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LABORATORY EVALUATION OF WHITE METAL AND RESIN CAPPINGS FOR USE AS WINDER ROPE TERMINATIONS

by

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EXECUTIVE SUMMARY

Previous work which was carried out on splices demonstrated that the efficiency of this type of termination was sensitive to both rigger skill and operating loads. It was therefore suggested that future research should be aimed at identifying and evaluating a less labour intensive, less skill dependent termination with better efficiencies. The work carried out here investigated the applicability of resin and white metal cappings as rope terminations on South African mines.

The first part of the project involved determining the efficiency of the socketed rope termination using resin and white metal as filler (capping) material. Ten resin and ten white metal socketed terminations were tensile tested, two of each immediately after the resin had cured and two after the white metal had cooled respectively and the other eight in each case after having been fatigued tested at different load ranges for various numbers of cycles. All the specimens tested failed clear of the sockets, which demonstrated that this type of termination is stronger than the rope i.e. has an efficiency of 100%.

There was also a concern amongst members of the mining industry about the effects of poor preparation on the efficiency of these terminations. To address these concerns a total of sixteen poorly prepared socketed rope terminations were tested. This involved tensile and fatigue testing four resin and four white metal sockets where the wires on the brush were only wiped prior to casting. The same tests were then repeated on eight additional samples, but in this case the wires on the rope brush were not cleaned at all. Although one resin capping (wiped wires) failed at the socket, the breaking strength of this termination was higher than the new rope breaking strength. All the other poorly prepared resin sockets failed clear of the termination i.e. had an efficiency of 100%. In all the tests on white metal sockets the rope pulled out of the socket, while the termination efficiency varied between 72,5% and 92,5%.

The effect of not heating the socket to the temperature specified by the National Coal Board (UK) was also investigated. White metal cappings were cast into sockets at five different temperatures ranging from room temperature up to 150°C above room temperature. Although the terminations cast at the two lower temperatures failed at the socket, they also failed at a breaking strength in excess of the new rope breaking strength. The other three terminations failed clear of the socket.

The last part of this investigation involved determining the effect of casting white metal cappings at high temperatures (500° C) on the efficiency of the termination using ropes of different tensile grades. The molten white metal cast at these high temperatures did not affect the efficiency of the termination since in all three tests the rope failed clear of the socket.

It was therefore concluded that both resin and white metal cappings are suitable replacements for splices as rope terminations on drum winders provided the recommended preparation procedures are adhered too. When compared to white metal, resin is a more suitable capping material based on its insensitivity to the cleanliness of the brush and its ease of preparation. White metal cappings are very sensitive to the cleanliness of the brush and to a lesser extent to the casting temperature of the socket. Further, the efficiency of white metal cappings

appear to be unaffected by the high pouring temperature of the white metal for rope tensile grades up to 2100 MPa.

An aspect that should still be investigated is the efficiency of socketed terminations after high numbers (> 100 000) of fatigue cycles to determine whether these terminations would be suitable rope terminations for Koepe Winders. In addition, effects of resin shelf life on the efficiency of the termination and alternative capping materials besides white metal and Wirelock™ resin should be investigated.

Contents

1. INTRODUCTION

The wire rope termination (WRT) is an integral part of any winding rope. The mechanical joint of the rope with itself or with the termination hardware will support a load which is a fraction of, or equivalent to, the rope breaking strength. The front end of a mine winding rope (which includes the termination) is known to deteriorate at a different rate to that of the rest of the rope and is an area of concern. Two recent rope failures at the termination in 1989 and 1990 led to detailed investigations into the performance of wire rope terminations. Terminations on winding ropes have to date been safeguarded by a high capacity factor (safety factor at the front end of the rope) although it is now believed that this capacity factor was not actually intended for termination protection.

1.1 Requirements for Rope Terminations

A rope termination should not be a "weak link" in the winding system. It is very important that a rope termination withstands the same load as the rope. Depending on the type of termination the forces that are usually involved in restraining the wires at a rope termination are:

- frictional forces
- wedging forces
- bonding forces

Obviously, not all these forces are necessarily present in any one type of termination.

Although in many types of terminations, frictional and wedging forces are essential in order that the termination can support the operating load, these forces also reduce the efficiency of some terminations (eg. splices and wedge sockets). These terminations rely on the lateral compression of the rope (in a wedge socket) or strands (in a splice) to generate frictional forces to maintain the load. This obviously imposes additional lateral compressive stresses on the wires. The combined lateral and tensile stresses on the rope result in maximum stresses being reached at the termination before the maximum tensile load the rope can withstand is reached. This results in failure at the termination, and typically an efficiency* of less than 100%.

Higher termination efficiencies are obtained with those types of terminations which utilise bonding forces to sustain the load. These types of terminations do not apply high lateral forces on the rope, and therefore do not affect the rope stresses significantly. Terminations of this kind are white metal, zinc and resin sockets, otherwise also known as conical cappings. Although these sockets also rely on frictional and wedging forces to sustain a load, the geometry of the sockets is such that these forces are far less severe on the rope than in other terminations.

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* The ratio of the breaking strength of a wire rope termination to the new rope breaking strength expressed as a percentage.

1.2   Background and Previous Work

As mentioned above, two rope failures at the termination during 1989 and 1990 led to the work on rope terminations. This work was initiated when the CSIR tested approximately 120 winder rope terminations (mainly splices) from industry during the latter half of 1990 and beginning of 1991. These rope terminations were tested at the request of the inspectorate. The CSIR then produced a report[1] on the results of these tests. The results showed that the efficiency of a splice could be as low as 67%, effectively reducing the static safety factor for rock winders at the front end of the rope from 9 to 6 (The cause of the low efficiency of the splice under discussion was due to a combination of efficiency of construction and deterioration in service).

Although one may argue that a capacity factor of 6 is still sufficient, it is generally accepted that the rate of deterioration increases rapidly once degradation of the rope at the termination has started. This situation can be exacerbated once the newly proposed regulations[2] are applied. The new regulations are expected to come into effect by June 1994. The more conservative regulation will allow ropes to carry loads slightly greater than current practice (Factor of Safety (FOS) of 4.5 and a Capacity Factor (CF) of 8). The second (more flexible) regulation will be based on a formula (FOS = 25000/4000+L, where L is the length of wind) which will govern the Factor of Safety provided a dynamic factor of safety of 2.5 is not exceeded. A termination efficiency of 67% would then effectively lower the capacity factor to 5,36 for the one regulation and 4.19 for the other. These are static factors and do not include real dynamic loads.

Due to a lack of data and a large number of variables it was not possible to determine what factors affected the splice strength. The CSIR then carried out an in-depth investigation into factors affecting splice efficiencies[3]. The effects of workmanship, rope and splice construction, rope diameter, rope tensile grade, fatigue loads, corrosion and corrosion fatigue on a splice were investigated.

The results of the tests on splices showed that the rigger has a large effect on the efficiency of a splice. It was also found that the variability in the workmanship of a single rigger can affect the efficiency of a splice by up to 6,4%. Splices are sensitive to rope diameter and it was found that lower splice efficiencies were obtained with larger diameter ropes. Splices with a higher tensile grade had better efficiencies than those with lower tensile grades and splices made from ropes with a wire main core had lower efficiencies than splices made from ropes with a fibre core.

The fatigue testing of splices indicated that a splice is sensitive to peak loads and load ranges, especially parallel splices. A splice typically experiences between 10 000 and 60 000 load cycles during a six month period. Tapered splices outperformed parallel splices during the fatigue test in terms of loss in efficiency. There seemed to be no clear difference between tapered and parallel splices in the as-manufactured condition for ropes of small diameter (<44 mm). For the larger rope diameters there were indications that there are benefits in tapering splices.

The corrosion tests did not yield very significant results mainly because the lubricant protected the rope very well when it was exposed to the corrosive atmosphere. This resulted in the corrosive attack being minimal.

In an attempt to move away from a very labour intensive and skill dependent termination with an average efficiency of 85% (see Figure 1), the CSIR was asked to investigate the feasibility of using resin cappings as a wire rope terminations. The first investigation[4] on resin cappings was carried out under the auspices of the Chamber of Mines Steering Committee on Factors of Safety of winder ropes, and examined the breaking strength of resin socketed terminations which had been subjected to various fatigue loading histories.

Although some literature is available on fatigue testing of sockets[5], these tests were carried out on a small diameter ropes (26 mm), full-lock-coil ropes which are not used on drum winders in South Africa and most ropes used are of diameter which is in excess of 26 mm. For these reasons it was decided that, although the literature contained very valuable information, this could only be used as a reference and the performance of these types of terminations should be established using rope diameters and rope constructions which are used in this country.

When the report on the socket tests[4] was presented to the Steering Committee, there were mixed reactions regarding the results. Some members expressed concern over the fact that the very high efficiency of the socket was obtained under controlled laboratory conditions with meticulous preparation procedures. It was reported that these conditions and methods of preparation would not be followed on the mines and the committee felt that it was necessary to determine the effects of poor preparation procedures on the efficiency of these sockets before the report could be released to industry.

In a report by Corden[6], which also contained the results of the previously mentioned investigation[5], the effects of the resin contamination by water and coal dust were described. The effect of poor socket preparation (not thoroughly degreasing the rope wires when a socket is made) was not investigated. It should however be noted that, according to Chaplin[7], the degreasing would have to be really inefficient for it to affect the efficiency of the termination. Verification of this type of information is essential in fully understanding the performance of sockets.

This report contains all the information and results of the first report produced by the CSIR on resin cappings[4] and the material is dealt with as if it was part of this investigation. The contents of the previous report were included at the request of the Steering Committee which felt that all the work carried out on resin cappings should be documented in one consolidated report. The author also considered it appropriate to include the results of the work carried out on white metal cappings in this report. This would enable the comparison of the two different types of cappings.

Although this report also explores the consequences of poor preparation of resin and white metal cappings it must be emphasised that when a rope socket is prepared, **under no circumstances should one deviate from the preparation procedures for**

capping of wire ropes as described in the Ropeman's Handbook[8] produced by the National Coal Board (UK).
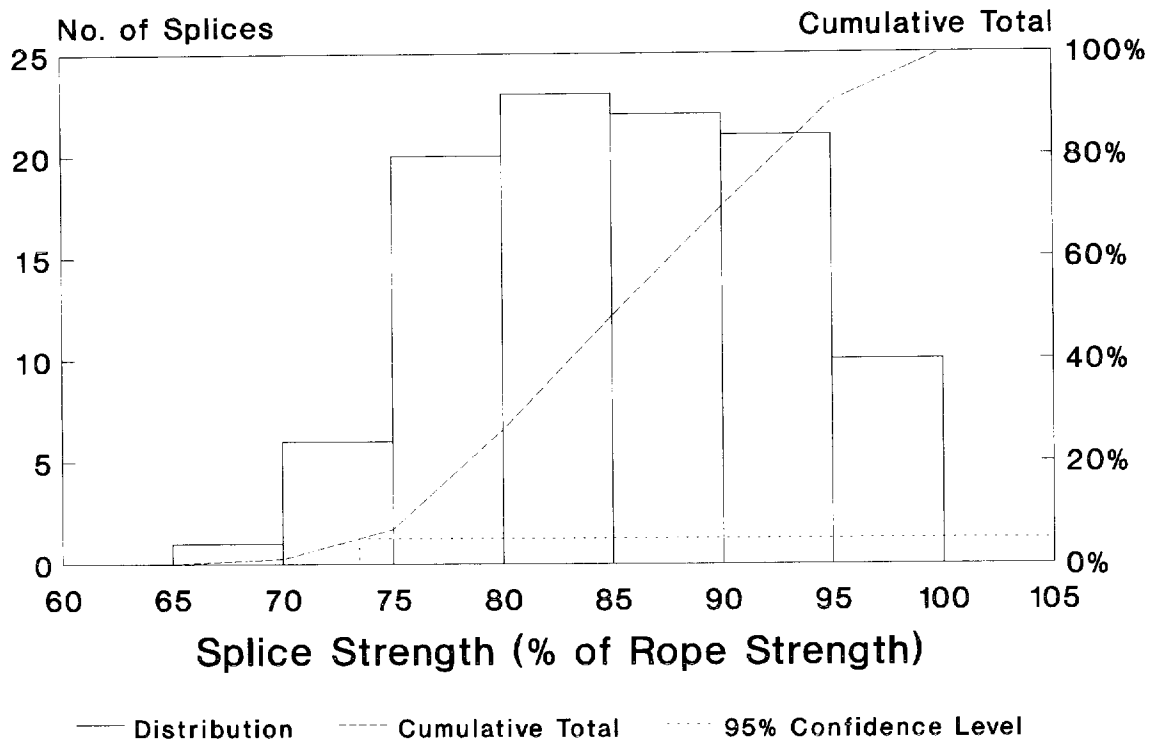
Figure 1: Distribution of splice strengths[9].

2. SCOPE

It is apparent from the results of work carried out to date on large diameter splices (40 mm to 54 mm) that the efficiency of this type of termination is largely dependent on rigger skill. It was therefore suggested that future research should aim at clarifying the suitability of less skill dependent rope terminations as winder rope terminations. The work documented in this report is aimed at addressing these concerns and, in particular investigating the effect of different factors on the efficiency of resin and white metal cappings. The factors investigated are:

- effect of fatigue on the efficiency of resin and white metal socketed rope terminations.

- sensitivity of the efficiency of resin and white metal socketed rope terminations to the cleanliness of the wire brush.

- sensitivity of the efficiency of white metal socketed terminations to the method of preparation (socket temperature).

- effect of high (500° C) white metal casting temperatures to the efficiency of the socketed termination for ropes of different tensile grades.

The work outlined above was essential in order to establish the performance and design criteria for rope terminations and to identify suitable and safe rope terminations less dependent on artisan skill.

3. SOCKETED ROPE TERMINATIONS

It is believed that the following three factors affect the as-manufactured efficiency of conical sockets:

- the socket geometry;

- the type of filler material;

- the method of preparation.

Work has been carried out by the National Coal Board (UK)[6] into the effect of contaminating the resin with 3% by volume of resin with water and coal dust. Chaplin[7] also concluded in his work that degreasing had to be really poor before the efficiency of the socket termination was affected, however no literature seems to exist of actual tests conducted, on the efficiency of a socket if the wires of the brush are not adequately cleaned. Metcalf and Matanzo[10] also carried out an extensive test program to evaluate the performance of nine wire rope terminations which included the resin and zinc sockets. At the time this proposal was presented to the Steering Committee the author was only in possession of the results of the programme which dealt with the results of the tensile tests. Even though from the abstract of this paper it was evident that tests were carried out by Metcalf and Matanzo[10] to evaluate the sensitivity of these nine rope terminations to poor workmanship and service life, it is believed that the test conditions were not representative of typical South African conditions.

During a previous investigation[4] resin cappings were prepared and tested to establish the efficiency of this type of termination in the as-manufactured condition, and after various tension-tension fatigue tests. The results of these tests indicated that resin capped sockets showed promise for field applications: all the specimens tested had efficiencies of 100%, ie. rope failure occurred remote from the termination.

It is felt that at this stage the sensitivity of the efficiency of the resin capping to the method of preparation should be investigated. In addition to this, a field trial using resin cappings should be carried out to evaluate actual in-service deterioration of resin capped terminations in South African working conditions.

4. THE CAPPING TECHNIQUE

In conical cappings, the wires of a rope are opened up to form a "brush", thoroughly cleaned and then pulled into the conical socket. The wires are then embedded in a matrix of capping material. As described in the previous section, there are three main forces restraining the wires from pulling out of a resin socket. The bonding forces are generated by adhesion between the capping material and the wires and are the forces which are responsible for preventing the wires from pulling out. These forces are also assisted by frictional and wedging forces in restraining the wires. In the absence of bonding forces and friction forces (the two cannot be separated), the wedging forces alone would not be sufficient to restrain the wires.

The bonding forces are generated by the adhesion between the resin and the wires. It therefore seems important to thoroughly clean the wire to ensure good adhesion. The second most important forces are the friction forces and they are dependent on the coefficient of friction between the wires and the resin. Once again the cleanliness of the wires will obviously affect these forces. In a resin socket friction forces are generated by the shrinkage of the resin during the curing process onto the wires. The wedging effect of the end-cone in the socket also increases these normal forces on the wires and will thus increase the friction forces.

An ideal capping material should have the following properties:

a) high bond strength between the material and the steel wires

b) high coefficient of friction between the material and the steel wires

c) high degree of contraction on setting

d) high modulus of elasticity (i.e. the capping material should exhibit little elastic deformation when loaded[6])

e) rapid curing time (to reduce winder downtime)

High individual performance for all the above properties are advantageous but not essential, provided that the forces generated are sufficient to restrain the wires from being pulled out of the socket.

The capping material should also be able to withstand the harsh environmental conditions which occur on mines for the duration of its intended life cycle (eg. continual exposure to water, grease and temperature variations). The capping material must also be able to withstand fluctuating loads and accidental impulsive loads.

4.1 Capping with Resin

During the development of the resin capping technique by the Safety in Mines Research Establishment (SMRE) which is now part of the Research and Laboratory

Services Division (RLSD) in the United Kingdom, both epoxide and polyester resins were investigated[6]. This work showed that epoxide resins produce higher bond strengths than polyester resins but have lower contraction characteristics and hence produce lower frictional forces on the embedded wires in the brush. Epoxide resins cure much more slowly than polyester resins unless the sockets are preheated to above normal ambient temperatures.

Polyester resins have been used for rope cappings in a number of laboratory and field trials for about 20 years in the United Kingdom. After extensive tests to study their performance, under conditions of static, fatigue and impulsive loading, and including environmental effects, RLSD had sufficient confidence in the technique for a supplier of polyester resins to make up a kit of resin which provided the optimum formulation found from the laboratory tests.

4.1.1 The Wirelock™ Resin Capping Kit

The original Wirelock™ capping kit was a tin containing the liquid polyester resin and the accelerator and a polythene bag containing the sand filler and the catalyst[5]. This kit was found to be ideal for site use since it did <u>not require weighing of small quantities</u> of curing agent and eliminated the possibility of the accelerator and the catalyst being mixed together which could result in a violent reaction. The current Wirelock™ kit is very similar to the original kit with the exception that it does require an accelerator at all[6].

Alternative capping kits do exist, however, none have been as rigorously tested as the Wirelock™ system. For this reason, and the fact that it was commercially available, it was decided that Wirelock™ would be used in this test program.

4.1.2 Curing of the Resin

The curing of polyester resins is exothermic. The temperature reached during the curing process depends upon the percentage of catalyst present and the total volume of resin being cured. If an accelerator is used, it would also influence the maximum temperature reached. Due to the low thermal conductivity of polyester resins, large variations in temperature exist within the end-cone which lead to high thermal stresses and cracking. This may be avoided by using a silica sand filler which reinforces the resin and acts as a heat sink. The silica does not take part in the curing reaction[6].

Wirelock™ kits are formulated for use at temperature of around 18°C. Use at these temperatures result in a gelling time of about 15 minutes and the resin is fully cured within an hour. It is however recommended that no load is

applied until a minimum period of one hour has elapsed from a satisfactory scratch test**.

4.1.3 Effects of Low Temperatures on Curing Times

When the temperature of a socket is below 8°C, there is an appreciable increase in gelling time. For this reason alternative methods should be adopted in conditions of low ambient temperature to avoid problems which may arise from a delayed gelling time. They are:

- The addition of a special booster pack to the kit at the mixing stage, or

- The warming of the socket to between 10°C and 15°C before the resin is poured.

The exact details and procedure of the above two alternative methods to be used in low temperature conditions can be found in the "Notes of guidance for the resin capping of wire ropes" produced by the British Coal Board[11].

4.2 Capping with White Metal

White metal is a very good medium for capping and has been used at the CSIR for statutory rope testing for many years. As with resin, white metal works on the principle of gripping wires individually in a single cone within a conical socket. The correct procedure for capping with white metal is described in the National Coal Board's "Ropeman's Handbook"[8]. Apart from the heating of the socket which is not required when capping with resin, the preparation procedure of the rope for capping is the same whether one uses with white metal or resin as a capping medium.

The capping procedure however differs somewhat when it comes to preparing the capping material. In the case of resin it is merely a matter of mixing the resin and the silica which already contains the catalyst. After mixing for two minutes the resin is poured and allowed to set. With the white metal the procedure is slightly more involved and according to the Ropeman's Handbook is as follows:

A predetermined weight of white metal in excess of that required to fill the socket is placed in a clean pot and heated in a furnace until molten. Flames can also be used but under no circumstances should the flame be allowed to make contact with the white metal. New ingots of white metal must be used for the capping of winder ropes. After bringing the molten metal to a temperature slightly in excess of pouring temperature (350°C ±14°C) and

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** Hardness should be determined by carrying out a scratch test on the surface of the resin with a sharp steel blade. This should only leave a shallow scratch mark.

immediately before pouring the molten metal should be stirred and all dross should be skimmed off the surface.

In order to prevent chilling of the white metal during pouring, the socket should be pre-heated to the correct temperature. This can be achieved by fitting a suitable furnace around the socket or by constantly moving blow torches over the surface of the socket. The recommended pre-heating temperatures for sockets are 100°C for mild steel sockets and between 100°C and 205°C for 1,5% manganese steel and other approved steels to BS 2772 Part2: 1977. If manganese steels or other approved steels are used they should be heated to the upper temperatures to ensure better penetration of the white metal. When heating nozzles are used care should be taken to ensure that the heat is evenly distributed over the socket and that any one area is never overheated. In addition extreme care must be taken that no heat is applied to the rope.

Once the socket is at the correct temperature the molten white metal should be poured into the socket in a continuous stream until it reaches the top of the basket. Pouring should be slightly off centre to allow venting. At the start of the operation white metal should be allowed to run for two or three seconds from the tell-tale hole in the centring clamp before the hole is plugged. If a depression occurs in the centre of the white metal during the early stages of cooling it should be topped up with a small amount of white metal. The socket should then be left to cool naturally and undisturbed for at least one hour.

It should be noted that although care was taken to ensure that the rope was centralised and perpendicular to the socket on all test samples a centring clamp was not used in the preparation of the laboratory test samples. This slight deviation allowed the capping process to be speeded up slightly. It was felt that such a procedure would also be adopted when end-capping was carried out on a mine, and therefore if there were any detrimental effects in deviating from the exact recommended procedures, it would be in the interest of the industry that these effects were identified in the laboratory testing.

5. SAMPLE PREPARATION

Apart from the rope samples used to investigate the effect white metal at high temperatures on the efficiency of the terminations, only two other ropes were used in this project. The one was a 43,5 mm diameter, 1750 MPa tensile grade triangular strand rope with a new rope breaking strength of 1 420 kN. This rope had been in service for six months. It was purchased from Stilfontein Gold Mine for the splice project, and it was decided that it would be appropriate to use the same rope in the socket tests for comparative purposes. Unfortunately this rope was not long enough to supply all the specimens required for this investigation and a second rope was obtained from Stilfontein Gold Mine. This rope was the front section of a 44 mm diameter, 1900 MPa, triangular strand rope which had operated for 2,5 years at Vaal Reefs Gold Mine.

Although the preparation of the rope ends for socketing for all the tests described later in sections 7.1.1 and 7.2.1 was carried out as specified in the Ropeman's Handbook[8], the amount of serving and two-bolt clamps used during the preparation was less than specified. This slight deviation allowed the capping process to be speeded up slightly and once again it was felt that such a procedure may be adopted when end-capping was carried out on a mine, and therefore if there were any detrimental effects in deviating from the exact recommended procedures, it would be in the interest of the industry that these effects were identified in the laboratory testing. The preparation procedure described below was thus adopted.

5.1 Cutting and Serving

In order to prevent loosening of the wires or strands, each end of the specimen was served before abrasive cutting. Once cut, the outside of the rope was washed in dieselene from the point where it was cut up to a point 1 m from each end. The specimen end was then dried thoroughly. Serving wire was then placed on the specimen over a distance of 4 rope diameters (4d) starting from a point equal to the length of the socket basket minus 2d from the end of the specimen, as illustrated in Figure 2.
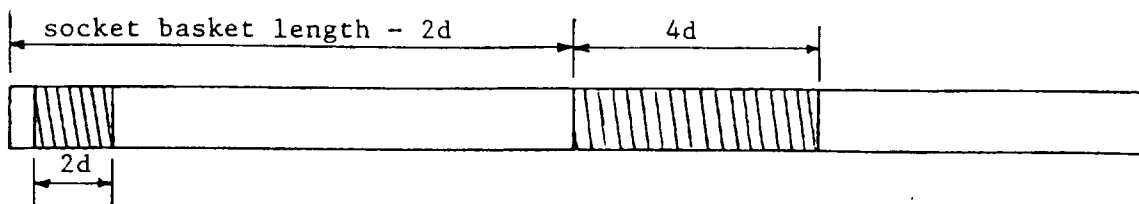

Figure 2: Serving of the rope specimen.

The end of the specimen was then pushed through the socket. When this procedure is carried out in the field, 2 two-bolt clamps should be placed at a point 1 metre from the end of the rope prior to pushing the rope through the socket. This will prevent the socket from sliding down the rope when working from a platform.

5.2 Clamping

Once the end of the rope specimen had been pushed through the socket, a two bolt clamp was placed at a point equivalent to the length of the socket basket less 2 rope diameters from the end of the specimen, i.e. on the serving wire as shown in Figure 3. This clamp ensured that the rope did not de-strand itself during the opening of the brush. It is essential to have at least one two-bolt clamp at this point when a rope is opened, as very high bending forces are required to open the six strands and the strength of the serving wire is not adequate to prevent the rope from unlaying.
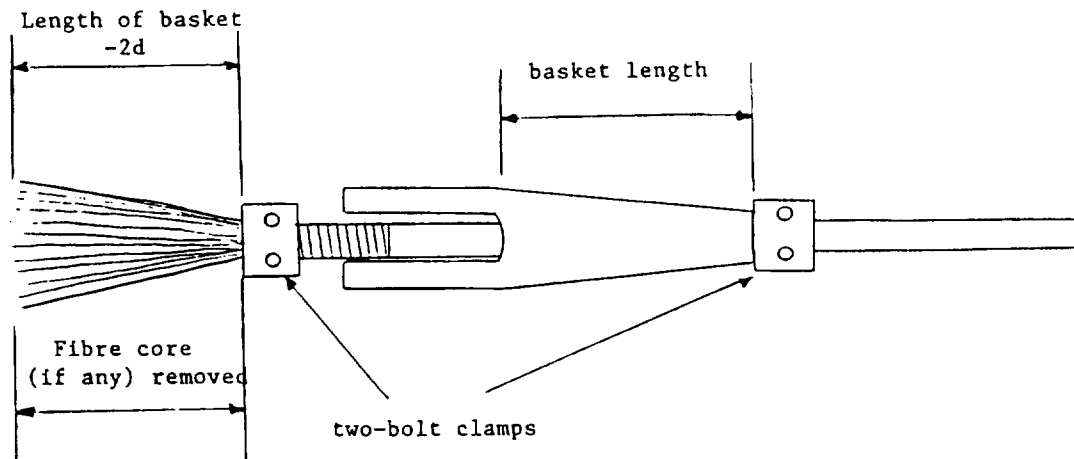
Figure 3: Positioning of two-bolt clamps.

5.3 Opening and Cleaning the Brush

In order to prepare a brush, the two-bolt clamp and the clamp was fastened in a vice or to a rigid structure as shown in Figure 4. When the ends were brushed out, the six strands were first separated from each other. Once that procedure was completed the fibre core was cut out as close to the two-bolt clamp as possible. Each strand was then opened up individually to form a brush leaving the plaited strand cores intact. During the opening of the rope and strands, **care was taken to avoid bending of the wires too sharply at the two-bolt clamp as this could caused individual wire failures at the neck of the socket during the test.** The appearance of the brush at this stage in the process is shown in Figure 4 below.

Figure 4: A photograph of the uncleaned, brushed end of the test specimen.

5.3.1 Degreased Brush

Once the ends of the specimen had been opened up, the brush was dipped in a solvent bath for a few minutes. A paint brush was then used with the solvent to clean off all the excess grease. In the laboratory, trichloroethylene was used as a solvent; on site any water-soluble degreasing fluid or a non-flammable organic solvent can be used, paraffin is not recommended[8]. During the degreasing operation the brush was always kept in the downward position and care was taken that no degreasing fluid entered the unopened part of the rope as this may affect the internal lubricant of the rope. Once all the wires had been cleaned, the brush was left to dry in the downward position. Once dry, a clean cloth was used to wipe any of the wires which still had traces of lubricant on them.

5.3.2 Wiped Brush

The rope samples used in the tests where the effect of a poorly cleaned brush was investigated were opened as described above. After opening a dry cloth was used to wipe the wires of the brush. Due to the nature of the brush it was very difficult to wipe the inner wires of the brush resulting in many wires either having been left unwiped or only being wiped at their extreme ends. Figure 5 below shows a typical brush after it had been wiped, prior to casting.
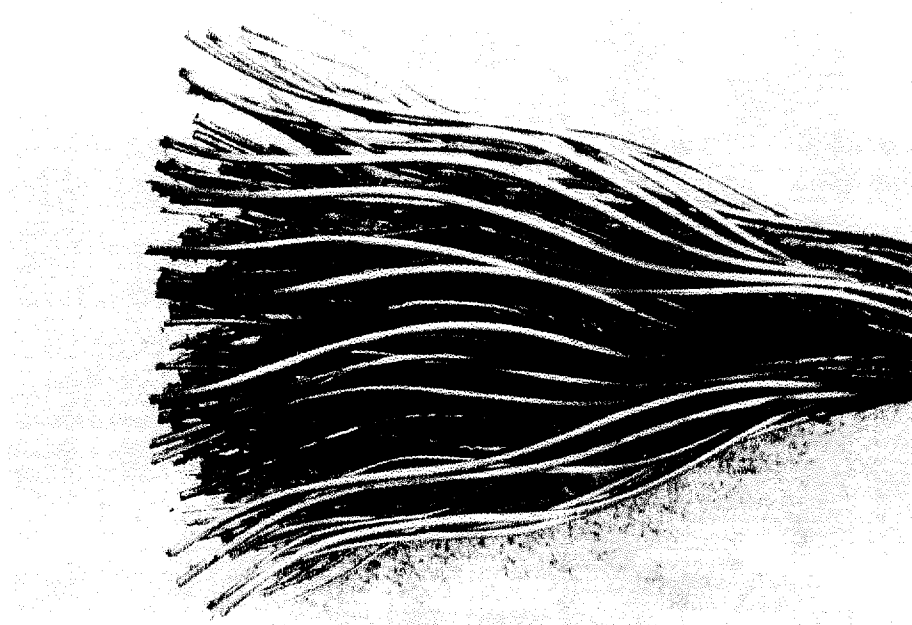

Figure 5:   A photograph of a brushed end of a test specimen after the wires of the brush had been wiped.

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5.3.3 Uncleaned Brush

As previously mentioned in the section describing the test programme, the effect of not properly cleaning the brush on termination efficiency was investigated. In one set of tests the brush was wiped clean as described directly above. In the worst case described here the rope samples used were first completely opened after which they the brush was pulled into the socket as described below, and cast. The condition of the brush at the time of casting was the same as that shown in Figure 4.

5.4 Positioning the Socket

After degreasing (where applicable) the two-bolt clamp was removed from the neck of the brush and the socket was pulled onto the brush so that the ends of the wires were approximately 5 mm above the top of the socket basket. This left a length of 2 rope diameters of serving contained within the mouth of the socket. Figure 6 shows the clean brush after the two-bolt clamp had been removed and prior to the socket being pulled over the brush.
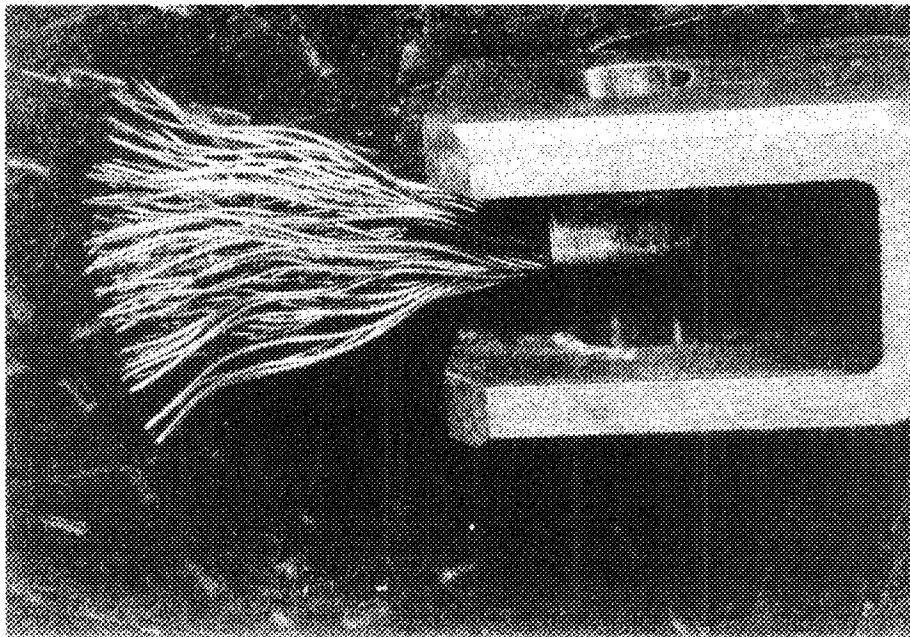
Figure 6:   Photograph of the brush prior to being pulled into the socket.

Once this operation had been completed, the socket was lifted to a point approximately 3 m above the floor. The rope was positioned in such a way that there was at least a 1,5 m straight vertical drop of rope directly below the socket. Care was taken in ensuring that the 1,5 m drop of rope was parallel with the socket. (This was a visual check; no aligning clamp was used as recommended in the Ropeman's Handbook[6].)

Once the rope was aligned, plasticine was used to seal the bottom of the socket. The serving wires were parted at the points below the socket where voids existed between the serving wire and the rope. This was done in order to be able to push plasticine in the valleys between the strands to prevent the filler material from leaking through under the serving wire. Once the bottom of the socket was sealed, the filler material was prepared.

5.5   Preparing and Pouring the Filler Material

5.5.1   Resin

Once the rope end had been prepared, pulled into the socket and the socket hoisted into position the mixing of the resin (in the cases where resin was used) began. Figure 7 shows the rope socket assembly prior to the resin being poured.

Figure 5:   Photograph of the socket prior to the resin being poured

The resin and silica containers which form the Wirelock™ kit were opened and mixed together in a clean container for two minutes. For each socket, two 1000 cc kits were mixed together. (The volume of resin required for a particular socket combination and rope size can either be calculated or may be obtained from a British Coal Board Publication[11].) Once thoroughly mixed, the resin was poured into the socket slowly in order to prevent any air pockets from being formed at the bottom of

the socket. Once poured the resin was left for two hours to cure. Figure 8 shows the back of the socket once the resin had been poured and it had set.

Figure 8:   Photograph of the back end of the socket prior to the fatigue tests. Note the shrinkage on the left side of the cone (arrowed).

After the resin had cured, and before each test was started, the resin end-cone was pushed out of the socket for a visual examination. This was done to ensure that the resin had penetrated the full length of the socket and that there were no air pockets remaining at the bottom of the cone. Once the resin end-cone was pushed back into the socket, the outside of the rope near the socket, which had been cleaned, was re-greased.

Figure 9 shows a resin end-cone which had been removed from the socket after a test. As can be seen, the resin penetrated effectively all the way to the bottom of the socket and no air pockets are visible.
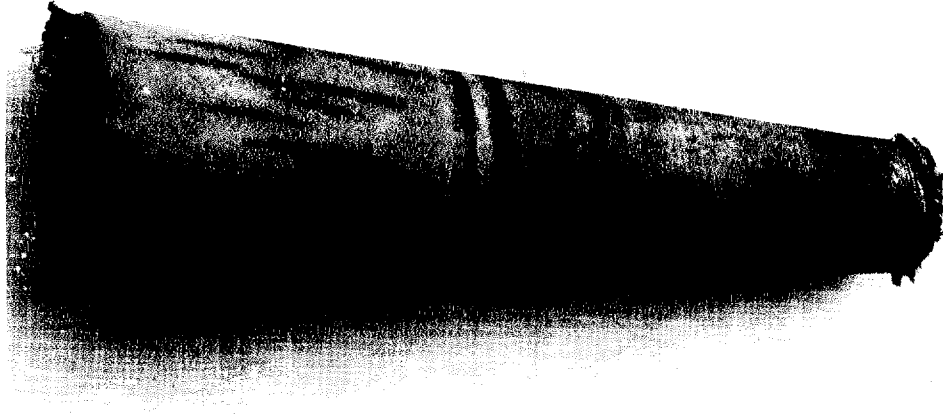
Figure 9:   Resin end-cone after a test.

After the first tensile tests, one of the resin cappings was cut into three sections in order to ensure that the resin pouring technique was correct and did not produce unwanted air pockets. In addition, it was required to confirm that the way the brush was being opened was also correct, since the wires must be evenly spread throughout the end-cone. Figure 10(a) shows the cross section of the end-cone approximately one third of the way up from the neck. The rope core is still visible at this point and the strand wires are still clustered together. Figure 10(b) shows a second cross-section of the cone, two-thirds of the cone length from the neck. The wires of the rope are very evenly spread across the cone, and no voids are present in either cross-sections. The results of this examination therefore indicated that the method of preparation was correct and, accordingly, all the other sockets were cast in the same way.
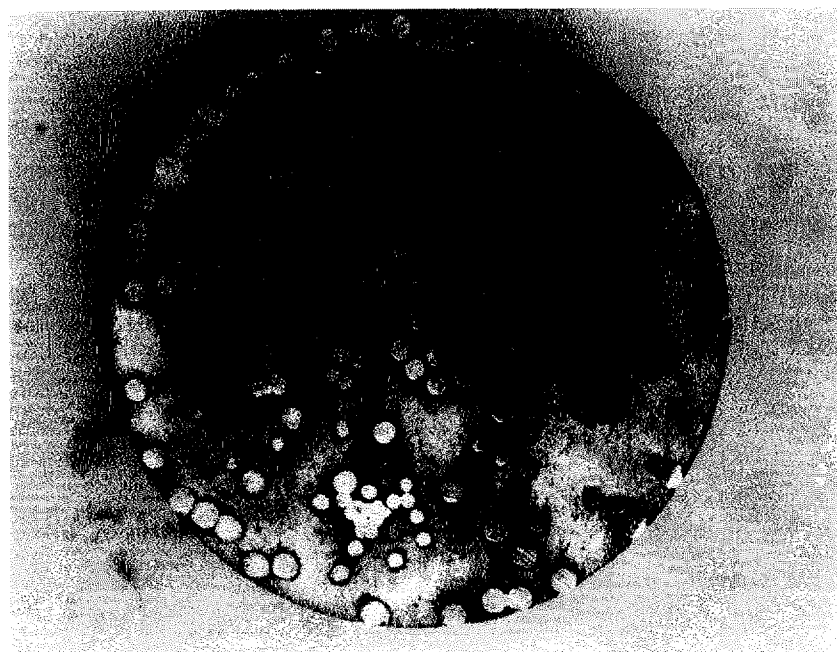
(a)
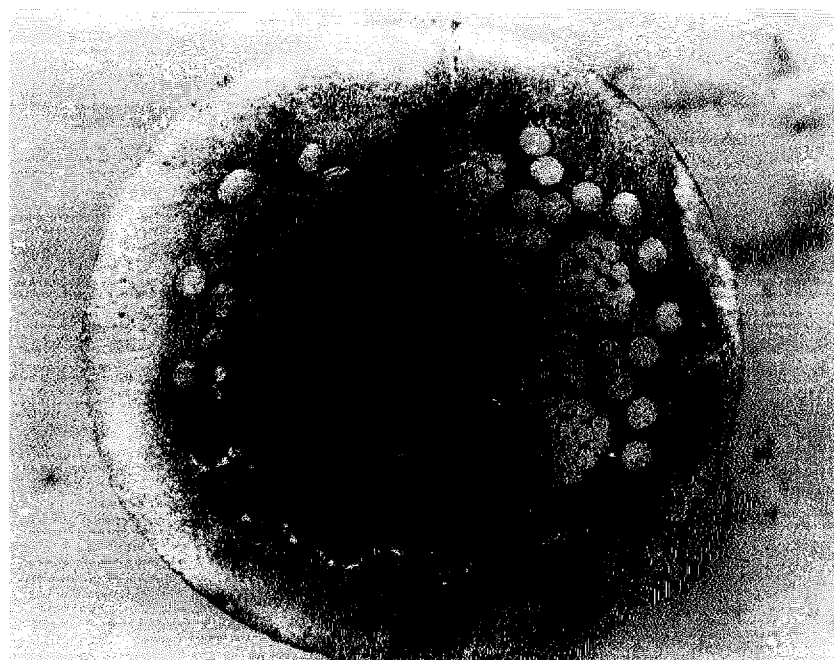
(b)

Figure 10: Cross-section through a resin end-cone at a distance from the neck of (a) one third and (b) two thirds of the length of the socket.

5.5.2   White Metal

5.5.2.1   Ordinary casting temperature

The procedure for casting white metal sockets is described below. All the tests which required the normal white metal casting procedure (independent of brush cleanliness) were prepared in this manner.

Due to the day to day rope testing activities at the CSIR rope testing laboratory white metal is kept molten in a bath at all times. The bath temperature is 310°C ±10°C. When the white metal sockets were ready to be cast white metal was tapped from these baths.

In order to prevent chilling of the white metal during pouring, the socket (made of 1,5% manganese steel) was pre-heated to approximately 200°C. This was achieved by dipping the socket into the bath of molten white metal for a predetermined amount of time. Naturally the time the socket spent in the bath of molten white metal was dependent on the amount of socket pre-heating that was required for the termination under preparation.

Once the socket was at the correct temperature the rope was aligned and centred in the socket and the bottom plugged using plasticine. The molten white metal was poured into the socket in a continuous stream until it reached the top of the basket. Pouring was slightly off centre to allow venting. A centring clamp was not used in the casting operation. The depression in the centre of the white metal which occurred during the early stages of cooling was topped up with a small amount of white metal. The socket was then be left to cool naturally and undisturbed for at least one hour.

5.5.2.2   High casting temperature

Three tests were conducted to determine the effect of overheated white metal on termination efficiency. Molten white metal from a bath was placed into a separate container and was further heated over a naked flame to 500°C. When this temperature was reached the white metal capping was cast using the same procedure as described in section 5.5.2.1 above.

6.   TEST PROCEDURE

All the socketed termination tests carried out in this investigation were performed in a 10 MN Avery tensile testing machine, using either Wirelock™ resin or white metal as capping material, Bellambie NCB 465(1965) WRS-28 winding rope sockets and a ropes of triangular strand construction, 43,5 or 44,0 mm in diameter.

6.1 Fatigue Tests

A total of twenty-four socketed rope terminations (twelve resin filled and twelve white metal filled) were fatigued prior to being tensile tested. The first set of fatigue tests (carried out on resin sockets as per section 7.1.1 below) were conducted on 6,5 m long rope specimens. Two sockets were cast one on each end of the rope thus enabling two specimens to be fatigue tested at the same time. After the fatigue test, the 6,5 m long rope samples were cut in half and white metal end-cones were cast on the free ends of the rope, (i.e. the part which was to be the centre of the fatigue specimen). This enabled a tensile test to be conducted on each termination.

The remainder of the fatigue test specimens (i.e. four resin sockets and twelve white metal sockets) were fatigued individually. The test procedure described above was changed to enable one socket to be prepared while the other was being tested. Although this doubled the test machine running time there was found to be an overall time saving for the complete test. Once the fatigue test was completed the specimens were immediately tensile tested to destruction.

6.2 Tensile Tests

Tensile tests were carried out on all forty-four specimens prepared for this investigation. The specimens which were not fatigue tested were cast and once the resin had cured (the specifications require that the resin was allowed to cure for one hour and a further hour should be allowed to pass prior to load being applied to the sockets), or the white metal had cooled to ambient temperature depending on the capping medium used, the samples were tensile tested. Naturally the white metal end-cone which was required to locate the free rope end in the test machine was cast on the rope prior to the casting of the socket to enable the tensile testing of the samples immediately after the resin had cured or the white metal had cooled.

In the case where the test specimens were fatigued the tensile tests were carried out immediately after the fatigue test.

7. TEST PROGRAMME

It is evident from the literature available that a fair amount of research work has been carried out on socketed terminations. Certain aspects like evaluating the effects of not degreasing the rope when it is socketed do not seem to have been evaluated. All the tests for which literature is available were conducted to simulated typical conditions which exist on mines in the United Kingdom. The conditions on South African mines are considerably different, especially with regards to rope constructions, rope loads at the termination, rope tensile grades, termination life, etc. It is felt that the work proposed here will contribute to the understanding of the performance of socketed terminations under South African conditions and will have an impact in making our mining industry safer and more profitable.

7.1 Resin Cappings

7.1.1 Resin as Filler Material

The socket geometry used for the tests on resin cappings is a type approved by the National Coal Board (UK) namely, Socket NCB 465 (1965) WRS-28. This type of socket can accommodate rope diameters ranging from 42 mm to 46 mm which was ideal for the 44 mm diameter triangular strand rope which was used. The method of socket preparation was in accordance with the procedure outlined in the National Coal Board's "Ropeman's Handbook".

The first set of tests on resin cappings was as follows:

- two specimens were tested to destruction in their as-manufactured condition once the resin had cured.

- two specimens were subjected to 10 000 tension-tension fatigue cycles at a load range of 5% and mean load of 10,5% of rope breaking strength and then tensile tested to destruction.

- two specimens were subjected to 30 000 tension-tension fatigue cycles using the loading conditions described above, and then tensile tested to destruction.

- two specimens were subjected to 10 000 tension-tension fatigue cycles at a load range of 10% and a mean load of 10,5% of rope breaking strength and then tensile tested to destruction.

- two specimens were subjected to 30 000 tension-tension fatigue cycles using the loading conditions described directly above and tensile tested to destruction.

All samples were monitored during the fatigue tests to detect any wire broken wires and were thoroughly inspected after the destructive tests, in order to identify the reason(s) for any losses in termination strength.

7.1.2 Sensitivity of Resin Cappings to Method of Preparation

Literature has shown that resin sockets performed very well in controlled laboratory tests where the method of preparation as described in the Ropeman's Handbook is closely followed. In the field, however, the method of preparation can vary from the ideal, especially with regard to degreasing of the rope end. It was therefore proposed that the tests be carried out to establish to what extent the efficiency of resin cappings would be affected by

poor rope degreasing. In order to address these concerns the following tests were conducted:

-   two tensile tests to destruction on resin cappings where the wires of the brush had only been wiped with a dry cloth during preparation.

-   two tensile tests to destruction on resin cappings where the wires of the brush are not degreased or cleaned at all.

-   two resin capped terminations where the wires of the brush were only wiped with a dry cloth during preparation were subjected to 30 000 tension-tension fatigue loading cycles. These terminations were exposed to a load range of 10% and mean load of 10,5% of new rope breaking strength. The terminations were then tensile tested to destruction.

-   two resin capped terminations where the wires of the brush are not degreased or cleaned at all were subjected to the same fatigue and tensile tests as described directly above.

All samples were thoroughly inspected after the destructive tests in order to identify the reasons for losses in strength. The results were compared to the resin capping test results of the tests described in section 7.1.1 and recommendations on the use of these cappings are made.

7.2   White Metal Cappings

7.2.1   White Metal as Filler Material

The tests on conical sockets were expanded to include the evaluation of white metal as filler material. The socket geometry which was used in the white metal tests was the same as that used for the tests on resin cappings, ie. Socket NCB 465 (1965) WRS-28, with a 44 mm diameter triangular strand rope. The method of preparation of the ten terminations tested in this section was in accordance with the procedure outlined in the National Coal Board's "Ropeman's Handbook". The test procedure for the white metal sockets tested in this section was identical to the procedure described in section 7.1.1.

All samples were thoroughly inspected after destructive testing, in order to identify the reason(s) for any losses in termination strength. This would then identify the aspects which need to be addressed in order to quantify the in-service performance of white metal cappings.

7.2.2 Sensitivity of White Metal Cappings to Method of Preparation

It was believed that as with the resin sockets, white metal sockets may also be sensitive to the method of preparation. The same tests as described in section 7.1.2 on resin sockets were carried out on white metal sockets.

In addition to the tests listed above the penetration of white metal into a socket at four different socket temperatures (room temperature (RT), RT+50°C, RT+100°C and RT+150°C) was investigated. The Ropeman's Handbook specifies that the socket temperature for white metal cappings should be between 100°C and 205°C when casting and it was felt that the implications of people not adhering to these instructions should be investigated. After casting each socket the termination was allowed to cool. The capping was then inspected and tensile tested to destruction.

There is a possibility of the white metal being overheated when used in the field since in most cases devices without temperature control would be used to heat the white metal. It was believed that this could have an effect on the metallurgical properties of ropes. In order to evaluate the effect of overheated white on the efficiency of a rope termination, white metal was be heated to 500°C, which is 180°C above the normal pouring temperature. Once the required temperature was obtained a capping was cast on ropes of three different tensile grades (1800 MPa, 2050 MPa and 2150 MPa). The terminations were then tensile tested to evaluate the efficiency.

8. RESULTS

8.1 Resin Cappings

8.1.1 Resin as Filler Material

The results of the tensile tests carried out on the ten resin socketed terminations described in section 7.1.1 are summarised in Tables 1 to 3 below. Table 1 contains the results of the tensile tests of the two as-cured resin sockets. Tables 2 and 3 contain the tensile test results of the four sockets fatigued at the low load range (5% load range) and the four sockets fatigued at the high load range (10% load range) respectively.

The one fatigue test which was meant to run for 30 000 cycles at a load range of 5% was run over a weekend but due to a malfunction in the cycle counter mechanism of the test machine, the test did not stop as planned, after 30 000 cycles. It was terminated manually at 62 000 cycles. It was decided to perform the tensile tests on only these two specimens and only repeat the test if the results showed a high loss in efficiency.

Table 1: Results of tensile tests on as-cured socket samples.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
1	0	1466	800	Ideal
2	0	1463	1300	Ideal

Table 2: Results of tensile tests on resin socket samples subjected to 5% (low) load range fatigue.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
3	10 000	1457	600	Ideal
4	10 000	1475	100	Ideal
5	62 000	1467	1300	Ideal
6	62 000	1485	500	Ideal

Table 3: Results of tensile tests on resin socket samples subjected to 10% (high) load range fatigue.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
7	10 000	1458	500	Ideal
8	10 000	1438	200	Ideal
9	30 000	1459	300	Ideal
10	30 000	1465	150	Ideal

8.1.2 Sensitivity of Resin Cappings to Method of Preparation

To evaluate the effect of poor degreasing two resin sockets were cast on rope specimens where the wires of the brush had only been wiped. The results of tensile test are summarised in Table 4 below. In the worst case the ends of a rope would not be degreased at all. Two sockets were cast on rope ends which had merely been

opened into a brush. The results of the tensile tests carried out on these two terminations are also summarised in Table 4.

An additional four terminations prepared in the same manner as those discussed above (two cast on a brush where the wires were only wiped and two cast on a brush where the wires were not cleaned at all) were subjected to 30 000 tension-tension fatigue cycles at a load range of 10% and mean load of 10.5% of new rope breaking strength. The results of the tensile tests which were subsequently conducted on these specimens have been included in Table 5 below.

Table 4:   Results of tensile tests on poorly degreased resin socket samples.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of specimen preparation
11	0	1487	1000	Brush wires wiped
12	0	1469	100	Brush wires wiped
13	0	1480	400	Brush wires not cleaned
14	0	1474	1375	Brush wires not cleaned

Table 5:   Results of tensile tests on poorly prepared resin socket samples subjected to 10% load range fatigue (mean load 10.5%).

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
15	30 000	1484	600	Brush wires wiped
16	30 000	1440	0	Brush wires wiped
17	30 000	1480	300	Brush wires not cleaned
18	30 000	1493	1000	Brush wires not cleaned

8.2 White Metal Cappings

8.2.1 White Metal as Filler Material

The same tests that were discussed in section 8.1.1 above on resin cappings, were carried out on white metal cappings. The results of these tests are summarised in Tables 6,7 and 8 below. Table 6 contains the results of the tensile tests on two white metal sockets that had been tested immediately after the socket had cooled to room temperature. Tables 7 and 8 contain the tensile test results of the four sockets fatigued at the low load range (5% load range) and the four sockets fatigued at the high load range (10% load range) respectively.

Table 6:   Results of tensile tests white metal socket samples.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
19	0	1469	1000	Ideal
20	0	1459	0	Ideal

Table 7:   Results of tensile tests on resin socket samples subjected to 5% (low) load range fatigue.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
21	10 000	1476	400	Ideal
22	10 000	1473	1215	Ideal
23	30 000	1470	400	Ideal
24	30 000	1459	300	Ideal

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Table 8: Results of tensile tests on resin socket samples subjected to 10% (high) load range fatigue.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
25	10 000	1487	500	Ideal
26	10 000	1539	300	Ideal
27	30 000	1490	1000	Ideal
28	30 000	1490	2500	Ideal

8.2.2 Sensitivity of White Metal Cappings to Method of Preparation

The tests carried out in this section of the project thus investigated the effect of poor degreasing on the efficiency of white metal cappings. A total of eight white metal capped sockets were tested. The results of tensile test are summarised in Table 9 below. A further two tensile tests were carried out on specimens were the brush was not degreased at all. The results of the tensile tests carried out on these two terminations are also summarised in Table 9.

Table 9: Results of tensile tests on poorly degreased white metal socket samples.

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of specimen preparation
29	0	1073	0	Brush wires wiped
30	0	1273	0	Brush wires wiped
31	0	1178	0	Brush wires not cleaned
32	0	1273	0	Brush wires not cleaned

An additional four terminations prepared in the same manner as those discussed above (two cast on a brush where the wires were only wiped and two cast on a brush where the wires were not cleaned at all) were subjected to 30 000 tension-tension fatigue cycles at a load range of 10% and mean load of 10.5% of new rope breaking

strength. The results of the tensile tests which were subsequently conducted on these specimens have been included in Table 10 below.

Table 10: Results of tensile tests on poorly prepared white metal socket samples subjected to 10% load range fatigue (mean load 10.5%).

Specimen No.	No. of Fatigue Cycles	Breaking Strength kN	Position of Failure from Socket mm	Description of Specimen Preparation
33	30 000	1298	0	Brush wires wiped
34	30 000	1208	0	Brush wires wiped
35	30 000	1354	0	Brush wires not cleaned
36	30 000	1369	0	Brush wires not cleaned

Five tensile tests were carried out on specimens which were cast with socket temperatures ranging between room temperature (25° C) and room temperature + 150° C. The results of these test are summarised in Table 11.

Table 11: Results of tensile tests on white metal cappings cast at different socket temperatures.

Specimen No.	New Rope Breaking Strength kN	Breaking Strength kN	Position of Failure from Socket mm	Socket Temperature °C
37	1480	1509	0	Room Temp. (RT=25°C)
38	1480	1498	0	RT+25°C
39	1480	1521	400	RT+50°C
40	1480	1523	1325	RT+100°C
41	1480	1521	1000	RT+150°C

White metal poured into a socket in an overheated state could effect the metallurgical properties of high tensile steel wire ropes. Three tests were thus conducted where white metal sockets were cast on ropes of different tensile grades (1900, 2050 and 2100 MPa) at high temperatures (500° C). The results of the tests are included in Table 12.

Table 12: Results of tensile tests on white metal cappings cast on ropes with different tensile grades with white metal at a temperature of approx. 500°C.

Specimen No.	Rope Tensile Grade MPa	New Rope Breaking Strength kN	Breaking Strength kN	Position of Failure from Socket mm	White Metal Temperature °C
42	1800	1471	1474	100	525
43	2050	1690	1651	1325	495
44	2100	1650	1697	300	484

9. DISCUSSION

The efficiency of a rope termination is affected by two factors. The first is the efficiency of construction of the termination and the second is deterioration accumulated during its working life. It is important to separate and quantify these factors since, for example, a termination with a high efficiency of construction may have a high rate of deterioration and may not be suitable for service. For this reason, tensile tests on the resin and white metal sockets were conducted on samples which had not been subjected to any axial fatigue.

When calculating the efficiency of the termination, the new rope breaking strength was used. This was done since it is the only true reference value and is the strength to which a rope is compared during its working life. The use of the new rope breaking strength in calculating the termination efficiency may create the impression that the termination has increased the load carrying capacity of the rope. Due to rope settling, ageing and other factors it is usual that a rope's strength increases in the initial stages of its life. The ropes used in this investigation (excluding the new ropes with different tensile grades) were used but still in good condition consequently, their strength was higher than the new rope breaking strength.

9.1 Resin Cappings

9.1.1 Resin as Filler Material

The results of the tensile tests carried out on the ten resin socketed terminations described in section 7.1.1 are summarised in Tables 1 to 3. Table 1 contains the results of the tensile tests of the two as-cured resin sockets. Both samples had a breaking strength in excess of the new rope breaking strength, with efficiencies of 103,2% and 103,0%. These efficiencies are however not the efficiencies of the termination but that of the rope at the point of failure. The most important factor, was that these specimens broke clear of the socket thus implying that these terminations are 100% efficient. Inspection of the sockets after each tensile test revealed that the resin cone had moved on average by 10 mm during the test embedding itself deeper into the socket. Tables 2 and 3 contain the tensile test results of the four sockets fatigued at the low load range (5% load range) and the four sockets fatigued at the high load range (10% load range) respectively. Again, the most important outcome of all eight tests is that there was no fatigue damage apparent at the socket and that the rope always failed clear of the socket during the tensile test. Figure 11(a) and (b) shows two specimens after the fatigue and tensile tests.
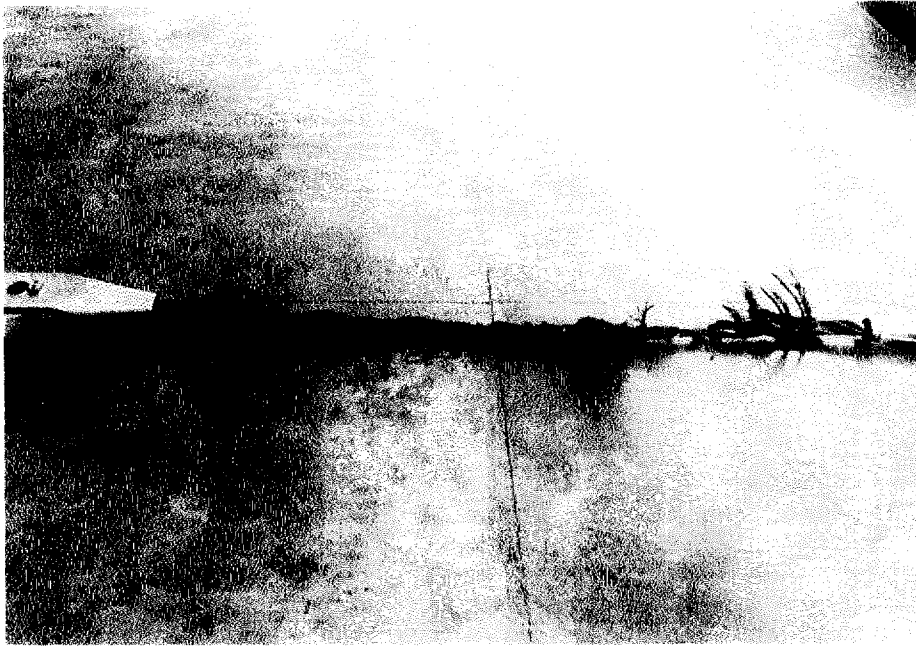
(a)

(b)

Figure 11: A resin socket specimen after tensile testing.

The results of the ten tensile tests in terms of efficiency relative to the new rope breaking strength are plotted against Number of Fatigue Cycles for the low and high load ranges in Figures 12 and 13 respectively. The fatigued specimens did not have a significantly lower efficiency than the unfatigued ones thus indicating that very little or no deterioration took place at the socket during the fatigue tests.

It will be recalled from the previous work performed on splices[3], that a series of fatigue tests was performed on nominally identical splices, at various mean loads and load ranges. Figure 14 shows a comparison between the splice test results[3] and the socket test results obtained for samples subjected to the same mean load and load range (10% of rope breaking strength).

These results demonstrate the superiority of resin sockets in comparison to the two sets of four splices which were fatigued between 10 000 and 40 000 cycles at the same loads and load ranges during the splice investigation[3]. The splice which had been subjected to 30 000 fatigue had a calculated efficiency of 83,7% compared to the 103% of the socket.

The tension-tension fatigue tests have indicated that a resin socket is a more efficient termination than a splice in terms of efficiency of construction and is less susceptible to tension-tension fatigue deterioration. Although two brittle wire breaks occurred in one of the specimens that was cycled to 62 000 fatigue cycles (Specimen No. 5) these were not fatigue wire breaks.

Apart from the benefits in efficiency, the preparing of a socket is also a less labour intensive operation than a splice. It takes two people less than an hour to cut the rope, open and clean the brush and cast the resin socket. This obviously excludes the curing period.
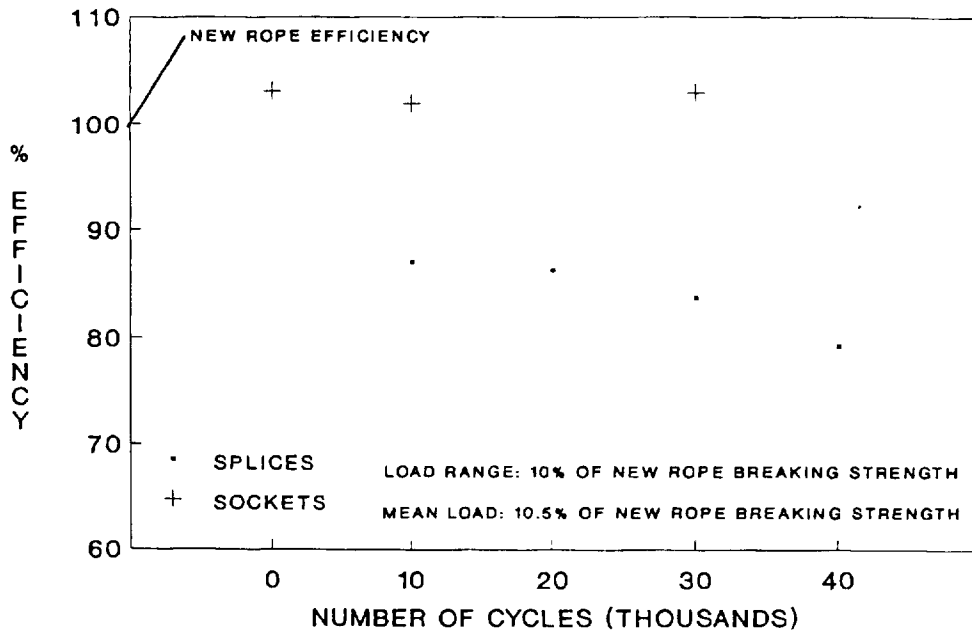
32

RESIN SOCKET TESTS
LOW LOAD RANGE
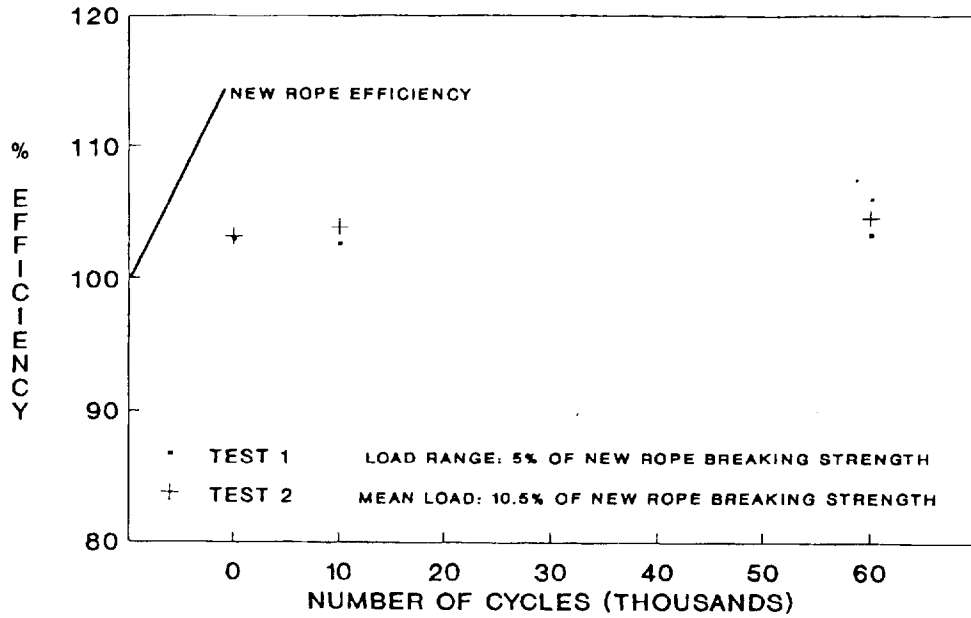
Figure 12: Graphical presentation of the fatigue test results on resin capped sockets subjected to low load ranges.

RESIN SOCKET TESTS
HIGH LOAD RANGE
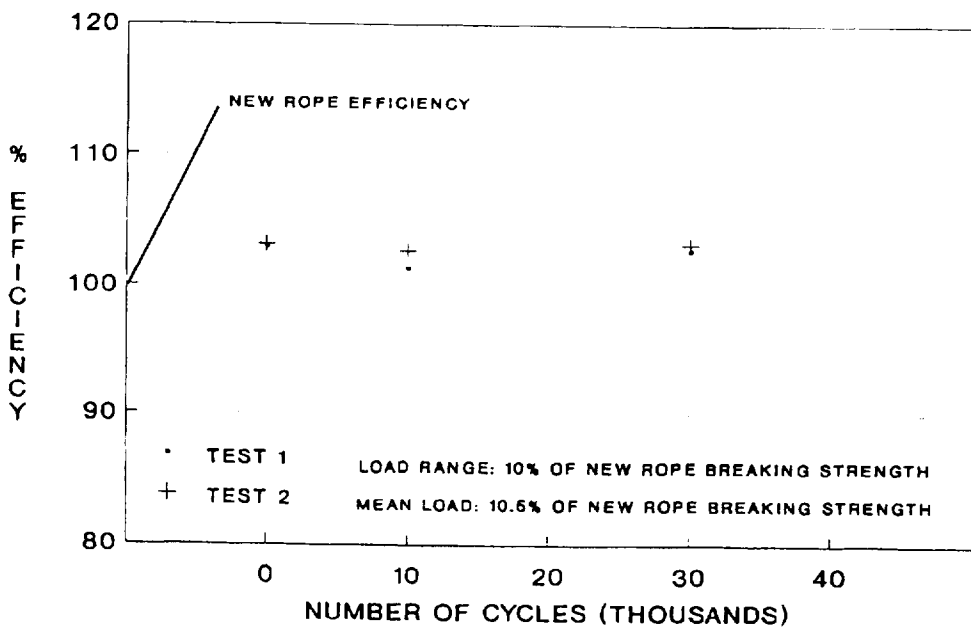
Figure 13: Graphical presentation of the fatigue test results on resin capped sockets subjected to high load ranges.

33

RESIN SOCKET AND SPLICE TESTS
HIGH LOAD RANGE

Figure 14: Comparison between the resin capped socket and the splice fatigue test results.

9.1.2 Sensitivity of Resin Cappings to Method of Preparation

Although the results on the first set of tests on resin capped sockets showed that in terms of both tensile strength and resistance to fatigue deterioration these rope terminations are suitable alternatives to splices, the sockets were prepared under ideal conditions. Although one **must never deviate from the method of socket preparation specified by the national coal board** there is always the chance that the specified procedure may not be adhered to. It is thus essential that the effects of deviating from this procedure be evaluated. It was felt that the most likely deviation from the specified procedure would be that the brush would not be adequately cleaned.

A total of eight resin capped sockets where the wires of the brush had only been wiped were tested. Figure 15 shows the condition of the brush after the wires had been wiped prior to casting. The results of the tensile tests on the unfatigued specimens are summarised in Table 4.
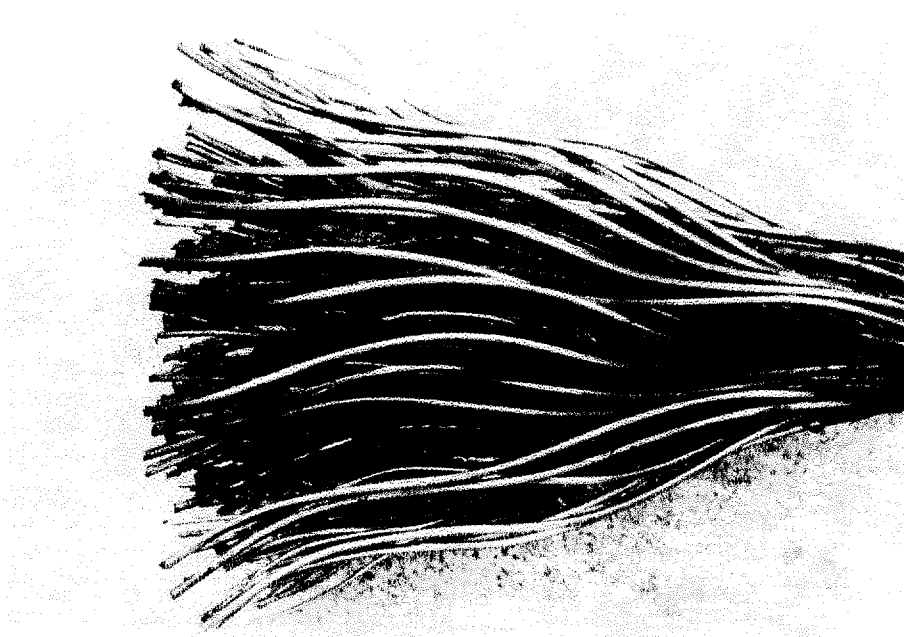
Figure 15: The appearance of the wire brush after the wires had been wiped.

In the worst case the ends of a rope would not be degreased at all. Two sockets were cast on rope ends which had merely been opened into a brush. Figure 16 shows the condition of the brush prior to casting. The results of the tensile tests carried out on these two terminations are also summarised in Table 4. As can be seen all four specimens failed clear of the sockets, i.e all had an efficiency of 100%. In the case of all four sockets there was no movement of the wires of the brush relative to the capping. As with the destructive tests on the "properly prepared" sockets there was a movement of approximately 10 mm of the capping relative to the socket. During a tensile test the capping socket is pulled into the socket and wedging effect increases the frictional forces on the wires of the rope.

The results of the tests carried out here coincided with the conclusions made by Chaplin and Sharman[7]. They stated that the coefficient of friction between the resin and the wire would have to be reduced significantly (although not figure was quoted) before the rope would pull out the socket. The resin socket is thus fairly insensitive to the cleanliness of the brush. The only other factor which could affect the efficiency of the termination more than not degreasing the brush is if the brush was not opened properly. This may warrant an additional investigation, however from the results of the laboratory tests it has been shown that a person would have to be extremely incompetent in preparing the socket before the efficiency of the termination is affected. Even if a socket was prepared by a person who had never before prepared a resin capping, as long as the procedure specified by the coal board is closely followed there is unlikely to be any detrimental effects on the efficiency of the termination.
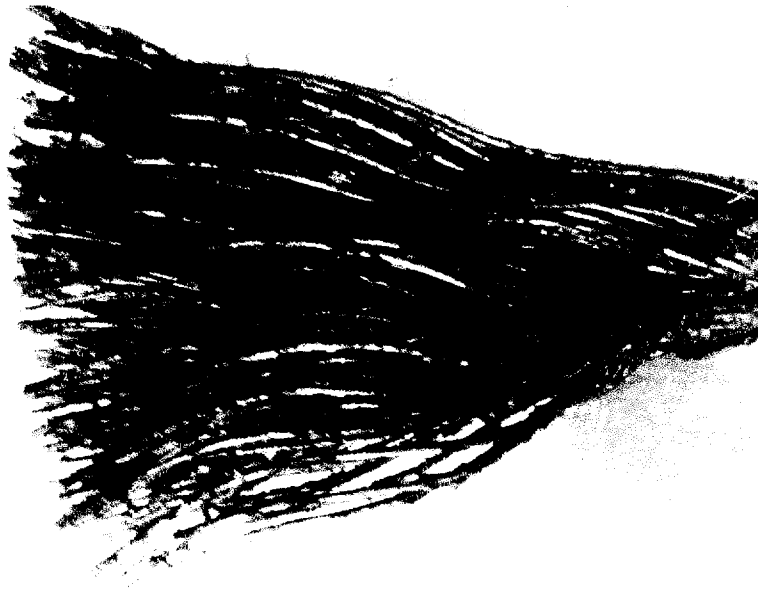
Figure 16:   The appearance of the uncleaned wire brush prior to casting.

An additional four terminations (two cast on a brush where the wires were only wiped and two cast on a brush where the wires were not cleaned at all) were fatigued prior to tensile testing. The results of the tensile tests which were subsequently conducted on these specimens have been included in Table 5.

Three of the four terminations failed clear of the socket. Although one termination failed at the socket, the breaking strength of the termination was higher than the new rope breaking strength but lower than the average of the other three terminations. A subsequent inspection of the termination revealed that there was a void at the bottom of the socket which was caused by an air bubble which was trapped at that point during casting. It thus is very important that the resin is poured in such a way (slowly and off centre) that no air pockets are created at the bottom of the socket. In this case the air bubble was at the centre of the bottom end of the capping and was not detected by the pretest (post curing) inspection. Should a capping be found to have an air pocket or should it be suspected that there could be an air pocket in a capping, the capping should be cut off and a new one cast. It should however be noted that despite this slight inefficiency this termination was still approximately 16% more efficient than a splice which had been exposed to the same loads and number of fatigue cycles.

There was no movement of the wires of the rope relative to the capping during the fatigue tests on any of the four sockets tested. However, all the strands partially failed at the socket and the remaining wires pulled out in the case of the termination that failed at the socket during the subsequent destructive tests.   Like the sockets discussed in the previous sections the resin capping moved by approximately 10 mm, embedding itself deeper into the socket during the tensile tests.

9.2   White Metal Cappings

9.2.1   White Metal as Filler Material

The same tests that were discussed in section 9.1.1 above on resin cappings, were carried out on white metal cappings. A question that may be asked at this stage is "Why were tests conducted on white metal sockets when firstly, resin sockets have proven to be excellent alternative rope terminations for splices and secondly, this type (white metal) of termination has been used for years in places like the United Kingdom?" The answer has many dimensions.

When this project was proposed it was discussed with representatives of most of South Africa's large mining houses. During the discussions it was clear that no consensus was going to be reached on which type of termination (of the two under discussion) was going to be used. Some members felt that they would most likely use resin sockets if they moved away from splices others said they would most likely use white metal sockets. Since this project is aimed at serving the whole mining industry it was decided not to single out any particular socket for testing.

What should also be realised is that although resin and white metal sockets appear to be identical apart from the filler material, they are mechanically very different. In a resin capping, when the resin cures it shrinks and thus creates a high frictional grip on each individual wire. When the rope is loaded the resin capping slips embedding itself in the socket. Due to the internal geometry of the socket the resin cone is compressed by this action thereby increasing the frictional grip on the wires of the rope. Chaplin and Sharman[7] stated that the total force required to overcome this frictional gripping and to pull the wires from the resin on a well prepared resin socket would be well in excess of the rope breaking strength. This was verified in the results above.

In the case of a white metal socket, the white metal bonds to the individual wires of the rope. This type of socket relies on bonding forces and not frictional forces to retain the load. Similar to resin capping when the rope is loaded the white metal cone imbeds itself in the socket and the compressive forces generated are transmitted onto the wires of the rope.

The results of the tensile tests carried out on the ten white metal socketed terminations described in section 7.2.1 are summarised in Tables 6,7 and 8. Table 6 contains the results of the tensile tests on two white metal sockets that had been tested immediately after the socket had cooled to room temperature. Both samples had a breaking strength in excess of the new rope breaking strength, however one termination failed at the socket at a breaking strength slightly lower than the one which failed clear of the socket. It can thus be said that the one termination had an efficiency of 100% since it failed clear of the socket. In the case of the other termination, there is a possibility that the rope failed at its weakest point which happened to be at the termination, and meant that the termination had an efficiency of 100%. However this is not known for certain and thus it must be assumed that the termination was not 100% efficient. Inspection of the sockets after each tensile test revealed that the white metal cone had not moved relative to the socket during the test. Tables 7 and 8 contain the tensile test results of the four sockets fatigued at the low and high load range respectively. The most important outcome of all eight tests

is that there was no fatigue damage apparent on the rope at the socket and that the rope always failed clear of the socket during the tensile test.

9.2.2 Sensitivity of White Metal Cappings to Method of Preparation

The results on the first set of tests on white metal capped sockets showed that in terms of both tensile strength and resistance to fatigue deterioration, if properly prepared these rope terminations are comparable in performance to resin cappings and are suitable alternatives to splices. As with the preparation of the resin sockets one **must never deviate from the method of white metal socket preparation specified by the National Coal Board**. However as stated before there is always the chance that the specified procedure may not be adhered to. The effects of the possible deviation from the procedure were investigated for resin sockets and it was appropriate to do the same for white metal cappings.

As explained in the previous section resin and white metal cappings have different rope restraining mechanisms. For this reason it would have been very foolish to assume that if poor preparation (poor brush degreasing) did not affect the efficiency of the resin cappings it would not affect the efficiency of the white metal cappings. In fact since the white metal capping relies on bonding between the white metal and the wires to sustain the load, poor degreasing would most likely prevent bonding and the efficiency of the termination would most likely be affected.

A total of eight white metal capped sockets were tested. Two white metal sockets were cast on rope specimens where the wires of the brush had only been wiped. The condition of the brush after the wires had been wiped prior to casting was similar to that shown in Figure 15. The results of tensile test are summarised in Table 9. A further two tensile tests were carried out on specimens were the brush was not degreased at all. The results of the tensile tests carried out on these two terminations are also summarised in Table 9.

In all four cases the rope pulled out of the socket at loads ranging from 72.5% to 86.0% of new rope breaking strength. These results confirm the fact that improper degreasing of the brush of a white metal socket does prevent bonding of the white metal to the wires, which results in the efficiency of the termination being reduced substantially. The wedging action of the capping in the socket was the main restricting force. Although the compressive force generated within the socket may have been large enough to prevent the rope from pulling out (since this is the case with resin), the fact that the white metal has a lower compressive strength that the resin prevented it from transmitting a large enough compressive force on the wires to restrain the rope. The white metal thus started to extrude during the test and the rope eventually pulled out of the socket. Although the efficiency of these terminations were significantly lower than the white metal sockets which were well prepared, when compared to the efficiency of a splice the difference in efficiency is fairly insignificant.

An additional four terminations (two cast on a brush where the wires were only wiped and two cast on a brush where the wires were not cleaned at all) were subjected to 30 000 tension-tension fatigue cycles. The results of the tensile tests which were subsequently conducted on these specimens have been included in Table 10.

Although no movement of the wires relative to the endcone was detected during any of the four fatigue tests, all four the specimens failed at efficiencies of between 81,6% and 92,5% (calculated) during the tensile test. The mode of failure was the same as that on the unfatigued specimens, i.e. the rope pulled out of the socket.

In the NCB procedures for the preparation of white metal sockets it is specified that the socket should be heated to between 100° C and 205° C before the white metal is poured. This is most likely another procedure which will not be adhered to especially if there is severe time constraints on the riggers. For this reason it was decided to investigate the effects deviating from this procedure.

Five tensile tests were carried out on specimens which were cast with socket temperatures ranging between room temperature (25° C) and room temperature + 150° C. The results of these test are summarised in Table 11. The two sockets cast at room temperature (RT) and RT + 25° C failed at the socket. The breaking strengths of both terminations however were higher than that of the rope when new. The other three sockets cast at RT + 50° C, RT + 100° C and RT + 150° C failed clear of the socket. Figures 17 to 19 show the white metal capping of the sockets cast at RT, RT + 50° C and RT + 100° C after the termination had been tensile tested.

As a result of the rapid cooling of the white metal when it came into contact with the socket, it did not embrace some of the outer wires completely (see Figure 17). This was not the case with the terminations cast with the socket at the elevated temperatures. Although it is not recommended that one deviates from the NCB casting specifications, the effect of casting a white metal capping with a socket at room temperature does not seem to have severe detrimental effects on the efficiency of the termination from a tensile strength point of view.

As mine shafts get deeper there is a tendency for rope manufactures to make ropes of higher tensile grades. These high tensile grades are sensitive to elevated temperatures. The final part of this project thus involved establishing the effect of white metal being poured at high temperatures (500° C) on the efficiency of the termination. On South African mines there is a tendency to heat objects that require heating with an oxy-acetylene flame. There would thus be an inclination towards heating white metal in this manner should the need arise. Since it is very unlikely that the temperature of the white metal is monitored or measured during such an operation there is a very good chance that the white metal may be poured into a socket in an overheated state. This could effect the metallurgical properties of high tensile steel wire ropes. Three tests were thus conducted where white metal sockets were cast on ropes of different tensile grades (1900, 2050 and 2100 MPa). The results of the tests are included in Table 12. All three specimens failed clear of the socket indicating that the white metal, even when cast at 500° C does not affect the tensile strength of the socketed termination even for ropes with a tensile grade of 2100 MPa.
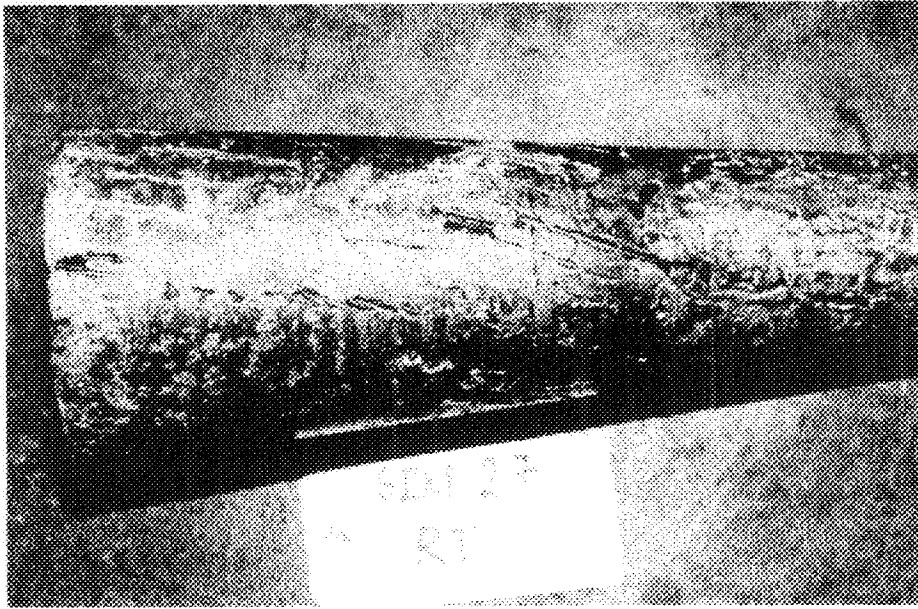
Figure 17: White metal capping cast with the socket at a temperature of 25° C.
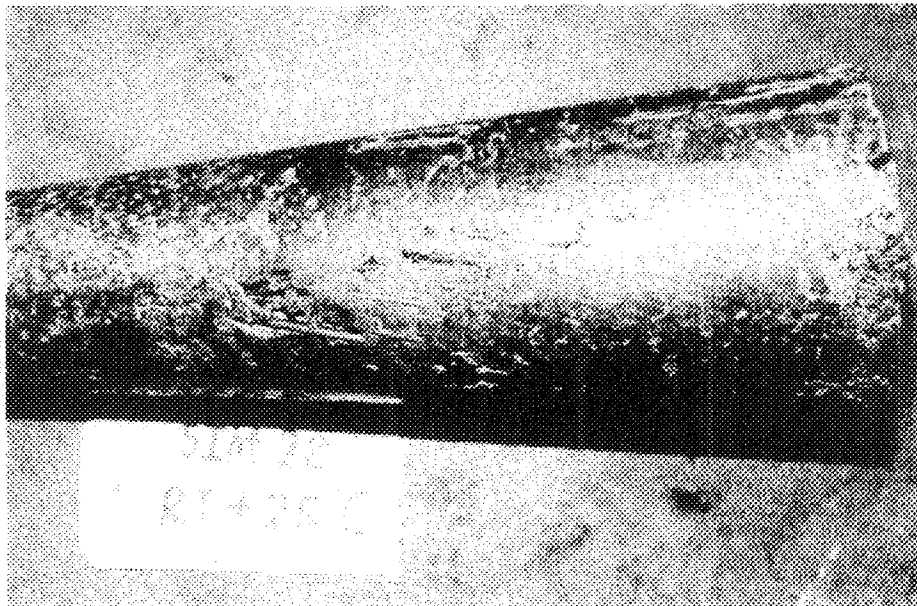
Figure 18: White metal capping cast with the socket at a temperature of 50° C.
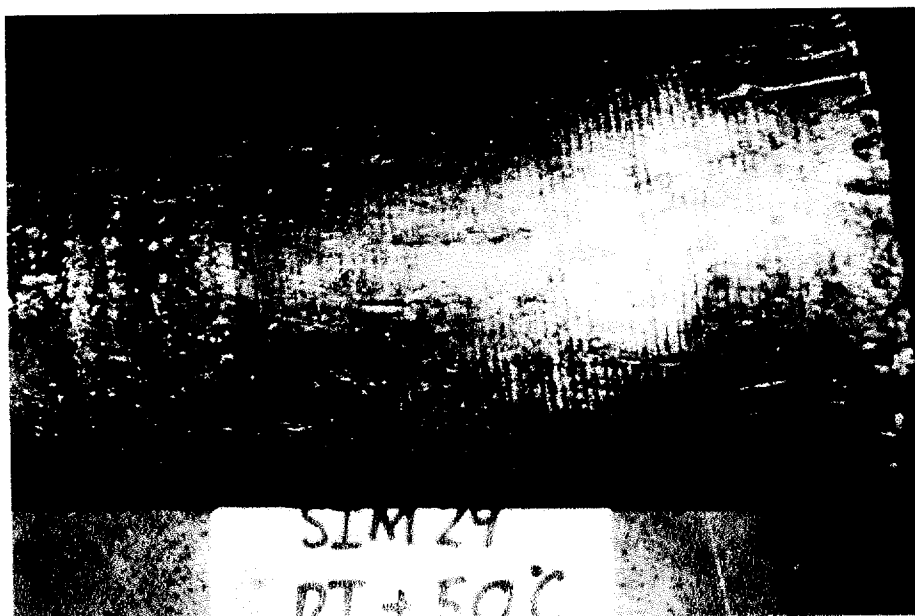
Figure 19: White metal capping cast with the socket at a temperature of 75° C.

10. CONCLUSIONS AND RECOMMENDATIONS

The work documented in this report was aimed at identifying suitable and safe rope terminations less dependent on artisan skill and establish the performance criteria for these terminations. Two types of rope terminations (resin and white metal cappings) were investigated and the effects of different factors (listed below) on their efficiency were established. The factors investigated were:

- effect of fatigue on the efficiency of resin and white metal socketed rope terminations.

- sensitivity of the efficiency of resin and white metal socketed rope terminations to the cleanliness of the wire brush.

- sensitivity of the efficiency of white metal socketed terminations to the method of preparation (socket temperature).

- effect of high (500° C) white metal casting temperatures to the efficiency of the socketed termination for ropes of different tensile grades.

10.1 Resin Cappings

10.1.1 Resin as Filler Material

The ten resin capped socket terminations which were prepared according to NCB specifications and were tensile tested failed at a point clear of the socket, and with a breaking strength in excess of the new rope breaking strength. This indicated that the efficiency of construction of a well prepared resin capping is 100%. A negligible amount of deterioration was accumulated by the resin cappings during the fatigue tests. This indicated that under non-corrosive conditions and under axial-cyclic

loading as carried out in this test program the resin socketed termination does not deteriorate significantly.

10.1.2 Sensitivity of Resin Cappings to Method of Preparation

Out of the eight poorly prepared resin cappings only one failed at the socket with a breaking strength in excess of the new rope breaking strength. The resin capped socket is thus fairly insensitive to the cleanliness of the brush.

The preparation of a resin socket is less labour intensive than a splice and if the resin curing time is included takes approximately the same time to fabricate as a splice.

In well prepared resin capped socket the weakest and most over stressed location is the rope body and not the termination and thus the termination performs better than the rope under both extreme loads and fatigue loading conditions.

10.2 White Metal Cappings

10.2.1 White Metal as Filler Material

The white metal cappings which were prepared according to the NCB specifications and subjected to tensile tests also had efficiencies of 100%. The axial fatigue loading that the well prepared white metal sockets were subjected to did not significantly reduce the strength of the termination even after 30 000 cycles at high loads.

10.2.2 Sensitivity of White Metal Cappings to Method of Preparation

White metal sockets are sensitive to the cleanliness of the brush. In the case of all eight white metal sockets tensile tested were the brush was not properly degreased the rope pulled out of the socket at loads ranging between 72,5% and 92,5% of new rope breaking strength. There was however no movement of the wires of the rope relative to the capping during the fatigue test.

Out of the five white metal sockets tested where the white metal was poured with the socket at different temperatures, the terminations cast with the socket at room temperature and RT + 50° C failed at the socket. The breaking strength of these two terminations however was higher than the new rope breaking strength. The other three terminations failed clear of the socket. The efficiency of the white metal termination is thus slightly affected by the socket temperature at the time of casting.

The high white metal casting temperature (500° C) does not affect the efficiency of a socketed termination even when ropes with a tensile grade of 2100 MPa are used.

10.3 Concluding Remarks

The laboratory test results obtained from well prepared resin and white metal capped sockets were superior to results obtained from the same tests that were carried out on

splices in a previous investigation, both in terms of termination efficiency and deterioration accumulated during axial fatigue tests.

The preparation of a resin socket is less labour intensive than a white metal socket to prepare however due to the curing time resin it takes slightly longer to prepare.

It can thus be said that both resin and white metal sockets are suitable alternative rope terminations for splices.

The results of the laboratory tests indicate that the resin sockets are superior to other terminations tested to date, and it is therefore recommended that a series of field trials be conducted to confirm the suitability of this termination for the South African Mining Industry. The field trial samples should be prepared according to the procedure documented in this report or in the NCB specifications.

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12. ACKNOWLEDGEMENTS

SPLICING TECHNIQUES FOR

MINE WINDER ROPES

by

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SPLICING TECHNIQUES FOR MINE WINDER ROPES

Splicing: Securing the ends of a rope into its own part by interweaving the strands[1].

There are various ways in which a splice can be made up. The different splicing methods give splices different properties, and in many cases using the wrong type of splice for the application can have serious consequences.

1.   TYPES OF SPLICES

After the first tuck of a splice, there are effectively two ways in which the remaining tucks of the splice can be made. These are with the lay of the rope **(Liverpool Splice)** or against the lay of the rope **(Cross-tuck or Admiralty Splice)**. Naturally one can vary the number of tucks within a splice or the size of the strands (by removing some of the wires after a minimum number of full tucks to produce a tapered splice), but the type of splice does not change.

1.1   Liverpool Splice

A Liverpool splice is made by splicing with the lay. It is also known as the "Round and Round" splice and this latter name closely describes this type of splice. After the first series of tucks have been made each tail (or dead strand) is wrapped around one and the same strand in the main part of the rope (live strand) throughout the splice. i.e. if stand 1 (dead strand) is wrapped around strand A (live strand) at the second series of tucks, strand 1 will be wrapped around strand A at each subsequent series of tucks until the required number of tucks have been achieved.

In the case of six stranded rope, once the splice has been completed each live strand of the rope will have a dead strand wrapped around it throughout the length of the splice thus maintaining the lay of the rope. Figure 1 shows a completed Liverpool Splice. A Liverpool splice is spliced in such a way that each live strand is independent from another (the strands are not locked together) even though it has a dead strand wrapped around it. Therefore if the rope is unlayed the spliced portion will also unlay. This reduces the frictional forces between the live and dead strands and can result in the dead strands pulling out.

Liverpool splices or splices made with the lay must never be used where the end of the rope is free to rotate.
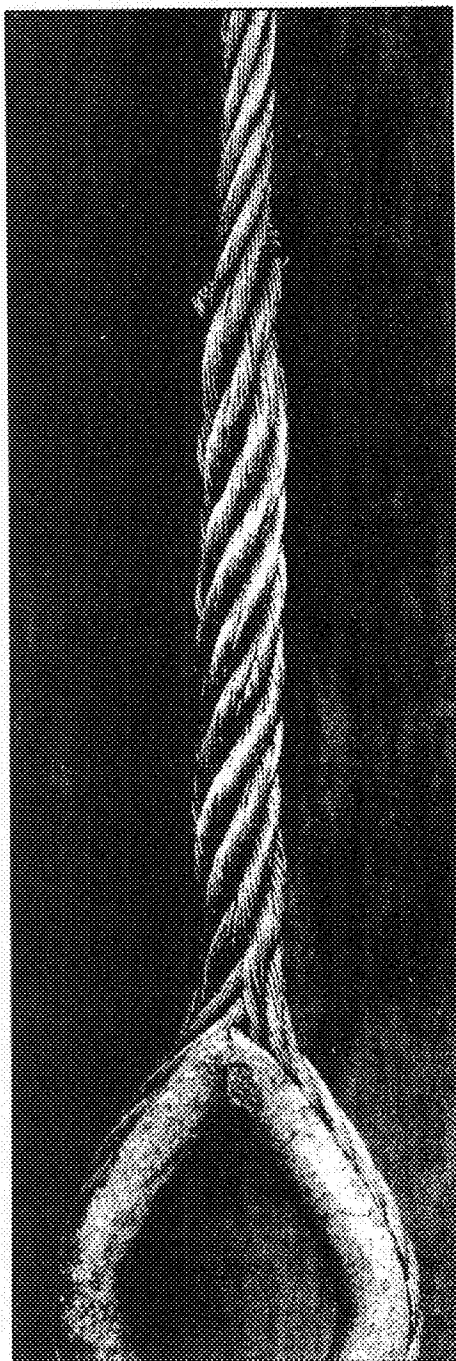
Figure 1:
A completed five tuck Liverpool Splice
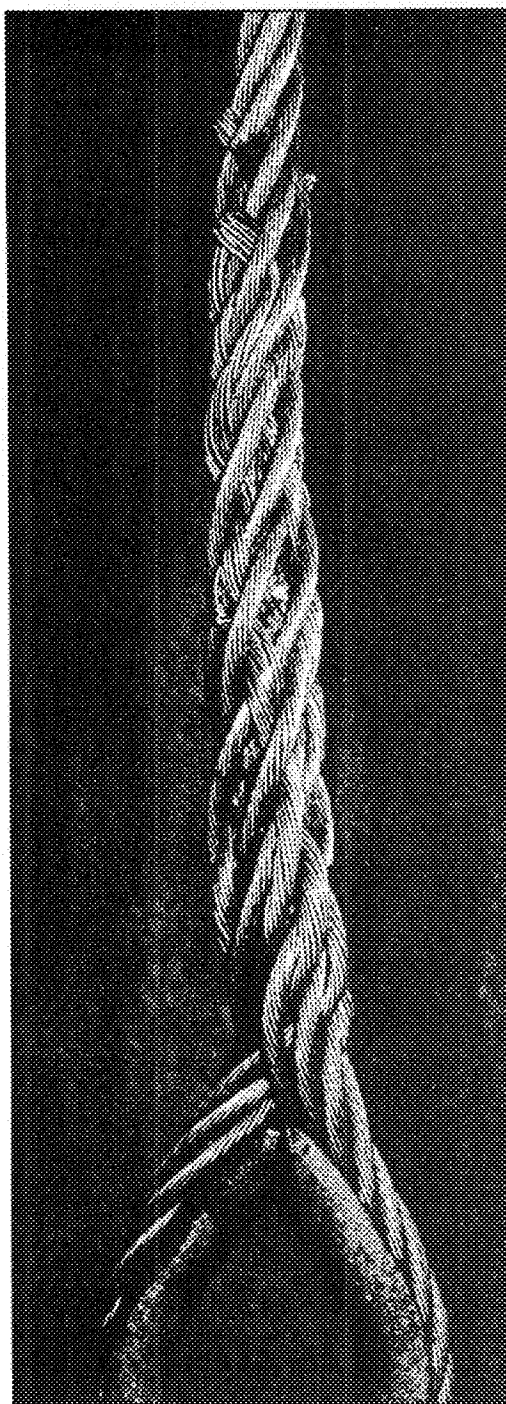
Figure 2:
A completed five tuck Admiralty Splice

1.2   Cross-lay or Admiralty Splice

An Admiralty splice is made by splicing against the lay. After the first series of tucks have been made each tail (or dead strand) is passed over the one strand in the main part of the rope (live strand) and under another (adjacent live strand) throughout the splice, i.e. in the case of a six strand rope if stand 1 (dead strand) is wrapped over strand A (live strand) at the second series of tucks, strand 1 will only be wrapped over stand A again at the eighth series of tucks. In this manner on a six strand rope each dead strand will have been interwoven with all six live strands by the seventh tuck in the splice.

The dead strands thus move across the splice from one live strand to the next, and thus do not conform with the lay of the rope, thus the term "against the lay". This method of splicing weaves the live strands together and makes the splice a compact unit. In this case if the rope is unlayed, the live strands in the rope will not be affected and the splice will not be weakened.

Admiralty splices or splices made against the lay can be used where the end of the rope is free to rotate.

2. THE SPLICING PROCEDURE

2.1 Preparation

This section concentrates on the eye or loop of the splice. It describes the fitting of the rope around the thimble and the first series of tucks. This operation is common to all splices even though there are different ways of making the first series of tucks.

It is important when making a splice that the first series of tucks are made correctly. The dead strands must emerge from the correct part of the rope after the first series of tucks. In the case of a six-strand rope as is being discussed here, one dead strand must emerge from each gusset of the live rope independent of the technique used to make the first series of tucks. Only solid thimbles should be used when making splices on winding ropes.

2.1.1 Preparation of the rope for splicing

All wire ropes need some preparation before splicing commences and, apart from a variation in the length of the tucking strands or tails, this preparation is normally as follows:

- Measure up the rope and mark where it is to form the centre of the crown of the eye, making due allowance for the loss in the straight length caused by the curving of the rope around the thimble. Place the thimble with its crown on this mark and bend the short end (tail end) of the rope around it, in the groove of the thimble, leaving the tail end of the rope to protrude which will provide the length for the tucking tails. (This length should be 80 × rope diameter).

- This can be done by hand on small diameter ropes but in the case of large diameter ropes a thimble throat clamp should be used. Force the two parts of the rope together at the point of the thimble, i.e. the crutch of the eye.

- Firmly seize these two parts together (live rope and tails end at the crutch of the eye) with strong wire - they should be in direct contact. This seizing should only consist of two or three turns of wire. Figure 3 shows the rope on the thimble once this operation has been completed.

This clamping procedure ensures that the rope is in solid contact in the groove of the thimble and that the two parts of the rope are together at the crutch. The rope is then ready for splicing.

During the preparation, and prior to making the tucks it is important that no "turn" is taken out of the rope.
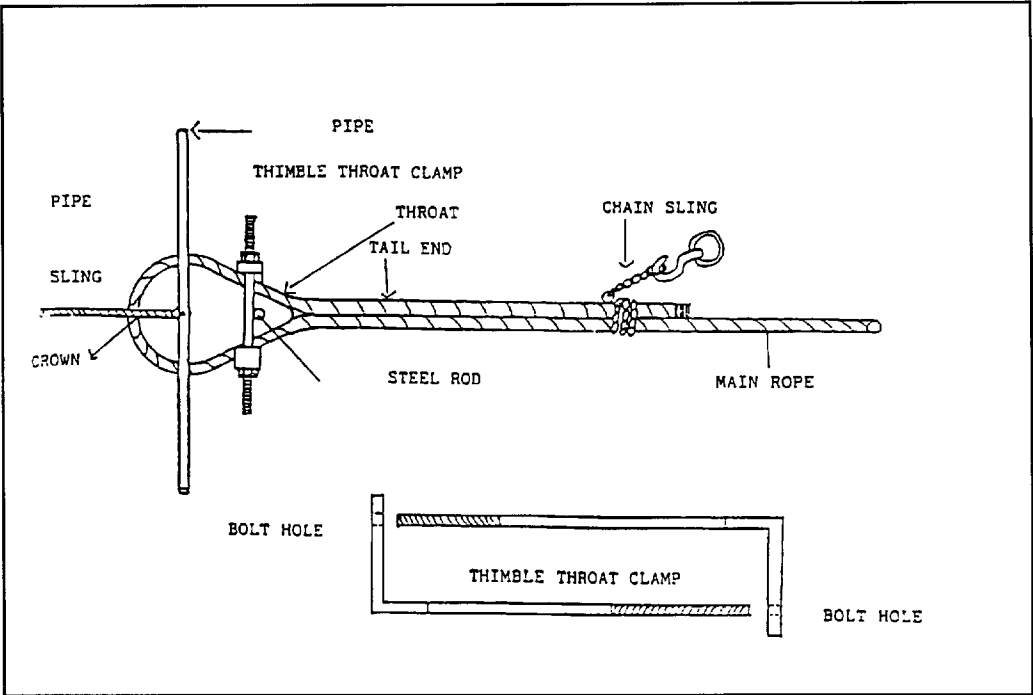

Figure 3: Illustration of the rope secured on the thimble with a thimble throat clamp.
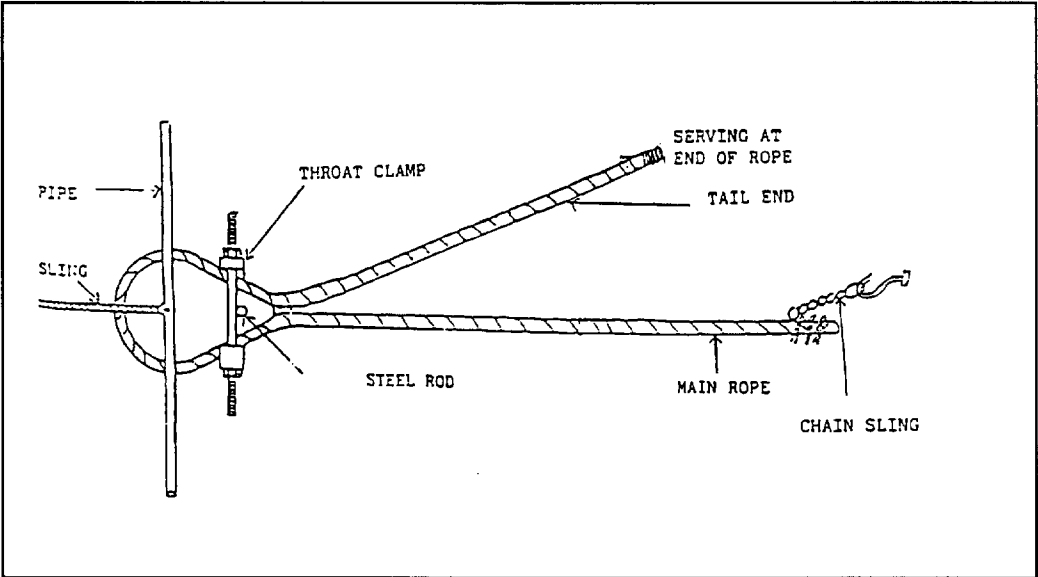
Figure 4: Illustration of the rope around the thimble with the ends secured prior to the opening of the tail.

- For small diameter ropes, place the thimble in a vice with the rope leading vertical and the short end, i.e. the "tails" end, on the left hand side. In the case of large diameter ropes the thimble and rope end should be held horizontally, each end attached to a suitable slings with the rope and tails being held as illustrated in Figure 4.

- Remove the end-binding and unlay the tail end of the rope to provide the tails for splicing (See Figure 5). Also remove the crutch seizing if one was used.
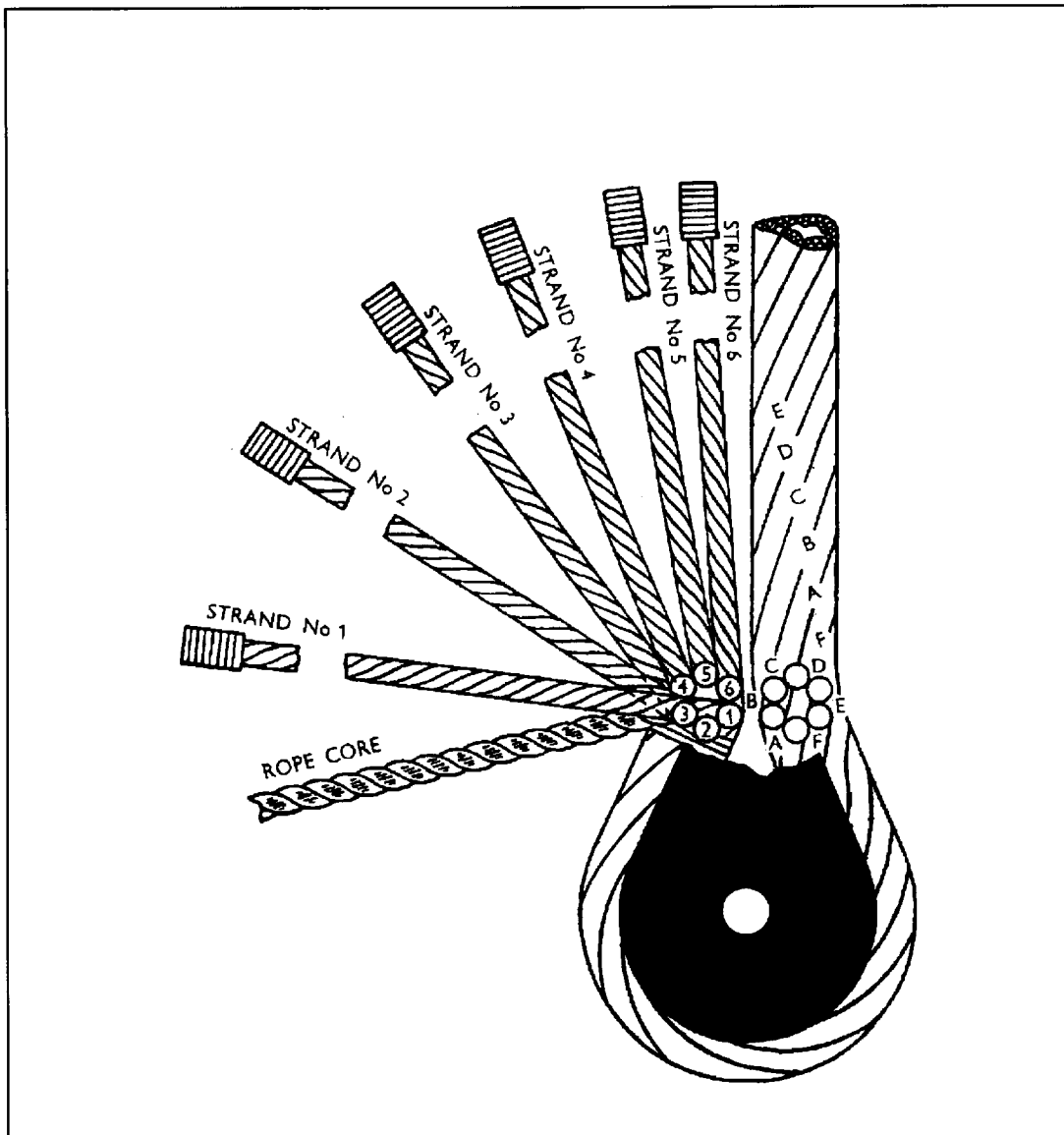
Figure 5: Illustration of the main rope with all the tails opened out.

2.1.2 Notes regarding the splicing procedure

- The fibre main core is to be tucked into the main part of the rope together with Tail No 1 for the first tuck and for a cross-tuck splice it will then be cut off where it

emerges from the main part. In the case of a Liverpool splice it will be run into the core of the rope to help support the strands of the splice.

- In the case of ropes that have a wire core, the wire core must never be cut from the rope. It must be split up, and the wires or strands distributed evenly among the tucking tails, and tucked with them for at least 3 tucks.

- If the rope is not preformed the ends of each tail must be bound separately. This will prevent the strands from opening up. It is advisable to do so even for a preformed rope.

- For the splicing of the six stranded ropes, three methods of making the first series of tucks are given, but although the second and third methods are more simple, the first method does enable the tucking strands to lie close up to the thimble.

- There are also two distinctly different methods of reeving the tucking strands after the first series of tucks have been made as mentioned previously. One is known as the "Liverpool" splice. or the round-and-round splice or the "Parallel-tuck" splice and the other as the "Admiralty" splice or "Cross-tuck" splice. The minimum number of tucks should be seven for a Liverpool Splice and nine for an Admiralty Splice. Splices with more tucks are allowed but increasing the number of tucks does not improve the splice strength.

- In all splices the spike must be entered as near as possible to the thimble, and the tucking tail must enter that portion of loop so formed which is nearest the thimble or end fitting, i.e. under the spike. All tucks must be pulled down hard, i.e. pulled through and pulled back as tightly as possible.

- When a tapered splice is made (a splice where the size of the tails is physically reduced by successively removing some of the wires at each tuck after a minimum number of tucks with a full strand), be it of the Liverpool or Admiralty type, the following procedure should be used to "break out" wires when reducing the number of wires per strand. Take each wire separately, snatch back to the point where it emerges from the rope and then twist wire reversing direction if necessary. The wire should part at the gusset.

2.2   Making an Admiralty Splice on a six strand rope

It will be assumed that the rope preparation procedure as described in section 2.1.1 has been completed and we have the following:

- Thimble secured
- Rope horizontal or vertical
- Main part of rope on right hand
- Tail strands on left hand
- Thimble fitted with a throat clamp
- Thimble and main part of rope secured with slings
- Strands for the tails unlaid and whipped at ends

Length of tails for a nine tuck splice, 80 × rope diameter.

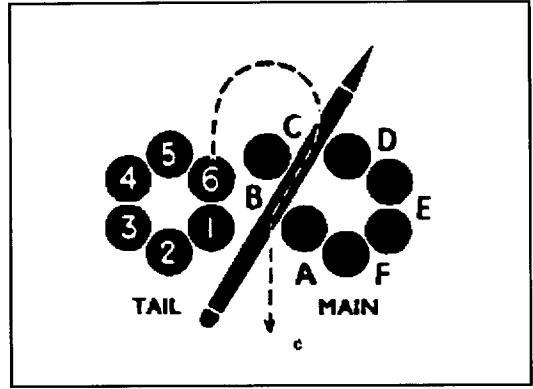## 2.2.1 First Series of Tucks

-       A fibre main core should be tucked with tail No 1, and then cut off. A wire main core must be split up, distributed among the tails, and tucked with them for at least three series of tucks. The first series of tucks should be made according to the table and illustrations that follow.
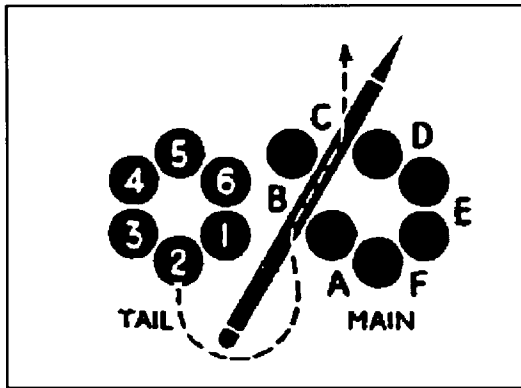
First Series

Tail No.	In at	Out at
1	B	A
6	C	B
2	B	C
3	C	D
5	D	F
4	D	E
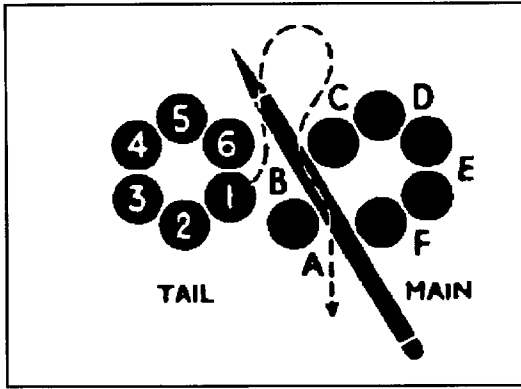
First Tuck

Second Tuck

Third Tuck
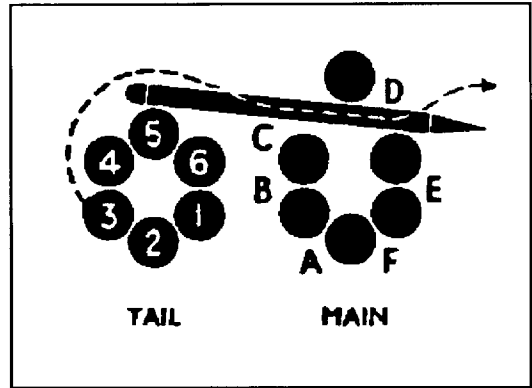
Fourth Tuck
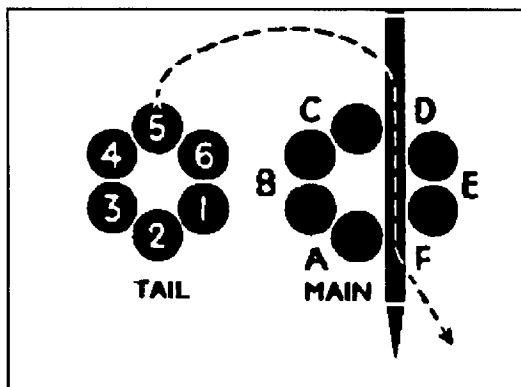
Fifth Tuck
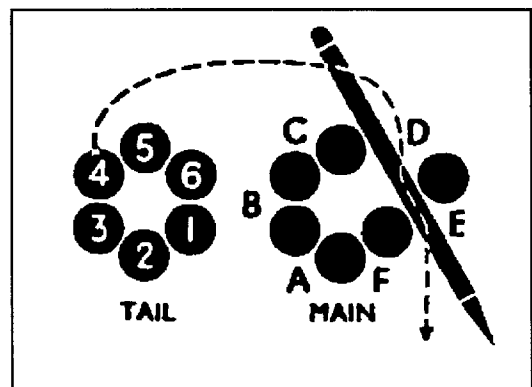
Sixth Tuck

Figure 6: Illustration of how the first series of tucks are made
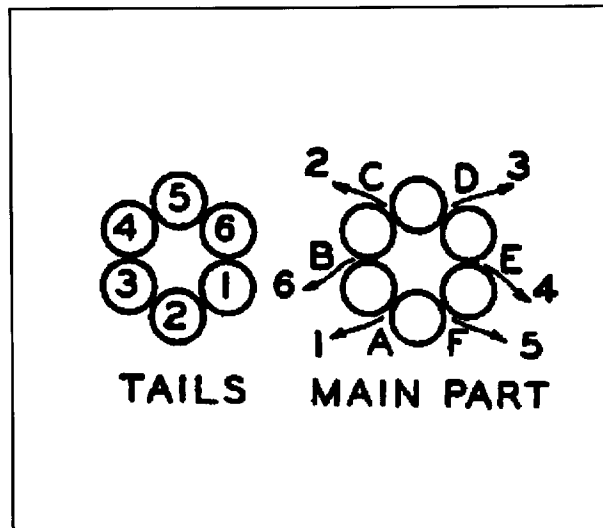
Figure 7: Diagram showing emergence of tails after the First Series is completed

After the first set of tucks have been pulled down tight against the point of the thimble the second, third and fourth tucks can be made in accordance with the following table. The tails must all be well pulled down before the following series of tucks is made.

Tail No.	Second Series		Third Series		Fourth Series	
	In at	Out at	In at	Out at	In at	Out at
1	B	C	D	E	F	A
6	C	D	E	F	A	B
2	D	E	F	A	B	C
3	E	F	A	B	C	D
4	F	A	B	C	D	E
5	A	B	C	D	E	F

- After the fourth series, if a tapered splice is required the wires of a main core may be "broken off", thereby reducing the number of wires in each of the main tails. The remaining wires must be twisted up to a rough strand formation, and at the same time enclosing the cut ends in the centre. After each successive tuck the number of wires in the tails can be further reduced by breaking out more wires.

The pattern for the remaining tucks is shown in the following tables.

Tail No.	Fifth Series		Sixth Series		Seventh Series	
	In at	Out at	In at	Out at	In at	Out at
1	B	C	D	E	F	A
6	C	D	E	F	A	B
2	D	E	F	A	B	C
3	E	F	A	B	C	D
4	F	A	B	C	D	E
5	A	B	C	D	E	F

Tail No.	Eighth Series		Ninth Series	
	In at	Out at	In at	Out at
1	B	C	D	E
6	C	D	E	F
2	D	E	F	A
3	E	F	A	B
4	F	A	B	C
5	A	B	C	D

- The splice shall be rounded up by hammering in the former, starting from the eye and working down the taper. This is to tighten up the tucks and to round up the taper. Remove protruding wire ends, preferably by "breaking out", and again round up over the broken-off ends. The taper (or at least that portion containing the wire ends of the tails) should be served with spunyarn or wire strand to give protection to the user when handling.

The need for thoroughly pulling down each strand as tightly as possible as splicing proceeds, cannot be over-emphasised. The tails should be pulled down in line with the centre line of the thimble. To get the tuck tight and short, it should be beaten by means of a mallet or hammer. One object is to get the tuck as nearly as possible at right angles to the axis of the rope. Working the tucks with mallet or hammer forces any slackness out of the tuckings through the loop, and the beating should start on the position of the tail before its entry into the rope, and continue on the tuck itself. The strands of the main rope where they have been lifted are beaten down to hold the tuck in place.

Alternative method for making the first series of tucks:

For the first series of tucks there is an alternative method which is claimed to be more simple. It is as follows:

First Series

Tail No.	In at	Out at
1	B	D
2	B	E
3	B	F
4	B	A
5	C	B
6	D	C

Figure 8: The figure shows the emergence of the tails after the first series of tucks have been completed.

Another method of making the first series of tucks:

First Series

Tail No.	In at	Out at
1	A	B
2	A	C
3	A	D
4	A	E
5	A	F
6	B	A

Then carry on with the tails over one strand and under the next in a direction against the lay each time as shown above.

2.3   Splicing a Liverpool Splice at the end of a six strand rope

The end of a rope will be prepared as previously described.

The length of the tails should be 80 × rope diameter.

A fibre core will be tucked with Tail No. 1, for one tuck only, and then run into the cone of the rope.

A wire main core must be split up and the strands or the wires distributed among the tucking tails, and tucked with them for five full tucks, i.e. broken off at the completion of the 5th series.
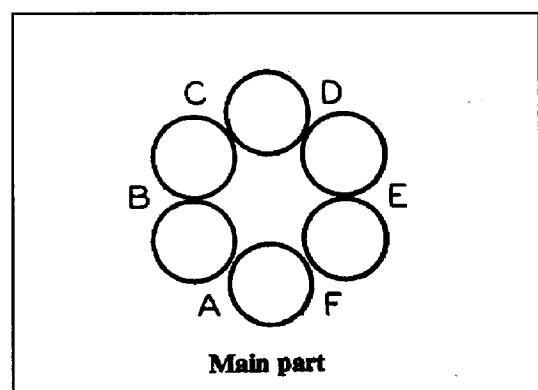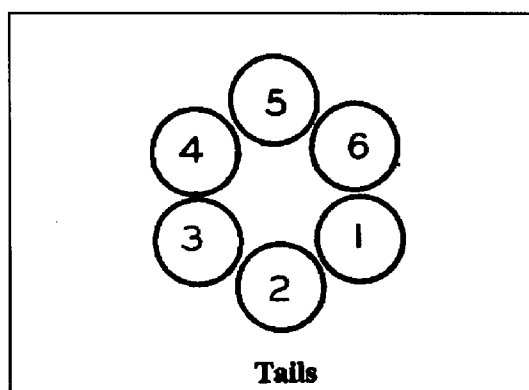
Figure 9:   The figures show how the tails and main part of the rope have been labelled

The final series of tucks are made as described for the Cross-tuck splice. i.e. as in the following table and Figure 10.

First Series

Tail No.	In at	Out at
1	B	A
6	C	B
2	B	C
3	C	D
5	D	F
4	D	E
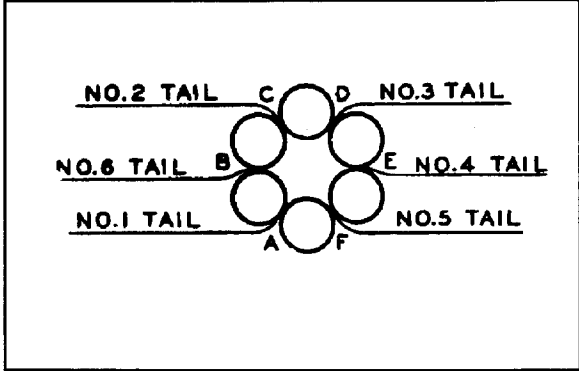
Figure 10: The figure shows the emergence of the tails after the first series of tucks have been completed.

Subsequent tucks are made as listed in the following table.

Tail No.	Second Series		Third Series		Fourth Series	
	In at	Out at	In at	Out at	In at	Out at
1	B	A	B	A	B	A
6	C	B	C	B	C	B
2	D	C	D	C	D	C
3	E	D	E	D	E	D
4	F	E	F	E	F	E
5	A	F	A	F	A	F

If a tapered splice is required reduce the number of wires in each tail by ¼, thus leaving ¾ of the original number. Then hammer down the tucks.

With a rope having a wire main core, the number of core wires must not be reduced at this stage. They should be included in the fifth series and then taken off.

Tail No.	Fifth Series		Sixth Series		Seventh Series	
	In at	Out at	In at	Out at	In at	Out at
1	B	A	B	A	B	A
6	C	B	C	B	C	B
2	D	C	D	C	D	C
3	E	D	E	D	E	D
4	F	E	F	E	F	E
5	A	F	A	F	A	F

Reduce the number of wires in each strand by ¼ of the original number, after the fifth, sixth and seventh tucks. The wire ends should be broken off.

It is important to "break off" ends in a liverpool splice as the slightly hooked end thus formed have some holding power to secure them when the splice bends. Hammer down the tucks and round up the taper.

Loose tucks will result in loose looping wires which will fatigue and break prematurely.

2.4   Making a Cross-tuck Splice on a 17 × 7 Non-spin Rope

The end of the rope and its terminal should be prepared and assembled in a manner similar to that described in section 2.1.1.

It is most important that the tucks be made under the outer strands of the main part of the rope only. The inner strands or inner rope must not be pierced with a spike or disturbed in any way.
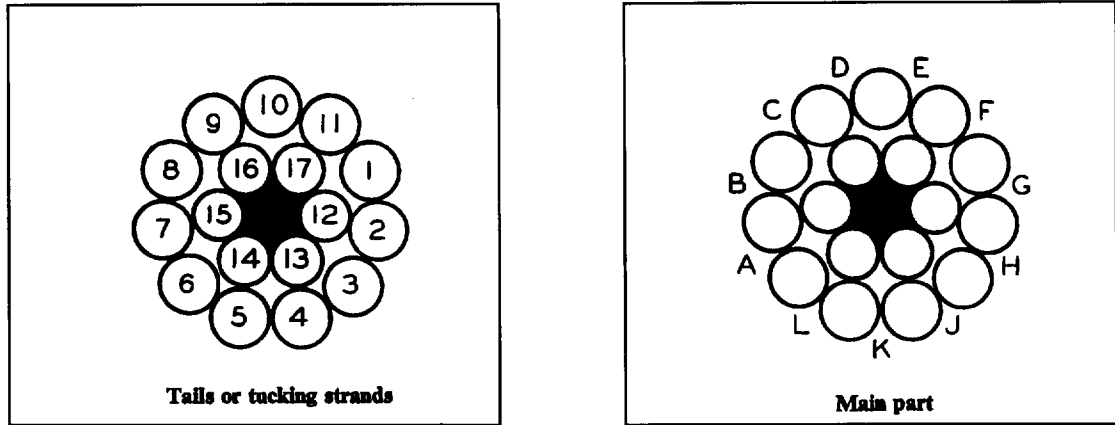
Figure 11: The figures show how the tails and main part of the rope have been labelled

First series of tucks

The table below shows how the strands in a 17 × 7 Non-spin rope must be grouped prior to making the first series of tucks.

In the case of ropes that have a wire strand core, the core is to be grouped with tail No's 11 and 12, i.e. Group Six.

Take Tails Nos.	In at	Out at	Direction	Group No.
3, 4, 14	A	E	Clockwise	Two
1, 2, 13	A	C	Clockwise	one
5, 6, 15	A	G	Anti-clockwise	Three
7, 8, 16	A	J	Anti-clockwise	Four
9, 10, 17	A	L	Anti-clockwise	Five
11, 12	C	A	Anti-clockwise	Six

Group No.	Second Series of Tucks		Third series of tucks	
	In at	Out at	In at	Out at
One	E	G	J	L
Two	G	J	L	A
Three	J	L	A	C
Four	L	A	C	E
Five	A	C	E	G
Six	C	E	G	J

Fourth and Fifth Series of Tucks

On the same principle as before.

When the fifth series of tucks have been completed, release the thimble end of the splice and hammer down the partially made splice, starting from the terminal. Remove one strand from each group (excepting 6 if this is only a two strand group). Secure the thimble end again.

Sixth and Seventh of Tucks

On the same principle as before.

Remove one strand from each group leaving one strand only in each group.

Eighth and Ninth Series of Tucks

On the same principle as before.

Remove from vice or end constraint and hammer down the partially made splice, starting from the terminal, and round up the taper. Break off surplus ends of the tucking strands and serve over the taper or the portion thereof which contains the wire ends.

A tighter splice will be made if at the first series of tucks the two outer strands are tucked first, e.g. 3 and 4, then 5 and 6, and so on, then tuck the inner strands separately and into the interstice given in the table, i.e. 14 with 3 and 4, 13 with 1 and 2, etc.

It is usual to splice an Admiralty splice with 9 tucks as described here, but in cases where 7 tucks are sufficient, one strand would be removed after the fourth series of tucks and another after the sixth.

When removing strands during splicing, the cut should be made as close to their emergence as possible - it is preferable that the wires should be "broken out" separately.

2.5   Making a Cross-tuck Splice on a 34 × 7 Non-spin Rope

It is most important that the tucks be made under the outer strands only of the main part of the rope. The inner strands or inner rope must not be pierced with a spike or disturbed in any way.

Length of the tails for tucking, 80 × rope diameter.

Tails or tucking strands

Group Nine
enters
here

All Groups
except
Nine
enter here

Clockwise
These
inner strands
must not be
disturbed
Tucks must
pass under
outer strands
only
Anticlockwise
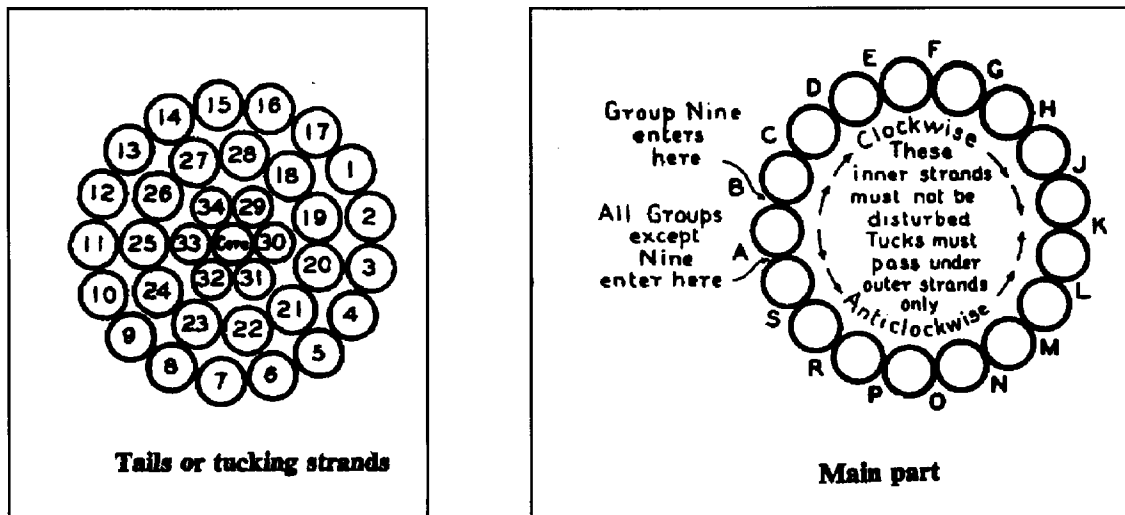
Main part

Figure 12: The figures show how the tails and main part of the rope have been labelled

The first series of tucks should be made as directed in the table below.

Take Tails Nos.	In at	Out at	Direction	Group No.
5, 6, 22, 29	A	G	Clockwise	Three
3, 4, 20, 21	A	E	Clockwise	Two
1, 2, 18, 19	A	C	Clockwise	One
7, 8, 23, 30	A	J	Anti-clockwise	Four
9, 10, 24, 31	A	L	Anti-clockwise	Five
11, 12, 25, 32	A	N	Anti-clockwise	Six
13, 14, 26, 33	A	P	Anti-clockwise	Seven
15, 27, 34	A	S	Anti-clockwise	Eight
16, 17, 28	B	A	Anti-clockwise	Nine

Emergence of groups of tails after the first series of tucks
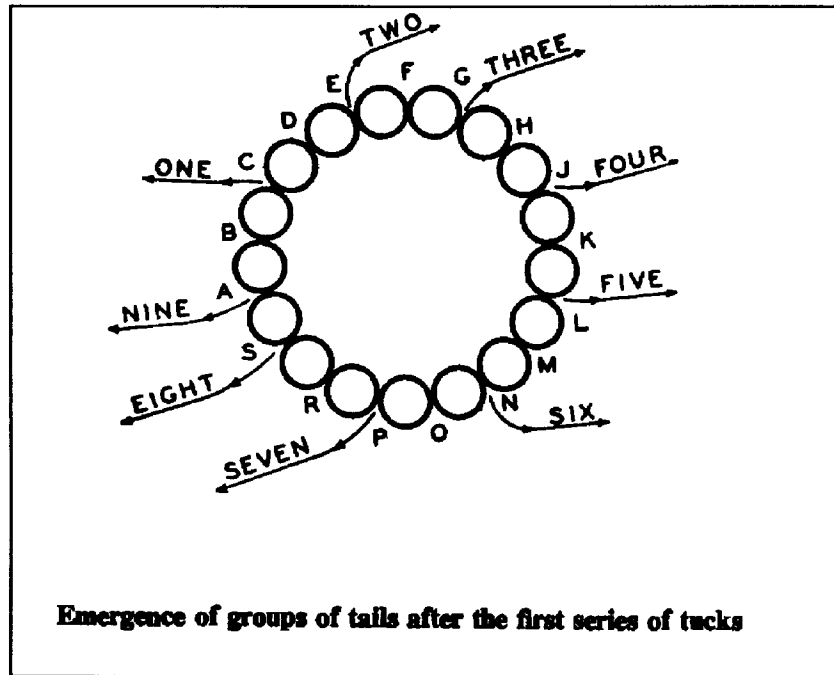
Figure 12: The figure shows the emergence of the tails after the first series of tucks have been completed.

Group No.	Second Series		Third Series		Fourth Series		Fifth Series	
	In at	Out at	In at	Out at	In at	Out at	In at	Out at
One	E	G	J	L	N	P	S	B
Two	G	J	L	N	P	S	B	C
Three	J	L	N	P	S	B	C	E
Four	L	N	P	S	B	C	E	G
Five	N	P	S	B	C	E	G	J
Six	P	S	B	C	E	G	J	L
Seven	S	B	C	E	G	J	L	N
Eight	B	C	E	G	J	L	N	P
Nine	C	E	G	J	L	N	P	S

After completion of the fifth series, remove one tail from each group except in groups eight and nine, to provide 9 groups each with three tails.

Sixth and Seventh Series

One the same principle as before. Remove one tail from each group after the seventh series of tucks.

Eight and Ninth Series

On the same principle as before. Hammer up splice - break off ends and serve over.

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1.   Linder, L. "Lifting Tackle, Part 1 - Ropes & Fittings", British Standard Handbook No4, 1959 Edition, PP 176 - 189.

2.   Watts, A.B. "Terminal Splicing of Wire Ropes", Technical Information Bulletin, British Ropes Limited.

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PERFORMANCE OF RESIN FILLED

SOCKETS PREPARED BY THE

MINING INDUSTRY

by

M. Borello

Prepared by:

Submitted to: Safety in Mines Research Advisory Committee
Engineering Advisory Group

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_____
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DIVISION OF MATERIALS SCIENCE AND TECHNOLOGY
CSIR
November 1994

ABSTRACT

Resin capped sockets, have to date, proved to be less labour intensive and less skill dependent to prepare and more efficient in laboratory trials than other terminations. Members of industry felt that the results could have been influenced by favourable laboratory conditions and that sockets prepared by mine personnel under harsher field conditions could influence the results.

It was therefore proposed that the efficiencies of resin capped sockets on triangular strand ropes prepared by mine personnel on site be investigated and is the basis for this investigation. This also presented the opportunity to investigate whether the available literature and specifically the National Coal Board video on the procedures for resin capped socket preparation, is adequate training material for successful future socket preparations.

Six mines were approached to participate in this investigation. Relevant literature and the socket preparation video were issued in advance to the relevant personnel. Two resin sockets were prepared by personnel from each mine. CSIR personnel were present during most of the actual socket preparations as observers. The prepared sockets were subsequently inspected and tensile tested to destruction at the CSIR laboratories.

It was concluded that there exists serious inadequacies with the current prescribed procedures (i.e. the video and the literature) for socket preparation. These procedures are confusing and too complex. A simple yet comprehensive document describing the resin capping procedure **for a mine rope** needs to be produced in the form of a standard or Code of Practice.

Despite the problems with the training material the results of the tests yielded socket strengths of 100% for eleven of the twelve samples. The breaking strength of one of the samples which fractured at the neck of the socket was 99,7% of the breaking strength of the new rope.

It was concluded that a new ropeman cannot become an expert in capping merely by reading a book on the subject; he must acquire his skill and experience under a man already skilled in the work.

CONTENTS

1.   **INTRODUCTION**

Traditionally triangular strand steel wire ropes on South African mine winders have
been terminated with splices. Winder rope splices have, however, distinct
disadvantages both in terms of their strength in static or fatigue loading and the
special skills required to make these terminations[1]. The resin socketed termination has
the advantages of being relatively easy to make and gives superior performance in
both static and fatigue loading[2].

Two mine winder rope failures at the termination in 1989 and 1990 led to detailed
investigations into the performance of wire rope terminations. Terminations on
winding ropes have to date been safeguarded by a high capacity factor (safety factor
at the front end of the rope) although this capacity factor was not actually intended
for termination protection. Termination protection was achieved by legislating that the
termination had to be made every six months.

1.1   **Background and Previous Work**

Work on rope terminations was initiated when the CSIR tested approximately 120
winder rope terminations (mainly splices) from industry during the latter half of 1990
and beginning of 1991. These rope terminations were tested at the request of the
inspectorate. The CSIR then produced a report[3] on the results of these tests. The
results showed that the efficiency of a splice taken from service after six months
could be as low as 67%, effectively reducing the static safety factor for rock winders
at the front end connection of the rope from 9 to 6 (The cause of the low efficiency
of the splice under discussion was due to a combination of efficiency of construction
and deterioration in service).

Although one may argue that a factor of safety of the termination of 6 is still
sufficient, it is generally accepted that the rate of deterioration increases rapidly once
degradation of the rope at the termination has started. This situation can be
exacerbated once the newly proposed regulations[4] are applied. The new regulations
are expected to come into effect by June 1995. The more conservative regulation will
allow ropes to carry loads slightly greater than current practice (Factor of Safety
(FOS) of 4.5 and a Capacity Factor (CF) of 8). The second (more flexible) regulation
will be based on a formula (FOS = 25000/(4000+L), where L is the length of wind)
which will govern the Factor of Safety provided a dynamic factor of safety of 2.5 is
not exceeded. A termination efficiency of 67% would then effectively lower the
termination Factor of Safety to 5,36 from 8 for the one regulation and to 4.2 from
6,25 for the other. These are static factors and do not include real dynamic loads.

Due to a lack of data and a large number of variables it was not possible to determine
what factors affected the splice strength. The CSIR then carried out an in-depth
investigation into factors affecting splice efficiencies[5]. The effects of workmanship,
rope and splice construction, rope diameter, rope tensile grade, fatigue loads,
corrosion and corrosion fatigue on a splice were investigated.

The results of the tests on splices showed that the rigger has a large effect on the efficiency of a splice. It was also found that the variability in the workmanship of a single rigger can affect the efficiency of a splice by up to 6,4%. Splices are sensitive to rope diameter and it was found that lower splice efficiencies were obtained with larger diameter ropes. Splices with a higher tensile grade had better efficiencies than those with lower tensile grades and splices made from ropes with a wire main core had lower efficiencies than splices made from ropes with a fibre core.

The fatigue testing of splices indicated that a splice is sensitive to peak loads and load ranges, especially non-tapered splices. A splice typically experiences between 10 000 and 60 000 load cycles during a six month period. Tapered splices outperformed parallel splices during the fatigue test in terms of loss in efficiency. There seemed to be no clear difference between tapered and parallel splices in the as-manufactured condition for ropes of small diameter (<44 mm). For the larger rope diameters there were indications that there are benefits in tapering splices.

In an attempt to move away from a labour intensive and skill dependent termination with an efficiency in the order of 85%, the CSIR investigated the feasibility of using resin cappings for wire rope terminations. The first investigation[6] on resin cappings was carried out under the auspices of the Chamber of Mines Steering Committee on Factors of Safety of winder ropes, and examined the breaking strength of resin socketed terminations which had been subjected to various fatigue loading histories.

The literature which is available on fatigue testing of sockets[7], describes tests which were carried out on small diameter ropes (26 mm) and full-lock-coil ropes which are not used on drum winders in South Africa. Also most ropes used are in excess of 26 mm diameter. For these reasons it was decided that, although the literature contained very valuable information, this should only be used as a reference and the performance of these types of terminations should be established using rope diameters and rope constructions which are used in this country.

When the report on the socket tests[6] was presented to the Steering Committee, there were mixed reactions regarding the results. Some members expressed concern over the fact that the very high efficiency of the socket was obtained under controlled laboratory conditions with meticulous preparation procedures. It was reported that these conditions and methods of preparation would not be followed on the mines and the committee felt that it was necessary to determine the effects of poor preparation procedures on the efficiency of these sockets before the report could be released to industry.

In a report by Corden[8], which also contained the results of the previously mentioned investigation[7], the effects of the resin contamination by water and coal dust were described. The effect of poor socket preparation (not thoroughly degreasing the rope wires when a socket is made) was not investigated. It should however be noted that, according to Chaplin[9], the degreasing would have to be really inefficient for it to affect the efficiency of the termination. Verification of this type of information is

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essential in fully understanding the performance of sockets.

1.2   Previous Laboratory Test on Resin Sockets

Initially the efficiency of the socketed rope termination using resin as capping material was determined. Ten resin socketed terminations were tensile tested, two of each immediately after the resin had cured and the other eight after having been fatigued tested at different load ranges for various numbers of cycles. All the specimens tested failed clear of the sockets, which demonstrated that this type of termination is stronger than the rope i.e. has an efficiency of 100%.

There was also a concern amongst members of the mining industry about the effects of poor preparation on the efficiency of these terminations. To address these concerns eight poorly prepared resin capped rope terminations were tested[6]. This involved tensile and fatigue testing four sockets where the wires on the brush were only wiped prior to casting. The same tests were then repeated on four additional samples, but in this case the wires on the rope brush were not cleaned at all. Although one resin capping (wiped wires) failed at the socket, the breaking strength of this termination was higher than the new rope breaking strength. All the other poorly prepared resin sockets failed clear of the termination i.e. had an efficiency of 100%.

It was therefore concluded that resin cappings are suitable replacements for splices as rope terminations on drum winders provided the recommended preparation procedures are adhered too.

Although the above mentioned work explored the consequences of poor preparation of resin cappings it must be emphasised that when a rope socket is prepared, **under no circumstances should one deviate from the preparation procedures for capping of wire ropes as described in the "Notes of Guidance for the Resin Capping of Wire Ropes[10]" produced by the National Coal Board (UK).**

2.   SCOPE

Previous work showed that resin capped sockets, compared to other rope terminations, are less labour intensive, less skill dependent and, more efficient. However, it was argued that these results were achieved under favourable laboratory conditions and that sockets prepared by mine personnel under harsher field conditions could influence the results. Consequently the efficiencies of resin capped sockets prepared by mine personnel on site, were investigated and are the basis for this investigation. The opportunity is also taken to investigate whether the available literature and specifically the National Coal Board video on the procedures for resin capped socket preparation, is adequate training material for successful future socket preparation.

Six mines were approached to participate in this investigation. Two samples were prepared by personnel from each mine. These samples were subsequently tensile tested to destruction at the CSIR laboratories. Relevant literature and the socket preparation video were issued in advance to the relevant personnel. CSIR personnel were present during the actual socket preparations as observers.

3.   INVESTIGATION PROCEDURE

Six mines were approached to participate in the above investigations. It was requested that two sockets be prepared by personnel from each mine. Mine personnel were issued with the following material in advance:

- a copy of the CSIR report, **"Laboratory Evaluation of White Metal and Resin Cappings for use as Winder Rope Terminations"**;

- a copy of the British Coal Board Specification, **"Notes of Guidance for the Resin Capping of Wire Ropes"**, and

- a copy of Chapter 4 of the British Coal Boards **"Ropemans Handbook"**[11].

- a copy of the British Coal Board video, **"Preparation Procedures for Resin Capped Sockets"**.

On the preparation date, the relevant mine personnel were supplied with the following items that were necessary for the socket preparations,

- two, 3 m lengths of used 43 mm diameter, 1800 MPa triangular strand ropes (Coil No. 124257/002),

- two sockets of type NCB 465 (1965) WRS-28,

- four 1 litre (1000 cc) kits of **"Wirelock™"** resin,

- two 2-bolt clamps, and

- putty.

A CSIR staff member was present during the socket preparations. Notes were made by CSIR on the preparation procedures that were followed by the mine personnel. Copies of these notes have been included in Appendix A. Once the terminations had been prepared they were transported to the CSIR laboratories where a pre-test inspection was conducted. The sockets were subsequently tensile tested to destruction in a 15 MN tensile testing machine.

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4. RESULTS OF SOCKET TESTS

4.1 Tensile Test Results

Table 1 below summarises the tensile test results of all the sockets.

TABLE 1: Results of tests conducted on the twelve resin sockets prepared by the mining industry.

SOCKET NO.	BREAKING STRENGTH kN	SOCKET EFFICIENCY %	POSITION OF FRACTURE FROM SOCKET mm
1	1530	103,4	1000
2	1508	101,9	400
3	1554	105,0	2200
4	1552	104,9	300
5	1475	99,7	At the socket
6	1554	105,0	1000
7	1540	104,1	1000
8	1528	103,2	At the socket
9	1556	105,1	2500
10	1551	104,8	2500
11	1538	103,9	2400
12	1558	105,3	500

4.2 Socket Preparation Observations

The following observations were noted during the preparation of the sockets:

• the attitude of mine personnel varied between being very negative to positive on the issue of using sockets as winder rope terminations,

• some personnel experienced interpretation problems with the video (did not understand English very well),

• the prescribed literature appeared to confuse certain people,

• a common problem experienced was that of socket alignment during the resin casting process,

- another common difficulty noted, was the unravelling and subsequent degreasing of the wires, and

- a common concern expressed by certain mine personnel was that of the Wirelock™ resin shelf-life.

Despite all the above mentioned problems, the results obtained from the twelve resin sockets tested were very good.

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5.   DISCUSSION

5.1   Results of Tests

The first two sockets (No's 1 and 2) were very well made. The rigger who made these sockets had witnessed a CSIR staff member (the author) making two sockets on a previous occasion. Apart from some rope dressing which was left on the plaited strand cores the sockets preparation was excellent. This supports the argument that a rigger needs to be taught how to make a sockets. As will be seen later with the other sockets, merely handing out written material and video demonstration is not adequate for training purposes. Although with the exception of one socket all the sockets had efficiencies in excess of 100%, in most cases the sockets were not correctly prepared. The excellent results that were obtained despite the incorrect preparation in most cases is an indication of the terminations low sensitivity to poor workmanship.

The socket efficiencies indicate that these results are generally in step with previous laboratory investigations. The rope on Socket No. 8 failed at the sockets but the strength of the termination was higher than the new rope strength. The preparation of this socket was however not carried out very well. The unravelling of the wires into a brush was carried out incorrectly. The strands were bent too far back and the wires were not properly separated in some cases. The socket was not aligned with the rope prior to casting. The wires were left to protrude excessively out the back of the socket which would have hampered the installation of the Jaw and Tang chase block if the sockets had to be used on a shaft. In addition the brush was not degreased properly. There was a large quantity of grease which was discharged during the resin curing process indicating improper degreasing on both sockets (Socket No's 7 and 8).

Poor preparation procedures explain the result of Socket No. 5. It appeared that the rigger had not watched the video, nor had he studied the relevant literature. Instead of fastening the rope with serving wire, two metal straps approximately 150 mm apart were used. The length of the brush (unravelled wires) was also incorrect. This measurement was assumed to be the basket length of the socket. In effect the brush started at the neck of the socket. Although the incorrect length of the brush did not seem to significantly influence the static strength of the termination, if this socket had been fatigued it is likely that some of the wires at the neck of the socket would have failed. In addition during preparation the bending back of the strands and wires exceeded the prescribed angle. Lastly the socket was totally skew when cast. This is very encouraging to note that this is perhaps the worst case of resin capped socket preparation, and the socket efficiency was still as high as 99,7%.

5.2   Socket Preparation Observations

Some of the negative attitude on sockets could be attributed to people not understanding the mechanics of the sockets and to the fact that people are basically

resistant to changes. This perhaps stems from the fact that people do not believe that the sockets can have superior performance when compared to splices. In terms of the socket preparation it is agreed that the video and the literature is not particularly "user friendly". Alignment problems during casting were anticipated since no alignment rig was supplied by the CSIR. The unravelling of the wires to form a brush and its subsequent degreasing is a new concept for mine personnel. Proper training is necessary to address this problem. On the issue of the Wirelock™ resin shelf-life, mine personnel are advised that each Wirelock™ resin kit is designated a specific shelf life. A resin kit must not be used if the shelf life of the product has been exceeded.

Although it has been found that mine staff learn very quickly how to make resin sockets (as in the case of the rigger that made Sockets No 1 and 2) a short practical training course is needed. The literature and the video can be used as back up or reference notes.

Some Wirelock™ resin capping kits are supplied with a socket preparation procedure (a copy is included in Appendix B) for the capping of general engineering ropes. It must be noted that this procedure differs from the recommended procedure for capping mine ropes. Only the recommended procedure for capping mine winder ropes by the National Coal Board, a copy of which has been included in Appendix C must be followed.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Socket Efficiency

The results of this investigation support the results of previous laboratory investigations. This emphasizes the superiority of resin capped sockets to any other rope termination, not only in strength, but also in terms of the terminations insensitivity to slight deviations from the recommended preparation procedure.

6.2 Resin Capped Socket Preparation

It is evident that the training material (i.e. the video and literature) is inadequate for successful resin capping. The following recommendations are made to address this problem:

*   firstly, the video should be dubbed into languages compatible with mine personnel,

*   pictorial wall charts, should be prepared to replace the sometimes confusing literature,

*   in addition a programme or workshop should be arranged to train mine personnel on how to practically prepare resin capped sockets,

*   a complete resin socket preparation procedure complete with illustrations and lists of recommended products should be drawn up as a Code of Practice or Standard.

7.   ACKNOWLEDGEMENTS

7.   REFERENCES

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10.   British Coal Board, "Notes of guidance for the resin capping of wire ropes".

11.   "Ropeman's Handbook", published by the National Coal Board in collaboration with the Health and Safety Executive, United Kingdom, 1982.

12.   Metcalf, J.T. and Matanzo, F.:   "Efficiency of wire rope terminations", Transactions of the ASME, Vol 103, April 1981.

APPENDIX A: Details of Socket Preparations

Sockets No's 1 and 2

The preparation of these two sockets was not witnessed by CSIR personnel. It should however be noted that the staff members of this mine had witnessed the CSIR preparing resin sockets on an earlier occasion. When the sockets were brought to the laboratory they were inspected. There was evidence that the strand cores were not very well degreased. This is evident by the rope dressing which was discharged during the resin curing process shown in Figure A1. Besides this the sockets were very well prepared (See Figure A2).
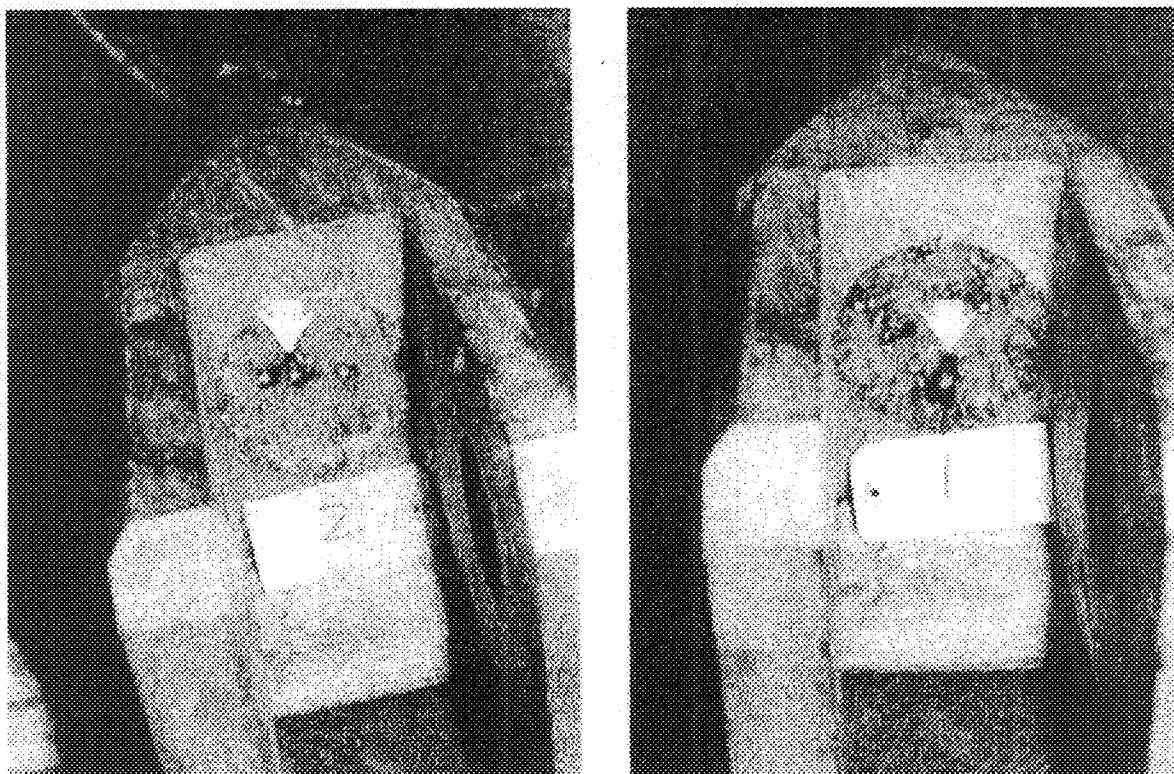
Figure A1   The figure shows the open end of two sockets (No's 1 and 2) with traces of rope dressing which was emitted (arrowed).
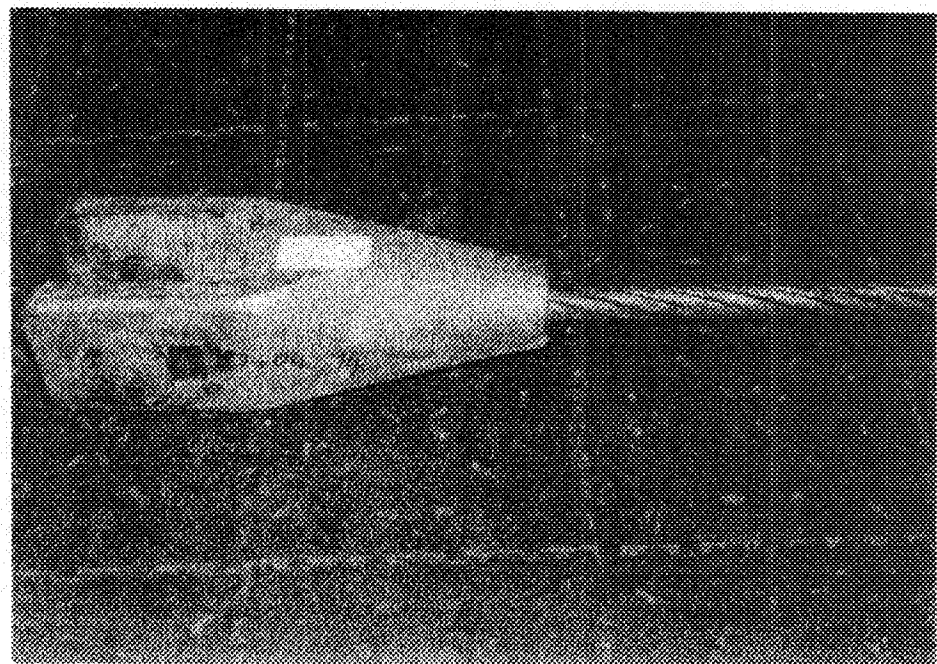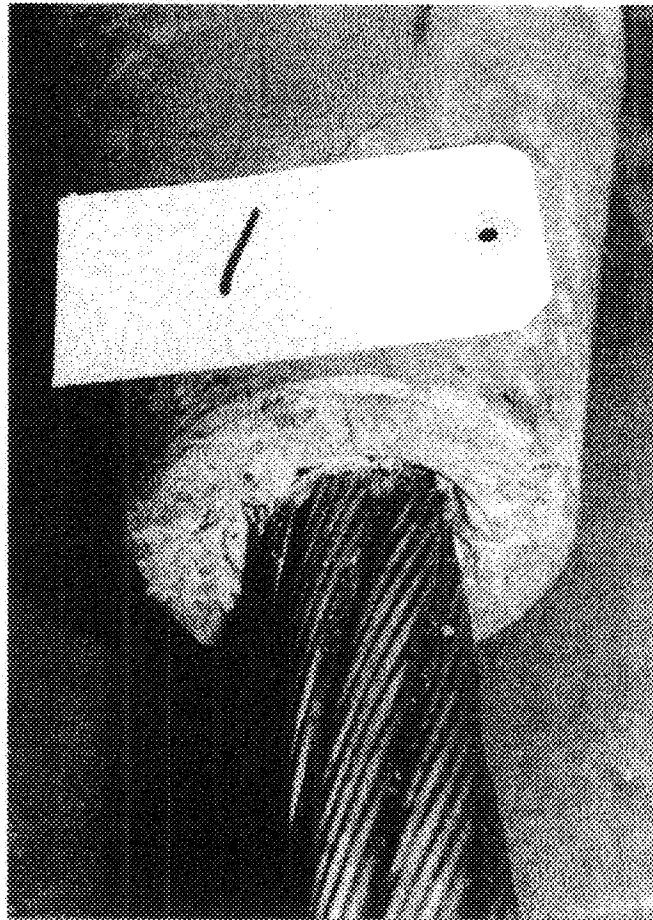
Figure A2   The figure shows the general condition of socket No 1 after it had been prepared.

Sockets No's 3 and 4

The section engineer was initially reluctant to get involved with this investigation due to work pressures. The foreman and rigger however indicated that they had the time and were willing to prepare the sockets. The relevant material was given to them to study and approximately a week later, CSIR staff returned to witness the preparation of the terminations.

The foreman and rigger claimed that although they had not watched the video, they had briefly read through the CSIR report. The foreman stated that he was under the impression that the CSIR staff would show his crew how to make the socket and for this reason he had not watched the video. It was evident that the mine employees had an idea of how to make a socket, but were not confident enough to proceed with the preparation. The CSIR staff member therefore guided their rigger through most of the preparation procedure.

Two areas where a fair amount of explanation was required by CSIR staff was during the unravelling of the wires to form a brush. The strands and wires were bent too far back. The rigger did not know how long the brush was supposed to be and a significant amount of explaining was required. The procedure of correctly mixing the resin and hardener appeared to have mine staff slightly confused.

With the guidance of the CSIR staff member the preparation of the first socket went fairly well and the quality of the termination was very good (See Figure A3). During the preparation of the second socket the mine personnel were left to complete the entire exercise by themselves. The quality of the second socket was very good. It was evident from this exercise that although a person learns how to make a socket in a very short time, the notes and video are not as easily understood as we had anticipated. Practical training backed up by written notes (which can be referred to) is required for the correct preparation of resin sockets for winder ropes.
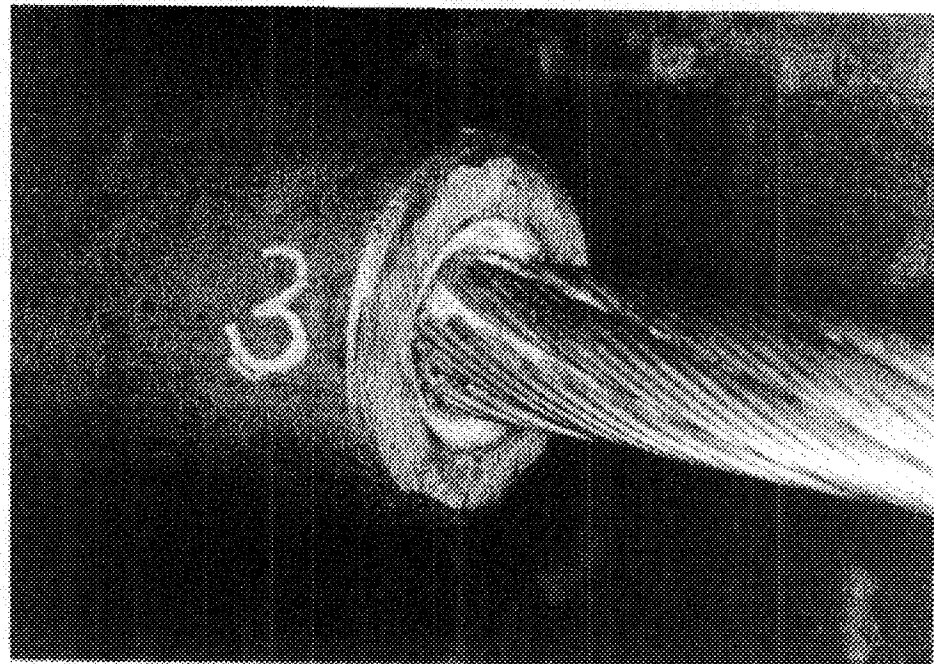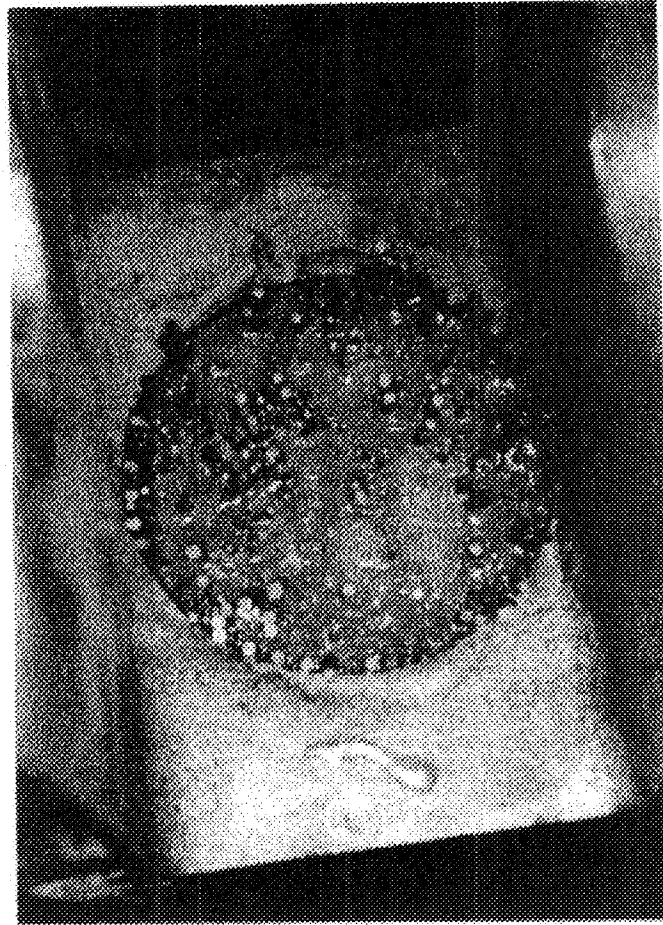
Figure A3   The figure shows the general condition of socket No 3 after it had been prepared.

Sockets No's 5 and 6

Despite the positive attitude of the engineer, the rigger appeared to have a negative attitude towards this exercise. The rigger claimed that although he had watched the video, it was actually unnecessary since he had prepared sockets in the past and knew exactly what to do. The rigger was also of the opinion that all he had to do was supervise and that the CSIR had to provide the labour.

The socket preparation was contrary to what the rigger had claimed. It appeared that the rigger had not watched the video, nor had he studied the relevant literature. Firstly, instead of fastening the rope with serving wire, two metal straps approximately 150 mm apart, were used (See Figure A4). The length of the brush was also incorrect. The basket length of the socket was measured and this was used as the brush length. In effect, the brushes started at the neck of the sockets (See Figure A5). This was a direct violation of the prescribed procedure. The unravelling of the wires to form a brush was also incorrect. The bending back of the strands and wires exceeded the prescribed angle. Lastly, the socket was not aligned with the rope prior to casting (See Figure A6).
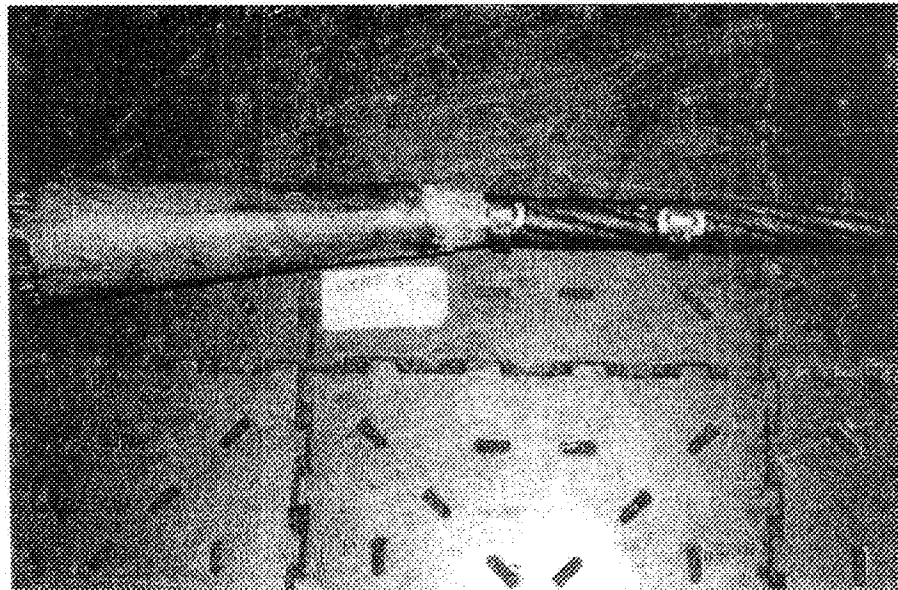
Figure A4   The figure shows the resin capping which was pushed out of the socket for inspection prior to testing. Notice the two metal straps on the rope and how the capping is not aligned with the rope.
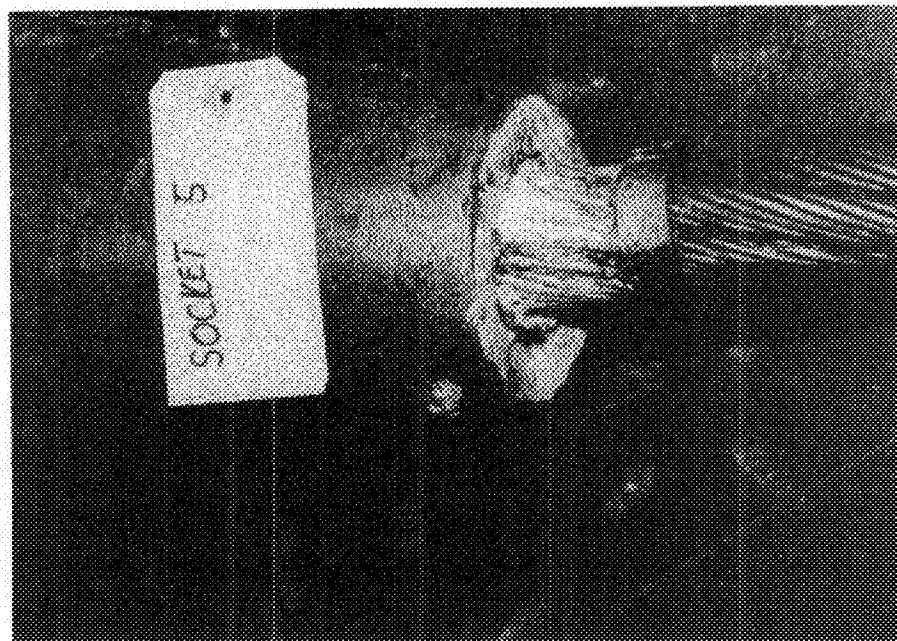
Figure A5   The figure shows the general condition of socket No 5 after it had been prepared. The length of the brush was incorrect and it protruded outside the neck of the socket.
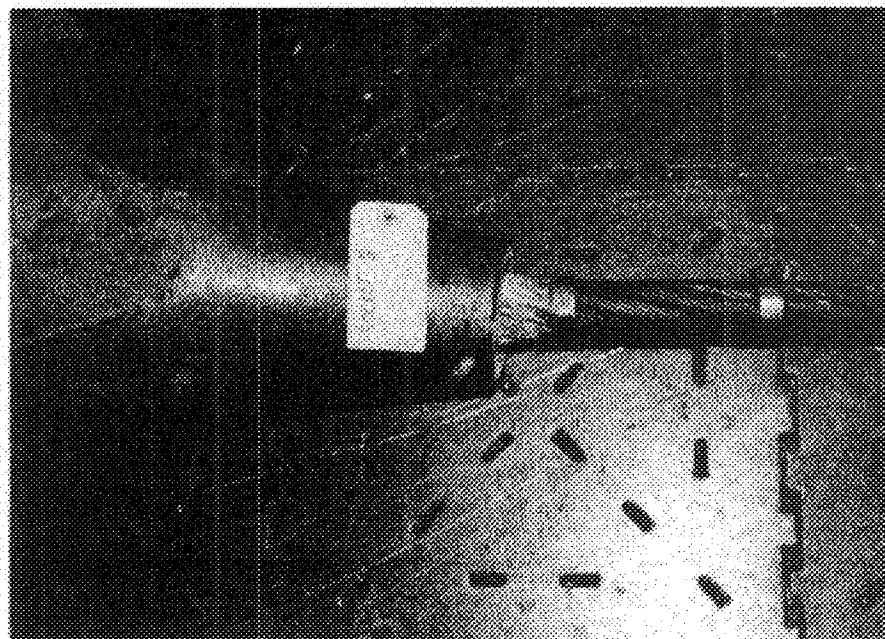
Figure A6   The figure shows the general condition of socket No 5 after it had been prepared. Apart from the length of the brush being incorrect the socket is also not aligned with the rope.

Sockets No's 7 and 8

The engineer, foreman and rigger were very enthusiastic and positive. The foreman and rigger both watched the video and studied the relevant literature. They appeared to be very knowledgeable on the socket preparation and have had some previous experience.

The preparation of the sockets was however not carried out very well. The unravelling of the wires into a brush was carried out incorrectly. The strands were bent too far back and the wires were not properly separated in some cases. The sockets were not aligned with the rope prior to casting. The wires were left to protrude excessively out the back of the socket which would have hampered the installation of the Jaw and Tang chase block if the sockets had to be used on a shaft. In addition the brush was not degreased effectively. There was a large quantity of grease which was discharged during the resin curing process indicating improper degreasing on both sockets. Figure A7 shows the back end of the socket No 8.
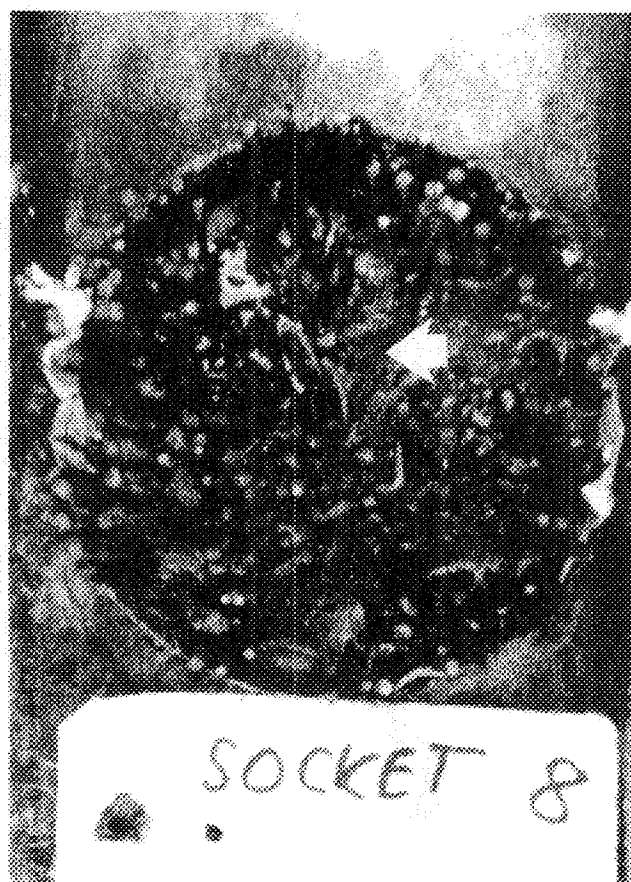
Figure A7   The figure shows the open end of socket No 8 with large quantities of rope dressing which was emitted (arrowed) during the resin curing process.

Sockets No's 9 and 10

The attitude of the foreman and rigger was very positive. The rigger had watched the video and studied the relevant literature. The rigger expressed his full confidence in the superiority of the sockets to splices and cappels. Two problems were however encountered during the socket preparation. Firstly the unravelling of the wires to form a brush was incorrect. The strands and wires were bent too far back. Secondly the rigger made a calculation error when calculating the length of the brush. He neglected to compensate for the 2d in the serving procedure. The brushes therefore started at the neck of the sockets.

Sockets No's 11 and 12

There were mixed feelings at this mine on the preparation of the sockets. Despite being very co-operative some mine personnel expressed their lack of confidence in the socket as an alternative to splices and cappels.

The riggers were very enthusiastic, however they lacked the communication skills required to interpret the video and the literature. Nevertheless, after a practical illustration of what was to be done, there were no problems.

APPENDIX B: Wirelock™ Resin Capping Procedure for General Engineering Applications

This procedure **must not** be used for socketing mine winder ropes.

USED AS A KIT
THIS KIT MUST BE
INSTRUCTIONS
WARNING AND APPLICATION
WIRELOCK®

TELEPHONE: (091) 264 8541
NEWBURN, NEWCASTLE UPON TYNE NE15 9RT, ENGLAND
16 SHELLEY ROAD, NEWBURN INDUSTRIAL ESTATE,
MILLFIELD ENTERPRISES (MANUFACTURING) LTD

DEVELOPED AND MANUFACTURED BY

WARNING

- Incorrect use of WIRELOCK® can result in an unsafe termination which may lead to serious injury, death, or property damage.
- Do not use WIRELOCK® with stainless steel rope in marine environment applications.
- Use only soft annealed iron wire for seizing.
- Do not use any other wire (copper, brass, stainless, etc.) for seizing.
- Never use an assembly until the WIRELOCK® has gelled and cured.
- Remove any non-metallic coating from the broomed area.
- Read, understand, and follow these instructions and those on product containers before using WIRELOCK®.
- If you have any questions, call or write to MILLFIELD ENTERPRISES (MANUFACTURING) LTD., 16 SHELLEY ROAD, NEWBURN INDUSTRIAL ESTATE, NEWBURN, NEWCASTLE UPON TYNE NE15 9RT. TEL: 091 264 8541 FAX NO.: 091 264 6962

The following simplified, step-by-step instructions should be used only as a guide for experienced users. For full information, consult ourselves or our local distributor.

STEP 1- SEIZING	STEP 2 - BROOMING
Seize the wire rope or strand as shown using soft annealed iron wire.	1. Unlay the strands of the wire rope and IWRC as far as the seizing. 2. Cut out any fiber core. 3. Unlay the individual wires from each strand, including the IWRC, completely, down to the seizing. 4. Remove any plastic material from broomed area.

* = 5D OR 50d (d=Diameter of one wire) WHICHEVER IS GREATER.

Strand   Wire Rope   Wire Rope   Strand

STEP 3 - CLEANING

1. Clean broom in ultrasonic cleaner or
2. Clean using Trichlorethane with dip and brush method.
3. Clean socket basket.

SOLVENT

ULTRA-SONIC CLEANER
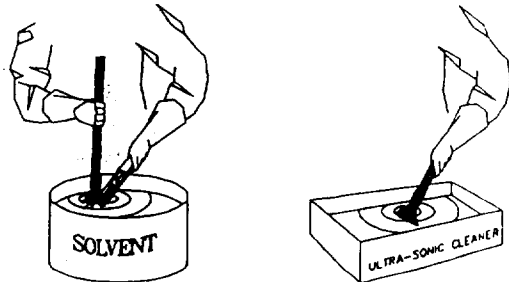
CAUTION

- **WIRELOCK®** resin, in liquid state, is flammable.
- **Chemicals used in this product can give off toxic fumes and can burn eyes and skin.**
- Always check expiration date on the cans.
- **Never use out-of-date material.**
- Use only in well-ventilated work areas.
- Never breath fumes directly or for extended time.
- Always wear safety glasses to protect eyes.
- **Always wear gloves to protect hands.**
- Avoid direct contact with skin anywhere.

STEP 4 - POSITIONING OF SOCKET

1. Position socket over broom until the wires are LEVEL with the top of the socket basket or to a minimum embedded length as shown.
2. Clamp rope and socket vertically ensuring alignment of their axes.
3. **CAUTION: DO NOT USE OVERSIZED SOCKETS FOR WIRE ROPE.**

Wire Rope   **Strand**
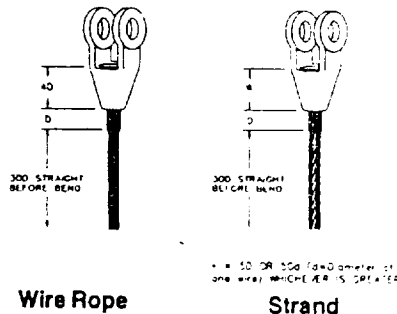
STEP 7 - MIXING AND POURING

1. Mix and pour WIRELOCK® within the temperature range of 48 degrees to 110 degrees F. Booster kits are available for reduced temperatures.
2. Pour all the resin into a container containing all the granular compound and mix thoroughly for two (2) minutes with a flat paddle.
3. Immediately after mixing, slowly pour the mixture down one side of the socket until the socket basket is full.
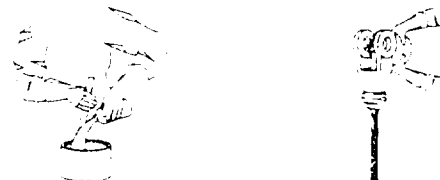
STEP 5 - SEAL SOCKET

Seal the base of the socket with putty or plasticine to prevent leakage of the **WIRELOCK®**

STEP 8 - CURING

1. **WIRELOCK®** will gel in approximately 15 minutes. in a temperature range 65 degrees F. to 75 degrees F.
2. The socket must remain in the vertical position for an additional ten (10) minutes after gel is complete.
3. The socket will be ready for service 60 minutes after gelling.
4. Never heat sockets to accelerate gel or curing.

STEP 6 WIRELOCK® KITS

1. WIRELOCK® kits are pre-measured and consist of two (2) containers - one (1) with resin and one (1) with granular compound.
2. Use the complete kit - **NEVER MIX LESS THAN THE TOTAL CONTENTS OF BOTH CONTAINERS.**
3. Each kit has a shelf life clearly marked on each container and this must be observed. **NEVER USE OUT OF DATE KITS.**

STEP 9 - RE-LUBRICATION

Re-lubricate wire rope as required.

STEP 10 - PROOF LOADING

Whenever possible. the assembly should be proof loaded.

APPENDIX C: NCB, Notes of Guidance for Resin Capping of Wire Ropes

A set of notes entitled "Notes of guidance for the resin capping of wire ropes" from the British Coal Board were supplied to each mine at least a week prior to the date the sockets were to be prepared. A copy of these notes has been included in this appendix. This is the procedure that must be followed when socketing mine winder ropes.

BRITISH COAL

HQ TECHNICAL DEPARTMENT

NOTES OF GUIDANCE FOR THE RESIN CAPPING OF WIRE ROPES

July 1987

BRITISH COAL   200,1(141)

NOTES OF GUIDANCE FOR THE RESIN CAPPING OF WIRE ROPES

1.0   INTRODUCTION

      This document covers the procedures to be used for the resin capping of
      wire ropes using the 'Wirelock'* system. (At present only the 'Wirelock'
      system is approved by British Coal for use on wire ropes).

      Guidance is also given on the use and limitations of the resin materials.

2.0   SCOPE

      This document applies to the resin capping of British Coal ropes using
      the 'Wirelock' system and sockets (or glands) as listed below, whether
      they are capped at the mine or at rope manufacturer's works.

              British Coal Spec 465/1965 - Sockets for Winding, Balance and
                                           Haulage Ropes
              British Coal Spec 461/1965 - Sockets for Haulage Ropes
              British Coal Spec 353/1966 - Sockets for Haulage Ropes
              Balance Rope Sockets to MECH/CIRC(81)82
              Guide Rope and Rubbing Rope Suspension Glands⁺

3.0   TRAINING

      All persons involved in the making of resin cappings shall be given
      adequate instruction and training. A copy of these Notes of Guidance
      should be given to each person involved with resin cappings.

4.0   SAFETY REQUIREMENTS

      4.1   There shall be adequate ventilation at the area of working.

      4.2   Dust masks, safety goggles and gloves shall be worn throughout the
            mixing and pouring operation.

Note *   Trade name of resin system supplied by Millfield Enterprises Ltd.,
             Paygate Works, Crawcrook, Ryton, Tyne and Wear NE40 4PA
             Tel: 091 4133153

Note ⁺   At present, no British Coal or British Standard Specification
             exists for guide rope or rubbing rope suspension glands.
             Suspension glands with a short basket length (ie those with a ratio
             of tapered length to rope diameter less than 6) shall not be used
             with half-locked coil guide or rubbing ropes. Additionally,
             British Coal Spec. 461/1965 sockets shall not be used as handling
             sockets for half-locked guide or rubbing ropes. Round rod guide
             ropes shall not be capped with resin.

4.3 If resin or powder enters the eye, the eye should be thoroughly irrigated with clean water for 15 minutes and medical advice obtained without delay.

The relevant Hazard Data Card number is 1209

5.0 MATERIALS

5.1 Resin capping materials shall be stored in a dry place specially designated for that purpose (MECH/CIRC(87)13 refers) and kept at a temperature between 10°C and 25°C and away from any source of direct heat.

5.2 The kits are marked 'WIRE ROPE CAPPING' and when withdrawn from store a check shall be made of the expiry dates marked on the containers. Date expired kits shall not be used.

5.3 The complete kits comprise separately measured and packed volumes of approved liquid resin and filler/catalyst powder, together with mixing vessel, stirrer and plasticine. Kits are available in three sizes to produce, after setting, volumes of 1000 cc of resin (identified in yellow containers), 1700 cc of resin (identified in blue containers), and 3400 cc of resin (identified in red containers), and the rope sizes covered by these kits are shown in Appendix I. Under no circumstances shall a part kit be used and kits should only be opened immediately prior to mixing.

5.4 Rope manufacturers, when capping British Coal ropes at their works, may use their own kits provided that they are approved by British Coal. -

6.0 PREPARATION, CLEANING AND POSITIONING OF THE ROPE AND SOCKET

Preparation, cleaning and positioning of the rope, socket and brush shall be the same as that described in the Ropeman's Handbook for capping with molten white metal, with the following qualifications:

(a) The served length of rope inside the socket or gland shall be as below:

Socket/Gland Type	Served Length
British Coal Spec 465/1965 - Winding, Balance and Haulage Rope Sockets	2 x d
British Coal Spec 461/1965 - Haulage Rope Sockets	1 x d
British Coal Spec 353/1966 - Haulage Rope Sockets	2 x d
Balance Rope Sockets to MECH/CIRC(81)82 (new design)	1 x d

Socket/Gland Type   Served Length

Guide or Rubbing Rope Suspension Glands having   2 x d
a ratio of tapered length to rope diameter of
6:1 and above.

Where d - rope diameter.

Before serving stranded ropes see Section 6(f)

(b)   When using sockets to NCB Specifications 461 and 353, a serving
      wire of 1 mm diameter should be used due to the restricted
      clearance in the socket neck.

(c)   Before putting the socket on to the rope, it is beneficial to
      lightly smear the inside of the socket with Dow Corning 7 silicone
      release compound. This will reduce the tendency of the resin to
      bond to the socket bore. When pulling the socket over the brush
      great care should be exercised to minimise contact between the
      cleaned wires of the brush and the silicone release compound. This
      is particularly important when capping half-locked coil guide ropes
      where there are fewer but larger diameter wires.

(d)   On guide ropes, the wires shall be distributed as evenly as
      possible within the gland and a space of approximately one wire
      diameter should be maintained between the bore and any wire at the
      head of the capping.

(e)   In order to prevent leakage of resin due to its thorough searching
      properties, it is essential when using any centralising clamp that
      all joint faces are completely sealed, together with any points
      necessary to contain the resin mix after pouring. Plasticine has
      been found to be a suitable sealing compound and a typical sealing
      arrangement is shown in Figure 1. The centralising clamp should be
      so mounted that the base of the clamp, and the rope immediately
      beneath it, remain visible to check for leaks.

(f)   On stranded ropes, it is possible for the resin to run down the
      interstices between the strands under the serving. To prevent this
      a small amount of plasticine should be placed in the valleys
      between the strands before the serving is applied.

7.0   TEMPERATURES

      7.1   Kits are formulated for use at socket temperatures* of around 18°C.
            Consequently, the socket temperature shall be checked immediately
            before mixing using a suitable thermocouple type thermometer.

      7.2   At socket temperatures higher than 18°C the mix will gel (solidify)
            and cure (harden to its full strength) more quickly, and less time
            will be available for topping up.

Note *   Socket temperatures are used rather than ambient air temperatures
         because of the large heat sink effect of the socket.

7.3   At socket temperatures lower than 18°C the mix will gel and cure more slowly. At 8°C or below special precautions should be taken to compensate for the slower gel times experienced at these lower temperatures; these are:-

   (a)   Booster Pack

         A booster pack may be introduced when the socket temperature is between 8°C and -5°C. These packs are made up of catalyst powder in sizes to cover the 1000 cc (yellow), 1700 cc (blue), and 3400 cc (red), capping kits. Only one booster pack of the appropriate size shall be used with each kit. A booster pack should not normally be used with pre-heated sockets and should be stored at the recommended temperature of 10°C to 25°C.

   (b)   Pre-heating Socket

         Pre-heating of the socket can be introduced when the socket temperature is 8°C or below. Prior to mixing, the socket should be gradually warmed to a uniform temperature between 10°C and 15°C measured at the socket bore. Care shall be taken not to overheat any part of the socket as above these temperatures the gelling rate may accelerate too much. Also, liquid resin is inflammable and consequently the source of heat should be removed from the socket before the resin is poured in.

8.0   MIXING

   8.1   On opening the powder container the powder shall be inspected; it should be coloured 'off-white' and free flowing. If the powder appears contaminated, discoloured (especially brown), or lumpy, it shall be returned to the manufacturer for investigation. The liquid resin should be free flowing and pour easily from its container. A spare kit should be available in case either the powder or liquid resin quality is suspect.

   8.2   To mix the constituent materials, pour the total amount of liquid resin from the kit(s) into the mixing vessel (polystyrene containers must not be used). Gradually add the total amount of powder, stirring continuously until a uniform colour is obtained. It is essential that complete mixing of the constituent materials takes place as quickly as possible and that no unmixed solids remain in the mixing vessel. To achieve this normally takes about two minutes.

   8.3   Sufficient resin mix shall be prepared to enable the socket to be completely filled at one pouring. If more than one kit is required to fill a socket they should be mixed together in one container, all of the liquid resin being poured in first, followed by all of the powder, so that the total mix can be prepared in one operation.

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

9.0 POURING

9.1 Once the resin is mixed it shall be poured immediately thus ensuring good penetration and allowing time to top up the socket before the resin gels.

9.2 No more than two cappings shall be poured from one mix.

9.3 The mix should be poured at a fairly slow and steady rate in one position to help prevent air from being entrapped at the bottom of the brush. Prodding into the basket for a few seconds with a length of clean, stiff wire will also help to release any air entrapped.

9.4 If the resin settles, topping-up of the cone using the original mix will be necessary. Prior to topping up, the mix should be re-stirred for a short period.

9.5 Any leakages can be critical and must be stopped immediately (see Sections 6(e), 6(f) and 10). If resin is lost to the extent that there is not sufficient resin to fill the socket using the original mix then the capping shall be completely re-made.

10.0 LEAKAGE

During the pouring and topping-up operation and early stages of gelling, it is essential that all leaks be identified and stopped as any such leaks may result in cavities being formed in the neck region. These leaks may occur not only from the neck of the socket and centralising clamp but also from the served section of the rope below the capping. Suitable sealing compound (i.e. Plasticine) should be available during and after pouring.

11.0 GELLING AND CURING

11.1 The kits are formulated to gel in approximately 15 minutes at a socket temperature of around 18°C.

11.2 The capping shall be left undisturbed for a period of at least 45 minutes from the time that the whole of the head of the cone has hardened. Hardness should be determined by carrying out a scratch test on the surface of the resin with a sharp steel blade. This should only leave a shallow scratch mark. The load shall not be applied until a minimum period of one hour has elapsed from a satisfactory scratch test.

12.0 CHECK ON PENETRATION

A check for penetration into the socket neck shall be made when the centralising clamp, any collar of excess resin round the mouth of the socket and serving have been removed.

13.0 RE-LUBRICATION OF THE ROPE

The "cleaned" part of the rope near to the socket shall be re-lubricated with an application of rope dressing taking care to seal the neck of the socket.

14.0 HANDLING

If the socket moves inadvertently back along the rope during handling, the socket should be moved clear of the cone and the cone examined to ensure that it is undamaged. If the cone is damaged or any wire displaced, the rope shall be re-capped. On haulage ropes, to prevent the socket moving back along the rope, a clamp should be placed close up to the neck of the socket. The clamp should be removed at intervals to inspect the rope for corrosion and fatigue damage.

15.0 DISPOSAL OF RESIN RESIDUE

Mixed materials should be allowed to harden and then be disposed of as normal rubbish together with used cans. The empty resin cans must not re-sealed.

16.0 PRECAUTIONS

Special care shall be taken to ensure that paint remover (or any other substances containing methylene chloride or caustic soda) does not come into contact with the resin capping since this will act as a solvent, thus reducing the integrity of the capping.

24 June 1987

SOCKET

PLASTICINE STRIPS
TO SEAL ALL
JOINT FACES

CENTRALIZING
CLAMP
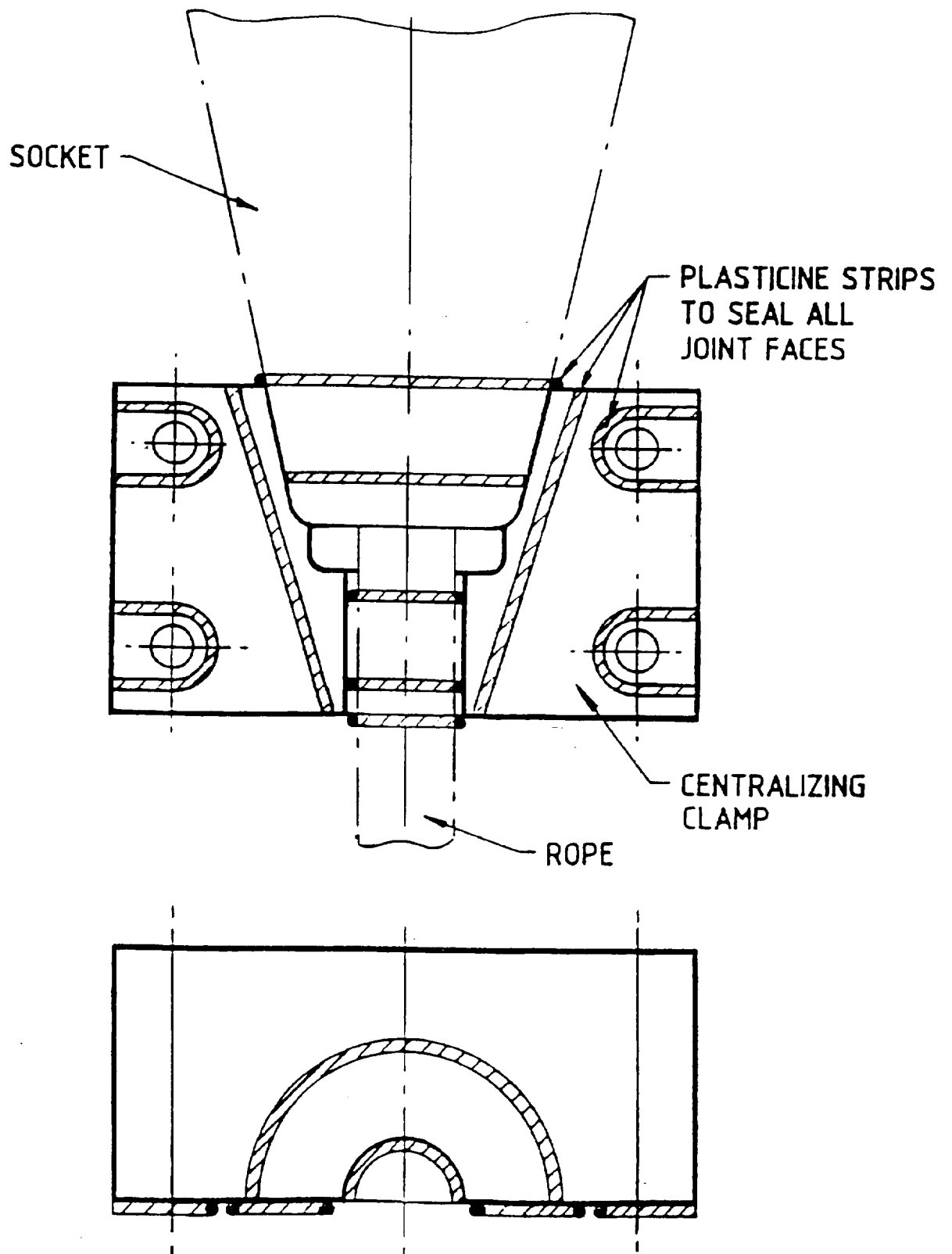
ROPE

FIGURE 1. TYPICAL SEALING ARRANGEMENT OF
CENTRALIZING CLAMP

SCHEDULE SHOWING ROPE SIZES COVERED BY RESIN KITS FOR VARIOUS SOCKET TYPES

(a) NCB Spec 465/1965 Sockets for Winding, Balance and Haulage Purposes

ROPE DIA	One Rope	16-32mm	33-40mm	41-48mm	49-53mm	54-64mm
	Two Ropes	16-24mm	25-30mm	31-35mm	36-40mm	41-48mm
RESIN KIT VOLUME		1000cc	1700cc	2700cc (ie 1000cc+ 1700cc)	3400cc	5100cc (ie 1700cc+ 3400cc)

(b) Balance Rope Sockets to MECH/CIRC(81)82 (new design)

ROPE DIA	One Rope	21-44mm	45-54mm	55-67mm	68-75mm
	Two Ropes	21-32mm	33-38mm	39-48mm	49-54mm
RESIN KIT VOLUME		1000cc	1700cc	2700cc (ie 1000cc+ 1700cc)	3400cc

(c) Guide or Rubbing Rope Suspension Glands

ROPE DIA	One Rope	29-32mm	33-38mm	39-48mm	49-51mm
	Two Ropes	-	-	29-35mm	36-38mm
RESIN KIT VOLUME		1000cc	1700cc	2700cc (ie 1000cc+ 1700cc)	3400cc

(d) NCB Spec 461/1965 Haulage Rope Sockets

ROPE DIA	One Rope	8-41mm	-
	Two Ropes	8-32mm	33-41mm
RESIN KIT VOLUME		1000cc	1700cc

APPENDIX I
(Sht 2 of 2)

(e) NCB Spec 353/1966 Haulage Rope Sockets

ROPE DIA	One Rope	13-35mm	-	-
	Two Ropes	13-22mm	23-32mm	33-35mm
RESIN KIT VOLUME		1000cc	1700cc	2700cc (ie 1000cc+ 1700cc)

NOTE:

1. The above tables are based on the cone volume of the socket plus 150 cc (neglecting the volume of the rope). This should be adequate to take account of any leakage or spillage that may occur.

2. At present, there is no British Coal or British Standard Specification for guide or rubbing rope suspension glands and the values in the table are based upon typical volumes of commercially available glands.

3. The resin kits are available in the following sizes:

	Net Weight (± 5%)	
	Solids	Resin
1000 cc - identified in yellow containers	1255 g	760 g
1700 cc - identified in blue containers	2172 g	1206 g
3400 cc - identified in red containers	4224 g	2427 g

PERFORMANCE EVALUATION OF RESIN

FILLED SOCKETS USED AT

PREMIER DIAMOND MINE

by

M. Borello

Prepared by:

Submitted to: Safety in Mines Research Advisory Committee
Engineering Advisory Group

_____
M. Borello

Reviewed by:

_____
R. Backeberg

MINE HOISTING TECHNOLOGY
DIVISION OF MATERIALS SCIENCE AND TECHNOLOGY
CSIR
December 1994

1.   INTRODUCTION

Traditionally triangular strand steel wire ropes on South African mine winders have been terminated with splices. Two mine winder rope failures at the termination in 1989 and 1990 led to detailed investigations into the performance of wire rope terminations.

At the request of the inspectorate, the CSIR tested approximately 120 winder rope terminations (mainly splices) from industry during the latter half of 1990 and beginning of 1991. The CSIR then produced a report[1] on the results of these tests. The results showed that the efficiency of a splice taken from service after six months could be as low as 67%.

In an attempt to move away from a labour intensive and skill dependent termination with an efficiency in the order of 85%, the CSIR investigated the feasibility of using resin cappings for wire rope terminations. The first investigation[2] on resin cappings was carried out under the auspices of the Chamber of Mines Steering Committee on Factors of Safety of winder ropes, and examined the breaking strength of resin socketed terminations which had been subjected to various fatigue loading histories.

From the above mentioned, and subsequent investigations[3] carried out by the CSIR, it was concluded that resin cappings are suitable replacements for splices as rope terminations on drum winders provided the recommended preparation procedures are adhered to. The last part of the investigation into the suitability of resin sockets for use as winder rope terminations involved conducting a field trial. This report documents the outcome of this field trial.

2.   SCOPE

For the purposes of this field trial it was essential that a winder was chosen with high front end loads (where loading was limited by the capacity factor) and a short winding cycle (in order to accumulate as many cycles as possible in the six-month period between rope front end cuts). Premier Diamond Mine was found to have a suitable winder for this field trial.

The aim of this field trial was to determine whether there were any deterioration mechanisms (other than those simulated in the laboratory tests) which would influence the strength of the termination.

3.   INVESTIGATION PROCEDURE

Installation of the resin sockets took place on the 27 March 1994. The socket in No 1 compartment was installed first. The cappel was removed from the rope by cutting the rope approximately 4 m from the end of the cappel. This was done to allow

enough rope for a statutory test piece. The outside of the rope was washed over a length of 1,5 m from the end of the rope using a non combustible cleaning agent. The rope was served over a distance of 200 mm starting at a point which was one socket basket length less two rope diameters from the end of the rope. A two-bolt clamp was then placed at a point approximately 1,5 m from the end of the rope. The socket was then slipped over the end of the rope and pushed back until it came to rest against the two-bolt clamp. A second two-bolt clamp was then positioned on the serving wire at a point which was one socket basket length less two rope diameters from the end of the rope. This was done in order to prevent the rope from breaking when the end of the rope was opened which could result in the destranding of the rope. The rope end was then opened into a brush. Once the brush was opened, it was thoroughly degreased.

The end of the capping was flush with the bottom of the socket basket when the resin was poured. During the curing process the resin shrunk, which resulted in the end of the capping being recessed by about 1 mm relative to the bottom of the socket. After curing and having allowed an additional hour to pass as recommended by the British Coal Board[4], the sockets were attached to the conveyance and the conveyance was lifted. The conical resin capping embedded itself an additional + 3 mm into the socket.

The sockets then operated in the shaft for six months and apart from the routine inspections carried out by mine personnel, CSIR staff also inspected the sockets on average every month. The sockets were then removed from service and taken back to the CSIR for inspection and tensile testing.

4.   WINDING PLANT DETAILS

Listed below are some of the details of the winder on which the sockets operated[5].

Shaft:	No 1
Compartments :	No 1 - Underlay
	No 2 - Overlay
Shaft condition:	Dry
Drum type:	Double
Drum diameter:	3, 965 m
Sheave diameter:	4,880 m
Rope diameter:	44 mm
Rope construction:	6 x 30
Tensile grade:	2000 MPa

Skip mass: 6297 kg
Rock mass: 11818 kg
Total attached: 18115 kg

Capacity factor: 9,2

5.   RESULTS

5.1   Monthly Inspections

First inspection of resin sockets, 22 April 1994

Inspection of No 1 compartment socket.

> The wires protruded by ~10 mm out of the bottom of the capping. This is
> exactly the same as when the socket was installed. There had been no
> movement of the wires relative to the socket. The capping had embedded itself
> an additional ~2 mm into the socket relative to the installation inspection.
> This movement ties up with the movement in the other socket and must have
> occurred when the skip was first loaded. The capping had sunk a total of
> ~6 mm into the socket.

> Inspection of the neck of the socket revealed no broken wires. The insulation
> tape which was placed around the rope at a point approximately 10 mm from
> the neck of the socket was still present and the distance from the socket to the
> tape had increased to about 12 mm ie ~2 mm more that at installation. This
> movement tied up with the movement of the resin capping relative to the steel
> socket.

Inspection of No 2 compartment socket.

> The capping had embedded itself an additional ~2 mm into the socket relative
> to the installation inspection. This must have occurred when the skip was first
> loaded. The capping had sunk a total of ~6 mm into the socket. Inspection
> of the neck of the socket revealed no broken wires. The insulation tape which
> was placed around the rope at a point approximately 10 mm from the neck of
> the socket was still present and the distance from the socket to the tape had
> increased to about 12 mm ie ~2 mm more that at installation. This movement
> ties up with the movement of the resin capping relative to the steel socket.

Second inspection of resin sockets, 20 May 1994

Inspection of No 1 compartment socket.

The wires protruded by ~ 10 mm out of the bottom of the capping. This is exactly the same as the previous inspection and when the socket was installed. There had been no movement of the wires relative to the socket.

The capping had sunk a total of ~ 6 mm into the socket. There had been no additional movement of the capping relative to the socket since the first inspection.

Inspection of the neck of the socket revealed no broken wires. The insulation tape which was placed around the rope at a point approximately 10 mm from the neck of the socket was still present and the distance from the socket to the tape was 12 mm ie ~ 2 mm more that at installation, but the same as at the first inspection. There was slight corrosion on the rope at the neck of the socket where the rope grease had been removed at the first termination inspection. The foreman was asked to ensure that point is lubricated again.

Inspection of No 2 compartment socket.

The capping had sunk a total of ~ 6 mm into the socket. There was no additional movement of the capping relative to the socket since the first inspection.

Inspection of the neck of the socket revealed no broken wires. The insulation tape which was placed around the rope at a point approximately 10 mm from the neck of the socket was still present and the distance from the socket to the tape was 12 mm, i.e. no additional movement of the capping had occurred relative to the socket since the last inspection. The foreman was asked to ensure that point is lubricated again.

Third inspection of resin sockets, 15 July 1994

Inspection of No 1 compartment socket.

The wires protruded by ~ 10mm out of the bottom of the capping. There had been no movement of the wires relative to the socket.

The capping had sunk a total of ~ 6 mm into the socket. There had been no additional movement of the capping relative to the socket since the first inspection.

Inspection of the neck of the socket revealed no broken wires. The insulation tape which was placed around the rope at a point approximately 10 mm from the neck of the socket was still present and the distance from the socket to the tape was 12 mm ie no additional movement since the previous inspection. There was slight corrosion on the rope at the neck of the socket.

Inspection of No 2 compartment socket.

The capping had sunk a total of ~6 mm into the socket. There was no additional movement of the capping relative to the socket since the first inspection.

Inspection of the neck of the socket revealed no broken wires. The insulation tape which was placed around the rope at a point approximately 10 mm from the neck of the socket was missing. The foreman was asked to ensure that the rope at the neck of the socket was lubricated again.

Fourth inspection of resin sockets, 19 August 1994

Inspection of No 1 compartment socket.

The wires protruded by ~10 mm out of the bottom of the capping. There had been no movement of the wires relative to the socket.

Inspection of the neck of the socket revealed no broken wires. The insulation tape which was placed around the rope at a point approximately 10 mm from the neck of the socket was missing. There was slight corrosion on the rope at the neck of the socket. Generally, the socket had not shown any signs of deterioration.

Inspection of No 2 compartment socket.

There had been no additional movement of the capping relative to the socket since the first inspection. Inspection of the neck of the socket revealed no broken wires. There was slight corrosion on the rope at the neck of the socket. Generally, the socket had not shown any signs of deterioration.

5. 2   Pre-test Inspection

Once the two sockets had arrived at the CSIR laboratories they were inspected prior to final testing. Figures 1 and 2 show the sockets on arrival at the laboratory. No 1 socket was in perfect condition with no signs of deterioration. The corrosion on the rope at the

neck of the socket was almost invisible after the rope had been cleaned. No 2 socket however had been damaged. For some reason the mine personnel attempted to remove the resin capping from the socket. This resulted in the fracturing of the capping and significant damage to the steel socket (See Figure 3).

5.3   Tensile Test Results

The table 1 below summarises the tensile test results of the sockets (for detailed results refer to Appendix A).

SOCKET NO	BREAKING STRENGTH OF NEW ROPE (kN)	TERMINATION BREAKING STRENGTH (kN)	POSITION OF FRACTURE (mm from socket)
1	1631	1674	150
2	1646	1668	At the socket
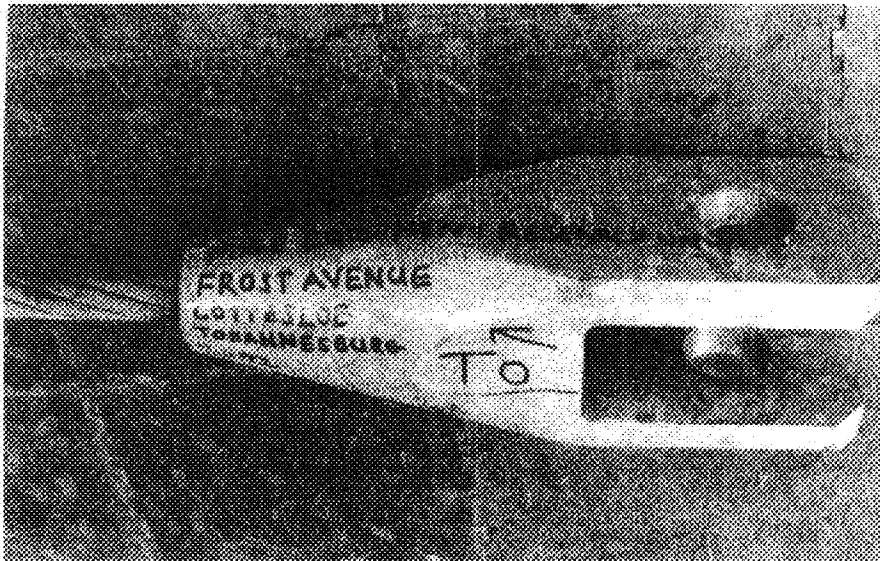
Figure 1:   The photograph shows the No 1 socket on the laboratory floor after it had been in service for six months
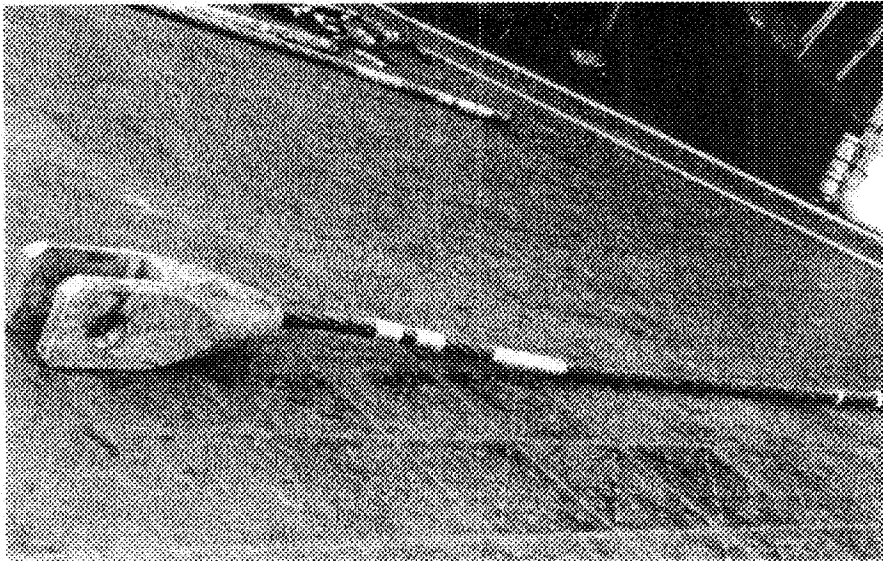
Figure 2: The photograph shows the No 2 socket on the laboratory floor after it been in service for six months
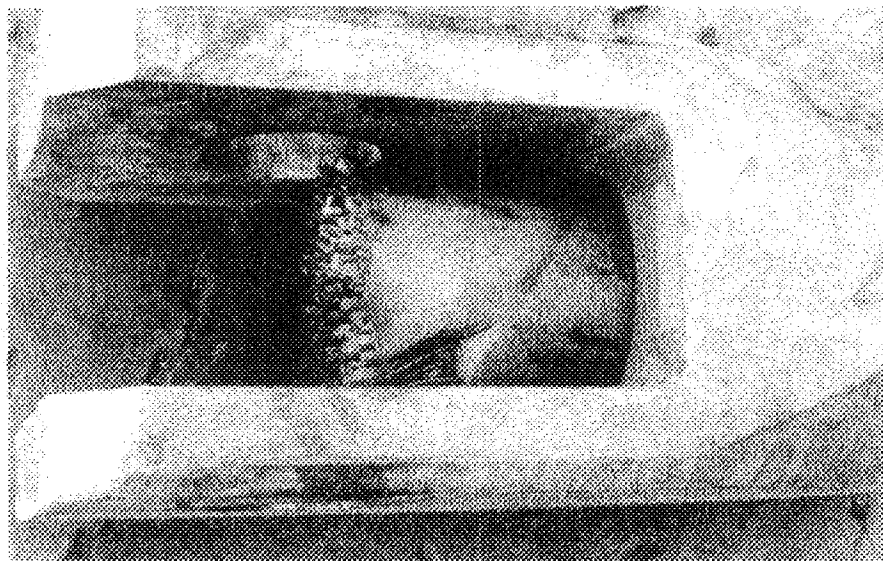
Figure 3: The photograph shows the No 2 socket on the laboratory floor after, damage to the resin capping and the steel socket is visible

6.   DISCUSSION

The sockets were installed on the 27 March 1994. It was the first time sockets were going to be used on this shaft and consequently the preparation process took longer than

anticipated. This resulted in the sockets being cast fairly close to midday. It was a particularly warm day, in addition to this the sockets were being prepared in the sun. This resulted in the accelerated curing time of the resin. The second socket cast started curing within two minutes after it had been cast. Although this did not affect the quality of the termination, this could cause problems in areas where high summer temperatures are experienced. The resin could start curing while it is being poured leading to voids being present in the socket. It is thus recommended that if resin sockets are used on mines where high summer temperatures are experienced, the resin casting process should not be carried out in direct sunlight or should be carried out early in the morning.

Conversely, it should be remembered that if sockets a.re cast during the early morning in winter, either a booster pack must be used, or the socket must be heated to approximately 20°C. In addition more time should be allowed for the resin to cure.

After the sockets had been prepared, they were attached to the Humble hook via a Jaw and Tang Chase Block which was in turn attached to the conveyance. Approximately one hour after the resin had cured the sockets were in turn loaded by lifting the respective conveyances with the winder. The resin cappings bedded themselves into the steel socket. The sockets were then inspected to ensure that there was no movement of the wires relative to the capping. After the inspection the conveyance support beams were removed and the winding plant was ready to start operating.

The sockets were inspected by CSIR personnel on numerous occasions during the six-month service period. The reports of these inspections are included in the results - section of this report. Apart from the very slight corrosion on the rope and the additional bedding in of the resin capping during the initial loading of the conveyance there was no visible difference between the sockets from when they were first installed to when they were removed. The winder completed 69 084 trips (34 542 cycles) during the period 27 March 1994 to 18 September 1994.

After the sockets had been removed from service, mine personnel attempted to remove one of the cappings from the sockets, consequently both the capping and the socket were damaged (See Figure 3). It should be noted that a capping can easily be removed from a socket after operation. One merely cuts the rope off as it enters the socket and with a pin and hammer the capping can be knocked out. In the case of this field trial it was important to have the entire rope and socket assembly intact for testing purposes. Attempting to remove the rope and capping from the socket is very difficult since the rope buckles if put into axial compression.

The dislodged capping was pulled back into position in the laboratory prior to testing which was the cause of the rope failing at the socket during the test. After a resin capping has been prepared some of the serving wire (2 x rope diameter) remains on

the rope at the neck of the socket. When the capping was pulled out this serving wire was uncoiled at the neck of the capping. When the capping was pulled back into the socket, all this loose serving wire accumulated at the neck of the socket. This induced additional compressive stresses on the rope at that point during the tensile test and resulted in the rope failing at that point. Despite this the strength of the termination was higher than the new rope breaking strength.

The termination which had not been damaged failed clear of the socket during the tensile test with a strength in excess of new rope breaking strength. From this field trial it has been shown that resin sockets can be used successfully as winder rope terminations. They not only have a very high efficiency when new, but in this field trial had an insignificant rate of in-service deterioration.

Resin sockets are suitable replacements as winder rope terminations for rope splices operating in vertical shafts.

7. CONCLUSIONS AND RECOMMENDATIONS

Apart from the very slight corrosion on the rope and the additional bedding in of the resin capping during the initial loading of the conveyance there was no visible difference between the sockets from when they were first installed to when they were removed.

After the sockets had been removed from service, mine personnel attempted to remove one of the cappings from the sockets, consequently both the capping and the socket were damaged. Despite this the strength of the termination was higher than the new rope breaking strength.

The termination which had not been damaged failed clear of the socket during the tensile test with a strength in excess of new rope breaking strength.

Resin sockets not only have a very high efficiency when new, but in this field trial had an insignificant rate of in-service deterioration.

From this field trial it has been shown that resin sockets can be used successfully as winder rope terminations.

Resin sockets are suitable replacements as winder rope terminations for rope splices operating in vertical shafts.

It is recommended that if resin sockets are used on mine where high summer temperatures are experienced, the resin casting process should not be carried out in direct sunlight or should be carried out early in the morning.

Conversely, it should be remembered that if sockets are cast during the early morning in winter, either a booster pack must be used, or the socket must be heated to approximately 20°C in addition more time should be allowed for the resin to cure.

8.   ACKNOWLEDGEMENTS

The assistance of Noel Pillay with the site work is gratefully acknowledged. The author would also like to thank the management and staff of Premier Diamond Mine for their contribution in this field trial a success. The success of this work is largely due to their efforts.

9.   REFERENCES

1.   Borello, M. "A survey of results of tests on rope terminations", CSIR Report MST(91)MC745, May 1991.

2.   Borello, M. : "Laboratory axial fatigue tests of resin cappings for use as winder rope terminations", CSIR Contract Report MST(92)MC1432, December 1992.

3.   Borello, M. "Laboratory Evaluation of White Metal and Resin Cappings for use as Winder Rope Terminations" CSIR Report MST(93) MC 1838, November 1993.

4.   British Coal Board, "Notes of guidance for the resin capping of wire ropes".

5.   Van Zyl, M. "Information on 99 drum winders and 7 11 discarded winder ropes", CSIR Contract Report MST(90)MHT3, May 1990

APPENDIX A

TENSILE TEST CERTIFICATES

Materials Science and Technology — CSIR

CERTIFICATE NUMBER: 201848
DATE OF TEST: 10.19.94
SPECIMEN/COIL NUMBER: 134105 002
DIAMETER (mm): 44.0
APPLICANT: DE BEERS PREMIER MINE.

00010047

STRAIN ENERGY TO FAILURE	151.9	kN.m
PLASTIC FRACTION OF ENERGY	98.3	kN.m
PLASTIC FRACTION OF ELONGATION	61.8	mm
SLOPE	25.7	kN/mm
MAXIMUM LOAD CARRIED	1674.4	kN
GAUGE LENGTH	2750.0	mm

Graph: LOAD (kN) vs ELONGATION (mm); 3000; 200.0

Engineer

Materials Science and Technology — CSIR

Mine Hoisting, Metallurgical & Corrosion Services

Private Bag X28
Auckland Park
2006 South Africa

National (011) 726-7100
International + 27 11
Fax: (011) 726-6418

Delivery Address:
Cor Manton Road and Frost Avenue
Coldstone 2092 Johannesburg

RESIN SOCKET

1994-10-19

Certificate No.: 201848
Date of Test: 1994-10-19

CERTIFICATE OF TEST CONDUCTED ON WINDING ROPE

Specimen supplied by: DE BEERS CONS MINES LTD - PREMIER MINE

Name of manufacturer: HAGGIE RAND LTD

No. 1
No. 2
791
134105002
44.0

Date of manufacture: 1993-04-20
Type of shaft: Vertical
Length of rope (mm): 583
Date rope put on: 1994-01-09

Length of rope (m): 900
Mass per length (kg/m): 8,24
Lay of lay: RHL
Nom length of lay (mm): 334

Compound Triangular Strand

6
GMEX
Fibre
30(12/12/6+3T)
3,20 1,92 1,64 1,24
Plaited

Ungalvanised

2000
1631
1685
1522

Length specimen supplied (m): 3,50
Date cut: 1994-09-18

RESULTS OF TEST AND EXAMINATION

1674
3,15

Gauge length at top specimen (m): 2,30
Length of lay (mm): 370
Diameter of rope (mm): 45,4 : 44,8

Traces inside the strands under the crown
Very slight pitting and corrosion on the outside of the rope

Fair
Ductile but two inner wires shear failures

Four
150 mm from socket

1994-11-11

Engineer

Materials Science and Technology

CSIR

(00010046)

STRAIN ENERGY TO FAILURE	123 kN.m
PLASTIC FRACTION OF ENERGY	64 kN.m
PLASTIC FRACTION OF ELONGATION	40 mm
SLOPE	24 kN/mm
MAXIMUM LOAD CARRIED	1668 kN
GAUGE LENGTH	2300 mm

CERTIFICATE NUMBER 201849
DATE OF TEST 94/10/19
SPECIMEN/COIL NUMBER 134105001
DIAMETER (mm) 44.0
APPLICANT: DE BEERS CONS MINES LTD.

3000

LOAD (kN)

ELONGATION (mm)

200.0

Engineer:

Private Bag x 28, Auckland Park 2006
Tel: (011) 726-7100

Mine Hoisting, Metallurgical & Corrosion Services

Materials Science and Technology

CSIR

Private Bag X28
Auckland Park
2006 South Africa

National (011) 726-7100
International +27 11
Fax: (011) 726-6416

Delivery Address
Cnr. Manton Road and Frost Avenue
Cottesloe 2092 Johannesburg

RESIN SOCKET

1994-10-19

Certificate No. 201849
Date of Test 1994-10-19

CERTIFICATE OF TEST CONDUCTED ON WINDING ROPE

Particulars supplied by Applicant

Name of mine if applicable	DE BEERS CONS MINES LTD - PREMIER MINE
Rope/wire supplied by	HAGGIE RAND LTD
	No. 1
	No. 1
	791
	134105001
	44.0
	Compound Triangular Strand
	6
	GMEX
	Fibre
	30(12/12/6+3T)
	3.20 1.92 1.64 1.24
	Plaited

Date of manufacture 1993-04-16
Type of lay Vertical
Length of haul (m) 583
Date received on 1994-01-09

Length of rope (m) 900
Mass per length (kg/m) 6.24
Type of lay RHL
Nom. length of lay (mm) 334

Ungalvanised

	2000
	1646
	1685
	1522

1.50
1994-09-17

RESULTS OF TEST AND EXAMINATION

| | 1668 |
| | 3.15 |

2.30
370
45.4 : 44.5

Traces inside the strands
Very slight pitting and corrosion on the outside of the rope

Fair
Ductile

Four
At socket
First wire failure at 1600 kN

1994-11-11

Project: MHTER
Ref: MATTEK 49/2

DIVISION OF

MATERIALS SCIENCE AND TECHNOLOGY

**AN INVESTIGATION INTO THE BEHAVIOUR
AND DETERIORATION OF WINDING ROPE
TANGENT POINTS ON CONVEYANCE MOUNTED
COMPENSATING SHEAVES OF BMR WINDERS**

by

Mike van Zyl

CSIR Contract Report No. 950132
Job no. MC2491
May 1995

Submitted to: The Safety in Mines Research Advisory Committee

This report consists of 65 pages.

AN INVESTIGATION INTO THE BEHAVIOUR AND DETERIORATION OF WINDING ROPE TANGENT POINTS ON CONVEYANCE MOUNTED COMPENSATING SHEAVES OF BMR WINDERS

SYNOPSIS

The failure of a BMR winder rope at the tangent point on the conveyance mounted compensating sheave some years ago, led to this investigation into the behaviour of the rope sections at compensating sheaves. The initial investigation concentrated on determining the strength of tangent point samples at the end of their service periods. The tensile tests that were carried out showed that tangent points deteriorated quite rapidly on some winders, while other installations operated without any problems. Strength losses of the order of 50% were not uncommon. The fact that tangent points are at the front ends of winder ropes, where the rope loads are the smallest, averted a greater occurrence of accidents in the past. This should, however, not make the situation less alarming.
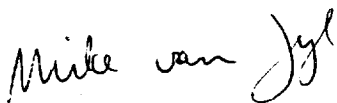
The differences in rates of deterioration from one winder to the next, led to the next part of the investigation, which was a general study into the behaviour of the compensating sheave and the ropes in the vicinity of the tangent points on three rock winders with different rates of tangent point deterioration. The intention of the field measurements was to provide general information so that any further investigations could be planned appropriately. The field measurements consisted of measuring the rotation of the compensating sheave, the lateral vibration of the rope above the compensating sheave, stresses on the outer rope wires, and the dynamic behaviour of the winder drum during normal rock hoisting.

The tensile tests carried out on the tangent point rope samples of the three winders on which the field measurements were carried out, suggested that their tangent point deterioration should be different, but nothing in the mechanical performance of the three winders was found to support this.

During this investigation no evidence could be found to show that lateral rope movement in the shaft, or the amount of compensating sheave rotation during a winding cycle, or the tensile grade of a rope influences tangent point deterioration significantly.

Unpredictable, inconsistent and unacceptable rates of tangent point deterioration are most probably caused by corrosion of the rope tangent points rather than by any mechanical means. The longer a tangent point is left in service on a winder, the greater the chance becomes for a tangent point to acquire an unacceptable degree of deterioration. Regular inspection of the condition of the tangent points is therefore the only proper action that will ensure safety.

Acceptable degrees of deterioration should be established for rope tangent points on BMR compensating sheaves, and appropriate discard criteria should be instituted.

Mike van Zyl
May 1995

CONTENTS

1. INTRODUCTION

During 1990, one of the ropes of a BMR winder failed at the tangent point* on one of its conveyance mounted compensating sheaves. Fortunately, the failure happened very shortly after the winder pulled the loaded skip out of the loading bay, and the consequences of the accident were not severe. At the time of the accident, the tangent points had already been in operation for six months and were due to be re-made. The current statutory winder regulations only require that the front ends of drum winder ropes be re-made every six months. The newly proposed regulations for winders will require BMR winders to cut and re-make their front ends every three months.

The static front end rope force for a fully loaded conveyance is normally in the order of 10% of the new rope breaking strength, and this value typically increases by 20% to approximately 12% of the new rope breaking strength during normal acceleration. For a tangent point to have failed, the remaining strength of that point had to be less than 20% of the new rope breaking strength at the time of failure.

The above led to this investigation into the behaviour and deterioration of compensating sheave tangent points. The investigation was carried out under the auspices of the SIMGAP Engineering Advisory Group of the Safety in Mines Research Advisory Committee (SIMRAC).

The first part of the investigation concentrated on determining the strength of tangent point samples at the end of their service periods, i.e. when these sections were discarded when the terminations at the compensating sheaves were re-made. Mines were requested to submit these rope samples for tensile tests at the CSIR. The tensile tests on tangent point samples are discussed in greater detail in section 5 of this report. The tensile tests showed that the rate of deterioration of tangent points were quite rapid on some winders while others operated without any apparent problems. It was therefore decided to expand the investigation into the measurement of the behaviour of the compensating sheave and the ropes in the vicinity of the tangent points on three rock winders with different rates of tangent point deterioration.

As very little experience existed on compensating sheave behaviour, the field measurements were constructed with the intention to provide general information on behaviour of the compensating sheave and the attached ropes. It was not intended that this investigation should yield all the required answers or spell out exactly how tangent points deteriorate, but rather to provide enough data so that any further investigations, that may have to be executed, could be planned appropriately. It has to be kept in mind that, to date, it has not been possible to quantify the deterioration of the rest of the drum winder rope.

The field measurements consisted of measuring the rotation of the compensating sheave, the lateral vibration of the rope above the compensating sheave, stresses on the outer wires of the rope, and the dynamic behaviour of the winder drum during normal rock hoisting.

---

* The point at which the rope first makes contact with a compensating sheave is referred to as the tangent point.

2.   THE WINDERS SELECTED FOR THE INVESTIGATION

Table 1 contains applicable winder and rope parameters of the three rock winders that were selected for the field measurements.

TABLE 1: ROPE, WINDER AND WINDING PARAMETERS

Winder no.	AA	BB	CC
Depth	2 360 m	2 085 m	1 377 m
Length of wind	2 350 m	2 080 m	1 370 m
Speed	15 m/s	15,25 m/s	15,2 m/s
Cycle time*	421 s	382 s	319 s
Skip mass	10 300 kg	12 632 kg	11 305 kg
Payload	20 000 kg	16 803 kg	19 000 kg
Rope diameter	48 mm	44 mm	42 mm
Construction	6x33	6x30	6x30
Tensile grade	1 900 MPa	1 900 MPa	2 100 MPa
Mass/length	9,95 kg/m	8,24 kg/m	7,51 kg/m
Breaking strength	1 780 kN x 2	1 530 kN x 2	1 530 kN x 2
Safety factor**	4,7	4,9	6,1
Capacity factor***	12,0	10,6	10,3
Static load range****	5,5%	5,4%	6,1%
Compensating sheave centre to rope centre	655 mm	590 mm	635 mm
Compensator D/d	27	27	30
Front end cutting frequency	3 months	8 weeks	3 months

*	The cycle time was an average cycle time at the time that the field measurements were performed, and included the loading-offloading time between trips.
**	The "safety factor" is the static safety factor at the headsheave for a loaded skip and a fully payed out rope calculated on the new rope breaking strength.
***	The "capacity factor" is the static safety factor at the skip.
****	The load range is the static weight of the payload expressed as a percentage of the new rope breaking strength.

At the time that the field measurements were performed, both skip of each of the three winders operated with a right hand lay and a left hand lay rope.

3. MEASURING EQUIPMENT AND PROCEDURES

The field measurements were carried out on the compensating sheave of the underlay ropes of Winder AA, and on the compensating sheaves of the overlay ropes of Winders BB and CC.

3.1 MEASUREMENT OF THE ROTATION OF THE COMPENSATING SHEAVES

The rotation of the compensating sheaves were measured with a small wheel that was placed such that it ran on the flange of the compensating sheave or on one of the sections of rope wrapped around the compensating sheave. The base of the structure that held the small wheel was connected to the conveyance transom. The shaft of the small wheel was connected directly to a potentiometer, which gave an electrical output proportional to the rotation of the wheel. Figure 1 shows a schematic of the compensating sheave rotation measuring device.
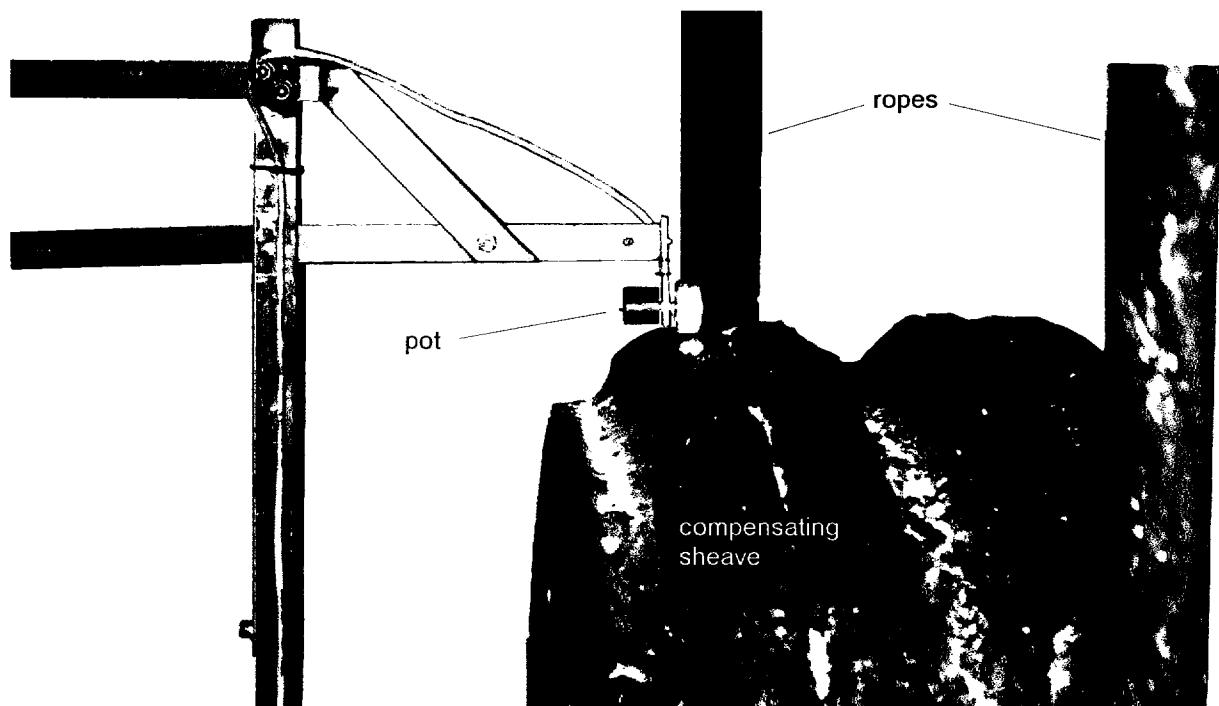
Figure 1: Compensating sheave rotation measuring device

3.2 MEASUREMENT OF THE LATERAL ROPE VIBRATION

The lateral vibrations of the ropes in the vicinity of a compensating sheave were measured with accelerometers mounted on both ropes one and a half to two metres above the sheave tangent points. The lateral vibration of the conveyance was measured on its transom. At each of these three points, the lateral accelerations were measured in the horizontal plane in two perpendicular directions. The positions and directions of the six accelerometers that were used for the measurements on each of the three winders are shown in Fig. 2.

	ZL in mm	ZR in mm
Winder AA	1 420	1 220
Winder BB	2 000	2 000
Winder CC	1 580	1 580
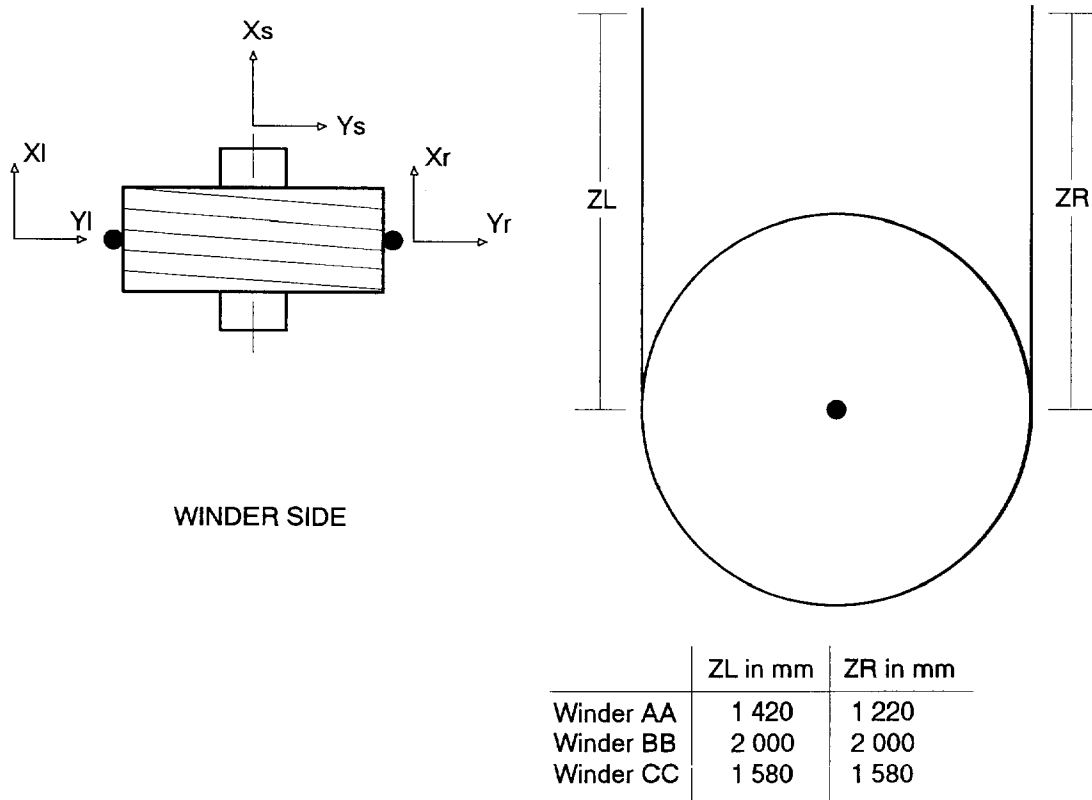
Figure 2: Accelerometer directions and positions

The accelerometers and the coupled instrumentation were set up to measure maximum accelerations of approximately 20 m/s^2. At 1 Hz such an acceleration would give a displacement with an amplitude of approximately 500 mm, while at 5 Hz the corresponding displacement would reduce to 20 mm.

3.3   MEASUREMENT OF THE STRESSES IN THE WIRES OF THE ROPES

It was intended to measure stress variations in the wires of the winding ropes with the aid of strain gauges installed in the vicinity of the compensating sheave tangent points. The following incidents would generate stress variations in the rope:

- Loading, winding and unloading.
- Lateral vibrations of the ropes.
- Bending of the rope when it is wound onto and off the compensating sheave during rotation of the compensating sheave.

It was possible to install strain gauges with 1 mm grid lengths on the 3 mm diameter rope outer wires on site without any major problems.

A compensating sheave on a conveyance is normally orientated such that the spindles of the sheaves point in the direction of the winder. The compensating sheaves of the conveyances of Winders BB and CC were placed between the two channel sections of the transoms of their conveyances. The ropes of these winders therefore operated close to the guide rails of the compartments. The entrances of the compartments in which the ropes of Winder AA operated were on the sides of the shaft, which meant that the guide rails of the two conveyances were positioned in line with spindles of the compensating sheaves. The compensating sheaves of the conveyances of Winder AA were therefore located crosswise between the guide rails, and were mounted on top of the conveyance transoms.

Removal of the cover of the compensating sheave on the underlay ropes of Winder AA provided relatively easy access to the tangent points sections of the ropes. On Winders BB and CC this was not possible because the tangent points were situated between the transom channel sections.

By good fortune, a site visit to Winder AA before the measurements were carried out, revealed that its underlay compensating sheave moved about 300 mm of winding rope onto and off the sheave during every winding cycle. Of the three selected winders, Winder AA was therefore the only one from which all the planned data could be gathered.

3.3.1 Strain gauge positions of Winder AA

The positions of the strain gauges installed on the ropes of Winder AA are shown in Fig. 3, (p. 16). The figure shows the compensating sheave in the rotational position that it was at the bank during installation of the measuring equipment. This was also the position at the start of the actual recordings. Figure 3 also shows the dimensions of the compensating sheave, sheave rotation directions, and general information on the ropes. The indicated rotation of the compensating sheave and the coupled rope movement on and off the sheave will be discussed further on in this report for all three winders on which the measurements were carried out.

The strain gauge positions were selected such that gauges nos 1, 2 and 3 would measure different degrees of bending as the rope moved off and onto the sheave, and gauges nos 5, 6, 7 and 8 would measure bending stresses as the rope first moved onto and then off the sheave. Strain gauge no. 4 was placed away from the sheave so that it would measure the tensile stress in the rope without any bending stress influences.

All the strain gauges were installed on the centre wires of a rope strands and at the strand crowns. All eight strain gauges were positioned with their measuring grids in line with the winding rope wires. The outside of the strands of the ropes of Winder AA laid at an angle estimated at 28° to the line along the length of the rope, while the angle of the centre wires at the crowns of the strands, and therefore the strain gauges, laid at an estimated 36°.

3.3.2 Strain gauge positions of Winder BB

The positions of the strain gauges installed on the ropes of Winder BB are shown in Fig. 4, (p. 17), together with the rest of the rope and sheave information. The figure shows the compensating sheave in the rotational position that it was at the bank during installation of the measuring equipment and at the start of the actual recordings.

The position of the compensating sheave of Winder BB between the beams of the conveyance transom restricted access to the tangent points, and strain gauges could not be installed close to the tangent points. Strain gauges nos 1 and 2 were installed as close to the tangent point areas as was physically possible. Strain gauges nos 3 and 5 on the one rope, and nos 4 and 6 on the other rope, were installed to measure the stresses at approximately the same rope section but on different strands and displaced 90° on the rope circumference. Gauges nos 7 and 8 were placed away from the sheave to ensure that they only measured the pure tensile behaviour of the rope.

Strain gauges nos 1 to 7 were installed on the centre wires of a rope strands as for Winder AA and in line with the winding rope wires. Strain gauge no. 8 was installed on the same strand as gauge no. 7, but two strand wires lower down. It was positioned with its measuring grid in line with the winding rope. The positioning of gauge no. 8 was decided on out of pure curiosity.

The outside of the strands of the ropes of Winder BB laid at an estimated angle of 25° to the line along the length of the rope, while the angle of the strain gauges was estimated as 33° from a

photograph of one of the gauge installations.

3.3.3 Strain gauge positions of Winder CC

The positions of the strain gauges installed on the ropes of Winder CC are shown in Fig. 5, (p. 18), together with the rest of the rope and sheave information. As before, the figure shows the compensating sheave in the rotational position that it was at the bank during installation of the measuring equipment and at the start of the actual recordings.

The position of the compensating sheave of Winder CC presented the same restrictions as that of Winder BB, and strain gauges could not be installed close to the tangent points. Strain gauges nos 1 and 4 were installed away from the compensating sheave to measure pure tensile behaviour. Strain gauges nos 2, 3, 5 and 6 were installed as close to the tangent point areas as was physically possible. Strain gauges nos 2 and 3 on the one rope, and nos 5 and 6 on the other rope, were installed on the same rope section but on different strands and displaced 90° on the rope circumference.

All the strain gauges were installed on the centre strand wires and in line with the winding rope wires as before. The outside of the strands of the ropes of Winder CC laid at an estimated 24° to the line along the length of the rope, while the angle of the strain gauges was estimated as 32°.

3.4   RECORDING OF THE MEASURED PARAMETERS

An instrumentation box, with the required amplifiers and recording instrumentation, was mounted on the conveyances for the duration of the measurements. The unit was battery powered and provided a recording time of 2 hours. Inside the instrumentation box the signals were multiplexed and digitized at 94 Hz per channel before being stored in digital form.

3.5   MEASUREMENT OF THE WINDER DRUM DYNAMICS

The winder drum dynamics at the three winders were measured with an encoded wheel that ran on one of the flanges of the winder drums. From the measured angular displacement of the winder drum, the linear rope speed and the drum acceleration could be calculated. Any abnormal (tensile) load behaviour of the winder ropes has to be coupled to abnormal drum dynamics.

At the same time that the recordings were performed at the compensating sheaves of Winders AA and CC, the drum dynamics were measured for some of the winding cycles. On Winder BB the wheel encoder did not function properly, and the drum dynamics could not be measured in parallel with the compensating sheave recordings. The drum dynamics on Winder BB were however measured, but only one week after the compensating sheave recordings. All three winders had automatic winding controllers, and it was considered unlikely that winder performance would change significantly in a week.

3.6   HOISTING CONDITIONS DURING THE RECORDINGS

All three winders were out of operation for at least nine hours prior to the start of the recordings at the compensating sheaves. The recordings started with empty skips at bank level, followed by normal rock hoisting at full production.

4.   RESULTS OF THE FIELD MEASUREMENTS

4.1   CONVERSION OF THE RECORDED DATA

The strains measured with the strain gauges were converted to stress by assuming a uni-directional stress in the winding rope outer wires and by using an elastic modulus of the steel wires of 204 GPa. The rotations of the compensating sheaves, which were measured either on the outer rope surface or on the flange of the compensating sheave, were converted to linear rope movement at a radius measured from the centre of the sheave spindle to the centre of the rope on the compensating sheave. Rotation of the compensating sheaves is therefore expressed in millimetres instead of degrees.

4.2   MEASURED WINDER DYNAMICS

Details of the skip depth, rope speed, and drum acceleration measured for each of the three winders are given and shown graphically in Appendix A, p. 29. The control of all three winders were different, but non of them showed anything out of the ordinary.

4.3   OVERVIEW OF THE MEASUREMENTS AT THE COMPENSATING SHEAVES

The complete data sets recorded at all three winders are shown and discussed in general in Appendix B, 34. From this overview of the behaviour of the compensating sheaves and the ropes sections at the compensating sheaves, the following were observed and concluded:

- The accelerations measured from lateral rope vibrations in the vicinity of the compensating sheaves were very similar on all three winders. The stress variations in the wires of the ropes at the tangent points on the compensating sheaves caused by the lateral rope vibrations were not significant compared to the stress variations caused by winding and bending of the ropes. Further analysis of the measured lateral vibrations of the ropes were therefore not considered necessary.
- The recordings on each of the three winders were very repeatable from one winding cycle to the next. It was therefore only considered necessary to analyse a single winding cycle of each of the winders.

4.4   DETAILED ANALYSIS

As it was explained in the introduction of this report, the field measurements were constructed with the intention to provide general information on behaviour of compensating sheaves and the sections of rope attached to the sheaves. The analyses that follow will therefore not try to explain the source of all the measured stress variations but will highlight anything that cannot be explained readily. The scope of this investigation did not allow for it, but more information could possibly be extracted from the recorded data through an expanded analysis.

Knowledge on the rotational behaviour of, and the torque generated in triangular strand ropes on drum winders are required for a full understanding of some of the explanations that will follow in this section of the report. Information on this behaviour of triangular strand ropes on drum winders are given in a report by Hecker and Van Zyl[1].

4.4.1 Measurements on Winder AA

The stresses measured with the strain gauges on the ropes at the compensating sheave of Winder AA are shown, together with the measured compensating sheave rotation, in Fig. 6 (p. 19), Fig. 7 (p. 20), and Fig. 8 (p. 21) for a single winding cycle. Details of the strain gauge positions of

Winder AA are shown in Fig. 3, p. 16.

Towards the end of the first descending trip recorded on Winder AA, strain gauge no. 5 was crushed between the rope and the compensating sheave. The portion of the recordings while this strain gauge was still operational are shown in Fig. 9 (p. 22) together with strain gauge no. 6 (on the same rope section as no. 5, but directly on the opposite side of the rope) and the rotation of the compensating sheave.

During the single winding cycle shown in Figs 6 to 8, the following occurred:

t = 0 s	The (underlay) skip was empty and stationary in the tip.
t = 12 s	The descending trip started.
t = 43 s	End of the drum acceleration; travelling at full speed.
t = 175 s	Start of the deceleration of the skip.
t = 196 s	End of deceleration.
t = 208 s	Skip stopped in loading bay, loading commenced.
t = 225 s	The hoisting trip with the fully laden skip started.
t = 255 s	End of the acceleration of the skip; travelling at full speed.
t = 385 s	Deceleration of the skip started.
t = 420 s	Skip off-loaded and stationary in the tip.

Strain gauge no. 4 was positioned away from the compensating sheave, and the stresses measured at this position will be discussed first. The decrease in stress at the start of the descending cycle was caused by the downward deceleration of the empty skip, and most probably also by a reduction in torque from the catenary that moved over the sheave. The increase in stress as the skip descended further was caused by the increase in rope torque. Before the winder stopped in the loading bay, the stress increased during the deceleration of the skip. Further stress increases were caused by loading and accelerating the loaded skip. During the ascending (hoisting) trip, one expects the stress to remain constant because the rope load at that point as well as the rope torque should remain constant. However, for reasons not known, the stress increased by 25 MPa during the hoisting trip. The stress range (difference between the maximum and minimum) measured at the position of strain gauge no. 4 was 154 MPa during the full winding cycle. It is of interest to note that the effect of layer cross-overs can be seen on the recorded stress.

The section of rope to which strain gauges nos 5, 6, 7, and 8 were attached, was gradually moved onto the compensating sheave during the descending trip and moved off the sheave during the hoisting trip. The section of rope to which strain gauges nos 1, 2, and 3 were attached, was gradually off the compensating sheave during the descending trip and moved onto the sheave during the hoisting trip.

When a section of rope is off the compensating sheave, one would expect the rope to behave as the rope at strain gauge no. 4, and when the rope is on the sheave, one would expect the stress variations to be damped due to friction between the rope and the compensating sheave. If a section of rope moves onto the sheave, one would expect tensile stresses (positive or less negative) to be generated on the outside of the rope, and compressive stresses (less positive or negative) to be generated on the inside of the rope. This would be the case if the wires in the rope would bend without the generation of any other secondary tensile or compressive forces during the (elastic) bending process.

The rope wires had a diameter of 3 mm and the compensating sheave a diameter of 1,263 m. The rope wires made an angle of 36° to the line along the length of the rope. From pure geometrical considerations, bending of the wires on this sheave at the given angle should produce stresses in the order of 400 MPa.

Inspection of the stress measurements on the ropes of Winder AA shows that the stresses on strain

gauges nos 6, 7, and 8 did increase due to the bending onto the sheave, while no. 5, on the inside of the rope, showed a stress decrease. The stress changes that could be associated with the bending were only of the order of 100 MPa instead of the estimated theoretical value of 400 MPa.

Only strain gauge no. 3 of the section of rope on which strain gauges nos 1, 2, and 3 were installed, showed a decrease in stress when the rope moved off the sheave during the descending cycle, and an increase in stress when it moved back onto the sheave. The strain gauges at positions no. 1 and 2 showed stresses that were opposite in direction to what were expected. These two behaved as if the bending of the rope generated a compressive stress at their positions that outweighed the effect of the bending of the wires.

Other interesting observations are the following:

-   The stress variations measured by strain gauges nos. 1 and 8 towards the end of the hoisting cycle (t = 390 s) were caused by lateral rope vibrations.

-   During loading, the strain gauges at positions nos. 7 and 8 were well onto the compensating sheave, while no. 6 were estimated to be partially on. All three of these strain gauges showed a **decrease** in stress during loading of as large s 50 MPa! A possible explanation for this behaviour could be that, although rope torque increases during loading, the rope at the bottom end unlays slightly. This effect could have been passed into the rope section on the compensating sheave and caused this behaviour. On the other rope, strain gauge no. 2 was situated on the compensating sheave during tipping of the skip, and showed an **increase** in stress during tipping.

-   The largest stress range was measured at the position of strain gauge no. 2, and was 201 MPa.

All of the above indicate that, firstly, the bending of a rope is far more complicated than was anticipated by the author of this report, and secondly, that the torque and rotations generated in a triangular strand rope also have an influence on the stresses of the rope sections on the compensating sheaves.

4.4.2 Measurements on Winder BB

The stresses measured with the strain gauges on the ropes at the compensating sheave of Winder BB are shown, together with the measured compensating sheave rotation, in Fig. 10 (p. 23), Fig. 11 (p. 24), and Fig. 12 (p. 25) for a single winding cycle. Details of the strain gauge positions of Winder BB are shown in Fig. 4, p. 17.

None of the strain gauges of Winder BB were installed very close to the tangent points for reason given earlier in this report. The strain gauges therefore all displayed the pure tensile behaviour of the rope (as was observed for strain gauge no. 4 of Winder AA).

The layer cross-overs, and periods of acceleration, deceleration, loading, and tipping can clearly be picked out from the results shown for this winder. The stresses during the hoisting trip are at a constant level for some of the strain gauges, while others show a behaviour more like that observed for strain gauge no. 4 of Winder AA.

Strain gauge no. 8 was installed on a rope wire in the direction of the length of the rope, close to strain gauge no. 7, which was installed in line with the wire of the rope. As was mentioned before, this was merely done out of curiosity. The wires of this rope made an angle of approximately 33° to the line of centre of the rope, and this was also be the difference in the angle between the two strain gauges. If the wires of the rope were subjected to a uni-directional stress fields at the crowns

of the strands, then strain gauge no. 8 should return 61% of the value of strain gauge no. 7 from considering the Mohr **strain** circle for a uni-directional stress field. The stress range of strain gauge no. 8 was 111 MPa as opposed to the stress range of 180 MPa of strain gauge no. 7; a 62% fraction. The measurements from strain gauge no. 8 will not be discussed further.

The stress ranges measured during the winding cycle by the strain gauges were:

-    On the left hand side rope:
       201 MPa for no. 2
       162 MPa for no. 4
       178 MPa for no. 6
       180 MPa for no. 7

-    On the right hand side rope
       156 MPa for no. 1
       127 MPa for no. 3
       196 MPa for no. 5

Although strain gauges could not be installed at the tangent points of Winder BB, and could therefore not shed any more light on the behaviour of the rope when bend around the compensating sheave, it did provide the opportunity to look at the stress levels at different sections in the rope in the vicinity of the compensating sheave. The stress ranges shown above have an average of approximately 170 MPa. Strain gauges nos 3 and 5, which were installed on adjacent strands, returned stress ranges 25% less than, and 15% greater than the average respectively. Strain gauge no. 2 gave a stress range 18% higher than the average. This shows that the stresses in the rope wires are not equally distributed amongst the strands of either of the ropes in the rope sections immediately above the compensating sheave. This could have an influence on the stresses generated at the tangent points.

It is of further interest to note that the compensating sheave rotated gradually during the full 2 080 m of the descending trip, but only really started to rotate after approximately 500 m of the hoisting trip had been completed. The total compensating length of this winder was approximately half of that of Winder AA.

4.4.3 Measurements on Winder CC

The stresses measured with the strain gauges on the ropes at the compensating sheave of Winder CC are shown in Fig. 13 (p. 26) and Fig. 14 (p. 27) for a single winding cycle. Figure 15 (p. 28) shows the measured compensating sheave rotation, together with the recordings from the strain gauges of the previous two figures which returned the largest values. Details of the strain gauge positions of Winder CC are shown in Fig. 5, p. 18.

As was the case for Winder BB, none of the strain gauges of Winder CC were installed very close to the tangent points. The strain gauges therefore all displayed the pure tensile behaviour of the rope. At Winder BB, the largest stress occurred during at the beginning of the acceleration phase after loading. On Winder CC, the largest stresses mostly occurred at the end of the hoisting cycle just before unloading the skip. At strain gauges no. 4 the stress generated at the first layer cross-over was slightly larger, while at strain gauges nos 5 and 6, the stress at the first layer cross-over was equal to that at the end of the hoisting cycle. No plausible reason for the increase in stress towards the end of the wind can be thought of at this stage. It is however possible that the torque in the rope could influence this behaviour.

The stress ranges measured during the winding cycle by the strain gauges were:

-    On the left hand side rope:
       95 MPa for no. 4
       199 MPa for no. 5
       132 MPa for no. 6

-    On the right hand side rope
       178 MPa for no. 1
       58 MPa for no. 2
       153 MPa for no. 3

The above stress ranges are on average lower than that of Winder BB, but show a greater variation. The variation in stress ranges again show that the stresses in the rope wires are not equally distributed amongst the strands of either of the ropes in the rope sections immediately above the compensating sheave.

The compensating length per winding cycle of this winder is far less than that of either Winder AA or Winder BB.

4.5 SUMMARY OF THE FIELD MEASUREMENTS

The field measurements carried out on the three selected winders showed the following:

- The normal winding dynamics measured as drum accelerations on the three winders were similar and showed nothing out of the ordinary.
- The lateral rope vibrations in the vicinity of the compensating sheaves of the three winders were very similar. Although the stresses generated by the lateral rope movement were visible at the rope tangent points, the amplitude of these stress variations were not significant.
- The stresses generated in the wires of a winding rope when bend around a compensating sheave are more complicated than anticipated. Although the bending stresses that were measured were less than anticipated, more information on the stresses generated from bending a rope is required before one can generalise. The bending stresses that were measured did not produce stress ranges that were greater than those in other sections of the ropes.
- The stress generated by torque in the rope is significant, and rope stresses are not evenly distributed amongst the strands of a rope.
- The measured stress ranges were of the same order on the ropes of the three winders.
- The compensating sheaves of the winders showed rope movements of between 30 mm and 300 mm per winding cycle.

Except for the differences in compensating sheave rotation, the field measurements produced nothing else that would indicate or suggest differences in the behaviour of the tangent points on the three winders. Although everything indicated that the ropes on the three winders behaved in the same way, a degree of uncertainty remains because it was found that the stresses produced through bending of the rope were not a straightforward matter, and the rope stresses were only measured right at the tangent points on one of the three winders.

The author of this report was always under the impression that the stress distribution amongst the strands of a triangular rope was reasonably uniform, and for that reason only one strain gauge (no. 4) was installed on Winder AA to measure the pure tensile behaviour of the rope in the area immediately above the compensating sheave. Differences in the stress distribution amongst the individual rope strands could have produced the unexplainable bending behaviour measured at some sections on the right hand side rope of Winder AA.

The non-uniform distribution of the stresses amongst the strands could have been generated by the way ropes are installed on the compensating sheaves.

Whether the measured stress variations are large enough to initiate fatigue cracks in the wires of the ropes is not known and falls outside the scope of this investigation.

5.   TENSILE TESTS ON TANGENT POINT SPECIMENS

Mines that operated BMR winders were requested to provide the CSIR with rope specimens that operated at the tangent points on BMR compensating sheaves. Details of the origins, and the results of the tensile tests on 128 tangent point rope specimens are given in Appendix C.

The results of Appendix C show the following:

- Tangent points in service could have reductions in tensile strength of as great as 50%. One in five of the tangent point specimens that were tested showed strenght losses of greater than 20%.

- The tangent points were sometimes still in a totally acceptable condition after six months in service, but they could also deteriorate by more than 10% in as little as 9 weeks.

- On the same compensating sheave of the same winder, the condition of tangent points that were in service for comparable periods and number of completed winder cycles ranged from totally satisfactory to totally unacceptable. Such a scatter in tangent point performance indicated that there had to be external factors that affected the deterioration of tangent points.

- Ropes of 2 100 MPa could perform as well at the tangent points as any other tensile grade.

- The longer a tangent point is left in service on a winder, the greater the chance for a tangent point to acquire an unacceptable degree of deterioration.

- If the deterioration of a BMR compensating sheave tangent point is to be maintained to less than the -10% to -20% range, then the presence of any broken wires at a tangent point, and/or any pitting and corrosion on the outside of the tangent point that is more than "slight" requires the re-making of the termination.

- Of the three winders selected for the field measurements, Winder CC generally showed the greatest rate of tangent point deterioration.

- If the onset of corrosion cannot be prevented or eliminated at the tangent points, the front ends of winders with "problematic" tangent points should be re-made every eight weeks.

The results of the field measurements and Appendix C indicate that unacceptable rates of tangent point deterioration is most probably caused be corrosion rather than by the mechanical operations of the ropes at the compensating sheaves.

6. CONCLUSIONS

The rope tangent points on BMR compensating sheaves can deteriorate quite rapidly, and strength losses of the order of 50% are not uncommon. The fact that tangent points are at the front ends of winder ropes, where the rope loads are the smallest, averted a greater occurrence of accidents in the past. This should, however, not make the situation less alarming.

The tensile tests carried out on the tangent point rope samples of the three winders on which the field measurements were carried out, suggested that their tangent point deterioration should be different, but nothing in the mechanical performance of the three winders was found to support this.

Although the stresses generated by lateral rope movement in the shaft were visible, the amplitudes were too low to be of significance. Evidence that the amount of compensating sheave rotation or the tensile grade of the ropes influences tangent point deterioration could also not be found.

Unpredictable, inconsistent and unacceptable rates of tangent point deterioration are most probably caused by corrosion of the rope tangent points rather than by any mechanical means.

The longer a tangent point is left in service on a winder, the greater the chance becomes for a tangent point to acquire an unacceptable degree of deterioration. Regular inspection of the condition of the tangent points is therefore the only proper action that will ensure safety. The re-making of the terminations at BMR compensating sheaves at intervals of three months, as proposed in the new winder regulations will therefore improve safety.

If the deterioration of a BMR compensating sheave tangent point is to be maintained to less than the -10% to -20% range, then the presence of any broken wires at a tangent point, and/or any pitting and corrosion on the outside of the tangent point that is more than "slight" requires the re-making of the termination.

Although stress ranges on the ropes were measured, an investigation is still required to determine whether these stress ranges are large enough to cause the initiation of fatigue cracks.

The compensating sheave arrangement of Winder AA, described in section 3.3, p. 4, probably provides better protection against the environment than the arrangements of Winders BB and CC, and so contributes to improved tangent point performance.

7.   RECOMMENDATIONS

The non-uniform distribution of the stress in the sections of winding rope immediately above the compensating sheave, the bending stresses generated in the wires of the rope when the rope is moved onto and off a compensating sheave, the influence of rope torque on both the rope stress and behaviour of the rope on the compensating sheave, as well as the influence of installation procedures on the stress distribution in the ropes are subjects that require greater attention in future research.

The magnitude of stress variations that will cause the initiation of fatigue cracks in winding rope wires need to be established.

Acceptable degrees of deterioration should be established for rope tangent points on BMR compensating sheaves, and appropriate discard criteria should be instituted.

Mines with BMR winders that have conveyance mounted compensating sheaves should implement procedures that will allow them to expose **both** tangent points on a compensating sheave for thorough inspection and re-lubrication.

The prevention of corrosion on the winding ropes at the tangent points will decrease the rate of deterioration.

Apart from improving corrosion protection, the following recommendations for the three winders on which the field measurements were carried out:

-   Winder AA: The 3 month/13 week cutting frequency is adequate.
-   Winder BB: The 8 week cutting frequency is adequate.
-   Winder CC: If inspection procedures and protection are not improved, an 8 week cutting frequency is recommended.

8. REFERENCES

1.   Hecker, G F K and Van Zyl, Mike: *Drum winder rope test facility: A feasibility study.* CSIR Contract Report MST(93)MC1233, January 1993.

2.   Borello, M: *A comprehensive study of the factors affecting splice efficiencies.* CSIR Internal Report MST(92)MC1117, April 1992.

Winder AA: Underlay compensating sheave as seen from the winder side.

| 48 mm LHL rope | New rope | 48 mm RHL rope |
| 286 mm laylength | laylength = 424 mm | 278 mm laylength |

Sheave diameter = 1,262 m

Rotation in terms of movement of the rope.
The indicated rotations are for when the numbered lines
are horizontal.

(1)(1) Horizontal line: Rotation at start at bank = 10 mm

(2)(2) Indicated rotation = 0 mm

(3)(3) Maximum rotation = -303 mm

No. 4

No. 6

No. 5

+ rotation

No. 7

No. 8

No. 1

No. 2

No. 3

Figure 3:   Winder AA: Compensating sheave layout, rope information, rotation direction and strain
gauge positions.

Winder BB: Overlay compensating sheave as seen from the winder side.

44 mm RHL rope
300 mm laylength

New rope
laylength = 378 mm

44 mm LHL rope
305 mm laylength

No. 7 — No. 8

Sheave diameter = 1,136 m

Rotation in terms of movement of the rope.
The indicated rotations are for when the numbered lines
are horizontal.

(1)(1) Horizontal line: Rotation at start at bank = -24 mm

(2)(2) Indicated rotation = 0 mm

(3)(3) Maximum rotation = 157 mm

No. 6 — No. 4

No. 3 — No. 5

No. 2

No. 1
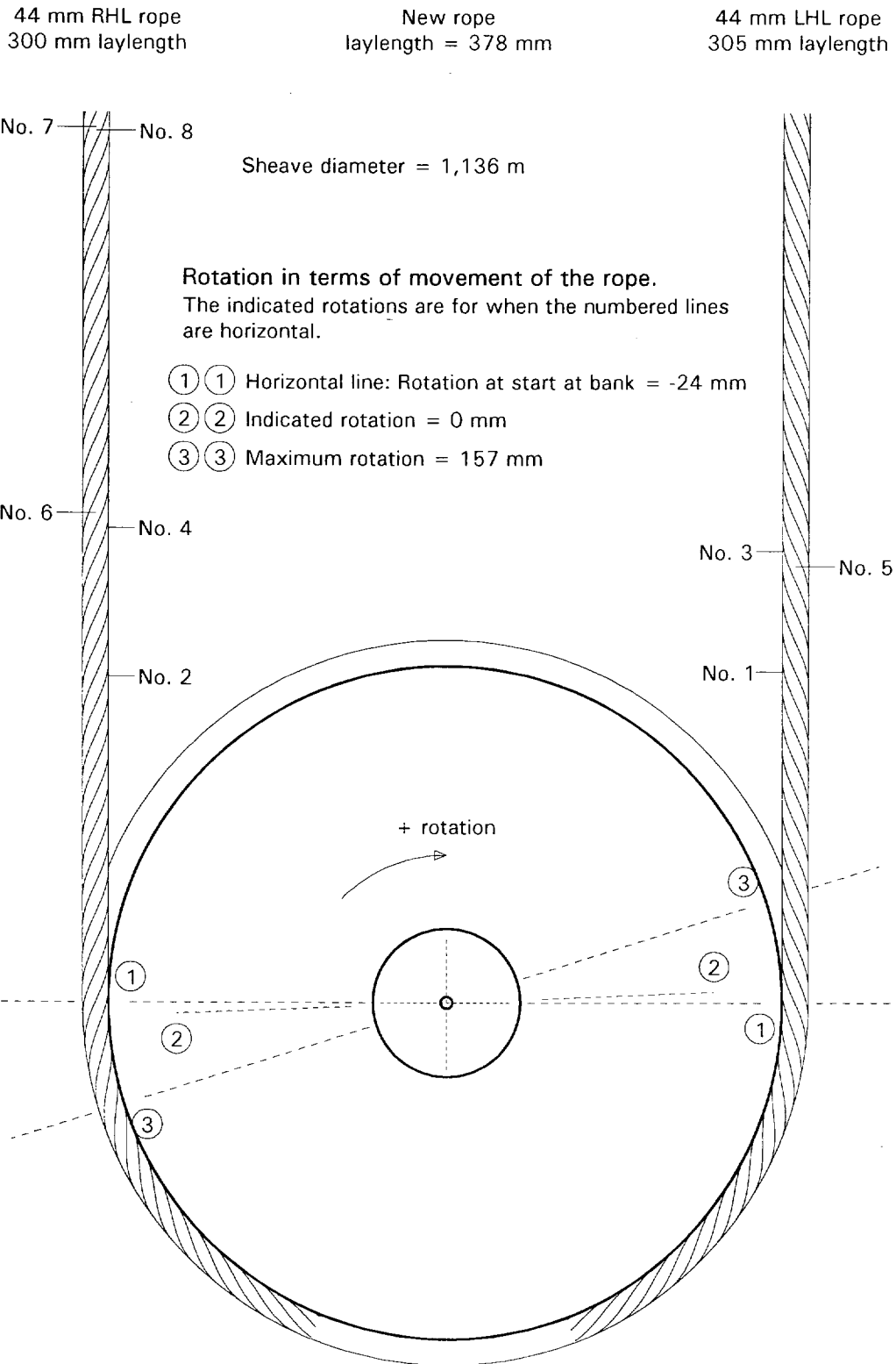
+ rotation

Figure 4:   Winder BB: Compensating sheave layout, rope information, rotation direction and strain
             gauge positions.

Winder CC: Overlay compensating sheave as seen from the winder side.

42 mm LHL rope   New rope   42 mm RHL rope
290 mm laylength   laylength = 366 mm   300 mm laylength

No. 4   No. 1

Sheave diameter = 1,228 m

Rotation in terms of movement of the rope.
The indicated rotations are for when the numbered lines
are horizontal.

(1)(1) Horizontal line: Rotation at start at bank = -40 mm

(2)(2) Indicated rotation = 0 mm

(3)(3) Maximum rotation = 44 mm

Actual positions of strain gauges Nos 1, 2, 4, and 5 are on the back
sides of the ropes, opposite to the positions shown on the front.

No. 6
No. 5   No. 3
                                                                          No. 2

+ rotation

Figure 5:   Winder CC: Compensating sheave layout, rope information, rotation direction and strain
             gauge positions.
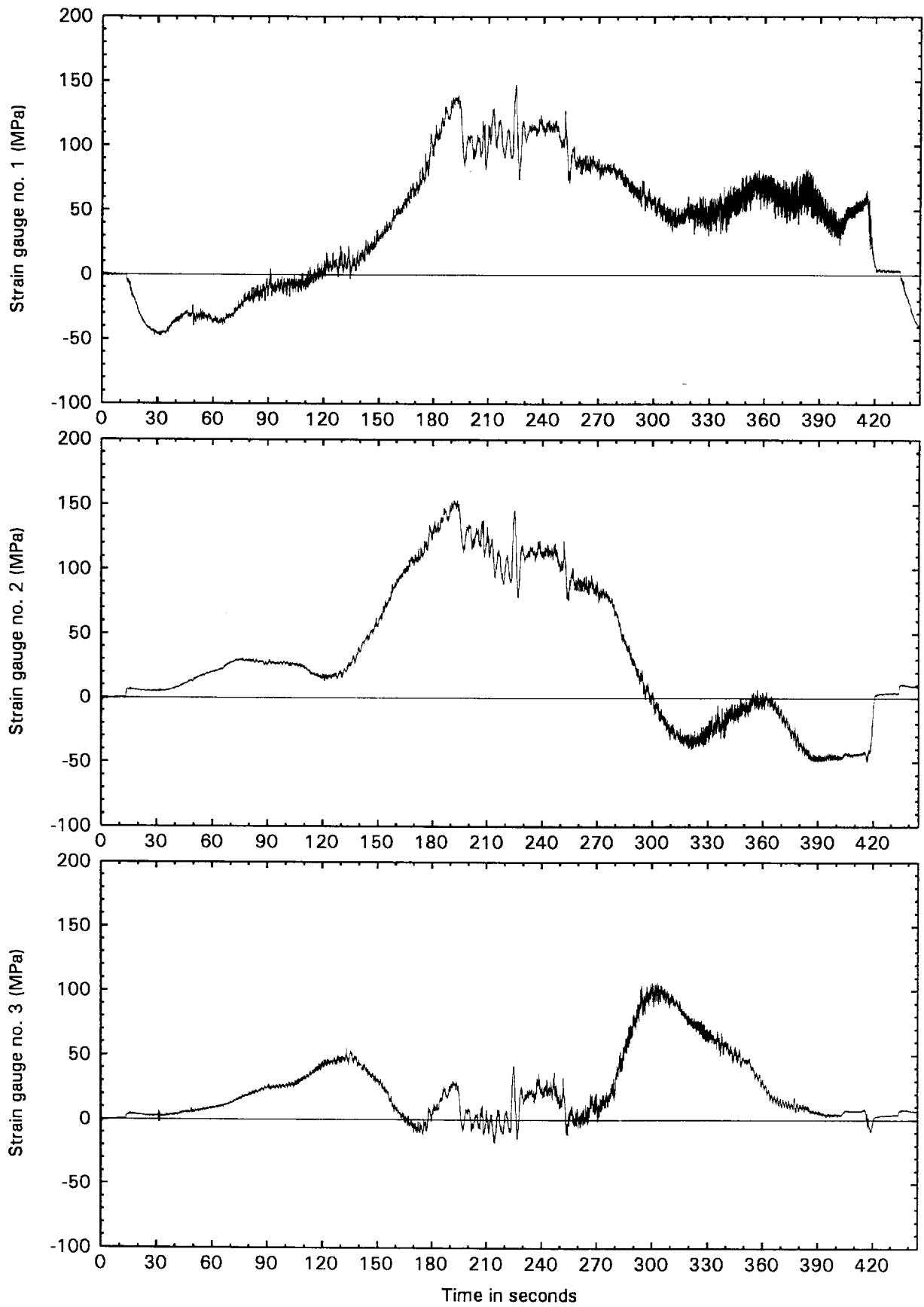
Figure 6:   Winder AA: Stress measurements during a single winding cycle.
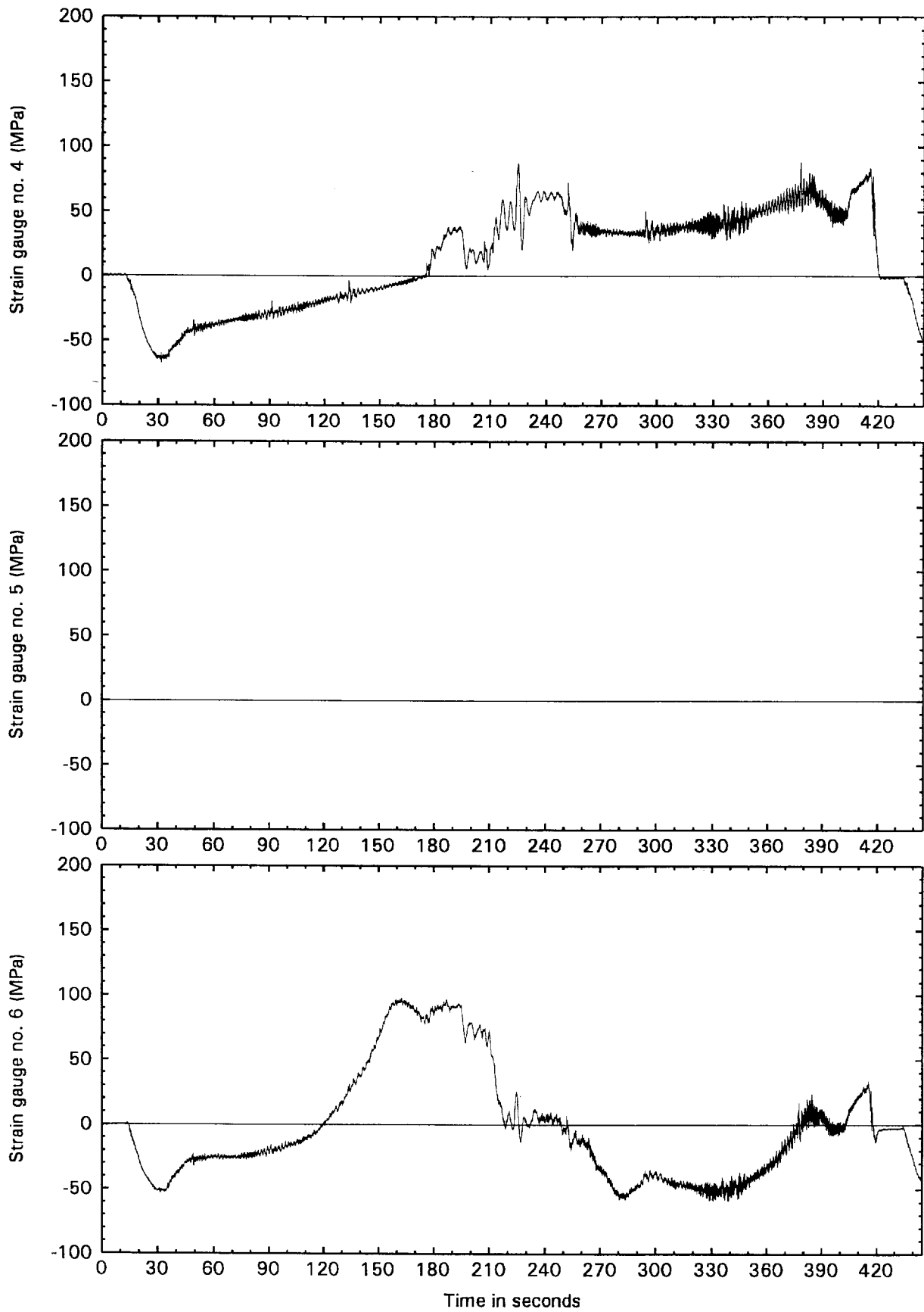
Figure 7:   Winder AA: Stress measurements during a single winding cycle.
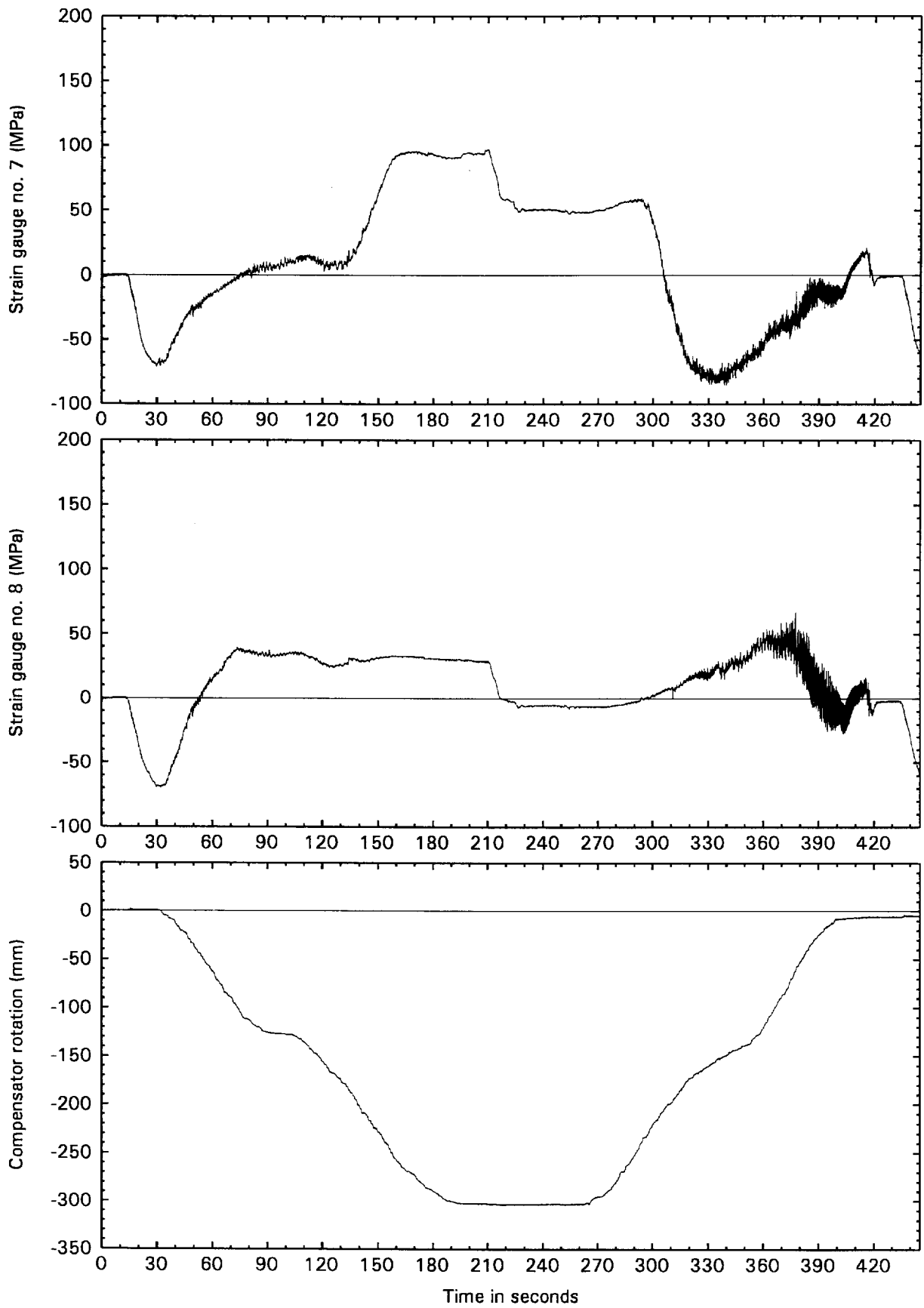
Figure 8:   Winder AA: Stress measurement and compensating sheave rotation during a single winding cycle.
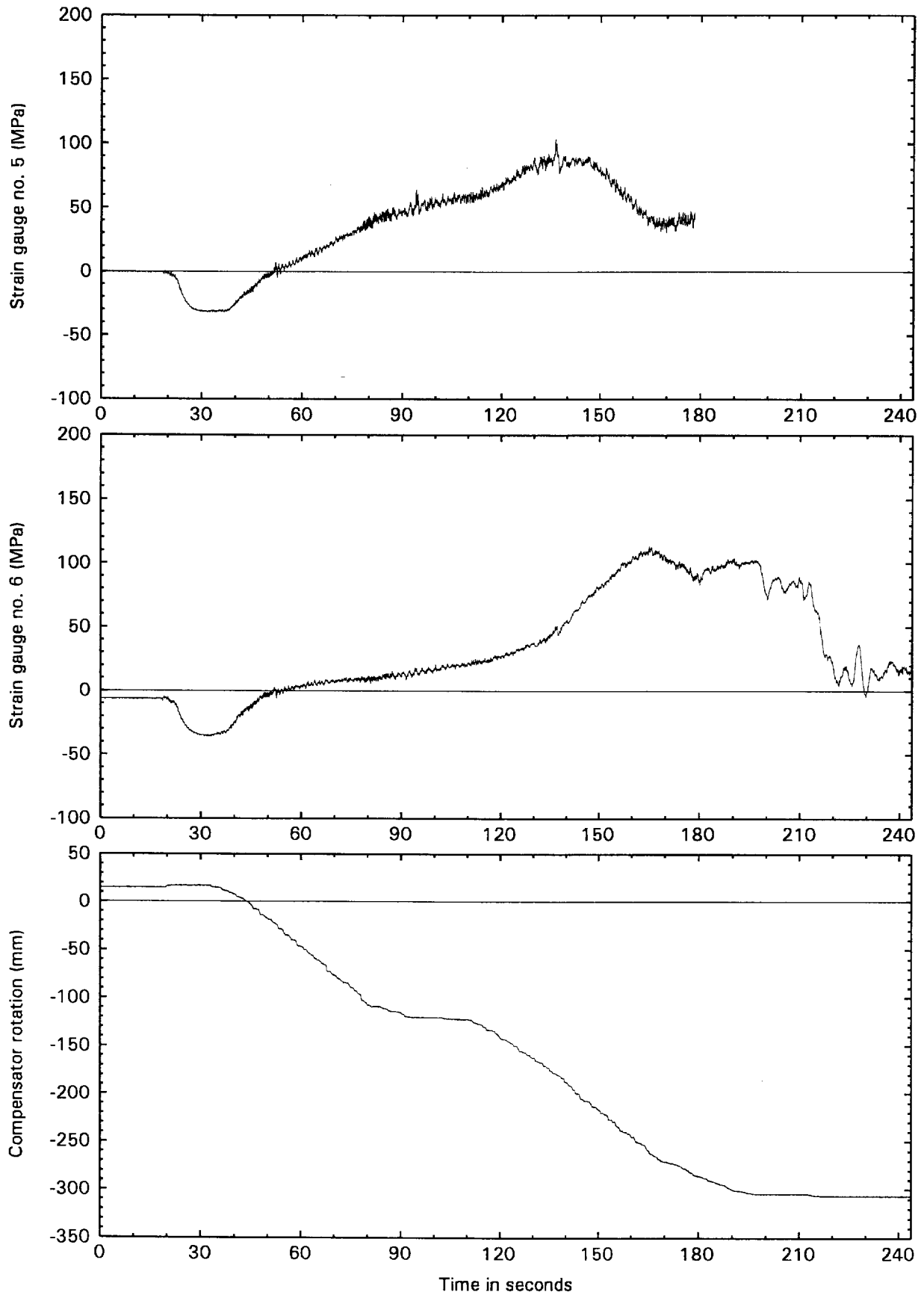
Figure 9:   Winder AA: Stress measurement and compensating sheave rotation during part of a winding cycle.
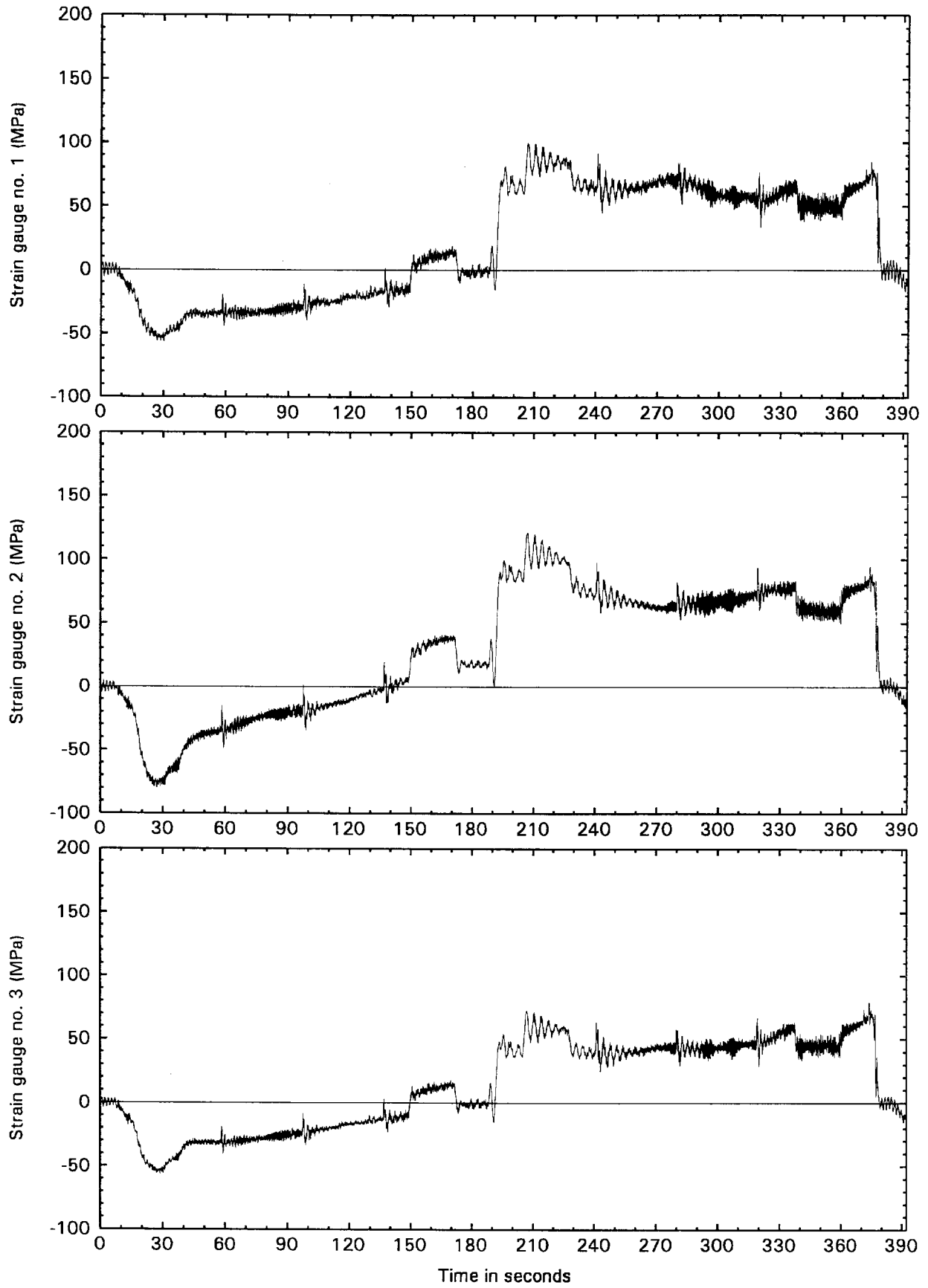
Figure 10: Winder BB: Stress measurements during a single winding cycle.
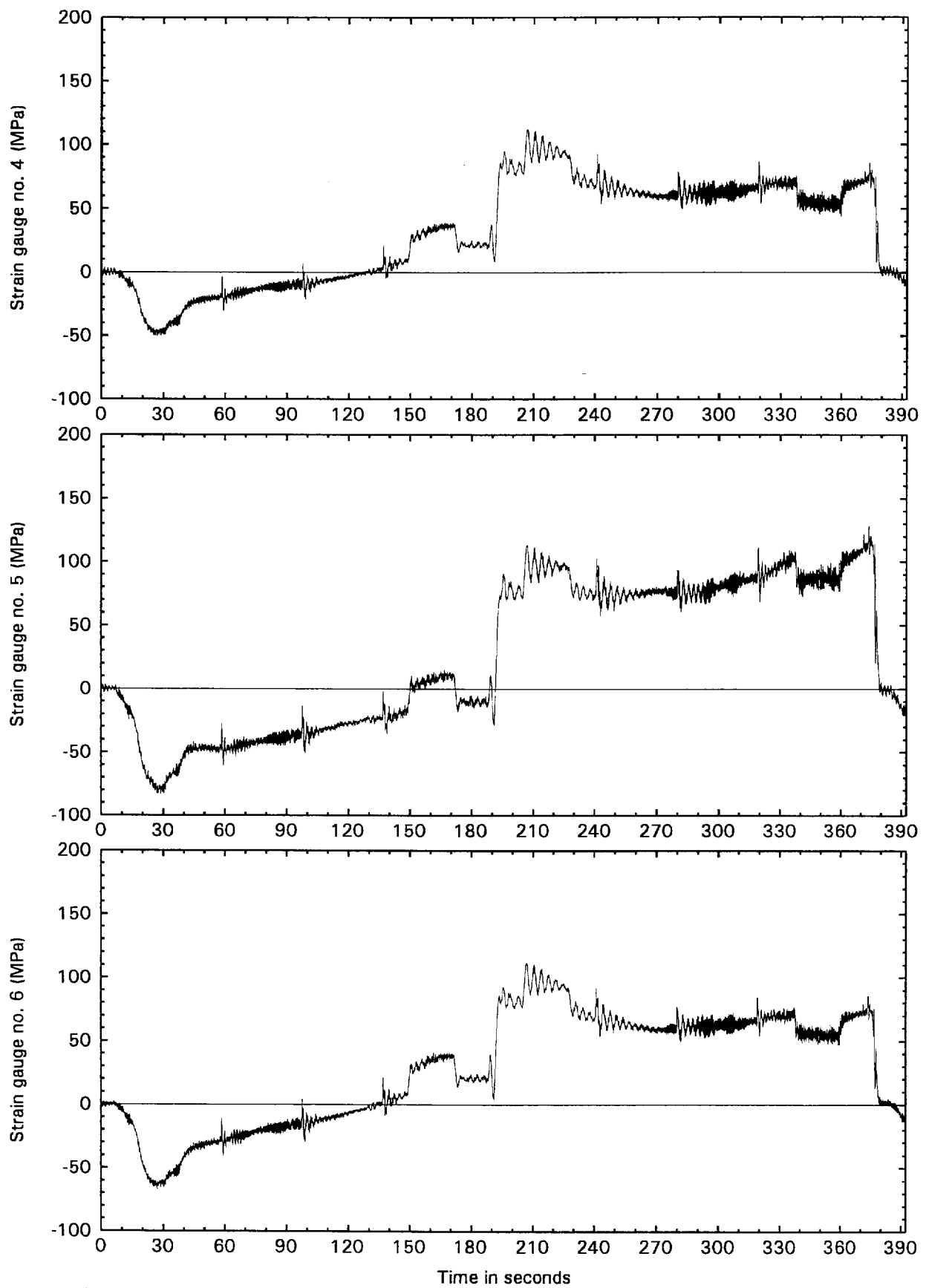
Figure 11:   Winder BB: Stress measurements during a single winding cycle.
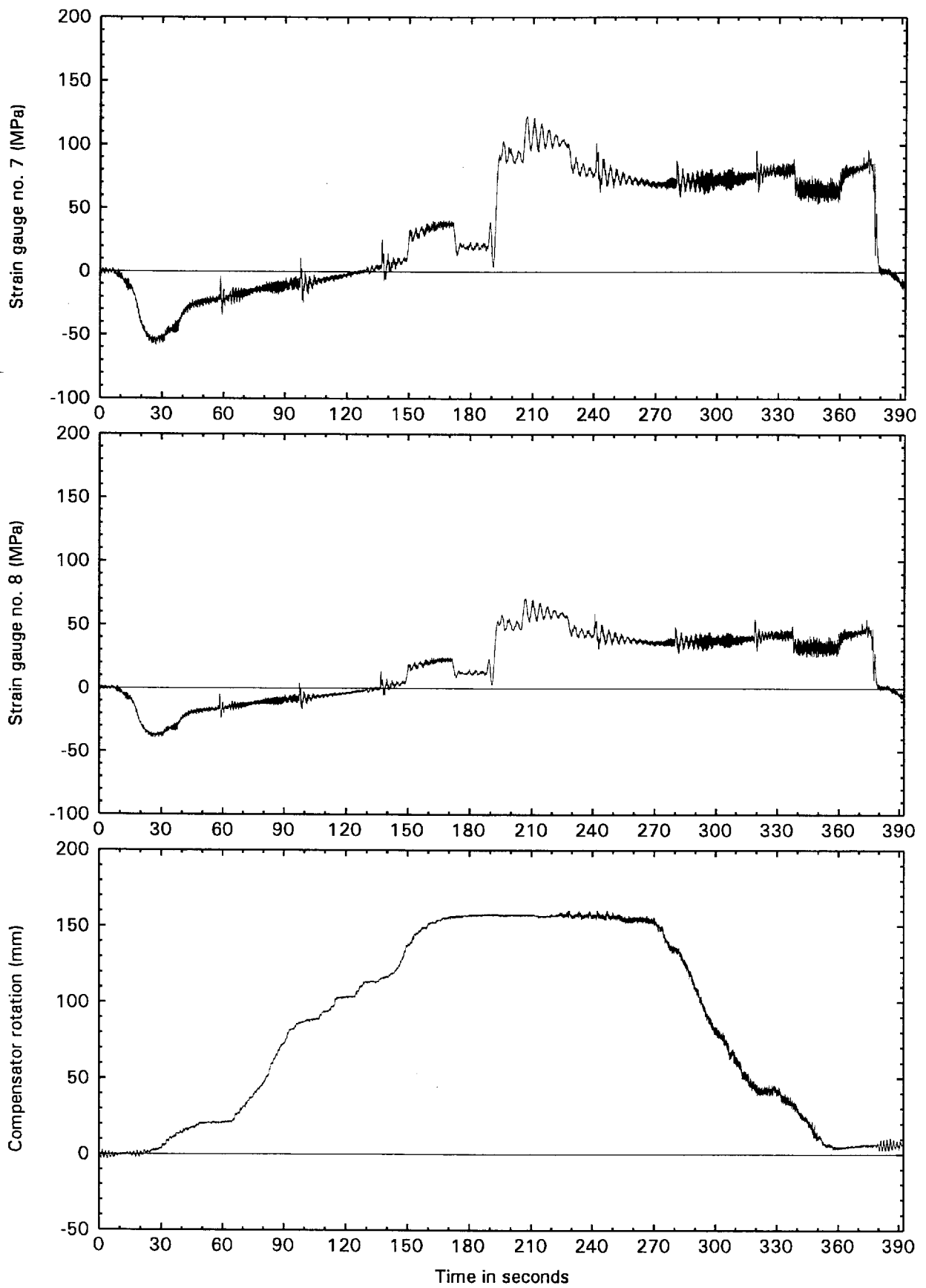
Figure 12: Winder BB: Stress measurement and compensating sheave rotation during a single winding cycle.
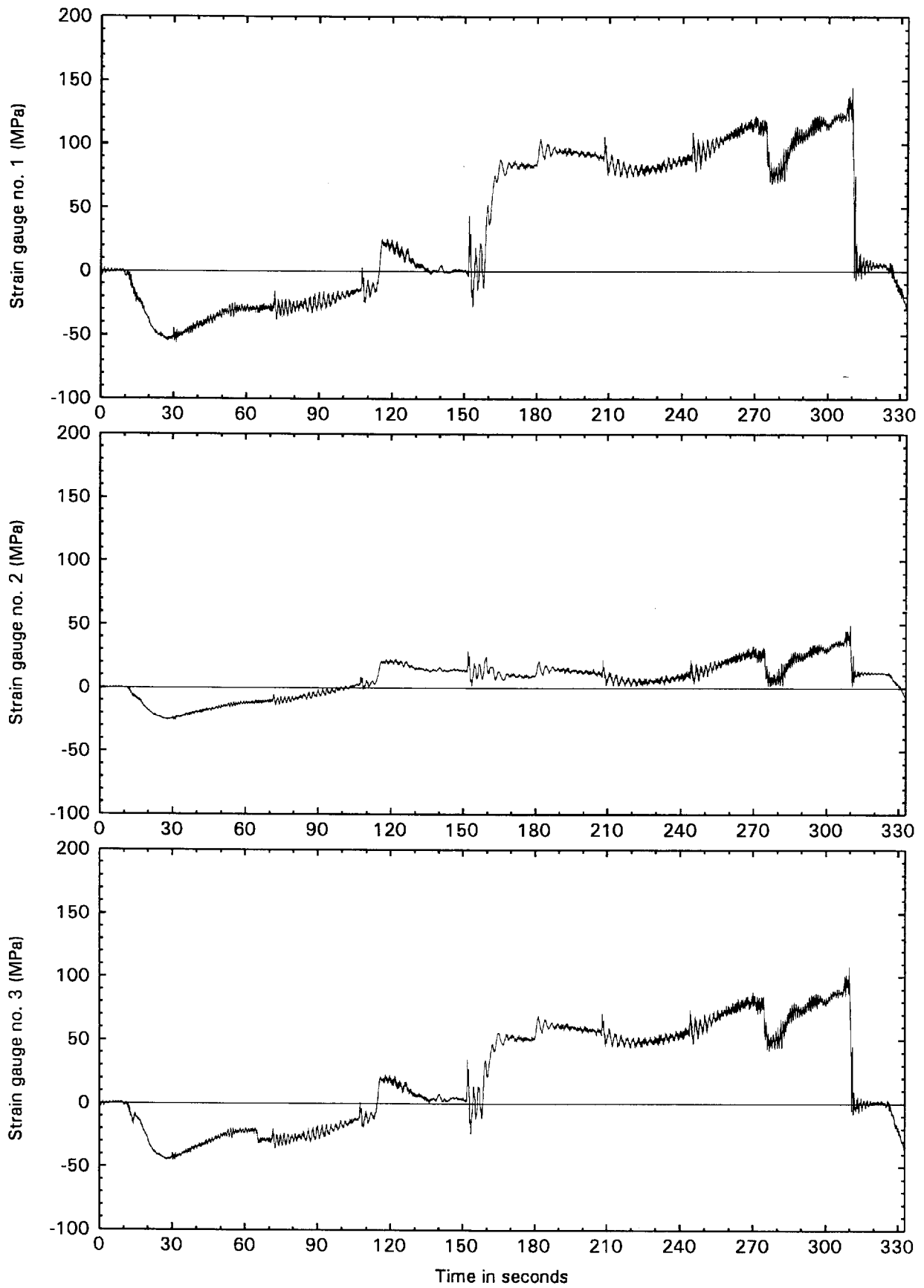
Figure 13: Winder CC: Stress measurements during a single winding cycle.
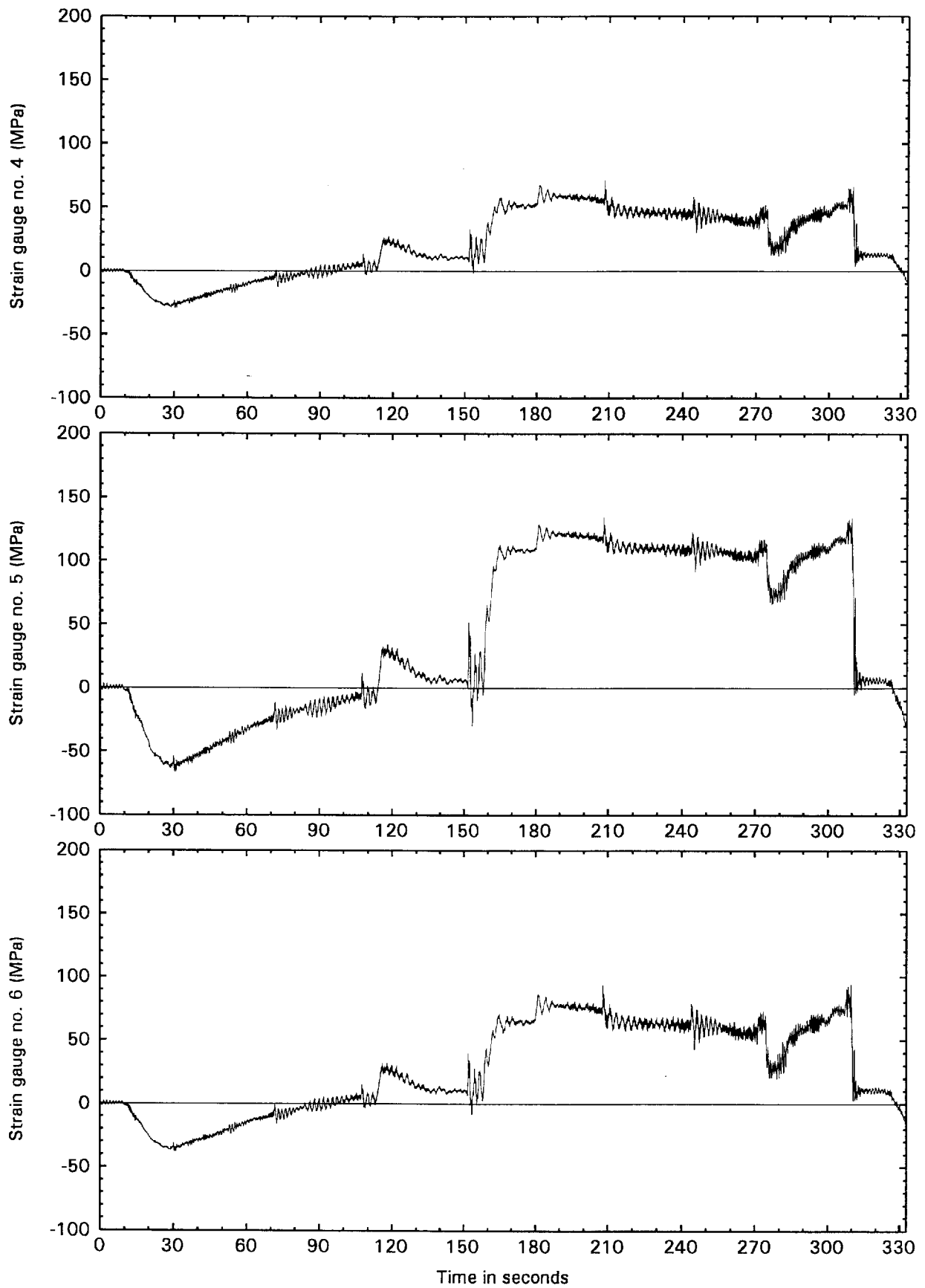
Figure 14: Winder CC: Stress measurements during a single winding cycle.
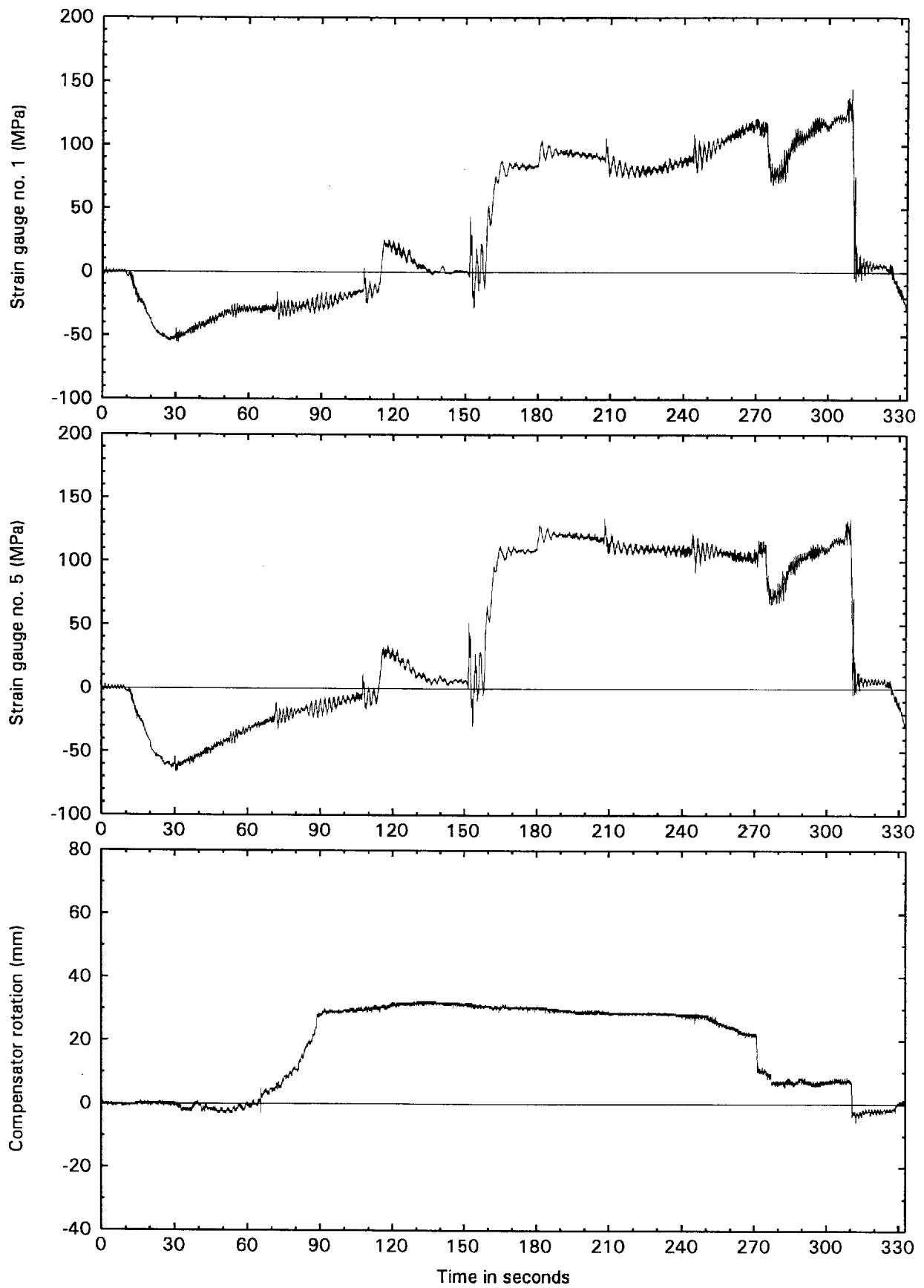
Figure 15:   Winder CC: Stress measurement and compensating sheave rotation during a single winding cycle.

APPENDIX A: WINDER DRUM DYNAMICS

A.1 CALCULATION OF SPEED AND ACCELERATION

The rotation of the winder drums were measured at the three winders. From the rotation and the length of wind of a specific winder, an average drum diameter could be calculated. The measured rotation could in this way be expressed as the position or depth of the skip in the shaft.

Rope position was differentiated with respect to time, which gave "rope speed". The effect of the small changes in drum diameter caused by rope layer changes were, of course, not taken into account in the speed calculations. The approximation was, however, considered adequate for the purposes of this report.

Drum acceleration was obtained by differentiating the speed with respect to time. Layer cross-overs do not effect the calculation of drum acceleration in the way it affects the rope speed, and the drum accelerations obtained in this way is therefore correct. The drum (rotational) acceleration was however converted to linear acceleration (in m/s²) by multiplying it with the average drum radius. Although this created somewhat of a misnomer (drum acceleration expressed in m/s²), it is customary to the industry for comparative purposes.

A.2 RESULTS OF THE MEASUREMENTS

Figure A1, p. 30, shows the skip position, rope speed and drum acceleration for a complete winding cycle of Winder AA, starting with the underlay skip in the loading box and the overlay skip in the tip. Rope speed is always shown as positive, while a positive acceleration will increase rope speed and a negative acceleration will reduce the speed. Differences in winder behaviour from one winding cycle to another can be determined from drum acceleration data. Measurements from a number of winding cycles on Winder AA showed excellent repeatability, and the results therefore only include a single winding cycle of this winder. It is of interest to note that the behaviour of the winder is different for the acceleration parts when the drum rotational direction is reversed.

Figure A2, p. 31, shows the position, speed and acceleration for a complete winding cycle of Winder BB, again starting with the underlay skip in the loading box and the overlay skip in the tip. Measurements from a number of winding cycles on Winder BB also showed excellent repeatability, with the acceleration and deceleration being the same for both directions of rotation. The cycle times for these measurements are 20 seconds longer than those measured one week earlier during the compensating sheave measurements. Closer inspection of the data revealed that the loading-tipping times at the end of each winding trip were indeed 10 seconds longer than the week before.

Figure A3, p. 32, shows the position, speed and acceleration for a complete winding cycle of Winder CC. The drive of Winder CC was reported to take some time to "warm up", and its behaviour for a complete winding cycle while still "cold" was obtained during the first half hour of the compensating sheave measurement, and is shown in Fig. A4, p. 33, for the sake of interest. After warm-up the behaviour of the winder became constant and repeatable.

There is nothing abnormal or out of the ordinary in the accelerations measured on the three winders.
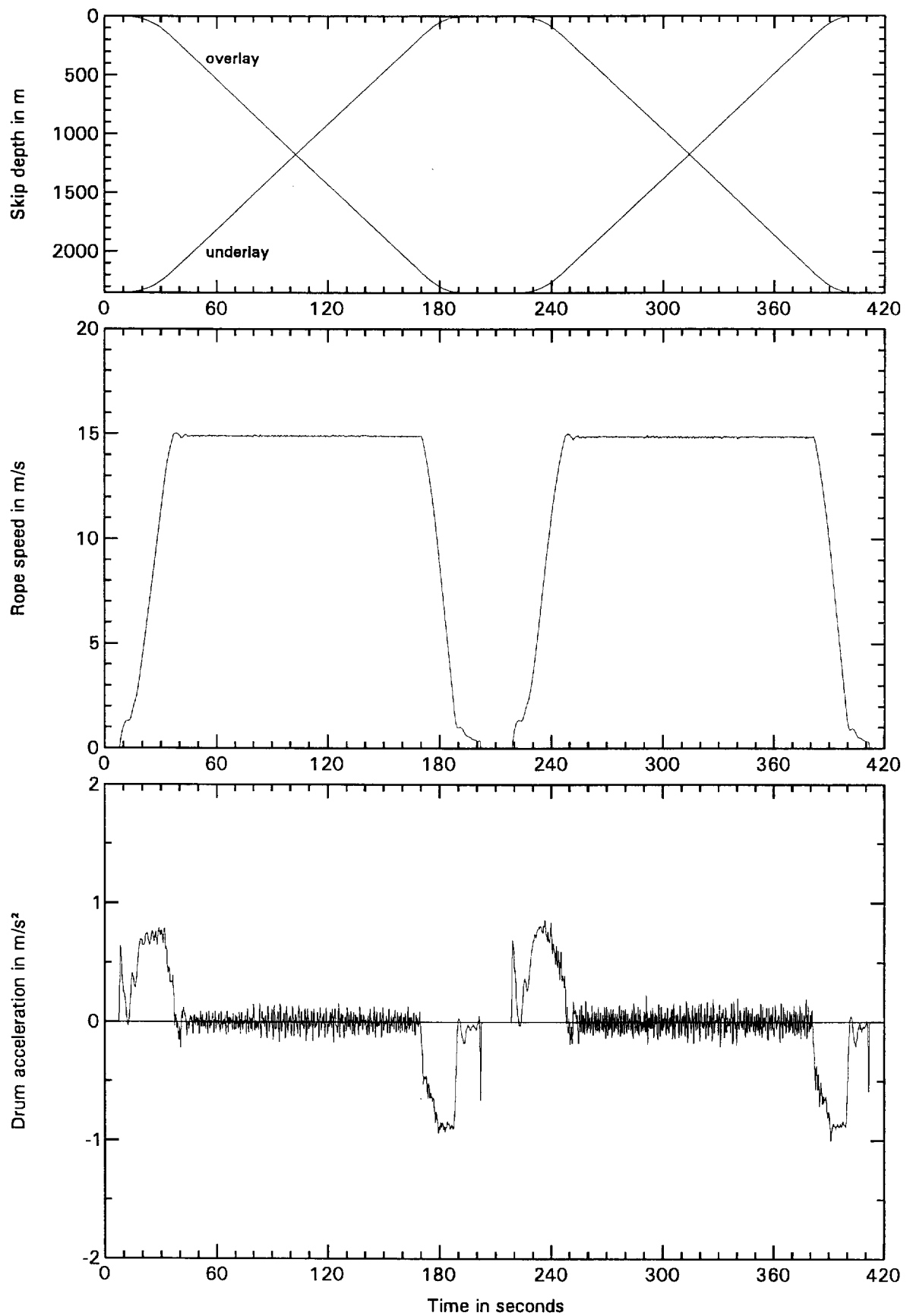
Figure A1: Winder AA: Skip position, rope speed, and drum acceleration.
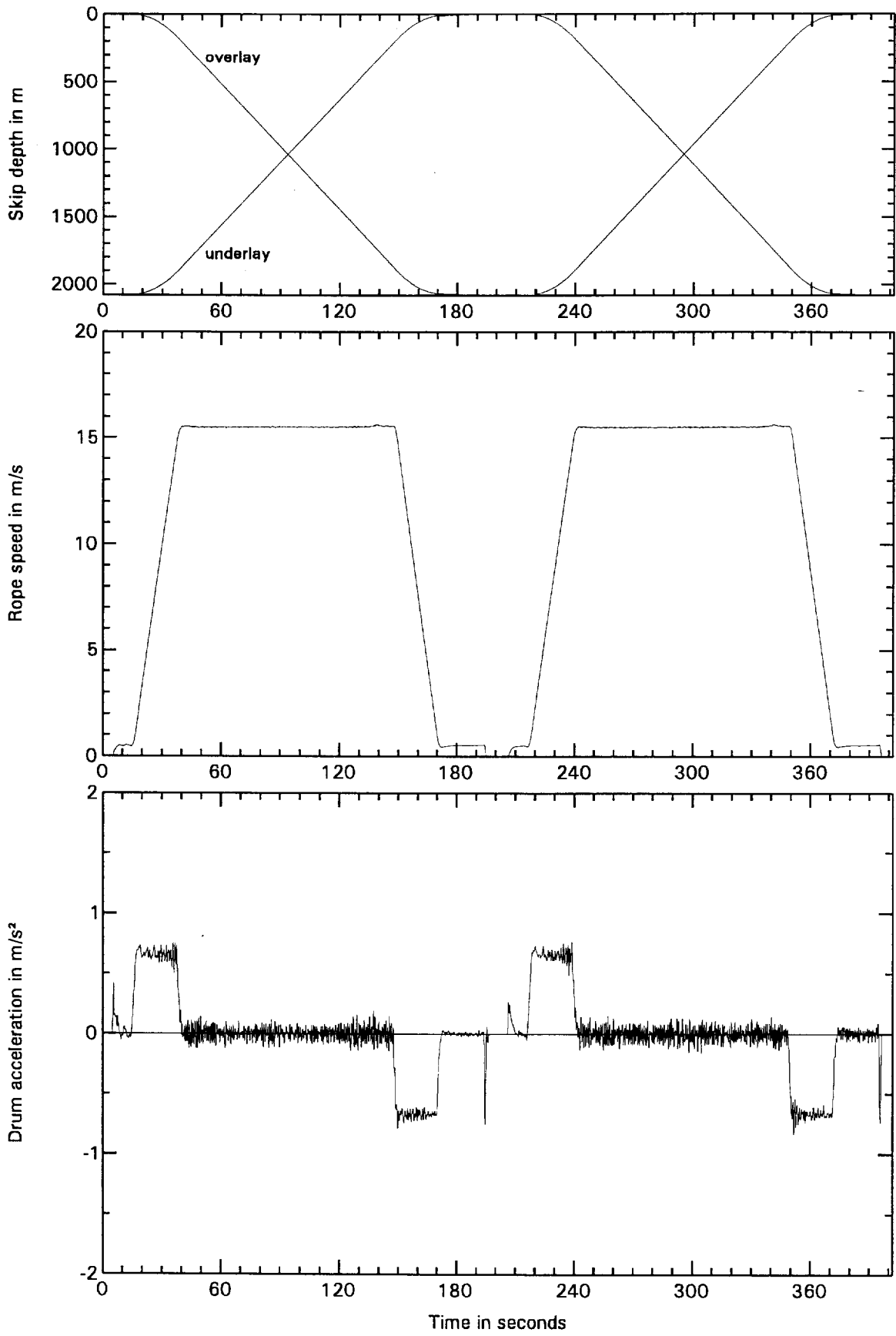
Figure A2: Winder BB: Skip position, rope speed, and drum acceleration.
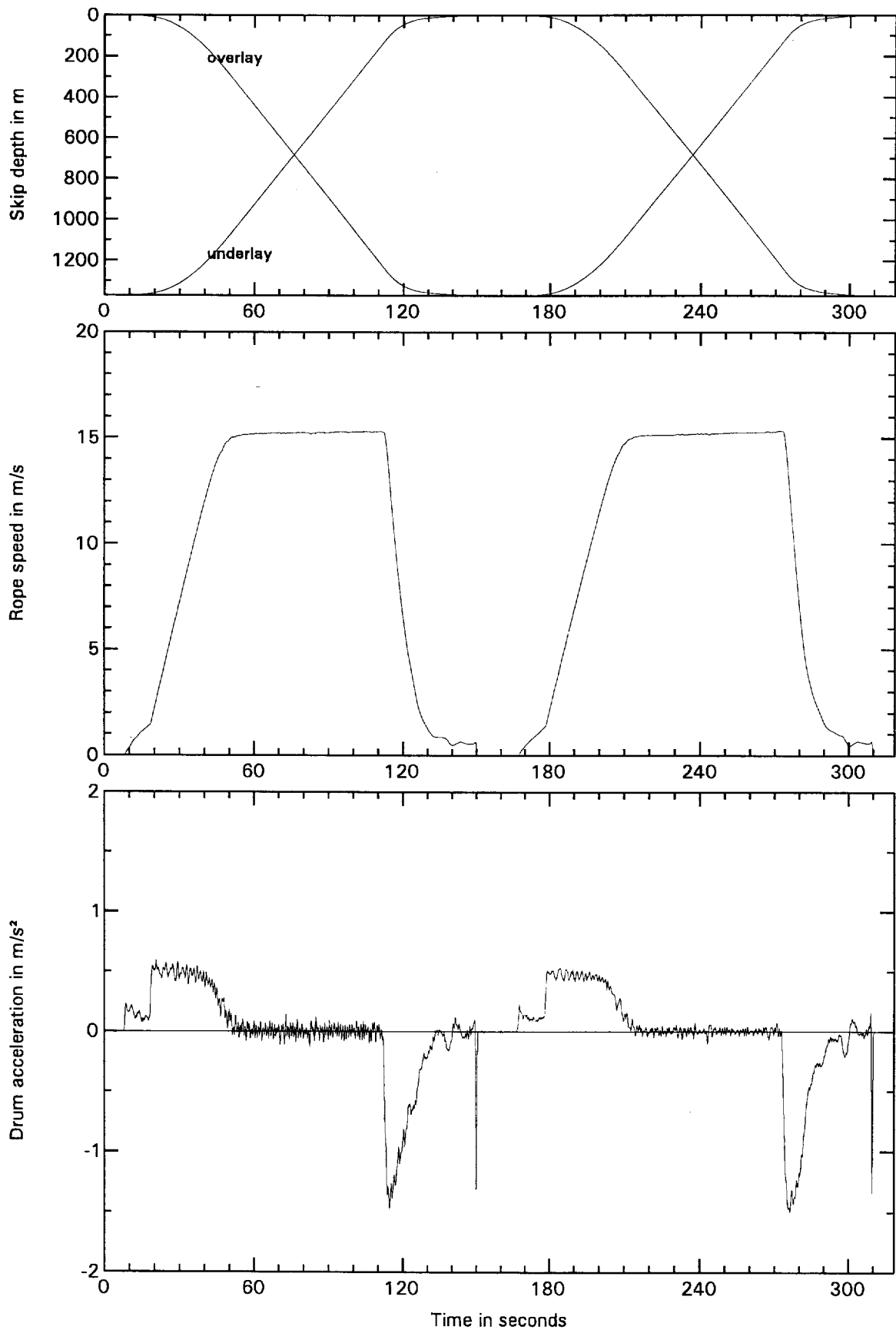
Figure A3: Winder CC: Skip position, rope speed, and drum acceleration.
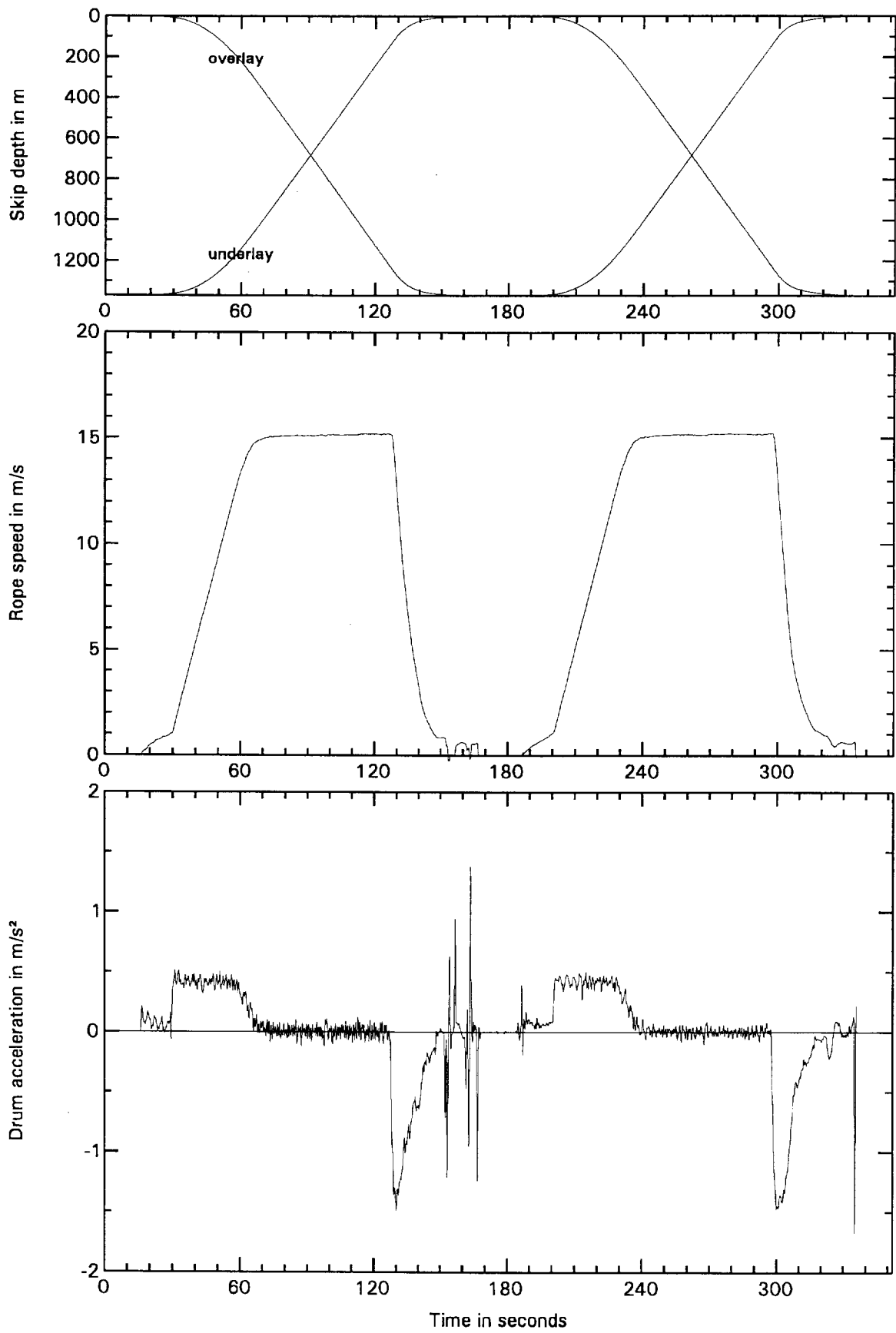
Figure A4: Winder CC: Skip position, rope speed, and drum acceleration for a cold winder drive.

APPENDIX B: OVERVIEW OF THE MEASUREMENTS AT THE COMPENSATING SHEAVES

The complete data sets recorded at all three winders are shown in this appendix to give the reader an overview of the behaviour of the compensating sheaves and the ropes sections at the compensating sheaves.

The location of the strain gauges and accelerometers on the different winders is discussed in section 3, p. 3.

B.1   WINDER AA

Details of the location of the strain gauges on the ropes at the compensating sheave of Winder AA are given in Fig. 3, p. 16. Accelerometer positions and directions are shown in Fig. 2, p. 2.

The measurements on Winder AA are shown in the graphs of this appendix as follows:

Figure B1:	Strain gauges in positions nos 1, 2, and 3.
Figure B2:	Strain gauges in positions nos 4, 5, and 6.
Figure B3:	Strain gauges in positions nos 7 and 8, and the rotation of the compensating sheave.
Figure B4:	Accelerations in the X-direction on the ropes and the skip.
Figure B5:	Accelerations in the Y-direction on the ropes and the skip.

The zero references for the measured stresses and for the rotation of the compensating sheave were at time (t) $\approx$ 40 minutes, when the skip was empty and positioned in the tip. The zero reference for strain gauge no. 5 was taken with the skip in the tip for the first time, shortly after the start of the recordings. The reason for this will follow. The zero references for the stress measurements do not represent zero stress in the rope wires, but represent the state of stress in the rope with the empty skip in the tip.

It was considered to be more meaningful to express the rotation of the compensating sheave in terms of linear rope movement. Where the rope is curved on the compensating sheave, this movement is at the centre of the rope.

In order to visualize the rotation of the compensating sheave of Winder AA, the measured extremes of the rotation are indicated on Fig. 3, p. 16, as the position at the start of the recording (t = 0), the selected zero reference point and the maximum rotation measured subsequently.

B.1.1   General observations

At the start of the recordings the (underlay) skip was first moved from bank level to the tip, after which normal rock winding commenced. The skip was emptied and stationary in the tip at t $\approx$ 2 min, 10 min, 17 min, 32½ min, 40 min, and 47 min, and reached the loading bay at t $\approx$ 6½ min, 13½ min, 20½ min, 36 min, 43 min, and 50 min. At the end of the recording period, the skip did not move all the way to the tip but stopped at bank level.

At t $\approx$ 27 minutes, Winder AA tripped out because of a conveyer problem on the down side from the tip, and the winder was inoperative for nearly one hour. The recorded data for this period is not shown.

Strain gauge no. 5, Fig. B2, was crushed between the rope and the compensating sheave towards the end of the first winding trip down the shaft, and stopped functioning.

Strain gauge no. 8, Fig. B3, became unstable from t = 10 min to t = 15 min, and data for that period is therefore not available. It is also possible that the strain gauge picked up a small zero shift in that period, but this cannot be verified.

It was mentioned that the winder was inoperative for at least nine hours prior to the start of the recordings, and settling of the ropes during the first winding cycle is the most probable reason for the shift exhibited by most of the strain gauges and the compensating sheave from the first to the second winding cycle. Creep in the ropes is the most probable reason for the step change in the data observed at t ≈ 27 min, when nearly an hour passed for which the recordings are not shown.

The measured stresses, compensating sheave rotation and accelerations displayed remarkable repeatability from one winding cycle to the next. It is therefore only necessary to perform a detailed analysis on the recordings from a single winding cycle of Winder AA.

B.1.2   Lateral rope vibrations

The accelerations measured near the compensating sheave from the lateral rope vibrations of Winder AA are shown in Fig. B4, p. 43 and Fig. B5, p. 44. The lateral accelerations measured on the skip are not significant compared to that measured on the ropes, and are not discussed further.

The resultant acceleration on a rope when combining the accelerations measured in the X-direction and the Y-direction is not given in this appendix, but an analysis showed that it was random, i.e. a dominant direction for the lateral vibration of a rope was not evident.

The amplitude of the lateral rope accelerations were larger when the full skip was hoisted than when the empty skip was lowered. The amplitude of the rope acceleration increased when the skip came closer to the top and was at a maximum during the last 1 min of the hoisting trip (the last 800 m). Although the accelerations during the lateral part of the hoisting cycle saturated the measuring equipment, it will be shown that the consequences of these lateral rope vibrations are not significant.

When the rope vibrations were at its largest, the rope oscillated at a frequency of approximately 17 Hz. The strain gauges closest to the compensating sheave tangent points during the period of largest rope vibration were strain gauge no. 1 (its rope cross-section just off the compensating sheave) and strain gauge no. 8 (its rope cross-section in the process of leaving the compensating sheave). Inspection of the stresses for these two gauges (Figs B1 and B3) for the one minute before the tip was reached (at t ≈ 10 min, 17 min, 32½ min, 40 min, and 47 min) do show stress variations at the frequency of the rope vibration, but the variations had peak-to-peak values of less than 30 MPa. Inspection of the rest of the stress measurements show that the stress variations due to the rope vibrations are far less significant than the stress variations from loading, winding and bending of the ropes.

Furthermore: The stress variations due to the lateral vibration of the ropes are visible on the recording for an estimated 10% of the winding time. At this period of significance, and at 17 Hz, it will take approximately one week to accumulate 1 million of these stress cycles. If they were a significant factor in the initiation of fatigue cracks (which ultimately lead to broken wires), the development of broken wires at the tangent points would have been far more rapid than observed in practice.

It is concluded that the influence of the lateral rope vibrations on the stress variations at the tangent points of the ropes on the compensating sheave is not significant, and will therefore not be analysed further. Lateral rope vibrations have to be at least of an order five times larger in amplitude than

those measured to generate stresses in the rope that will be comparable to the stresses generated by normal winding and bending of the ropes on the compensating sheave.

B.2   WINDER BB

Details of the location of the strain gauges on the ropes at the compensating sheave of Winder BB are given in Fig. 4, p. 17. Accelerometer positions and directions are shown in Fig. 2, p. 2.

The measurements on Winder BB are shown in the graphs of this appendix as follows:

Figure B6:	Strain gauges in positions nos 1, 2, and 3.
Figure B7:	Strain gauges in positions nos 4, 5, and 6.
Figure B8:	Strain gauges in positions nos 7 and 8, and the rotation of the compensating sheave.
Figure B9:	Accelerations in the X-direction on the ropes and the skip.
Figure B10:	Accelerations in the Y-direction on the ropes and the skip.

The zero references for the measured stresses and for the rotation of the compensating sheave were at $t \approx 61\frac{1}{2}$ minutes, when the skip was empty and positioned in the tip. As before, the zero references for the stress measurements do not represent zero stress in the rope wires, but represent the state of stress in the rope with the empty skip in the tip. Rotation of the compensating sheave is again expressed as linear rope movement at the centre of the rope.

The measured extremes of the rotation of the compensating sheave of Winder BB are indicated on Fig. 4, p. 17, as the position at the start of the recording ($t = 0$), the selected zero reference point and the maximum rotation measured subsequently.

B.2.1   General observations

At the start of the recordings the (overlay) skip was first moved from bank level to the tip, after which normal rock winding commenced. The skip was emptied and stationary in the tip at $t \approx 2$ min, $10\frac{1}{2}$ min, 17 min, 30 min, 49 min, $55\frac{1}{2}$ min, $61\frac{1}{2}$ min, 68 min, $74\frac{1}{2}$ min, $80\frac{1}{2}$ min, and 87 min, and reached the loading bay at $t \approx 7$ min, $13\frac{1}{2}$ min, $26\frac{1}{2}$ min, $35\frac{1}{2}$ min, 52 min, $58\frac{1}{2}$ min, $64\frac{1}{2}$ min, 71 min, $77\frac{1}{2}$ min, and 84 min. At the end of the recording period, the skip was emptied in the tip and moved back to bank level.

At $t \approx 35\frac{1}{2}$ min, the result of a skip overload trip-out on the overlay skip of Winder BB is shown. At $t \approx 55$ min, the electrical connector of accelerometer Xr (Fig. B9) came loose, and no further results were obtained from it.

The recordings for Winder BB also show that the ropes experienced a degree of settling during the first winding cycle. After the first winding cycle the measured stresses, compensating sheave rotation and accelerations also displayed the same type of repeatability from one winding cycle to the next as was observed for Winder AA. It is therefore also only necessary to perform a detailed analysis on the recordings from a single winding cycle of Winder BB.

B.2.2   Lateral rope vibrations

The accelerations measured near the compensating sheave from the lateral rope vibrations of Winder BB are shown in Fig. B9, p. 48 and Fig. B10, p. 49. As was observed for Winder AA, the lateral accelerations measured on the skip are not significant compared to that measured on the ropes, and are not discussed further.

The lateral accelerations of the ropes of Winder BB are similar in all respects to what was discussed for Winder AA, except that in the periods of the largest rope accelerations, the oscillations were at 13 Hz, and occurred during the last 500 m of the hoisting trip.

Although there were no strain gauges installed at the tangent points of Winder BB, it can be assumed that the influence of the lateral rope vibration on the stress variations at the tangent points of Winder BB is not significant, because of the great similarity to the accelerations measured on Winder AA. The lateral rope vibrations of Winder BB will therefore also not be analysed further.

B.3 WINDER CC

Details of the location of the strain gauges on the ropes at the compensating sheave of Winder CC are given in Fig. 5, p. 18. Accelerometer positions and directions are shown in Fig. 2, p. 2.

The measurements on Winder CC are shown in the graphs of this appendix as follows:

Figure B11:   Strain gauges in positions nos 1, 2, and 3.

Figure B12:   Strain gauges in positions nos 4, 5, and 6.

Figure B13:   Strain gauges in positions nos 1 and 5, and the rotation of the compensating sheave. Only six strain gauges were installed on Winder CC, and it was decided to repeat the results of the strain gauges with the largest readings on this graph.

Figure B14:   Accelerations in the X-direction on the ropes and the skip.

Figure B15:   Accelerations in the Y-direction on the ropes and the skip.

The zero references for the measured stresses and for the rotation of the compensating sheave were at t $\approx$ 48 minutes, when the skip was empty and positioned in the tip. As before, the zero references represent the state of stress in the rope with the empty skip in the tip. Rotation of the compensating sheave is again expressed as linear rope movement at the centre of the rope.

The measured extremes of the rotation of the compensating sheave of Winder CC are indicated on Fig. 5, p. 18, as the position at the start of the recording (t = 0), the selected zero reference point and the maximum rotation measured subsequently.

B.3.1   General observations

At the start of the recordings the (overlay) skip was moved from bank level directly to the loading bay, after which normal rock winding commenced. The skip was emptied and stationary in the tip at t $\approx$ 6 min, 12 min, 17½ min, 25 min, 31 min, 36½ min, 48 min, 53½ min, 58½ min, 64 min, and 69 min, and reached the loading bay at t $\approx$ 3 min, 8½ min, 14½ min, 20 min, 27½ min, 33½ min, 44 min, 50½ min, 56 min, 61 min, 66½ min, and 71½ min. At the end of the recording period, on the final hoisting trip, the skip did not move all the way to the tip but stopped at bank level.

At t $\approx$ 21 min and 44½ min, the winder tripped because of skip overloading. At t $\approx$ 40½ minutes, Winder CC was stationary because of a trip-out. The data for the following 20 min, during which the winder remained stationary, were removed from the results shown for Winder CC.

The recordings for Winder CC show that the ropes experienced very little settling during the first winding cycle compared to the ropes of the other two winders. This is merely an observation and no effort will be made to explain this. It can be added that the ropes on Winder were relatively new: They were put on only 5 months before the field measurements were carried out, as opposed to 10 months for Winder AA and 20 months for Winder BB.

The strain gauge and acceleration measurements of Winder CC were again very repeatable from one winding cycle to the next, but the sheave rotations were somewhat peculiar compared to the other two winders. The rotation of the compensating sheave was similar from one winding cycle to the next, but the sheave gradually accumulated movement in the positive rotation direction. During each descending trip, the compensating sheave moved approximately 30 mm in the positive direction, while it would remain approximately in one position during the hoisting trip until the skip was about 250 m (45 s) from the tip. At that point, the sheave jerked between 10 an 15 mm in the negative direction within 0,2 s. This jerking occurred nearly at the same point during nearly every winding cycle that was recorded. The jerking of the compensating sheave suggests that the sheave was a bit "sticky" on its spindle for negative rotations. For the compensating sheave to be first rotated in the one direction and then in the other demonstrated that the tension in the one rope could not always have been higher than the tension in the other rope, and tension differences could therefore not be the reason for the gradual drift of the compensating sheave of Winder CC.

The gradual drift of the compensating sheave in the positive direction was not caused by malfunctioning of the rotation measuring device. During these measurements the small wheel of the measuring device ran on top of a section of rope on the sheave that was smoothed with rope dressing. The track it made in the dressing was measured roughly at the end of the recording session as 80 mm, which ties up with the actual recordings. If the drift was caused by temperature differences in the two overlay ropes of the winder, a temperature difference of 3 °C would be required over the full lengths of the ropes. No other reasons for the drift could be thought of.

None of the strain gauges on the ropes of Winder CC showed any significant stress variations at the time that the compensating sheave jerked in the negative direction. A 10 mm change in length on a 300 m length of rope (250 m from the bank plus at least 50 m of catenary) would only give a stress change of the order of 3 MPa. As was observed, such a change in stress would hardly be noticeable amongst the other stress variations recorded, and is far less than the stress variations generated by drum layer cross-overs.

As for the other two winders, it was also only considered necessary to perform a detailed analysis on the recordings from a single winding cycle of Winder CC.

Of passing interest: Note that when the fully laden skip was stopped close to the bank level at the end of the recording session, relatively high stress variations were generated in the rope. The winder was at that time most probably under manual control and the stop was more severe than during normal operation.

B.3.2   Lateral rope vibrations

The accelerations measured near the compensating sheave from the lateral rope vibrations of Winder CC are shown in Fig. B14, p. 53 and Fig. B15, p. 54. As before, the lateral accelerations measured on the skip are not significant compared to that measured on the ropes, and are not discussed further.

The lateral accelerations of the ropes of Winder CC are similar in all respects to what were discussed for the other two winders, except that in the periods of the largest rope accelerations, the ropes oscillated at 16 Hz, and occurred during the last 500 m of the hoisting trip.

As was the case for Winder BB, there were no strain gauges installed at the tangent points of Winder CC, but the rope vibrations of Winder CC were very similar to that of Winder AA, and it can be assumed that the influence of the lateral rope vibrations on the stress variations at the tangent points is not significant. The lateral rope vibrations of Winder CC will therefore also not be analysed further.

B.4   SELECTION OF DATA FOR FURTHER ANALYSIS

The following single winding cycles were selected for further analysis and discussions in the main section of this report. The times refer to the time-scales of the figures of this appendix.

Winder AA:	t = 40 min to t = 47 min
Winder BB:	t = 61½ min to t = 68 min
Winder CC:	t = 48 min to t = 53½ min

The recordings of Winder AA between t = 2 min and t = 6½ min will also be analysed because strain gauge no. 5 was still operational during that period.
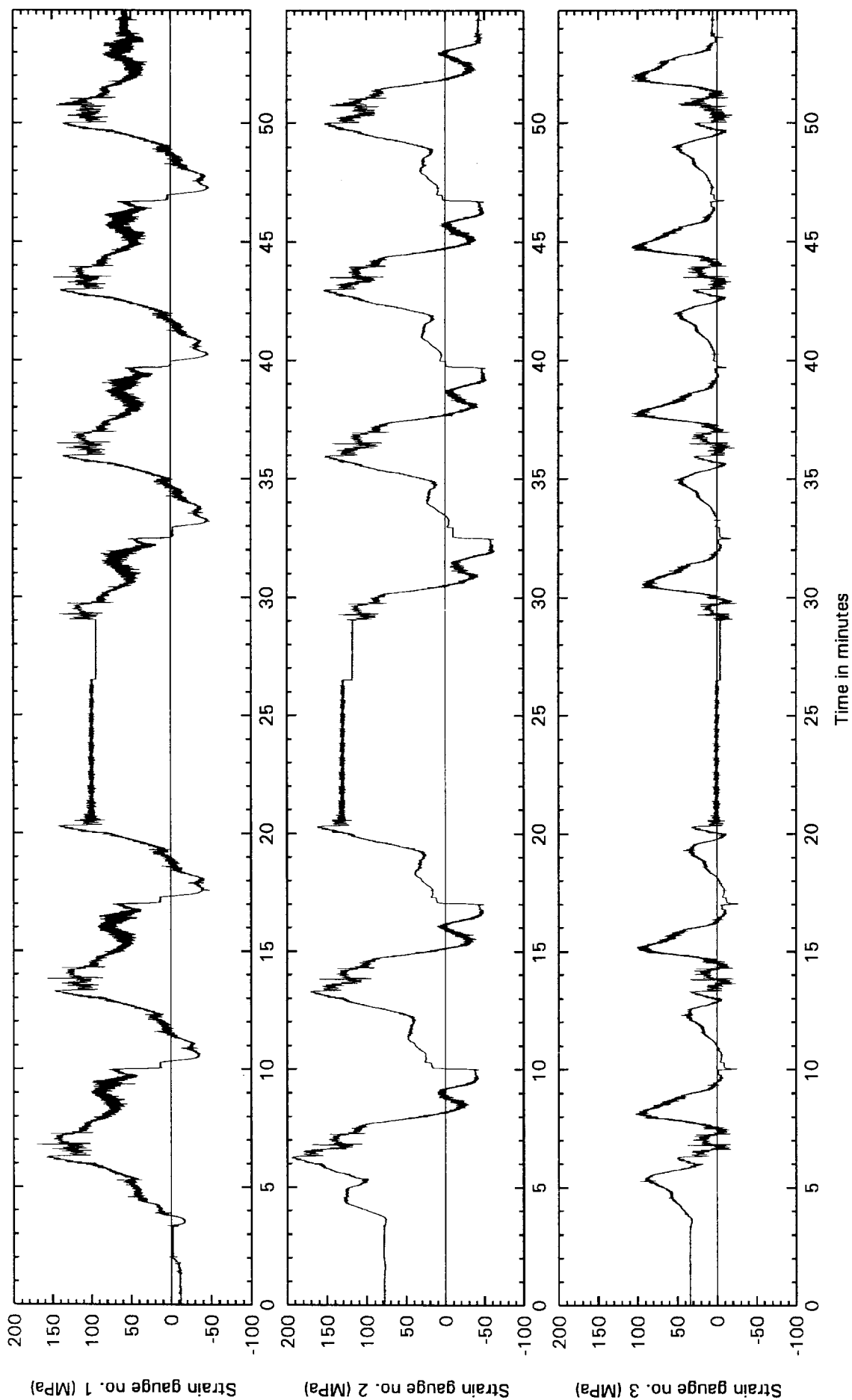
Figure B1:   Winder AA: Stress measurements.
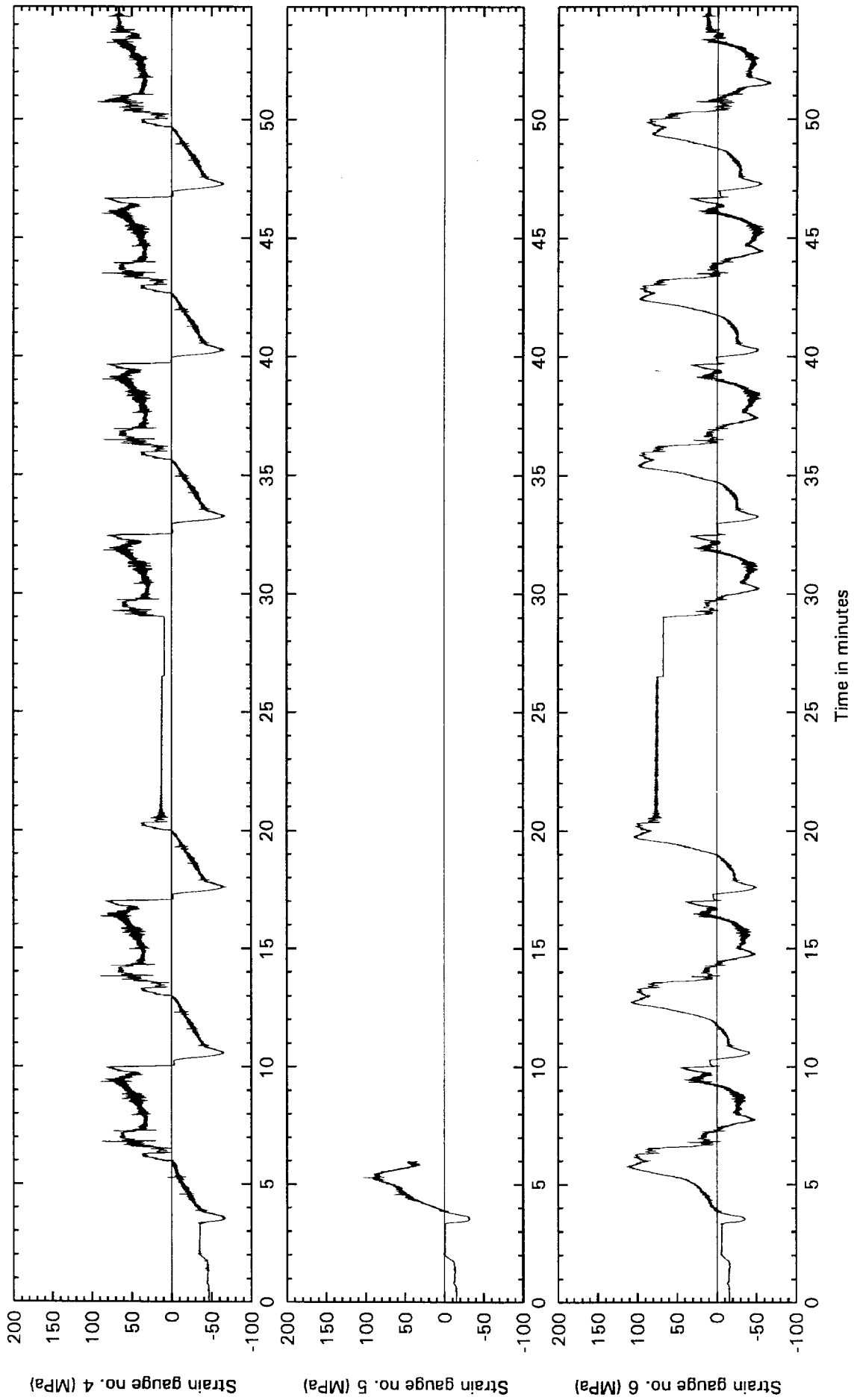
Figure B2: Winder AA: Stress measurements.
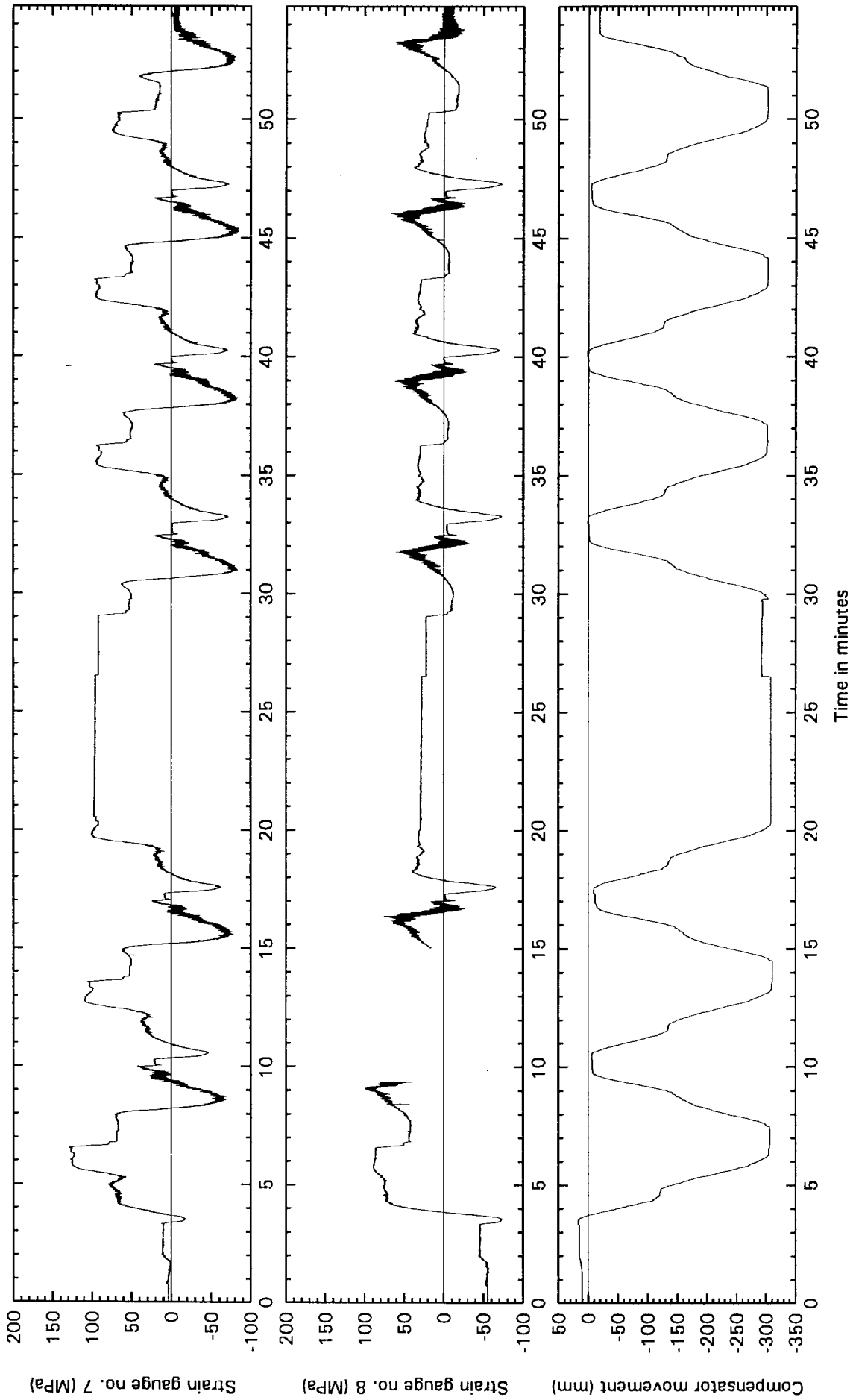
Figure B3: Winder AA: Stress measurements and compensating sheave rotation.
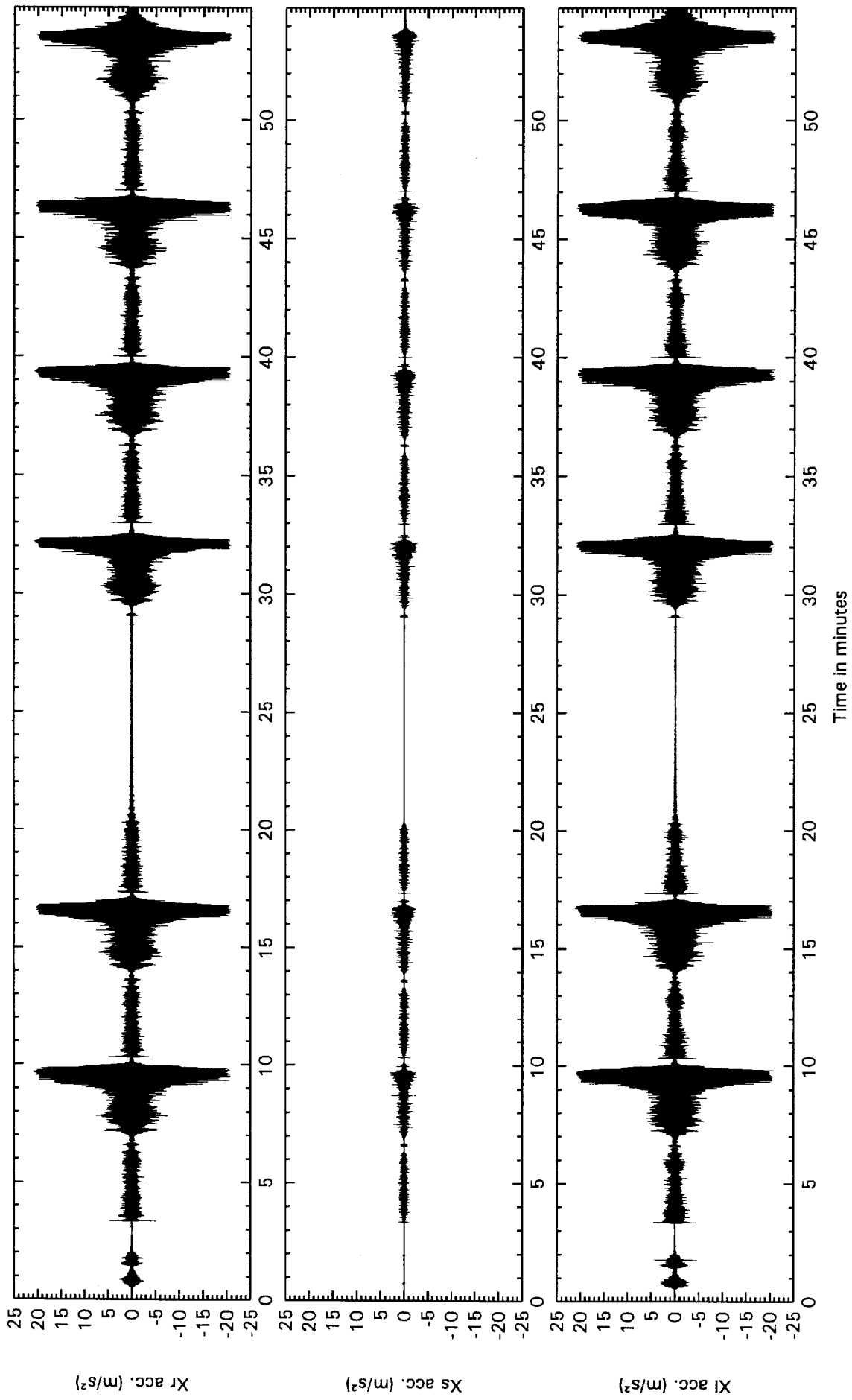
Figure B4: Winder AA: Rope acceleration measurements in the X-direction.
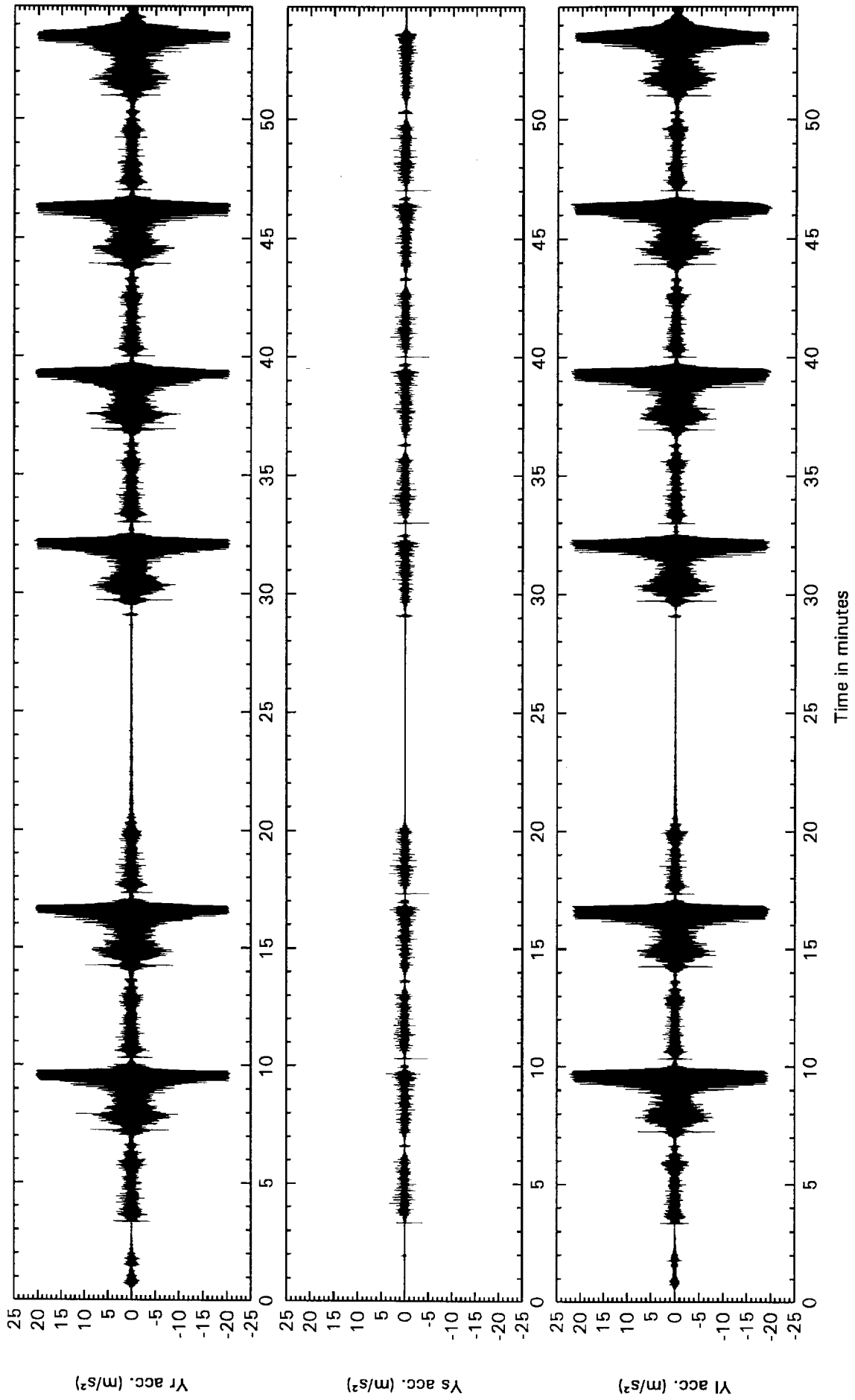
Figure B5:   Winder AA: Rope acceleration measurements in the Y-direction.
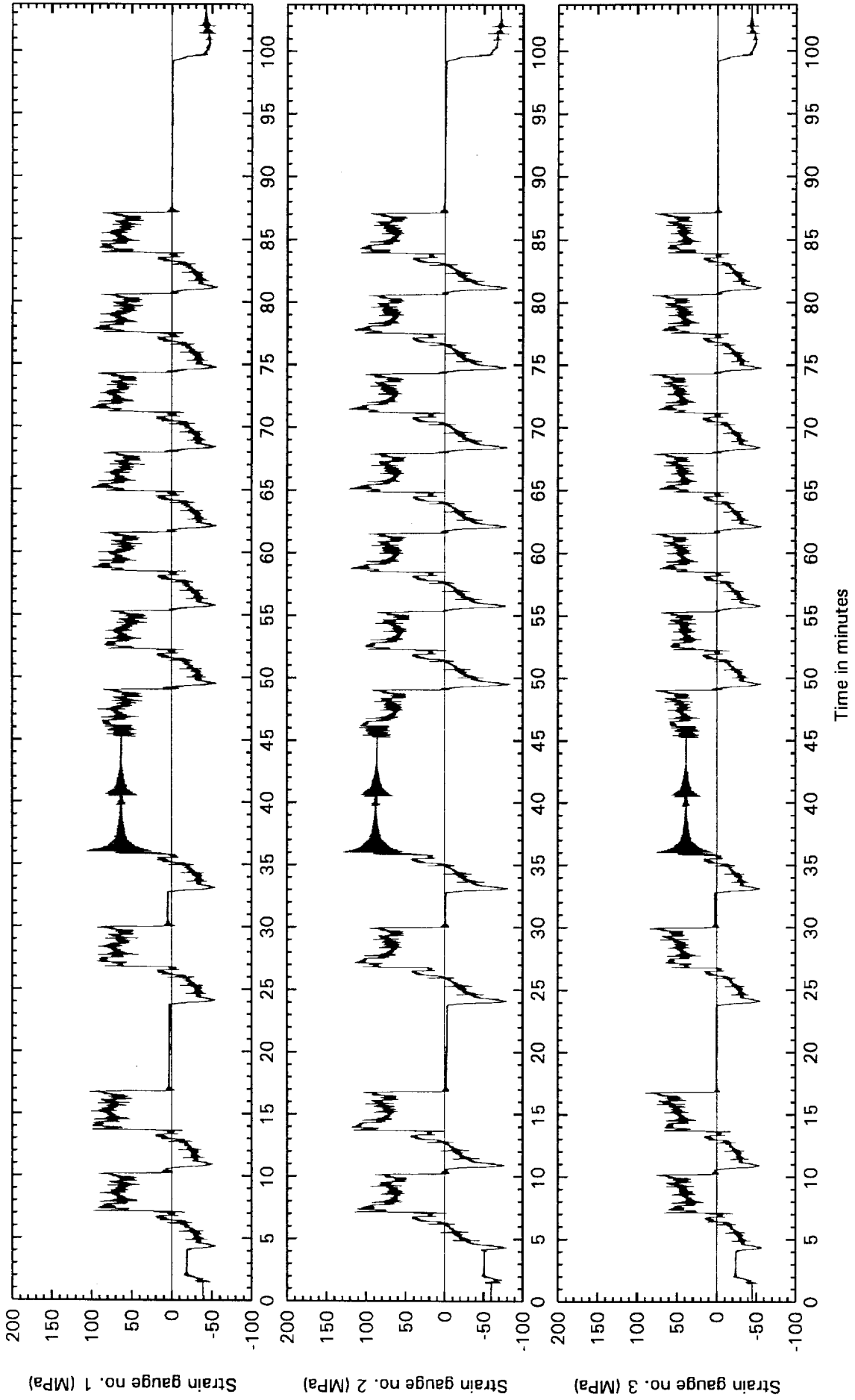
Figure B6: Winder BB: Stress measurements.
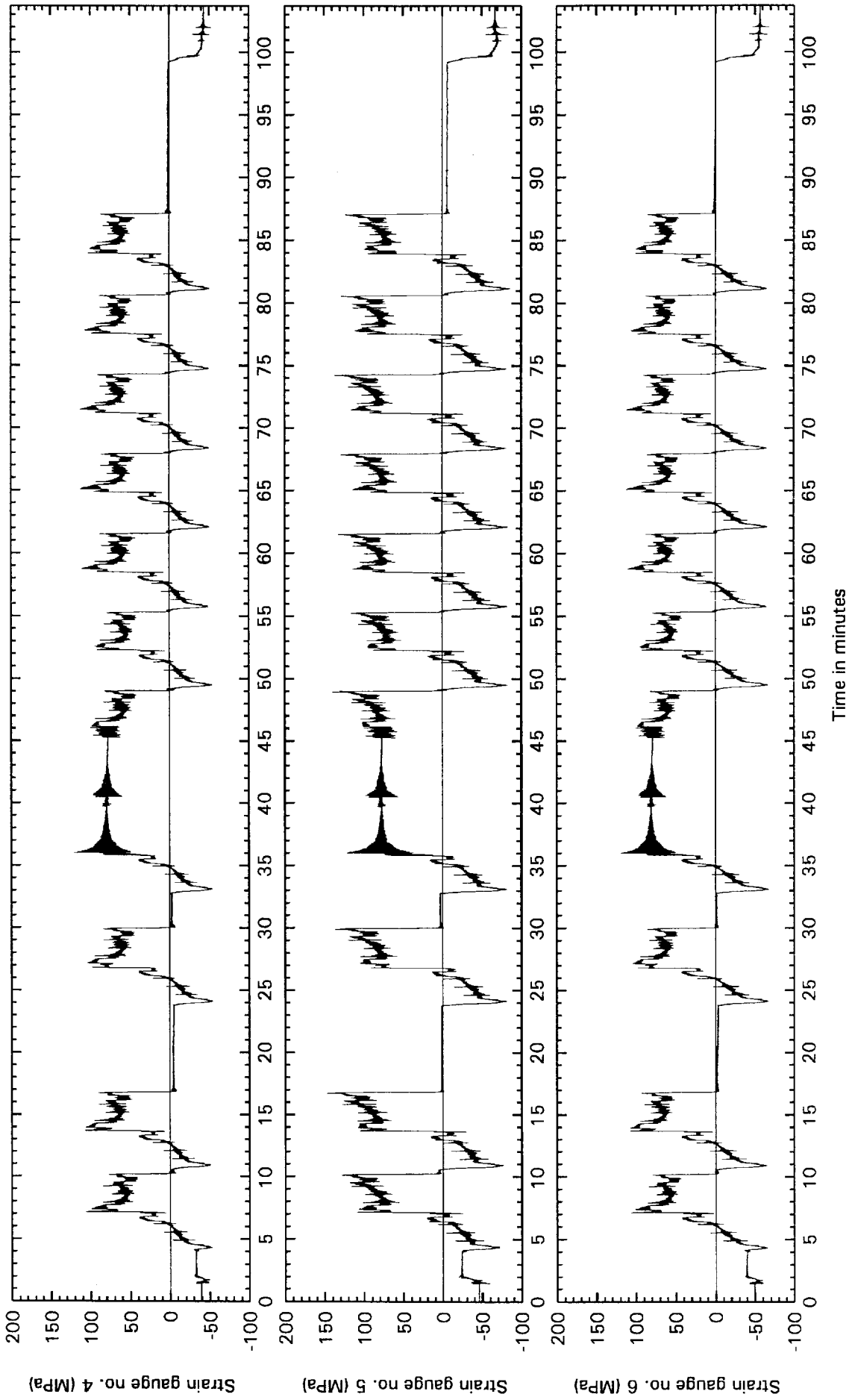
Figure B7:   Winder BB: Stress measurements.
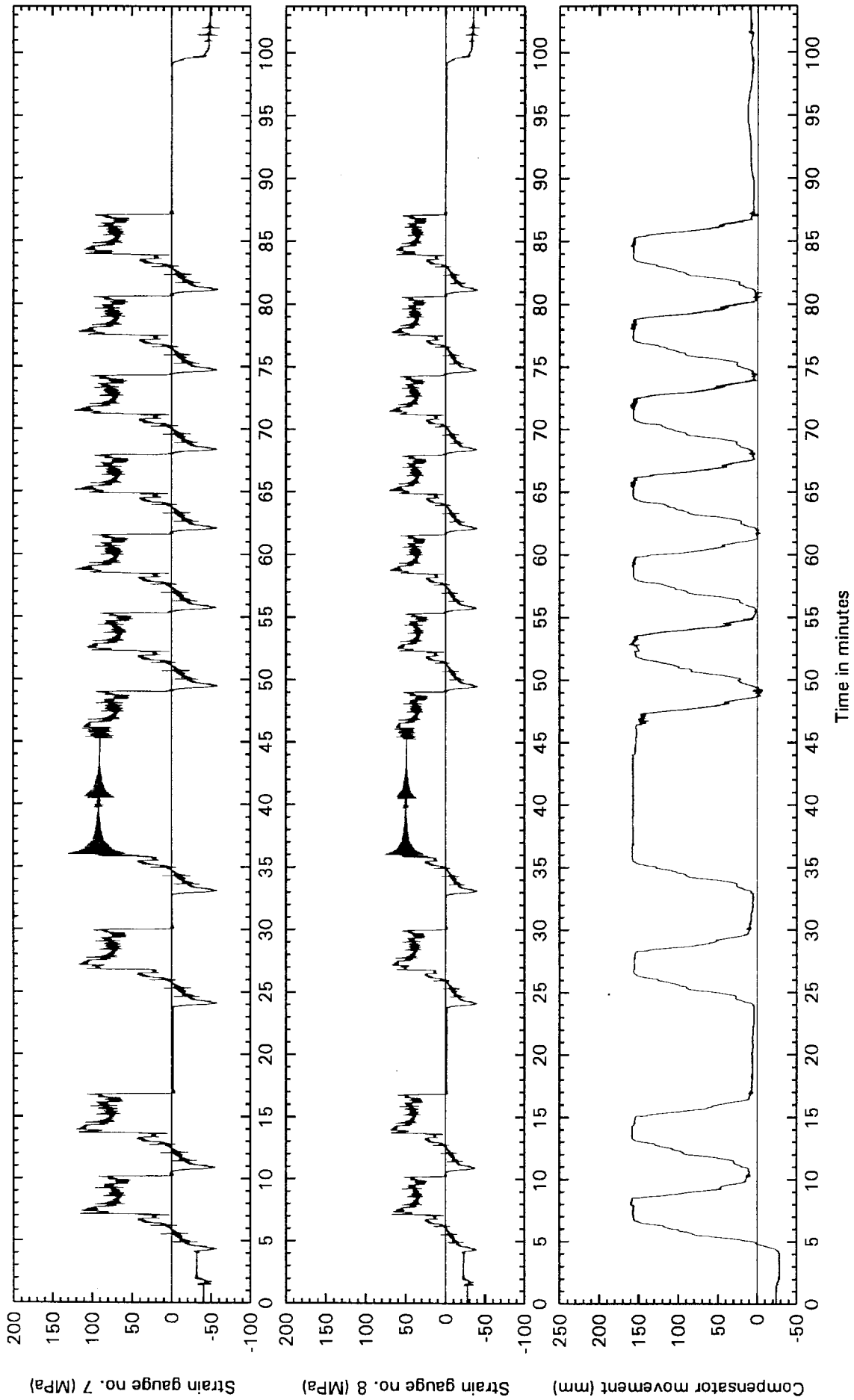
Figure B8: Winder BB: Stress measurements and compensating sheave rotation.
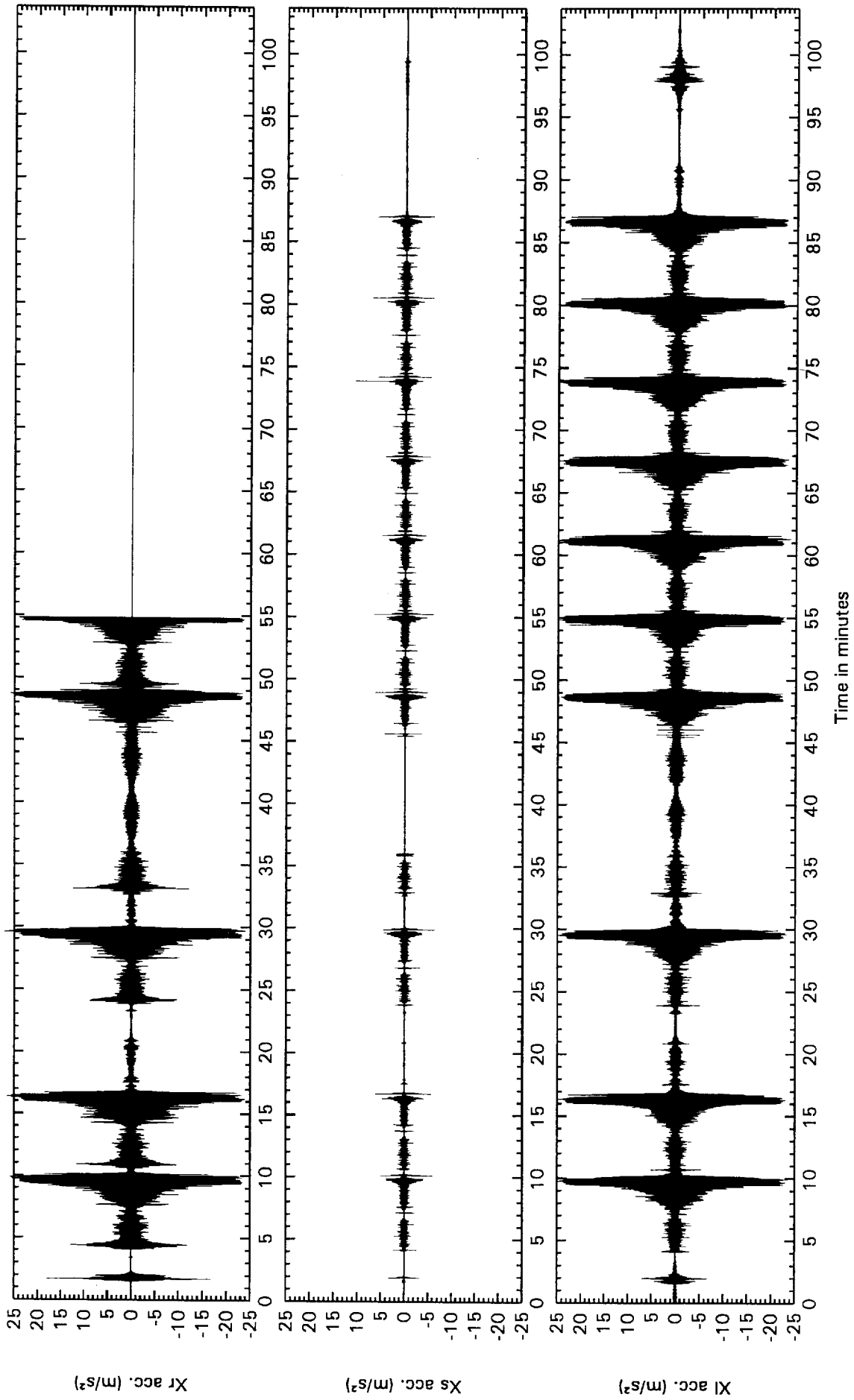
Figure B9:   Winder BB: Rope acceleration measurements in the X-direction.
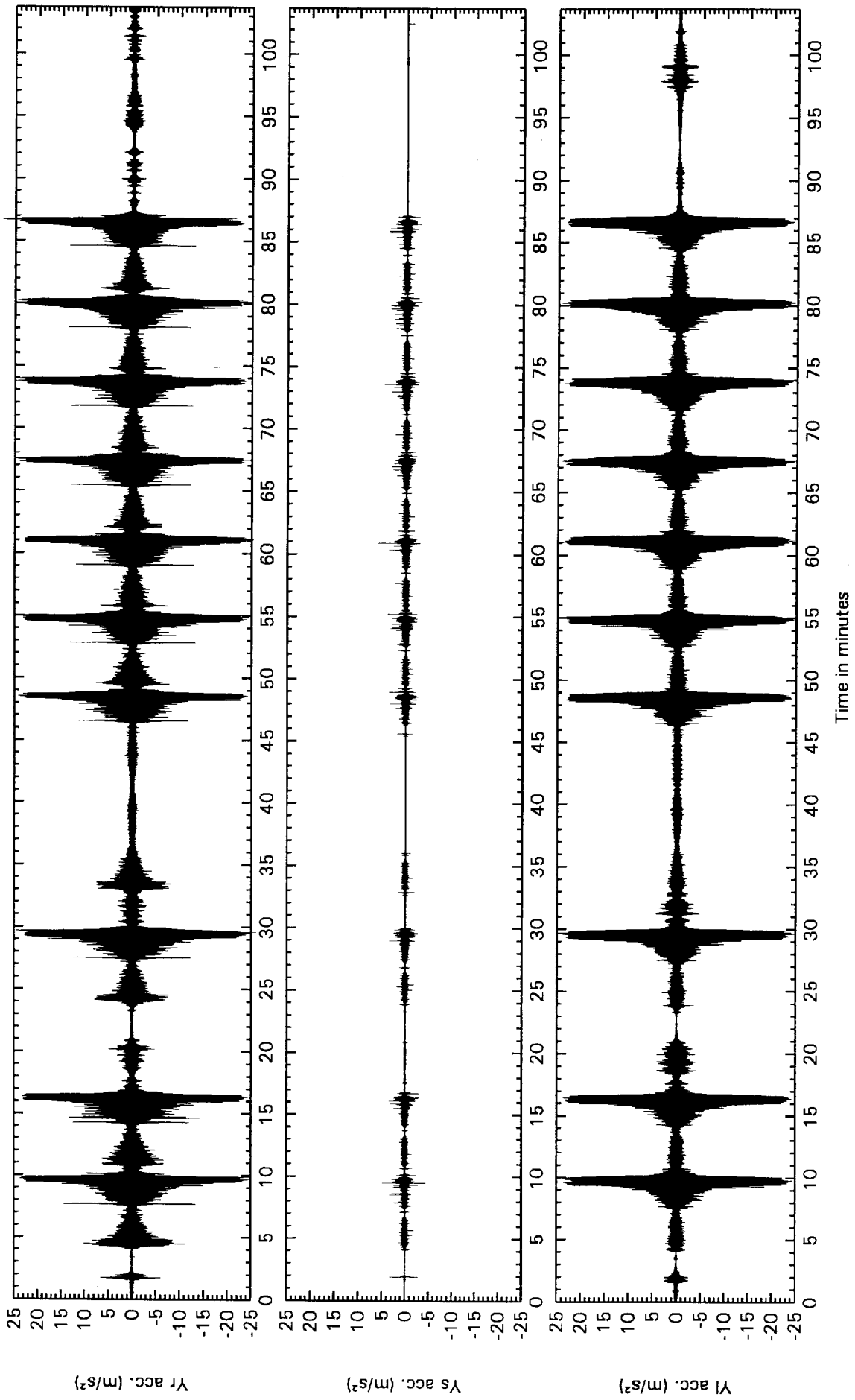
Figure B10: Winder BB: Rope acceleration measurements in the Y-direction.
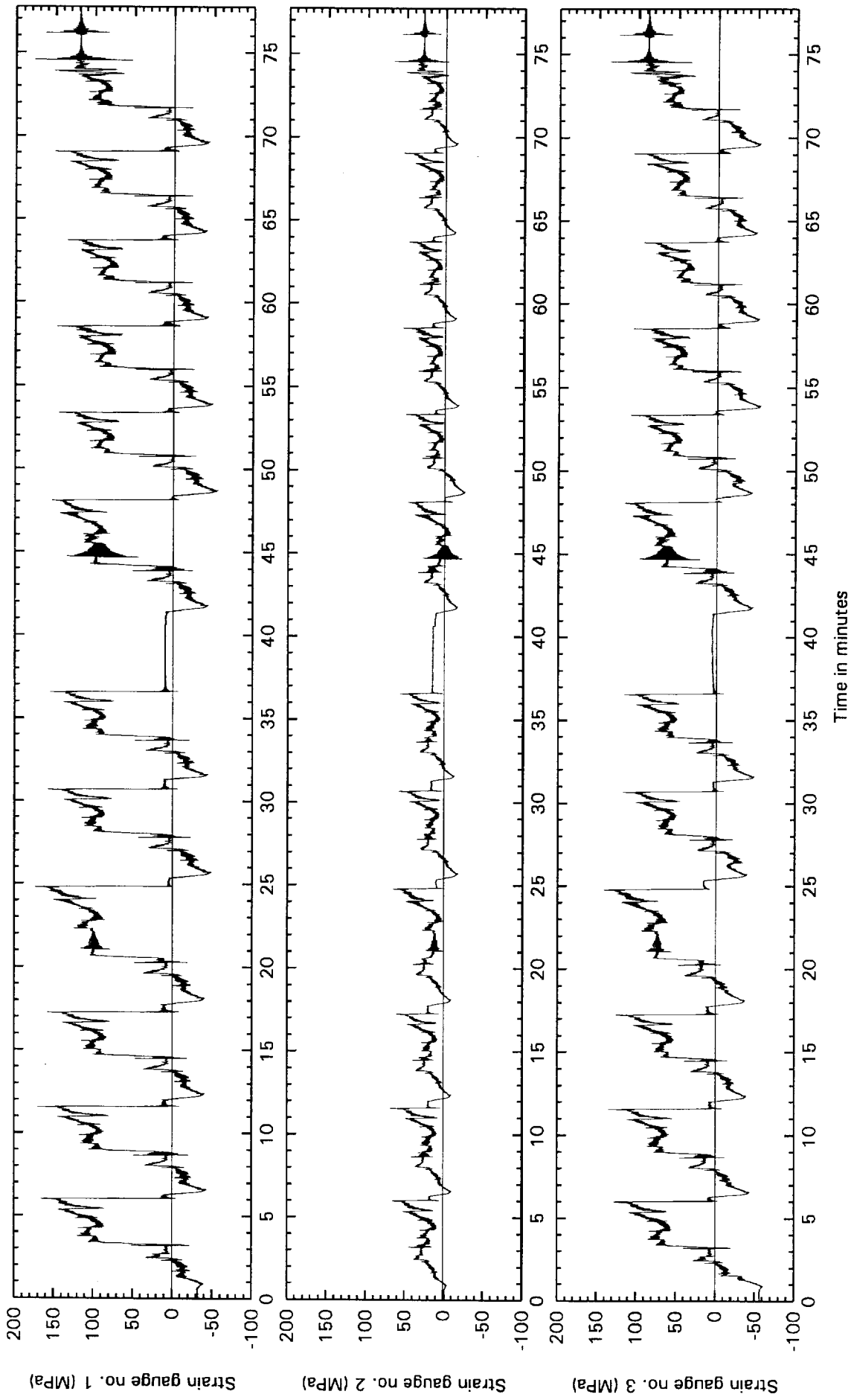
Figure B11: Winder CC: Stress measurements.
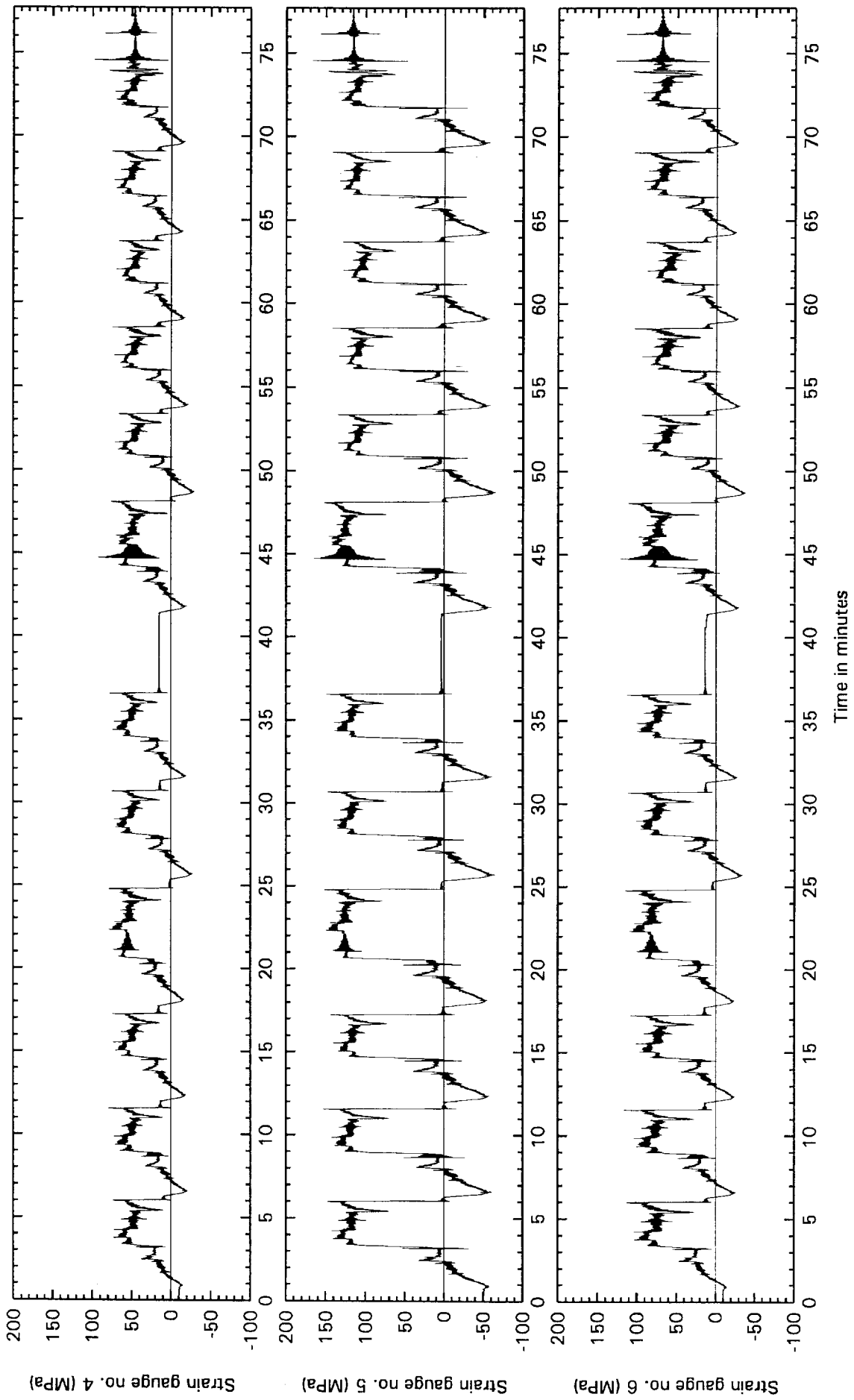
Figure B12:   Winder CC: Stress measurements.
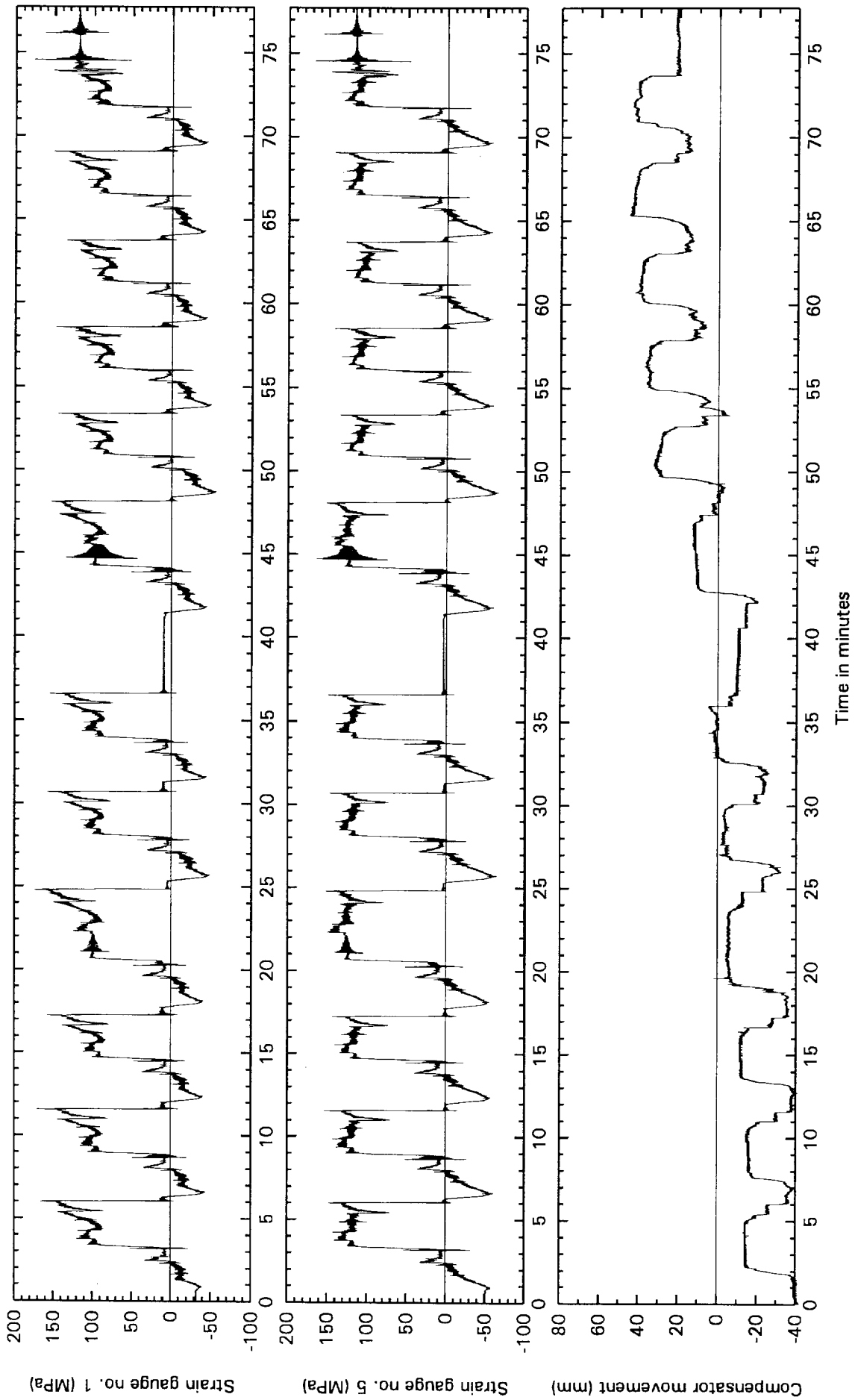
Figure B13: Winder CC: Stress measurements and compensating sheave rotation.
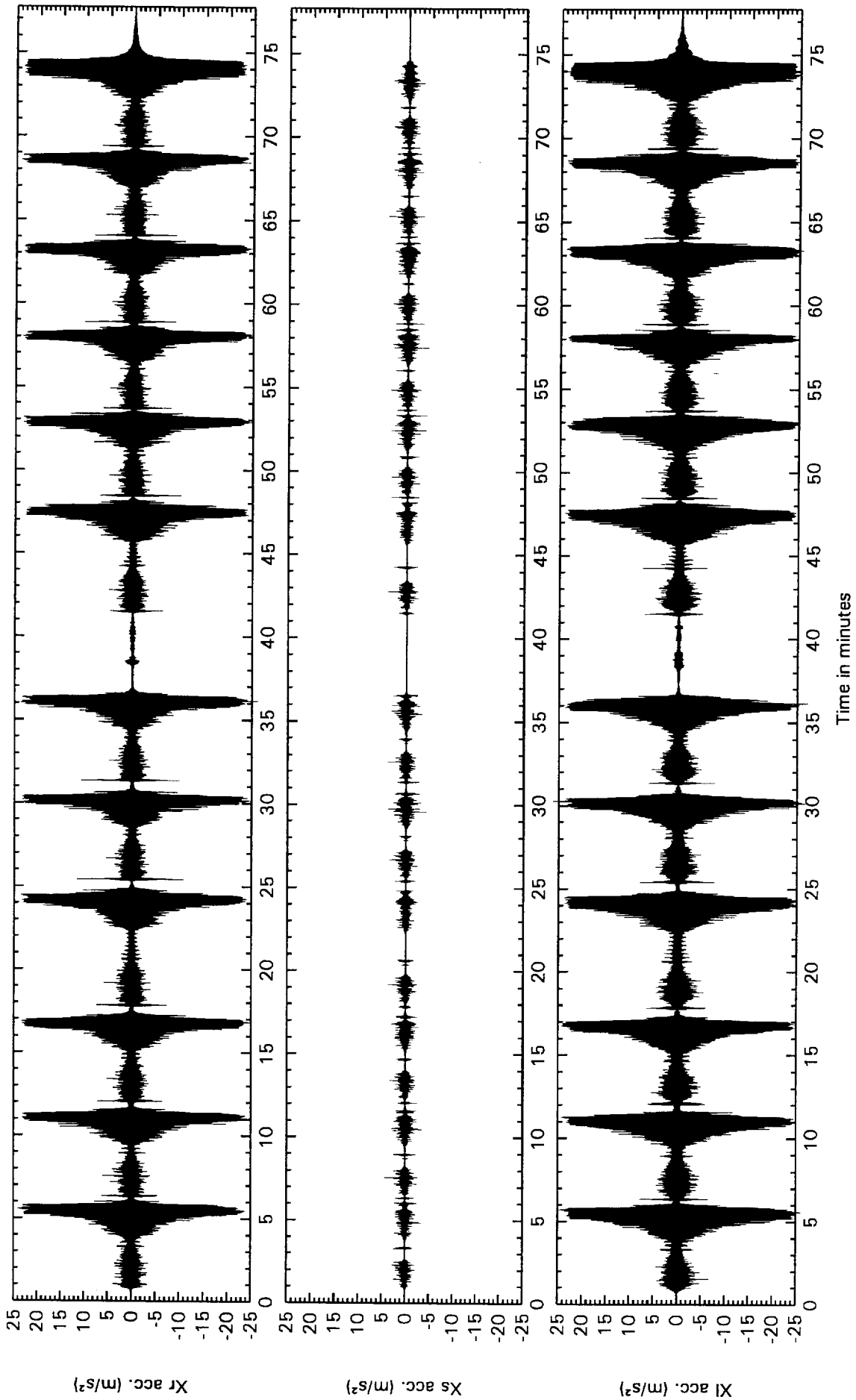
Figure B14: Winder CC: Rope acceleration measurements in the X-direction.
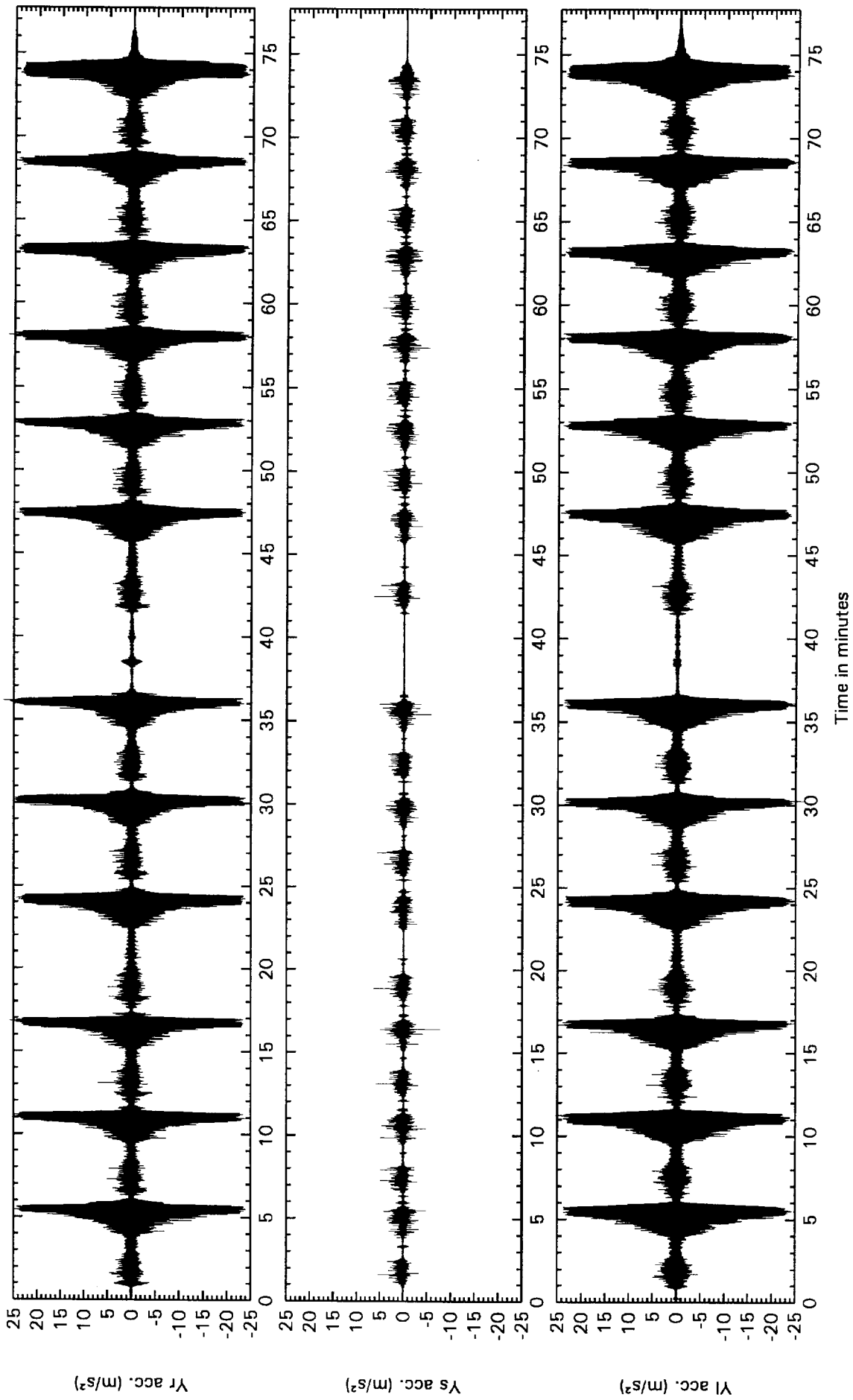
Figure B15:   Winder CC: Rope acceleration measurements in the Y-direction.

APPENDIX C: RESULTS OF TENSILE TESTS ON TANGENT POINT SPECIMENS

C.1 ORIGIN OF THE TANGENT POINT SAMPLES

During 1993, mines were requested to supply rope specimens from tangent points on compensating sheaves of BMR winders for tensile testing at the CSIR. Where possible, the time period that a tangent point was in operation as well as the number of winding cycles that the winder completed in that period were obtained from the mines.

In most cases the mines supplied the CSIR with the number of "trips" completed by a winder in the operating period, which then had to be divided by two to get to the number of cycles. In the absence of rock tonnages hoisted in the operating periods, the author of this report used his discretion in deciding whether cycles or trips were furnished.

The results of the tensile tests were supplemented from data available in the CSIR rope test data base on earlier tangent point tests. In some cases the operating periods of these tangent point samples could be established, but it was not possible to establish the number of winding cycles completed. The maximum allowable period, under the current statutory regulations, for a tangent point to be in operation is 6 months. The "? weeks" and "? cycles" in the tables of this appendix indicate unknown values. Not all tests done on compensating sheave tangent point rope samples could be recovered, because mines sometimes submitted such specimens for "special tests" without disclosing the origins of the samples.

C.2 TENSILE TESTS

All rope samples were subjected to the standard rope tensile test carried out by the CSIR. The presence of any broken wires visible on the outside of a rope specimen was established during a pre-test inspection.

The description of the surface condition of the outer rope wires of a tensile specimen is that which is normally given on the CSIR tensile test certificates, and is one of the following: (The names in brackets are the abbreviated names used in the tables of this appendix.)

- traces of pitting and corrosion   (traces)
- very slight pitting and corrosion   (very slight)
- slight pitting and corrosion   (slight)
- more than slight pitting and corrosion   (more slight)
- considerable pitting and corrosion   (considerable)
- excessive pitting and corrosion   (excessive)

The corrosive state of the inside of the rope samples, which could be examined after the tensile tests had been performed, is not given or discussed in this report because it is not of use in determining the state of a tangent point while still in operation.

Tables C1 to C12 show the results of 128 tensile tests on tangent point samples. A rope strength of -26% means that a rope sample broke at a force equal to 74% of the new rope breaking strength.

The field measurements described in the main section of this report were performed on Winders AA, BB and CC (Tables C1 to C3).

C.3   DISCUSSION OF THE RESULTS

The current winder rope discard criteria in South Africa is based on a maximum reduction in tensile strength of a rope of 10% of the new rope breaking strength. Any rope specimen which has deteriorated such that its breaking strength is more than 10% below the new rope breaking strength should therefore be considered as unacceptable. On the other hand, tests on **newly** prepared rope slices[2] have shown that they could have strengths of 20% less than the new rope strength. Acceptable limits for the strength and deterioration of drum winder rope terminations have not yet been established and are not addressed by the statutory regulations.

The data for rope samples for which the periods in service and number of winding cycles are known are too few for an expansive analysis. However, there were enough data to come to the following conclusions:

- 20% of the rope specimens tested had strength losses of more than 20%, and some even had strength losses of more than 50%.

- The data show that the tangent points were sometimes still fine after six months in service (Tables C7 and C10), but that they could also deteriorate by more than 10% in as little as 9 weeks (Tables C3 and C12).

- Winder CC (Table C3) is the only winder for which a considerable number of tangent points were tensile tested. The data set for "12 weeks/16 600 cycles" showed deterioration of 13% and 22% for the underlay ropes, while the overlay ropes were still totally acceptable. On the next set tested (14 weeks/15 200 cycles) the overlay ropes showed excessive deterioration, while one of the underlay ropes was still totally acceptable. Such a scatter in tangent point performance indicate that there have to be external factors that affect the deterioration of tangent points. The fact that a set of tangent points could still be fine after 16 600 winding cycles on this winder at least demonstrates that the 2 100 MPa ropes can perform as well as any other tensile grade. However, the results of Table C3 show that the longer a tangent point is left in service on this winder, the greater the chance for a tangent point to acquire an unacceptable degree of deterioration.

- In only four cases does the presence of one or more broken wires not indicate a loss in strength of more than 10%.

The most disturbing observation, however, is that rope specimens on which no broken wires where observed prior to the tensile test:

- There were 11 cases for which the outside rope conditions were only given as "very slight" to "slight" pitting and corrosion while breaking strength losses of 11% up to 23% were recorded.
- In the "more than slight" pitting and corrosion category there were 8 cases in which the breaking strength losses ranged from 13% up to 35%.

From this general analysis it can be concluded that if the deterioration of a BMR compensating sheave tangent point is to be maintained to less than the 10% to 20% range, then:

- The presence of any broken wires at a BMR compensating sheave tangent point, and/or any pitting and corrosion on the outside of the tangent point that is more than "slight" requires the re-making of the termination.

There are a number of cases (e.g. Table C5) that did not show any or appreciable reduction in breaking strength but with the degrees of pitting and corrosion indicated as "considerable" on the

outside of the rope. It has to be assumed that the person that carried out the assessment of the degree of corrosion on these ropes was too severe in his judgement.

Winders AA (underlay), BB (overlay) and CC (overlay) were selected for the investigation described in the main section of this report. These three winders exhibited different rates of tangent point deterioration, with Winder CC generally having the highest rate of deterioration.

The specimens of the last set of results of Table C1, and the last two sets of results of Table C3, were obtained after the field measurements were carried out. The specimens from Winder AA were cut three weeks before the field measurements were carried out on that winder, while the specimens from Winder CC were cut one week and 14 weeks after the field measurements of Winder CC were carried out.

The field measurements did not produce any indication of differences between the operating conditions of the investigated winders, except for a difference in the compensating sheave rotation during each winding cycle. It was therefore decided to undertake a closer examination of the condition of these 12 rope specimens both before and after the tensile tests. The specimens from Winder CC showed a much greater degree of pitting and corrosion than those of Winder AA, and also showed large and unacceptable losses in strength (as much as 44%).

Experience has shown that corroded ropes exhibit very little plastic deformation during a tensile test, and consequently will show a large number of brittle fractures. This was indeed the case for the specimens from Winder CC. It is more likely that the severe reduction in tensile strength of the specimens from Winder CC was the result of corrosion, rather than by the mechanical operations of the ropes at the compensating sheaves.

Local flat spots were also noticed on some of the specimens from both Winder AA and Winder CC. Inspection of the ropes after the tensile tests showed that the flat spots were caused by wear (removal of material) and not by plastic deformation.

An inspection of the overlay compensating sheave of Winder AA during a site visit showed that the overlay rope compensating sheave only moved approximately 50 mm of rope on and off the sheave during every winding cycle as opposed to the 300 mm of the underlay compensating sheave. Although Table C1 does not show consistent differences between the two sides, there is a hint that the side with the longer compensating length may be more susceptible to damage. However, on the last set of specimens from Winder AA that were tested, the side with the longer compensating length performed better.

It is the opinion of the author of this report that inconsistency and the scatter of the performance of compensating sheave tangent points are largely due to corrosion at those points.

If the onset of corrosion cannot be prevented or eliminated at the tangent points, the front ends of winders with "problematic" tangent points should be re-made every eight weeks. Winders BB and CC are such examples.

Lastly: When tested in the laboratory, the specimens have laylengths approximately 20% longer than when in service, because of the torque characteristics of triangular strand ropes. The specimens are also straight when tested as opposed to the tangent points that are curved on the compensating sheaves. It is considered that these differences would not have influenced the tensile test results appreciably.

TABLE C1: WINDER AA: RESULTS OF THE TENSILE TESTS

Also see Table C11 for results from an identical winder.
Rope: 48 mm, 6x33, 1 900 MPa, ungalvanized   New strength: 1 820 kN
D/d: 27   Depth: 2 360 m   Winder ID: 4129

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope*		Overlay rope	
	Outer rope (LHL)	Inner rope (RHL)	Inner rope (RHL)	Outer rope (LHL)
? weeks ? cycles	5 + very slight -26%	very slight -5%	very slight +2%	very slight 0%
? weeks ? cycles	very slight -9%	1 + very slight -6%	slight +2%	very slight +1%
10 weeks 9 000 cycles	very slight +1%	very slight +2%	very slight +1%	slight 0%
	next rope set			
? weeks ? cycles	very slight -17%	6 + very slight -23%	very slight -2%	very slight -1%
13 weeks 9 000 cycles	2 + very slight -4%	very slight -6%	2 + very slight -27%**	very slight -7%

* The compensating sheave of this side of the winder were used for the field measurements described in the main section of this report.

** The two broken wires were located in different strands, but in the same cross-section of the rope. At one of the broken wires, the rest of the outer wires in that strand showed quite severe nicking. During the tensile test, that strand of the rope failed at the nicked points. The nicking was the cause of the relatively large reduction in strength of that rope specimen. The indications were that the nicking was caused by a section of the first broken wire being trapped between the rope and the compensating sheave for two or more winding cycles.

TABLE C2: WINDER BB: RESULTS OF THE TENSILE TESTS

Also see Table C12 for results from an identical winder.

Rope: 44 mm, 6x30, 1 900 MPa, ungalvanized   New strength: 1 530 kN
D/d: 27   Depth: 2 085 m   Winder ID: 6064

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope*	
	Outer rope	Inner rope	Inner rope	Outer rope
	RHL	LHL	RHL	LHL
6 months ? cycles		23 + more slight -37%	17+ more slight -34%	
	2nd rope set later			
	RHL	RHL	RHL	RHL
8 weeks 4 500	very slight -3%	very slight -2%	slight -7%	more slight -10%
	next rope set			
	RHL	LHL	RHL	LHL
8 weeks ? cycles				more slight -14%

*   The compensating sheave of this side of the winder were used for the field measurements described in the main section of this report.

TABLE C3: WINDER CC: RESULTS OF THE TENSILE TESTS

Rope: 42 mm, 6x30, 2 100 MPa, ungalvanized   New strength: 1 520 kN
D/d: 30   Depth: 1 377 m   Winder ID: 7574

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope*	
	Outer rope (RHL)	Inner rope (LHL)	Inner rope (LHL)	Outer rope (RHL)
13 weeks ? cycles	very slight -8%	2 + very slight -39%	very slight -11%	very slight -6%
10 weeks ? cycles	very slight -6%	very slight -9%	very slight -7%	very slight -1%
15 weeks ? cycles	1 + very slight -17%	2 + very slight -41%	very slight -18%	very slight -3%
next rope set				
12 weeks 8 000 cycles	3 + more slight -18%	more slight -15%	3 + more slight -38%	more slight -35%
16 weeks 10 600 cycles	4 + more slight -42%	1 + more slight -18%	13 + more slight -58%	10 + more slight -52%
9 weeks 6 000 cycles	slight -16%	very slight -15%	2 + slight -8%	1 + very slight -4%
3 weeks 2 000 cycles	very slight +2%	very slight +3%	very slight +2%	very slight +3%
14 weeks 9 600 cycles	5 + slight -38%	2 + slight -24%	slight -15%	slight -20%
12 weeks 16 600 cycles	very slight -13%	very slight -22%	very slight -2%	very slight -2%
14 weeks 15 200 cycles	very slight -3%	slight -15%	very slight -19%	1 + slight -25%
11 weeks ? cycles	slight -3%	slight -2%		very slight -7%
7 weeks ? cycles	very slight 0%	very slight 0%	slight +3%	very slight +1%
next rope set				
22 weeks 17 200 cycles	more slight -9%	1 + more slight -39%	2 + slight -44%	slight -23%
16 weeks 16 000 cycles	more slight -13%	more slight -21%	more slight -15%	slight -19%

*   The compensating sheave of this side of the winder were used for the field measurements described in the main section of this report.

TABLE C4: WINDER DD: RESULTS OF THE TENSILE TESTS

Rope: 33 mm, 6x26, 1 900 MPa, ungalvanized   New strength: 830 kN
D/d: ?   Depth: 1 721 m   Winder ID: 7548

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	Outer rope - (LHL)	Inner rope (RHL)	Inner rope (LHL)	Outer rope (RHL)
? months ? cycles	considerable -11%	3 + excessive -23%	more slight -10%	1 + considerable -17%

TABLE C5: WINDER EE: RESULTS OF THE TENSILE TESTS

Rope: 41 mm, 6x29, 1 800 MPa, ungalvanized   New strength: 1 290 kN
D/d: 29   Depth: 1 099 m   Winder ID: 7558

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	RHL rope	LHL rope	LHL rope	RHL rope
3 months 11 000 cycles	considerable -2%	considerable 0%	considerable 0%	considerable 0%

TABLE C6: WINDER FF: RESULTS OF THE TENSILE TESTS

Rope: 45 mm, 6x30, 1 800 MPa, ungalvanized   New strength: 1 580 kN
D/d: 26   Depth: 2 043 m   Winder ID: 4066

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Overlay rope		Overlay rope	
	RHL rope	LHL rope	LHL rope	RHL rope
3½ months 8 000 cycles	considerable -3%	more slight -2%	considerable -10%	considerable -7%

TABLE C7: WINDER GG: RESULTS OF THE TENSILE TESTS

Rope: 48 mm, 6x32, 2 000 MPa, ungalvanized   New strength: 1 920 kN
D/d: 26   Depth: 2 285 m   Winder ID: 5515

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	RHL rope	LHL rope	LHL rope	RHL rope
6 months 8 000 cycles	slight -6%	slight -7%	slight -2%	very slight -9%

TABLE C8: WINDER HH: RESULTS OF THE TENSILE TESTS

Rope: 42 mm, 6x30, 2 100 MPa, ungalvanized   New strength: 1 520 kN
D/d: 27   Depth: 2 388 m   Winder ID: 5505

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	Outer rope (RHL)	Inner rope (LHL)	Inner rope	Outer rope
4 months 15 000 cycles	10 + excessive -26%	1 + excessive -15%		

TABLE C9: WINDER II: RESULTS OF THE TENSILE TESTS

Rope: 48 mm, 6x32, 1 800 MPa, ungalvanized   New strength: 1 760 kN
D/d: 24   Depth: 2 225 m   Winder ID: 4089

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	Outer rope (LHL)	Inner rope (RHL)	Inner rope (LHL)	Outer rope (RHL)
11 weeks 5 000 cycles	slight 0%	considerable -3%	very slight -8%	1 + more slight -4%

TABLE C10: WINDER JJ: RESULTS OF THE TENSILE TESTS

Rope: 44 mm, 6x30, 1 800 MPa, ungalvanized   New strength: 1 460 kN
D/d: 35   Depth: 2 073 m   Winder ID: 6569

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	Outer rope (LHL)	Inner rope (RHL)	Inner rope (LHL)	Outer rope (RHL)
6 months 14 500 cycles	very slight +3%	more slight +2%	very slight +3%	very slight +2%

TABLE C11: WINDER KK: RESULTS OF THE TENSILE TESTS

This winder is identical to Winder no. AA
Rope: 48 mm, 6x33, 1 900 MPa, ungalvanized   New strength: 1 820 kN
D/d: 27   Depth: 2 360 m   Winder ID: 4137

Period in service and number of winding cycles completed	Number of broken wires + pitting and corrosion condition, and tangent point strength expressed as a percentage change of the initial rope breaking strength			
	Underlay rope		Overlay rope	
	Outer rope (RHL)	Inner rope (LHL)	Inner rope (LHL)	Outer rope (RHL)
? months ? cycles	very slight -1%	very slight 0%	very slight -1%	more slight -4%
	next rope set			
? months ? cycles	traces +2%	very slight +1%	very slight +2%	very slight +2%
3½ months 2 500 cycles	very slight +3%	very slight +1%	very slight +1%	very slight +2%

Project No.: MHSOC

ROPE TERMINATIONS FOR

MINE HOISTING APPLICATIONS

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MINE HOISTING TECHNOLOGY
DIVISION OF MATERIALS SCIENCE AND TECHNOLOGY

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1 INTRODUCTION.

On its own a wire (or fibre) rope is not a particularly useful entity. To be of use it must be connected to equipment, or anchors, at each end. To this extent the termination is as important as the rope. A termination can be as simple as a knot in a fibre rope or as complicated as is necessary to connect a large diameter rope to a mine winder conveyance with provision for detaching in the event of an overwind and maintaining tension equalisation with other ropes in the system.

The prime requirements of a termination are that it is strong enough for the application, that it should not disconnect accidentally and without warning and that it does not deteriorate (or cause the rope to deteriorate) so quickly that its strength is reduced by more than is allowed in the regulations within an inspection period.

There are many types of rope termination which have been developed for particular applications. In all cases there are rules and guidelines which have been established to ensure safe operation. Some of these are self evident but the majority have been the result of experience, research and observation. As far as possible, these rules and guidelines will be examined and explained to establish the rationale for safe operation.

One of the most onerous and sensitive applications, from the point of view of safe operation, is the termination of wire ropes used in mine winding. Mine winders are called on to operate almost continuously in difficult conditions comprising such factors as vibration, corrosion and high loads including dynamic loading. The safety record of rope terminations for mine hoisting is extremely good and a credit to the personnel who operate and maintain the equipment.

The type of rope termination used is predicated by the type of winder and the conditions of operation. Other factors in the choice are the sophistication of operating and maintenance personnel, the established level of technology on the mine and the availability of advanced back-up facilities in the community. Features which need to be considered are such concepts as the efficiency[#] of the termination, the time taken for making the termination and the expected period before the termination has to be remade. Additional factors which have a bearing on the choice are the compactness of the termination and its suitability with respect to other equipment such as detaching gear. Each type of winder presents features which tend to limit the choice to only a few of the available terminations.

[#] The efficiency of a termination is defined as the ratio of the breaking strength of the rope with termination attached to the actual breaking strength of the rope, expressed as a percentage.

2 ROPE TERMINATIONS FOR DRUM WINDERS.

In South Africa, the vast majority of mine winders are drum winders. These vary from the simplest type of winder (or winch) to complicated high powered winders operating at depths of wind of 2500 m, with plans for even greater depths of wind.

2.1 GUIDELINES FOR USE.

Due to the basic simplicity of drum winders, there are very few restrictions regarding the types of termination which can be used to connect the rope to the conveyance and these relate mostly to the operating conditions rather than to basic winder characteristics.

2.1.1 Conventional.

A conventional drum winder is one with only one hoisting rope per drum. It can be a single drum winder or a double drum where one rope is payed out from one drum while the other is being wound onto the other drum. The double drum winder can either operate with two conveyances or with a conveyance and a counterweight.

The major criteria for choice of rope and termination relate to the shaft and loading arrangements.

2.1.1.1 Vertical Shaft. The use of a detaching device between the rope and the conveyance was required in the old regulations. This is still a recommended practice for permanent installations. The use of detaching devices in shaft sinking, however, is not usual.

Most of the termination types are suitable for vertical shaft hoisting, the major requirement being that they easily pass through the catch plate of the rope detaching device, in the event of an overwind. This requirement eliminates the use of thimble type capels as these are rather bulky and can easily catch on headgear equipment in the event of a detachment.

Many winders operate with keps to support the conveyance when loading or unloading. A complication of this procedure is that the rope sometimes becomes slack at the connection to the conveyance. It is important that a termination be chosen that can survive this occurrence. All termination types will be affected in some way. A badly made splice will fatigue and sockets or capels can develop rope fatigue where the rope enters the fitting.

All ropes develop a torque when subjected to a tensile load and those with high torques will develop lay length changes to adjust and maintain a constant torque along their length. Six strand ropes have high torque factors resulting in reduced lay lengths at the connection to the conveyance. End connections must be able to withstand this localised change in lay. In contrast, non-spin ropes do not exhibit much change in lay. When used as kibble ropes in shaft sinking, non-spin ropes operate with the conveyance end free to rotate. Because this tends to allow the outer strands to become slack, the use of spliced end connections is limited to the cross-tuck (or Admiralty) splice. The tendency for a

Liverpool splice to loosen when the strands unlay slightly makes this type of splice unsuitable for this application..

2.1.1.2 Incline Shaft. Detaching devices are never used in incline shafts, but other considerations come into play when choosing a termination for this application. Steeply inclined shafts are operated much like vertical shafts. However when the angle of inclination is less than 30°, techniques for operating the shaft have a direct bearing on the type of rope termination which should be used.

When operating incline shafts of less than 30°, the conveyance is often brought onto the shaft stations for loading and unloading material. In this case the rope is allowed to go slack and, due to the low angle, the connection often forms an angle with the centre-line of the conveyance and with the rope. This continual bending of the rope at the connection often leads to rapid fatigue at the neck of a capel or socket. The preferred method of terminating the rope is by means of a splice, which is less sensitive to this type of treatment even though it is more sensitive to the effect of low loads (i.e. high load range).

A further disadvantage of a capel is its bulk and weight which makes it more prone to sag when tension is reduced. The rings of wedge type capels are also a disadvantage as they could easily be dislodged and become loose.

A viable alternative for this type of winder is the use of thimble and rope clips.

2.1.2   BMR Winders.[1] [2]

The Blair Multi Rope winder is currently designed with two hoist ropes per drum. Because it is a drum winder a detaching device is required which must be incorporated with a tension equalisation device.
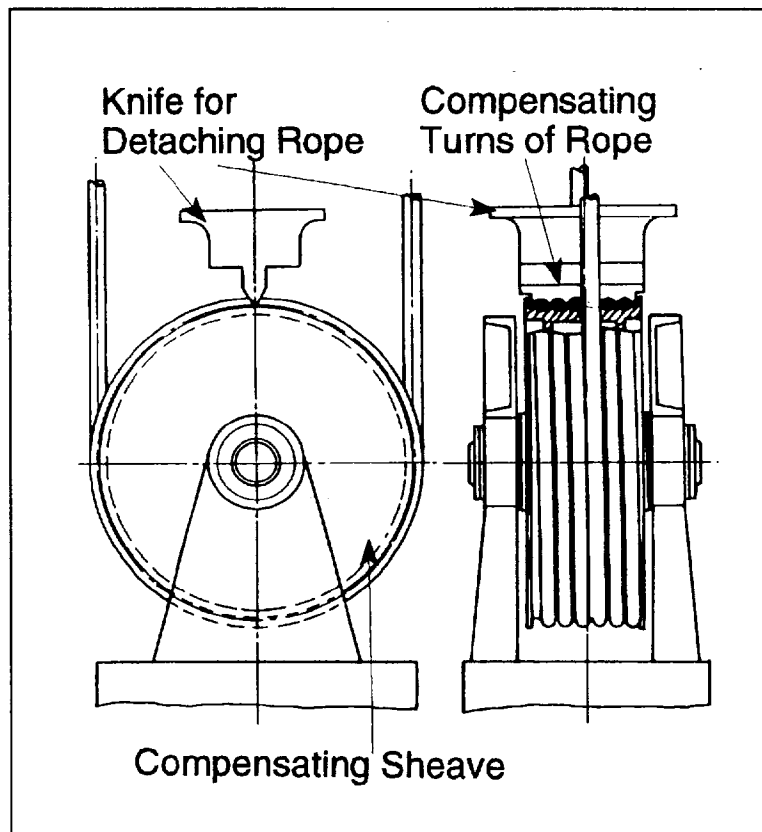
Figure 1   Schematic Diagram of Conveyance Mounted Equaliser Sheave

2.1.2.1 Equalisers on Conveyance. The Blair design comprises an equalising sheave, Figure 1, mounted on the conveyance and provided with a spiral groove with six turns, to accommodate the ropes. The ends of the hoist ropes are each wound on the sheave for about two and a half turns, in opposite directions, and secured to the sheave by means of a circular wedge cam type arrangement. The sheave is secured to the conveyance by means of plummer blocks with freely rotating bearings. In order to adjust for any tension variation the sheave rotates with the high tension rope unwinding from the sheave and the lower tension rope being wound up. In the original Blair design the sheave also incorporated a brake to arrest the sheave in case one rope failed. This feature has been discontinued following the initial trials with the system.

In any system there is inherently some dimensional tolerance. This means that there is a slight difference in the actual diameter of each rope and also that there is a difference in drum diameters of the two parts of the drum on which the ropes are wound. These differences result in the rope coiling on the drum at slightly different diameters, so that more rope is wound onto the drum with the larger effective diameter compared with the rope on the other part of the drum. The cumulative effect of this difference, over the length of the wind, can amount to as much as 4 m. This can satisfactorily be taken up by the movement of the equalising sheave. In addition to this adjustment the sheave must be able to take up differences which would be caused by any miscoiling of rope on the winder drum occurring during a winding cycle. A winder drum coiling monitoring device is always provided to ensure that the winder is tripped if miscoiling should occur on the winder drum. There should never be less than one full turn of either rope on the sheave in the worst possible combination of events.
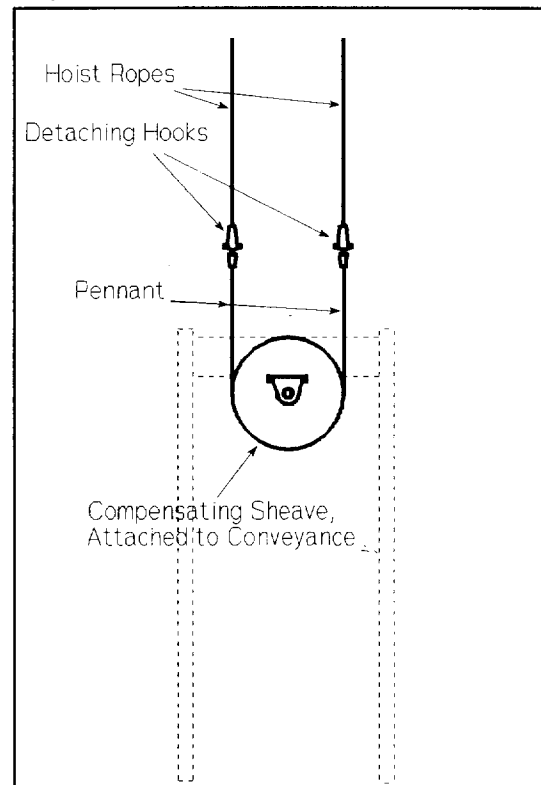
Figure 2 Alternative Compensation Arrangement with a Pennant

Detaching of the ropes in the event of an overwind is achieved by means of a knife mounted in the headgear, see Figure 1. This knife is in the form of a hardened steel wedge which cuts the ropes in the event of an overwind and the conveyance forces the sheave into contact with the knife which then severs the rope.

An alternative arrangement is one where a conventional sheave is mounted on the conveyance and a pennant passed round the sheave and attached to each hoisting rope. The ends of the pennant have open socket terminations connected to the main body of conventional detaching hooks. The hoist ropes can be terminated by any of the terminations used for conventional drum winders. In this case if an overwind occurs the

conveyance would be supported by the pennant to which the detaching hooks are attached. This arrangement is illustrated in Figure 2.

2.1.2.2 Equalisers in Headgear. In order to reduce the conveyance and attachment mass, an alternative tension equalisation device has been developed. Instead of being fixed in the headgear, the pair of sheaves for the ropes supporting each conveyance are supported on hydraulic cylinders which are interconnected so that any uneven tension between the ropes is compensated for by the hydraulic balancing action which allows movement of the sheaves. Conventional end connections and detaching hooks are used to connect the ropes to the conveyance.
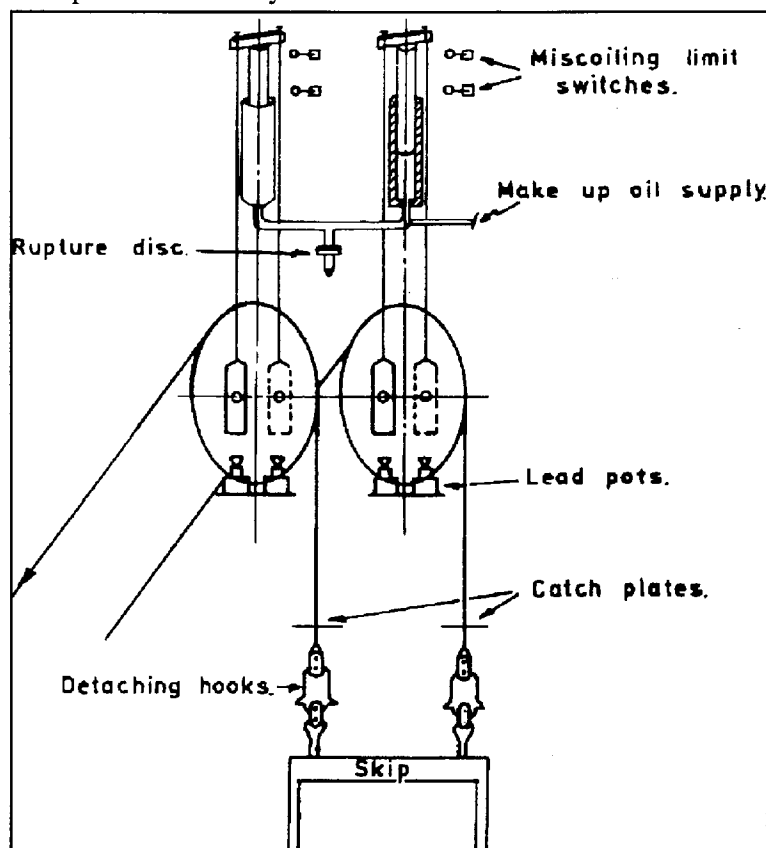
Figure 3   Schematic Diagram of Headgear Sheave Compensator

2.2   DESIGN CONSIDERATIONS.

In a drum winder system that operates without a balance rope (i.e. the normal arrangement in South Africa), the part of rope adjacent to the connection to the conveyance is subjected to the least tensile load. The regulations limit this to a maximum of eight times the total end load, but in most cases the tension will be much lower. Because of this there is no definite requirement for an end termination which develops the full strength of the rope. A termination with an efficiency of as low as 75 % will operate safely and satisfactorily, provided the requirements for inspection and re-termination, as specified in the regulations, are observed.

If balance ropes are used, it is appropriate to consider parameters relating to Koepe head-rope terminations in addition to requirements for drum winders.

2.2.1 Winder Characteristics.

In general, winder characteristics are dependent on the depth of wind. For a shallow wind accelerations tend to be high and, of course, cycle times are very short. The change in load due to the pay load as a percentage of the rope breaking strength is also relatively higher than for deep winds. The use of keps or other conveyance holding systems must be considered; especially as excessive loads can be generated, as well as the possibility of completely unloading the rope. However, unless winder characteristics are extremely severe, they may be disregarded from the point of view of rope terminations.

2.2.2 Splices.

A spliced end can be made on a rope either with or without a thimble. The use of a soft eye (i.e. without a thimble) is inappropriate for terminating a mine winder rope. The rope must be supported in a way that avoids relative movement between the rope and the connections to the conveyance. This is achieved by the use of a thimble. Of the two types of thimble that can be used the solid thimble is recommended. Open thimbles can be used,

Figure 4   Recommended Dimensions for Thimbles

provided that they are adequately designed. In this respect it must be noted that thimbles suitable for general engineering ropes must not be used since the dimensions are not suited to the types of rope used on mine winders. Recommended dimensions for solid thimbles are illustrated in Figure 4. Similar dimensions should be used for open thimbles, provided that the thimble be manufactured from suitable section material and that the point of the thimble be suitably strengthened.

2.2.2.1 Hand Splices. The most important consideration for a good hand splice is that the rope is made to fit snugly in the groove of the thimble. Suitable thimble dimensions ensure that the rope can be satisfactorily formed round the thimble and a well made splice will hold the thimble firmly and not allow any relative movement or distortion.

Both the Liverpool and the cross-tuck (or Admiralty) splice are satisfactory when used with ropes that are fixed at both ends. **However, if an end of the rope is free to rotate, the Liverpool splice must never be used, as it becomes dangerous and may pull out.** The cross-tuck (or Admiralty) splice is the one to use in this case as the interlocking

action of the tails tightens the splice if there is any tendency to unlaying. This applies particularly to shaft sinking kibble ropes.

Descriptions of how to make the various types of hand splice are to be found in Appendix A (page 27 onwards).

2.2.2.2 Thimble Eye with Rope Clips. Small winders operating in shallow shafts often have ropes terminated by means of a thimble and rope clips. Properly done, this type of termination is safe and reliable. When assembled in accordance with the instructions[3][4][13] (see paragraph 1.5 in Appendix A, page 46), an efficiency of about 80 % can be expected. However, this method is only appropriate if suitable rope clips are available. Properly designed and manufactured clips must be used with the saddle suitably formed to match the lay of the rope. Incorrectly made saddles are dangerous to use. Detailed instructions for assembling and tightening rope clips may be found in Appendix A, page 46. It is equally dangerous to use clips which have been incorrectly installed as the efficiency can be reduced to as low as 40 %. In addition, excessive torque on the bolts results in damage to the rope with a consequent reduction in efficiency.
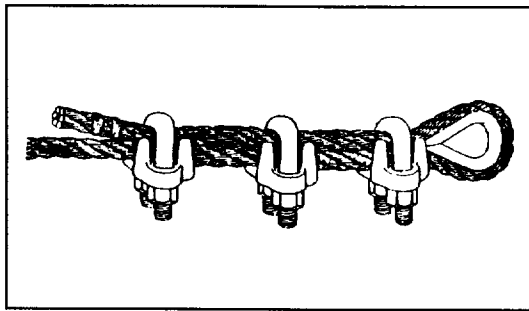
Figure 5   Correctly Assembled Rope
             Clip Termination
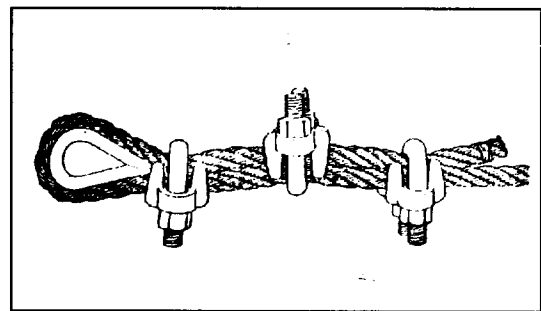
Figure 6   Incorrect and Dangerous
             Arrangement of Rope Clips

The saddle of the clip should always be fitted on the working, or live, part of the rope (see Figure 5). The U-bolt of any of the clips should never be fitted on the live part of the rope, Figure 6 and Figure 7.

2.2.3   Sockets.

Sockets provide an efficient and compact end termination for mine winder ropes. They consist of a fitting with a tapered basket into which the rope end, which has been opened out and cleaned, is cast. The socketing (or casting) material can be white metal, zinc or a polyester resin. In all cases the socket should be designed with at least a factor of safety of 10. The same design can be used for any of the socketing materials.

Figure 7   Incorrect and Dangerous:
             U-bolts on Live Rope

Figure 8 and Table I illustrate recommended dimensions for a few rope sizes. Reference should be made to the socket manufacturers for more detailed information and a more comprehensive list of sizes.
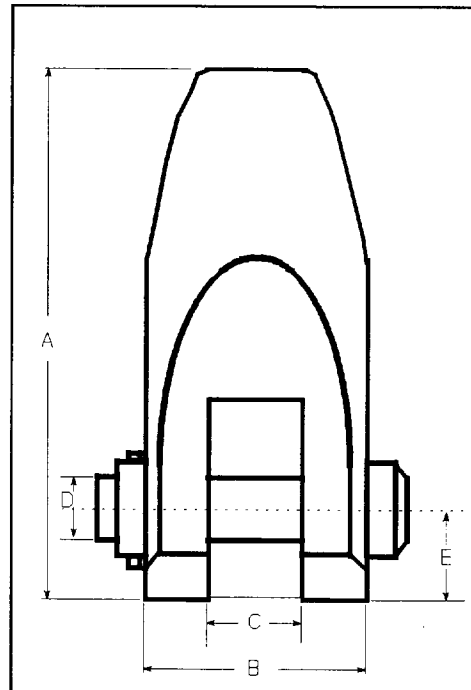
Figure 8   Open Socket

Table I Typical Dimensions of Sockets

Dimensions, mm						Safe Load kN
Rope Dia.	A	B	C	D	E	
32	432	146	88	59	82	132
35	474	146	88	59	89	162
38	530	176	103	70	96	186
41	566	176	103	70	108	220
44	608	200	117	80	112	265
48	641	200	117	80	119	304
51	684	226	132	90	127	240

2.2.3.1

White Metal. White metal has been the traditional material for use in making socket end terminations. The composition of the metal is specified in British Standard BS 643-70 "White metal ingots for capping steel wire ropes."[5] Considerable care is required in preparing the rope for socketing and in the casting. Detailed instructions may be found in Appendix A, paragraph 3.1 on page 51.

White metal has a tendency to extrude at temperatures in excess of 40 °C. Consequently other socketing materials such as zinc or resin should be used if high ambient temperatures are to be encountered. Also, because of this tendency to extrude, oversize sockets must on no account be used. The correct size socket is required for every rope size.

2.2.3.2 Zinc.   Pure zinc must be used for zinc socketing in accordance with SABS 20-77 "Primary zinc".[6] Methods and care required are similar to procedures required for white metal socketing with the additional requirement that care must also be taken to ensure that the rope is not overheated. See Appendix A, paragraph 3.2 on page 54.

The advantages of zinc are that it is readily available in the required purity and that it is not subject to deterioration in storage.

2.2.3.3 Resin.   Polyester resins have been developed which are excellent for socketing of wire ropes. Resin sockets are commonly used in the United Kingdom and comprehensive evaluation of this material is being undertaken in South Africa. Except for the fact that it deteriorates in storage, its properties make it the socketing material of choice for socketing hoisting ropes and the South African investigation is aimed at establishing if there any local conditions which could make it unsuitable. For instance it has been found that certain resins deteriorate in sea water and it has to be confirmed that the polyester resin does not deteriorate in water found in South African conditions. Another aim of the investigation is to establish the sensitivity of the resin socket to socketing procedures. Indications are that resin is less sensitive to socketing methods than the other materials. See Appendix A, paragraph 3.3 on page 55 for instructions for making resin socket terminations.

2.2.4   Capels.

Capels are simple to attach, dependable and safe. These terminations rely on friction and the force developed in a wedging action to provide an efficient unit. The differing designs have applications in which they are appropriate.

2.2.4.1 Wedge Capels.   Besides the other features of capels, wedge capels are noted for compactness. They also provide a termination where the rope is not disturbed, except for the safety block outside the wedges. The general arrangement is shown in Figure 9 and detailed instructions for assembly can be found in Appendix A, paragraph 2.1 on page 48.

The compact design of these capels makes them suitable for use with detaching hooks since there is little danger of them making contact with the catch plate. Although they are shorter than a thimble splice, it is recommended that the distance from the sheave to the catch plate should not be less than for a spliced end. It is also important that there is no possibility of the capel coming into contact with shaft steelwork or any other fixture, to avoid the possibility of the bands being knocked off.

Wedge capels are particularly suited to non-spin ropes and locked coil ropes as these ropes are sensitive to being disturbed in other capping methods. Another advantage is the

fact that the rope is kept straight and is not bent round a thimble. This makes them suitable for relatively stiff rope constructions. When used with such constructions as triangular strand and round strand ropes with fibre cores there may be a problem if the construction is loosely laid up. In this case it is common practice to remove the fibre core in the area of the capel wedge and replace it with a steel strand of suitable size.

2.2.4.2 Thimble (or Pear Shaped) Capels. Due to their size with respect to detaching hooks this type of capel is not recommended for use on drum winders. See Figure 12 for a schematic diagram of this type of capel.

3 ROPE TERMINATIONS FOR SINKING STAGE WINDERS.

Figure 9   Wedge Capel

There are many arrangements for ropes used on stage winders and the particular layout usually determines the type of termination which should be used.

3.1   GUIDELINES FOR USE.

o **Single Fall Arrangement with Multiple Drums.** In this case the ropes are individually connected to the platform (or stage). Splices, sockets or wedge capels are suitable for stranded ropes, but either sockets or wedge capels must be used for locked coil ropes.

o **Multiple Fall Arrangements.** When an odd number of falls are used, the same considerations as for the single fall arrangement apply. An even number of falls (see Figure 10) implies that the rope end connection will be secured at or near the top of the shaft. Since this means that the rope connection is subjected to the maximum rope tension, a termination that develops the full strength of the rope is advisable. This limits the choice to either a socket, a wedge capel or a suspension gland. The use of a socket is recommended, as wedge capels would be suspended "upside down" and although it is claimed that this makes no difference, there is an inherent danger of the rings loosening. The suspension gland is also a suitable option and is commonly used for the end termination of guide ropes.
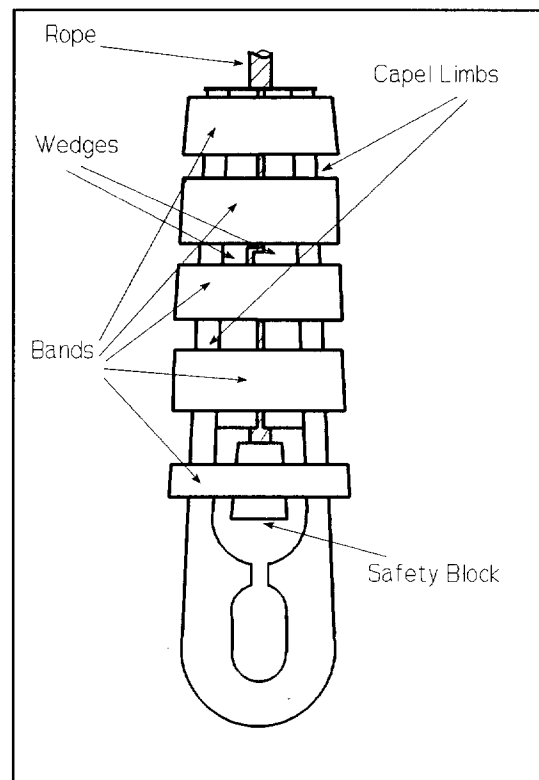
3.2　DESIGN CONSIDERATIONS.

A stage rope which is used for guiding a kibble is specifically allowed a factor of safety of 4,5 in the regulations, However, because it is also a winding rope an end connection attached to the conveyance has to be renewed every six months and the rope tested to destruction. In order to carry out this procedure the end connections must be simple to make and be easily manoeuvred. The thimble splice and the socket both meet these requirements.

3.2.1　Winder Characteristics.

The two basic rope layouts for sinking winders subject the terminations to differing duties.

3.2.2　Odd Number of Falls.

Figure 10 Sinking Stage with Even Number of Rope Falls

With this arrangement the rope end termination is always connected to the conveyance. The effect of this is that the termination is subjected to the same type and degree of loading for the complete shaft sinking operation. Loads do not vary-excessively unless there is a problem with the stage becoming caught in the shaft for some reason, in which case greatly increased loads or zero loads can be expected. The normal load variation is due to the operation of the installed rock loading device.

Shaft sinking experience in South Africa has shown that problems with end terminations on stage winder ropes have never been significant. Splices, sockets or capels can all be used successfully with this arrangement.

3.2.3　Even Number of Falls.

In this case the rope end termination is connected to the headgear or anchor point at the top of the shaft. At the start of the sinking process the load on the termination is at its lowest value. As sinking progresses the load on the termination increases due to the added weight of suspended rope. The tension in the termination only reaches its designed value when the shaft has reached its final depth.

Although spliced end terminations have been used satisfactorily in this arrangement, they are not recommended due to the average splice efficiency of 85 %. Sockets are preferred, although capels can be used with success.

An advantage of having the termination in the headgear is that the operating conditions are good and there is little likelihood of corrosion or damage to the rope or its termination.

4   ROPE TERMINATIONS FOR KOEPE WINDER HEAD-ROPES.

A feature of the Koepe system is that it does not permit the regular cutting of the head-ropes for testing. However ropes do fatigue at the connections so it is important that suitable end terminations are chosen.

4.1   GUIDELINES FOR USE.

O **Stranded Ropes.** When Koepe winders operate with two conveyances, the effect of permanent rope stretch needs to be considered. Permanent stretch characteristics of stranded non-spin ropes are illustrated in Figure 11. The curves indicate the tolerance as maximum and minimum stretch which can be expected. This stretch has to be taken up by moving the rope in the end connections. Adequate design of skip loading arrangements or over-run space at the top of the wind will ensure that, in the initial stages of rope operation, length adjustment can be done at convenient intervals.

Figure 11 Expected Permanent Rope Stretch for 15 strand "Fishback" Non-spin Koepe Head-rope

As can be seen, the rope continues to stretch progressively throughout its life. This feature makes it possible to regularly move the rope in the end connection and so avoid localised fatigue occurring at the connection. The fact that there is a requirement to take up rope stretch fairly often in the first few days of the rope's life makes it sensible to choose an end connection which is relatively quick and easy to adjust. The thimble type capel, Figure 12, fills this requirement admirably.

When there is a conveyance and a counterweight, the restrictions on the amount of stretch which can be tolerated are considerably reduced. However it is still necessary to change the position of the rope in the capel at regular intervals.

O **Locked Coil Ropes.** The amount of stretch experienced when Full Locked Coil head-ropes are used is considerably less than that experienced with stranded ropes. In view of this it is not so important to use an end connection which can quickly be attached to the rope. Because of its relative bending stiffness, locked coil ropes are not suitable for use with normal size thimbles. The preferred attachments are either sockets or wedge capels. In view of the reduced stretch of these ropes, it is usual to also provide chase blocks so that the rope can be moved in the connections at regular intervals.

4.2   DESIGN CONSIDERATIONS.

There are two basic rope maintenance operations that must be considered when choosing a suitable termination.

O **Rope Length Adjustment.** It must be possible to quickly and easily adjust the length of the head-ropes, both with respect to the depth of wind to adjust for rope stretch and also to ensure that all ropes in a multi-rope arrangement are of equal length. Terminations must be easily supported to allow for this type of handling.

O **Release of Accumulated Spin.** Non-spin ropes, and to some extent Locked coil ropes, develop a certain amount of torque due to internal wear and bedding in of the rope. This torque is generally in a direction to slacken the outer strands or wires and if it is not removed the rope can become slack or sometimes develop some form of distortion such as a corkscrew. Releasing the torque is generally achieved by loosening the rope in the termination or alternatively uncoupling the termination and allowing the rope to spin freely, thus eliminating the torque. The rope is then reconnected after checking for correct length.

4.2.1   Winder Characteristics.

The Koepe winder system needs to operate with tail-ropes to maintain balance in the system, as far as possible. This means that the change in tension at each point in the head-rope in every winding cycle is a combination of the change due to the payload and the weight of the tail-rope. The effect of the tail-rope on head-rope tension is least at the mid point of the head-rope and increases to a maximum at each end. Consequently the end terminations are subjected to the highest loads in addition to the highest load ranges in every cycle.

In view of this it is advisable to use terminations on the head-rope which develop the full strength of the rope and which have the best fatigue performance. In addition, the effect of the end-for-ending of the head-rope during every trip is a change in the lay length or torque at the termination during every cycle when the conveyance is descending. This is greatest for six strand ropes and least for non-spin and locked coil ropes and must be tolerated by the termination and not lead to premature deterioration.

4.2.2   One To One Roping.

This is the normal arrangement for a Koepe winder where each head-rope is attached to a conveyance at each end. Lever type compensators are sometimes used but are usually inadequate in fully compensating for tension differences.

4.2.2.1   Splices. The use of splices for terminating Koepe head-ropes is not recommended. The average efficiency of a splice is approximately 85 %, the load on the termination is equal to the maximum load to which the head-rope is subjected and, in addition, this part of the system is also subjected to the maximum load range and so to the most fatigue damage (ignoring the effect of deflection sheaves). The rate of splice deterioration increases with an increase in load range.[7] In six strand ropes the lay length change during every cycle will have a damaging effect on the rope and, in Liverpool splices, a tendency to loosen the splice.

4.2.2.2 Sockets. Sockets are suitable terminations for Koepe head-ropes, especially when locked coil head-ropes are used. There are disadvantages when used with stranded ropes because of the stretch characteristics of these ropes. It is usual to incorporate adjusting links in the termination to allow for stretch, but with stranded ropes not enough allowance can be made. Consequently the rope has to be re-socketed fairly often which is a time consuming activity in the early life of a stranded rope.

Similar considerations apply with respect to the type of socketing material used; as discussed on page 8 with respect to drum winders.

4.2.2.3 Capels. Each type of capel has its appropriate application when used for terminating Koepe head-ropes.
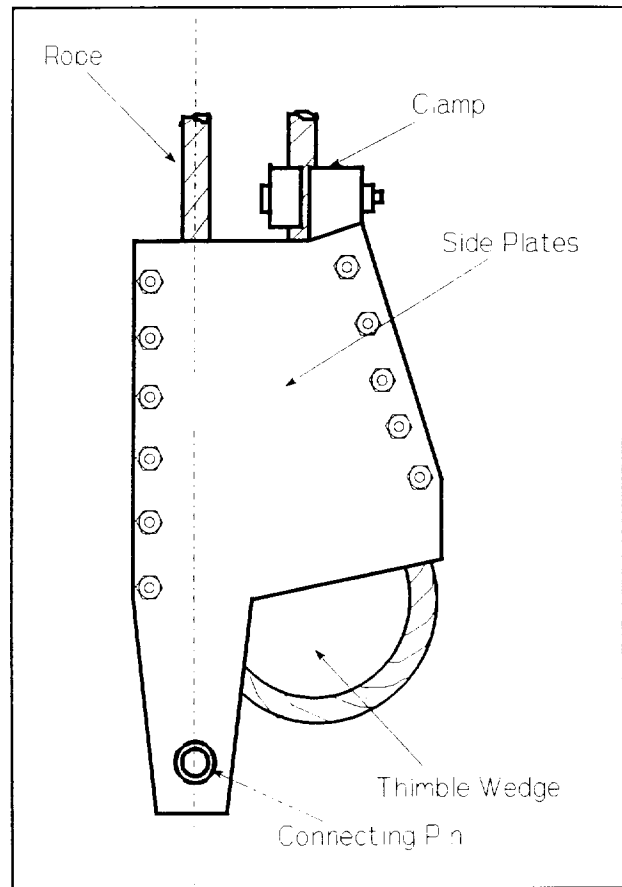
Figure 12 Thimble Type Capel

○ **Wedge Capels** are satisfactory end terminations for this application and similar considerations apply as for sockets.

○ **Thimble Type Capels** are not suitable for locked coil ropes but are eminently suitable for use with stranded ropes. Rope length can be easily and quickly adjusted which makes for ease of use when having to frequently adjust for rope stretch after new stranded ropes have been installed. A schematic diagram of this type of capel is illustrated in Figure 12.

4.2.3   Two to One Roping.

This arrangement is fairly common; especially when heavy loads, such as trackless mining machines, have to be transported. The ends of the head-ropes are secured to anchor points at the top of the shaft, often attached to hydraulic compensators. In this arrangement the end terminations are subjected to the maximum load in the system but the load range is somewhat reduced. In other respects the comments for one to one roping also apply.

5   TAIL-ROPES.

All Koepe winders operate with tail-ropes and it is sometimes the practice to use tail-ropes on drum winders, although there are none operating in South Africa at present.
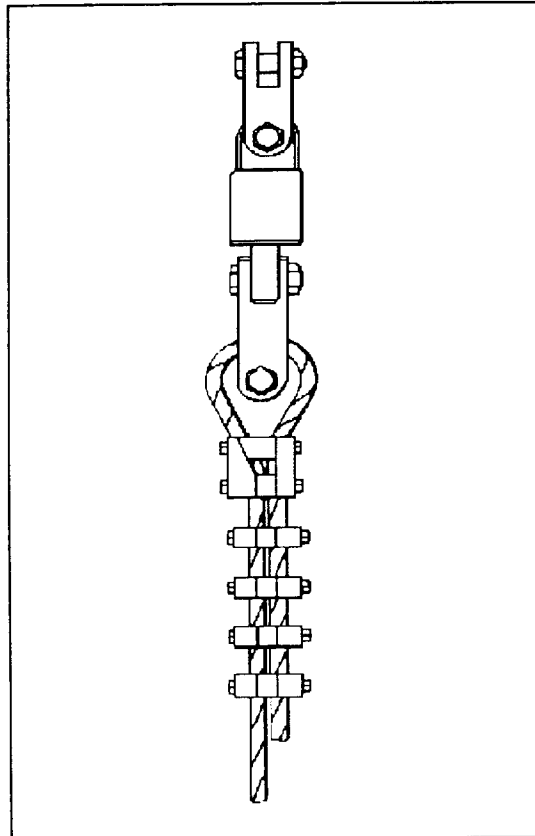
Figure 13 Tail Rope Termination

5.1   GUIDELINES FOR USE.

Tail-ropes operate under fairly arduous conditions. Design factors are generally higher than required in the regulations as the rope has only itself to support when operating with free loops or, in addition, a relatively light tail sheave when the loop is controlled. Tensile strengths are often only 1600 MPa and never higher than 1800 MPa. Terminations are usually simple and must be secure.

5.2   DESIGN CONSIDERATIONS.

Tail-ropes usually operate in a poor environment and are subject to spillage and any water and grit which leaks from skips hoisting rock. Wedge type capels are not favoured and the most common termination is a thimble with rope clips or clamps (see Figure 13). These are easily examined and have proved to be satisfactory in service.

o   **Free Loops.** Besides the end termination, tail-ropes with free loops must be equipped with swivels at both ends of the rope. The connections between the swivel and the

conveyance and those between the swivel and the rope must be by means of chase blocks that allow movement in any direction. This is necessary to ensure that there is no bending stress on the swivel or the rope termination.

○ **Tail Sheaves.** Swivels are not required for tail ropes operating with a controlled loop. However the other requirements, as for free loops, should be followed.

5.3   SPLICES.

Hand splices with thimble eyes can be used for tail-ropes. However the most favoured termination is the thimble eye with rope clips or clamps.

5.4   CAPELS.

Suitably designed wedge capels are sometimes used for tail-ropes but thimble type capels are unsuitable.

5.5   SOCKETS.

Sockets make compact and reliable end terminations for tail-ropes. Any of the socketing materials can be used provided they are not affected by shaft environmental conditions.

6   INSPECTION AND MAINTENANCE.

The end connection of a wire rope is always a discontinuity where vibrations in the rope become arrested. It is also a place where wires and strands are prevented from the normal movement which makes a wire rope such a versatile component of a hoisting system. One of the effects of this is the tendency for the rope at the end connection to deteriorate more rapidly than other parts of the rope. Because of this, regulations are drawn up to ensure that end connections are remade on a regular basis and that adequate inspections are carried out.

The following extracts from the regulations specify inspection requirements with respect to end connections and rope terminations.

'attachments' shall include everything suspended from or attached to the conveyance other than the winding rope and shall include any balance rope;

'rope connection' means any appliance or combination of appliances together with all the associated links, pins, shackles and hooks, but excluding the top transom of the conveyance and any dead eyes or other part of which the failure is not material to safety, used for the connection of the rope or ropes to the conveyance;

16.14   No rope connection shall be used for winding purposes unless it is of good quality, manufacture, of adequate calculated strength and manufactured from a class of steel approved by the Director-General.

16.15   The rope connection shall be such that no accidental disconnection can take place.

16.16   At intervals of not more than six months the rope connections shall be removed, stripped, cleaned and thoroughly examined in accordance with an approved safety standard.

16.17   A proper record shall be kept of the examinations and working life of the rope connections referred to in regulation 16.16 and the engineer shall add to the record the report on the procedure followed in such examinations and his comments on the results. All such rope connections, and their component parts shall be marked clearly for the purpose of identification.

16.34.1   Unless the winding system is such that it does not allow of the shortening of the winding rope, a portion of the winding rope shall be cut from the end attached to the conveyance as the case may be, at intervals not exceeding six months where the rope is connected directly to the conveyance and three months where the ropes are connected to a compensating sheave on the conveyance and the rope shall be re-terminated. The length of the portion so cut off shall be as specified by the approved testing station.

16.34.2.1   The manager shall send a sample of the rope cut off in terms of regulation 16.34.1 without delay for test to an approved testing station where the actual breaking strength and general condition shall be determined at the expense of the owner. Provided that in the case of the ropes being connected to a compensating sheave, the sample cut off the rope need only be sent for test without delay at intervals not exceeding six months.

16.59   The engineer or competent person appointed in terms of regulation 2.13.2, as the case may be, shall appoint in writing a competent person whose duty it shall be to examine, at the periods specified, to verify that the following equipment conforms with an approved safety standard -

         (a)   at least once in each day the winding rope or the balance rope, the connection of the winding ropes to the drums, the connection referred to in regulation 16.16, the conveyance and the main members by which they are suspended and any safety catches attached thereto, the brakes, the depth indicators, the safety devices and all external parts of the winder upon the proper working of which the safety of persons depends: Provided that these examinations will not be necessary on Sundays and statutory holidays referred to in Section 9 of the Mines and Works Act, 1956, if the winder makes less than 50 trips during any such day; and ....

Although the regulations refer to all the items which make up the connection to the conveyance, the rope termination is the subject of this discussion.

6.1   GENERAL CONSIDERATIONS.

The regular and careful inspection of terminations is the prime requirement for safe operation. Maintenance procedures are generally only the remaking of the termination and are determined by the observations made in the inspection. The different winder applications also require slightly modified procedures.

6.1.1   Drum Winders.

There are very few restrictions regarding the remaking of terminations on drum winder ropes. Rope length is not critical as extra rope is generally stored on the winder drum and length adjustment is made by clutching the drums into different relative positions. Permanent rope stretch is accommodated in this manner and not by remaking terminations. It is even possible to remove significant lengths of rope if fatigue or corrosion becomes apparent in the rope near the termination; which can significantly extend rope life in some cases.

6.1.2   Koepe Winders.

The management of end terminations for Koepe winders is complicated by the fact that Koepe head-ropes must be maintained to fixed lengths within fairly small tolerances. All ropes stretch in service, the stretch being composed of two components:-
       a) elastic stretch due to tension in the rope and
       b) constructional (or permanent stretch) which is due to constructional and metallurgical features of the rope and wire.[8]
Elastic stretch is allowed for in the design of winder layout. However only limited allowance can be made for permanent stretch and so terminations and end connections must be designed to allow for quick and easy adjustment.

6.1.3   Stage Winders.

The end terminations of stage ropes must be removed, stripped, cleaned and thoroughly examined every six months in accordance with the regulations, see page 17. For convenience the termination would be replaced to allow for examination at leisure. Because of the complication of multiple falls it is good practice to provide equipment for supporting and handling the rope for this operation.

6.2   HAND SPLICES.

O **Examination.** It is common practice to wrap the spliced tails of a thimble splice with spun yarn or sometimes a canvass wrapping. This is not necessary for hoist rope terminations and makes for unreliable and difficult examination: especially the daily examination in accordance with the regulations. The objective of daily and other examinations is to determine if there has been any movement (or pulling) of the tails in the splice and to establish if there are any wires broken due to damage or fatigue in any part of the splice. The most usual and critical areas where splices deteriorate are indicated in Figure 14. These areas must be carefully examined for broken wires. If the splice has not been well made due to an incorrect thimble, it will be noted that the thimble does not fit snugly but has moved as illustrated. This feature commonly leads to the early occurrence of

broken wires and in the case of installations
where the minimum load reduces to zero
(kibble ropes) can result in pulling of the
splice.

O **Maintenance.** When more than 2 broken
wires are found at the throat of the splice or
at the last tuck, the splice should be remade.
The splice should also be remade with a
replacement thimble with the correct profile if
it is noted that the thimble is not snugly held
in the spliced end.

When the splice is being remade it is
sometimes noted that there are brittle wires
that break while the tucks are being made.
This brittleness is usually associated with
corrosion or the development of fatigue at the
end of the rope. If more than 2 wires per
strand break while the splice is being made,
the rope should either be discarded or a
sufficient length cut off the rope to bring

Figure 14 Critical Areas for
               Inspection of Thimble
               Splice

unaffected rope into the splice. The occurrence of only one or two brittle wires is not of
particular concern but the broken wire ends should be examined to establish whether there
are early signs of corrosion or fatigue or whether there is a defect related to wire
manufacture. In the latter case there will only be a few wires affected and the rope can be
left in service with confidence. In the case of corrosion or fatigue, steps should be taken to
establish the cause with a view to eliminating it as far as possible.

6.3   ROPE CLIPS.

O **Examination.** Daily, careful examination of end connections made with rope clips is
important for the safety of this type of termination. The termination must be examined at
every clip to determine the tightness of the U-bolt nuts as well as the correct orientation of
the clip with respect to the live rope. At the same time the rope at each clip must be
examined at each side of the U-bolt to establish whether there are any broken wires or
whether there has been any movement, or slipping of the rope under the bolt. At the same
time the rope in contact with the saddle must be evaluated to assess whether the saddle is in
correct contact with the rope. The rope at the thimble must also be examined for broken
wires or for any looseness of the thimble in the bight of the rope.

O **Maintenance.** It is important that this type of termination is always kept clean and free
from extraneous material. There should not be any excess lubricant on the rope, the normal
lubrication applied in manufacture of the rope should be maintained. Any excess should be
removed to ensure ease of examination.

When any slipping of the rope under the U-bolts is noted or there are any broken wires, the
termination must be remade. All nuts on the U-bolts must be maintained at the correct

torque as specified for the particular clip being used. It should be noted that excessive torque on the bolts results in damage to the rope and a reduction in termination efficiency.

6.4   SOCKETS.

○ **Examination.** Sockets, like other attachments (e.g. detaching hooks) need to be "Non destructively tested" every six months. This is done at the time of the statutory six monthly recapping. The daily and other visual inspections are just as important in ensuring safe operation.

No matter what socketing material is used, the basic procedure for examining sockets is the same. The condition of the rope at the neck of the socket, the condition of the socketing material and the external condition of the socket itself must be assessed.

The rope at the neck of the socket is examined to establish whether there are any broken wires. A useful aid in assessing the condition of the rope is to apply a ring of paint around the rope about 25 mm from the socket just after the socket is poured. Any movement of wires which occurs due to a broken wire is readily observed. Broken wires must be carefully examined to establish the reason for failure. The most common cause of broken wires is fatigue and the appearance of the fracture surface can give an indication of factors which have affected the termination. A square ended fracture would merely indicate tensile fatigue, whereas a stepped fracture suggests that the termination has been subjected to bending or torsional loading. Besides broken wires the rope must be examined for signs of corrosion. Because the brush has to be thoroughly cleaned prior to pouring the socket, there is always the possibility of corrosion developing due to lack of lubricant in the rope at the mouth of the socket. The importance of this examination cannot be over-emphasized. Any corrosion noted must be compared with any corrosion which occurs one or two metres away from the socket.

The socket body must now be examined to determine whether there is any mechanical damage which might have distorted the socket or the lugs. Any distortion of the pin holes must be noted.

Finally the socketing material must be examined. When the socket is poured, the ends of the wires are allowed to protrude to allow for inspection. These ends must be examined for any signs of movement. The rope at the neck of the socket must also be examined for signs of movement. In the case of resin sockets, the resin must be examined for any signs of cracking.

○ **Maintenance.** The occurrence of one or two broken wires which can be identified as being due to a wire manufacturing defect is of little consequence. Broken wires due to fatigue or damage, on the other hand, indicate unacceptable loading or other condition that causes this deterioration. Because sockets have to be remade every six months broken wires should not normally occur. The socket termination should be remade away from the area of broken wires. The cause of the broken wires must be established and remedied, if possible.

Corrosion of the rope at the socket is not of great concern if it matches that on the rope a few metres away and is within acceptable limits. However, any sign of internal corrosion is cause for concern and re-casting the socket after cutting back the affected rope. An

assessment must be made of reasons for the internal corrosion and every effort made to rectify the cause.

After a socket is cast and loaded, there will be a certain amount of draw which should be noted and recorded soon after the socket is put into service. The amount of draw must be measured immediately after the statutory initial trips through the shaft and again after a day in service. If further movement is detected during service, there is the possibility of overloading or of incorrect casting procedure. The socket should then be re-cast.

6.5   CAPELS.

O **Inspection.** Different procedures are required for wedge and thimble type capels. These are addressed seperately.

O **Maintenance.** The occurrence of one or two broken wires that can be identified as being due to a wire manufacturing defect is of little consequence. Broken wires due to fatigue or damage on the other hand indicate unacceptable loading, or other condition, that is causing this deterioration. Because capels have to be remade every six months, broken wires are not expected as a normal feature. The capel termination should be reassembled after cutting off the affected portion of rope and the cause of the broken wires established and remedied, if possible. Other maintenance procedures relate to the specific type of capel.

6.5.1   Wedge Capels

O **Inspection** The first thing to look for when examining a wedge capel is whether there has been any movement or slippage of the rope or wedges. The marks on the wedges will indicate if they have moved and the distance between the safety block and the wedges will indicate whether there has been any movement of the rope in the wedges.

The rope at the entrance to the capel is now examined to establish whether there are any broken wires. A useful aid in assessing the condition of the rope is a ring of paint around the rope about 25 mm from the capel, applied just after the capel is assembled. Any movement of wires that occurs due to a broken wire is readily observed. Broken wires must be carefully examined to establish the reason for failure. The most common cause of broken wires is fatigue and the appearance of the fracture surface can give an indication of factors which have affected the termination. A square ended fracture would merely indicate tensile fatigue, whereas a stepped fracture suggests that the termination has been subjected to bending or torsional loading. Besides broken wires, the rope must be examined for signs of corrosion. Any corrosion noted must be compared with any corrosion which occurs one or two metres away from the capel.

All the rings of the capel must be checked to ensure that they are all tight and have not moved.

O **Maintenance** Should any of the rings be found to be loose, or there is any evidence of rope movement in the wedges, the rope should be cut and the capel removed to the workshop for further evaluation. The termination should be remade with another capel. If the wedges have moved in the yoke, there is the possibility of overload, which must be investigated.

6.5.2   Thimble Capels

○ **Inspection** The body of the capel must be examined for any loose bolts or sign of damage. The tail end of the rope should be examined to establish whether there has been any movement or slippage of the rope round the thimble.

The rope at the entrance to the capel is now examined to establish whether there are any broken wires. In addition, the condition of the stationary wedge and the thimble must be determined to ensure that there is no wear or "rifling" of these parts. Broken wires must be carefully examined to establish the reason for failure. The most common cause of broken wires is fatigue and the appearance of the fracture surface can give an indication of factors which have affected the termination. A square ended fracture would merely indicate tensile fatigue, whereas a stepped fracture suggests that the termination has been subjected to bending or torsional loading. Besides broken wires the rope must be examined for signs of corrosion. Any corrosion noted must be compared with any corrosion which occurs one or two metres away from the capel.

○ **Maintenance** If there are any signs of rope movement round the thimble or if there are any loose bolts or damage to be seen the capel should be replaced.

6.6   SHEAVE TYPE EQUALISERS.

The sheave type equalisers used on Blair multi-rope winders move to some extent during every winding trip, depending on tolerance variations of ropes and drum treads. This movement coupled with the vibration normally experienced in ropes at the terminations tends to result in fairly rapid fatigue deterioration of the ropes at the tangent to the sheave. Because of this, it is proposed to revise the regulations to require re-terminating the rope at the equalising sheave every three months instead of six monthly.

○ **Examination.** Because of the location of the equalising sheave, the daily examination poses considerable difficulties, unless the design has specifically catered for this requirement. In addition, protective covers often hinder quick and easy inspection. The importance of the daily visual examination cannot be overstressed and specific attention must be given to the finding and evaluation of any broken wires. In addition, any grit or particles of rock should be removed, at the tangent between the groove and the rope.

The rope is normally fixed to the sheave by means of clamps or a cam type wedge. This point of attachment must be examined for any signs of slipping or damage. In addition, the position of the ropes on the sheave must be noted to ensure adequate rope length for compensation.

○ **Maintenance.** If any broken wires are found, they must be carefully inspected to determine the cause. Wires that have failed due to fatigue, wear or corrosion indicate that the termination should be remade as soon as possible. Wires that have broken due to some wire manufacturing defect are of little consequence if there are only one or two, because these are usually isolated occurrences.

When remaking the termination, the tread of the sheave grooves must be examined for any rifling, that must be removed before the rope is reattached to the sheave.

The clamps or wedges securing the rope to the sheave should be checked for tightness. Should there be any sign of movement or slipping between the rope and the clamps, the cause should be ascertained and the termination remade.

Finally, the number of turns of rope on the sheave must be adjusted if there are less than two and a half turns of each rope on the sheave. Before making the adjustment, the amount of movement of the sheave during a wind must be determined. If this movement is excessive, the cause must be established and rectified.

7   TERMINATIONS FOR SLINGS AND OTHER EQUIPMENT USED IN ASSOCIATION WITH MINE WINDERS.

Slings are used for handling conveyances, for slinging equipment to be lowered down the shaft and many other purposes. Terminations used for slings are as important as the terminations of the winding ropes when considering the importance of slinging operations and the possibilities of damage due to failure. Slings, by their nature of being portable, are prone to damage that would not occur with a winding rope or its termination. In view of this, special care needs to be taken in choosing appropriate terminations for slings.

7.1   SLINGS ATTACHED TO THE CONVEYANCE.

When handling difficult material in the shaft, such as pipe or large mechanical parts, it is often necessary to sling under the conveyance. These slings are sometimes used on a single part and are free to rotate. For this reason, ordinary lay ropes are used as slings and the type of termination chosen must operate satisfactorily under these circumstances.

Figure 15 Spliced Thimble Termination

O **Spliced End Terminations.** The most universally used end termination for slinging in shafts is the hand splice. It has been noted that the Liverpool splice is often used for this application. This is of little consequence when two or more slings are used to support the load, but is dangerous if used on a single part. The Cross-tuck (or Admiralty) splice must always be used when splicing slings.

Soft eyes are often used for hand spliced slings. These allow for a great deal of flexibility in slinging procedures, but are more prone to wear on the inside of the eye and to other forms of damage due to being bent round small diameter pins. The use of a thimble eye with a shackle is the recommended end termination for hand spliced slings. Thimbles in accordance with SABS 0811-74 "Rope thimbles.", BS 0464-58 "Thimbles for wire ropes." or ISO 02262-84 "Rope thimbles." can be used.

○ **Ferrule Secured Eye Terminations.** Instead of hand splicing, mechanical means are often used for forming the eyes of slings. There are two basic systems. In one the end of the rope is turned back to form an eye which is then secured by pressing, or swaging, a ferrule over the rope and tail.
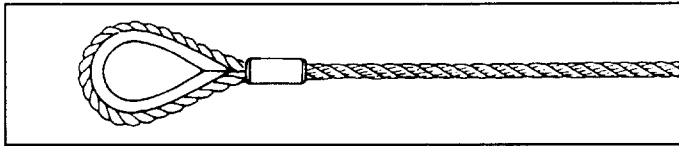
Figure 16 Ferrule Secured Eye Termination

In the other a Flemish eye is formed as illustrated in Figure 17. In this case the rope is split into two tails that are then bent in opposite directions and reformed into a rope eye. The tails are secured with a pressed or swaged sleeve. Although more difficult to make, this termination can also be fitted with a thimble.
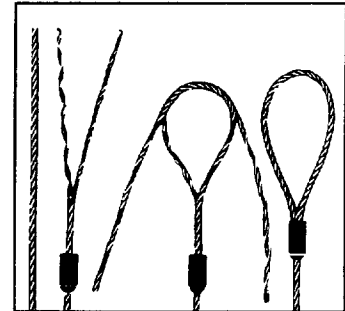
Figure 17 Ferrule Secured Flemish Eye

Both these terminations have an efficiency of about 80 %. However, the Flemish eye type of termination is recommended for use in shafts, either with or without a thimble.
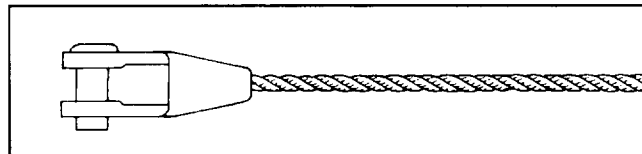
Figure 18 Open Socket Termination

○ **Sockets.** For many sling applications, the use of either open or closed sockets makes a satisfactory and efficient termination. Because general engineering ropes are used for these applications standard engineering type sockets can be used. Suitable specifications are:
BS 0463:2-70 "Sockets for wire ropes. Part 2. Metric units."
ISO 03189:1-85 "Sockets for ropes for general purposes. Part 1: General characteristics and conditions of acceptance."
ISO 03189:2-85 "Sockets for ropes for general purposes. Part 2: Special requirements for sockets produced by forging or machined from the solid."
ISO 03189:3-85 "Sockets for wire ropes - Part 3: Special requirements for sockets produced by casting."

Methods of casting the sockets with white metal or resin are as specified in Appendix A, page 51.

○ **End Termination Secured with Rope Clips.** Although this is a simple and inexpensive method for terminating wire ropes, this type of termination should not be used for slinging purposes.
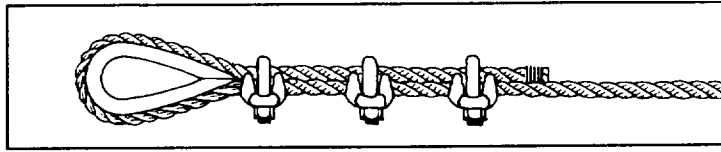
Figure 19 Terminations with Rope Clips are Not
Recommended

7.2   OTHER ROPE TERMINATION APPLICATIONS.

There are many other devices used for handling equipment and material in and around mine
winding plant. These range from overhead cranes used for the winders themselves to mobile
cranes used on the bank or shaft stations and winches mounted in headgears and shaft
stations. Any of the foregoing terminations are commonly used. The equipment
manufacturer's recommendations should be observed for both rope and termination.

Appendix A

Guidelines and Methods
for
Preparation of End Terminations

1   SPLICES

Splicing: An eye or loop splice can be considered as "securing the ends of a rope into its own part by interweaving the strands"[9].

There are various ways in which an eye splice can be made up. The different splicing methods give splices different properties, and in some cases using the wrong type of splice for the application can have serious consequences.

The first tuck of an eye splice is the basis of a satisfactory splice. After the first tuck of a splice, there are effectively two ways in which the remaining tucks of the splice can be made. These are with the lay of the rope (**Liverpool Splice**) or against the lay of the rope (**Cross-tuck or Admiralty Splice**). Combinations of these are sometimes used but are not necessarily satisfactory. Naturally one can vary the number of tucks within a splice or the size of the strands (by removing some of the wires after a minimum number of full tucks to produce a tapered splice), but it is recommended that the type of splice does not change.

1.1   LIVERPOOL SPLICE[10]

A Liverpool splice is made by splicing with the lay. It is also known as the "Round and Round" splice and this latter name closely describes this type of splice. After the first series of tucks have been made each tail (or dead strand) is tucked around one and the same strand in the main part of the rope (live strand) throughout the splice. i.e. if tail strand 1 (dead strand) is tucked around strand A

Figure 20 A Completed Five Tuck Liverpool Splice

(live strand) at the second series of tucks, strand 1 will be tucked around strand A at each subsequent series of tucks until the required number of tucks have been achieved.

In the case of six strand rope, once the splice has been completed each live strand of the rope will have a dead strand tucked around it throughout the length of the splice thus

maintaining the lay of the rope. Figure 20 shows a completed Liverpool Splice. A Liverpool splice is spliced in such a way that each live strand is independent from another (the strands are not locked together) even though it has a dead strand wrapped around it. Therefore if the rope is unlaid the spliced portion will also unlay. This reduces the frictional forces between the live and dead strands and can result in the dead strands pulling out.

Liverpool splices or splices made with the lay must never be used where the end of the rope is free to rotate.

1.2   CROSS-TUCK (OR ADMIRALTY) SPLICE[11]

A Cross-tuck Splice (also known as an Admiralty splice) is made by splicing against the lay. After the first series of tucks have been made each tail (or dead strand) is passed over the one strand in the main part of the rope (live strand) and under another (adjacent live strand) throughout the splice, i.e. in the case of a six strand rope if strand 1 (dead strand) is wrapped over strand A (live strand) at the second series of tucks, strand 1 will only be wrapped over stand A again at the eighth series of tucks. In this manner on a six strand rope each dead strand will have been interwoven with all six live strands by the seventh tuck in the splice.

The dead strands thus move across the splice from one live strand to the next, and so do not conform with the lay of the rope, thus the term "against the lay". This method of splicing weaves the live strands together and makes the splice a compact unit. In this case, if the end of the rope is allowed to rotate, the live strands in the rope will not be affected and the splice will not be weakened.

Cross-tuck (Admiralty) splices or splices made against the lay can be used where the end of the rope is free to rotate.

1.3   THE SPLICING PROCEDURE

This section concentrates on the eye or loop of the splice. It describes the fitting of the rope around the thimble and the first series of tucks. This operation is common to all splices even though there are different ways of making the first series of tucks.
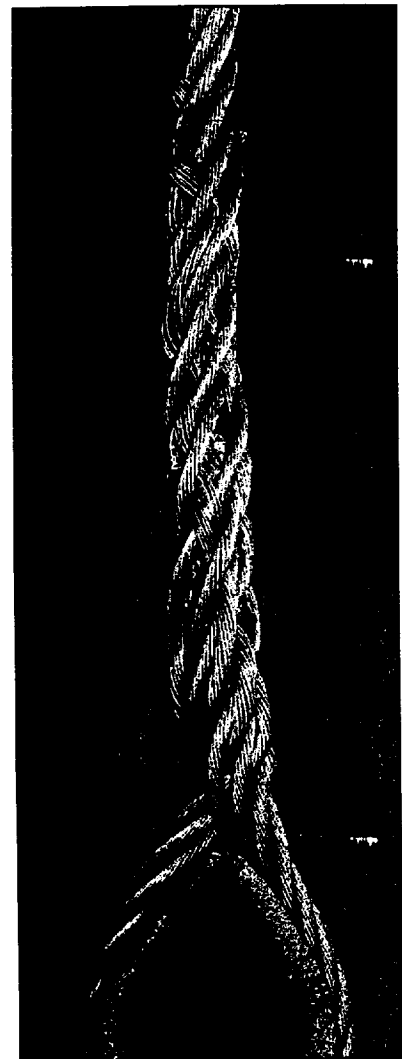
Figure 21 A Completed Five Tuck Cross-tuck Splice

It is important when making a splice that the first series of tucks are made correctly. The dead strands must emerge from the correct part of the rope after the first series of tucks. In the case of a six-strand rope as is being discussed here, one dead strand must emerge from each gusset of the live rope independent of the technique

used to make the first series of tucks. Only solid thimbles should be used when making splices on winding ropes.

1.3.1 Preparation of the Rope for Splicing

All wire ropes need some preparation before splicing commences and, apart from a variation in the length of the tucking strands or tails, this preparation is normally as follows:

O   Measure up the rope and mark where it is to form the centre of the crown of the eye, making due allowance for the loss in the straight length caused by the curving of the rope around the thimble. Place the thimble with its crown on this mark and bend the short end (tail end) of the rope around it, in the groove of the thimble, leaving the tail end of the rope to protrude which will provide the length for the tucking tails. (This length should be 80 × rope diameter).

O   On small diameter ropes, bending the rope round the thimble can be done by hand, but in the case of large diameter ropes a thimble throat clamp should be used. Force the two parts of the rope together at the point of the thimble, i.e. the throat of the eye. Figure 22 shows the rope on the thimble once this operation has been completed.
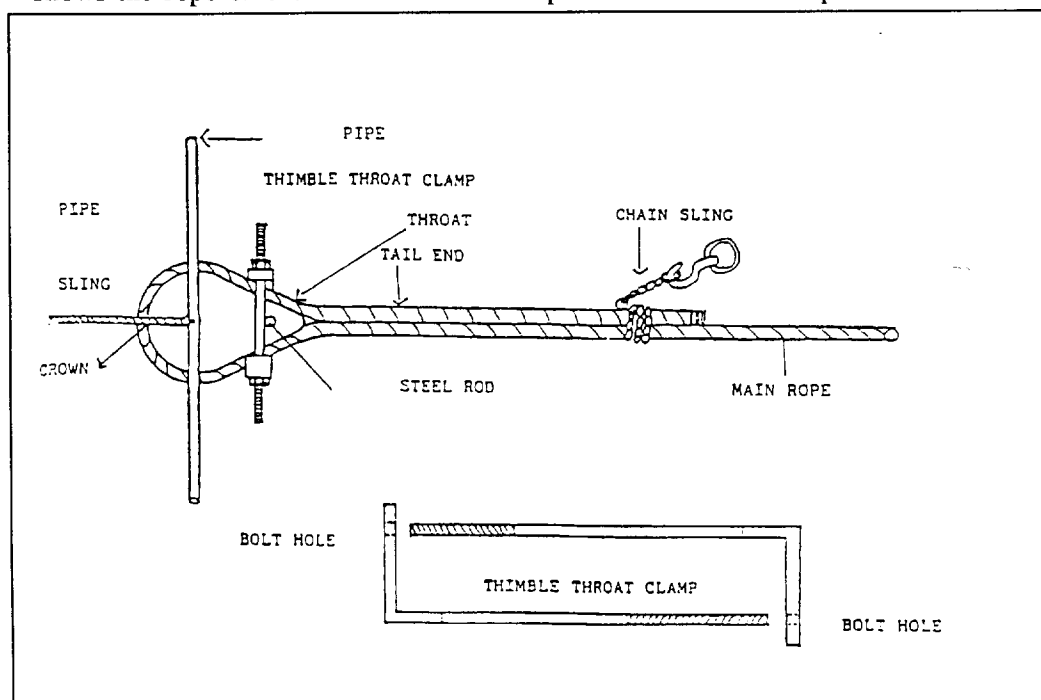
Figure 22   Illustration of the Rope Secured on the Thimble with a Thimble Throat Clamp.

O   Firmly seize these two parts together (live rope and tail end at the throat of the eye) with strong wire - they should be in direct contact. This seizing should only consist of two or three turns of wire.

This clamping procedure ensures that the rope is in solid contact with the groove of the thimble and that the two parts of the rope are together at the throat. The rope is then ready for splicing.

During this preparation, prior to making the tucks, it is important that no "turn" is taken out of or put into the rope.

○ For small diameter ropes, place the thimble in a vice with the rope leading vertical and the short end, i.e. the "tails" end, on the left hand side. In the case of large diameter ropes the thimble and rope end should be held horizontally, each end attached to a suitable sling with the rope and tails being held as illustrated in Figure 23.

○ Remove the end-binding and unlay the tail end of the rope to provide the tails for splicing (See Figure 24). Seize the ends of the tails to prevent the tails from unlaying, especially in the case of non-preformed ropes. Also remove the throat seizing if one was used.
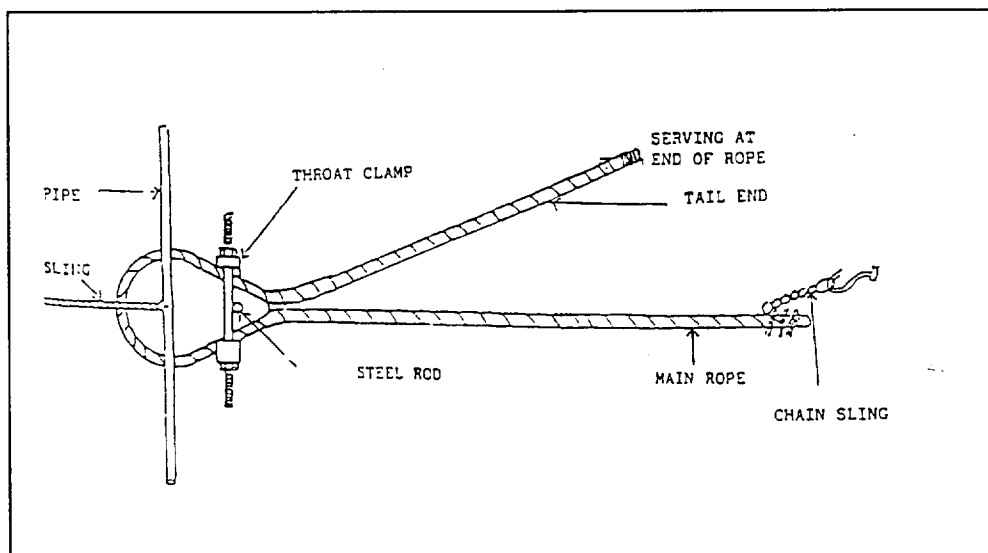
Figure 23 Illustration of the Rope Around the Thimble with the Ends
Secured Prior to the Opening of the Tail.

1.3.2 Notes Regarding the Splicing Procedure

○ The fibre main core is to be tucked into the main part of the rope together with Tail No 1 for the first tuck of a cross-tuck (or Admiralty) splice. It is then run into the core of the rope for the equivalent length of three tucks and then cut off. In the case of a Liverpool splice it will be run into the core of the rope for up to five tucks to help support the strands of the splice.

○ In the case of ropes that have a wire core, the wire core must never be cut from the rope. It must be split up, and the wires or strands distributed evenly among the tucking tails, and tucked with them for at least 3 tucks.
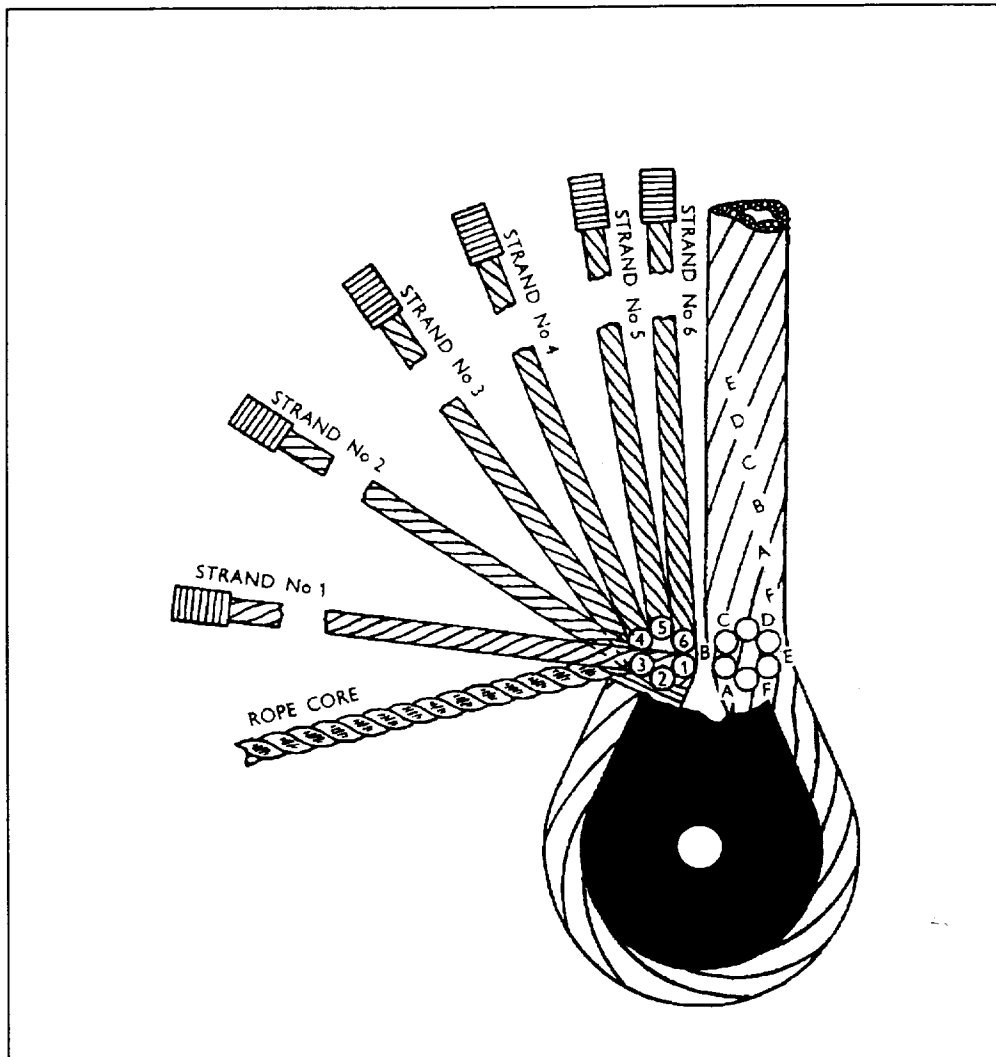
Figure 24 Illustration of the Main Rope with all the Tails Opened Out.

○ For the splicing of six strand ropes, three methods of making the first series of tucks are given. Although the second and third methods are simpler, the first method does enable the tucking strands to lie close up to the thimble and is the recommended method. The second method, however, is the one commonly used in South Africa.

○ There are two distinctly different methods of reeving the tucking strands after the first series of tucks have been made. One is known as the "Liverpool" splice, the round-and-round splice or the "Parallel-tuck" splice and the other as the "Admiralty" splice or "Cross-tuck" splice. The minimum number of tucks should be seven for a Liverpool Splice and five[9][11] for a Cross-tuck Splice, however, it is recommended that seven or nine[10] tucks be used. Splices with more tucks are allowed but increasing the number of tucks does not improve the splice strength. The higher number of tucks ensures that the splice does not pull out under adverse conditions.

○ In all splices the spike must be entered as near as possible to the thimble, and the tucking tail must enter that portion of loop so formed which is nearest the thimble or end fitting, i.e. under the spike. All tucks must be pulled down hard, i.e. pulled through and pulled back as tightly as possible.

○ When a tapered splice is made (a splice where the size of the tails is physically reduced by successively removing some of the wires at each tuck after a minimum number of tucks with a full strand), be it of the Liverpool or Cross-tuck (Admiralty) type.

○ When wires are removed, they can either be cut by means of an abrasive cutter, or an oxy-acetelyne torch. If the latter method is used, the rope and remaining wires must be well protected from the open flame.

1.3.3   Making an Cross-tuck (or Admiralty) Splice in a Six Strand Rope

It is assumed that the rope preparation procedure as described in section 1.3.1 on page 29 has been completed and we have the following:

○ Thimble secured

○ Rope horizontal

○ Main part of rope on right hand

○ Tail strands above the main part of the rope

○ Thimble fitted with a throat clamp

○ Thimble and main part of rope secured with slings

○ Strands for the tails unlaid and whipped at ends

○ The illustrations show a cross-section of the rope and tails viewing from the main part of the rope to the thimble

The length of tails for a nine tuck splice should be 80 × rope diameter. A fibre core should be tucked with tail No 1, and then cut off. A wire main core must be split up, distributed among the tails, and tucked with them for at least three series of tucks. The first series of tucks should be made according to Table II and illustrations that follow. (Figure 25, Figure 26, Figure 27, Figure 28, Figure 29 and Figure 30).

Table II   First Series of Tucks for a Six
Strand Rope Cross-tuck Splice

Tail No.	In at	Out at
1	B	A
6	C	B
2	B	C
3	C	D
5	D	F
4	D	E
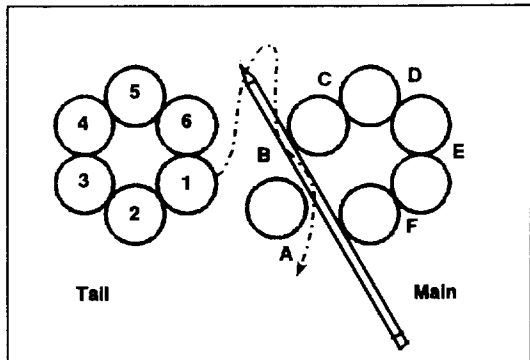
Figure 25 First Tuck of First Series
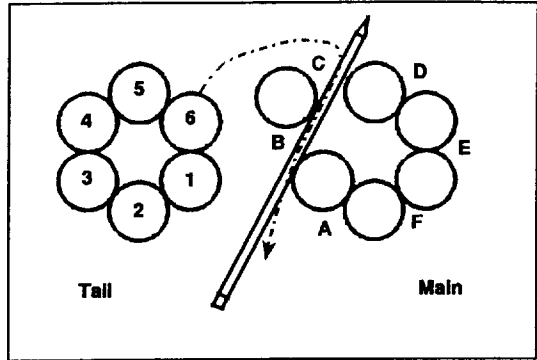
Figure 26 Second Tuck of First Series
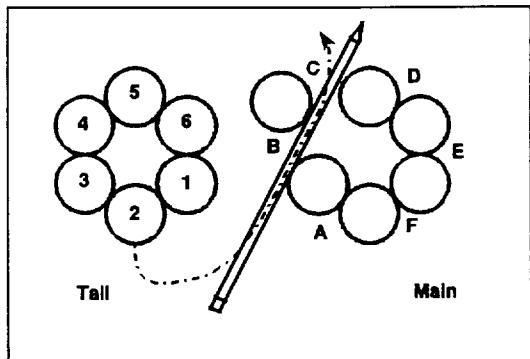
Figure 27 Third Tuck of First Series
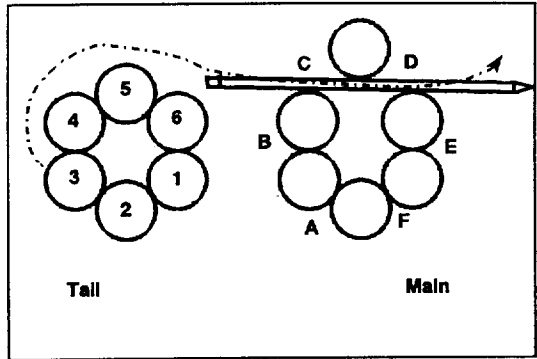
Figure 28 Fourth Tuck of First Series
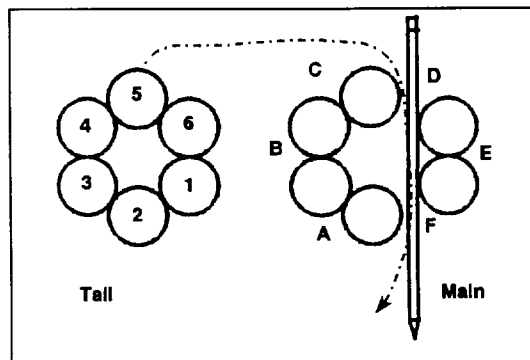
Figure 29 Fifth Tuck of First Series
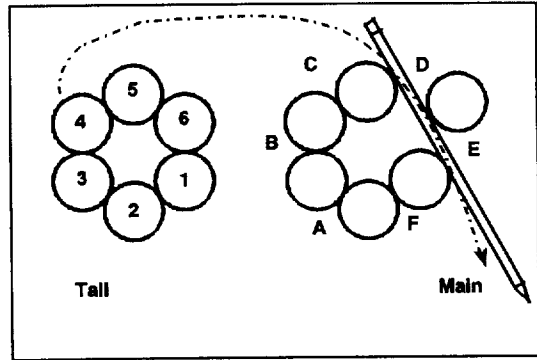
Figure 30 Sixth Tuck of First Series

Figure 25 to Figure 30 illustrate how the first series of tucks are made

After the first set of tucks have been pulled down tight against the point of the thimble the second, third and fourth tucks can be made in accordance with the following table. The tails must all be well pulled down before the following series of tucks is made. Figure 31 illustrates where the tails of the first series of tucks should emerge from the main body of the rope.

Figure 24 shows the identification of the interstices of the rope which are referenced in Table III and Table IV as entry and exit points for tails as numbered. The tucks should be made in the order indicated in the table.

Figure 31 Diagram Showing Emergence of Tails after the First Series of Tucks has been Completed

Table III   Second to Fifth Series of Tucks

Tail No.	Second Series		Third Series		Fourth Series		Fifth Series	
	In at	Out at	In at	Out at	In at	Out at	In at	Out at
1	B	C	D	E	F	A	B	C
6	C	D	E	F	A	B	C	D
2	D	E	F	A	B	C	D	E
3	E	F	A	B	C	D	E	F
4	F	A	B	C	D	E	F	A
5	A	B	C	D	E	F	A	B

○ After the fourth series of tucks has been completed, if a tapered splice is required the wires of a wire main core may be cut off, thereby reducing the number of wires in each of the main tails. The remaining wires must be twisted up to a rough strand formation, and at the same time enclosing the cut ends in the centre. After each successive tuck the number of wires in the tails can be further reduced by cutting out more wires.

The pattern for the optional remaining tucks is shown in Table IV.

Table IV   Sixth to Ninth Series of Tucks

Tail No.	Sixth Series		Seventh Series		Eighth Series		Ninth Series	
	In at	Out at	In at	Out at	In at	Out at	In at	Out at
1	D	E	F	A	B	C	D	E
6	E	F	A	B	C	D	E	F
2	F	A	B	C	D	E	F	A
3	A	B	C	D	E	F	A	B
4	B	C	D	E	F	A	B	C
5	C	D	E	F	A	B	C	D

o The splice is rounded up by hammering in a former, starting from the eye and working down the taper. This is to tighten up the tucks and to round up the taper. Remove protruding wire ends, preferably by cutting off and again rounding up over the cut-off ends.

o The need for thoroughly pulling down each strand as tightly as possible as splicing proceeds, cannot be over-emphasised. The tails should be pulled down in line with the centre line of the thimble. To get the tuck tight and short, it should be beaten by means of a mallet or hammer. One object is to get the tuck as close as possible at right angles to the axis of the rope. Working the tucks with mallet or hammer forces any slackness out of the tuckings through the loop, and the beating should start on the position of the tail before its entry into the rope, and continue on the tuck itself. The strands of the main rope where they have been lifted are beaten down to hold the tuck in place.

Alternative methods for making the first series of tucks:

There are alternative methods for making the first series of tucks which are claimed to be simpler. The entry and exit of the tails indicated in Table V and Figure 32 to Figure 38 are commonly used when splicing winding ropes in South Africa. It should be noted that most of the tails enter at one of the interstices, which is likely to result in some distortion, unless carefully done. The other alternative arrangement, indicated in Table VI, is not recommended although it is included for completeness.

Table V Alternative Arrangement for First Series of Tucks

Tail No.	In at	Out at
1	B	D
2	B	E
3	B	F
4	B	A
5	C	B
6	D	C
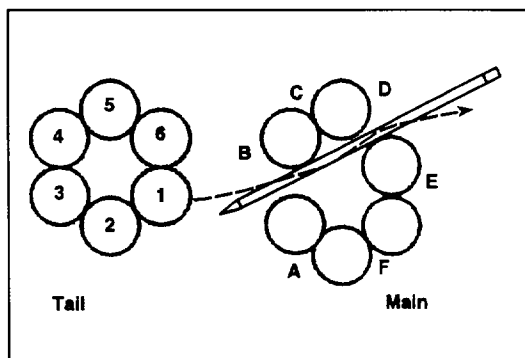
Figure 32 Alternative - First Tuck of First Series
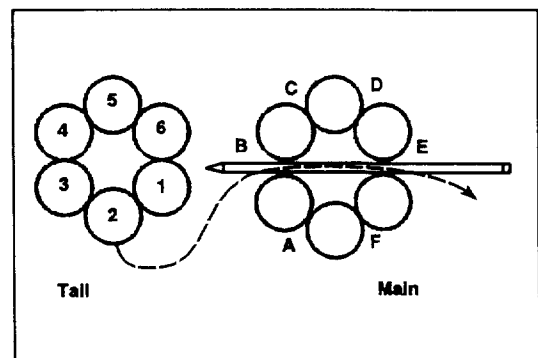
Figure 33 Alternative - Second Tuck of First Series
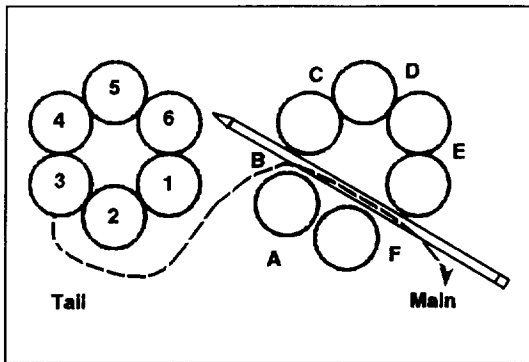
Figure 34 Alternative - Third Tuck of First Series
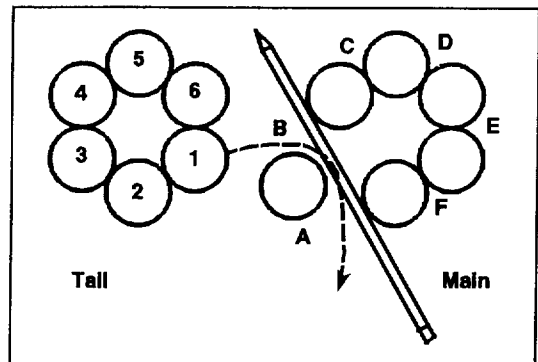
Figure 35 Alternative - Fourth Tuck of First Series

After the fourth tuck has been made the spike is again inserted under two strands, as for the first tuck. The strands are lifted up and the fibre core is inserted under these strands and then run into the centre of the rope for the length of three tucks.
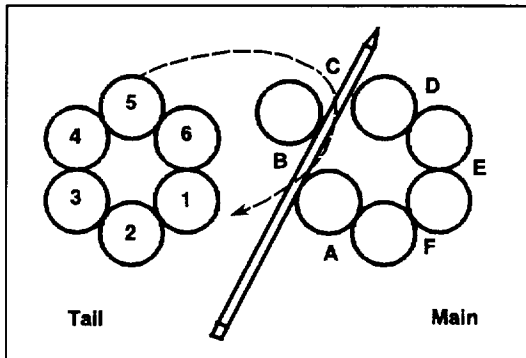
Figure 36 Alternative - Fifth Tuck of First Series
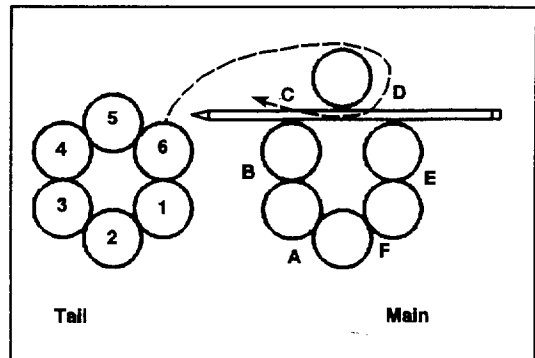
Figure 37 Alternative - Sixth Tuck of First Series
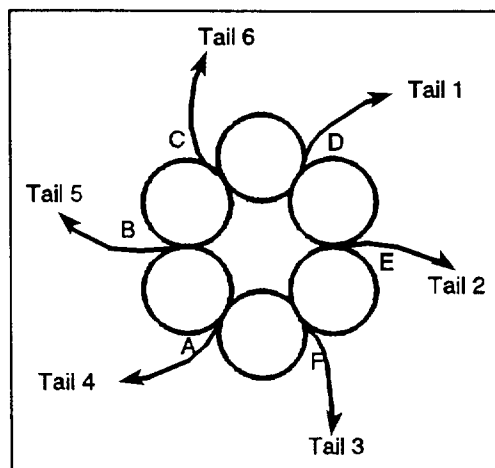
Figure 38 Alternative - Diagram Showing the Emergence of the Tails after the First Series of Tucks have been Completed.

Then carry on with the tails over one strand and under the next in a direction against the lay each time as previously described.

The other alternative in making the first series of tucks is indicated in Table VI.

Table VI   Another Method of
Making the First Series of Tucks

Tail No.	In at	Out at
1	A	B
2	A	C
3	A	D
4	A	E
5	A	F
6	B	A

1.3.4   Splicing a Liverpool Splice at the End of a Six Strand Rope

○   The end of a rope is prepared as previously described in section 1.3.1 on page 29.

○   The length of the tails should be 80 × rope diameter.

○   A fibre core is tucked with Tail No. 1, for one tuck only, and then run into the core of the rope.

○   A wire main core must be split up and the strands or the wires distributed among the tucking tails, and tucked with them for five full tucks, i.e. cut off at the completion of the 5th series of tucks.
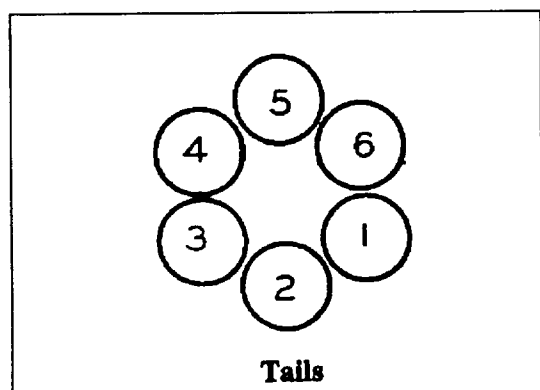
Tails

Figure 39 Labelling of Tails for a Six
Strand Rope Liverpool
Splice
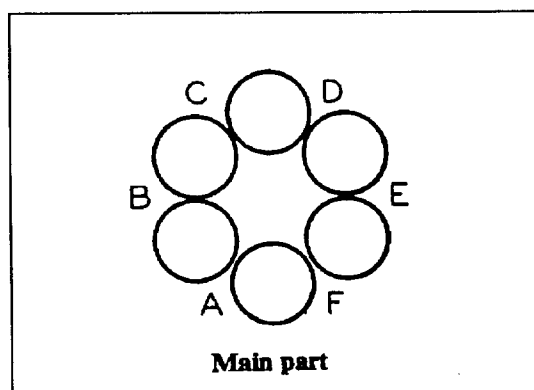
Main part

Figure 40 Labelling of Main Part of
Rope

The first series of tucks are made as described for the Cross-tuck splice in Table II and Figure 25 to Figure 30. i.e. as in Table VII and Figure 41.

Table VII First Series of Tucks for Liverpool Splice

Tail No.	In at	Out at
1	B	A
6	C	B
2	B	C
3	C	D
5	D	F
4	D	E
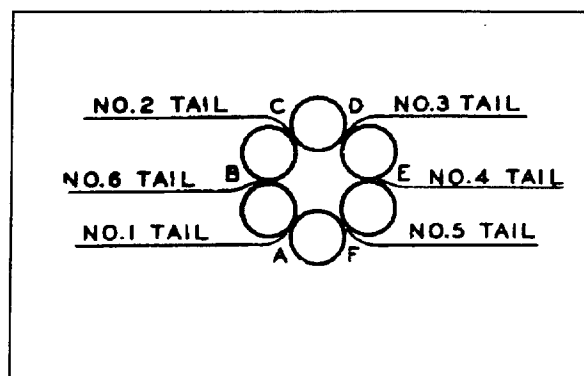
Figure 41 The Emergence of Tails After the First Series of Tucks Have Been Completed

Subsequent tucks are made as listed in Table VIII and Table IX.

If a tapered splice is required, reduce the number of wires in each tail by ¼, thus leaving ¾ of the original number. Then hammer down the tucks.

With a rope having a wire main core, the number of core wires must not be reduced at this stage. They should be included in the fifth series and then taken off.

Reduce the number of wires in each strand by ¼ of the original number, after the fifth, sixth and seventh tucks. The wire ends should be cut off.

Hammer down the tucks and round up the taper.

Loose tucks will result in loose looping wires which will fatigue and break prematurely.

Table VIII Second to Fourth Series of Tucks for a Liverpool
Splice

Tail No.	Second Series		Third Series		Fourth Series	
	In at	Out at	In at	Out at	In at	Out at
i	B	A	B	A	B	A
6	C	B	C	B	C	B
2	D	C	D	C	D	C
3	E	D	E	D	E	D
4	F	E	F	E	F	E
5	A	F	A	F	A	F

Table IX Fifth to Seventh Series of Tucks for Liverpool
Splice

Tail No.	Fifth Series		Sixth Series		Seventh Series	
	In at	Out at	In at	Out at	In at	Out at
1	B	A	B	A	B	A
6	C	B	C	B	C	B
2	D	C	D	C	D	C
3	E	D	E	D	E	D
4	F	E	F	E	F	E
5	A	F	A	F	A	F

1.4   SPLICING NON-SPIN ROPES[11] [12]

Except for the very large sizes, or ropes with a large number of outer strands, non-spin ropes can be spliced just as efficiently as six strand ropes. It is generally advisable to use some other method of termination for ropes in excess of 54 mm diameter.

Before bending the rope around the thimble it is important to serve it securely along the portion of rope which will lie in the groove of the thimble, after which the seizing at the end of the rope may be cut. This ensures that any inequality in strand lengths brought about by the severe bending round the thimble will not be transmitted back into the rope.

The principle and method of splicing is just the same as for a six strand rope except that inner strands and wire main core (if any) are grouped with outers to form tails of roughly the same size and in the correct number to suit the number of outer strands.

It is most important that the tucks are made under the outer strands only of the main body of the rope. The inner strands must not be disturbed in any way. It is also important that in all cases the inner strands are carried through and used in the last series of tucks of the taper.

1.4.1   Making a Cross-tuck (or Admiralty) Splice on a 17 × 7 Non-spin Rope

The end of the rope and its terminal should be prepared and assembled in a manner similar to that described in paragraph 1.3 on page 28.
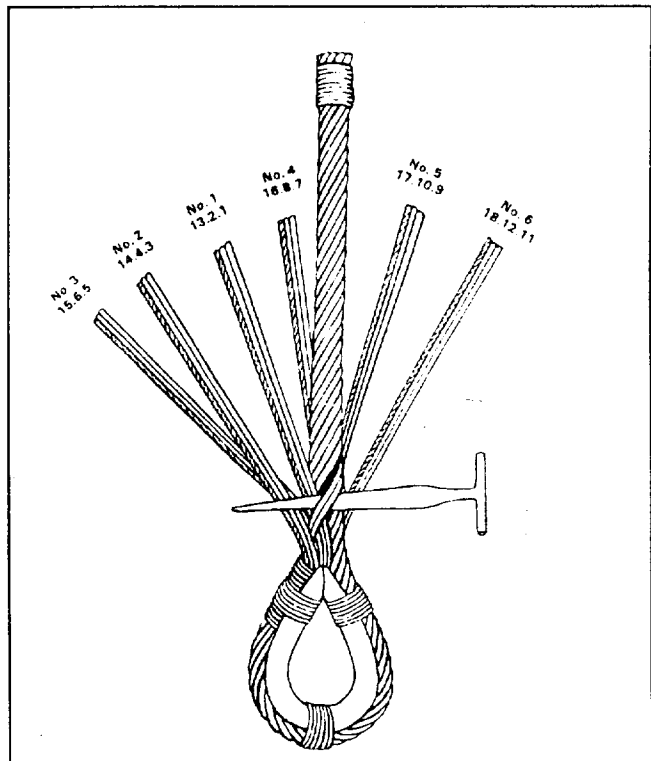
The outer strands, numbered as in Figure 42, must be grouped as indicated in column 1 of Table X. The first series of tucks are made in accordance with the designated letters for the interstices of the outer strands shown in Figure 43 and in the order listed.
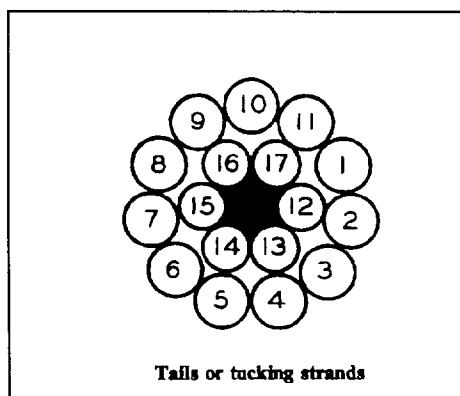
Figure 42   Labelling of Tails for 17×7 Non-spin
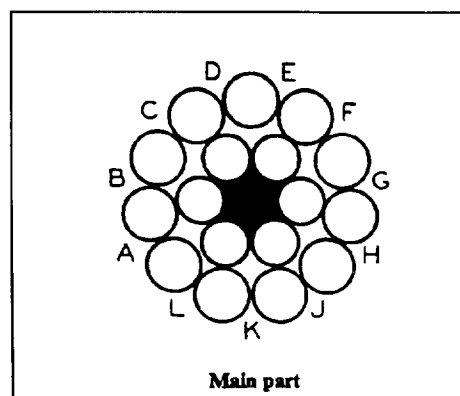
Figure 43   Labelling of Main Part of 17×7 Non-spin

In the case of ropes that have a wire strand core, the core is to be grouped with tail No's 11 and 12, i.e. Group Six. In the case of a fibre core, this would be cut off.

Table X Grouping of Strands and Details of First Series of Tucks for 17×7 Non-spin

Take Tails Nos.	In at	Out at	Direction	Group No.
3, 4, 14	A	E	Clockwise	Two
1, 2, 13	A	C	Clockwise	One
5, 6, 15	A	G	Anti-clockwise	Three
7, 8, 16	A	J	Anti-clockwise	Four
9, 10, 17	A	L	Anti-clockwise	Five
11, 12	C	A	Anti-clockwise	Six

A tighter splice will be made if at the first series of tucks the two outer strands are tucked first, e.g. 3 and 4, then 5 and 6, and so on, then tuck the inner strands separately and into the interstice given in the table, i.e. 14 with 3 and 4, 13 with 1 and 2, etc.

The second and third series of tucks are tabulated in Table XI. Successive tucks follow the same pattern and are not tabulated.

Table XI Second and Third Series of Tucks for 17×7 Non-spin

Group No.	Second Series of Tucks		Third series of tucks	
	In at	Out at	In at	Out at
One	E	G	J	L
Two	G	J	L	A
Three	J	L	A	C
Four	L	A	C	E
Five	A	C	E	G
Six	C	E	G	J

○ The fourth and fifth series of tucks are made in the same pattern as before.

When the fifth series of tucks have been completed, release the thimble end of the splice and hammer down the partially made splice, starting from the terminal. Remove one strand from each group (excepting group 6 if this is only a two strand group). Secure the thimble end again.

O   The sixth and seventh series of tucks then follow on the same principle as before.

Remove one strand from each group leaving one strand only in each group.

O   Finally the eighth and ninth series of tucks are completed as before.

After the tucks have been completed, remove from vice or end constraint and hammer down the splice, starting from the terminal, and round up the taper. Cut off surplus ends of the tucking strands. When removing strands during splicing, the cut should be made as close to their emergence as possible.

1.4.2   18 Strand Non-spin Rope Splice

The end of the rope and its terminal should be prepared and assembled in a manner similar to that described in paragraph 1.3 on page 28.

The following splicing sequence is applicable to 18 strand "Fishback" non-spin ropes as well as to the simpler constructions such as an 18 × 7 non-spin with fibre core.

If there is a fibre core this is cut off, but a wire main core is tucked together with the other strands. Six tails are grouped together as indicated in Figure 44, in the case of a wire main core this would be grouped with group No. 1. These groups of strands are tucked into the six pairs of outer strands. The pattern followed should be similar to that described for a six strand rope.

Figure 44   Grouping of Strands. First Tuck Made

Paragraph 1.3.1 on page 29. The fifth (or the sixth) tuck of the first series should be under 4 strands instead of two which ensures that the thimble is held tightly in the splice.

Figure 45 shows the second tuck after the first tuck has been worked under the spike.

Figure 46 shows the other side of the thimble with the sixth strand under the four outer strands, having completed the first series of tucks, and group No.4 tucked again starting the second series of tucks.

Figure 45 Second Tuck Made

Continuing, the next three series of tucks are made with full tails. The fifth, sixth and seventh series of tucks are made with one strand cut out of each tail. The eighth and ninth series are made with tails further reduced to one strand of the inner strands, so completing the taper. Figure 47 shows one outer strand from each group bent back ready to be cut at the fourth tuck. At position A (seventh tuck) a further outer strand is cut from each group and at position B the remaining inner strands are cut. Figure 48 shows the completed splice.

Figure 46 Sixth Strand Tucked Under Four Strands Completing First Series of Tucks

1.4.3   14 Strand (8/6/WMC) Non-spin Rope Splice

The end of the rope and its terminal should be prepared and assembled in a manner similar to that described in paragraph 1.3 on page 28.

In the case of a 14 strand non-spin splice four tails are formed by grouping two outers with two others made up from the six inners and the wire main core.

The four tails are tucked into the four pairs of outer strands in a similar manner to the 18 strand non-spin splice.

The second, third and fourth series of tucks are made with full tails. The taper is then effected by cutting one strand out of the tails in the fifth, sixth and seventh series of tucks and a further strand removed from the eighth series of tucks.

In between periods of tucking the splice should be removed from the vice and the tucked part of the splice swaged down with a copper hammer. Finally when the splice is completed all tucks are hammered down starting at the thimble and round up the taper.

Figure 47 Last Tuck and
          Cutting Off Strands
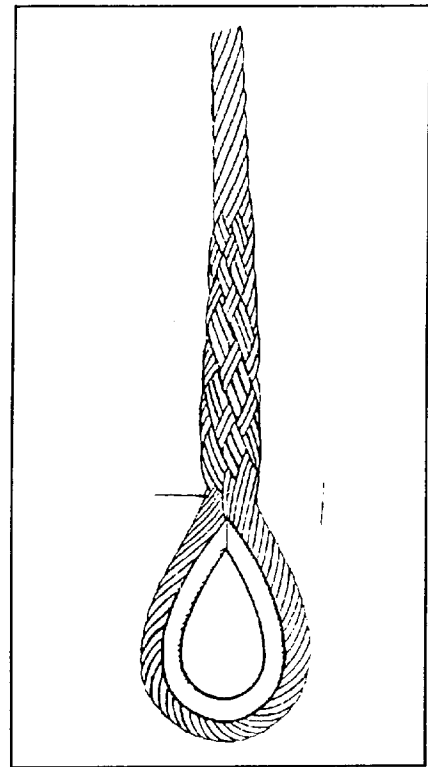
Figure 48 Splice Complete

1.4.4   Alternative 14 strand (8/6/WMC) Non-spin Rope Splice

Instead of grouping the strands into four groups as described in the previous paragraph, a satisfactory splice can be made using six groups of strands as illustrated in Figure 49. The groups of strands would be tucked similarly to the method used for six strand ropes. The groups of tails would be tucked under two pairs of outer strands (Nos 1 & 2 and Nos 5 & 6) on opposite sides of the rope and under just one strand for the others as appropriate.
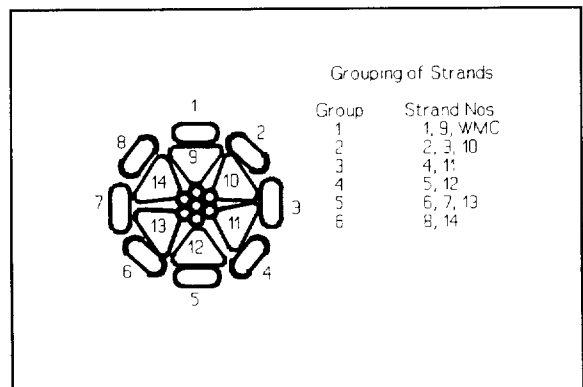
Figure 49 Alternative Strand Grouping
          for 14 Strand Non-spin Splice

1.4.5   15 Strand (9/6/WMC) Non-spin Rope Splice

A 15 strand non-spin splice is made in a similar manner to the 14 strand non-spin splice just described.

As there are 9 outer strands in the construction of the rope the grouping of the tails is varied as follows:-

No.1 and No.2 tails: 2 outer and 2 inner strands.

No.3 tail: 3 outers and 1 inner strand.

No.4 tail: 2 outers, 1 inner strand and WMC.

The tails are tucked under four groups of outer strands comprising three pairs of outer strands and one group of three outer strands.

1.4.6   Alternative 15 Strand (9/6/WMC) Non-spin Rope Splice

Instead of grouping the strands into four groups as described in the previous paragraph, a satisfactory splice can be made using six groups of strands as illustrated in Figure 50. The groups of strands would be tucked similarly to the method used for six strand ropes. The groups of tails would be tucked under three pairs of outer strands (Nos 1 & 2, Nos 4 & 5 and Nos 7 & 8) and under just one strand for strand Nos 3, 6 & 9 as appropriate.
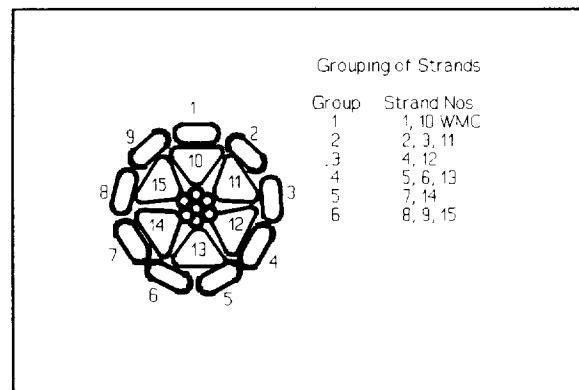
Figure 50   Alternative Strand Grouping for 15 Strand Non-spin Splice

1.5   THIMBLE EYE WITH ROPE CLIPS[13] [14]

This is an alternative method for making an eye termination in the end of a rope. It is not a splice but naturally comes under this grouping.

The base of the rope clips to be used must be of forged steel and the threads on the U-bolts should be rolled. Relevant details of dimensions and installation requirements are given in Table XII.
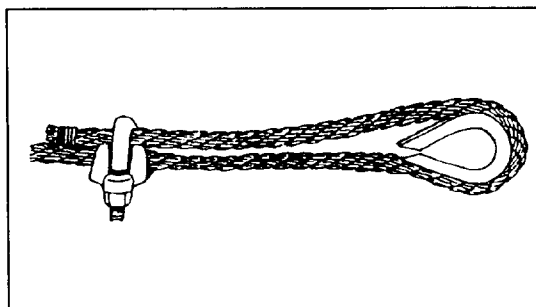
Figure 51   First Step in Installing Clips
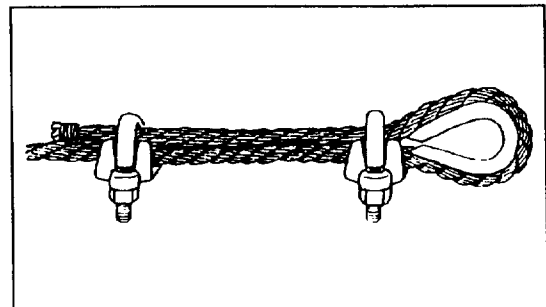
Figure 52   Second Step in Installing Clips

U-bolt clips must have the U-bolt section on the dead (or short) end of the rope and the saddle on the live (or long) end of the rope. The wrong positioning with the U-bolt on the live instead of the dead end, of even one clip, can reduce the efficiency of the connection to 40 % instead of the expected 80 %. Always use new clips.

Apply the first clip one base width from the end of the wire rope, see Figure 51, and tighten the nuts. Apply the second clip adjacent to the thimble, Figure 52, but don't tighten the nuts. Fit all the other clips, leaving equal space between each, see Figure 53. For maximum efficiency the clips should be installed 6 to 7 rope diameters apart. Take rope slack by applying some tension to the eye and then tighten all the nuts evenly on all the clips to the recommended torque specified in Table XII. After the rope has been in operation for an hour or so, all nuts on the clip bolts must be re-tightened. They should be checked for tightness at frequent intervals thereafter. This is necessary because the rope will stretch slightly, causing a reduction in diameter which will slacken the clips.
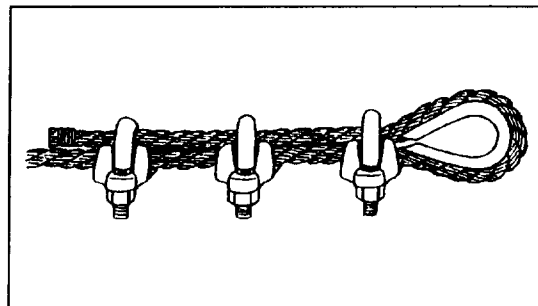
Figure 53 Third Step in Installing Clips

Table XII   Wire Rope Clip Requirements

Rope Diameter mm	U-bolt Diameter mm	Minimum Number of Clips	Torque Nm	Length of Rope to Turn Back -mm
16	14	3	129	305
20	16	4	176	406
22	20	4	305	483
26	20	5	305	660
28	20	6	305	864
32	22	7	488	1118
35	22	7	488	1118
38	22	8	488	1372
42	26	8	583	1473
44	28	8	800	1549

2   CAPELS

Capels provide a simple, reliable and safe method of terminating winding ropes. Wedge type capels are suitable for all types of wire rope and can be used for all hoisting applications. The thimble capel provides a quick and easily made connection and is designed specifically for friction winders.

2.1   WEDGE CAPELS[15]

Wedge capels, see Figure 54, work on the principal of gripping the unopened rope between interlocking tapered wedges that are grooved to suit the rope diameter. The wedges are enclosed in limbs encircled by heavy bands. After initial bedding down the rope should not move in the wedges and, because of their interlocking action, the wedges cannot move independently of each other. The wedges and the rope however must be able to move as a unit so that if the load is sufficient to cause movement of this unit, the force on the wedges will be increased with a consequential increase in grip. A safety block is fitted to assist movement of the wedges should this become necessary and act as a rope movement indicator.
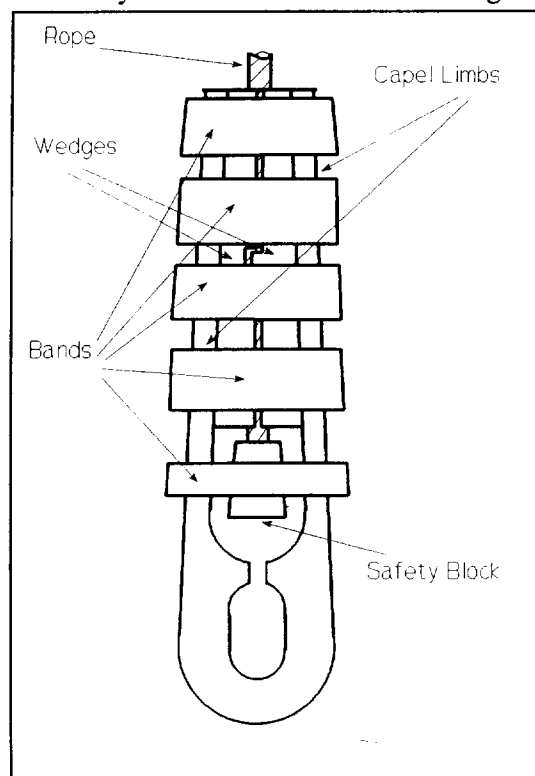
Figure 54 Wedge Type Capel

Capel wedges are stamped with the rope size for which they are grooved and also with the capel identification numbers. Wedges should only be fitted to the capel with the same identification number.

o **Assembly.** The rope must be securely seized and clamped on both sides of the proposed cut. Cutting should be done taking care not to disturb either the seizing or the rope wires. The use of an abrasive disc cutter is recommended for cutting the rope.

Prior to assembly, all components must be clean and free from grease and rust. All burrs and damage must be removed.

The bands are threaded onto the rope in their number order (band with smallest aperture first) making sure that the inside taper of the bands matches the outside taper of the limbs. This is shown by arrows stamped on the bands which should point in the direction of the capel eye.

The safety block is then threaded over the rope with the large end towards the rope end. The block should be clean and dry and radiused at the mouth. The safety block is cast on to the rope with white metal or resin using the same procedures as described for socketing. See paragraphs 3.1 on page 51 and 3.3 on page 55.

Thoroughly clean any grease and lubricant from that portion of the rope which will be
gripped by the wedges and ensure the rope is straight. Clean the backs of the wedges and
the inner limbs then apply a light smearing of grease to the **BACKS (not GROOVES)** of
the wedges and inside the limbs. Only grease recommended by the capel manufacturer
should be used. Do not use tallow, graphite or molybdenum disulphide based greases or
copa slip. The wedge **GROOVES** must be **CLEAN AND DRY**.

Place the wedges around the rope in approximately the position they will occupy when in
the capel. Fit the capel limbs over the wedges and draw downwards until the ends of the
limbs are flush with the thin ends of the wedges. The rope should be drawn through the
wedges until the safety block is 20 mm from the wedge ends. Draw the bands into position
and tap them onto the limb ensuring No 1 band is encircling the safety block. Band 1 is
intended only as a protection for the safety block and need not be set to a very tight fit. It is
not a working band and its position on the limb is not critical.

The bands are pressed onto the limbs using a hydraulic banding machine, Figure 55. The
capel manufacturer will supply the correct pressures for use for the different sizes of capel.
However the force required to set the bands can be calculated from the following formula:

$$Force = \frac{U.B.S. \ of \ Rope \ \times \ 0,386}{No \ of \ working \ bands}$$

After pressing each band in turn the procedure should be repeated at least twice more to
ensure correct bedding of rope and wedges.
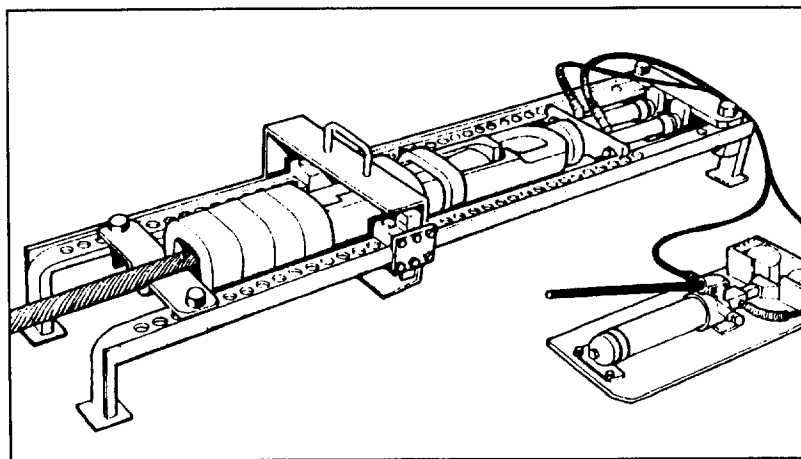
Figure 55 Hydraulic Banding Machine for Setting Bands
on Wedge Capels

○ **Important Points.**
1. Capels should never be used with a size of rope different to that stamped on the wedge.
2. Under no circumstances should liners be used in the grooves or at the backs of the
   wedges.
3. Under no circumstances should a capel be assembled without a safety block.
4. Banding pressures should be carefully monitored using calibrated gauges.
5. Hydraulic banding machines should always be used for assembly and disassembly.

2.2   THIMBLE (OR PEAR SHAPED) CAPELS

These capels work on a wedging principle using a thimble pulling into shoes instead of the tapered wedges of the wedge type capel (see Figure 56). They provide an easy method of adjustment which makes them ideal for multi-rope Koepe winders. However they are bulky in construction and will not pass through a catch plate for a detaching hook and so are not used on drum winders.

O **Assembly.** The rope must be securely seized and clamped on each side of the cut and care must be taken not to disturb either the seizing or the rope wires. The use of an abrasive disc cutter is recommended.

The seized, cut rope end is thoroughly cleaned of any grease and lubricant in the area which will be gripped by the thimble. The grooves in the thimble and casing must also be clean and free from grease.

The rope is inserted into the top of the capel, with sufficient rope to wrap around the thimble. The thimble with the rope is then pushed into the capel body and the tail end clamped off. The capel should then be gently loaded so that the thimble takes up its final position in the casing. After the capel has taken the final load and is firmly gripping the rope the tail end clamp should be re-positioned and an additional 2-bolt clamp fitted above it at 90°.
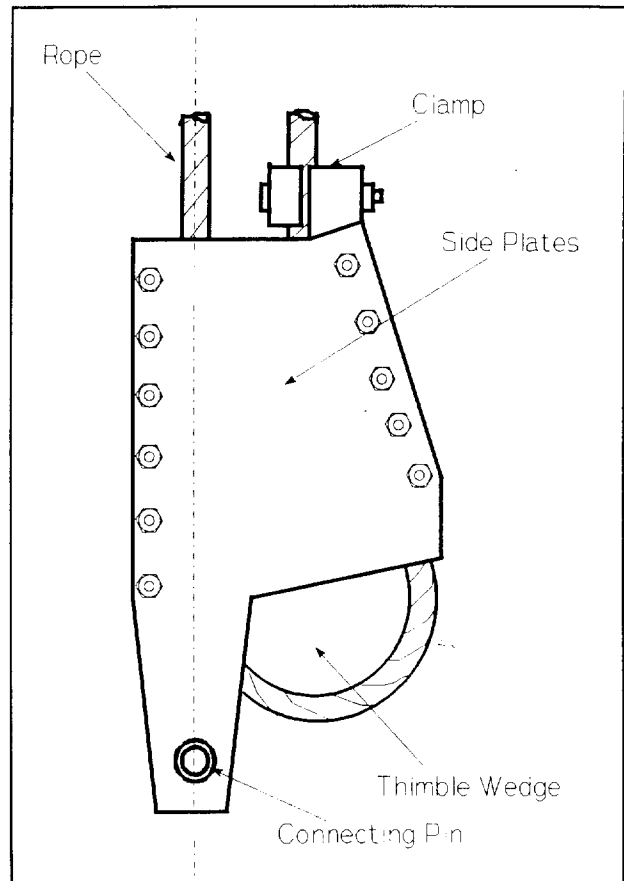
Figure 56 Thimble Type Capel

Disassembly should be carried out using the built in jacking system.

O **Important Points.**
1. Never use hammers and drifts for dismantling. Always use the built in jacking system.
2. Under no circumstances should liners be used in the grooves.
3. Never use incorrectly grooved thimbles and shoes.
4. The rope should be pulled through at predetermined intervals depending on wear and corrosion characteristics of each particular shaft. This period should be between one and three months.

2.3   OTHER TYPES

Other types of capel are basically variations in the detail of these two types of capel.

3   SOCKETS

A socket comprises a cone shaped body machined to accommodate the rope end and a threaded pin with a nut and split cotter. The rope is held in place with either white metal, zinc or polyester resin. The design of winding rope sockets should conform to NCB 465 - 1965, or be designed by a professional engineer. On no account should sockets designed for general engineering ropes be used.

In regard to the actual capping operation, it should be noted that regardless of the kind of material used in casting the cone, the strength of any socket termination is dependent on proper bonding between each wire and the socketing material. With white metal there is an adhesive bond, with zinc there is a chemical bond; but with polyester resin the bond is frictional, generated by internal compressive forces in the resin.

3.1   WHITE METAL[12] [16]

O **Preparation.** In order to prevent any loosening of the wires during the cutting and capping operations the rope must be securely seized with soft wire for a length of at least four rope diameters at a distance from the end of the rope equal to the length of the basket, less twice the rope diameter. Before cutting the rope a two bolt clamp should be fastened either side of the cutting point. After cutting the two bolt clamps are removed and the socket is placed over the rope and pushed down over the seizings, Figure 57. The socket basket must be clean and dry and care must be taken to avoid fouling the inside of the basket with grease from the rope. If necessary the rope should have excess grease removed before fitting the socket.

O **Cleaning.** The end of the rope must now be unlaid and the fibre or plastic core cut out. Independent wire main cores or wire main cores remain and must be opened out with the other wires to form a brush. Wires must not be straightened and great care must be taken to avoid bending or twisting any wire too sharply as deformed wires may fail in fatigue during

A = Length of Basket

B = Wire Serving, 4 × Rope Diameter
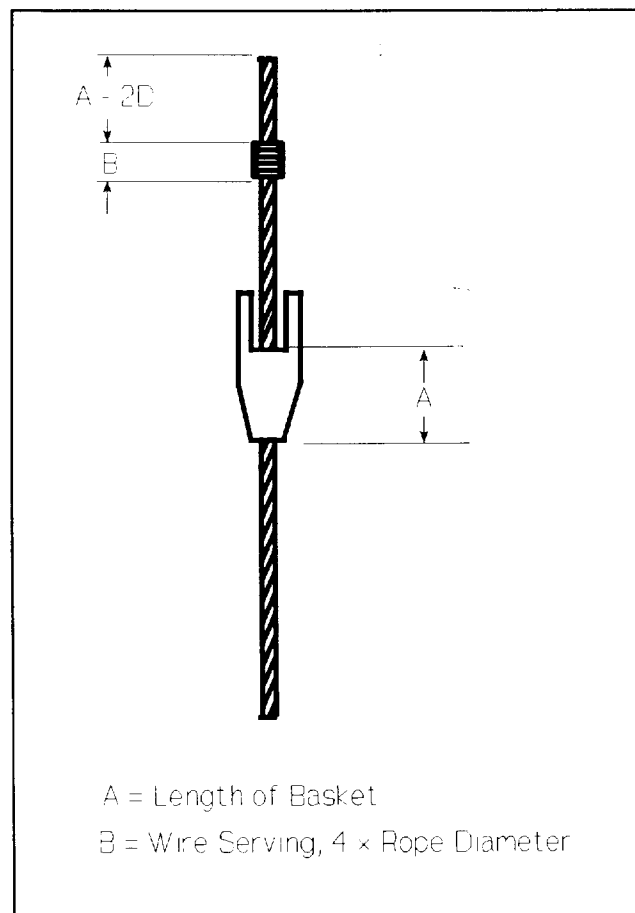
Figure 57 Wire Serving Applied and Socket Threaded on rope

service, especially at the neck of the socket if the wires are bent too far and then bent back again. The outer wires should have an angle of no more than 45° to the axis of the rope. See Figure 58.

Each wire must be thoroughly cleaned of all traces of lubricant and dirt with a water soluble degreasing fluid or non-flammable organic solvent. Paraffin must not be used. After the degreasing operation the brush must be immersed, brush downwards, in a solution of equal parts of hydrochloric acid and water; finally being washed in fresh hot water.

Galvanised ropes are stripped of zinc by immersion into a solution of one part of hydrochloric acid and two parts water. The wires should not be left in the acid solution longer than necessary to strip the zinc and should be thoroughly washed with fresh hot water after stripping.

Special care must be taken during all the brush cleaning operations to ensure that the brush end faces downwards in order to prevent saturating the remainder of the rope with solvent or acid, which could lead to early and rapid corrosion of the rope.

B = Wire Serving, 4 × Rope Diameter
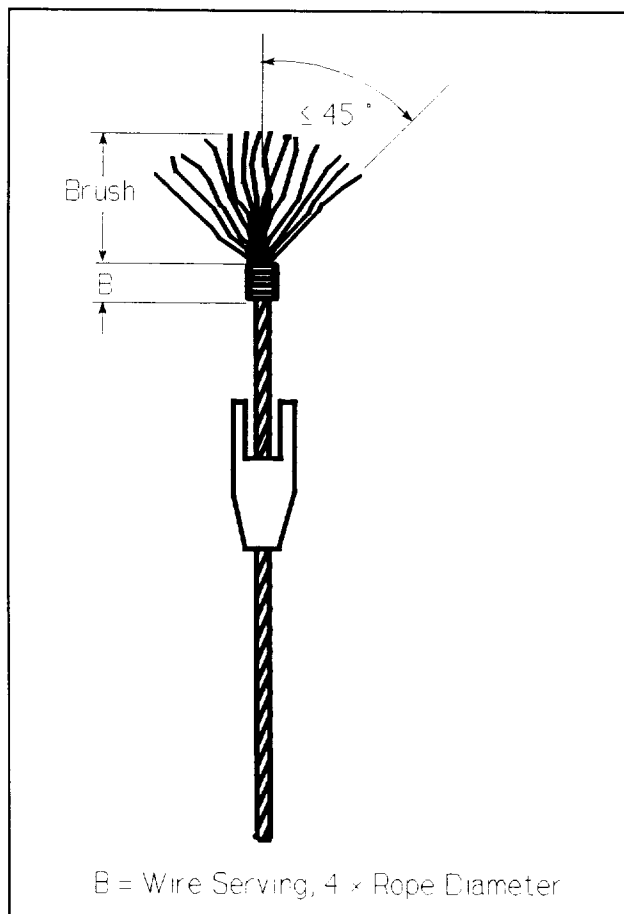
Figure 58 Brush Formed and Cleaned

The brush is now drawn into the basket of the socket. Before doing so the inside of the basket should be checked to ensure that it is free of grease or dirt. If necessary a single turn of serving wire can be used as a twitch to draw the wires together sufficiently to ease entry to the basket. It is likely that the twitch will be drawn from the brush during this operation.

○ **Set Up.** The brush is drawn into the basket and the ends of the wires positioned up to 5 mm above the top of the basket. It is advisable to fit a self centring clamp, designed for the specific socket and rope combination, to align socket accurately with the rope. Figure 59 illustrates a suitable clamp.

After the self centring clamp has been fitted, the rope end with the clamp and socket is positioned vertically. A spirit level should be used on both the rope and the socket to ensure exact alignment. It is essential that the rope should be exactly vertical for at least 24 rope diameters directly below the socket. A distance of 2 m is recommended for ropes up to 56 mm diameter. The junction of the rope with the self centring clamp should now be sealed with clay to prevent any leakage of metal.

○ **Casting.** Prior to pouring the molten metal the socket must be gradually and evenly heated all round the outside by means of a blow lamp. Oxyacetylene flame cutters should not be used and care must be taken so that the flame does not play on the rope. The heating operation should be carried out slowly, allowing plenty of time for the mass of the socket to attain the required temperature. A socket temperature between 150 °C and 200 °C is required and should be checked by means of suitable temperature sticks.
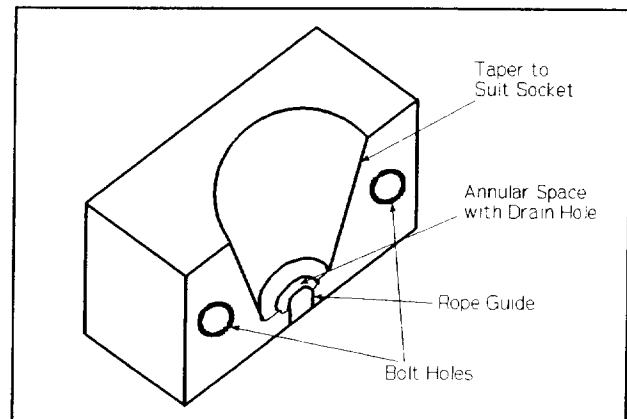
Figure 59 Schematic Diagram of Half of Self Centring Socket Clamp

In the case of a very large socket which by nature of its volume would preclude effective heating in the normal way a special pre-heating funnel should be provided. Heating of the socket to the correct temperature is essential for the free flow of the molten metal in the basket.

While pre-heating the socket the white metal must be heated to a pouring temperature of 350 ± 14 °C. The white metal should be new metal and must be in accordance with BS 643 - 70, the composition being:

  15 % Antimony ± 0,5 %
  5 % Tin ± 0,25 %
  Lead the remainder.

The metal must be free from Zinc and the total impurities must not exceed 0,2 %.

The temperature of the metal is checked by means of a suitable thermometer or thermocouple. Immediately before pouring any dross is skimmed from the surface of the white metal.
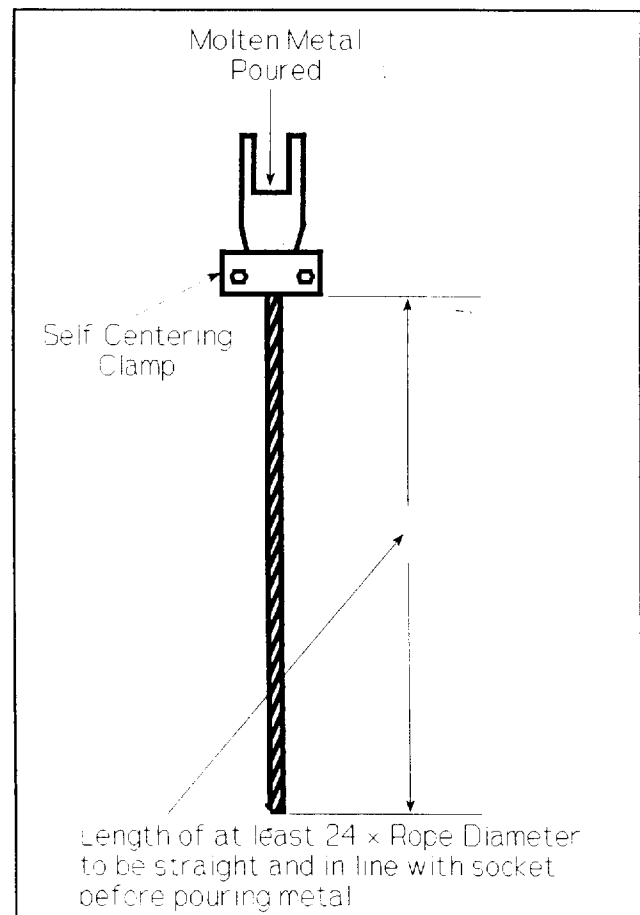
Figure 60 Metal Poured

When the socket is at the correct temperature and immediately before pouring the molten metal, a flux such as powdered resin or some suitable proprietary brand of flux must be applied to the hot brush in the basket of the socket. The molten metal must be poured in a

continuous stream until it reaches the top of the basket compartment. At the start of the pouring operation, the white metal should run from the "tell-tale" hole in the self centring clamp. The metal should be allowed to run for two or three seconds and the hole then plugged using a suitable stopper.

The pouring must be done with a heated ladle of sufficient capacity to fill the basket in one operation. It is helpful in this operation to use a ladle with a baffle adjacent to the pouring lip and extending down to within 25 mm of the bottom as shown in Figure 61. This allows only clean metal to be poured.

The socket must be left to cool naturally at room temperature and must be left undisturbed until the metal is fully set. On no account should the socket be quenched with water. If during the early stages of cooling a depression or "pipe" occurs in the centre of the white metal cone, this should be topped up with a small amount of molten metal.

Dividing Plate.
Does not extend to
bottom of ladle

Molten Metal

After the completed socket has cooled the self centring clamp is removed and the socket neck examined to make that penetration of the white metal has occurred around the whole circumference of the rope. The seizing wire is then removed up to the white metal. It can be useful for later examination to paint a well defined line 12 mm wide round the rope about 50 mm from the neck of the capel. The rope adjoining the socket must now be thoroughly dressed with a suitable dressing.

Figure 61 Sectional View of Bottom
Pouring Ladle

3.2   Zinc.

The preparation of the rope and the method for zinc socketing is similar to the described for white metal with the following variations.

○ **Fluxing.** The wires of the brush after cleaning are fluxed by dipping in a clean, hot (70 °C to 90 °C) solution of zinc ammonium chloride for at least one minute. The solution is made up of 0,7 kg zinc ammonium chloride in 4,5 l water. The brush is allowed to air dry and must not be disturbed or contaminated.

○ **Casting.** High grade zinc to SABS 20 - 70 is heated to a temperature of 460 °C to 480 °C in a ceramic or earthenware container. Before pouring the metal must be cleaned of dross which might have accumulated on the surface. The metal is poured rapidly and continuously in one operation. In view of the higher temperature required for melting the zinc, there is a greater risk of overheating and consequent loss of tensile strength of the wires. A pyrometer must always be used to measure the temperature before pouring.

3.3   RESIN[17]

This is the procedure to be used for the resin capping of wire ropes using the "Wirelock"* system. The use of resin kits as supplied to the National Coal Board, UK is recommended.

○ **Safety Requirements.** In addition to normal safety requirements it is important that there is adequate ventilation in the area of working and that dust masks, safety goggles and gloves be worn throughout the mixing and pouring operations. If resin or powder enters the eye, the eye should be irrigated with clean water for 15 minutes and medical advice obtained without delay.

○ **Materials.** Resin capping kits must be properly stored as recommended by the manufacturer. Before use the expiry date must be checked and date expired kits are not to be used. Kits should only be opened immediately prior to mixing.

○ **Preparation.** Preparation, cleaning and positioning of the rope, socket and brush are to be the same as described for white metal socketing in paragraph 3.1. Before putting the socket onto the rope it is beneficial to lightly smear the inside of the socket with Dow Corning 7 silicone release compound. When pulling the socket over the brush great care must be taken to ensure that there is minimal contact of the wires with the release compound.

In order to prevent leakage of resin when using the self centring clamp it is essential that all joint faces are completely sealed, together with any points necessary to contain the resin mix after pouring. Plasticine has been found to be a suitable sealing compound and a typical sealing arrangement is shown in Figure 62. The centralising clamp should be mounted so that the base of the clamp and the rope immediately below it remain visible to check for leaks. As it is possible for the resin to run down the interstices of stranded ropes it is recommended that small amounts of plasticine be placed in the interstices before the seizing is applied.

○ **Casting.** Kits are formulated for use at socket temperatures of about 18 °C. Consequently the socket temperature should be checked immediately before mixing using a suitable thermocouple type thermometer. At temperatures above 18 °C the resin will gel and solidify more quickly and at lower temperatures it will gel and cure more slowly. At 8 °C or lower special precautions must be taken such as pre-heating the socket to a uniform temperature of about 15 °C. Care must be taken to ensure that no part of the socket is overheated as the gelling rate may accelerate too much. Since the resin mixture is flammable the heat should be removed from the socket before pouring.

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* Trade name of resin system supplied by Millfield Enterprises Ltd. UK.

To mix the constituent materials, pour the total amount of liquid resin from the kit into a mixing container (polystyrene containers must not be used). Gradually add the total amount of powder, mixing continuously until a uniform colour is obtained. It is essential that complete mixing of the materials takes place as quickly as possible and that no unmixed solids remain in the mixing vessel. This operation usually takes about two minutes. Sufficient resin must be prepared to fill the socket in one pour. If more than one kit is required to fill the socket they should be mixed in one container, all of the liquid being poured in first, followed by all of the powder, so that the total mix can be prepared in one operation.

Once the resin is mixed it must be poured immediately at a slow and even rate and in one position to help prevent air from being trapped in the brush. Prodding into the basket with a length of clean stiff wire will also help to release any trapped air. If the resin settles, topping-up of the cone will be necessary using the original mix. Before doing so the mix should be re-stirred for a short period.

Figure 62 Sealing of Self Centring Clamp for Resin Socketing

During the pouring and topping-up operation and early stages of gelling, it is essential than any leaks be identified and stopped; as any leaks may result in cavities being formed in the neck region of the socket.

The capping must be left undisturbed for at least 45 minutes from the time the whole head of the cone has hardened. Hardness can be determined by a scratch test on the surface of the resin with a hardened steel blade. This should only leave a shallow scratch mark. The socket should not be loaded for at least an hour after a satisfactory scratch test. The top of the socket must be examined; the wires should be well distributed and there should be no cracks in the resin. If any cracks are found the termination must be remade.

A check into the penetration of resin into the socket neck must be made after removing the centralising clamp. The seizing and any collar of excess resin must be removed and the check made around the circumference of the rope. The cleaned portion of the rope adjacent to the socket must be re-lubricated with suitable rope dressing and the neck of the socket sealed with the same dressing.

○ **Precaution.** Special care must be taken at all times to ensure that paint remover or any substances containing methylene chloride or caustic soda do not come into contact with the resin capping since these act as a solvent, reducing the integrity of the capping.

Appendix B

The Advantages and Disadvantages of Various End Connections for Triangular Strand Winding Rope

1   THIMBLE SPLICE

Advantages	Disadvantages
1. Simple.	1. 80 % efficiency.
2. Always available.	2. Badly made has lower efficiency.
3. Anyone can be taught.	3. Must be regularly inspected.
4. Easily inspected.	4. Does not perform well when wire load reduces to zero.
5. Does not usually develop dangerous fatigue .	5. A poorly made splice broke due to bad conditions and no inspection.
6. Large rope can be spliced in 1½ hours.	
7. Excellent performance in the last 90 years.	
8. When rope becomes excessively corroded or fatigued broken wires occur in splicing which is an indication that the rope should be discarded.	

2   SOCKETS

Advantages	Disadvantages
1. Develops full strength of rope.	1. Takes a long time to make.
2. Neat in appearance.	2. Zinc or white metal takes time to cool and resin needs time to cure.
3. Short length.	3. Sensitive to cleanliness.
4. Will not loosen if turn is taken out of rope.	4. Sensitive to temperature.
	5. Needs precision setup of socket and rope.
	6. Problems sometimes occur with fatigue at neck of socket.
	7. Corrosion can be a problem.

3 WEDGE CAPELS

Advantages	Disadvantages
1. Suitable size capels have efficiency greater than 95 %. 2. Length shorter than a splice. 3. Neat in appearance. 4. Will not loosen if turn is taken out of rope.	1. Takes longer to make than a splice. 2. Can loosen due to vibration. 3. Safety block takes time to cool or cure. 4. Sensitive to cleanliness. 5. Needs expert assembly and fitting. 6. Problems with localised fatigue at neck of capel. 7. Corrosion can be a problem. 8. On some rope constructions fibre core needs to be replaced by a steel core in capel area.

4 THIMBLE (OR PEAR SHAPED) CAPEL

Advantages	Disadvantages
1. Suitable size capels have efficiency greater than 90 %. 2. Length shorter than a splice. 3. Quick to fit. 4. Easy to move rope in capel.	1. Sensitive to cleanliness. 2. Problems with localised fatigue in neck of capel. 3. Corrosion can be a problem. 4. Clumsy in appearance. 5. Not suitable for use with a detaching hook.

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