any traces of rust which may have accumulated on the wedge backs and grooves, and also on the inside of the limbs over the area on which the wedges operate. Remove any burrs or damage on wedges and limb sections that have occurred in handling, storage or transit, particularly the areas over which the wedges operate.

138 Assemble the capping as follows:

- (a) Thread the capping bands onto the rope in order of their numbers (always the band of smallest aperture first - usually the one with the highest number). Make sure that the taper on the inside of the bands is in the

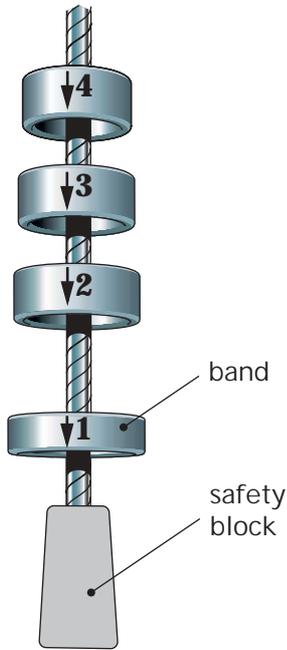


Figure 43c: Arrows pointing in the same direction

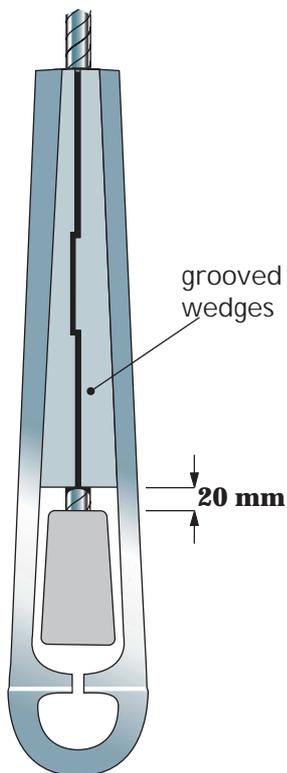


Figure 43d : Fitting capping limbs

same direction as the taper on the outside of the capping limbs. This is often shown by arrows stamped on each of the bands and on the limbs; these must all point in the same direction (Figure 43c).

(b) Thoroughly clean any grease and lubricant from the portion of the rope which will be gripped by the wedges and ensure that the rope is straight, clean and dry.

(c) Clean the backs of the wedges and the inner sides of the capping limbs. Then apply a light smearing of grease to the backs, **not the grooves**, of the wedges and the inside of the limbs.

Note: only greases recommended by the capping manufacturer should be used. Do not use tallow, graphite grease or grease containing molybdenum disulphide. The grooves of the wedges must be clean and dry.

(d) Place the wedges around the rope approximately in their final position.

(e) Fit the capping limbs over the wedges and draw downwards until the ends of the limbs are flush with the thin end of the wedges. Draw the rope through the wedges until the safety block is 20 mm from the bottom of the wedges (Figure 43d).

(f) Draw the bands over and tap them down on the capping limbs.

(g) Using purpose-made sets, which should fit snugly on the edges of the bands adjacent to the capping limbs, partially tighten each working band (starting with No 2). Repeat this procedure driving the bands tight together one by one (Figure 43e).

(h) The suggested weights of hammers to be used for driving on the bands are:

(i) 3 kg (7 lb) - for ropes up to 38 mm diameter;

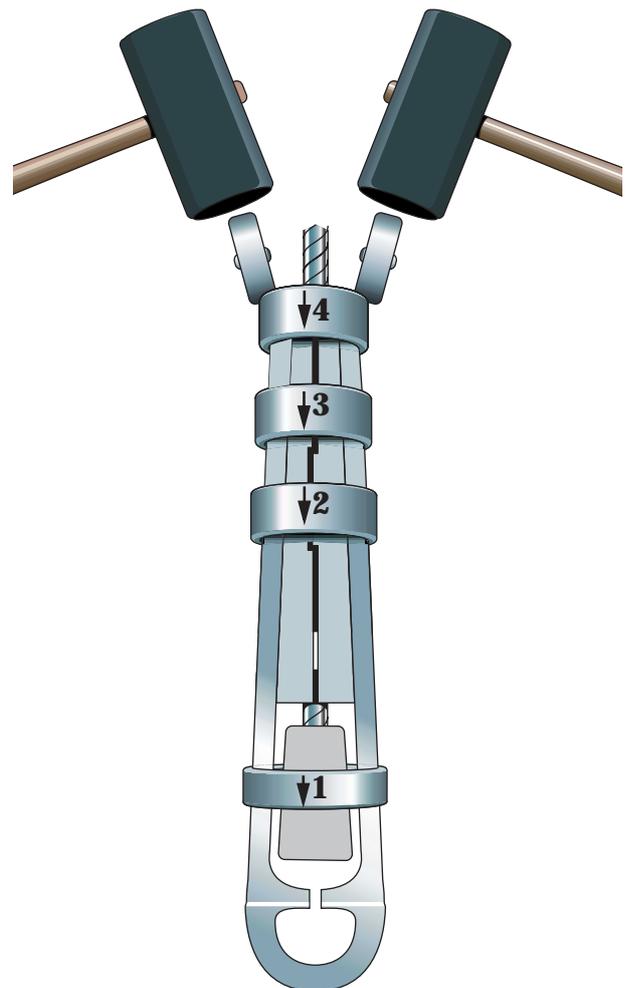


Figure 43e: Tightening bands

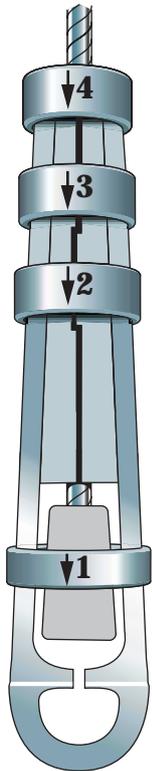


Figure 43f :

'Working' bands

(ii) 5.5 kg (12 lb) - for ropes between 38 mm and 48 mm diameter; and

(iii) 6.5 kg (14 lb) - for ropes above 48 mm diameter.

- (i) Two people, one on either side, should drive the bands simultaneously to ensure that they tighten uniformly. They should also ensure that they do not strike the side of the bands adjacent to the wedges, as this can cause burrs which may then foul the wedges and hinder their movement. Band No 1 is intended only to encircle the safety block to protect it and need not be driven on to a very tight fit.

The 'working' bands in the example shown in Figure 43f (Nos 2, 3 and 4 in the illustration) when properly driven on, should be spaced about equally along the capping limbs, the top (or 'point') band being slightly beyond the end of the capping.

139 Hydraulic banding machines are a better way of tightening the bands on the capping limbs and, where available, should be used in preference to hammers and sets (Figure 44). Capping manufacturers will advise on the correct pressure settings to use for the different sizes of capping.

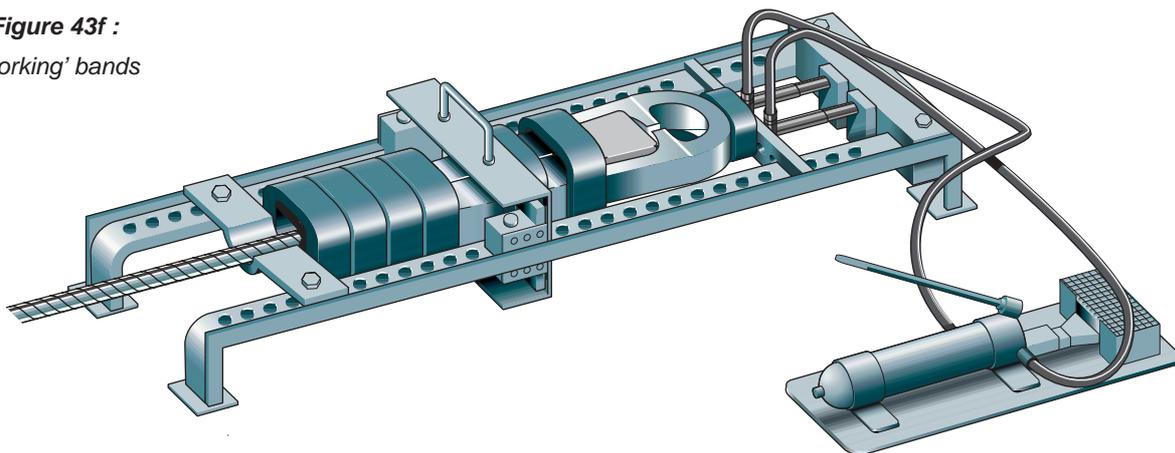


Figure 44:

Hydraulic banding machine

140 It is important that the detailed advice given in the literature provided by the manufacturers of wedge cappings is observed.

141 Under no circumstances should a capping be applied to a rope without the white metal safety block.

142 If slack rope occurs in a winding rope fitted with wedge-type capping, care must be taken when the rope is being reloaded. The capping bands must not foul obstructions otherwise they could be pushed off the capping limbs.

CAPPING OF BALANCE ROPES

143 Balance ropes are often supplied pre-stretched and cut and capped to the correct length by manufacturers. The two types of terminal fitting generally used for capping balance ropes are:

- resin or white metal capping for round ropes (Figure 21);
- thimbles and clamps for flat ropes (Figure 45).

Resin or white metal cappings

144 The method of fitting resin and white metal cappings to balance ropes is the same as that used for winding ropes and is described earlier in this guidance. Following capping, a report should be made in accordance with Appendix 1.

Thimble and clamp terminal fastenings for flat balance ropes

145 Balance ropes may be attached to the conveyance by means of a specially formed pear-shaped thimble (or bobbin). The free end of the rope is bent around the thimble, then laid back along the working rope and adequately secured by a number of two or four-bolt clamps.

146 The whole assembly is then suspended beneath the conveyance by purpose-designed suspension links or solid stirrup arrangements. The thimble is retained within the suspension links, or stirrups by a captivated retaining pin. Figure 45 shows the arrangement for a flat balance rope.

CAPPING OF GUIDE AND RUBBING ROPES

147 The principal method of suspending guide ropes is by means of a resin or white metal capping or a wedge-type suspension gland in the headframe. White metal and resin cappings should have a taper length of eight times the rope diameter and an included taper of 1 in 6. A typical suspension gland for resin and white metal capping is shown at Figure 46a.

148 Guide rope and rubbing rope cappings or suspension glands are normally above the supporting structure where there is usually adequate space for lifting, rotating and recapping the ropes.

White metal capping

149 The procedure is the same as for winding ropes as described earlier in this guidance. This type of capping is being progressively replaced by resin capping in UK mines.

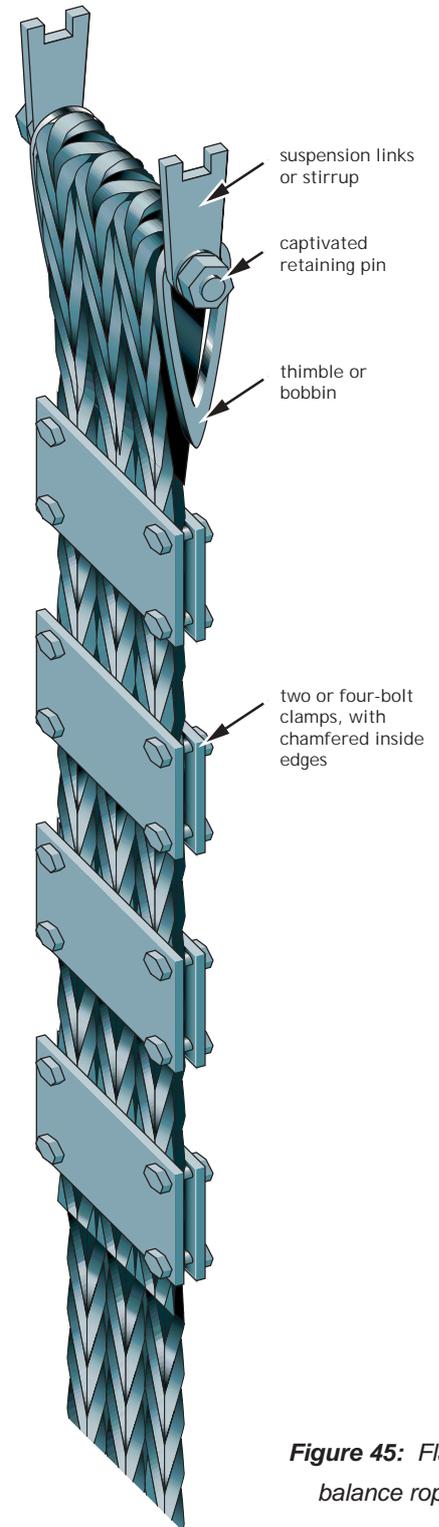
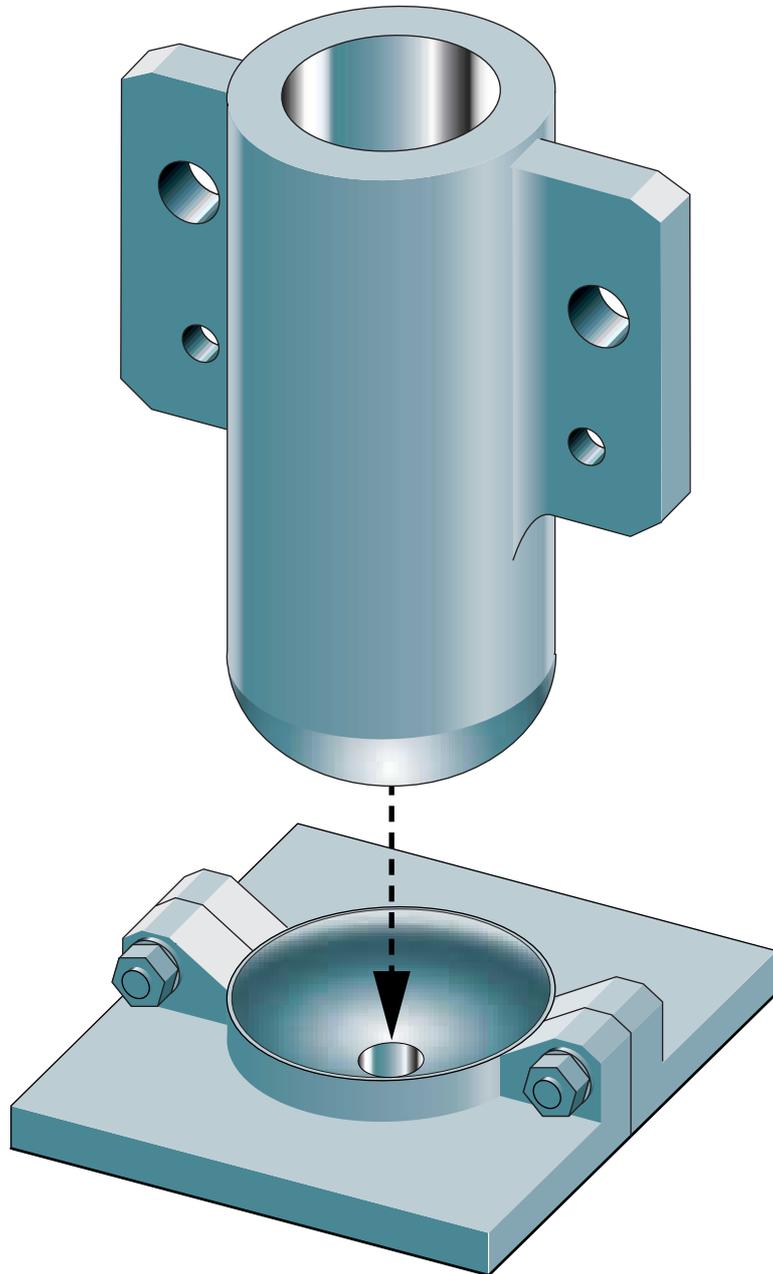


Figure 45: Flat balance rope

Figure 46a:
*Suspension gland for resin
and white metal*



Resin capping

150 For the reasons described earlier in this guidance, resin cappings are recommended in preference to white metal, and the procedure is the same as previously described for winding ropes. However, on large diameter guide ropes, the resin may crack during the curing stage if the outer wire rods are allowed to press heavily against the inner wall of the socket. It is probably caused by a combination of the stresses in the outer rods, that are created by them being restrained by the wall of the socket, and the force induced by the resin as it contracts inwards away from the wall of the socket.

151 To avoid this situation, space out the wire rods as evenly as possible within the socket, allowing none of them to touch the socket wall at the wide end of the socket. Try to maintain a space of one wire rod diameter between the bore and any wire rod at the wide end of the socket.

152 As with other ropes, once the rope termination is complete, a report should be made in accordance with Appendix 1.

Wedge type suspension glands

153 This type of guide rope suspension (Figure 46b) has generally been superseded by resin type capping, however, the procedures explained are applicable to manoeuvring glands which continue to be used for shaft work. Wedge suspension glands should be fitted in the following manner and before assembling the gland, the following points should be checked:

- (a) Measure accurately the diameter of the rope at the point of suspension to determine the maximum and minimum diameters. No gland should be fitted to a rope which differs in diameter by more than ± 0.75 mm of the diameter stamped on the wedges.
- (b) Check that the safe working load (SWL) stamped on the gland is not less than the static load that will be imposed on the rope.
- (c) Check that the assembly numbers stamped on the wedges and the gland case are the same. Gland cases should be fitted only with wedges bearing the same number.

Assembling the gland

154 Wedge suspension glands should be assembled in the following manner:

- (a) Clean the gland case and wedges to remove any protective grease or paint. Using 'emery cloth' only, remove any traces of rust from the backs of the wedges, the grooves and the recess in the gland case. Remove any burrs from the wedges or gland case recess. If left, they may interfere with the free movement of the wedges.

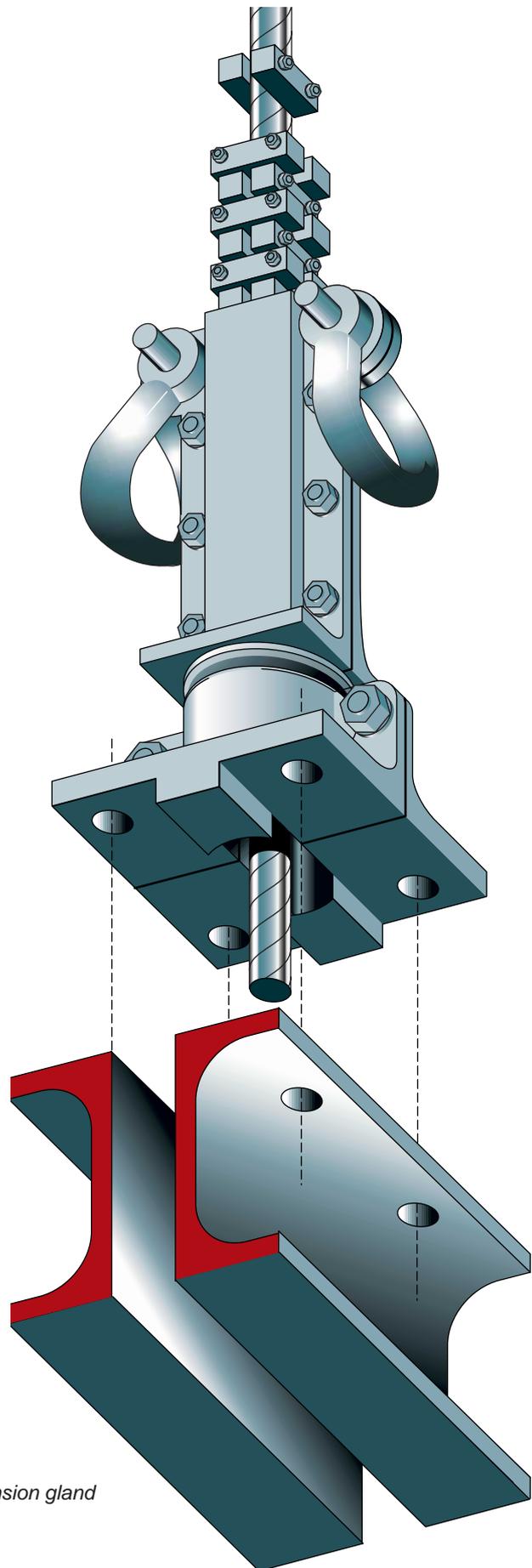


Figure 46b: Suspension gland

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- (b) Thoroughly clean the grease from that part of the rope to which the gland is to be attached, and ensure that this part of the rope is straight, clean and dry.
 - (c) Bolt the gland case round the rope at the required position. With all types of suspension gland the joint of the casing must be supported across the joists ie the joint should be at right angles to the girders (Figure 46b).
 - (d) Grease the backs, **not the grooves**, of the wedges before placing them in position around the rope. Also, lightly grease the recess in the gland case into which the wedges fit, using only suitable greases. Do not use tallow, graphite grease or any grease containing molybdenum disulphide.
 - (e) Insert the wedges and drive them firmly in to ensure that they are down on the rope and starting to grip and that they are level and tight. To prevent burring, use a suitably shaped brass or copper set in conjunction with the hammer, taking care not to damage the rope when driving in the wedges. When fitted correctly, the tops of the wedges should be approximately 1½ to 2 times the rope diameter above the top of the gland case.
 - (f) Then fit correctly sized two-bolt clamps (not four-bolt clamps, which are less efficient). The clamps should be bolted onto the rope in contact with and at 90° to one another, and with the bottom clamp in contact with the tops of the wedges. The clamp bolts, after cleaning and lightly greasing, should be tightened to the torque shown in Table 13.

Rope diameter	Bolt size	Tightening torque	Load carrying capacity per clamp
16-24 mm	M20	150 Nm (110 lbf ft)	1 tonne
45-64 mm	M30	450 Nm (330 lbf ft)	2 tonnes

Table 13: Tightening torques for two-bolt clamp bolts

155 The required number of two bolt clamps is derived from the table and is determined by the total load to be manoeuvred or supported. In addition to the required number of contact clamps a marker or tell-tale clamp should be fitted approximately 25 mm above the top contact clamp. This space will act as an indicator should any rope slip occur.

Dismantling a gland

156 Make sure the suspended load (ie weight and rope) is properly secure, that the slack rope is properly secure, that there is slack rope immediately beneath the gland, and that there are suitable arrangements to control the slack rope before attempting to release it. Then:

- (a) Remove all of the two-bolt clamps.
- (b) Raise the gland approximately 75 mm above the supporting structure.

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- (c) Loosen the gland case bolts.
 - (d) Strike the gland case downwards with a sharp blow, avoiding the wedges or rope, to release the wedges in the gland case.
 - (e) Remove the wedges.
 - (f) Remove the bolts from the gland case, split the case and set it aside. If the gland is to be stored all parts should be thoroughly protected with a rust preventing grease.

157 It is important that the detailed advice given in the literature provided by the manufacturers of wedge capping is observed.

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TECHNICAL ANNEX 4 - MAINTENANCE PROCEDURES, DETERIORATION AND DISCARD CRITERIA FOR SHAFT ROPES

MAINTENANCE PROCEDURES

Introduction

- 1 All shaft ropes need careful maintenance to maximise their working life. This part of the Technical Annex provides guidance on the care and lubrication of shaft ropes, but mines will also need to refer to the appropriate manufacturer's instructions provided with the specific rope types.
- 2 There is a need to identify any lengths of rope where there is localised drying effect on the rope lubricant. This may occur in specific areas of the rope that are in vulnerable places, for example, to winding and balance ropes when, conveyances are in their normally parked positions, from shaft heaters, opposite fan drifts or shaft insets, shaft sumps, etc.
- 3 Balance ropes should be kept well lubricated, since moisture will otherwise penetrate the loop in the lowest part of the rope in the sump, causing internal corrosion. Water and debris levels in the sump must be kept below the bottom of the loop.
- 4 Both guide and rubbing ropes may deteriorate in fatigue where they leave the headframe capping or fixings. To prevent this, the position of the capping or fixing should be moved along the rope from time to time. It is better to lift the rope rather than to lower it, to get rid of any fatigued part near the top of the rope. Recommended good practice is to lift the rope through a distance of at least 1.5 times the length of the headframe capping at not more than five yearly intervals. The rope should also be turned through 90° during the lifting and recapping operation, to help spread any effects of localised wear. Further advice on this subject can also be found in paragraphs 202 and 203 of the ACOP to the 1993 Regulations.³
- 5 Sump tension weights (or cheese weights) should be inspected regularly to check that corrosion has not weakened the centre rod to an extent that might lead it to fail, or cause it to bend due to a build-up of rust between the cheese weights.
- 6 Tension springs in the sump should also be inspected regularly to confirm that the springs are effectively applying the required tension to the ropes. In deep downcast shafts, seasonal temperature changes may require that the springs be adjusted to maintain the required rope tension.
- 7 Routine inspections should check that weights or springs are not being fouled by accumulated spillage. Similarly, water should not be allowed to rise around the weights since buoyancy effects will reduce the rope tension.

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ROPE LUBRICATION

8 The purpose of wire rope lubrication is to allow the wires within the rope to move freely against one another, reducing friction and internal wear and improving the distribution of load. Secondly, it protects both internal and external surfaces of the wires from corrosion.

9 External lubricant reduces friction and external wear between the rope and any drum or pulley over which it passes; and it can also help to reduce internal wear by restricting penetration of dirt and grit which could otherwise cause increased abrasion. In certain conditions, however, too liberal use of too sticky an external lubricant will attract grit and so reduce rope life.

10 The essential properties of a wire rope lubricant are:

- it must be tough enough to resist abrasion but sufficiently plastic to remain intact as the rope flexes in service;
- it must adhere firmly to the wires and be viscous enough to resist gravitational forces where ropes hang vertically, and centrifugal forces where ropes pass quickly around drums, sheaves or pulleys;
- it must be non-corrosive and stable over the range of temperatures and environmental conditions likely to be encountered. Under no circumstances should it give rise to any by-products which would attack the metal strands;
- it must be water-repellent to protect internal and external surfaces from corrosion;
- it must not deteriorate with age, exposure or temperature changes, eg by hardening or cracking; and
- a lubricant (dressing) applied externally during service should have good penetration to compensate, as far as possible, for any loss of the manufacturer's internal lubricant. It must also be fully compatible with the lubricant used in manufacture.

Lubrication of ropes during manufacture

11 Because it is difficult to lubricate fully the internal part of a rope once it is made up, ropes are thoroughly lubricated at the manufacturing stage. The majority of lubricants now used for this fall into two main classes:

- petroleum-based compounds;
- bitumen in mineral oil compounds.

12 Chemicals are added to the basic lubricant to improve the performance. These additives include anticorrosion, anti-oxidation, water-repellent, anti-fret agents, etc. Except in certain cases, the lubricant is applied during all stages of

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manufacture. It is sometimes applied cold but more generally heated, according to its viscosity, to obtain the optimum condition for application.

13 The completed rope may be passed through a final bath of lubricant. For locked coil friction-winding ropes, specially developed bitumen-based lubricants may be used. General practice is to heavily lubricate the inner layers of the rope with a bitumen-in-oil compound, laying up the outer one or two layers in a virtually dry condition. In service the lubricant spreads to the outer layers but should still be contained within the rope, avoiding contamination of the drive drum linings and, hence, rope slip.

14 Lubricants known as batching fluids are needed during the spinning of natural fibre cores to prevent the fibres from breaking. To avoid internal corrosion of the rope, these lubricants must be free from acids and water. The core fibres themselves must be free from acids and salt and should contain only the combined water necessary to prevent brittleness. BS 525:1991¹⁹ gives the requirements for such cores. Before incorporation into a rope, a fibre core may be impregnated with further lubricant.

**Lubrication and
cleaning during
service**

15 If a rope is to remain in good condition it is important to re-lubricate it at intervals during service. The oil or grease (the rope 'dressing') used should be one specially designed for ropes, and should be free from all harmful substances such as acids. It should be a mineral oil, as animal and vegetable oils tend to break down and produce acids. Rope manufacturers and oil companies will advise on suitable lubricants, including the additives to improve the properties.

16 The kind of dressing used and the frequency of application varies with the type of rope and its usage, but there are certain general principles to be followed:

- Whenever practical apply the dressing as soon as the rope is put to work.
- Reapply the dressing at regular intervals, normally before the rope shows any signs of corrosion or dryness.
- Periodically clean existing lubricant from the rope before relubricating, particularly in dirty or dusty conditions (eg skip winding shafts).
- If loose corrosion products are present on the rope surface, remove them before applying fresh dressing.
- The dressing and method of application should be such that a thin, even adherent coating covers all the surface of the rope.

Drum-winder ropes

17 Drum-winder ropes should be re-lubricated at regular intervals; this should be at least once a week for busy ropes in wet shafts. There are lubricants that contain additives with anticorrosion, tackiness, water-repellent and, in some cases, de-watering properties, that will be suitable in these circumstances.

18 The de-watering additives in bitumen-based dressing emulsify with the water present on the rope and ensure that oil is kept in close contact with the surfaces of the wires. It is necessary to clean this type of dressing from the rope before it becomes saturated with water. The appropriate time to clean and re-lubricate the rope can be judged from the colour of the dressing which changes as its water content increases.

19 With petroleum-based compounds containing de-watering additives, water is removed from the rope but it is not absorbed by the compound to the same extent as by bitumen-based compounds. Winding ropes may be cleaned and regreased manually. This method has the advantage of enabling the rope exterior to be examined at the same time, but it takes a long time.

20 Automatic lubrication of winding ropes can be achieved by pumping lubricating oil from a small reservoir positioned either in the winding engine house or at the headgear pulley level. The oil is distributed by small flexible pipes to the point of application onto the rope (Figure 47), or into the tread of the pulley. Bending of the rope around the pulley then assists penetration and distribution of the lubricant.

21 The quantity of oil dripped onto the rope is usually determined by experience, and is normally applied when the rope is travelling in one direction only. Care must be taken to ensure that control of the supply is kept under close supervision, as excess oil on the rope may result in contamination of the winding drum brake path and linings, the headgear and the engine house.

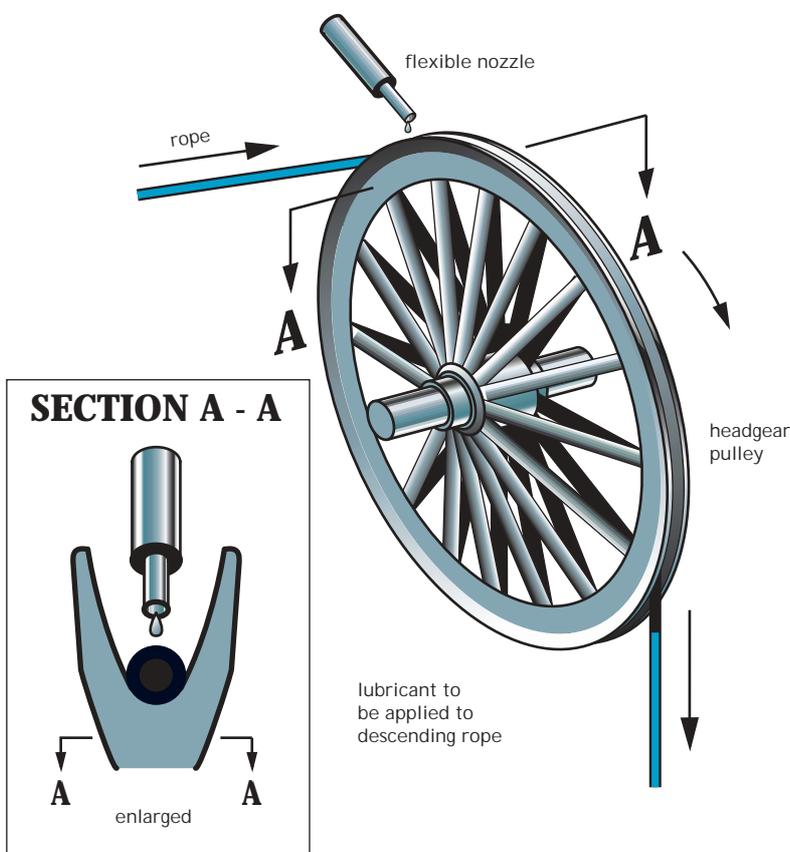


Figure 47:
Automatic rope lubrication

22 Automatic lubricators apply oil to ropes more uniformly than manual methods and use less oil. As the drip feed method applies oil at the headgear pulley, the rope lengths that do not pass the lubrication point (ie those between the capping and the headgear pulley, and between the headgear pulley and the drum) will need to be oiled manually.

23 Ropes require periodic cleaning to free them from dirt and grit, etc. A simple method is to run the rope through a wire brush rope cleaner (Figure 48). A method for cleaning locked coil ropes, which also serves as a broken outer wire detector, is to use a manually tensioned, high tensile steel wire

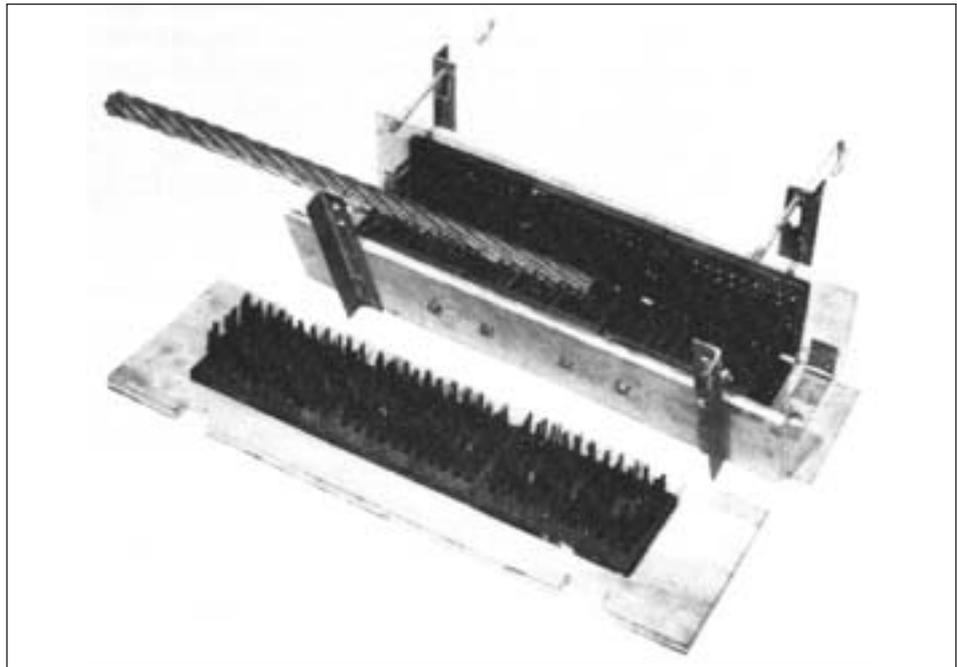


Figure 48: Typical wire brush rope cleaner

looped around the rope (Figure 49). The rope should only move slowly when using this method, and the work procedure must make provision to stop the rope quickly in the event of the cleaning wire snagging on a broken rope wire.

Friction winder ropes

24 Externally applied lubricants or dressings must not reduce significantly the coefficient of friction between the rope and the driving drum. Use only dressings specifically designed for friction-winder ropes. These can be applied manually, taking care not to over-lubricate, as too much lubricant could cause rope slip or uneven rope travel (and hence unequal tensions in the ropes). To minimise the chance of this occurring the dressings should be wiped back with a cloth after application.

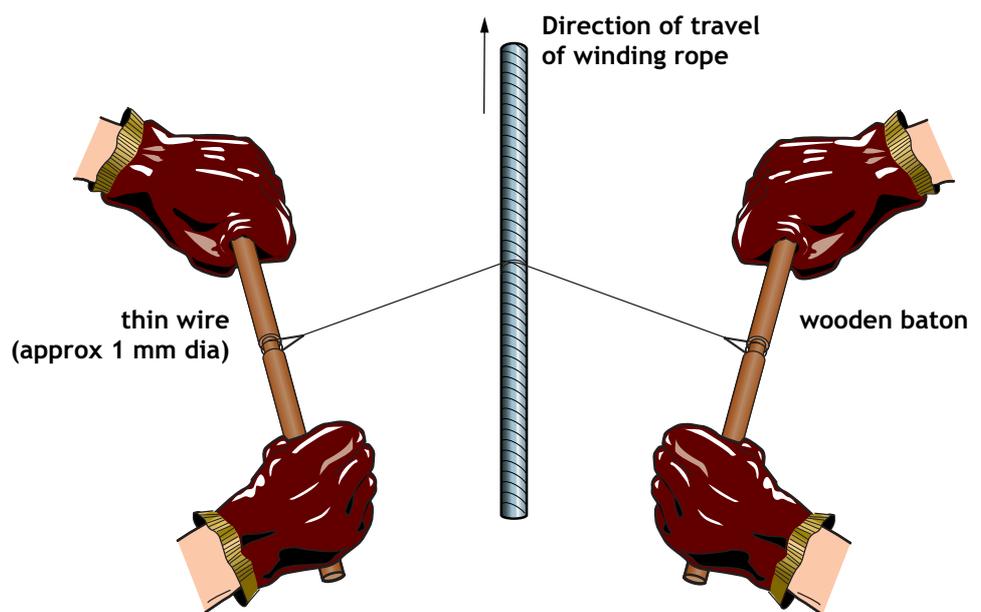


Figure 49: Looped wire method of cleaning and examining locked-coil winding ropes

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25 The interval between cleaning and application will vary depending on the shaft environments in which the ropes run; the more corrosive the environment, the shorter the interval between successive applications.

26 For multi-rope friction-winders, cleaning and re-lubrication can be phased; for example, one rope per week or one per day, depending on operating conditions.

27 Despite the precautions taken during manufacture, newly installed ropes sometimes exude excess lubricant and need frequent and careful examination during the initial operating period. Use a cloth (moistened, if necessary, with an appropriate solvent or specialised dressing) to remove any excess, then wipe dry with a clean cloth. Avoid using drying agents such as gritty dusts.

28 On friction winding systems, the length of rope between the capping and the drum, pulley or deflection sheave, whichever is the first point of contact, may be further protected by a coating of lubricant with anticorrosive properties.

Pressure lubrication

29 Externally applied dressings are unlikely to penetrate effectively the internal layers of a locked coil rope. Pressure lubrication is a method of injecting lubricant into ropes to replace the manufacturer's lubricant which may dry out in some shaft conditions. This can be for either the whole length of the rope, or in specific areas where loss of the internal lubricant creates a rope problem; for example, distortion of the outer cover of the length of rope on the driving drum during the acceleration phase of the winding cycle.

30 The most appropriate time to apply pressure lubrication during the life of a rope is normally determined by experience and advice from the rope manufacturer. It is most beneficial at the end of the period when external exudation of the internal lubricant has ceased, and when the lubricity of the lubricant between the outer layer of the rope and the first of the inner layers becomes ineffective.

31 Rope manufacturers will advise on the most appropriate pressure injection technique.

Balance ropes

32 Balance ropes, whether galvanised or not, should be kept well lubricated for they often work in corrosive conditions. Cleaning is just as important as lubricating for, if the lubricant cannot reach the rope surface, it is ineffective. Relatively thin, spray-applied lubricants are most appropriate, as penetration is better, and ropes remain cleaner and therefore easier to examine.

Guide ropes

33 A commonly used type of dressing which gives good results in dry or damp conditions, is a viscous, bitumen-based compound containing anti-rust, tackiness, water repellent and de-watering additives.

34 In wet shafts, dressings with adhesive and emulsifying properties generally give better results. Under the most severe conditions, where large amounts of corrosive water are present, appropriate dressings will contain anti-rust and

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dewatering additives, and no emulsifying agents. This type of lubricant is difficult to apply, as it is necessary to thoroughly dry the rope surface prior to application. However, it will last for a relatively long time before a fresh application is needed.

Lubrication after capping

35 When a rope is capped or recapped with a white metal socket, it is possible for some of the internal lubricant to be lost from the part of the rope adjacent to the capping. This loss could encourage corrosion and fatigue of the wires at this critical part of the rope; therefore, after completion of the capping process the rope close to the mouth of the capping should be thoroughly relubricated. Rope manufacturers have developed special lubricants for this purpose.

36 For fibre-cored ropes, a lubrication tube, fitted with a grease nipple, can be cast into the white metal, having been previously pushed down the wire brush and its end inserted into the fibre core. When the completed capping is cold, lubricant is pumped in to replace any which may have melted out. The process can be repeated as necessary during the life of the rope.

DETERIORATION IN SHAFT ROPES

37 The main forms of deterioration in shaft ropes are:

- wear;
- corrosion;
- fatigue;
- corrosion-fatigue;
- surface embrittlement;
- accidental damage and distortion, leading to local deterioration.

38 If a rope is of unsuitable type or construction, some of the above forms of deterioration are more likely to occur. For instance, flexible type ropes having small outer wires of less than 2 mm diameter are likely to suffer deterioration by wear and corrosion. Ungalvanised ropes working under corrosive conditions are almost certain to deteriorate by corrosion, especially if they are not kept well lubricated at all times.

WEAR

39 Both external and internal wear occurs in all ropes; but if unusually heavy wear occurs, engineers will need to identify and correct the cause. It should be remembered that corrosion aids the advance of wear by helping to remove

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steel, just as wear aids the advance of corrosion by removing the corrosion scale and presenting a fresh surface for further corrosion.

External wear 40 External wear may take the form of abrasive wear (Figure 50a), in which metal is removed from the crowns, or it may take the form of plastic wear (Figure 50b), in which metal is displaced to form fins at the edges of the worn



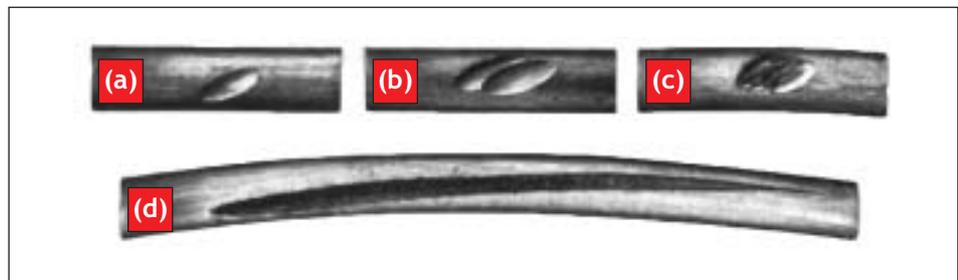
Figure 50a: Abrasive



Figure 50b: Plastic

crowns. Abrasive wear suggests that the rope has been rubbing too much against some hard and abrasive surface which has rubbed off some of the steel of the wire surfaces. Plastic wear suggests that the rope has been bearing heavily on some hard surface, such as a pulley groove or drum. If there is only a small contact area between the rope and the pulley or drum the wire surfaces will deform into fins under the high pressure.

Internal wear 41 Wires in the rope interior which cross one another are bound to cut into one another to some extent. If they are of opposite direction of lay they will produce short indentations or nicks on one another; if they are of the same direction of lay or in parallel lay they will produce long grooves. Figure 51 shows examples of nicks and grooves.



Figures 51a-d: Examples of nicks and grooves

- **Figure 51a** shows a simple nick.
- **Figure 51b** shows a twinned nick caused by a crossing wire slightly changing its point of contact with the wire shown, as a result of the rope becoming loosely laid up.
- **Figure 51c** shows a scuffed nick formed by a crossing but very loose wire playing against the wire shown.
- **Figure 51d** shows a long groove made by a wire of the same direction of lay as the wire in the illustration.

42 Deep nicks or grooves, in the absence of corrosion, suggest that the wires

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are being pressed together too heavily, or driven together too forcibly by impact. Excessive pressure suggests that the rope is running in pulleys with too small a diameter or too tight a groove. Impact indicates that the rope is striking against some object, in which case there will probably be intermittent wear or damage on the exterior. Impact on a moving rope can also produce martensitic surfaces (see paragraphs 81 to 84) on the wires with subsequent wire breakage.

How wear leads to breakage

43 When the round outer wires of a rope or strand (or the round outer rods of a guide rope) become reduced to half their original depth by external wear or corrosion, there are no longer any valleys remaining between adjacent outer wires, and they can be readily displaced by overriding one another (Figure 52a).

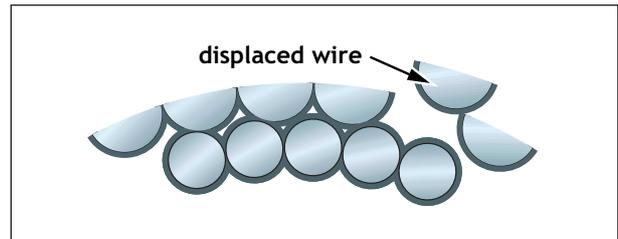


Figure 52a: Outer wires worn to half

44 When the wires become reduced to less than half their original depth they will also be reduced in width and will no longer be in contact with their neighbours, and there will then be spaces or gaps between them (Figure 52b). Such 'loose' wires are very easily moved about in the rope and very readily override one another. In

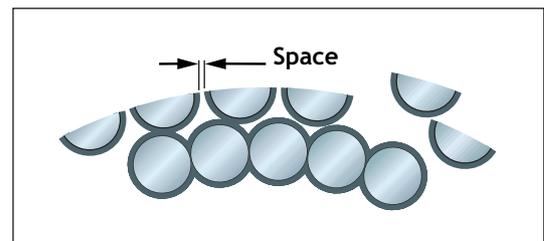


Figure 52b: Outer wires worn to less than half

addition, if internal wear (or internal corrosion) has removed the 'undersides' of the outer wires and left those wires loose on their inner wires (Figure 52c), then the outer wires will be very loose indeed and will be even more readily displaced.

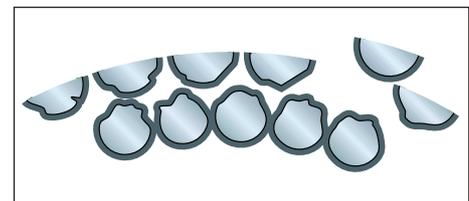
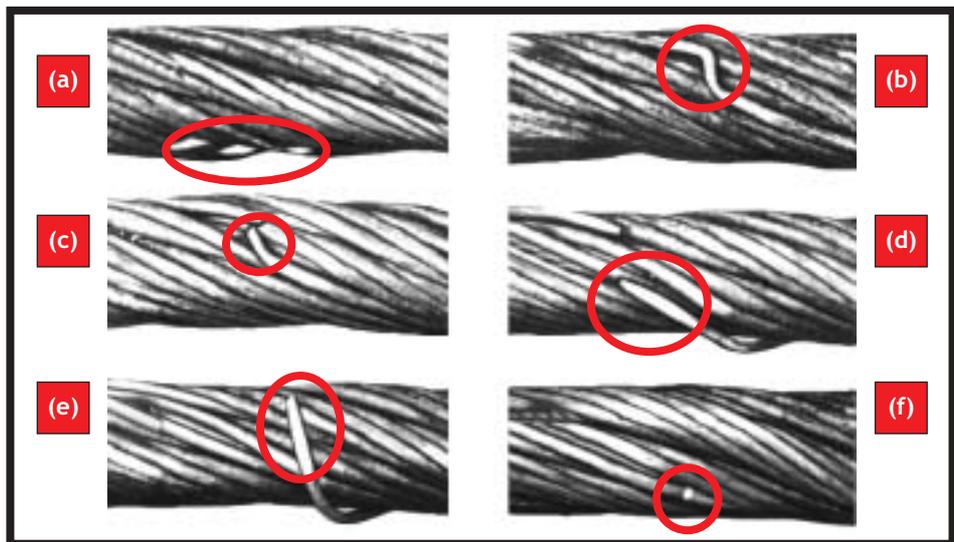


Figure 52c: Internal wear and corrosion

45 When wires become loose and override one another they will rapidly break. If a rope is allowed to remain in service after it has reached a condition in which wires have become loose and displaced, that rope will quickly proceed to fail wire by wire until its strength is so reduced that it can no longer carry the load and the remaining wires then break in tension. A rope in this highly dangerous condition can be detected by looking to see if there are spaces between or underneath its outer wires.

46 Six stages of failure, wire by wire, of a loosened rope which broke in service are shown in Figure 53.

■ **Figure 53a** - The wires are so loose that spaces or 'daylight' can be seen underneath some.



Figures 53a-f:
Stages of failure

- **Figure 53b** - A loose wire has become displaced and bent into a Z-bend.
- **Figure 53c** - A wire has broken at a Z-bend.
- **Figure 53d** - The broken ends of a wire are protruding from the rope so that they are liable to catch on obstructions.
- **Figure 53e** - One of the broken ends has been hooked back on itself as a result of catching on obstructions.
- **Figure 53f** - That end has broken off short leaving a stubby flexion (bending) fracture at an unworn part between strands, which is not the original fracture at a greatly worn crown.

WEAR FRACTURES

47 When a rope breaks as a result of excessive wear many of the wires will show sharp chisel-end fractures (Figure 54a) indicating that they have been severed or almost severed by wear.

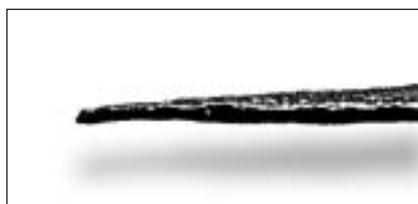


Figure 54a: Severed by wear



Figure 54b: Flexion

48 Some wires will probably show stubby flexion (bending) fractures with slightly hooked ends at unworn parts (Figure 54b). These too will have severed by wear (or broken in some manner at their crowns) but their ends have subsequently worn down.

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49 Some wires will show typical tension fractures at less worn parts (Figure 54c). These wires will have failed in tension when the rope weakened to the extent that it could no longer carry the load. A tension fracture can always be recognised by the waisting (necking), ie the reduction in diameter, that occurs at the broken end (Figures 55a and 55b).

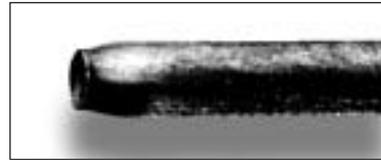


Figure 54c: Tension

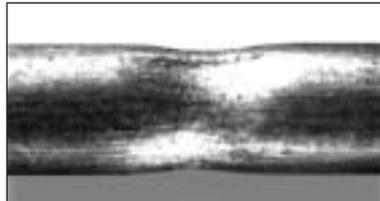


Figure 55a: Wire wasting

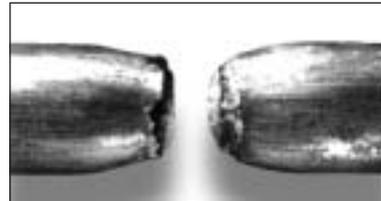


Figure 55b: Fractured ends

Corrosion 50 Corrosion is a major cause of deterioration in shaft ropes. As previously mentioned, corrosion aids the advance of wear by helping to remove steel, just as wear aids the advance of corrosion by removing the corrosion scale and presenting a fresh surface for further corrosion. It is caused by water spray, steam, fumes, acids, unsuitable lubricants, chloride solutions etc. Common salt (sodium chloride) is very corrosive and can appear in solution in strata water seeping into shafts, or in sea spray at coastal mines.

51 Corrosion affecting only a short length of a rope is indicative of a rope being attacked while it is stationary. For instance, it may be caused by a leaking service pipe or by condensation at the rope access hole in the hooding of an upcast shaft. The high air velocity at the fan drift and air seals in a shaft can also displace the rope lubricant, encouraging the onset of corrosion. Corrosion may affect both the outside of the rope (external corrosion) and the inside of the rope (internal corrosion). However, it can be controlled.

External corrosion 52 External corrosion usually takes the form of mild rust or scale and is seldom more serious than it appears, unless winding shocks have contributed to deterioration by corrosion-fatigue. It may take the form of pitting, as in the

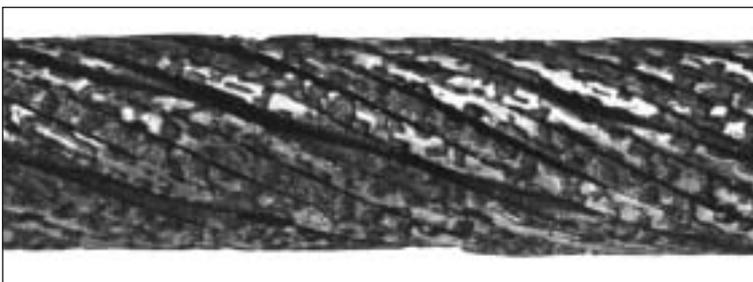


Figure 56a: Severe pitting of a six strand rope

triangular strand rope in Figure 56a and the outer wire of a locked coil rope in Figure 56b. It must be remembered that the corroded wires are no stronger than their weakest parts, ie at the largest or deepest pits. It may also occur as edge pitting, in which some or all of the pits lie at the sharp edges of heavily worn crowns (ie at the contacts between adjacent outer wires).



Figure 56b: Severe pitting on a fully locked wire from a locked-coil rope

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53 Edge pitting is more serious because it means that the corrosion is attempting to enter the rope between the wires. In Figure 56a some of the pits have attacked the sharp edges of the heavily worn crowns and have caused those edges to become serrated or saw-edged. Thus, the rope in the illustration may be in a much worse condition than the external pitting and wear would, at first, suggest. The ropeman should, in such a case, suspect the presence of internal corrosion.

Internal corrosion

54 Internal corrosion is dangerous and difficult to detect. People examining ropes need the training, experience and knowledge to recognise the external signs that may indicate its presence. Severe internal corrosion will cause the loosening of wires by eroding their bearing surfaces in a similar manner to severe internal wear (Figure 52c).

55 In Figure 56a the outer wires are loose; there are spaces between most of these, some are riding high above the level of others and would soon override them, and some are slightly displaced so as to leave a large space at one side and none at the other. Corrosion has entered the rope and has attacked the undersides of the outer wires, leaving those wires loose on their inner wires, as in Figure 52c. In fact, the rope is approaching the highly dangerous condition of the rope shown in Figure 53.

Corrosion fractures

56 When corrosion is so severe that the wires are reduced to the extent that they can no longer carry their intended load, they will break in tension and develop tension fractures. However, the corrosion pitting and scale may mask the waisting and make it difficult to recognise the type of fracture (Figure 56c).



Figure 56c:
Corroded tension

Fatigue



Figure 56d: *Fatigue*

57 Fatigue is the term used to describe the progressive deterioration of a rope subjected to repeated loading. For example, if a rope is repeatedly loaded to 75% of its breaking strength it will not break immediately but it will eventually break in fatigue, and its wires will show fatigue fractures (Figure 56d). Fatigue fractures appear quite different from tension fractures.

58 If the rope is repeatedly loaded to 50% of its breaking strength it will still break in fatigue, but only after a greater number of loadings because the loadings are not so severe.

59 If the rope is repeatedly loaded to 25% of its breaking strength it will probably never break, because the fatigue strength of rope wire under normal operating conditions is about one-quarter of the breaking strength of the wire. This means that if the repeated load in each wire can be kept below one-quarter of its breaking strength, the wire and the rope will not deteriorate in fatigue.

60 The repeated loading in an individual rope wire comprises:

- its share of the maximum tensile load;

- shock loads during use;
- the primary bending load in the wire, due to repeated bending of the rope over pulleys and drums;
- the secondary bending load in the wire, due to repeated bending of the wire over other wires in the rope as the tension varies.

The following subsection contains further details.

61 To cover these extra loads, and the normal loss in strength during service, a safety factor is adopted when calculating the size and breaking strength of rope required.

62 Sharp-edged surface irregularities, such as small but relatively deep corrosion pits, narrow scratches, surface cracks, etc, encourage fatigue because the intensity of load (N/mm^2) close to an irregularity is always greater than in other parts of the wire. In a galvanised rope, apparent nicking may be due only to localised displacement of the surface zinc coating.

63 Fatigue can occur in ropes that are free from corrosion. If corrosion is occurring at the same time, the wires may break in corrosion-fatigue rather than in pure fatigue.

Secondary bending fatigue

64 One cause of fatigue is accentuated secondary bending of rope wires as opposed to normal secondary bending that does not lead to fatigue (Figures 57a and 57b).

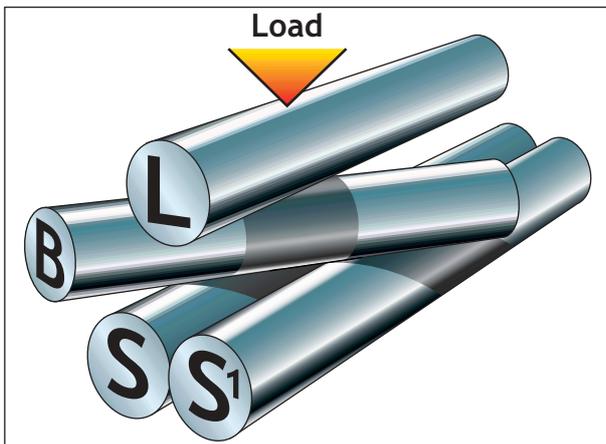


Figure 57a: Normal secondary bending in a well laid-up rope

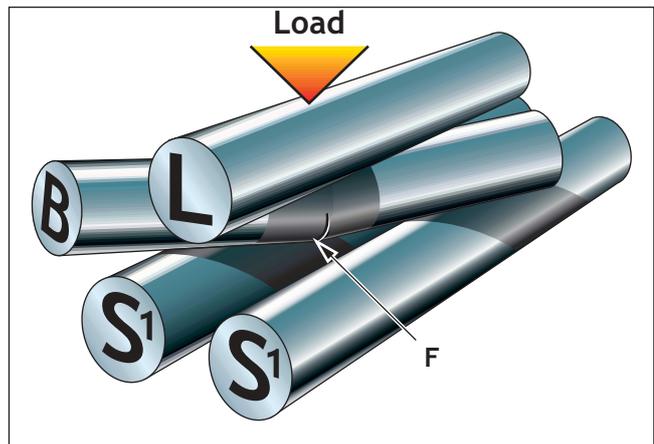


Figure 57b: Accentuated secondary bending in a loosely laid-up rope

65 Normal secondary bending only will occur in a rope that is in good (well-laid-up) condition, where all wires in the rope are in hard contact with one another (Figure 57a). Wire **B** crosses over two supporting wires in the layer beneath, **S** and **S¹**, and supports wire **L** in the layer above. Provided that all wires remain in hard contact with one another, the valley between **S** and **S¹** remains narrow and the bending moment on wire **B** is low.

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66 If a rope is loosely laid up, either because it was supplied in that condition, or through handling or use, the wires can move apart (Figure 57b). The gap between the wires **S** and **S¹** is wider and deeper than before and leads to a greater degree of bending or flexing in the bridge wire **B** for a given load. As wire **L** is not now held in position by adjacent wires in the same layer, it can slide down the bent wire **B** to the mid-span position, maximising the bending moment on it. This causes pronounced flexing, which is repeated every time the rope tension varies. Because the bridging wire **B** in a loose rope is repeatedly bent to a much greater extent than in a well-laid-up rope, a fatigue crack may develop on the stretched side of the bent wire at point **F**, on the opposite side of the wire to the indentation (nick) due to the load applied by wire **L**. The position of such a fatigue crack is a good indication that it was caused by accentuated secondary bending.

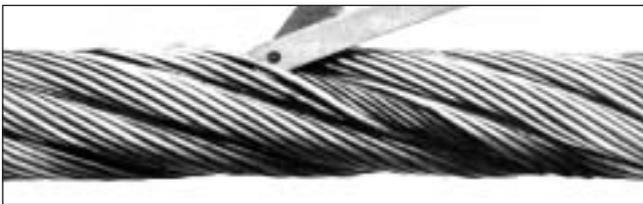


Figure 58a: Rope that broke in fatigue

67 Figure 58a shows part of a rope that broke in fatigue. Four outer wires have been removed to reveal that the remaining outer wires were so loose that the two hacksaw blades (total thickness 1.3 mm) could be inserted beneath them.

68 In Figure 58b one strand of the rope has been placed in front of a mirror so that both sides of the strand can be seen at once. One wire on each side of the strand has completely broken in fatigue, where it has been in contact with wires in adjacent strands and caused a line of nicks on its surface. The fatigue cracks leading to these wire fractures did not start in the nicks; all the cracks in that rope will have started on the opposite (inside) side of the wire, and some spread across the wire to reach the nicks.

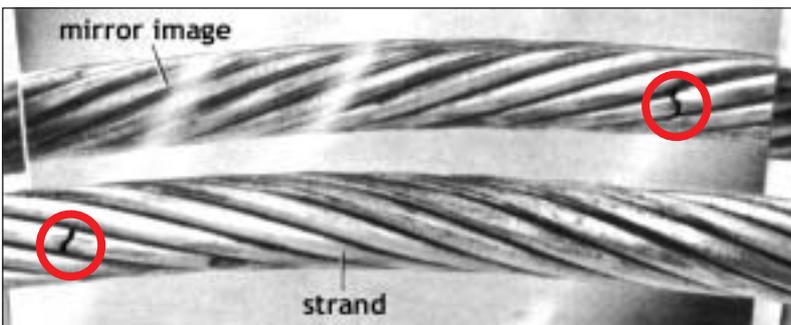


Figure 58b: Rope that broke in fatigue

69 This point is best illustrated by choosing a wire which is cracked but not completely broken. In Figure 58c, a cracked wire from the rope has been placed in front of a mirror; the fatigue crack is directly on the opposite side of the wire to the nick on the contact side. This indicates that the fatigue in that rope was due to accentuated secondary bending which, in turn, was due to either loose or loosened lay.

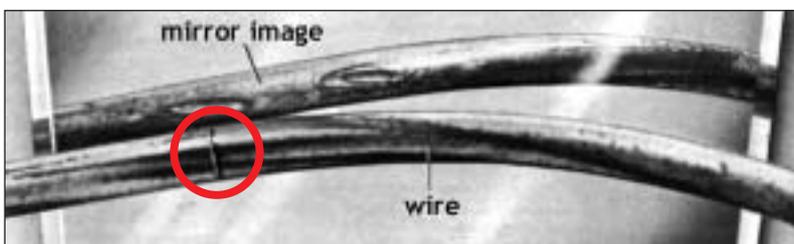


Figure 58c: Rope that broke in fatigue

70 In this particular case, the nature of the nicking indicates that the accentuated secondary bending is due to loosened lay. In Figure 58c, the two nicks are not normal, and are twinned nicks, each being made up of two mainly-overlapping nicks. The cause of this was a permanent change in the contact points between this wire and other wires, which could only occur in a loosened rope.

71 Furthermore, the two long grooves that cross the crack were made by the two supporting inner wires, **S** and **S**¹ in Figure 57b. These grooves are wider at the crack than elsewhere, indicating that the wire was repeatedly pressed down into the valley between the supporting wires, widening the grooves. The two grooves overlap, and the crack is halfway along the length of the overlap; this means that the crack (and the nick opposite) were at mid-span in the bridging wire **B** in Figure 57b, which also formed a greatly skewed bridge. The second nick, which has no crack opposite to it, is due to the nick being opposite only one groove, and so opposite a part which was riding right on top of one inner wire and, therefore, at one end of the small bridge where it could not be repeatedly bent down into the valley.

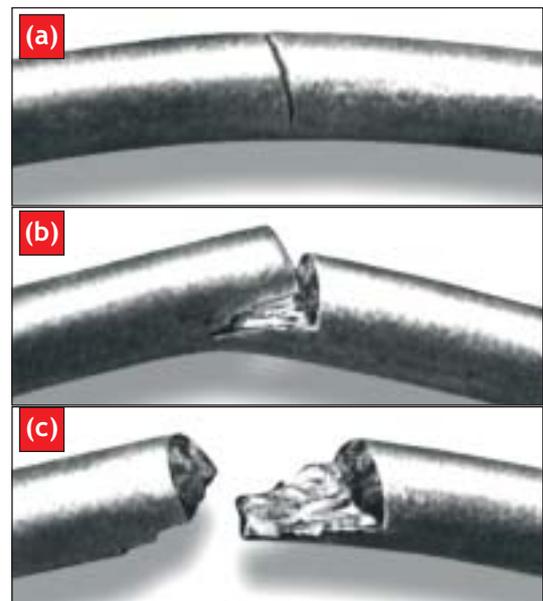
Fatigue fractures

72 When a wire is deteriorating by fatigue it will show no signs of that deterioration until it has completed more than 90% of the loading cycles necessary to break it in fatigue. Then a small crack will appear on the wire surface, so small and fine that the person inspecting or examining the rope will have little chance of finding it unless looking specifically for such evidence. Figure 59 shows several fatigue cracks in an inner layer of wires of a locked coil rope. As the cracks deepen, the wires will break with a partly splintered end.



Figure 59: *Fatigue cracks in an inner layer of a locked-coil rope*

73 Figure 60 shows a wire breaking in this way at a fatigue crack. The splintered part of the fracture (Figures 60b and 60c) has nothing to do with fatigue; it shows only that the final fracture of the cracked wire occurred in bending. The smooth, flat-surfaced part of the fracture is the part that formed one side of the fatigue crack. The smooth part is usually dark or discoloured, because the crack existed for some time before the wire broke. If the cracked wire is not subjected to bending in service, the fatigue crack will extend completely or almost completely across the wire, giving a smooth flat-surfaced fracture with little or no splintered part.



Figures 60a-c: *Stages in the breaking of a wire at a fatigue crack*

74 In all cases the fracture will be very abrupt or sharp-edged, without any of the waisting found in tension fractures, and at least a small part of its end surface will be smooth and probably dark in colour. These are the signs of a fatigue fracture in a wire, just as waisting is the sign of a tensile fracture.

75 If a wire in a rope has been broken for some time, its ends may have become battered (Figure 61a), masking the characteristics of fatigue fracture. However, the absence of waisting should still suggest fatigue to the person inspecting or examining the rope. If some lengths of wire from the rope snap at unseen fatigue cracks when bent by hand, this will prove the rope is affected by fatigue.

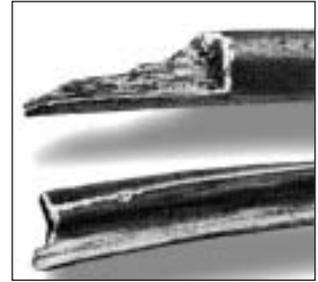


Figure 61a: Battered fatigue

Corrosion-fatigue

76 Corrosion-fatigue occurs due to a combination of conditions favouring both corrosion and fatigue; namely repeated loading under corrosive conditions with insufficient lubricant or galvanised coating to prevent corrosion. There is no corrosion-fatigue limit or level of loading below which rope wire is safe from corrosion-fatigue. Even if the value of the repeated load is kept very low the corrosion may still be severe enough or of a type for corrosion-fatigue to occur. However, if corrosion can be eliminated, corrosion-fatigue is unlikely to occur.

Corrosion-fatigue fractures

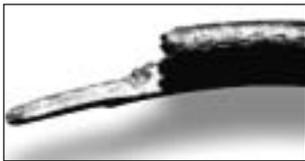


Figure 61b: Corrosion fatigue

77 The fractures shown by wires which have failed in corrosion-fatigue (Figure 61b) are often very similar to those occurring in pure fatigue (Figure 56d), but there will be some degree of corrosion present, though perhaps very little. The only way to determine whether a wire has broken in corrosion-fatigue or in pure fatigue, is through metallurgical examination of the broken ends under a microscope. However, if fatigue fractures are found in a corroded rope, the person inspecting or examining the rope should assume that corrosion-fatigue is the cause.

78 Fatigue and corrosion-fatigue cracks tend to occur in a line along the longitudinal axis of the rope, often on the compression side where the rope is in contact with the pulley or drum, and this symptom may indicate their origin.

SURFACE EMBRITTLEMENT

79 Some ropes may deteriorate as a result of surface embrittlement, either by heavy pressure, for example, from rope drums or sheaves, causing plastic deformation (Figure 62b), or by the rope rubbing heavily against metallic obstructions causing martensite (Figure 62a).



Figure 62a: Martensite embrittlement leading to cracks

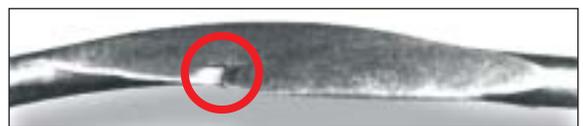


Figure 62b: Plastic wear leading to cracks

Plastic-wear embrittlement

80 Plastic wear will occur on the outer wires if the rope bears too heavily on some hard surface. The metal of the crowns of the outer wires deforms or splays at the edges of the worn crowns (Figure 50b). These fins are brittle and likely to crack. The cracks that form are sharp-edged surface irregularities that may become fatigue cracks causing the wire to break in fatigue. The cracks can also turn through a right angle and extend parallel to the wire (Figure 62b), and cause

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the fins to flake off. In the case of plastic-wear embrittlement, it is a matter of chance whether the wire breaks (Figure 62c) or the embrittled fin flakes off.

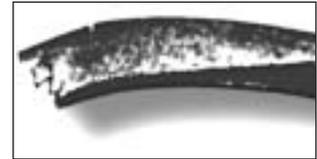


Figure 62c:
Plastic-wear embrittlement

Martensitic embrittlement

81 Where martensitic embrittlement occurs, for instance if a balance rope is rubbing on a steel joist, the situation should be corrected by repositioning the joist or fixing a rubbing timber to the joist that can be readily replaced as necessary when wear occurs. The person inspecting or examining the rope should recognise that martensitic embrittlement may have occurred and closely examine the rope with a magnifying glass for fine martensitic cracks on the worn crowns. The presence of such cracks should trigger a more frequent examination, and the withdrawal of the rope from service as soon as the wires begin to break at the worn crowns.

82 Martensite is a very hard and brittle form of steel produced when steel is heated to a high temperature (ie above 700°C for steels used in wire rope manufacture) and then suddenly cooled. It is like the steel of which files are made; if a file is dropped or bent it will break, for it has virtually no ductility. If a fast moving rope rubs even lightly against a metal obstruction, or if a slower moving rope grinds heavily against such an obstruction, the resulting friction can heat almost spontaneously the surface of the rubbed wires to above 700°C, but only to a depth of about 0.02 mm. As soon as the source of friction is removed the heat is quickly carried away to the colder metal of the wire just underneath the heated surface. The surface of the wire cools very quickly and results in the surface becoming brittle martensite. As the crowns of the outer wires are in hardest contact with the metal obstruction, the martensite tends to form there.



Figures 62d:
Martensitic embrittlement

83 When the wire is subsequently bent, the brittle surface will develop a series of cracks along or near its centre line (Figure 62d), each about 0.02 mm deep and running across the worn crown of the wire. These cracks will in time become fatigue cracks, leading to wires breaking in fatigue. Martensitic embrittlement is therefore a potentially dangerous form of deterioration if it is not discovered.

84 When corrosion affects a martensitic surface it enters the cracks and attacks the normal steel below the surface rather than the hard martensitic steel. A corrosion pit forms at the bottom of each crack and extends to join up

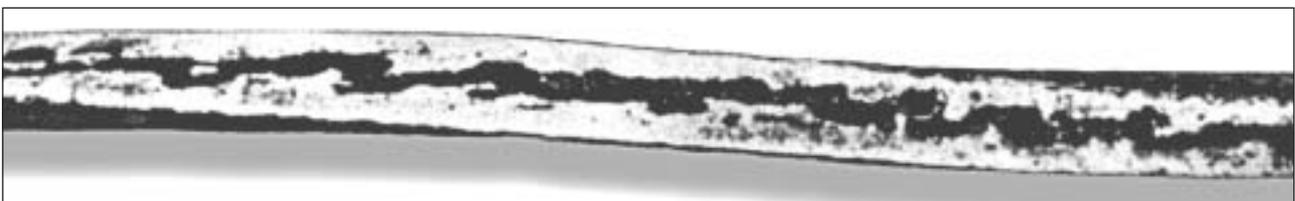


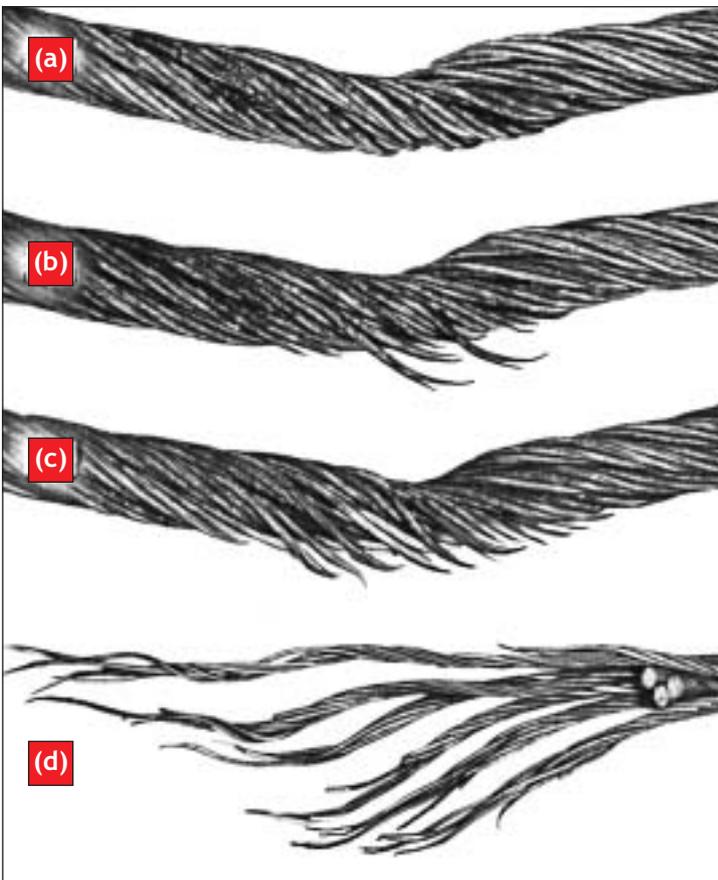
Figure 62e: *Chain pitting on a wire*

with a pit at the bottom of the next nearby crack. The undermined surface then flakes off leaving a chain or chains of elongated corrosion pits following the strip(s) of martensite on the surface. Such chain pitting (Figure 62e) is one of the signs of martensitic embrittlement, and is different from the normal random pitting shown in Figure 56a.

Surface embrittlement fractures

85 Surface embrittlement fractures are always fatigue type fractures, because they form only when the original surface cracks become fatigue cracks of sufficient depth to break the wires. They are always situated at the worn crowns of the wires and nowhere else.

86 Those examining ropes can detect surface embrittlement by removing some unbroken wires from a suspect rope and bending one wire to stretch the worn crown. If the surface of the worn crown is embrittled cracks will open, and if bending is continued the wire will break. If the cracks start to open at the edges of the worn crown where there are fins, then the rope has plastic-wear embrittlement. If the cracks start to open at or near the centreline of the worn crown and not at the edges, then the rope has martensitic embrittlement.



Figures 63a-d: Kinking

ACCIDENTAL DAMAGE AND DISTORTION

87 Accidental damage and distortion are not really forms of deterioration, but it is very important that the person inspecting or examining the rope realises that they may lead to unexpectedly rapid deterioration at the affected part.

88 A rope which has been dented by an impact may still appear to be in reasonably good condition, but fatigue may subsequently develop at the damaged part. If the impact has permanently deformed some of the wires into elbow-shaped bends, then every time the load varies during operation the bent wires will partly straighten and then return to their bent condition. In other words they will be repeatedly bent at one point, as in the case of accentuated secondary bending, and they will probably break in fatigue. If the impact has forced apart some wires or strands, leaving the rope open at that place, moisture will enter readily and internal corrosion or corrosion-fatigue may develop at the damaged part.

Kinking

89 A true kink is formed when a rope goes slack, forms itself into a close loop, and is pulled tight. The resulting kink forms a short but very tightly twisted spiral, with a shortened length of lay. The elbow-shaped deformations formed can result in concentrated and rapid wear on their outer sides. Figure 63 shows a kink at four different stages of failure in the same rope.

90 If a rope is permanently deformed into an elbow-shaped bend, but with no change in length of lay at the deformation, then the deformation is not a true kink

but a permanent bend which may have been caused by irregular coiling on the drum or in some similar incident. The rate of deterioration of a rope in such a case will depend on the extent to which the individual wires are bent at the deformation.

Slack rope 91 If slack rope forms so that a coil or coils fall over the side of a winding drum and are pulled tight before being noticed, wires are likely to be damaged and sheared at that part which has contacted the drum shaft and drum flange (X and Y Figure 64).

Distortion in ropes 92 Waviness (or corkscrewing) is a form of distortion usually confined to locked coil ropes, but it can also affect a stranded rope working in too tight a pulley tread. In this form of distortion the rope assumes a spiral form, something like a corkscrew, over a considerable length (Figure 65a). Bright external wear is concentrated at the crests or high spots of the waves.

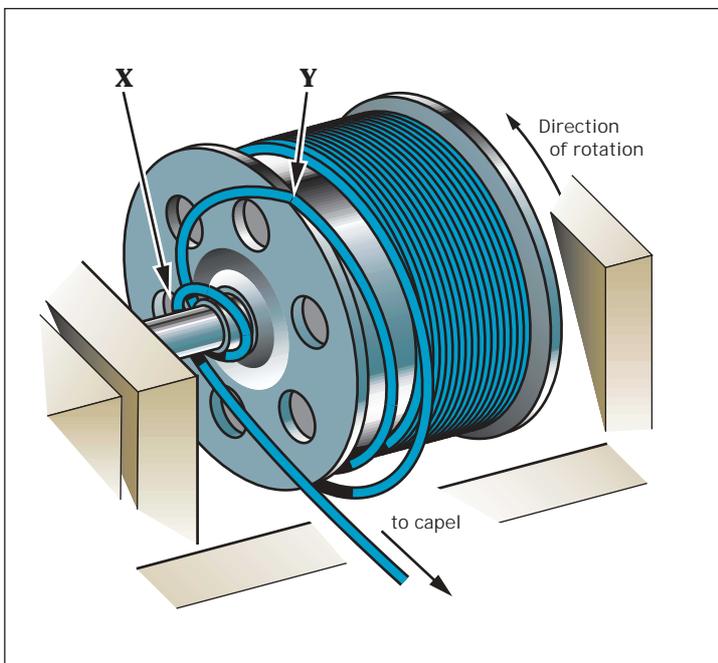
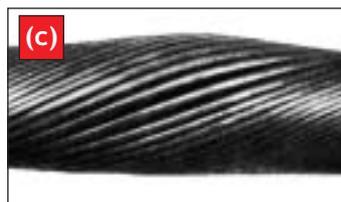


Figure 64: Damage through slack rope

93 A rope which is fixed at both ends can rotate in one direction at one part of its length provided that it rotates in the opposite direction at some other part. Part of the rope might therefore rotate such that the inner layers tighten while the wires in the outer layer loosen (Figure 65b). This tightening of the inner layers shortens that part of the rope, at the same time loosening the outer wires allowing them to lift and overlap.

94 In locked coil ropes, one cause of distortion is lack of lubricant between and directly underneath the outer wires; this leads to the outer wires binding or seizing up, instead of slipping freely on one another and on the underlying wires. Another cause is loose or loosened lay; the inner layers tend to rotate the rope around its centreline, and unlay themselves. If the outer layer (laid in the opposite direction to the inner layers) is not tightly laid on the inner layers the rope will tend to rotate (unwind) until the outer wires tighten. The loosened inner layers tend to bulk and exert outwards pressure on the outer layer, so causing a bulge or hernia (Figure 65c).



Figures 65a-c: Corkscrew distortion in a locked-coil rope

95 Most ropes tend to twist or rotate when loaded, although some types are designed to reduce this to a minimum; for example, locked coil winding ropes and multi-strand ropes.

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96 The amount of twist depends upon the load applied and the length of the rope. In the case of winding ropes operating without balance ropes, the length of rope and the tension decrease as the conveyance is wound up the shaft, and therefore the amount of twist will vary along the rope's length.

97 Locked coil ropes less than 38 mm diameter have fewer layers of wires and are less easily affected by those factors which can cause waviness - corrosion, drying out of lubricant, pinching in pulleys or incorrect handling. This is one reason why in modern friction winding installations several small winding ropes are used (multi-rope friction winding) instead of one large rope (single-rope friction winding).

98 Another cause of rope rotation is a large fleet angle because, to take the case of a descending rope, the rope will first land on the flange of the headframe pulley and then roll into the tread as it travels around the pulley. This rolling again involves rotation of the rope.

99 In tower mounted friction winders, misalignment of the driving groove and the deflection sheave will create a constant fleet angle causing the rope to rotate in one direction throughout the wind.

**Fractures at damage
and distortions**

100 There may be no wire fractures at damaged or deformed parts unless the rope is allowed to remain in use too long after deformation. If wire fractures appear, their type will depend on the nature of the damage or deformation and on the working conditions. For instance, a kinked winding rope will develop fatigue fractures because a winding rope wears only slowly and fatigue will, therefore, have time to develop. People who inspect ropes should examine thoroughly any deformation they find and assess how the deformed wires will act during further service:

- If they are repeatedly bent and straightened, they are liable to break in fatigue.
- If they protrude above the level of other wires, localised wear could occur.
- If they have been displaced leaving the rope open, localised internal corrosion might occur.

101 Even if there are no broken wires, a distorted rope may still cause excessive sheave wear.

REPAIR OF LOCKED COIL WINDING ROPES

102 If a broken wire is detected in the outer layer of a locked coil winding rope, it should be repaired by lifting out the wire over a distance of approximately 500 mm either side of the break, then either annealing and caulking them back

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into position, leaving a small gap between the wire ends, or by brazing in a new length of wire. These are highly skilled operations that only the rope manufacturer's personnel should undertake.

NON-DESTRUCTIVE TESTING (NDT)

103 The non-destructive testing (NDT) of ferromagnetic wire ropes is a specialised operation often involving the use of equipment purpose-designed for particular types of rope. Appendix 6 contains an outline procedure for the NDT of locked coil ropes. Where applicable, it can also be used as a guide for the NDT of other rope types.

104 Different rope constructions are used for different applications in mines and some of these present more difficult NDT and visual examination problems than others. This particularly applies to locked coil and half locked coil ropes which have a greater density of wires than those in a stranded rope of the same diameter. It is essential therefore to select appropriate NDT equipment. There are a number of different instruments that are suitable for the NDT of stranded ropes, but there is a more limited choice for locked coil ropes.

105 NDT can be carried out using alternating current (AC), direct current (DC) and permanent magnet type instruments. Data are presented in graphical form and will indicate the presence of broken wires, internal and external corrosion and general wear in a rope. If a rope is severely corroded, the NDT instrument may not detect internal broken wires.

106 It is also essential to recognise that winding ropes are safety critical components and as such, testing and the reporting of tests should only be carried out by suitably trained and experienced personnel, which is also covered in Appendix 6. European Standard prEN 12927-8, *Safety requirements for passenger transportation by rope - Part 8: Non-destructive testing*²⁰ also provides valuable advice in the practice of NDT of wire ropes.

107 It should be understood that the NDT is an aid to visual inspection, but it has the advantage of being able to detect internal or hidden defects. It is therefore useful as a routine periodic condition monitoring test providing data to inform judgements on the condition of the rope. Although data can be obtained from a single test to ascertain the condition of the rope at the time of test, the main advantage of NDT lies in the collection of data as a result of routine periodic monitoring. Comparing data from routine periodic NDT allows any rope deterioration to be detected at an early stage, and the rate of deterioration can be assessed during its service life.

108 Where it is intended to monitor the condition of a winding rope throughout its operational life then it is recommended that an NDT be carried out on the winding rope when first installed in order to reveal any manufacturing discrepancies, and to provide a database against which the findings of further

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tests may be evaluated. The provision of such a condition monitored database is an essential requirement when applying to the Health and Safety Executive for permission to use a rope beyond the end of its specified life.

109 The interpretation of the results requires expert knowledge. Rope manufacturers and specialist testing companies can provide an NDT expert service.

110 An ultrasonic testing method is available for the NDT of resin capped guide ropes in the area of the headframe capping, where fatigue effects are most likely and where other NDT methods described above are unsuitable. It is applied both to the outer wires of the rope, immediately below the guide rope capping, and to the inner wires of the rope where they protrude above the top of the capping, and can detect broken wires in the rope in that area. It is good practice to undertake such tests periodically; the interval between tests depending on shaft operating and environmental conditions. NDT should also be used when considering an extension to the normal recapping period of five years. Ultrasonic NDT is unreliable for white metal capped guide ropes.

WHEN TO DISCARD A ROPE

111 In order to decide when a rope should be discarded it is necessary to take into account the state of the rope and the conditions under which it works. A rope which shows some deterioration but which has done little work may be suitable for continued use, whereas another rope with the same degree of deterioration, but which has done a great deal of work may have reached the end of its useful life, as the onset of fatigue or corrosion-fatigue will be much more likely in the busy rope.

112 As a general rule a shaft rope should be taken out of service when any one of the following occurs:

- when the factor of safety has become too low (when the reserve of strength is no longer sufficient to ensure that the rope can safely withstand the repeated shock loads, bends, etc);
- when the loss in rope strength due to wear, corrosion, or both is approaching one-sixth (or 16%) of the original strength;
- when the loss in rope strength due to fatigue, corrosion-fatigue, or surface embrittlement, or due to cracked or broken wires of any kind, is approaching one-tenth (or 10%) of the original strength. The loss in strength may be estimated by regarding all broken or cracked wires within a length of two rope lays as no longer contributing any strength to that part of the rope;
- when the outer wires have lost about one-third (or 33%) of their depth as a result of any form of deterioration;

- when the outer wires are becoming loose and displaced for any reason;
- when the rope has become kinked or otherwise deformed, distorted, or damaged, and the affected part cannot be cut out;
- when the rope has been subjected to a severe overwind or overload, or to severe shock loading, as a result of an accident or incident;
- when an examination or NDT of the rope leaves any doubt as to its safety on any grounds;
- when a rope, which is still in good condition reaches the end of its specified life (see paragraph 129 to 130 of the ACOP to the 1993 Regulations for further guidance³).

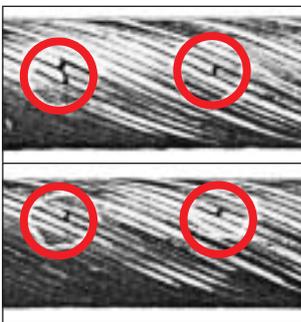


Figure 66: Fatigue cracks (within circles) along one side of a locked-coil rope

TYPES OF DETERIORATION IN SHAFT ROPES

113 Some of the guidance in this section is in repetition of that given earlier, but is provided for completeness and ease of reference to the accompanying tables.

TYPES OF DETERIORATION AFFECTING WINDING ROPES

114 Table 14 lists the main types of deterioration found in winding ropes together with the possible causes and suggested remedies.

Deterioration found	Position and extent of deformation	Possible cause	Possible remedy
Wear, external abrasive (Fig 50a)	Localised along one side	Rope slip on pulley as a result of rapid braking of winding machine	Change in winding procedure
	Intermittent	Rope vibrating excessively and rubbing against	Check drum surface for irregularities (vibrations may arise at crossover points on multi-layer winders)
Plastic deformation	External (Fig 50b) or internal (severe interstrand nicking)	Obstructions	Replace round strand rope by triangular strand or locked coil, or use larger diameter drum (see Table 15) or use rope of more flexible construction Pulley groove diameter should be at least 5 to 10% greater than the actual rope diameter

Deterioration found	Position and extent of deformation	Possible cause	Possible remedy
Corrosion (Fig 56 a-c)	Localised	Cages always parked in same positions; same part of rope always exposed to corrosive conditions	Vary parking positions; attempt to remove or reduce cause of corrosion
	Throughout length of rope	Inadequate lubrication	More frequent lubrication or use of more effective lubricant
		Severe environmental conditions	Use of galvanised rope; more frequent lubrication; some form of weather protection, if possible
Corrosion fatigue	At any part	Conditions likely to cause fatigue together with those favouring at least some degree of corrosion	Removal of conditions likely to encourage corrosion and fatigue
Numerous broken wires, all showing evidence of fatigue	(i) throughout rope	a) excessive rope vibrations caused by misaligned rigid guides or uneven drum surfaces, or	Improvements to guides or drum
		b) too small a drum or pulley diameter, or	Using rope of more flexible construction
		c) excessive looseness in rope; secondary bending, or	Consider using ropes of equal lay
		d) overloading of rope	Check loads
	(ii) along two lines parallel to one another and at about 140° round rope circumference from one another (Fig 66)	too small a pulley groove	Enlarge pulley groove diameter to at least 5 to 10% greater than the actual rope diameter
	(iii) at neck of capping (Figs 42 and 68)	(a) frequency of winding cycle	Increase frequency of recapping until cause of broken wires can be found remedied
(b) insufficient length of undisturbed rope within mouth of socket		Use correct capping procedures	
(c) wires in brush not properly cleaned causing uneven distribution of load		Wire brush, always very thoroughly degreased before being capped with resin or white metal	

Deterioration found	Position and extent of deformation	Possible cause	Possible remedy
Numerous broken wires, all showing evidence of fatigue	(iv) localised, outer wires only, martensite possible present	(d) lack of penetration of white metal; incorrect white metal capping temperature or type of socket used (e) mouth of socket or capping wedges not smoothly radiused (f) excessive rope vibrations caused by misaligned rigid guides, uneven drum surface or unbalanced skips Damage by falling object	Use correct capping procedures, sockets to NCB Spec 465 and white metal to BS 643 or NCB Spec 483 Check radius of these edges and inform superior so that effective action may be taken Improvements to guides or drum
Distortion (Figs 15, 65, 69)	(i) sometimes localised (hernia), but often throughout length of rope (waviness) (ii) localised; kink or permanent bend	a) loss of useful internal lubricant, or b) too large a fleet angle, or c) too small a pulley groove Occurrence of slack rope	More frequent lubrication by more penetrating lubricant Fleet angle should not exceed 1.5° Enlarge pulley groove diameter to at least 5 to 10% greater than the actual rope diameter Greater care in rope handling
Martensite embrittlement	Possibly localised, along one side	Rubbing at speed against steel obstruction	Removal of the obstruction

Table 14: Winding ropes - Types of deterioration and possible causes

WEAR

115 When external wear on a winding rope is heavy and of the abrasive type it may have been caused by the rope vibrating excessively and striking some obstruction such as the edge of the rope hole in the engine house or the detaching plate in the headframe. Such vibrations can be caused by the crossover points on multi-layer winders and particularly if the 'risers' which are used to aid the rope to rise at the crossover point are poorly designed; which

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may also cause premature wear on the rope at that point. Similar wear can also be caused by the rope slipping on the pulley during braking, etc.

116 Plastic deformation on a rope, either externally or internally, is usually the result of high bearing pressures, against the drum, against other coils, or in a pulley groove which is too small for the rope. A small ratio (drum to rope), ungrooved steel-surfaced drum will provide only a small area of contact for each coil of rope and could cause plastic deformation.

117 The values given in Table 15 are the minimum drum and pulley/rope diameter ratios recommended for all winding ropes.

Rope type	Rope size	Ratio
Locked coil ropes	< 26 mm	80
	26-44 mm	100
	> 44 mm	120
Stranded ropes	All sizes	80

Table 15: Minimum drum and pulley/rope diameter ratios for winding ropes

118 Alternatively, the wear may be a combination of plastic deformation and abrasion as a result of the rope bearing heavily against the flange of the pulley, or against the next coil on the drum when the rope makes its largest fleet angle with the pulley; this angle should not exceed 1.5° (1 in 38).

119 A round strand rope which coils on top of itself in two or more layers on the drum will tend to show plastic deformation, for there is only wire to wire contact, of very little area, between a coil of rope in the top layer and coils in the under layer. A triangular-strand rope or a locked coil rope has a greater bearing surface and a change to such a rope may avoid further plastic deformation. Such damage may also be caused by a pulley groove which is the wrong size for the rope; the diameter of the groove for a locked coil rope that operates on steel or cast iron pulleys should be at least 5% to 10% greater than the nominal diameter of the rope and for a stranded rope that value is 7.5% to 10%. Where polyurethane inserts are installed on headgear pulleys or friction winder deflection sheaves the groove radius should be maintained within the range of 12 to 20% of the actual rope radius. A more specific value within that range is dependent on the grade and hardness of the polyurethane and advice on the matter should be sought from the supplier of the inserts and the rope manufacturers.

120 If a rope is subjected to corrosive conditions as well as wear, the rate of deterioration will be increased. The external wear will continuously remove the outer layer of corrosion products leaving fresh metal open to attack whilst

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corrosion will deepen further the nicks and grooves at contact points between wires within the rope.

Corrosion

121 The most efficient method of preventing corrosion is, of course, to remove all causes of corrosion, but that is not always feasible. However, leaking pipes should not be allowed to blow steam on a rope, nor should water be allowed to drip on a rope if it can be collected and led elsewhere. The parking positions of the conveyances during idle periods should be changed from time to time so as to prevent any one part of the rope length being exposed to the most corrosive location for too long.

122 Ropes should be kept well lubricated at all times, as a defence against corrosion, unless there is a sound reason against lubrication. For instance, the outside of a friction-winding rope must not be permitted to become greasy in case it slips on the driving sheave, but the engineer may agree to different parts of the rope length being lubricated at different times, using a thin proprietary oil which will penetrate the rope to some extent and which can be wiped off the exterior before winding is restarted.

123 In general, only rope lubricants should be used on ropes. Special lubricants exist which contain additives to improve their usefulness such as substances that help to prevent corrosion (rust inhibitors) and those that get the lubricant into direct contact with the wire surface even when the surface is wet (water repellents). Rope manufacturers and oil companies will advise on the use of such lubricants or other corrosion inhibitors. Every effort should be made to ensure that the service dressings are compatible with the manufacturer's original lubricant.

124 The best defence against corrosion is the use of ropes of galvanised finish. Even if there were no lubricant present, the zinc coating on the wires of such ropes would protect the steel for many months under corrosive conditions, but eventually the zinc would be corroded away. Unless there are sound reasons to the contrary (eg friction winders) galvanised ropes should be kept well lubricated at all times, particularly in those areas that may be subject to corrosion when the conveyances are in their park positions ie, shaft insets, fan drifts, shaft air heaters, rope holes in towers or headgears. Specialist products may be available for additional protection in difficult areas, however every effort should be made to ensure that such products are compatible with the manufacturer's original lubricant. Under such conditions the zinc coatings will protect the wires throughout the life of the rope except, perhaps, on the rope exterior where the zinc may be removed by wear to an extent which permits corrosion of the steel. The exterior, however, can always be readily examined.

Fatigue

125 Fatigue is one of the causes for the premature discard of winding ropes. The onset of fatigue can be delayed if precautions are taken to avoid winding shocks, sharp bending of the rope around pulleys and drums of insufficient size, loosening of the lay of the rope with consequent accentuation of secondary bending and by correct selection of the rope to suit the application.



Figure 67a: Vertical acceleration

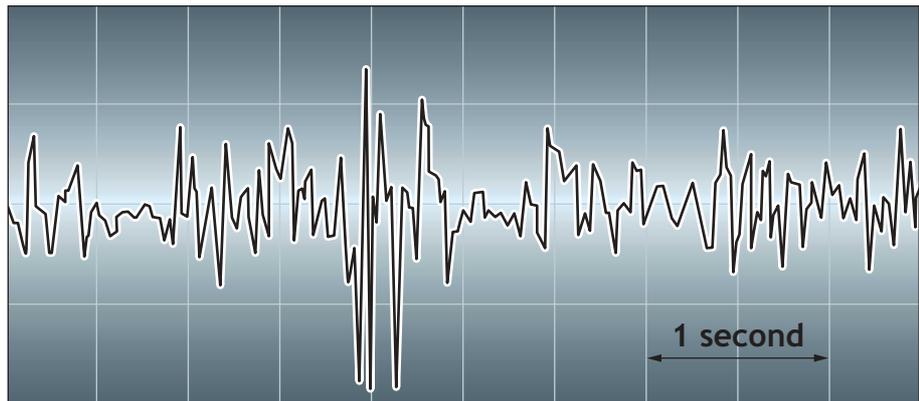


Figure 67b: Horizontal acceleration

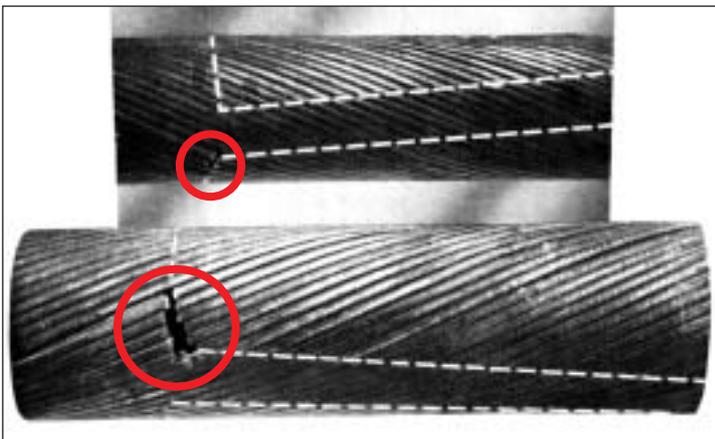


Figure 68: Front and rear views showing broken outer wires on a guide rope where rope was in contact with corners of wedges (position of wedges indicated by broken lines)

126 Severe rope oscillations, indicated by peaks on the decelerometer records for that installation (Figure 67) cause increased stresses in the rope leading to broken wires either throughout the working length or localised at the capping as a result of sideways flexion. The mouth of a resin or white metal socket or the narrow end of capping wedges should always be smoothly radiused.

127 If, at the beginning of a wind, the cage is accelerated smoothly, the resulting winding shocks will be small. If, however, slack rope or slack chains are abruptly snatched tight, the load on the rope may be doubled for a

moment and the cage will bounce on the rope, causing further shocks; which is one reason why the rope length should be kept properly adjusted. Badly aligned rigid guides or unbalanced skips may set up cage chatter and also cause wires to fail in fatigue near the capping (Figure 68).

Corrosion-fatigue

128 Corrosion-fatigue occurs in conditions which favour both corrosion and fatigue. It is the most dangerous form of deterioration since there is no lower limit of loading below which the rope wire is safe from such deterioration. However, if corrosion can be eliminated, corrosion-fatigue cannot occur and

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only the possibility of pure fatigue remains. Thus, the first step is to eliminate corrosion by using galvanised ropes, by keeping the rope well lubricated at all times (unless there are sound reasons to the contrary) and, if possible, by the removal of the cause of corrosion.

Distortion **129** The likelihood of distortion will be reduced if the rope is kept tightly laid up, if the pulley tread is within the correct limits for the rope, if the fleet angle does not exceed 1.5 degrees and if the outer wires are not allowed to become seized through lack of lubricant.

130 Waviness has little adverse effect on the breaking strength of a rope, but the decision to allow the rope to continue in service or to be replaced should be taken in consultation with specialists, for example, the rope manufacturers. The decision will be based on operating duties, the length and depth of the wave, the rate of development and its position in the rope.

131 Birdcages (Figure 65b), resulting from loose outer wires and hernias (Figures 65c and 69), resulting from inner wires protruding and displacing outer wires have a different effect from that of a wave on the strength of the rope and the rope should be removed.

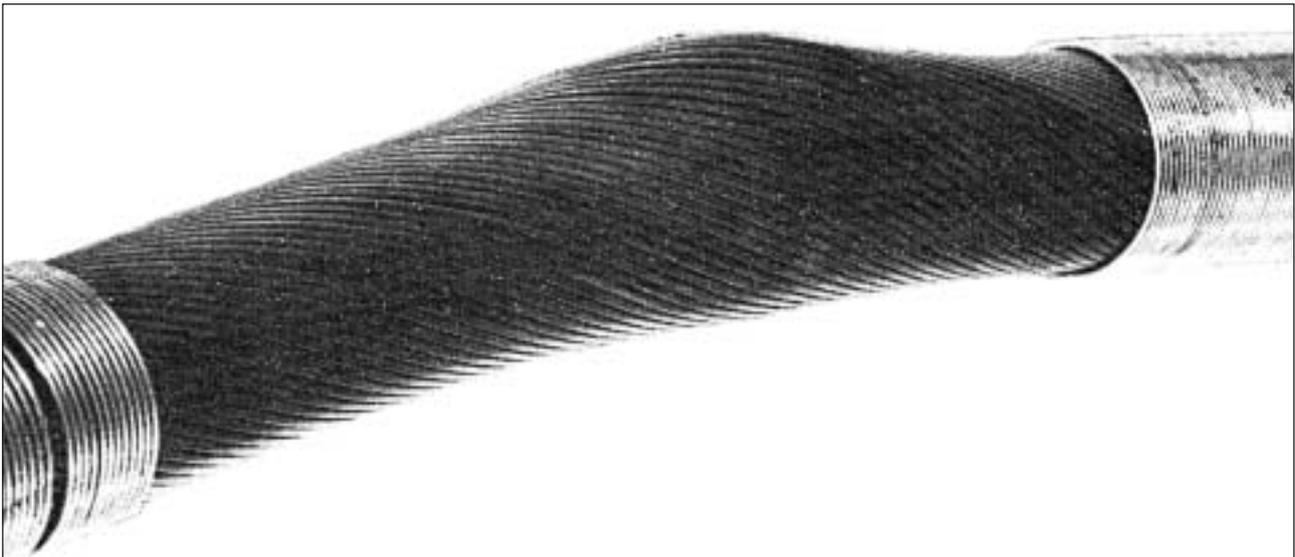


Figure 69: Distortion in locked coil rope (hernia)

132 Kinking can occur only while a rope is very slack and the only time a winding rope is likely to become so slack is during installation, recapping, cage suspension gear changes or cage changing. Thus kinking can usually be avoided by preventing slack rope.

Martensitic embrittlement **133** Impact on a moving rope can produce a martensitic surface on the wires with subsequent wire breakage. It is important, therefore, to ensure that close to the rope path there are no steel joists or other obstructions which the rope might contact as it oscillates during a wind.

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TYPES OF DETERIORATION AFFECTING BALANCE ROPES

134 Table 16 lists the main types of deterioration found in balance ropes together with the possible cause and suggested remedies.

Deterioration found	Position and extent of deterioration	Possible cause	Possible remedy
Corrosion	Sometimes localised but often throughout length of rope		(a) collection and drainage of shaft water (b) use of galvanised rope (c) more frequent lubrication (d) use of more effective lubricant
External wear probably quite light	Probably localised	Bumping against relatively soft obstructions such as wooden beams	(a) greater care during rope installation to avoid permanent bends in rope (b) minor shaft modifications to remove obstructions
External distortion (Fig 70)	Possibly localised	Damage by falling object	Careful watch on rope required to ascertain appropriate action
Tangled rope (Fig 71)	Long length tangled together	(a) a large amount of spillage in the sump (b) inadequate balance rope loop control	Frequent collection of spillage Reassess balance control system

Table 16: Balance ropes - Types of deterioration and possible causes

Corrosion 135 The most common form of deterioration in balance ropes is corrosion. When inspecting a multi-strand balance rope, the examiner should look for evidence of external corrosion entering the rope between the strands and for looseness of the outer strands that would occur when corrosion between the layers of strands became advanced.

Wear 136 Internal wear in a balance rope will be heavy if it strikes any shaft fittings even timber, too often and too violently. It should not be assumed that there is no internal wear merely because the only evidence of external wear or pressure is light polishing of the rope surface.

137 Striking of a rope against timber may give only moderate polishing and show moderate external wear on the rope exterior but deep nicking in the rope interior.

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138 Those responsible for examining ropes should check for any localised reduction in diameter and, if possible, check the behaviour of the loop during winding. Should it be necessary, it is possible to examine the interior of the rope by twisting it between two suitable clamps to expose the interior.

139 In flat ropes, wear and breakage of the stitching strands is fairly common; this leads to individual ropelets becoming detached and calls for re-stitching of the affected length, which is normally carried out by the rope manufacturer.

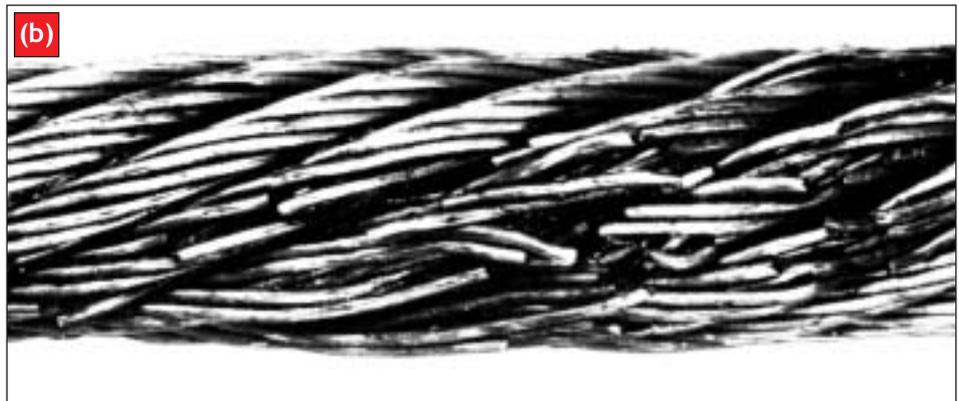
Damage and distortion

140 Occasionally, a balance rope may be damaged by an object falling down the shaft and striking the rope sufficiently hard to displace some of its outer strands. Although the external damage may appear relatively slight, fatigue breaks are likely to develop in the inner wires as a result of the increased secondary bending that will take place. Figure 70 shows one such example four months after being damaged. A damaged balance rope should be regularly and carefully examined.

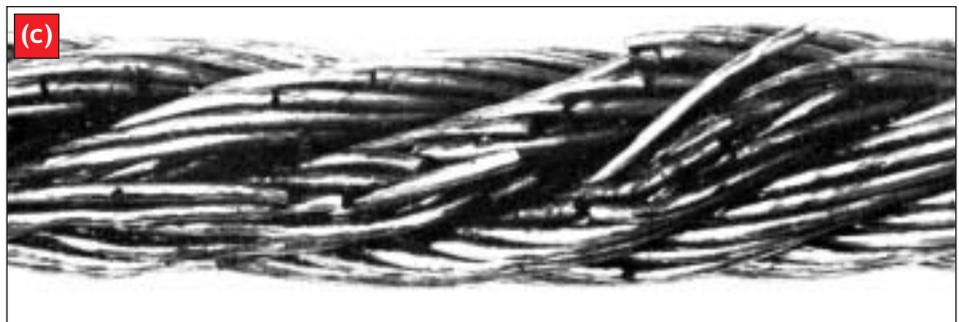
Figures 70a-c: Fatigue breaks in inner strands of balance rope as a result of external damage



(a) damaged outer wires, front and back views



(b) intermediate strands



(c) inner strands

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141 If spillage in the sump is allowed to build up to reach the balance rope, the loop will become displaced; it may then become entangled (Figure 71), and fail under holdfast conditions. Methods of controlling spillage and of monitoring any unusual rise in the balance rope loop have been discussed earlier in this chapter.

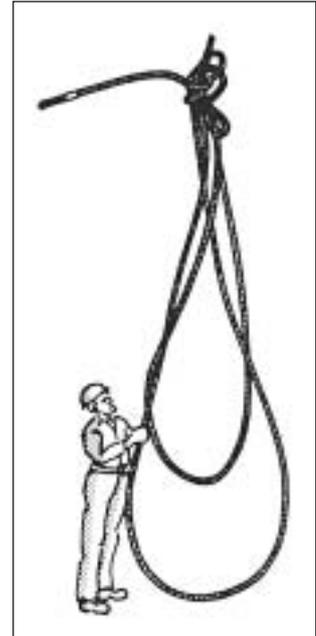


Figure 71: *Knotted balance rope, the result of spillage in the sump*

When to discard a balance rope

142 The part most likely to be weakened by deterioration is the lengths of rope that form the loop when one or other of the conveyances is at pit bottom. The rope is more likely to break when one of the conveyances is near the top of the shaft, when the most weakened part of the rope has to support the greatest length of rope.

143 Should the balance rope break under these circumstances it would fall on the lower cage, and at the same time throw the winding system out of balance increasing the likelihood of either an over-wind on a drum winder, or rope slippage on the driving sheave of a friction-winder.

144 ACOP 129 of the 1993 Regulations³ requires that balance rope life should not exceed five years on drum winders and three years on friction winders unless other directions have been given by an HSE inspector.

TYPES OF DETERIORATION AFFECTING GUIDE AND RUBBING ROPES

Wear

145 Table 17 lists the main types of deterioration affecting guide and rubbing ropes together with the possible cause and suggested remedies.

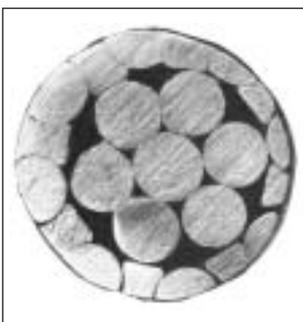


Figure 72: *Half-locked guide rope, showing one-sided wear*

146 One-sided wear affects all the wires because of the rope construction (Figure 72), rapidly reducing rope strength. The use of brass or phosphor-bronze cage shoes helps to minimise such wear and rotating the rope at intervals helps to equalise it round the rope circumference.

147 Where sleeves are fitted to guide ropes in the sump, localised wear may occur. It is critical that the sleeves should be removed at intervals depending on shaft conditions to examine the rope and re-pack with lubricant (Figure 73).

148 Appendix 7 shows a chart that gives the reduction in effective cross-sectional area of a guide rope for both even and uneven wear.

Corrosion

149 If corrosion (Figure 74) throughout the length of the rope is a problem more frequent lubrication or a different type of lubricant may cure the trouble. Any shaft water, even if not particularly corrosive, should be diverted away from

Deterioration found	Position and extent of deterioration	Possible cause	Possible remedy
Wear	(i) along one side of rope (Fig 72)	Lateral force on conveyance	Ropes should be given a quarter turn at intervals to spread the wear evenly
	(ii) localised	(a) permanent bend, or (b) opposite fan drift, at insets, at point of entry or exit from receivers, at sump timbers (c) immediately below headgear capping (between supports)	Greater care during installation Lift rope at intervals to change position of increased wear Correct positioning of termination
Corrosion (Fig 74)	(i) throughout length of rope	Lack of sufficient lubrication, use of unsuitable lubricant, or water in the shaft	More frequent lubrication, divert water away from ropes, use lubricant with water-displacing additives
	(ii) localised	Possibly in confined space, eg where passing through hole in sump boards	Fit sleeve well packed with grease (Fig 73)

Table 17: Guide and rubbing ropes - Types of deterioration and possible causes

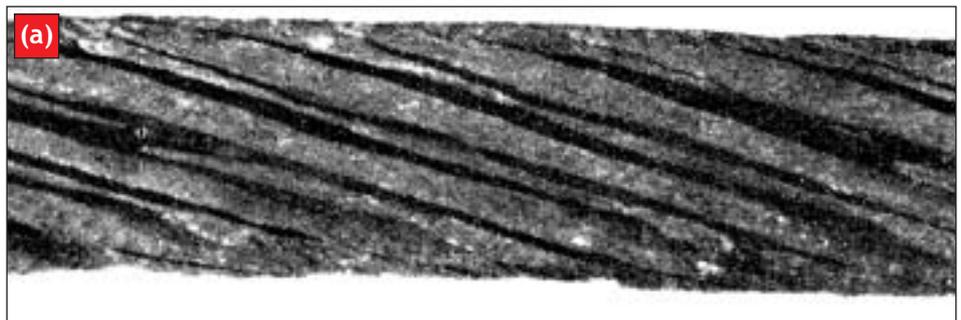
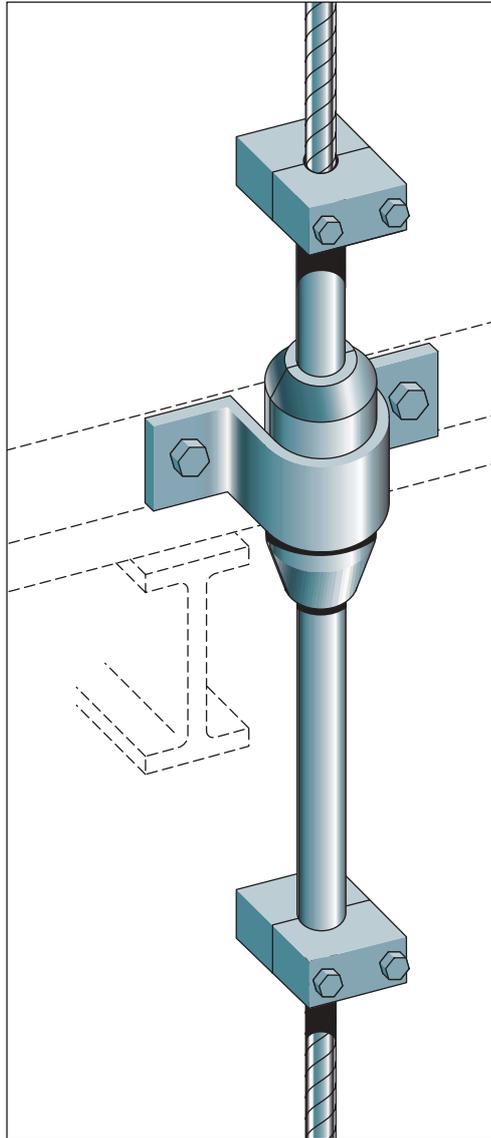
the ropes. Close scrutiny should always be kept for localised corrosion, even on ropes which are otherwise little affected by it.

150 Localised corrosion may occur in confined spaces such as the holes where the rope passes through the sump boards or at parts where the lubricant is dried by the effect of shaft heaters and more frequent lubrication should be given to these parts.

When to discard a guide or rubbing rope

151 As with other ropes, a guide or rubbing rope should be discarded when the outer wires have lost one-third (about 33%) of their depth by wear or corrosion or both, or when the rope appears to be no longer in a safe condition for any reason such as the appearance of broken wires. There is no legal or statutory limit to the length of life for guide ropes and rubbing ropes. It is unusual for a rope to remain in service for more than 20 years, and many shafts ropes need replacing much earlier in their lives. ACOP paragraphs 202 and 203 of the 1993 Regulations³ provide further advice on this matter.

Figure 73: Guide sleeve



(a) sample after cleaning

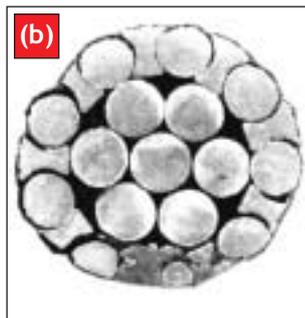


Figure 74:
Corroded guide rope

*(b) x-section of corroded
guide rope*

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APPENDIX 1

REPORT ON THE CAPPING OF SHAFT ROPES USING RESIN

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APPENDIX 2

**REPORT ON PERIODIC EXAMINATION OF WINDING ROPES AND
BALANCE ROPES**

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APPENDIX 3

**REPORT OF INTERNAL EXAMINATION OF LENGTH OF WINDING ROPE
CUT OFF DURING RECAPPING**

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APPENDIX 4

**SAMPLE OF A REPORT OF THE THOROUGH EXAMINATION AND
TESTING OF A ROPE SAMPLE**

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APPENDIX 5

REPORT OF PERIODIC EXAMINATION OF GUIDE AND RUBBING ROPES

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APPENDIX 6

PROCEDURE FOR THE NON-DESTRUCTIVE TESTING (NDT) OF LOCKED COIL ROPES (Can also be used, as appropriate, as a guide for the NDT of other types of rope)

General requirements

- 1 Only suitably trained people authorised by the mine manager should undertake the NDT of wire ropes.
- 2 Those carrying out the operation should follow managers' rules for such work.
- 3 The mine mechanical engineer should ensure that a competent person:
 - (a) carries out a risk assessment and produces a method statement covering the NDT operation and associated activities, including access to temporary workplaces;
 - (b) supervises the safe completion of the NDT operation and associated activities;
 - (c) ensures that only authorised winding engine drivers operate the winding apparatus during testing;
 - (d) ensures that any guards, covers, etc, that have been removed to allow NDT to take place, are replaced;
 - (e) ensures that safety harnesses are provided and worn by all persons at risk of falling from height;
 - (f) ensures the availability at all times of adequate communications between the NDT operatives, the winding engine operator, and, where appropriate, the banksman and onsetter.

Other precautions

- 4 NDT equipment in contact with the rope must be securely anchored to prevent the equipment moving excessively.
- 5 People must stand clear of the winding apparatus, eg headgear pulleys, while it is moving.
- 6 People must handle all substances that are potentially hazardous to health in accordance with the instructions for their safe use, provided in accordance with the requirements of the COSHH Regulations.¹⁰

Training

- 7 Adequate training and experience for NDT operatives is that which meets the requirements of prEN 12927-8 - Safety requirements for passenger transportation by rope - Part 8: Non-destructive testing.

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8 The operator should have sufficient technical knowledge to understand how the NDT method works, and appreciate the implications and importance of NDT as an aid to visual inspection and the condition monitoring of winding ropes.

9 All NDT operators should be able to read the Jaeger J2 eye chart at a distance of 0.5 m, with the aid of spectacles if necessary.

Principle of operation

10 A test head containing permanent magnets, local faults (LF), cross sectional area (CSA) sensors and a distance measuring device is positioned around the rope. Data is transferred from the test head to an electronics signal processor. The processed signals are then sent to a recorder that meets the requirements of prEN 12927 - 8. It should incorporate an instantaneous visual output for on-the-spot analysis of the condition of the rope, and to aid any necessary visual re-examination.

11 All new NDT equipment should be subjected to an overall performance test on the locked coil test ropes at the Health and Safety Laboratory of the Health and Safety Executive.

Positioning of test head

12 The position of the test head at the start of the test should be selected to ensure the testing of the maximum length of rope possible. Its location will depend upon the type of installation, the accessibility of the rope, and the positioning of landings or platforms etc.

Drum winding systems

13 To ensure maximum coverage of the rope, the test head should be placed beneath the headgear pulley but above the detaching bell or catch plate. This will also ensure the testing of the rope's acceleration zone, ie the portion of the rope which passes over the headgear pulleys or onto the drum during the acceleration period of an ascending wind.

14 If the rope between the capping and the bell or catch plate is to be tested, the method statement should include the provision of suitable platforms to allow for safe access to the rope.

15 It is not normally practicable to test the length of rope between the drum and the headgear while the cage/skip is approaching the bottom of the shaft. Lateral and vertical motion of the rope at a test position close to the drum can make the test difficult to carry out.

Friction winding systems

16 The test head should be placed on the rope at a position as close as practicable to the conveyance or counterweight suspension point. To test the portion of the rope lying on the winding sheave, which cannot be tested from this position, the test head will need to be placed on the opposite side of the sheave.

Test procedure

17 In order to accurately determine the rope signature (benchmark) a new rope should be NDT'd as soon as possible following installation.

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General procedure

18 Before commencing the test establish that adequate communication facilities exist with the winding engineman, and that it is safe to approach the rope. All the signals and instructions to the winding engineman must be clear and unambiguous. Ensure that the rope to be tested is in the fully wound condition, ie with one of the conveyances at the surface.

19 Ensure that the internal diameter of the test head rope guide is such as to enable the rope to pass freely through the test head. Any adjustments required must be made at this stage.

20 Position the test head around the rope and ensure that the head is securely anchored to the structure in order to prevent excessive movement of the head.

21 After making all electrical connections, check that the distance indicator, LF and CSA channels are operating correctly. Carry out a simple function test by inserting a length of small diameter (eg 5 mm) wire into the test head between the rope and the sensors and observe the response on the LF and CSA channels as the wire is moved through the test head. If there is no response then check the equipment connections and repeat the test. The absence of any response indicates a fault in the test equipment.

Test sensitivity

22 Adjust the LF test sensitivity to give an indicated rope signature of typical amplitude between 5% and 10% of the full width of the on-site display unit.

23 Adjust CSA test sensitivity to give a drift of not more than 10% nominal at a background noise level of approximately 2% of the full width of the on-site display unit.

24 The overall test sensitivity should comply with the requirements of prEN 12927-8.

Rope speed and direction

25 The rope should pass through the test head at a uniform speed. The speed at which the rope can be tested will vary depending upon the type of installation and the response of the test equipment used, but should not exceed 2.5 m/s.

26 Testing should normally be carried out with the rope travelling in a downwards direction through the test head. If the direction of rope travel is reversed, the rope should run at no more than the slowest speed or 'creep speed' unless the test head is removed from the rope prior to rewinding.

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Distance of travel indication

27 Equipment conforming to the requirements of prEN 12927-8 will produce an indication for every 1 m of rope travel. It is often useful to have additional 'bench marks' which may be obtained from the conveyance position monitoring system.

Visual observations

28 Anomalies observed on the visual display, in particular LF indications which could possibly have arisen from external wire breaks should be investigated immediately. The suspect region of the rope should be thoroughly cleaned and subjected to a close visual examination. A record should be made of the position of any significant LF indication along the length of the rope and of the result of the visual inspection of the rope at those points.

Test precautions

29 The test head and rope should be closely supervised during testing to ensure:

- (a) that the test head remains securely anchored and firmly positioned around the rope. If it moves excessively the test should be stopped and the test head repositioned;
- (b) free movement of the rope through the test head.

30 Magnetic rope striping, where a series of uniformly spaced magnetic imprints are induced in the rope, is sometimes used as a means for the determination of the position of a conveyance within a shaft. The NDT operation can erase or corrupt the magnetic stripes in such ropes and therefore it is essential to ascertain whether the rope has been magnetically striped.

Method of reporting

31 The test supervisor should notify the mine mechanical engineer or a person nominated by the engineer of the test results before the test supervisor leaves the site. This will enable an appropriate decision to be made regarding any remedial action that may be necessary.

32 The test supervisor should submit an adequate written report as soon as practicable after carrying out the test. The report should include the following details:

- (a) identity of the NDT personnel and the employer;
- (b) the date of the test;
- (c) the date of any previous test;
- (d) the site and installation tested;
- (e) identification of the ropes tested;

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- (f) rope details (ie date put to use, manufacturer, diameter, construction etc.);
 - (g) type and make of test equipment used;
 - (h) test positions;
 - (i) identification of the length or region of the rope actually tested;
 - (j) approximate rope speed at which testing was carried out;
 - (k) any additional tests carried out.

33 An adequate report will identify the position, type and extent of any significant indications or observations. It should compare with previous test results, any increase in the size, number or extent of the indications or observations, and include a summary of the results and conclusions.

34 A record of all tests carried out together with details of the test equipment settings should be retained by the NDT operator and made available for the mine manager as necessary.

Interpretation of results

35 It is not possible to provide a definitive guide to the interpretation of the test results due to the variability between test equipment, difference in the method of display, physical differences between ropes etc. As a consequence it is important that the NDT personnel are familiar with the history of previous ropes on the same installation since this will provide valuable information which can be used as an aid to interpretation, and will supplement the skills and experience of such personnel.

36 Interpretation should be carried out in two stages. First, note the nature of all recorded LF indications and calculate their positions in the rope. The LF indications normally arise either as a consequence of an apparent increase in the rope cross section or an apparent decrease in cross section. The nature of the LF indications will allow apparent defects to be categorised. The CSA channel should be analysed in conjunction with the LF channel.

37 Secondly, carry out a more detailed analysis of the LF indications in order to identify wire break indications, particularly external wire break indications, and other factors which may give rise to a recordable indication.

38 Wherever possible the test results shall be correlated with previous test results on the same rope, and on the previous rope at a similar stage in its service life.

39 Further guidance may be obtained from HSL research report NoFE/02/07, entitled *Evaluation of instruments for non-destructive testing of wire ropes*.

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APPENDIX 7

**REDUCTION IN EFFECTIVE AREA DUE TO WEAR ON HALF LOCK GUIDE
ROPES**

Reduction in effective area due to wear of metric half locked coil guide ropes.

EVEN WEAR								Measured diameters (millimeters)	ONE SIDED WEAR							
Percentage of effective area remaining ROPE DIAMETERS (mm)									Percentage of effective area remaining ROPE DIAMETERS (mm)							
29	32	35	38	41	45	48	51		29	32	35	38	41	45	48	51
82.9								23								
68.5								24								
74.3	61.0							25	52.4							
80.4	66.0	55.2						26	62.9							
86.7	71.2	53.5						27	74.3							
93.2	75.5	64.0						28	85.7	56.3						
	62.1	88.7	58.2					29		66.0						
	87.9	73.5	62.3					30		76.7						
	93.8	78.4	66.5	57.2				31		87.9	59.5					
		83.5	70.9	60.9				32			68.7					
		88.9	75.4	64.8	53.8			33			78.4	54.3				
		94.4	80.1	88.8	57.1			34			89.9	62.3				
			84.8	72.8	60.5			35				71.0				
			89.8	77.1	84.0	56.3		36				80.1	57.2			
			94.8	81.4	67.6	59.4		37				89.8	64.8			
				85.9	71.3	62.7		38					72.9			
				90.5	75.1	66.0	53.5	39					81.4	53.8		
				95.2	79.0	68.4	61.5	40					90.5	60.5		
					83.0	73.0	94.6	41						67.5		
					87.1	76.6	67.8	42						75.1	56.3	
					91.3	80.3	71.1	43						83.0	62.7	
					95.6	84.0	74.4	44						91.3	69.4	
						87.9	77.9	45							75.6	53.5
						91.8	81.4	46							84.0	84.8
						95.9	84.9	47							91.6	71.7
							88.6	48								77.9
							92.3	49								84.9
							96.1	50								92.3

Notes:

1. Figures above zig-zag lines indicate wear in excess of one third outer wire depth where wire depth is 17.5% of the rope diameter for ropes up to and including 41 mm and 7.6 mm for all other types of rope.
2. Various manufacturers may supply ropes with different sizes of outer wires.

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APPENDIX 8

ROPES ON LIFTS IN MINE SHAFTS

1 Where a lift is installed in a mine shaft, then the design, operation and maintenance of the installation should comply with the relevant sections of the Regulations and ACOP³ and appropriate standards for lift practice.

2 To assist mine management in the operation and maintenance of a lift system, the following publications and guidance should be readily available to the management for consultation and use as necessary:

- BS EN 12385-5:2002 *Steel wire ropes. Safety. Stranded ropes for lifts*;²¹
- Health and Safety Executive Guidance Note PM7 - *Lifts: thorough examination and testing*;²²
- OTIS - Field Engineering Instruction:PM7 *Examination and testing*;²³
- Bridon Ropes publication - *Ropes for lifts*;²⁴
- BS 2655 : Part 1 : 1970 : *Specification for lifts, escalators, passenger conveyors and paternosters : Part 1 - General requirements for electric, hydraulic and hand-powered lifts*;²⁵
- BS 5655 - *Lifts and service lifts - Safety rules for the construction and installation of electric lifts*.²⁶

3 The above documents provide good advice on the application and maintenance of suspension, compensating, governor and tail/balance ropes on lifts. It is important to emphasise that due to operating conditions in shafts all the ropes on a lift installation need to be examined critically and thoroughly to determine indications of deterioration.

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REFERENCES AND FURTHER READING

- References**
- 1 *Guidance on the selection, installation, maintenance and use of steel wire haulage ropes at mines* HSE Books 2004 ISBN 0 7176 2680 6
 - 2 *Mines (Shafts and Winding) Regulations 1993* SI 1993/302 The Stationery Office ISBN 0 11 033302 0
 - 3 *Shafts and winding in mines. Mines (Shafts and Winding) Regulations 1993. Approved Code of Practice L42* HSE Books 2000 ISBN 0 11 882164 4
 - 4 *Management and Administration of Safety and Health at Mines Regulations 1993* SI 1993/1897 The Stationery Office ISBN 0 11 034897 4
 - 5 *Steel wire ropes. Safety. General requirements* BS EN 12385-1:2002 British Standards Institute
 - 6 *Stranded steel wire ropes. Specification for ropes for mine hoisting* BS 302-6:1987 British Standards Institute
 - 7 NCB Specification No 186: 1970 Out of print
 - 8 NCB Specification No 388/1970 Out of print
 - 9 *Safe manriding in mines report* - available from HMSO Parts 1A and 1B - ISBN 0 11 880491 X, Parts 2A and 2B - ISBN 0 11 883281 6
 - 10 *Control of Substances Hazardous to Health Regulations 2002* SI 2002/2677 The Stationery Office ISBN 0 11 042919 2
 - 11 *Coal and Other Mines (Shafts, Outlets and Roads) Regulations 1960* SI 1960/69 The Stationery Office
 - 12 NCB Specification 465:1965 Out of print
 - 13 *Capping locked coil winding ropes with resin* -Video -Admiral Training Ltd, Leeds
 - 14 *Management of Health and Safety at Work Regulations 1999* SI 1999/3242 The Stationery Office ISBN 0 11 085625 2
 - 15 MECH/CIRC(81)82 *Balance Rope sockets*
 - 16 BCC Specification 353:1966 *Sockets, pins and zinc cone and tail strand units for haulage ropes. Amendments 1 and 2 (1987)*
 - 17 *Colliery haulage and winding equipment. Specification for wrought steel* BS 2772-2:1989 British Standards Institute

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- 18** *Specification for white metal ingots for capping steel wire ropes*
BS 643:1970 British Standards Institute
 - 19** *Specification for fibre cores for wire ropes* BS 525:1991 British Standards Institute
 - 20** *Safety requirements for passenger transportation by rope - Part 8: non-destructive testing* prEN 12927-8
 - 21** *Steel wire ropes. Safety. Stranded ropes for lifts* BS EN 12385-5:2002 British Standards Institute
 - 22** Note PM7 -*Lifts: thorough examination and testing*
 - 23** Field Engineering Instruction: *PM7 Examination and testing*
 - 24** Bridon Ropes publication - *Ropes for lifts*
 - 25** *Specification for lifts, escalators, passenger conveyors and paternoster. General requirements for electric, hydraulic and hand-powered lifts*
BS 2655-1:1970 British Standards Institute
 - 26** *Lifts and service lifts - safety rules for the construction and installation of electric lifts* BS 5655-1:1979 British Standards Institute

Further reading and legislation

Health and Safety at Work etc Act 1974 The Stationery Office ISBN 0 10 543774 3

Mines and Quarries Act 1954 The Stationery Office ISBN 0 10 850389 5

The Mines (Safety of Exit) Regulations 1988 SI 1988/1729 The Stationery Office ISBN 0 11 087729 2

The Supply of Machinery (Safety) Regulations 1992 SI 1992/3073 The Stationery Office ISBN 0 11 025719 7

The Provision and Use of Work Equipment Regulations 1998 SI 1998/2306 The Stationery Office ISBN 0 11 079599 7

The Lifting Operation and Lifting Equipment Regulations 1998 SI 1998/2307 The Stationery Office ISBN 0 11 079598 9

Steel wire and wire products. Non-ferrous metallic coatings on steel wire. Zinc or zinc alloy coatings BS EN 10244-2:2001 British Standards Institute

Specification for sockets for wire ropes Inch units BS 463-1:1958 British Standards Institute

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Specification for sockets for wire ropes. Metric units BS 463-2:1970 British Standards Institute

Specification for round carbon steel wire for wire ropes BS 2763:1982.1970 British Standards Institute

BS EN 1179:1996 *Specification for zinc and zinc alloys: Primary zinc.* British Standards Institute

Guide/rubbing rope suspension sockets - There are no standard specifications for guide rope/rubbing rope suspension sockets. White metal and resin type suspension sockets should have a taper length of eight times the rope diameter and an included taper of 1 in 6. NCB Spec 461:1965 sockets should not be used with half lock ropes.

Note: European standards are currently being prepared that will ultimately supersede some or all of the above British Standards and the National Coal Board (NCB)/British Coal(BC) Specifications that are listed.