

Deep Mined Coal

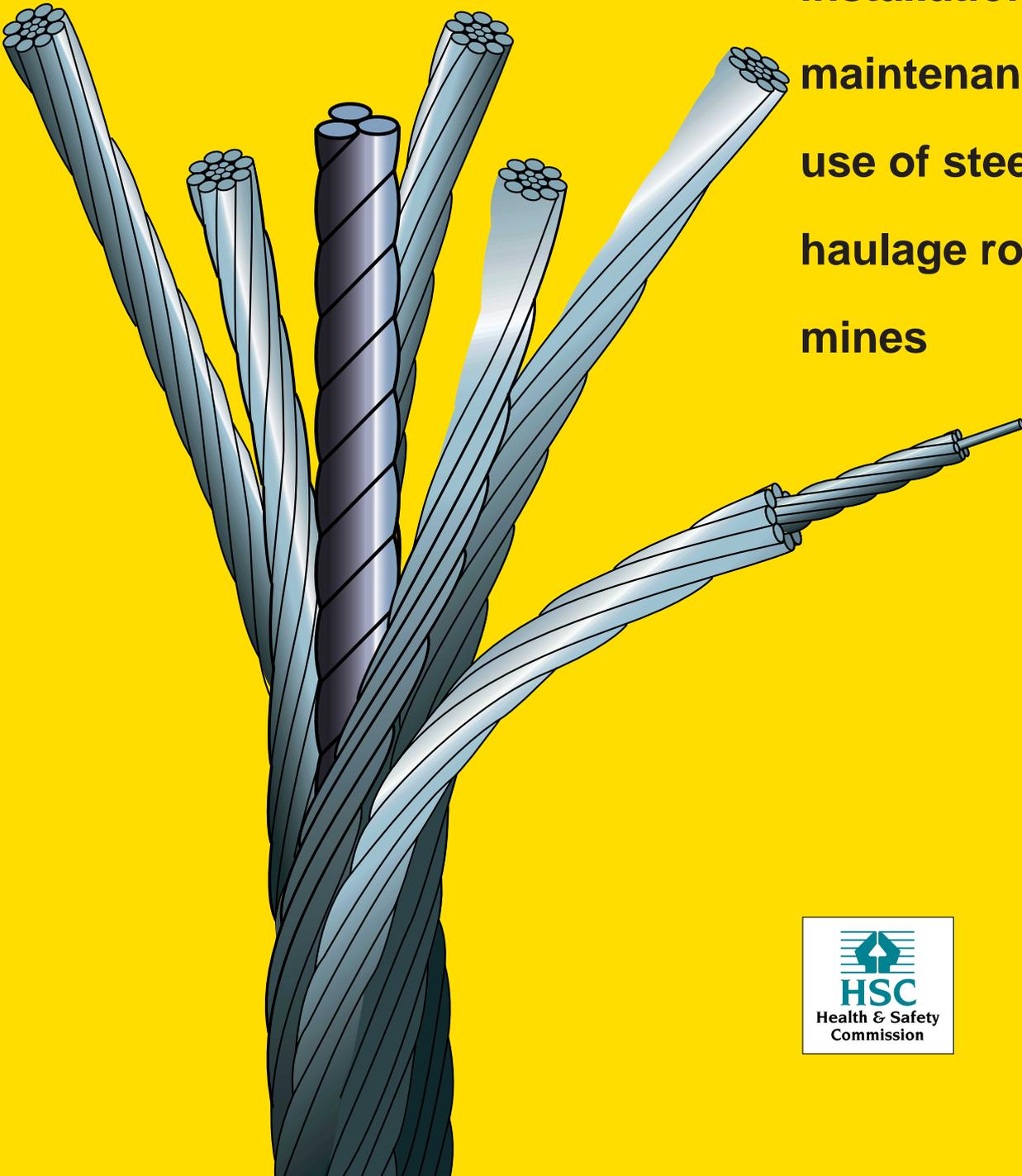
Industry

Advisory

Committee

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**Guidance on the
selection,
installation,
maintenance and
use of steel wire
haulage ropes at
mines**



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

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First published 2004*

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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 The failure of a steel wire haulage rope while in service is potentially disastrous, particularly when being used on a haulage system transporting a large number of people on steep gradients. A rope failure during materials transport can allow vehicles to run out of control, putting at risk any people in the roadway and potentially causing damage to haulage equipment, vehicles, the track and even the roadway itself. Failure of any rope while under tension results in the release of stored energy in the rope, which usually causes the broken rope ends to whiplash violently, resulting in danger to any people in the immediate vicinity of the breakage.

Who should read this document

2 This guidance is primarily aimed at owners, managers, members of the management structure and any other person who selects, installs, inspects, examines or maintains haulage ropes at mines. However, much of the technical detail is applicable to any stranded wire rope and other industry sectors using such ropes will find this guidance useful.

3 The guidance deals with the selection, installation and maintenance of steel wire haulage ropes. It is split into an overview section, which gives a broad outline of good practice, and four technical annexes, which cover in detail:

- types of haulage rope;
- rope storage and handling;
- rope installation;
- maintenance operations.

Also included at the back of this booklet are:

- two sample report forms;
- an appendix of legislation and standards relevant to steel wire haulage ropes.

4 This booklet does not cover in any detail ropes used in shaft winding systems. Information and guidance on shaft ropes can be found in the booklet *Guidance on the selection, installation, maintenance and use of steel wire ropes in vertical mine shafts*.¹

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ROPE SELECTION

Choosing the right rope

5 For a wire haulage rope to be suitable it has to be:

- strong enough and flexible enough for the work it will have to do;
- matched as closely as possible to the conditions in which it will have to operate.

6 The work a haulage rope has to do and the conditions in which it does it are known as its **duty**. There are a number of factors to consider when selecting a suitable wire haulage rope of the right duty:

- length and type of haulage;
- existing or planned layout of the rope haulage system;
- size and power of the haulage engine;
- gradients and bends;
- loads to be transported;
- frequency of use;
- conditions in which it is to be used;
- rope maintenance skills available to the mine.

7 Only people who have the necessary knowledge, experience and expertise should select ropes. If there is any doubt about which rope is most suitable, seek help from either a rope manufacturer or any other person with knowledge, experience and expertise in this field. They can provide assistance in matching a rope to a particular duty and can undertake any calculations that might be necessary.

8 Once the duty has been estimated it is then possible to determine the:

- rope size;
- rope and strand construction;
- type and direction of lay;
- tensile grade of steel;
- surface finish.

Rope size 9 The single most important factor in the selection of wire ropes is the determination and specification of a rope size which:

- gives the breaking strength necessary to deal with the maximum working tension (or pull) in the rope;
- allows a satisfactory safety factor.

For details of how to calculate this see 'A method of determining the minimum rope breaking strength for a direct haulage system' at the end of Technical Annex 1.

Rope and strand construction 10 Only two rope constructions, round strand and triangular strand, are normally used as haulage ropes. The choice between a round strand rope or a triangular strand rope will depend on whether flexibility or strength and resistance to external wear is the most important for a particular application. The advantages and disadvantages of each type of rope are outlined in Table 1.

Rope type	Rope characteristics	
	<i>Advantages</i>	<i>Disadvantages</i>
Round strand	Fairly wide range of flexibility	<p>Weaker than a triangular strand rope of equivalent diameter</p> <p>More vulnerable to external wear than a triangular strand rope</p>
Triangular strand	<p>Stronger than a round strand rope of equivalent diameter</p> <p>Withstands external wear better than a round strand rope</p>	Less flexible than round strand rope

Table 1 - Advantages and disadvantages of round strand and triangular strand ropes

Type and direction of lay 11 There are two main types of lay, Lang's lay and ordinary lay. The best lay for normal haulage purposes is Lang's right-hand lay. Lang's lay is better than ordinary lay for withstanding wear. In ordinary lay the wires are bent very sharply around the strand on the outside of the rope, and wear is therefore concentrated on a short length of wire and is likely to be deeper. Lays other than Lang's lay should be used only when there is a special reason for doing so.

Tensile grade of steel 12 Only two tensile grades, 1570 and 1770, are available under BS 302:Part 5:1987 *Stranded steel wire ropes. Specification for ropes for haulage purposes*.² Type 1570, the weaker grade, has all but disappeared and most

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new ropes are of the 1770 grade. For the majority of mining applications 1770 grade is strongly recommended. Higher tensile grades can be used for some specialised applications.

Surface finish **13** Galvanised ropes are suitable for use in conditions which are known to be wet or corrosive. Non-galvanised ropes are suitable only where conditions are dry.

MINIMISING ROPE WEAR AND DAMAGE

14 Unsatisfactory working conditions shorten rope life. Haulage ropes cannot be guaranteed to stand up to heavy wear (requiring large outer wires) and at the same time to work satisfactorily around small drums and pulleys (requiring small outer wires for flexibility).

15 When planning a haulage installation, or when installing a rope, aim to:

- provide a smooth and steady haul;
- avoid all unnecessary bends in the rope;
- plan roadways which are as straight as possible;
- maximise the radius of any bend around which the haulage rope must travel;
- guide the rope smoothly around bends on large wheels or on arcs consisting of a number of smaller pulleys;
- use large haulage engine drums or surge wheels;
- use the largest pulleys or wheels practicable. If the rope has to change direction by more than 10° at any one pulley or wheel the pulley or wheel should be at least 48 x diameter of the rope;
- control the rope so that it runs between the rails on well-maintained and free-running rollers mounted in pockets which are clear of water;
- ensure that there are no obstructions, abrasives or water elsewhere in the path of the rope.

STORING HAULAGE ROPES

16 If a rope is stored prior to installation precautions should be taken to prevent external or internal corrosion. For further guidance on rope storage and handling, see Technical Annex 2.

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ROPE INSTALLATION

17 Prior to installing any haulage, identify rope hazards and eliminate them when possible. Assess the risks arising from the hazards that can't be eliminated. Only the significant findings of any risk assessment need to be written down. This will help those determining the installation procedure. Writing down significant findings should not take long, even for relatively large jobs. If a risk assessment is long and excessively detailed it is probably more than the law requires.

18 Once the installation procedure has been determined, draw up statements detailing:

- what work is to be done;
- how it is to be done;
- the procedures to avoid, control or mitigate risks.

19 When installing a haulage rope, take care to prevent damage. If the rope is supplied on a reel then it should be paid out by revolving the reel. If it is supplied in the form of a coil, then it should be paid out by revolving the coil. Never pull a rope out sideways from a stationary coil, as this will cause it to kink.

20 Once installed, check that the rope is not rubbing against roof girders, arch legs, seized rollers, rails, vehicles or other obstructions - particularly metal ones. Rubbing causes increased wear and is very likely to cause surface embrittlement. Ropes should not be allowed to:

- run in the gaps in rails or other potential traps which might give rise to a danger of overloads or hold-fast conditions;
- bear against the axles of vehicles or other conveyances.

Serving **21** A serving (sometimes referred to as a 'seizing') usually takes the form of a wrapping of wire laid tightly around the rope. Servings are usually applied to prevent slackening or movement of the wires at rope ends.

22 The efficient serving of rope is an essential skill for anyone involved in haulage rope maintenance. The ability to serve a rope properly is a skill that can only be acquired through proper training. Technical Annex 3 gives some guidance on the serving of haulage ropes.

Splicing **23** Only trained and competent people, with the necessary skills, knowledge and experience, should carry out or supervise splicing. Splicing skills can only be acquired under the tuition of a person experienced in splicing various types of rope.

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24 Ropes in endless rope haulages are spliced together using the long splice technique to form, in effect, a single long rope. The long splice is described in Technical Annex 3.

25 Use the 'long splice' to:

- join the ends of haulage ropes to form an endless rope;
- insert a new length of rope into an endless rope.

26 Splices need to be suitably identified so that they can be readily located.

27 Ropes in direct rope haulages should not be spliced.

Capping

28 It is important that the ends of a haulage rope are properly secured to the haulage engine or other prime mover, and to the vehicle(s) or article(s) being transported. The method recommended for allowing the proper attachment of haulage ropes is known as 'capping'. There are several different types of capping:

- inserted cone-and-tail;
- white metal;
- resin.

Inserted cone-and-tail cappings

29 The inserted cone-and-tail capping works by inserting a pre-cast zinc cone into the rope end, between the strands, so as to form a conical enlargement at the rope end which can be held in a conical socket. It is relatively quick and easy to fit, and has proven to be reliable provided that a few simple principles are followed.

30 The cone-and-tail unit should:

- never be re-used, only new units should be used for capping or recapping;
- be of a size that is compatible both with the rope and with the socket in which it is to be fitted;
- have a zinc cone;
- have grooves equally spaced around the surface of the cone, to take the rope strands, the depth of the grooves being about half the diameter of a strand;
- have a tail strand of an appropriate length.

31 Further guidance on inserted cone-and-tail capping can be found in Technical Annex 3 and BCC Spec 353/1966.³

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**White metal cappings
and resin cappings**

32 In safety lamp mines a flame cannot normally be used below ground to melt the white metal or serving solder used on rope servings. Consequently, white metal capping is generally used only on haulage ropes that can be capped at the surface, such as surface drift haulages.

33 Resin capping is a suitable procedure to carry out below ground and tends to be regarded as an alternative to white metal capping.

34 Those requiring details of the procedure to follow for white metal capping and resin capping can find it in the booklet *Guidance on the selection, installation, maintenance and use of steel wire ropes in vertical mine shafts*.¹

Wedge-type cappings

35 Wedge-type cappings are not suitable under any circumstances as haulage ropes cappings.

INSPECTION, EXAMINATION AND TESTING

The manager's scheme

36 All haulage ropes should be included in the manager's scheme for the systematic inspection, examination and testing of plant and equipment. The purpose of inspection and examination is to:

- check that a rope remains safe to operate;
- determine the general condition of the rope, and in particular to identify the nature and severity of any damage, deformation or deterioration;
- identify and prevent, when possible, the causes of such damage etc.

37 Details on the types of damage, deformation and deterioration that might be found during inspection or examination are given in Technical Annex 4. Table 2 gives a summary of the types of deterioration of haulage ropes and possible causes.

38 Criteria to help determine when to discard worn out, damaged or defective ropes are given towards the end of Technical Annex 4.

39 Rope inspection, examination or testing should only be carried out by people competent to do so, or under the close supervision of such people.

**Routine external
inspection**

40 A competent person should inspect ropes daily where haulages carry people. Inspection may be less frequent for other haulages depending on:

- conditions;
 - frequency of use;
 - risks arising from the failure of the rope.
-

Deterioration found	Position and extent of deformation	Possible cause	Possible remedy
Corrosion - usually in the form of pitting	Localised or throughout length of rope	(a) Inadequate lubrication (b) Water or other corrosive material in roadways	(a) More frequent lubrication; use of more effective lubricant (b) Diverting water etc away from rope, rollers etc; use of galvanised rope
Abrasive wear - usually in the form of polished and/or flattened wires	(1) Throughout length of rope (2) Localised (3) Uneven, over length of splice	(a) Rope rubbing along floor (b) Outer wires too small Kink or permanent bend in rope Poor standard of splicing	Use of additional roadway rope rollers Use of rope with outer wires of larger diameter Examination by competent person to decide the action to be taken Better training in splicing
Worn out wires; broken surface wires	Localised or throughout length of rope	Martensite embrittlement due to: (a) Rope rubbing on steel eg arches, girders, rails, seized rollers etc (b) Excessive slip on surge wheel	Improvements to path of rope along roadway Check tensioning system
Deformation of outer wire crowns; broken wires	Localised or throughout length of rope	High bearing pressures between rope and pulleys, drums or surge wheels etc	Improve the rope support to reduce bearing pressures; check suitability of rope construction
Flattened and sheared wires	(1) Localised (2) At intervals along rope	Rope falling over side of drum and being damaged by edge of drum flange Rope run over by vehicles or rope partially trapped between rails	Avoidance of slack rope Check and adjust rope line

Table 2 - Types and possible causes of deterioration in haulage ropes

Periodic thorough examination

41 Periodic thorough examination of a rope should be made at least every 30 days for haulages that carry people but may be less frequent for other haulages.

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Non-destructive testing of wire ropes (NDT)

42 Non-destructive testing (NDT) methods of rope examination can help locate defects in ropes, whether those defects are on the rope surface or concealed in its inner layers. Such techniques are particularly useful for long ropes and for ropes where the underside is difficult to view. Further guidance on NDT can be found in the booklet *Guidance on the selection, installation, maintenance and use of steel wire ropes in vertical mine shafts*.¹

ROPE MAINTENANCE

43 The main elements of rope maintenance are:

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

44 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 type and condition of the haulage engine and ancillary equipment;
- the environment in which the rope runs.

45 Rope maintenance or repair should only be carried out by people competent to do so, or under the close supervision of such people.

46 Risks associated with periodic maintenance work and for other jobs which occur repetitively should already have been assessed and method statements drawn up. There should be no need to draw up a new method statement each time such work is to be carried out unless circumstances change, in which case the risks will need to be reassessed.

Lubrication

47 The life of a haulage rope can be increased by effective lubrication. The main benefits of effective lubrication are:

- to allow free movement between strands which helps to reduce internal wear;
-

-
- to prevent or reduce the ingress of minewater or other potentially corrosive or abrasive materials.

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

Other preventative maintenance

49 Systematic and periodic maintenance, which is designed to avoid problems, should be incorporated into the manager's scheme. It needs to address:

- ropes;
- haulage engines;
- other ancillary equipment.

50 The two sample report forms at the end of Technical Annex 4 give details of things that need checking, maintaining and reporting on.

Repair and renewal

51 If defects are found during inspection, examination, testing or in use, deal with them promptly.

52 If the nature, extent and severity of a defect is sufficient to prejudice continued safe running, prevent the haulage from running until a repair is completed or the rope has been replaced.

53 For minor defects, assess whether 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. Similarly, a few broken wires might not give rise to immediate concern unless they are close together and are likely to have significantly weakened the rope.

54 Take care to ensure as far as possible that unattended minor defects do not suddenly worsen. Action is required when, for instance, a rope has a broken wire standing proud which might snag and cause more serious damage. As well as cutting or breaking off the proud wire and making a note in the record, seek out the cause of the damage so it can be put right.

INSPECTION AND MAINTENANCE OF TRANSPORT ROADS

55 In addition to the normal roadway inspections carried out at the mine, the person examining a haulage rope should also look at the roadway in which the rope runs to determine whether or not there are any matters which might adversely affect the condition of the rope. Particular things to look for include:

- rope fouling or rubbing on obstructions;

-
- wet areas;
 - presence of corrosive or abrasive substances;
 - seizure of pulleys on the floor, roof, or wall;
 - any other defects that need correction.

56 If problems cannot be remedied immediately, record and report them so that appropriate action can be taken.

KEEPING RECORDS

57 It is important to keep proper records of haulage rope inspection, examination, testing, maintenance and repair. Technical Annex 4 contains examples of two sample report forms, for:

- routine external inspection;
- periodic thorough examination.

They can be freely copied.

58 The forms list the matters to look at during inspection, examination or testing. Other information could be included in the records, such as the dates on which new lengths were spliced into ropes along with any details which could be used to plan systematic replacement of the older parts of the rope; including splice location and recognition details.

59 Report books or electronic data storage can be used for keeping records provided that they cover the same matters shown on the sample report forms.

60 Whatever form of record is used, it is important that any person who might need the recorded information has access to it while the mine is being worked.

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TECHNICAL ANNEX 1 - HAULAGE ROPE CONSTRUCTION

HAULAGE ROPE CHARACTERISTICS

1 A steel wire rope consists of many individual wires laid into a number of strands which are, in turn, laid around a centre core (Figure 1).

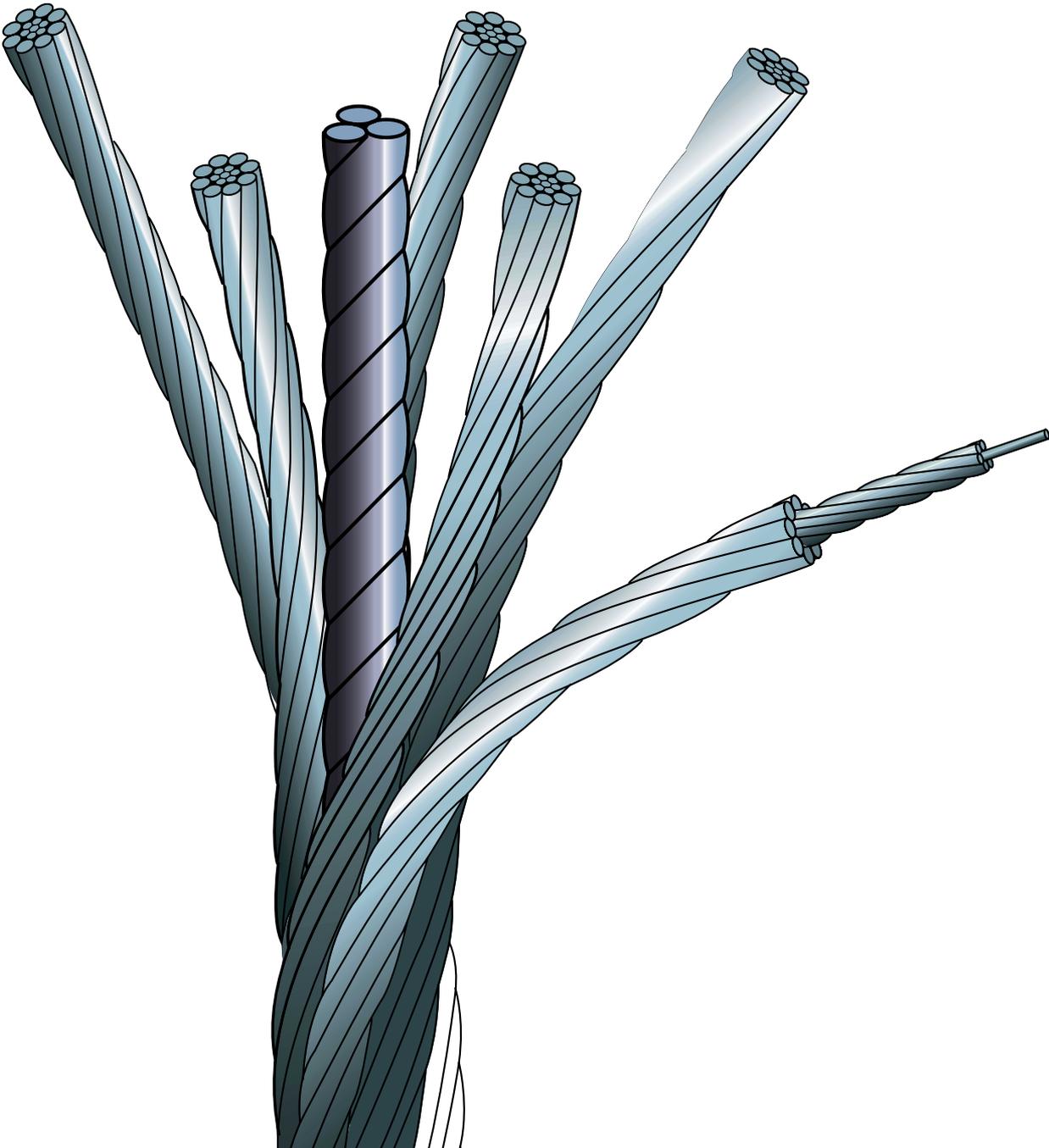


Figure 1:
Components of a rope

2 The characteristics and strength of a wire rope of any given diameter and the uses for which it is suitable are determined by:

- type and size of wire;

- the number of wires in the strands;
- the type of core;
- the rope's construction.

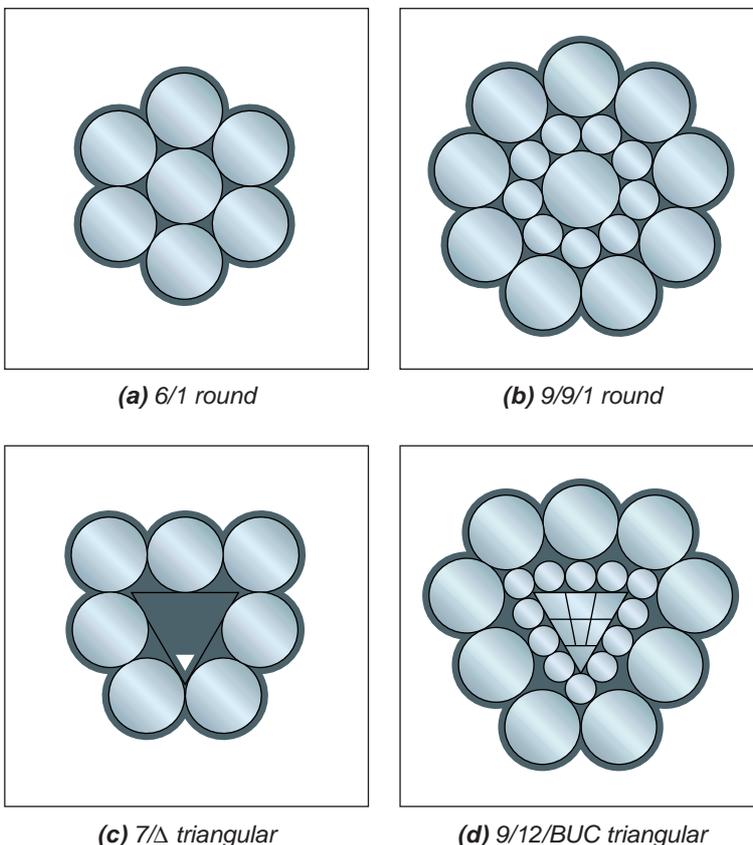
WIRES

3 Wires for haulage ropes 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 progressively smaller tapered holes in metal blocks or dies, steadily decreasing its diameter and increasing its length. This elongates the grains of steel within the wire into longer, fibre-like structures, leading to an increase in its tensile strength.

4 Tensile strength is measured in Newtons per square millimetre (N/mm²). Hanging a 1 kg weight on a wire would create just under 10 N (10 Newtons) 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. The tensile strength of wires in most general purpose haulage ropes is normally 1770 N/mm² (the so-called 1770 grade).

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

Figure 2: Strand shapes



6 The wire shapes used in the manufacture of haulage ropes are as follows:

- round - ie circular in cross section (Figures 2a and b);
- triangular - ie triangular in cross section, as used for the centre wires of some strands (Figures 2c and d).

STRANDS

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

- round (Figures 2a and b);
- triangular (Figures 2c and d).

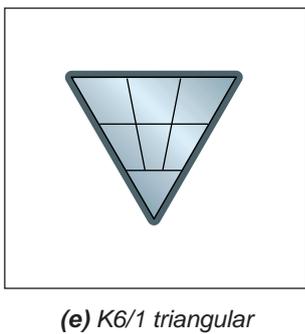
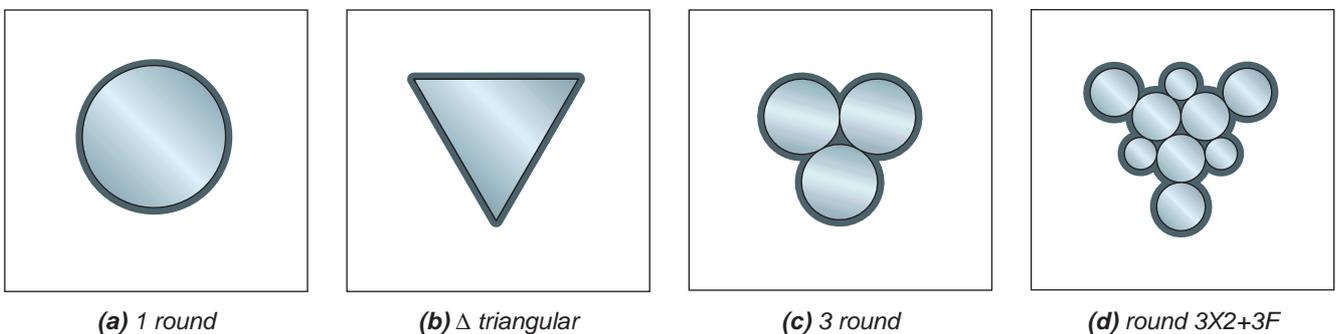
Describing strand construction

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. For example:

- 'round 6/1' (Figure 2a);
- 'triangular 9/12/BUC' (Figure 2d).

9 Figure 3 shows the types of strand centres in general use. Those shown in Figures 3c, d and e are BUCs.

Figure 3: Strand centres



Round strand construction

- 10 Round strand construction can be:
- 'single lay' - with only one layer of wires around the strand centre (Figure 2a);
 - 'equal lay' - with more than one layer of wires (Figure 2b).

11 In any strand of a given size, the more wires there are:

- the smaller those wires will be;
- the more flexible the strand.

12 There is a limit to increasing strand flexibility by using smaller wires. When the outer wires of a strand are less than 2 mm diameter, they may not be strong enough to stand up to wear and corrosion.

Triangular strand construction

13 Triangular strands (Figures 2c and d) have triangular strand centres, such as those shown in Figures 3b-e.

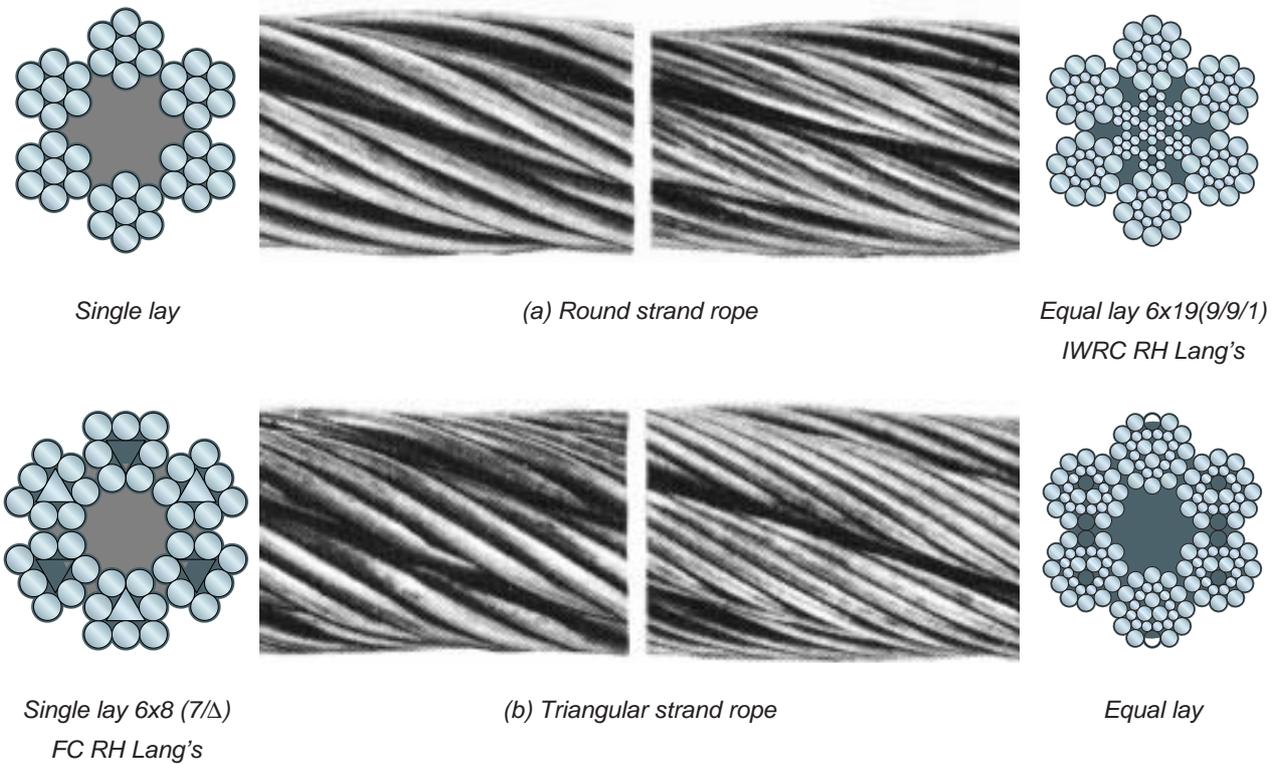
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ROPES

14 The two main types of haulage rope construction are:

- round strand (Figure 4a);
- triangular strand (Figure 4b).

Figure 4: Ropes and rope sections



Both types are formed by laying up a layer of strands around a main core. The strands can be of either simple construction with only one layer of wires around the strand centres (left-hand side cross sections), or of compound construction with more than one layer of wires (right-hand side cross sections).

Describing rope construction

15 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;
- the type of rope core.

16 For example, the rope shown on the right of Figure 4a is 'Round strand, 6x19 (9/9/1) IWRC RH Lang's'. This means it is a round strand rope with six

strands, each having a total of 19 wires (6x19). The 19 are wires arranged as nine wires, over nine wires over one wire (9/9/1), with an independent wire rope core (IWRC), laid up in right hand Lang's lay. The rope on the left of Figure 4b is a triangular strand, '6x8 (7/Δ) FC RH Lang's'. This means it is a triangular strand rope with six strands, each having a total of eight wires (6x8) consisting of seven wires over one triangular wire (7/Δ), laid up in right-hand Lang's lay over a fibre main core (FC).

Strands in ropes 17 In a stranded rope the strands twist around the 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 5a and c). If the strands twist in the opposite direction it is in left-hand lay (Figures 5b and d).

18 The individual wires also twist around the strands. If the wires twist in the same direction as the strands, then the rope is in Lang's lay (Figures 5a, b and 6a). If the wires twist in the opposite direction to that of the strands, then the rope is in ordinary lay (Figures 5c, d and 6b).

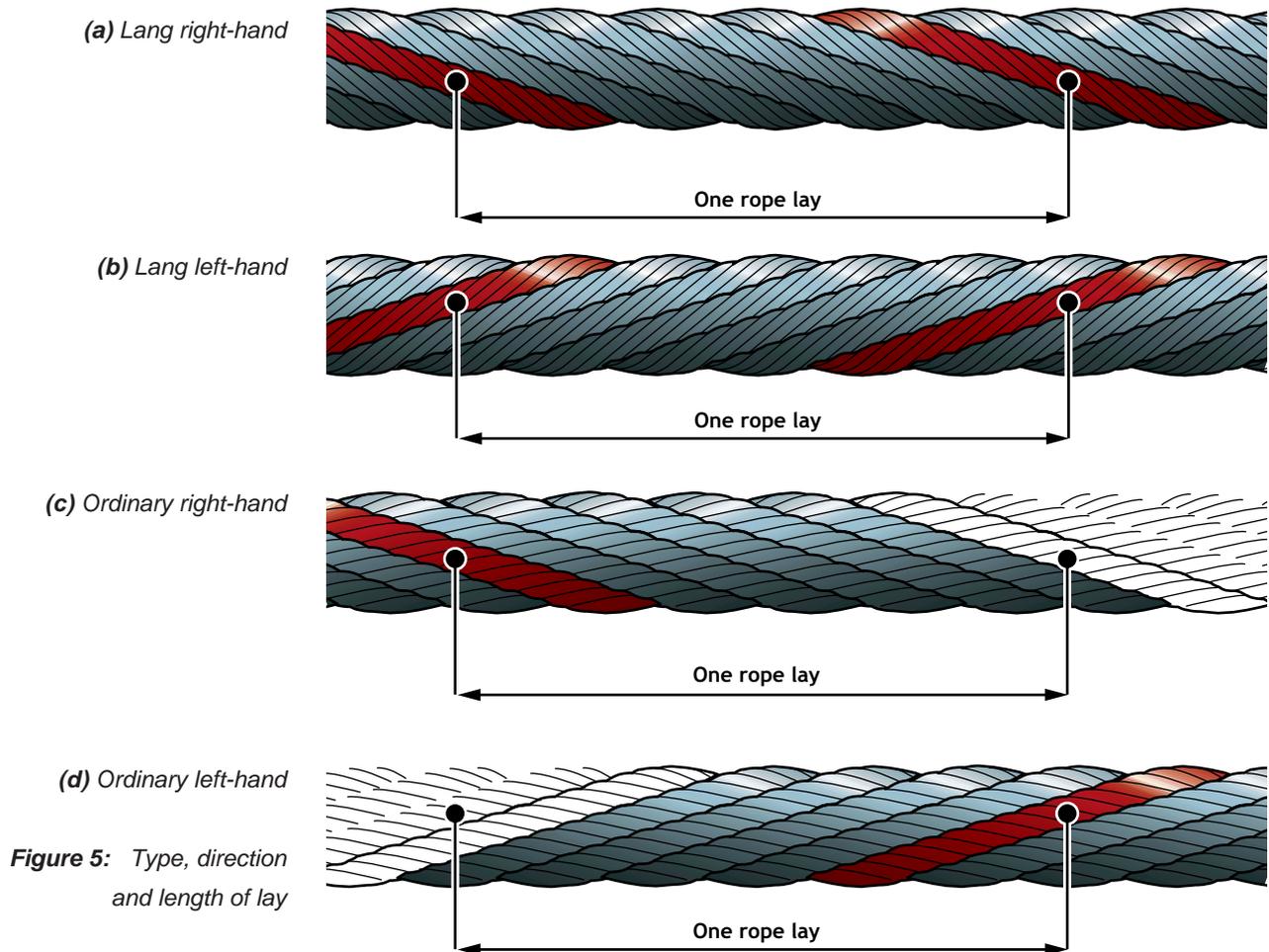


Figure 5: Type, direction and length of lay

19 A stranded rope may be in Lang's right-hand lay (Figure 5a) or in one of the other three lays shown in Figure 5. In most cases it does not make any difference whether right-hand or left-hand lay is used (but see Technical Annex 2 on rope

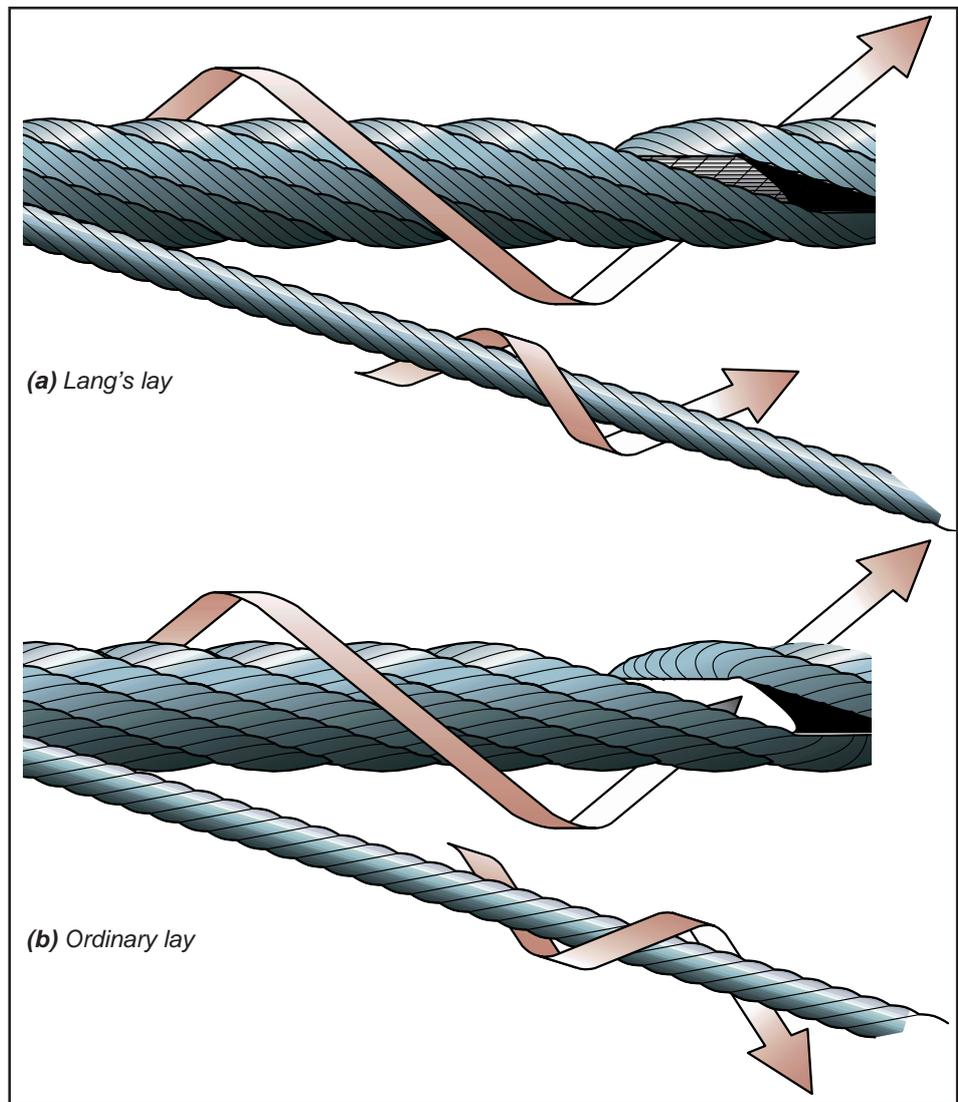


Figure 6:
Identification of lay

storage). If neither is specified, the manufacturer will always supply right-hand lay as standard.

20 The length of lay (pitch) of a stranded rope is the distance, measured along the rope, between the crown (highest point) of a strand and the next crown of that strand along the rope. In Figure 5, one strand has been shaded and the distance between the two crowns, representing one rope lay (one length of lay), is marked.

Rope cores

21 The main core of a stranded rope is designed to support the strands. The core can be:

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

22 A synthetic or natural fibre core is flexible and suitable for all conditions except those in which the rope is subjected to severe crushing (eg working under high load and on small pulleys or drums, or coiling in a number of layers on a drum, etc).

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23 The wire strand core makes the rope more resistant to crushing but also makes it less flexible. The independent wire rope core (Figure 4a right) makes the rope resistant to crushing without greatly reducing its flexibility. Further information can be found in relevant standards listed at the back of this booklet.

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

- easier to manufacture;
- rot-proof;
- more resistant to crushing, so giving better support to the wire strands;
- they hold lubrication better than a rope with a steel core.

25 When using ropes with synthetic fibre cores take extreme care when capping with white metal. Polypropylene, for example, melts at about 130°C and there is a danger that the part of the core close to the capping could be adversely affected by heat during the capping process.

26 To reduce corrosion and friction between wires, the various specifications for ropes (see References, Legislation and Standards section) require that the wires and any natural fibre core must be thoroughly lubricated during manufacture. 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.

Round strand ropes

27 Round strand ropes have a relatively simple construction consisting of six round strands laid around a main core, the strands being either of single lay construction with only one layer of wires (Figure 4a left), or of equal lay construction with more than one layer of wires (Figure 4a right). Rope construction can range from the comparatively inflexible haulage rope, with strands of six wires over one, to the flexible type with strands of 36 wires.

28 Approximately 55% of the cross-section of a fibre core round strand rope is steel. It will have a tendency to twist (rotate about its own centre-line) when the load changes.

29 Round-strand ropes are relatively easy to examine in service as about half the length of each outer wire lies on the surface.

Triangular strand ropes

30 Triangular strand ropes have six near-triangular strands laid around a main core. The strands can be either single lay construction (Figure 4b left), or equal lay construction (Figure 4b right). As the strands are triangular and have almost flat sides, they fit together more closely than round strands and give a more compact rope.

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31 In a fibre core triangular strand rope about 62% of the cross-section is steel. For this reason triangular strand ropes are about 10% stronger than round strand ropes of the same size and material. They have a smoother, more circular cross-section than a round strand rope and tend to resist wear better. They are also more crush resistant as the strands have a greater bearing area.

32 However, triangular strand ropes are slightly less flexible than round strand ropes. They are also more difficult to visually inspect in service as a smaller proportion of total length of wire in the rope can be examined at the surface.

33 Both round strand rope and triangular strand ropes have a tendency to twist when the load changes.

Preforming

34 Most types of stranded haulage 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)**

35 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).

36 Standards relating to galvanised round carbon steel wire ropes are listed at the end of this booklet.

37 It is good practice to use galvanised ropes that will have to work in wet or corrosive conditions. The galvanised coating will protect the steel, partly by acting as a physical barrier between the steel and the corrosive(s), and partly because the corrosive(s) attack the coating rather than the steel.

38 It is better to use type Z galvanised rope (light coating). The thicker coating of soft zinc in type A galvanising is easily indented or nicked and could lead to loosening of the lay, and rope distortion.

39 Non-galvanised ropes should be used only where conditions are dry.

40 Keep galvanised ropes well lubricated during storage and service unless there is a good reason why they should not be lubricated, eg if there is a likelihood of causing haulage clips to slide or slip on a haulage rope working on a steep incline.

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A METHOD OF DETERMINING THE MINIMUM ROPE BREAKING STRENGTH FOR A DIRECT HAULAGE SYSTEM

The tension in the haulage rope on an incline is due to two major factors ((a) and (b)), and other factors ((c)):

(a) the gravitational pull on the load and on the rope - for a given load, the steeper the incline, the higher the tension in the rope;

(b) the frictional resistance - results from the combined effect of vehicle friction and rope friction. To approximate frictional resistance use the following approximations:

- for vehicles having roller bearings - take vehicle friction as 1% of the maximum loaded weight of the vehicle;
- for vehicles having plain bearings - take vehicle friction as 3% of the maximum loaded weight of the vehicle;
- ropes - take rope friction as 10% of the total rope weight;

(c) other loads result from:

- acceleration;
- rope tensioning arrangements (endless rope haulages);
- rope bending around deflecting pulleys and sheaves.

The sum of these tensions gives the maximum working tension. When this is multiplied by the safety factor it gives the required rope breaking strength.

A safety factor is used to take into account the extra tensions in the wires caused, for example, by:

- sudden changes in speed outside normal operating values;
- rope jerking.

The value of the factor varies with the type of haulage. For direct rope haulages, which involve more starting and stopping, and therefore more repeated shock loads, use a safety factor of **at least five**. Endless haulages generally run more smoothly (ie fewer shock loads), use a safety factor of **four or more**.

In order to determine the minimum required breaking strength of a direct haulage rope the following formula may be used:

-
- If
- S = minimum required breaking strength of the rope (kgf)
 - F = factor of safety
 - W = total weight of vehicles and contents (kg)
 - w = total weight of the line rope (kg)
 - θ = maximum angle of inclination of the roadway (degrees)
 - α = average angle of inclination of the roadway (degrees)
 - μ_v = vehicle friction (typically 0.01 for rolling bearings to 0.03 for plain bearings)
 - μ_r = rope friction (typically 0.1)
 - g = acceleration due to gravity (ie 9.81 m/s²)
 - a = maximum rate of acceleration or deceleration of the haulage system (m/s²)

Then:

$$S = F[W(\frac{a}{g} + \sin \theta) + w(\frac{a}{g} + \sin \alpha) + W\mu_v + w\mu_r]$$

or

$$S = F[W(\frac{a}{g} + \sin \theta + \mu_v) + w(\frac{a}{g} + \sin \alpha + \mu_r)]$$

Where a is not known, $\frac{a}{g}$ can be assumed to be 0.125 for all reasonable service conditions.

Main and tail and endless rope haulages

In the case of main and tail and endless rope haulage systems the formula becomes more involved and the person responsible for the mechanical engineering function at the mine will normally calculate the minimum breaking strength required of the rope. Seek expert advice if necessary.

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TECHNICAL ANNEX 2 - ROPE STORAGE AND HANDLING

STORING ROPES

- 1 When storing ropes it is essential to take precautions against external and internal corrosion. Wherever possible, store reels in a dry, cool, well-ventilated building and out of direct sunlight.
- 2 To avoid condensation forming on stored ropes the temperature should be reasonably steady. It should not rise much above 16°C, to avoid the lubricant thinning and running 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 Do not store ropes outside unless there is no other option. Ash floors in particular are corrosive and could lead to rope damage. Tarpaulin or plastic sheeting provides insufficient protection, even when enclosing the rope completely.
- 4 When ropes have to be stored outside, protect them from the weather. The best arrangement is to use a hood consisting of corrugated steel sheeting fastened to a frame which rests on top of the reel flanges. This keeps off the rain, grit, etc, but allows air to circulate around the reel.
- 5 Ropes and their reels have to be able to 'breathe'. Any condensation collecting under a waterproof cover must be able to escape easily, otherwise the reel is likely to rot and cause the rope to corrode.
- 6 Whether storing ropes inside or outside, stand the coils or reels on timbers rather than on the floor. If the reels or coils are stored vertically, rotate them from time to time to prevent lubricant draining to the bottom. Inspect all reels and coils periodically to determine if further lubrication is necessary.

UNCOILING AND UNREELING OF ROPES

- 7 Always take care when handling reels of rope and rope coils. Never drop them from a lorry or truck when unloading.



Thread a suitable bar through the central hole of the reel so it can be lifted with suitable slings. Never lift a coil of rope by its securing bands; pass a sling through the centre of the coil.

- 8 Remember the following when unwinding coils or reels of rope:

■ When unrolling a light coil of rope along the ground, make sure the floor is clean, and

Figure 7: Right and wrong ways of uncoiling a rope

(a) Right: rolling the coil along the ground



(b) Wrong: pulling the rope from a non-rotating coil



(c) Right: using a turntable

that the remaining rope is held together so that no tight coils or kinks occur (Figure 7a).

- Never pull a rope from a stationary coil (Figure 7b).
- Where possible lay a coil or small reel of rope on a turntable, and pull off the free end as the turntable revolves (Figure 7c).



(d) Right method of unreeling

- For larger reels, pass a bar through the centre hole of a reel and mount the reel on a suitable stand, so that the reel rotates as the rope is pulled off (Figure 7d).

The figure shows a vertical stand, but a horizontal stand may also be used. If loops form take them out carefully by rolling them to the free end of the rope, otherwise kinks will form. The rate of rotation of large reels may need controlling by some simple form of braking.

CORRECT COILING OF STRANDED ROPES ON DRUMS

9 If a stranded rope is secured incorrectly to a smooth-surfaced drum it may coil badly, forming open or widely spaced coils instead of closely packed coils. Looking at the drum in a direction towards the roadway in which the haulage operates, the correct way to fit a rope to a drum is as follows:

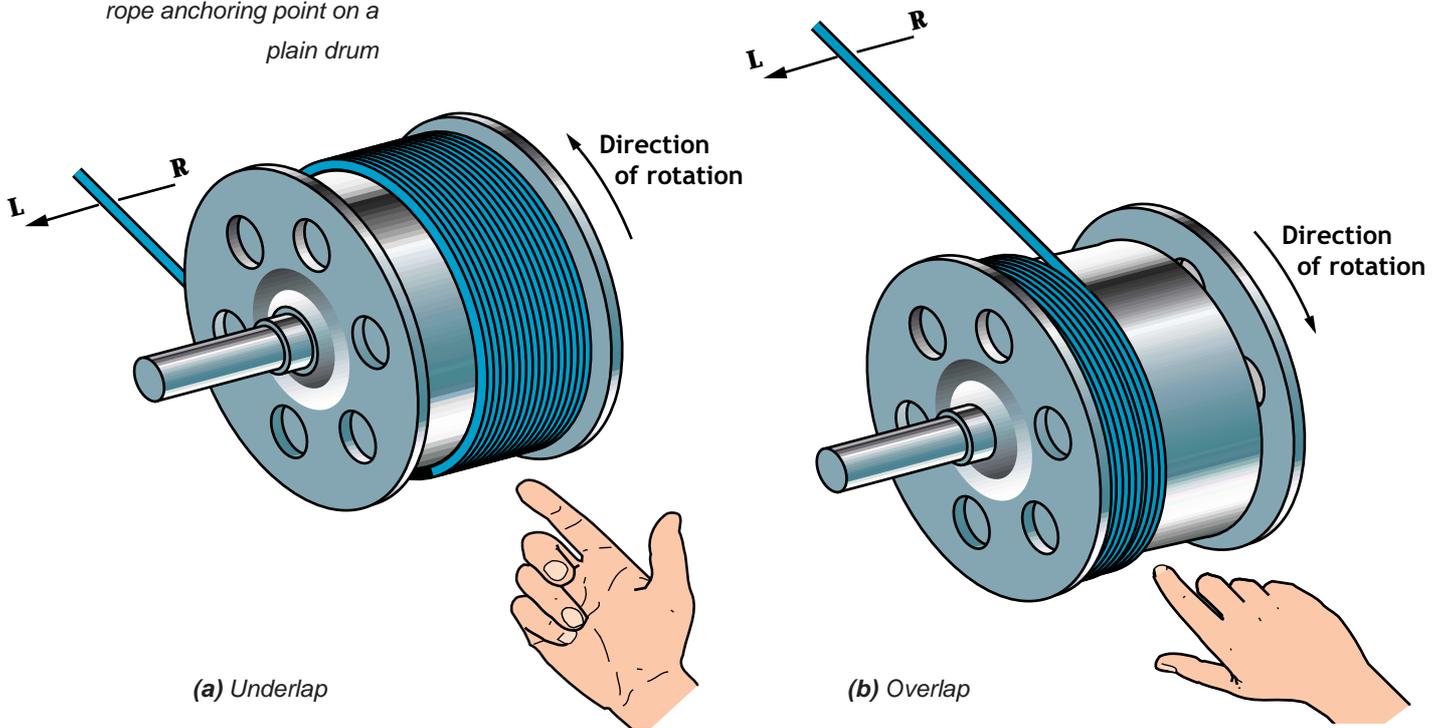
- a right-hand lay underlap rope should have its dead end secured at the right-hand flange of the drum;
- a right-hand lay overlap rope should have its dead end secured at the left-hand flange of the drum.

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10 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 roadway in which the haulage operates:

- For an **underlap** rope, extend the right hand towards the underside of the drum. The palm should face the drum (ie facing upwards) and the index finger should point towards the haulage road. The thumb then points to the right-hand flange of the drum where the dead end of the underlap rope should be fixed (Figure 8a).

Figure 8: Proper method of locating right-hand lay rope anchoring point on a plain drum



- 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 the index finger pointing towards the haulage road. The thumb points to the left-hand flange of the drum where the dead end of the overlap rope should be fixed (Figure 8b).

11 If using a left-hand lay rope, 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.

12 If a haulage rope coils badly in the first or subsequent layers, it may be that the incoming rope is flapping in front of the drum. To overcome this mount a pulley on a shaft which extends across the full width of the front of the drum. Running the rope over this pulley will dampen any flapping. At the same time the pulley will move slowly along its long shaft to feed the oncoming rope onto the correct part of the drum.

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TECHNICAL ANNEX 3 - ROPE INSTALLATION

SERVING

1 A serving (sometimes referred to as a 'seizing') is a wrapping of wire or seven-wire strand wound tightly around a rope. Servings prevent rope wires from unlaying or moving and slackening when the rope is cut (usually between two adjacent servings).

2 A serving may be insufficient, particularly on a larger rope, if it consists only of a few turns of wire, string or insulating tape. A serving should be:

- applied to the rope tightly, under proper tension;
- in neatly laid parallel coils which are in hard contact with one another, otherwise the coils could move sideways and become slack.

3 Serving wire or serving strand should be soft enough to bend to fit closely to the shape of the rope. The rope strands might otherwise loosen by 'kicking' to accommodate themselves to the shape of the serving. A good serving on a six-strand rope will have six distinct sides.

Size of serving wire or strand

4 Recommended sizes of serving wire or serving strand for ropes of 13 mm diameter and greater are given in Table 3:

Rope diameter (mm)	Diameter of single serving wire (mm)	Diameter of 7 wire serving strand (mm)
13 to 22	0.90	1.35
23 to 32	1.00	1.65
33 to 42	use strand	1.65 to 2.70
43 to 56	use strand	3.00

Table 3 - Recommended sizes of serving wire or strand

Length of serving

5 The length of rope to be served depends on why the serving is being applied, and on the size and type of the rope. For preformed round or triangular strand haulage ropes which are going to be cut, the length of serving should never be less than two rope diameters. Apply one serving either side of where the rope is going to be cut. If the rope is not preformed, apply two such servings on either side of where the rope is to be cut, with a distance of one rope diameter between the two inner servings.

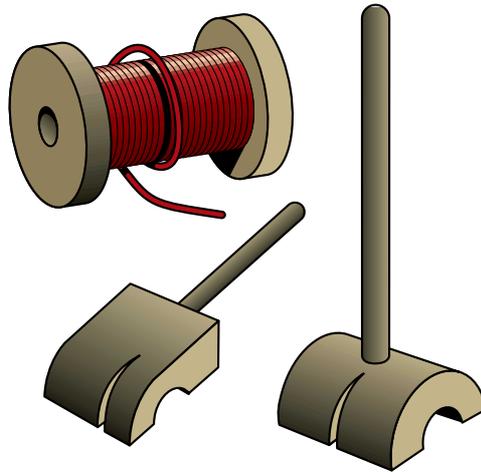
Serving tools

6 The tools essential for proper serving are as follows:

- **A vice or other means of holding the rope.** Vice jaws should be faced with a soft material to avoid rope damage.

- **Serving machines or serving mallets.** Mallet-heads should be shaped to enable them to sit on the rope. Heads should be made of brass or other soft material, which will not score the rope. Make sure the handles are long enough to take a reel of wire or strand.
- **A serving reel** mounted on the handle of the mallet, big enough to take sufficient to complete a serving.
- **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.

The ordinary or buried wire serving



7 This is the most common type of serving for stranded ropes, and where soldering is not permitted; for example, below ground in a mine where a potentially explosive atmosphere may be present. It is applied by using a serving mallet and reel (Figure 9a).

Figure 9:

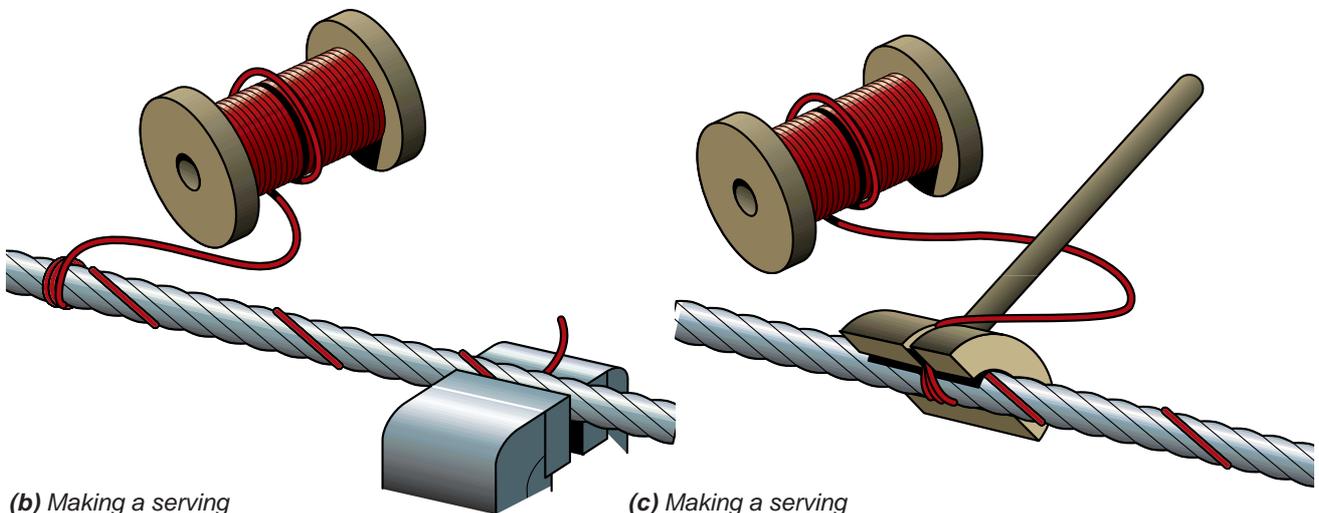
Buried wire method of serving a stranded rope

(a) Serving tools

8 The first part of the serving wire is laid along the length of rope to be served. The remaining wire is then wound

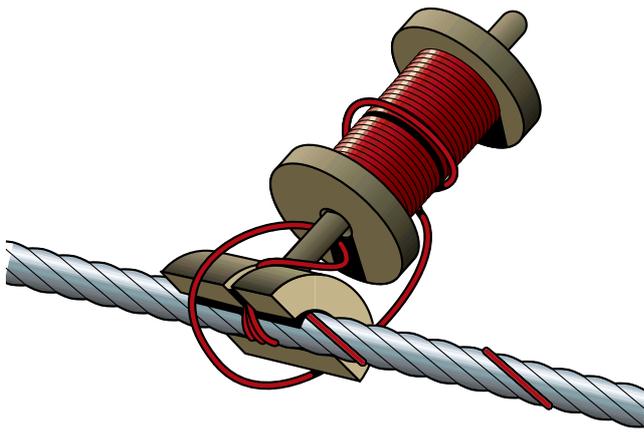
tightly over it so that the two ends of the serving wire finish at the same place. The ends can then be twisted together and cut off short to complete the serving. The procedure for making such a serving is described below:

(a) Pay out the free end of the serving wire for about 0.5 m and clamp one end in a vice together with the rope (Figure 9b).

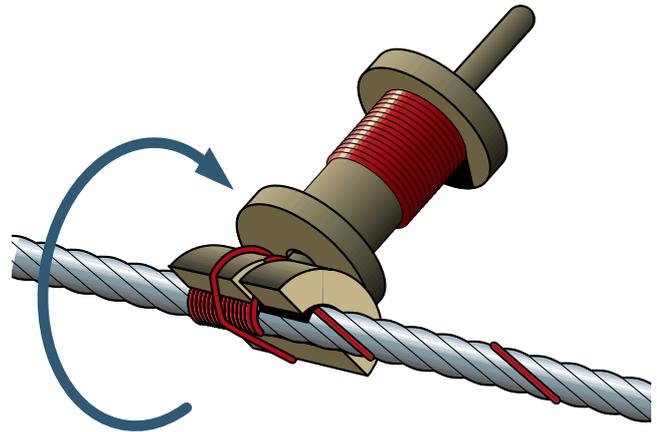


(b) Making a serving

(c) Making a serving



(d) Making a serving



(e) Making a serving

(b) Lay the serving wire along the rope to the far end of the rope length to be served. Lay it in the 'valley' between two strands such that it spirals around the rope. This part of the wire is known as the 'buried wire'.

(c) Bend the wire so it lays at right angles to the rope. Turn it twice around the rope, so that it lays on top of the buried wire to form the beginning of the serving (Figure 9b).

(d) Place the serving mallet on the rope, on top of these two turns, and pass the serving wire over the top edge of the mallet and round the back of the handle (Figure 9c).

(e) Pass the wire over the top edge of the mallet again, under the rope, up over the other edge of the mallet and place the reel on the handle of the serving mallet (Figure 9d).

(f) Rotate the reel to take up any slack wire.

(g) Rotate the mallet round the rope to continue the serving. 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 (Figure 9e).

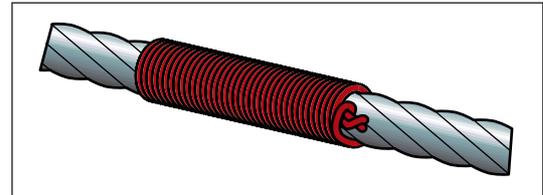
Pay out the serving wire only at the rate at which it is needed; slack wire will mean slack serving. Make sure each turn of serving wire is tight to the rope and is in hard contact with the last turn. If the turns of wire are not in hard contact it will be necessary to tap them more closely together with a soft-headed hammer. A method of guiding the wire into close packed coils is to cut a guide-groove for the wire in the head of the mallet (see Figure 9a).

(h) When the full length of serving has been applied, cut the serving wire. Make sure the end is long enough to twist together with the end of the buried wire. Pull the ends tight and twist them together enough to keep them tight.

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(i) Trim the ends to leave about four twists (Figure 9f).

(j) Finally, tap down the twisted ends with a hammer to lay against the rope in a valley between two strands.



(f) Completed serving

The wiped (soldered) serving

9 This is an alternative type of serving which may be used for heavy duty haulages. With this method serving wire or strand is served directly on to the rope. There is no buried wire or strand, so that the two ends lie at opposite ends of the serving. The ends of the serving wire or strand are not twisted together but are held in place by solder. Figure 10 shows the type of serving machine used to apply a wiped serving.



Figure 10: Method of applying soldered serving to a stranded rope using a serving machine

10 To apply a wiped serving:

(a) Pull some wire (or strand) from the bobbin of the serving machine and fasten it to a nearby object. Alternatively, lash the end of the serving wire to the rope with yarn or tape.

(b) Rotate the serving machine around the rope until the wire holds it in position where the cut is to be made. Apply the serving from left to right by raising the handle of the machine upwards and towards the body, passing it over the rope and down and away from the body.

(c) When the serving is about 150 mm long, wipe its surface thoroughly clean ready for soldering.

(d) Apply either Coraline flux or powdered rosin. Do not use Baker's fluid or killed spirit as a flux. Either of these can penetrate between the turns of the serving and cause rope corrosion.

(e) To complete the serving, solder the turns of wire along one side of the rope using tinman's solder. Pass the hot iron several times across the surface of the serving so that the solder flows into the gaps between the turns of serving wire.

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SPLICING

11 Splicing is a means of joining together two ropes. It is important to ensure that any ropes being spliced together are compatible; in particular, they should be:

- of similar size;
- of the same construction;
- have similar lengths of lay.

The long splice

12 The long splice is a neat and strong method of joining two ropes together. It is based on the principle of replacing alternate strands of one rope with alternate strands of the other. The 'joints' of the six strands are spaced at well-separated intervals along the rope.

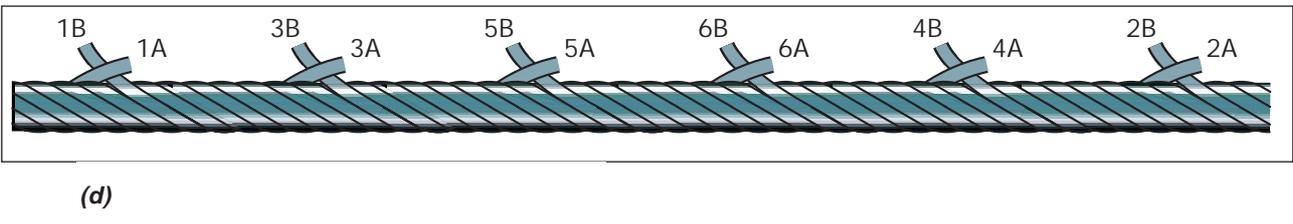
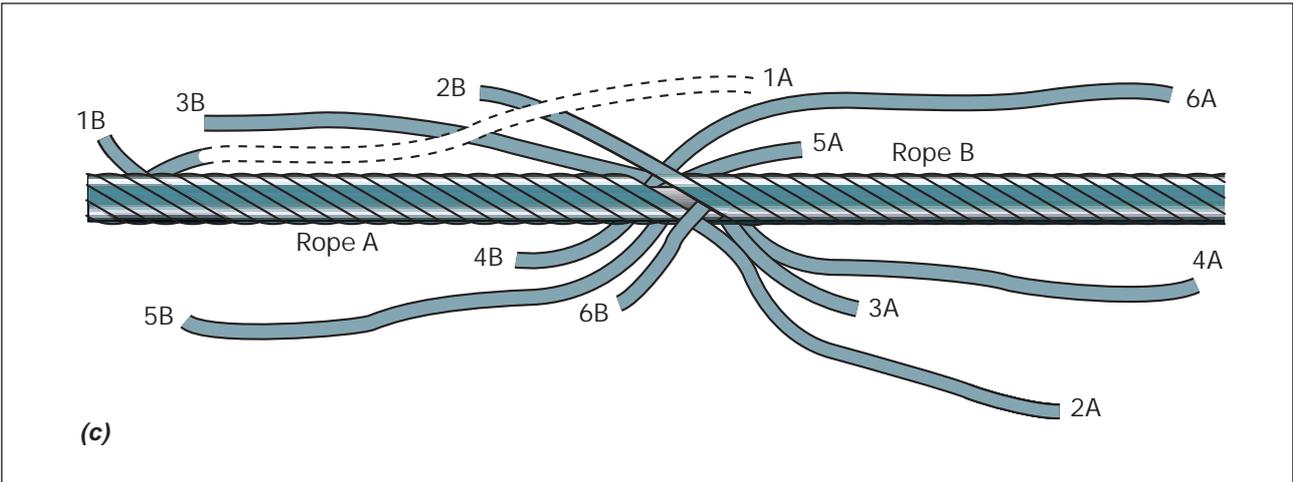
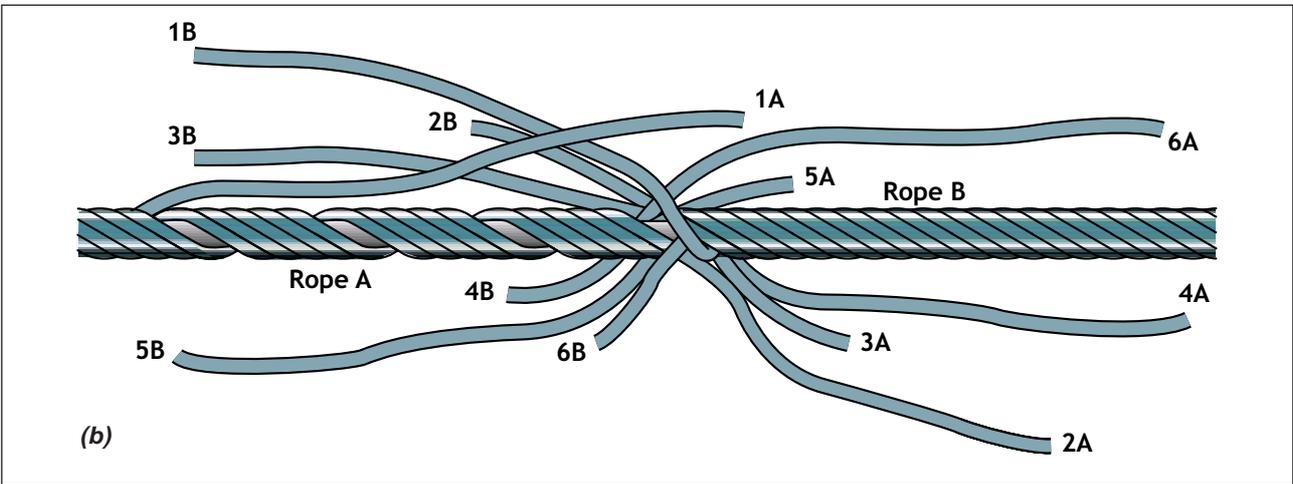
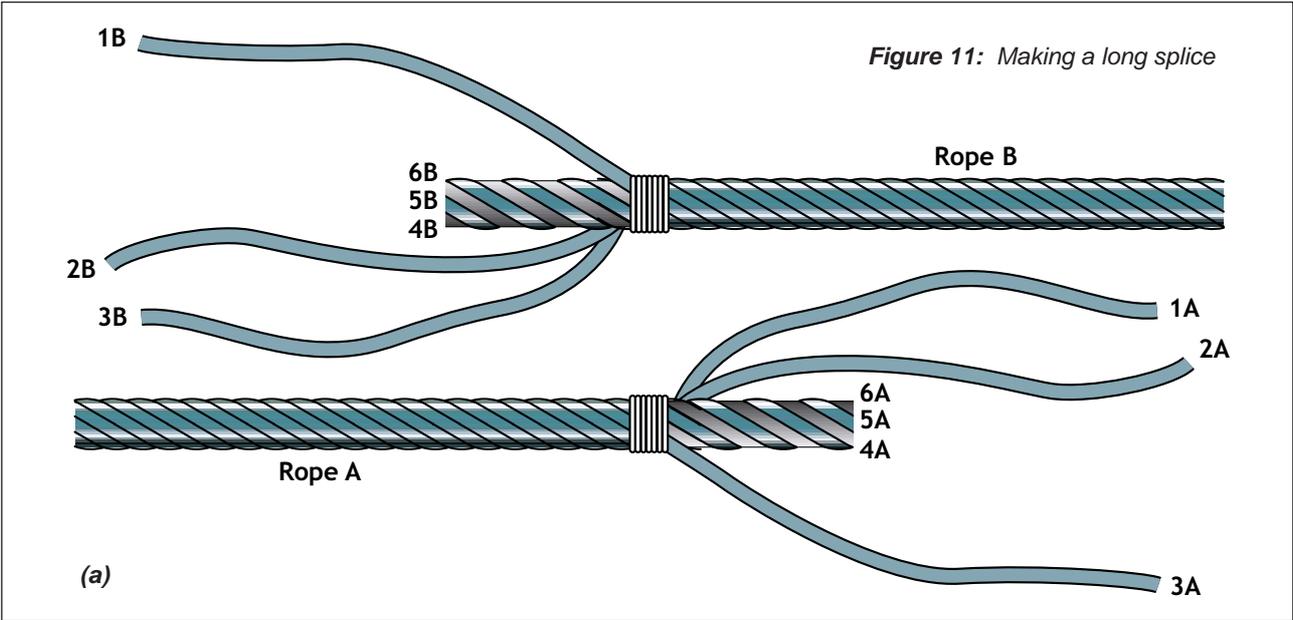
Rope diameter (mm)	d (rope diameter)
Length of tucked tail	50d
Length between tucks	125d
Length of core between tails	25d
Length of splice	1000d

Table 4 - Minimum lengths of tucks and splices (for ropes with fibre cores)

Forming a long splice

13 There are several varieties of long splice and several orders in which the operations may be carried out. The principles are the same for each type of splice. The following is a description of one type:

- (a) Calculate the length of splice from Table 4 above.
- (b) Apply a serving to each rope (A and B in Figure 11a) at a distance from their ends equal to half the length of the splice.
- (c) Apply a short serving or binding of string to the free end of each strand.
- (d) Unlay alternate strands of both ropes as far back as the main serving and cut the remaining three strands and core of each rope approximately 750 mm from the main serving (Figure 11a).
- (e) Unlay the short strands (Figure 11b).
- (f) Bring the two rope ends close enough together so that the strands of Rope A lie regularly and in order between the strands of Rope B. Pull the two ropes hard together, fix them in that position and remove the two servings (Figure 11b).



-
- (g) Divide the strands into pairs. Each pair should consist of a long strand from one rope and the corresponding short strand from the other rope - 1A/1B, 2A/2B etc.
 - (h) Take one pair of strands, say 1A and 1B. Run 1A out of rope A and lay 1B in its place until the whole length of 1B, except the length to be tucked, has been used up (Figures 11c and d).
 - (i) Cut 1A so that only the length to be tucked remains (Figure 11d - extreme left).
 - (j) Tuck in the two ends, or tie them in place ready for tucking.
 - (k) Do the same with the next pair of strands, but in the opposite direction along the rope. That is, run 2B out of rope B and lay 2A in its place, leaving only the tucking lengths free as before.
 - (l) Run the third pair in the same direction as the first pair, but up to a point $125d$ (where d = rope diameter) nearer to the marrying point than the joint for 1A and 1B. Cut 3A and 3B so as to leave free only their tucking lengths.
 - (m) Do the same with the next pair, 4A and 4B, but in the opposite direction. Cut the ends so as to leave only the tucking lengths free.
 - (n) Run 5A out of its rope and replace it by 5B up to a point another $125d$ nearer to the marrying point than the joint for 3A and 3B. Trim the ends to leave only the tucking lengths free.
 - (o) Do the same for the last pair but in the opposite direction. Trim the ends to leave only the tucking lengths free. The tucking length of each strand is then tucked into the rope, in place of an equal length of the main core which is cut out. Further information on tucking can be found later in this annex.

14 There should now be three pairs of strand ends at each side of the marrying point (Figure 11d).

15 In Figure 11d the joints are shown in the order: 1, 3, 5, 6, 4, 2, reading from left to right. In other varieties of the long splice the order of the joints may be different; for instance the order: 1, 3, 5, 2, 4, 6 may be considered better because it keeps the joints in neighbouring strands further way from each other. The form of splice and the order of operations adopted in a particular case is best decided by an experienced splicer.

Notes to Figure 11d

1 To fit them into the illustration, the joints are shown very much closer together than they would be in practice.

2 It is usual to run successive pairs of strands in opposite directions, but there are alternative ways.

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Tucking 16 Tucking is the most skilled part of splicing. When a strand is tucked in, it is buried in the heart of the rope in place of an equal length of the main core which is intentionally cut out (Figure 12). When tucking a pair of strands into the rope being spliced the strands must pass one another before being tucked; otherwise they cannot transfer load between them.

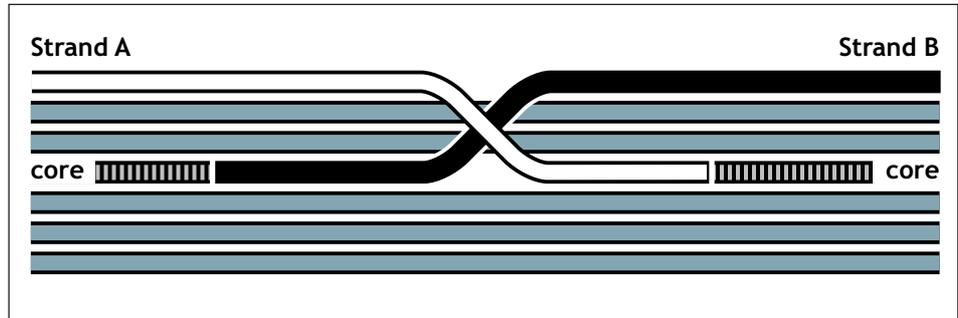


Figure 12: Tucking tails into a rope

17 Following tucking it is very important to get the rope back to its proper shape, and as near as possible to its original diameter at the point where the tucked strands enter the rope.

18 The minimum length of each strand which must be tucked in order to give a secure joint, and therefore the minimum length of the whole splice, depends on:

- strand diameter;
- length of lay of the rope;
- the conditions under which the rope works.

19 Rope manufacturers will advise on tucking lengths. The minimum length of the whole splice is twenty times the tucked length of each strand. The tucked length of each strand should be at least $50d$. This has been found reliable for all but the most exceptional conditions and requires a length of core of $25d$ between the butt end of each strand.

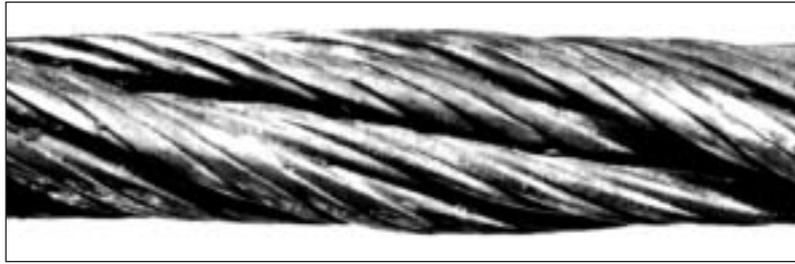
20 Ropes with steel cores require the tucked tails to butt up to each other, in which case there will be no length of core between the ends of the tails. The overall length of the splice will remain the same as for ropes with fibre cores.

Types of tuck 21 There are two main types of tuck:

- the side-by-side, parallel, or flat tuck, recommended for ordinary lay ropes;
- the locked, crossed, or round tuck, recommended for Lang's lay ropes.

22 In the side-by-side tuck the two strands to be tucked enter the rope without first crossing one another. The strands lie parallel or side-by-side at the joint and appear somewhat flat (Figure 13a).

Figure 13:
Types of tuck used in
splicing



(a) Side-by-side tuck

23 In the locked or crossed tuck the two strands cross one another or are locked before entering the rope. They appear more rounded (Figure 13b).



(b) Locked or crossed

24 When a strand is to be tucked, reduce the tension in the rope enough to allow for the insertion between the strands of a tucking tool, spike or needle.

25 For a round-strand rope, wrap the whole of the tucking length of each strand with twine or tape, from the extreme end up to a point about 25 mm from the joint. This is to make it at least the same size as the main core that it is to replace and will help to ensure that the tucked length will be securely held inside the rope.

26 For a triangular strand rope, the strands are already larger than the main core so wrapping the strands is not necessary. However, in this case, the extreme end of each tucking length should be served or bound with fine string or tape to prevent it collapsing. If the rope is of the preformed type straighten the tucking lengths before tucking them.

27 The general method of tucking a pair of strands is as follows:

- (a) Fix the rope in a vice, or by some other suitable means, so that the joint of the two strands to be tucked is just clear of the vice or fixing.
- (b) Insert a spike, needle or tucking tool into the rope under the core at the point where the two strands cross.
- (c) Lift out the main core and cut it.
- (d) Drive a spike through the rope between the cut ends.

.....

(e) Rotate the spike around and along the rope with the lay, moving away from the joint or crossing point of the two strands. At the same time, progressively pull out the main core and replace it with the strand being tucked in. Continue until the whole length of the tail is tucked.

(f) Cut the main core so that the end of the core remaining in the rope abuts hard against the end of the tucked strand and no part of the rope is left hollow - a hollow rope will collapse or distort; make the strands fit properly into the rope by hammering on a pair of splicing tongs or swage.

(g) Repeat the procedure in (e) to (g) above to run in the second strand.

(h) Tuck the other pairs of strands in the same way.

(i) Tap the rope back into shape over the tucked lengths, either by using a hammer on tongs or swage, or by hammering the rope itself between two wooden mallets which will not damage the wires. The tucked strands should now lie within the rope.

28 If parts of the tucked strands (or any strands) protrude from the rope or 'stand proud' at this point, they will rapidly become worn through during service. Even if the two tucked strands lie neatly in the rope, the two adjacent strands (under which the tucked strands are first tucked) will become heavily worn if they are left standing proud.

29 Figure 14 shows where the two tucked strands have not worn, but the strands on each side of the joint have become severely damaged by wear.

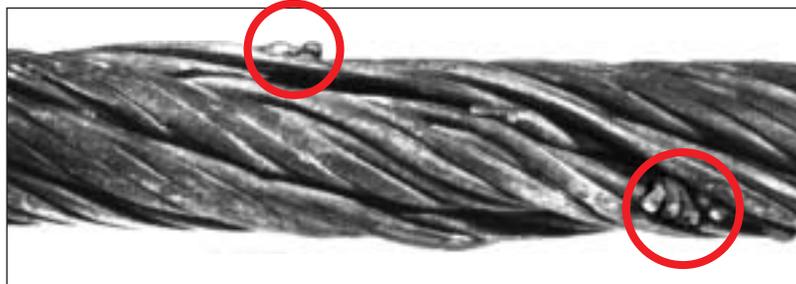


Figure 14: *Rope worn at faulty tuck*

30 If the ends of the tucked strands are not tucked well into the rope the ends may catch on some obstruction and be torn out of the rope, as shown in Figure 15.



Figure 15: *Protruding tail ends*

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Getting the rope back into shape

31 At a joint, it is difficult to get a rope back into shape, and to its original diameter, because at some point in the joint two strands are attempting to occupy the space intended for only one.

32 One method to overcome this is to slightly untwist the two strands to be tucked, over a length of 25 mm or so at the part where they lie together in passing one another. This makes this part of each strand soft and spongy so that it can be re-shaped by the pressure of the tongs or swage. In the case of a crossed tuck, there is the added benefit that the loosened outer wires of the two strands mesh together to some extent.

33 For larger ropes with a diameter of 29 mm or above it may be necessary to insert a short purpose-made plug immediately underneath the tuck in order to prevent the rope from distorting. This should not be so large that it increases the rope diameter at the tuck by more than 10% of the nominal rope diameter.

Splicing for repair

34 The procedure for splicing in a new piece of rope to replace a damaged piece is identical to the procedure used when installing spliced ropes.

Physical identification of splices

35 Splices need to be identified so they can be found easily. One way of doing this is to paint them in different colours. To do this, the spliced length should be cleaned first, painted, and then regreased when the paint is dry. The paint will quickly wear off the strand crowns but will remain visible in the valleys between the strands for some time. Splices should be repainted as and when necessary.

Summary

36 The main points to remember in connection with splicing are:

- Get the tucked strands and their neighbours at the joint to fit snugly into the rope so that no strand stands proud, otherwise that strand will rapidly wear through in service.
- If a strand does wear through or breaks, cut out several metres of the defective strand and replace that length by a similar strand. The tucks at the end of the replacing strand should be made so that the strands pass one another before being tucked (Figure 16).

EMERGENCY REPAIRS

Replacing a defective strand

37 If a strand stands proud in a joint and wears through it will unravel from the rope and may cause an accident or other damage. Those inspecting or examining ropes will sometimes need to make a quick repair during a shift. One fairly common practice is to trim the broken ends of the strand and to tuck them into the rope so that they do not pass one another before entering the rope. This leaves the rope with only five useful strands as the tucked strand has no strength at its cut ends. There have been many occasions when ropes have broken due to the inadequate nature of the emergency repair.

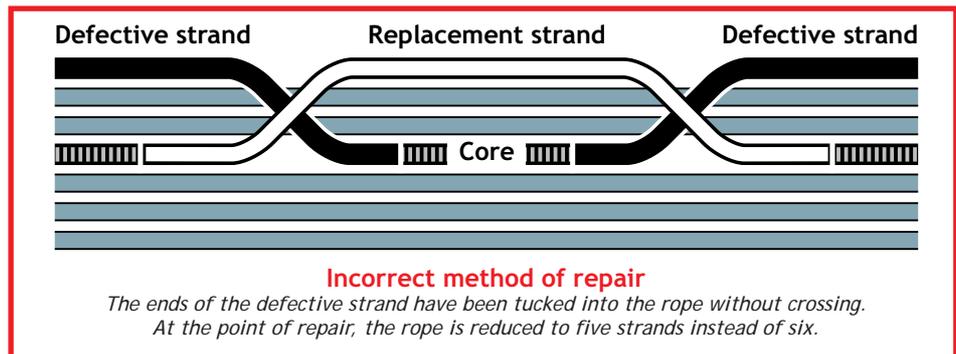
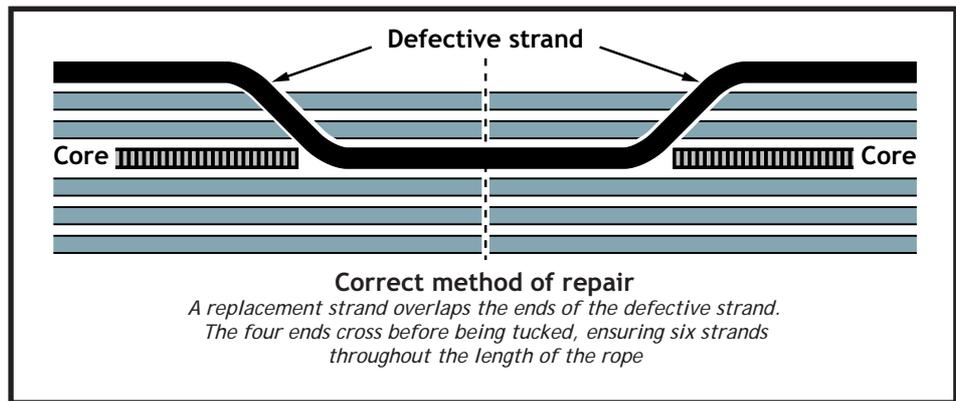


Figure 16 Right and wrong method of replacing a defective strand in a six-strand rope

38 Even following an emergency repair the rope must have six strands on the outside. The correct procedure in making such a repair is to:

- Cut out several yards of the defective strand.
- Insert a longer piece of similar strand in its place.
- Tuck all four ends so that their ends pass before being tucked (Figure 16).

CAPPING

39 The predominant method of capping haulage ropes underground is the inserted cone and tail method. The procedure for capping with white metal or resin is contained within the booklet *Guidance on the selection, installation, maintenance and use of steel wire ropes in vertical mine shafts*.¹

40 Cone and tail capping is a simple method of attaching sockets to six-strand ropes. The cone and tail unit consists of a tail or length of steel wire strand, on one end of which is cast a grooved zinc cone. The grooves allow the six strands of the rope to be positioned at equal intervals around the cone. The cone is shaped so that it will fit closely into the inside of either an open or closed socket.

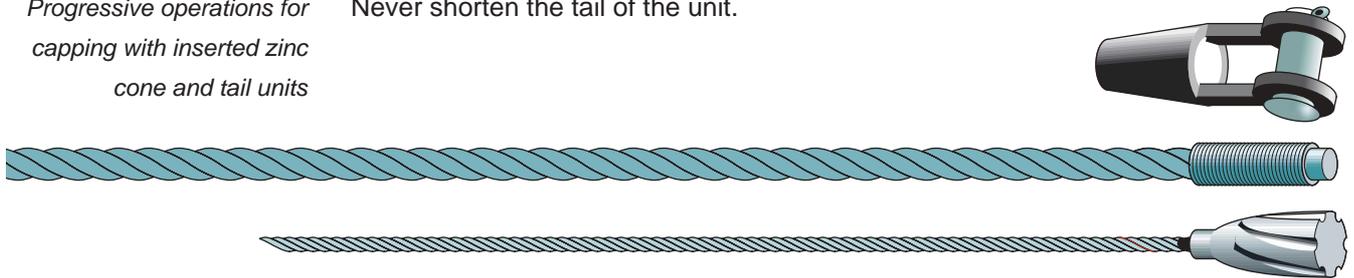
41 Cones and tails together with their matching sockets should be purchased to the specification shown in the References, legislation and standards section of this book.

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Method of fitting

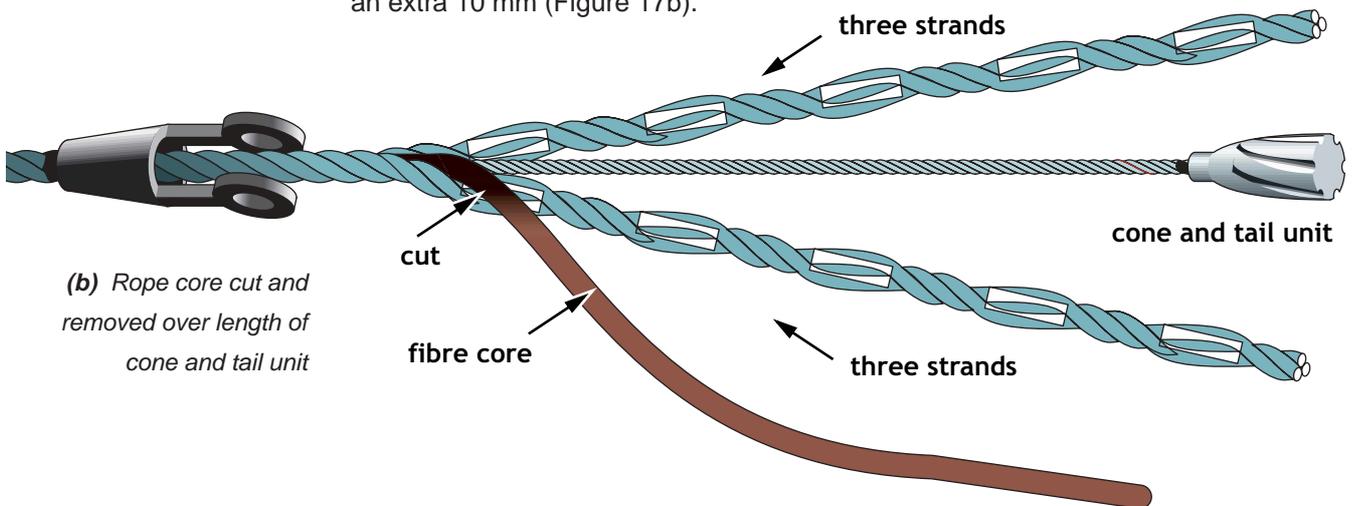
42 The preparatory stage (Figure 17a), shows the rope end, the socket and the cone and tail unit. Only use the correct size of socket and a new cone and tail unit. Both are stamped with the rope diameter for which they are designed. Never shorten the tail of the unit.

Figure 17:
Progressive operations for capping with inserted zinc cone and tail units

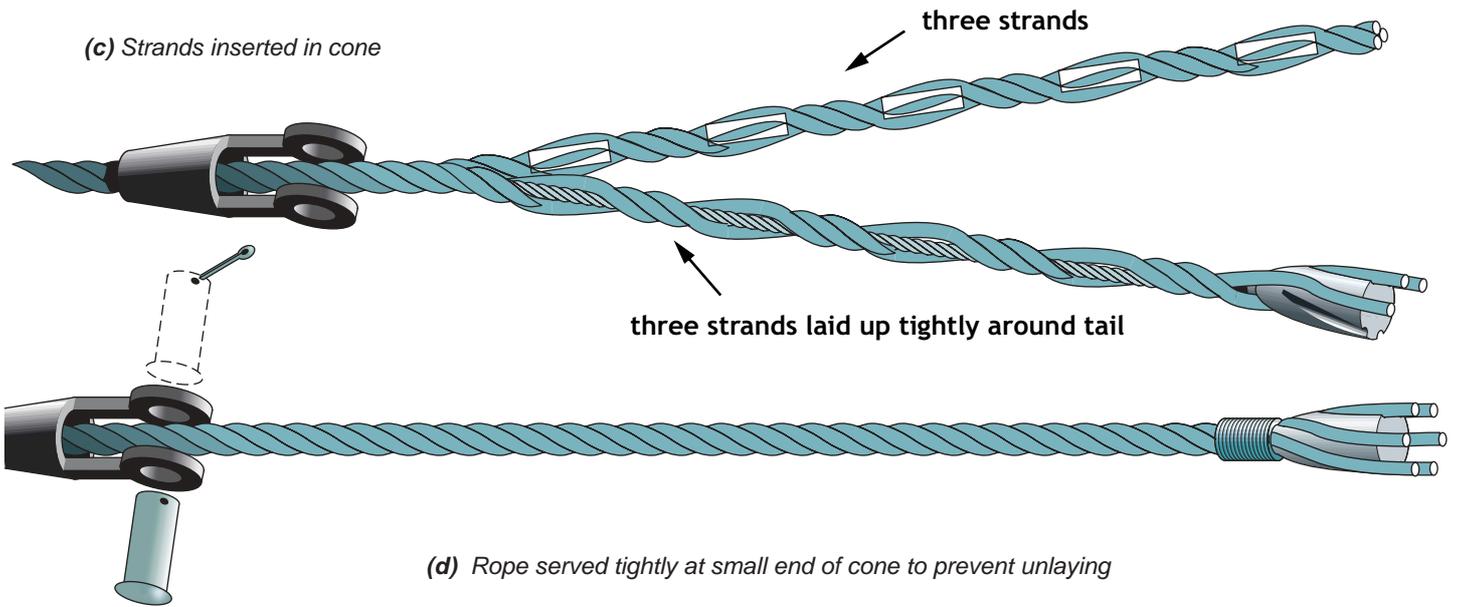


43 The method of fitting is as follows: **(a)** Rope end, socket and cone and tail unit

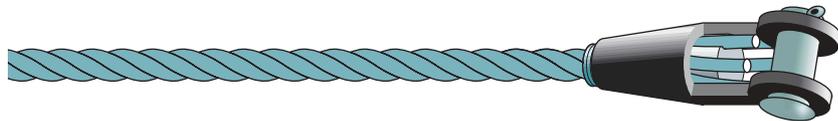
- (a) Thread the socket onto the rope.
- (b) Remove the serving from the rope end and unlaid three strands for a length of approximately 75 mm more than the length of the tail of the cone and tail unit.
- (c) Cut and remove the rope core over the length of the cone and tail unit plus an extra 10 mm (Figure 17b).



- (d) Insert the tail strand in place of the removed core and relay the unlaid strands to reform the rope.
- (e) Place each of the six strands in one of the grooves in the cone, taking care to follow the natural lay of the rope and ensuring that the strands protrude over the end of the cone (Figure 17c).
- (f) Tightly serve the rope at the small end of the cone to prevent it unlaying. Use fine wire of a size which will allow the rope to pass through the small end of the socket (Figure 17d).
- (g) The length of the serving should be a minimum 1.5 x the rope diameter (1.5d).



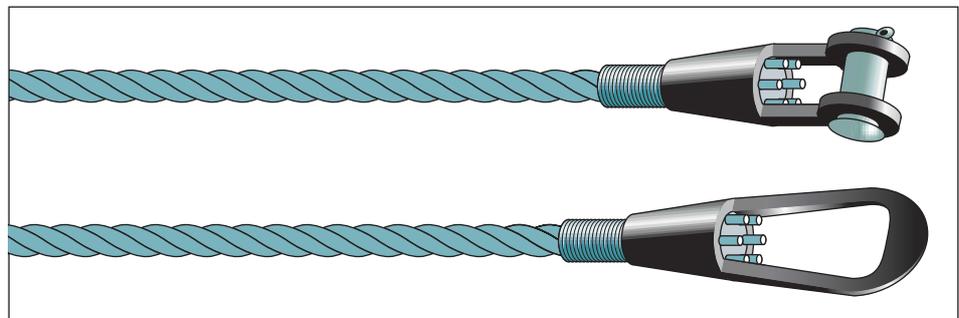
(e) Strands must be big enough to prevent socket moving over rope



(h) Now draw the socket into position by applying a load equal, if possible, to the working load.

(i) After the load has been applied, or preferably while it is still on, serve the rope with soft iron wire or strand so that the serving is close up to and touching the mouth of the socket (Figure 17f).

(f) Open and closed type sockets



(j) The wire or strand must be big enough to prevent the socket passing over in order to prevent the socket moving on the rope.

44 This method of assembly is used for the open socket and for the closed type socket (Figure 17f).

45 After the capping is complete and the socket has been fitted, make a trial run and then examine the termination, especially the coarse binding at the small end of the socket. If this binding ceases to meet the socket after a period of service, it should be replaced.

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Other important points

46 Important points to remember are that:

- Only new zinc cone and tail units should be used. Never re-use an old cone and tail unit.
- Never hammer the cone into the socket. Hammering could severely distort the zinc cone, preventing it from pulling properly into the socket and gripping all the rope strands evenly.
- Draw the cone-and-tail unit into the socket by applying a load equal, if possible, to the working load.
- After fitting the capping and pulling the socket into place, a final coarse serving is essential to prevent the socket moving back along the rope when the load is released.

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TECHNICAL ANNEX 4 - MAINTENANCE OPERATIONS

INSPECTION, EXAMINATION AND TESTING

1 It is a legal requirement to systematically inspect, examine, test, maintain and, if necessary, repair or renew all plant and equipment at mines, including haulage ropes. Only those people who are suitably qualified and competent should undertake the work and they should be supervised by a competent person or people in the management structure.

2 At mines with few workers, just one person may have responsibility for ropes among other duties. They should nevertheless be capable of taking on all of the roles described above.

3 It is essential that arrangements are in place to ensure that all ropes are periodically inspected, examined, tested, maintained and, if necessary, repaired or renewed. Each rope will need to be separately identified within the manager's written scheme which will specify the nature and frequency of inspection, examination, test or other action which is required.

Routine external inspection

4 Routine external inspection is the term used to describe a periodic visual examination of a haulage rope to assess its general condition and to look for signs of any obvious damage or defects to:

- establish if the rope is still safe to be used;
- determine whether or not it needs any special attention over and above the preventative maintenance requirements described later in this Annex.

5 Where possible, carry out routine external inspection of haulage ropes in good light while the rope is running slowly. Pay particular attention to any splices. Kinks and permanent bends in direct haulage ropes can be seen more easily by looking along the rope, especially when it is lightly loaded or not loaded at all. Include cappings in the inspection, to check that they are not drawing or pulling out of their sockets. Check inserted cone-and-tail cappings to confirm that the final coarse serving is present and in its correct position hard against the neck of the socket.

6 Each rope used in a passenger carrying haulage should be subjected to a routine external inspection at least once in every working day that the haulage is used to carry people. If a haulage has not been used for more than 24 hours the rope should be inspected before the haulage is used to carry people again.

7 Ropes used in haulages which do not carry people can be subjected to routine external inspection less often. The frequency of inspection can be set after taking into account such matters as:

- duty;

- condition of the rope;
- operating conditions.

8 Inspect ropes more frequently in the following circumstances:

- ropes operating towards the limits of their duty;
- if there is some concern over the condition;
- in particularly arduous operating conditions.

Periodic thorough examination

9 Periodic thorough examination is carried out less frequently than the routine external inspection, but is more detailed. The rope should be cleaned, measured, and examined at points along its length for evidence of deterioration by wear, corrosion, fatigue, corrosion-fatigue, or surface embrittlement. Look carefully for damage, deformation (kinks and bends) and localised deterioration; paying particular attention to such places as the tucks in splices.

10 It is good practice to have available a short specimen of the rope in new condition for comparison. All such specimens should carry a securely attached label giving the full recognition details of the rope from which it was cut.

11 Each rope used as part of a passenger-carrying haulage needs a periodic thorough examination at least once in every 30 days. Where a haulage has not been used for more than 30 days, thoroughly examine the rope before the haulage is used to carry people again.

12 Ropes used in haulages which are not used for carrying people need thorough examination less often. The frequency of examination will depend on the level of risk. When deciding on the maximum interval between examinations take into account those factors described in paragraphs 7 and 8.

Non-destructive testing (NDT)

13 NDT services for haulage ropes are provided by rope manufacturers and specialist companies. Alternating current (AC), direct current (DC) and permanent magnet types of NDT instruments working on magnetic induction or electromagnetic principles are available.

14 The result of the examination is presented in graphical form and will indicate the presence of broken wires, internal and external corrosion and general wear in a rope. Interpreting the results is the role of the operator of the instrument who will have expert knowledge in this field. As mentioned earlier, further guidance on NDT can be found in the booklet *Guidance on the selection, installation, maintenance and use of steel wire ropes in vertical mine shafts*.¹

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PLANNED PREVENTATIVE MAINTENANCE (PPM)

15 Most of the maintenance carried out in mines is of the PPM type, designed to keep plant and equipment running at or close to its optimum performance levels. Such periodic maintenance can involve repetitive but important attention such as lubrication and systematic replacement of parts or components as they approach the ends of their useful lives. PPM arrangements can either be time-based or condition-based or a combination of the two.

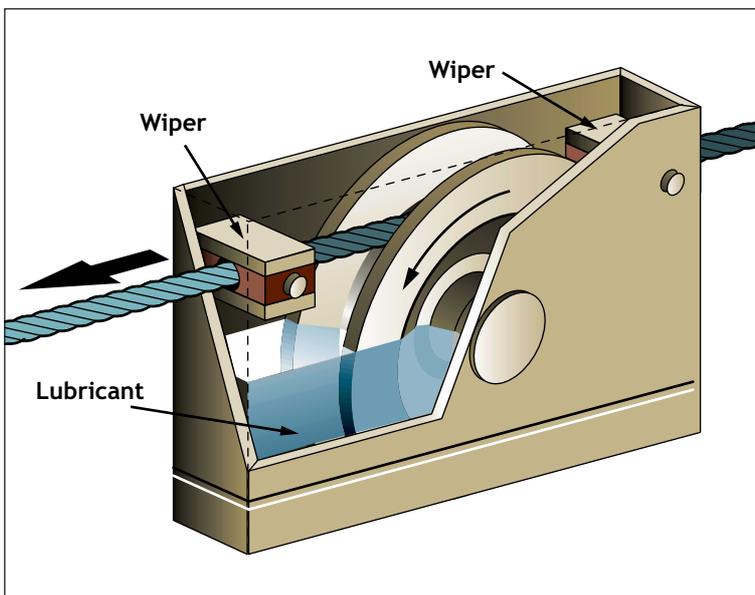
16 Time-based arrangements involve the maintenance of plant and equipment at regular intervals.

17 Condition-based arrangements rely on the measurement or monitoring of certain key indicators until certain action levels are reached. For instance, rope diameter or number of broken wires per metre might be two key indicators for haulage ropes. Action would be taken when the diameter of the rope or parts of it had reduced to the level specified in the manager's scheme or when the percentage of broken wires exceeded the allowable limit.

18 In setting either intervals for time-based maintenance or parameters for condition-based maintenance take due regard of:

- manufacturers' recommendations;
- previous experience.

Lubrication **19** All haulage ropes, including galvanised ropes, will suffer from wear and corrosion and should be kept well lubricated. The dressings most suited to combating wear and corrosion are either very viscous oils or soft greases which contain tackiness additives together with either molybdenum disulphide or graphite. Other dressings which may be used are heavy residual oils and bituminous compounds.



20 A mechanical lubricator suitable for haulage ropes is shown in Figure 18. As the rope is drawn slowly through, the pulley transfers lubricant from the bath onto the rope, the wiper removing excess lubricant, distributing the remainder and working it into the rope.

21 High pressure lubrication offers a more effective means of rope lubrication than mechanical or manual methods. Several systems for pressure lubrication are available from rope and lubricant suppliers.

Figure 18: Mechanical lubricator

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TYPES OF DETERIORATION AFFECTING HAULAGE ROPES

22 The main forms of deterioration in haulage ropes are as follows:

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

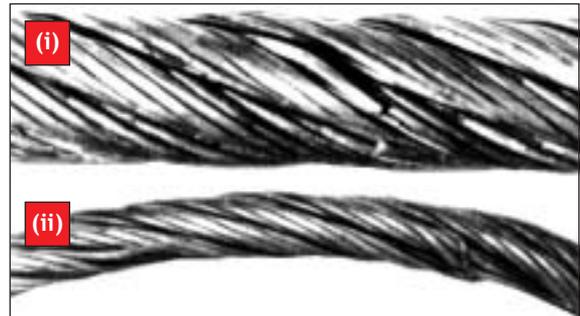
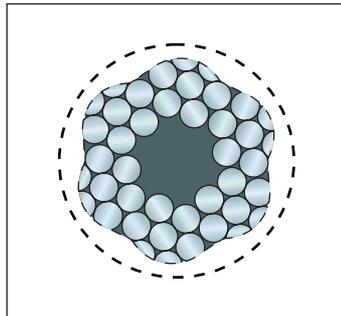
23 If a rope is of unsuitable type or construction, some of the above forms of deterioration are more likely to occur, for example:

- flexible type ropes having small outer wires of less than 2 mm diameter when new are likely to suffer deterioration by wear and corrosion;
- non-galvanised ropes working in corrosive environments are almost certain to deteriorate by corrosion, especially if they are not kept well lubricated at all times.

Wear 24 Wear on a haulage rope can take several forms. If the rope rubs relatively slowly against the floor, rails or other obstructions, the wear may be purely abrasive with metal being gradually eroded from the external wire crowns (Figures 19 and 20).

Figure 19: Effect of heavy wear on a haulage rope

(a) Cross-section of heavily worn rope (original diameter shown as dotted line)



(b) Heavy external wear (i) wires broken at crown (ii) displaced and broken wires

25 Removing obstructions, or guiding the rope away from them using extra rollers, should reduce such wear.



26 Because of the working conditions for most haulage ropes, the outer wires of these ropes should never be less than 2 mm in diameter, otherwise they will not be robust enough to withstand the wear and corrosion likely to be encountered (Figure 21).

Figure 20: Haulage rope showing wires severed by severe external wear



Figure 21: Deterioration of a small flexible haulage rope

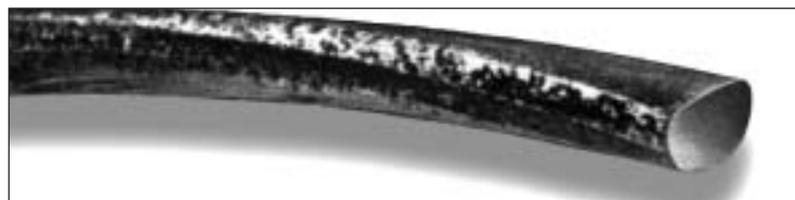
27 Both external and internal wear are bound to occur to some extent in all ropes; but when wear becomes heavy the cause should be found and corrected. Remember that corrosion increases wear by helping to remove steel, just as wear helps corrosion by removing the corrosion scale and exposing a fresh surface for further corrosion.

External wear

28 External wear may take the form of:

- abrasive wear in which metal is removed from the crowns (Figure 22a);

Figure 22: External wear on wires



(a) Abrasive

- plastic wear in which metal is displaced to form fins at the edges of the worn crowns (Figure 22b).



(b) Plastic

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29 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. In other words, the area of contact between the rope and the hard surface is insufficient to give proper support to the rope and the steel of the wire surfaces has been splayed or deformed into fins by the heavy pressure.

Internal wear

30 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 23 shows examples of nicks and grooves:

- Figure 23a shows a simple nick
- Figure 23b shows a twinned nick caused by a crossing wire permanently changing to a slight extent its point of contact with the wire shown, as a result of the rope becoming loosely laid up.
- Figure 23c shows a scuffed nick formed by a crossing but very loose wire playing against the wire shown.
- Figure 23d shows a long groove made by a wire of the same direction of lay as the wire in the illustration.

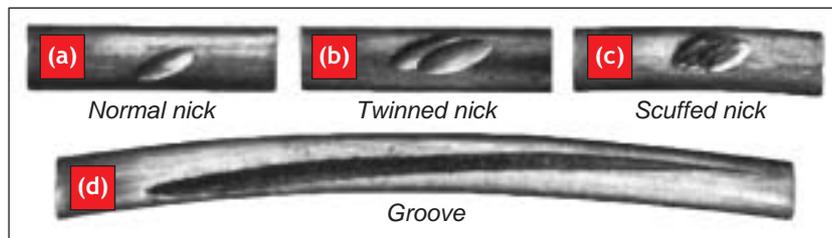


Figure 23: Internal wear on wires

31 When nicks or grooves become deep, and there is no corrosion present, it suggests that the wires are being pressed together too heavily or driven together too forcibly by impact. Excessive pressure can result when the rope is bearing too heavily on some object such as a small drum or pulley, or being pinched, for instance, by a tight pulley groove. In such cases the resulting damage is characterised by continuous plastic wear on the rope exterior.

32 Impact damage can result from the rope striking against an 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 on the wires with subsequent wire breakage (see also 'Martensitic embrittlement', paragraphs 88-91).

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Localised wear at kinks or permanent bends

33 Localised wear can occur at a kink or at a permanent bend. A true kink is formed when a rope goes slack, forms itself into a close loop, and is pulled tight (Figure 24).

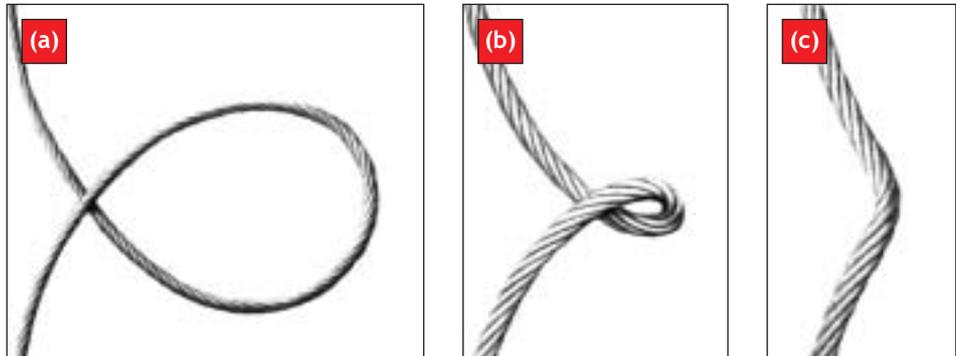


Figure 24: Stages in the formation of a kink

34 Ropes may go slack for a number of reasons, such as when vehicles leave a gradient and enter a level part of the road, or when the rope is disconnected.

35 Normally, a slack rope forms a loop in order to relieve twist. When such a loop is pulled tight the resulting kink (Figure 24c) is not just an elbow-shaped bend; it is a short but very tightly twisted spiral, because all the twist taken out of a long length of rope and stored in the original loop (Figure 24a) has been put back into the short length of rope at the kink (Figures 24b and c).

36 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.

37 Permanent elbow-shaped bends, somewhat similar in shape to true kinks, may be formed by irregular coiling on the drum; a coil in one layer may span the gap between two open or separated coils in the underlying layer and then be forced into that gap by the pressure of a coil in the overlaying layer. Such bends may also be caused by a haulage rope clip pulling too heavily on an endless rope when the vehicles are held back by an obstruction.

38 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.

39 Kinks and bends may pose more risk than is first apparent. A kinked or bent rope may break within a few shifts as a result of concentrated and rapid wear on the outside of these deformations. Such ropes should be examined by a competent person to ascertain the degree of damage and decide the action to be taken.

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Stages of deterioration of a rope kink or permanent bend

40 Figure 25 shows a kink at four different stages of failure in the same rope:

- Figure 25a shows unevenly laid strands and resulting variable cross-section at the kink.
- Figure 25b shows worn and fractured wires on the point of the elbow.
- Figure 25c shows the progressive fracturing of wires.
- Figure 25d shows one half of a fractured rope.

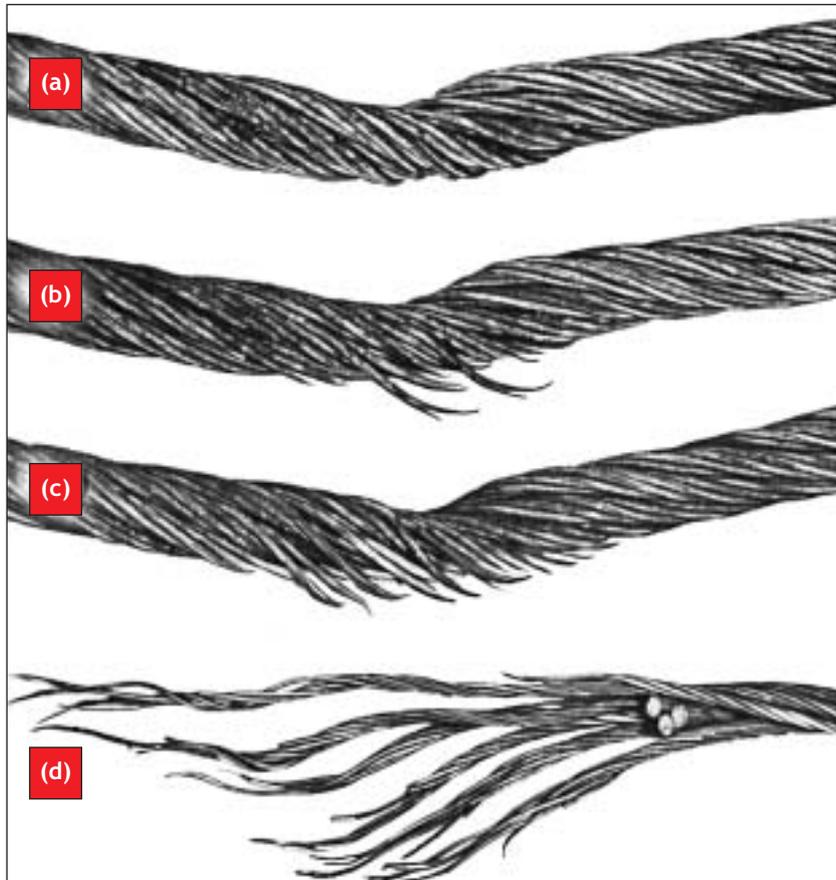


Figure 25: Stages of deterioration at a kink in a haulage rope

41 The rope shown in Figure 25d shows the characteristic 'echelon' type fracture. Each strand is longer than the strand before and, within a strand, each wire is longer than the wire before. This is because each strand and wire has been worn heavily along only one side of the rope at the outside of the kink or bend. The most heavily worn strands will be the two whose fractures lie half-way along the rope fracture. This is because they lay on the point of the elbow and will be the first to break. The longest and shortest strands at the rope fracture will be the least worn and the last to break; in fact one of these may be pulled out straight at its end because it was the last of all the strands to break.

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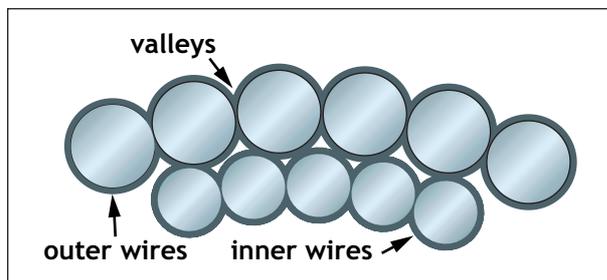
42 Similar concentrated wear can occur on the raised strands of a badly made splice, as previously illustrated in Figures 14 and 15. Wear is also likely to occur at a splice if the ends of the tucked strands are not pushed well into the centre of the rope. A protruding end can catch against obstructions so that the whole tucked strand is pulled out and result in a hold-fast and rope failure.

How wear leads to breakage

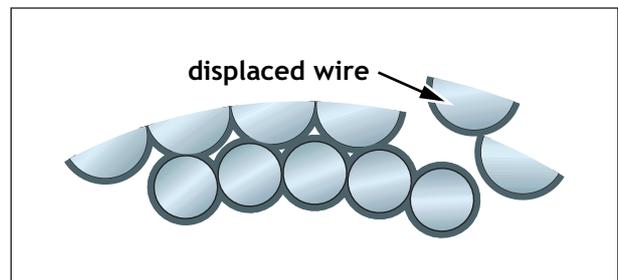
43 When the round outer wires of a rope or strand (Figure 26a) become reduced to half their original diameter by external wear or corrosion (Figure 26b), there are no longer any valleys remaining between adjacent outer wires and they can be readily displaced by overriding one another.

Figure 26: Wires in a strand loosened by wear and corrosion

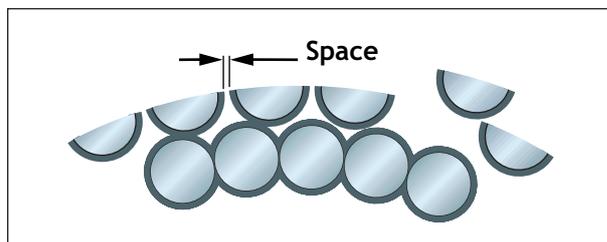
44 When the wires become reduced to less than half their original diameter they will also be reduced in width and will no longer be in contact with adjacent wires and there will be spaces or gaps between them (Figure 26c). They will



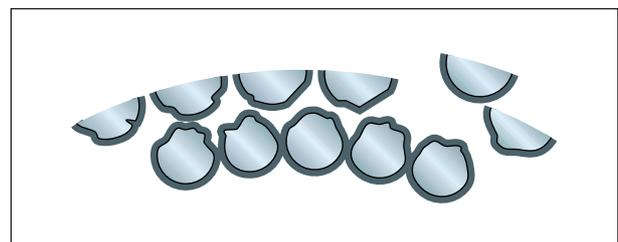
(a) Unworn condition



(b) Outer wires worn to half



(c) Outer wires worn to less than half



(d) Internal wear and corrosion

even more readily override one another. If, in addition, internal wear or internal corrosion has removed the 'undersides' of the outer wires they will sit loosely on the inner wires (Figure 26d) and be even more readily displaced.

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.

Wire by wire failure

46 Figure 27 shows six stages of failure, wire by wire, of a man-riding haulage rope which broke in service:

- The wires are so loose that spaces or 'daylight' can be seen underneath some (Figure 27a).
- A loose wire has become displaced and bent into a Z-bend (Figure 27b).
- A wire has broken at a Z-bend (Figure 27c).
- The broken ends of a wire are protruding from the rope so that they are liable to catch on obstructions (Figure 27d).
- One of the broken ends has been hooked back on itself as a result of catching on obstructions (Figure 27e).
- The 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 (Figure 27f).

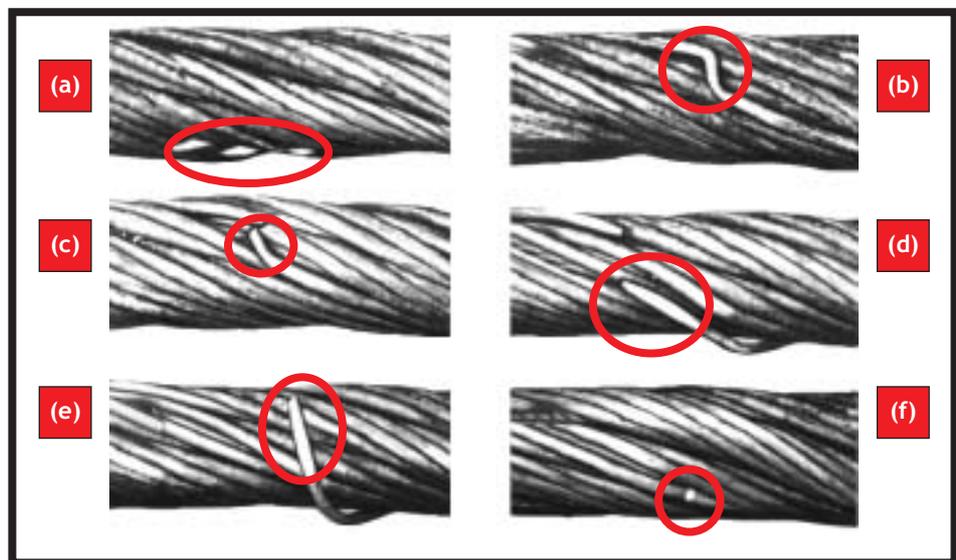


Figure 27: Stages of failure of a wire in a loosened rope

Wear fractures

47 Most of the wires will show chisel ends because they have been worn through, or almost worn through (Figure 28).

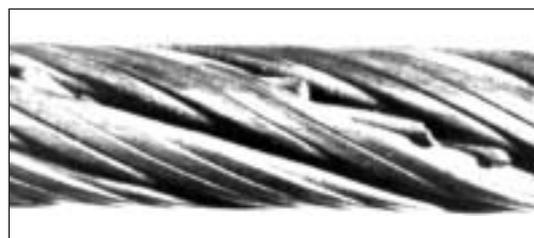


Figure 28: Flexion wire fractures in a rope

48 Some will probably show stubby flexion (bending) fractures with slightly hooked ends at unworn parts (Figure 29).

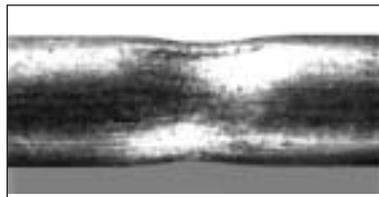
49 These wires were also severed by wear or broken in some manner at their crowns, but have since lost their original broken ends as a result of their catching on obstructions and being wrenched off.



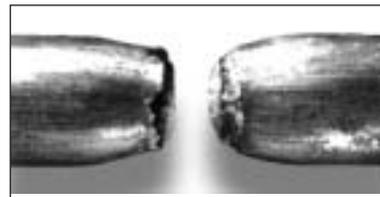
Figure 29: Flexion wire fractures in a rope - fractured end

50 A proportion of the wires will show typical tension fractures at less worn parts (Figure 30).

Figure 30: Stages in the breaking of a wire in tension



(a) Wire waisting



(b) Fractured ends

51 These are wires that failed in tension when the rope became so weakened that it could no longer carry the load. A tension fracture can always be recognised by the waisting (necking); that is, a reduction in diameter, that occurs at the broken end.

Corrosion

52 Corrosion is the main cause of deterioration in haulage ropes. Any water in roadways should be diverted away from the rope and its supporting rollers and pulleys. Water should not be allowed to accumulate in roadways.

53 A galvanised rope is likely to give longer service than an ungalvanised one. Even if the galvanised coating wears from the strand crowns, it should remain in the rope interior to give protection there.

External corrosion

54 External corrosion usually takes the form of mild rust or scale and is seldom more serious than it appears, unless shocks have contributed to additional deterioration by corrosion-fatigue (paragraph 81). It may take the form of pitting, as in the triangular strand rope in Figure 31, in which case the strength of the corroded wires will be much reduced.

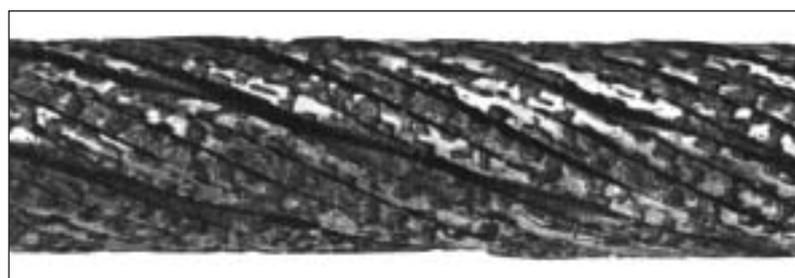


Figure 31: Severe pitting of a six-strand rope

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55 External corrosion may also occur as edge-pitting, in which some or all of the pits lie at the sharp edges of heavily worn crowns; that is, at the contacts between adjacent outer wires. Edge-pitting is the more serious as it indicates corrosion is starting to enter the rope between the wires. In Figure 31 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. The rope in the illustration may be in a much worse condition than the external pitting and wear would, at first, suggest and indicates the presence of internal corrosion.

Internal corrosion

56 Internal corrosion can be dangerous as it is difficult to detect and may remain undiscovered unless the person inspecting or examining the rope is aware of the external signs that indicates its presence. Internal corrosion, when severe, loosens the wires by removing their bearing surfaces in the same way as severe internal wear (see Figure 26d).

57 The external signs of internal corrosion are demonstrated in Figure 31:

- The outer wires are loose.
- There are spaces between most of the wires.
- Some are riding high above the level of others and can override them.
- Some are slightly displaced leaving a space at one side and none at the other.

58 This indicates that corrosion has entered the rope and has attacked the undersides of the outer wires, leaving those wires loose on their inner wires (see also Figure 26d). A rope in this condition may not be safe to use and it should be replaced at the earliest possible opportunity.

Corrosion fractures

59 When corrosion is so severe that the wires are reduced to the extent that they can no longer carry their load, they will break in tension and develop tension fractures (with waisting) of the type shown in Figure 30. However, corrosion pitting and scale may mask waisting and make it difficult to recognise. Figure 32 shows a corroded tension fracture.

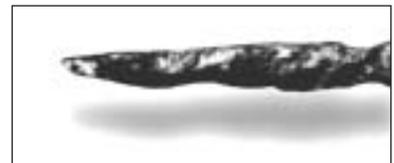


Figure 32: Corroded tension

60 When a broken wire is so reduced by corrosion that it can no longer be expected to carry its load, the person inspecting or examining the rope can assume that the wire has broken in tension, especially if other wires in the rope show definite waisting at their fractures.

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Fatigue 61 Fatigue is a form of deterioration leading to broken wires. It can occur in ropes that are free from corrosion. If a rope is corroded, the wires may break in corrosion-fatigue rather than in pure fatigue.

62 Sharp-edged surface irregularities, such as small but relatively deep corrosion pits, narrow scratches, surface cracks, etc, encourage fatigue because the stress at the bottom or root of the 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 is not easy to define but an example will show clearly what it means. If a rope is subjected to a single overload equal to its breaking strength, it will immediately break in tension and its wires will show typical tension fractures with waisted ends (see Figure 30). If the rope is repeatedly loaded to only 75% of its breaking strength it will not break immediately but it will eventually break in fatigue. In this case its wires will show fatigue fractures which are quite different from tension fractures (Figure 33).



Figure 33: Fatigue

64 If the rope is repeatedly loaded to only 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.

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

66 The repeated loading in an individual rope wire is not only due to its share of the maximum tensile load. To this must be added:

- shock loads in the wire during use;
- primary bending load in the wire due to repeated bending of the rope over pulleys and drums;
- secondary bending load in the wire due to repeated bending of the wire over other wires in the rope as the tension varies (see paragraphs 68-75 on secondary bending fatigue).

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

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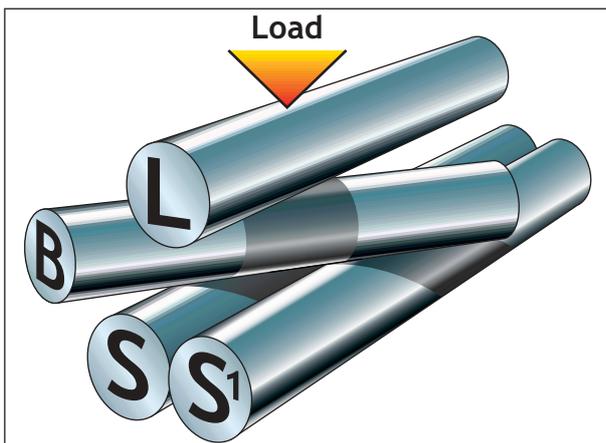
Secondary bending fatigue

68 One fairly common cause of fatigue is accentuated secondary bending of wires, which is illustrated in Figures 34 and 35.

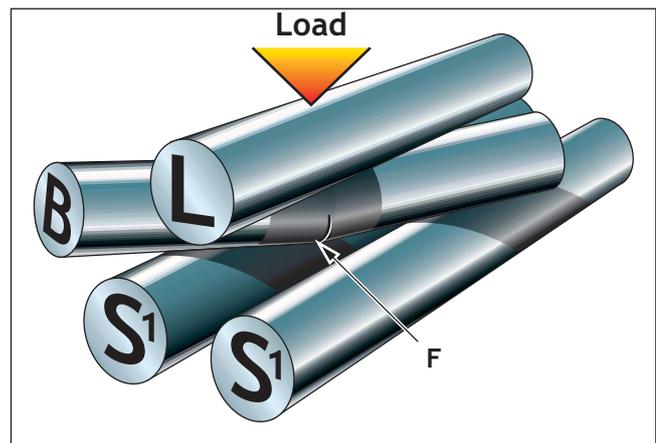
69 If a rope is in good condition and well laid up, adjacent wires will be in hard contact with one another. In Figure 34a, a wire of one layer (wire **B**) is shown crossing over two supporting wires (wires **S** and **S¹**) while being pressed downwards or loaded by another wire (wire **L**). Wire **B** is acting like a small bridge, spanning the gap between wires **S** and **S¹**, and being loaded by wire **L**. Provided that the wires remain in hard contact with one another the gap will remain narrow and shallow and wire **B** will only be slightly bent. This represents the normal secondary bending conditions which do not lead to fatigue.

70 If a rope is loosely laid up because it was supplied in that condition, or has become loosely laid up in handling at the mine, or for some other reason, the wires can move apart as shown to an exaggerated degree in Figure 34b.

Figure 34: Secondary bending in wires



(a) Normal secondary bending in a well laid-up rope



(b) Accentuated secondary bending in a loosely laid-up rope

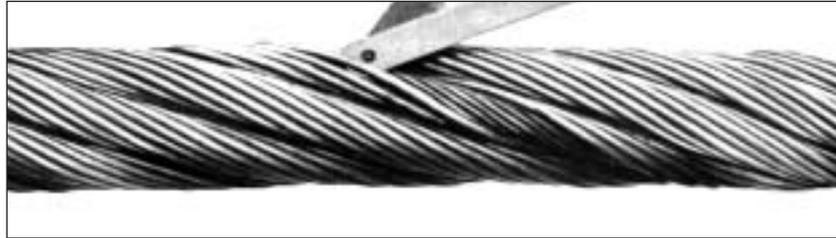
The gap between the wires **S** and **S¹** is wider and deeper than before. This will allow the bridge wire (wire **B**) to bend and flex to a greater degree than in a well laid up rope. Wire **L** is not held in position by adjacent wires in the same layer, and will slide over the bent wire **B** and take up a position at mid-span. This increases the bending stress in wire **B** which can bend much more than when the rope was well laid up. This in turn causes pronounced flexing every time the rope tension varies and produces a variation in the pressure exerted by wire **L**. This effect is called 'accentuated secondary bending'. Because the bridging wire (wire **B**) will be repeatedly bent to a much greater extent than in a well laid up rope, fatigue cracking may develop on the stretched side of the bent wire, at **F**. That crack will then be directly on the opposite side of the wire to the nick made by the pressure of the loading wire (wire **L**).

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The effects of secondary bending fatigue

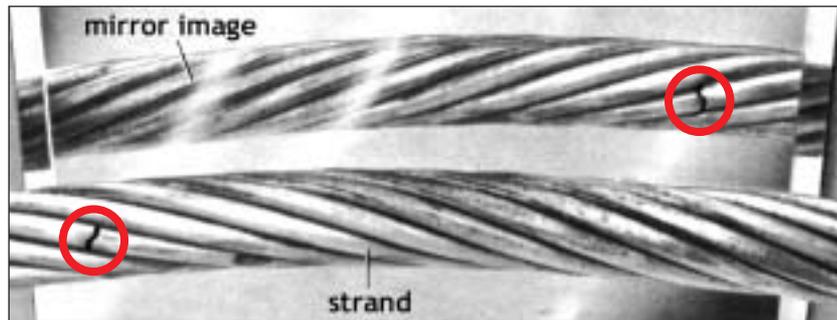
71 Figure 35a shows a rope which broke in fatigue at a part some distance from that shown in the illustration. In the illustration four outer wires have been cut out to reveal that the remaining outer wires were so loose that the two hacksaw blades (total thickness 1.3 mm) could be slipped underneath them.

Figure 35: The effects of secondary bending on a rope



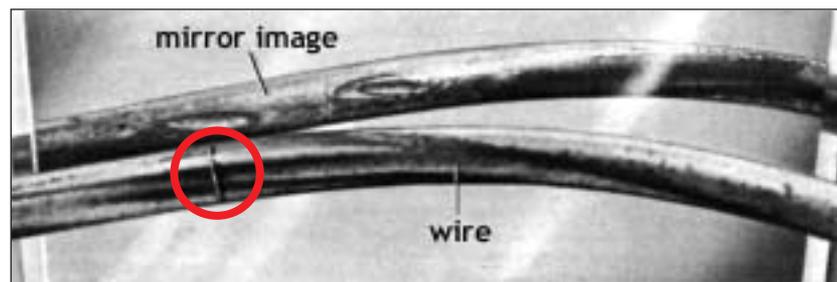
(a) Loose rope

72 In Figure 35b 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 at the line of nicks made by the neighbouring strands. The fatigue cracks leading to these wire fractures did not start in the nicks; all the cracks in that rope started on the opposite side of the wire and some spread across the wire to reach the nicks.



(b) Fatigue fractures and nicks marking contact points between strands

73 This point is best illustrated by choosing a wire which is cracked but not completely broken. In Figure 35c a cracked wire from the rope has been placed in front of a mirror; the crack is directly on the opposite side of the wire to the nick - the sign of accentuated secondary bending. 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.



(c) Fatigue crack starting on side of wire opposite to nick on contact side

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74 In this particular case, the nature of the nicking indicates that the accentuated secondary bending is due to loosened lay; the rope having become loose at some time after manufacture. In Figure 35c the two nicks are not normal; they are twinned nicks, each being made up of two mainly-overlapping nicks. In other words, the contact points between this wire and other wires changed permanently at some time when the rope became loosened.

75 The two long grooves which cross the crack were made by the two supporting inner wires (see S and S¹ in Figure 34). These grooves are wider at the crack than elsewhere. This is because the wire was repeatedly pressed down into the valley between the supporting wires and the grooves made by those wires became widened by that movement. The two grooves overlap, and the crack is half-way along the length of the overlap. This means that the crack (and the nick opposite) were at mid-span in the greatly skewed small bridge. The second nick, which has no crack opposite it, is due to the nick being opposite only one groove. It is opposite the part which was riding right on top of one inner wire. It was, therefore, at one end of the small bridge where it could not be repeatedly bent down into the valley.

Fatigue fractures

76 When a wire is deteriorating by fatigue it will show no signs of that deterioration until it has completed more than 90% of the repeated loading necessary to break it in fatigue. Then small cracks will appear on the wire surface, so small and fine that the person inspecting or examining the rope will have little chance of finding them unless looking specifically for such evidence. As the cracks deepen, wires will break in the same way as a wire which has been partly sawn through and bent; ie it will break with a partly splintered end.

77 Figures 36 a-c shows a wire breaking in this way at a fatigue crack.



78 The splintered part of the fracture in Figure 36c 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.

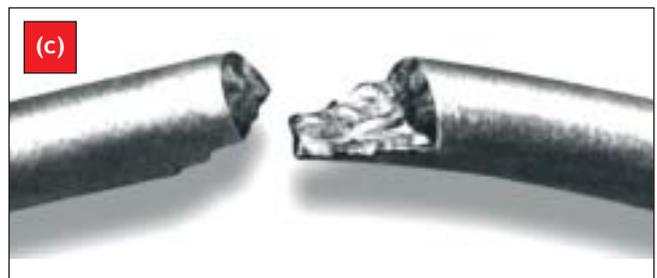


Figure 36: Stages in the breaking of a wire at a fatigue crack

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

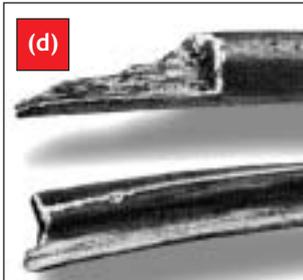


Figure 36d: *Battered fatigue*

80 If a wire in a rope has been broken for some time, its ends may have rubbed against each other and become battered, as shown in Figure 36d, so that it is difficult to recognise the characteristics described above. However, the absence of waisting will suggest fatigue to the person inspecting or examining the rope. If some lengths of wire from the rope snap at unobserved fatigue cracks, when bent by hand, then the examiner will have proved that the rope is affected by fatigue.

Corrosion-fatigue

81 Corrosion-fatigue occurs when there is a combination of 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 be of a severity or type that will still lead to corrosion-fatigue. However, if corrosion can be eliminated, corrosion-fatigue is unlikely to occur.

Corrosion-fatigue fractures

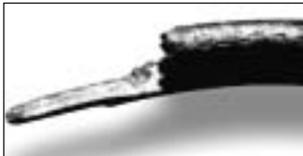


Figure 37: *Corrosion fatigue*

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

83 The fractures that are shown by wires which have failed in corrosion-fatigue (Figure 37) are often very similar to those occurring in pure fatigue (Figure 33) but there will be some corrosion present - though perhaps very little. To establish definitely whether a wire has broken in corrosion-fatigue or in pure fatigue it is necessary for an expert to examine the broken ends under a microscope. However, if wire fractures of the fatigue type are found in a rope which shows any degree of corrosion, the person inspecting or examining the rope should assume that corrosion-fatigue was the cause of the fractures and take steps to avoid corrosion-fatigue in future.

Surface embrittlement

84 Some haulage ropes deteriorate as a result of surface embrittlement. This may be caused by the rope rubbing heavily against metallic obstructions causing the formation of Martensite, a brittle variant of steel (Figure 38a). Deterioration can also be caused by heavy pressure on drums causing plastic deformation (Figure 38b).

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85 For example, the rope may have worn a groove in a low girder, or a protruding arch leg, or a seized road roller. The person inspecting or examining the rope should realise that martensitic embrittlement may have occurred. The obstruction should either be removed or the rope guided past it by means of free-running rollers. The rope should then be closely examined through a magnifying glass for the fine martensitic cracks on the worn crowns. If such cracks are found the rope should be examined more

frequently and withdrawn from service as soon as wires begin to break at the crowns.

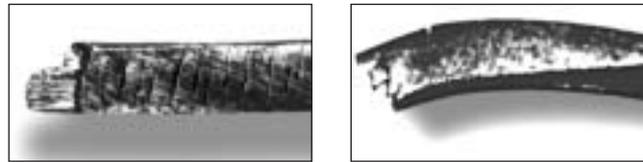


Figure 38 : *Martensite / plastic wear*

(a) *Martensite*

(b) *Plastic*

Plastic-wear embrittlement

86 Plastic wear will occur on the outer wires if a rope bears too heavily on some hard surface. The metal of the crowns of the outer wires will deform or splay into fins at the edges of the worn crowns (see Figure 22b). These fins are brittle and likely to crack. The cracks are sharp-edged surface irregularities and may become fatigue cracks extending across the wire causing it to break in fatigue. Alternatively, the cracks may turn through a right angle and extend parallel to the wire (Figure 39) causing the fins to flake off.

87 In the case of plastic-wear embrittlement, it is a matter of chance whether the wire breaks (see Figure 38b) or the embrittled fin flakes off.

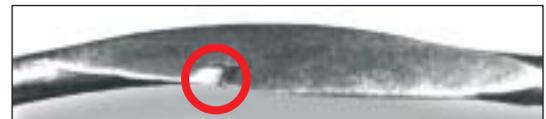


Figure 39: *Plastic wear leading to cracks*

Martensitic embrittlement

88 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.

89 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 the surface of the rubbed wires above 700°C. The wire is heated almost spontaneously to that temperature but only to a depth of about 0.02 mm. When the source of friction is removed (ie when the rope has passed the obstruction) 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 which results in the surface becoming brittle martensite to a depth of about 0.02mm.

90 When the wire subsequently bends for the first time, the brittle surface will develop a series of cracks along or near its centre line (see Figure 38a).

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As expected, each of the cracks running across the worn crown of the wire is only about 0.02 mm deep. These cracks are perfect examples of sharp-edged surface irregularities and will, in time, develop into fatigue cracks. As the cracks are formed in the wire itself, it is certain to break in fatigue when the fatigue crack has extended far enough into the wire. Martensitic embrittlement can therefore be an extremely dangerous form of deterioration.

91 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 with a pit at the bottom of the next nearby crack. The undermined surface then flakes off and the worn crown eventually displays a chain or chains of elongated corrosion pits following the strip or strips of martensite on the surface. This chain pitting (Figure 40) is one of the signs of martensite; it is different from the normal random pitting shown in Figure 31.

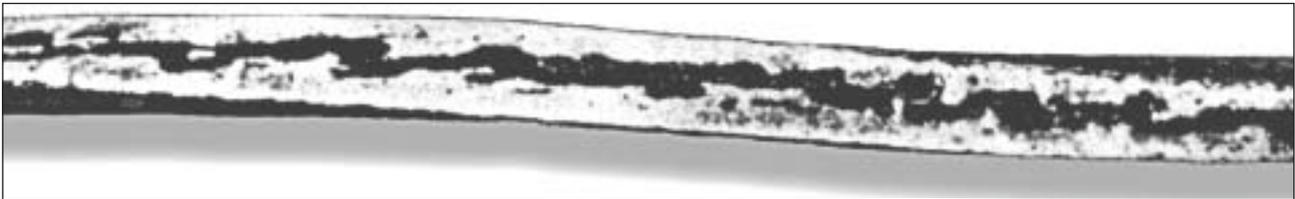


Figure 40: Chain pitting on a wire

Surface embrittlement fractures

92 Surface embrittlement fractures are always fatigue type fractures that occur when the original surface embrittlement cracks extend under fatigue until they reach sufficient depth for the wires to break. Because surface embrittlement always occurs at the worn crowns of the wires, surface embrittlement fractures will be found only in those locations. In the case of plastic-wear embrittlement there will be fins present at the edges of the worn crowns and the fatigue cracks will have originated at the fins (see Figure 38b). In the case of martensitic embrittlement the fatigue cracks will have originated in the worn crowns themselves. These cracks are often so close together along the wire that a fracture may be of a stepped type extending from one crack to the next (see Figure 38a).

93 If some unbroken wires can be removed from a rope suspected of showing surface embrittlement, the person inspecting or examining the rope should bend each wire gradually to stretch the worn crown, closely watching the crown all the time, preferably through a magnifying glass. The following are indicators of the various types of surface embrittlement:

- 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 cause of the trouble is plastic-wear embrittlement.

- If the cracks start to open at or near the centre-line of the worn crown and not at the edges, then the cause of the trouble is martensitic embrittlement.

ACCIDENTAL DAMAGE AND DISTORTION

94 While accidental damage and distortion are not really forms of deterioration, people inspecting or examining ropes should realise that they may lead to rapid deterioration.

95 A dented rope may appear to be in reasonably good condition but may break within a relatively short time, either because of the development of fatigue due to accentuated secondary bending, or internal corrosion or corrosion-fatigue due to moisture entering the rope at the damaged part, or a combination of these.

Bending around a sharp object

96 If slack rope forms so that a coil or coils fall over the side of the 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 41).

97 When damage of this type becomes apparent, the rope should be carefully examined by a competent person to determine the appropriate action.

Runovers



Figure 42: Sheared end

98 When a haulage rope is run over by a tub or mine car, and is trapped between the wheel and the rail track, the rope will be severely dented and some wires may be partially or completely cut through (Figure 42).

99 The rope will, almost certainly, break at the damaged part if that part is not withdrawn immediately from service.

100 Ropes that have been runover may show:

- some fractured wires with chisel ends if the rope was permanently bent at the deformation (see Figure 28);
- wires with tension fractures (see Figure 30);

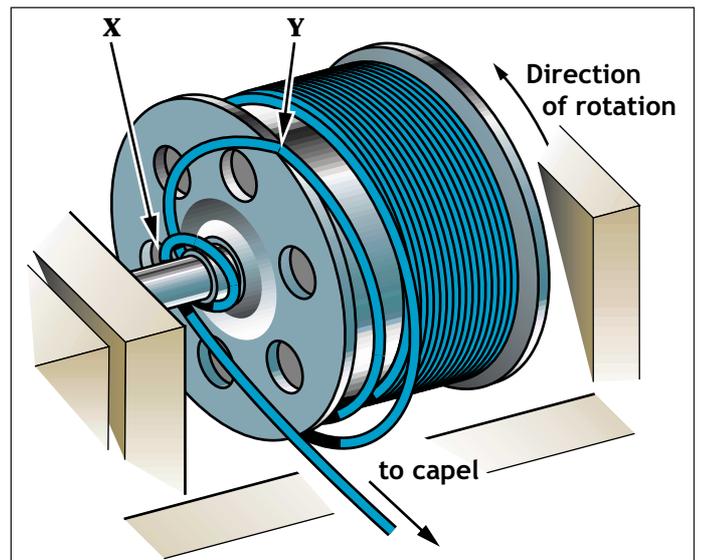


Figure 41: Damage through slack rope

- some wires with smooth bright, sheared ends where the wires were cut through, or almost cut through, by the tub wheels (see Figure 42).

Trapping

101 A rope may become trapped just once and be broken by the resulting overload. The rope will show typical tensile fractures (see Figure 30) at the wire ends but, probably, no other useful evidence.

102 However, some ropes may be repeatedly trapped but, because they free themselves as the vehicles approach the trapping point, no action is taken to rectify matters. This is dangerous, because such ropes are almost certain to break eventually. A rope which is repeatedly trapped by an obstruction is likely to cut a groove in the obstruction and eventually be unable to free itself when the groove becomes too deep. Examples of repeated trapping are where ropes repeatedly get on the wrong side of a guide rail, or behind a large bolt head or nut, or in the gap in the rails at a crossing or parting.

103 Consider the last example. When a rope runs in the gap in the rails (Figure 43) it will be pulled free as the vehicles approach on all occasions until the rope has undercut the top flange of the rail so deeply that it will be unable to free itself. If the track is not pulled up by the rope, then the rope will break.

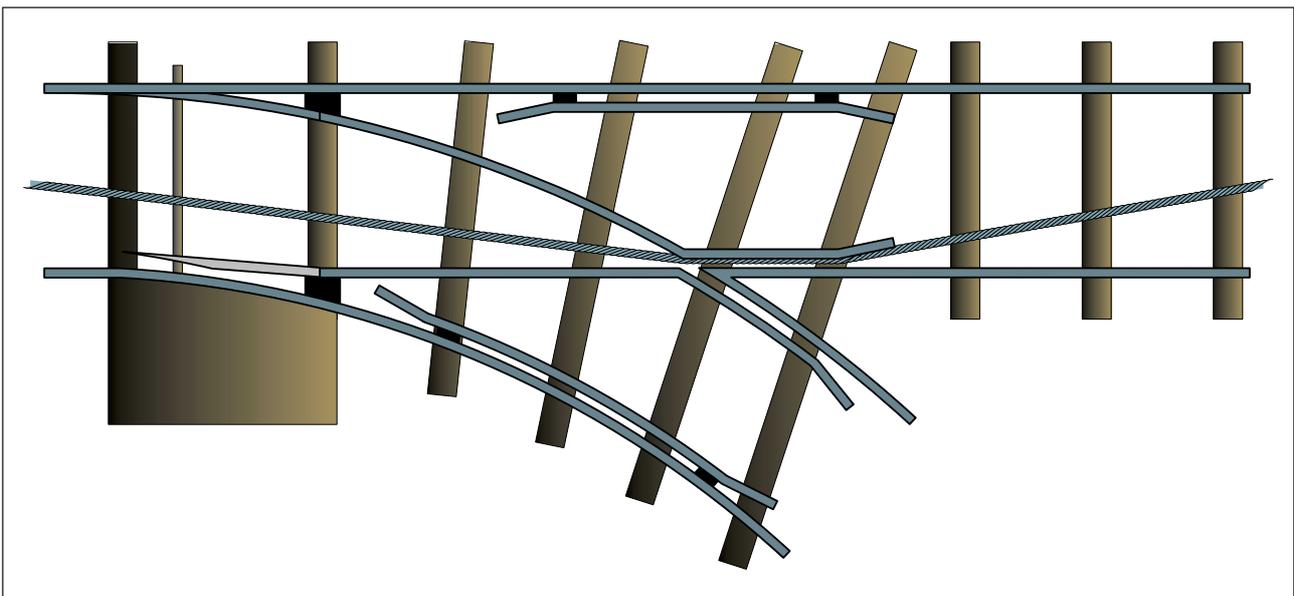


Figure 43: Haulage rope trapped in rails

104 The broken end of the rope will show many wire fractures of the tension type, because the rope has been overloaded on a single occasion. Some wires may show sheared or partly sheared ends if the rope was pulled hard against a sharp edge of the rail end. On the leading side of the rope fracture one side of the rope surface will probably show a succession of bruises or bind marks spaced at decreasing intervals as the fracture is approached and with the final mark at the fracture. These are the points at which the rope successively seized in the gap with increasing force during the final occasion on which it was trapped. A crossing designed to prevent this type of damage is shown in Figure 44.

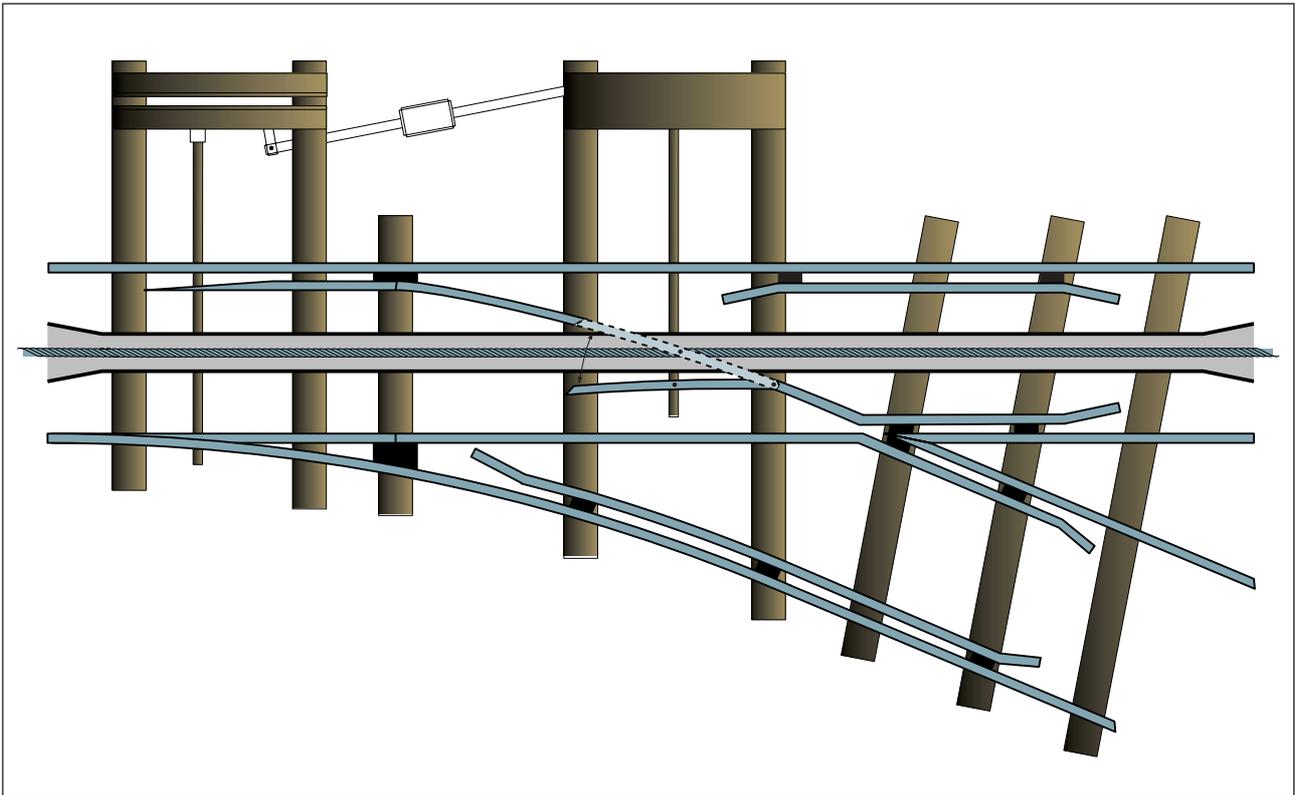


Figure 44: Type of rail crossing designed to reduce trapping of the rope to a minimum

Fractures at damage and distortions

105 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;
- working conditions.

106 For instance, a kinked haulage rope will rapidly wear through at the kink before fatigue has time to appear. The person inspecting or examining the rope should study the nature of any deformation which they find and should try to foresee how the deformed wires will act during further service:

- Will they be repeatedly bent and straightened and, therefore, liable to break in fatigue?
- Do they protrude above the level of other wires and become exposed to localised wear?
- Have they been pushed aside so as to leave the rope open and subject to localised internal corrosion?

107 A rope which shows distortion will probably not show broken wires at all, but it may cause excessive sheave wear.

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WHEN TO DISCARD A ROPE

108 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.

109 A rope which shows some deterioration but which has done little work may be considered to be in reliable condition. Another rope which shows the same degree of deterioration but has done a great deal of work may be considered to have reached the end of its useful life. The onset of fatigue or corrosion-fatigue will be much more likely in the busy rope.

110 There are certain degrees of deterioration that cannot be safely exceeded under any circumstances. If wires have been loosened by internal corrosion or internal wear, or have worn half through, there is a risk that outer wires readily override one another and break one by one. This will rapidly lead to rope breakage.

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

- 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);
- the loss in rope strength due to wear, corrosion, or both is approaching one-sixth (or 16%) of the original strength;
- the loss in rope strength due to fatigue, corrosion-fatigue, surface embrittlement, 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;
- the outer wires have lost about one-third (or 33%) of their depth as a result of any form of deterioration;
- the outer wires are becoming loose and displaced for any reason;
- the rope has become kinked or otherwise deformed, distorted, or damaged, and the affected part cannot be cut out;
- the rope has been subjected to a severe overwind or overload, or to severe shock loading, as a result of an accident or incident;
- an examination or NDT of the rope leaves any doubt as to its safety on any grounds;
- a rope, which is still in good condition, reaches its maximum statutory life or the maximum life specified by a competent person.

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**SAMPLE REPORT FORM 1 - EXAMINATIONS OF HAULAGE ROPES AND
ANCILLARY PLANT. REPORT OF PERIODIC THOROUGH EXAMINATION
OF HAULAGE ROPE**

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**SAMPLE REPORT FORM 2 - EXAMINATIONS OF HAULAGE ROPES AND
ANCILLARY EQUIPMENT. REPORT OF ROUTINE EXTERNAL INSPECTION**

SAMPLE REPORT FORM 2

Examinations of haulage ropes and ancillary equipment.
Report of routine external inspection

Mine	Day/Date	Shift
Name and location of rope haulage		Type: Direct Endless Main and tail
Nominal rope diameter		Rope length

The following checks (where appropriate) should be carried out. The findings should be ticked in the appropriate column.
 When you tick a grey box, note the details of the defect in the comments section below, together with any action taken.
 Continue on the back of the sheet if necessary.

		Yes	No	N/a
1	Evidence of damage - broken wires, kinks, displacement of lay etc			
2	Evidence of wear on rope			
3	Are possible cause(s) of rope wear apparent			
4	Evidence of corrosion on rope			
5	Lubrication of rope sufficient			
6	Splice(s) in good condition			
7	Rope capels and pins in good condition			
8	Attachment to haulage drum in good order			
9	Safety rope and attachments in good condition			
10	Rope tensioning arrangements operating correctly			
11	Rope wheel treads in good condition			
12	Deflection wheel(s), return wheel(s) and anchorage(s) in good condition			
13	All guards in position			

Comments (Continue on back of sheet if ne cessary)

Signed **Name** **Date**

Signature of Mine Mechanical Engineer **Date**

Signature of Mine Manager **Date**

* Delete where not applicable

.....

REFERENCES, LEGISLATION AND STANDARDS

- References**
- 1 *Guidance on the selection, installation, maintenance and use of steel wire ropes in vertical mine shafts* HSE Books 2004 ISBN 0 7176 2680 6
 - 2 *Stranded steel wire ropes. Specification for ropes for hauling purposes* BS 302-5:1987 British Standards Institute
 - 3 BCC Specification 353/1966 *Sockets, pins and zinc cone and tail strand units for haulage ropes* Amendments 1 and 2 (1987)

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The Stationery Office ISBN 0 11 085625 2

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

Control of Substances Hazardous to Health Regulations 2002 SI 2002/2677
The Stationery Office ISBN 0 11 042919 2

**Further standards
relevant to steel wire
haulage ropes**

Steel wire ropes. Safety. General requirements BS EN 12385-1:2002
British Standards Institute

*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 fibre cores for wire ropes BS 525:1991 British Standards
Institute

Specification for white metal ingots for capping steel wire ropes BS 643:1970
British Standards Institute

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

Colliery haulage and winding equipment. Specification for wrought steel
BS 2772-2:1989 British Standards Institute

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

Specification for large (vee throated) rope pulleys for mines and quarries
BS 4878:1973 British Standards Institute.

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.