Safety in Mines Research Advisory Committee

Final Report

Deterioration and Discard of Mine Winder Ropes

Volume 1

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Table of Contents

1 Introduction

The introduction of new factors of safety for winding ropes is accompanied with codes of practice for the design, operation and maintenance of winders and for the condition assessment of winder ropes. The studies undertaken during this project were aimed towards refining the requirements in these codes of practice.

This report is divided into the four main sections of the contract scope. Since the sections are complete on their own, each one contains its separate introduction.

2 Numerical relationship between winder parameters and rope life

A major part of a previous SIMRAC contract (GAP054: *The safe use of mine winder ropes*) consisted of drafting a safety standard[1] as required by the Mine Health and Safety Act[2] The requirements in this safety standard were drawn up by members of the mining industry, taking into account the results of the research done under contract GAP054. In many instances, however, the requirements were based on the experience of the mine representatives and not on the results of scientific investigations. Although it may be assumed that these requirements ensure safe winding, it may be assumed that they are too stringent. The question therefore arose:

How do winder design parameters affect rope life and safety?

We can only answer this question if we can distinguish between the different modes of rope deterioration and to quantify the degree to which each rope operating parameter contributes to each deterioration mode. Operating parameters include:

- winder design and control parameters,
- winder and rope maintenance procedures,
- environmental conditions, and
- rope tensile grade and construction.

The approach used to gain insight into the interrelation between rope operating parameters and rope life consisted of the following two steps:

- Re-work a statistical rope life model to clearly illustrate what can (and what cannot) be extracted from historical rope life data.
- Observe the rates of rope deterioration on critically selected drum winders, together with the operating conditions and maintenance procedures.

2.1 Statistical evaluation of rope lives obtained on drum winders

2.1.1 Choice of method

A meeting was held between Mr T C Kuun and the authors. The purpose of this meeting was do discuss the most appropriate strategy for relating drum winder design parameters to rope life. The following was agreed:

- The historical rope life data is severely influenced by inconsistent rope discard criteria and unsystematic rope maintenance practices.
- The analysis done previously by van Zyl[3] are the best treatment that the rope life data could be subjected to. Van Zyl's life prediction model should therefore be used to relate winder parameters to rope life.
- Further statistical analyses should also not be influence by inadequate rope maintenance procedures.

It was agreed therefore, that the investigation should entail the application of the rope life model to parametric life predictions.

2.1.2 Rope life model

From the rope life model presented by van Zyl[3], model DII01 was chosen. This model is based on the mean rope survival probability as a function of number of accumulated winding cycles as depicted in Figure 2.1.1 This survival probability function $S_m(t)$ applies to a winder that has parameters equal to the mean of all the parameters that the winders had on which the model was based. The survival probability curve for a specific winders with p parameters X (that differ from the mean parameters X_m) is given by

$$S(t) - S_m(t) \cdot e^{\left(\sum_{i=1}^{p} (X_i - X_{mi}) \beta_i\right)}$$

The β-coefficients for the chosen model are given in the table below:

Variable	X_m	β
Load range	0,057	-200
Capacity factor	10,502	-0,47
Static factor	5,736	-0,52
Minimum bending factor	95,32	-0,092
Sheave tread pressure	2,791	-1,26
Normalised creep at the back end	0,4803	18,6
Dummy work at the back end	413,44	0,0203
Average dummy work	264,85	-0,0222
Tensile grade 2*	0,3348	-0,09
Tensile grade 3*	0,1418	-0,95
6 × 27 construction*	0,0543	1,53
6 × 29 construction*	0,1146	-0,55
6 × 30 construction*	0,2157	0,43
6 × 33 construction*	0,0875	0,58

* These are indicator variables and have values of zero or one

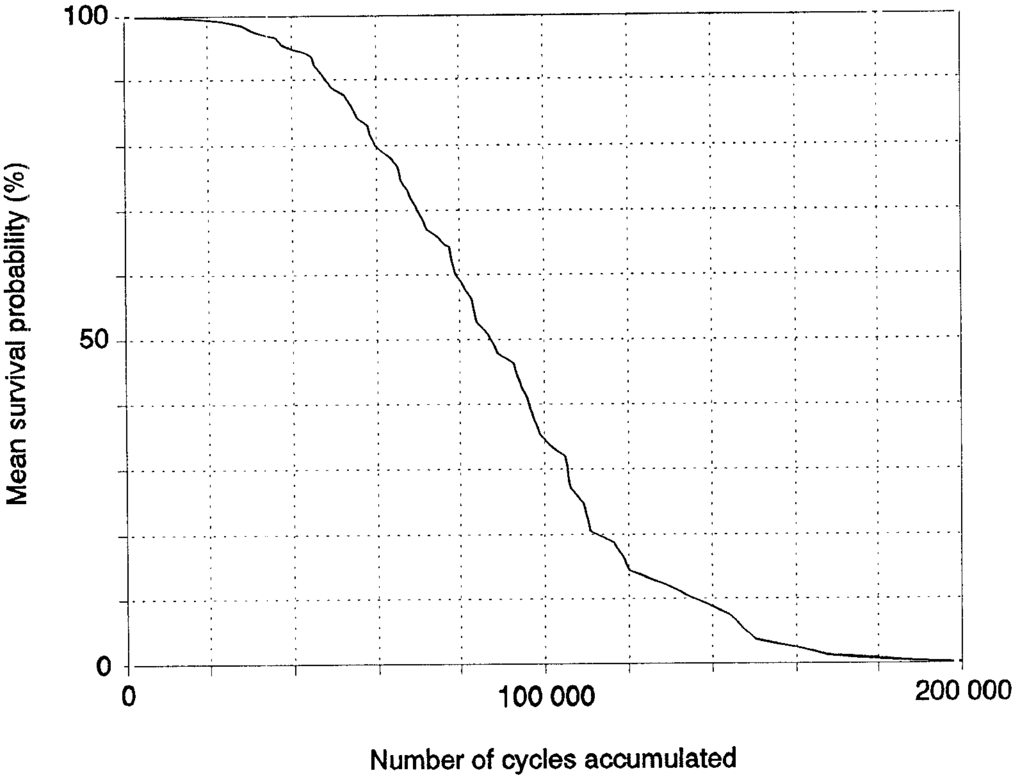


Fig. 2.1.1: ***Mean rope survival probability***

Figure 2.1.1 shows that the rope does not have a specific life under a given set of operating conditions. The curve should be interpreted as the manner in which the probability of the rope surviving an inspection reduces with the number of winding cycles that have been accumulated. To compare rope lives on different winders, the number of cycles at a 50 per cent survival probability has been chosen. For the winder with the mean parameters (fondly referred to by the researchers as the *mean machine*), the 50 per cent rope life is 87 500 cycles.

The rope life model was programmed onto a computer spreadsheet and a range of winder parameters was varied to study their effect on rope life. The rope life model takes certain winder design parameters as input data for the life predictions. These parameters are interrelated and cannot be studied in isolation. This must be kept in mind when interpreting the results.

2.1.3 Results

The results of the rope life calculations are presented in Appendix A

2.1.4 Discussion

From this study it is possible to list the drum winder parameters which have an influence on rope life. The life prediction model provides the basic information in that the model is built on the specific parameters, namely:

- Load range
- Capacity factor
- Static Factor of safety
- Minimum bending factor (D/d ratio)
- Sheave tread pressure
- Normalised creep at the back end
- Dummy work at the back end
- Average dummy work
- Tensile grade of the rope
- Rope construction

These parameters are calculated from the following basic data as follows:

- *Maximum length of suspended rope*
  Used to calculate factor of safety, sheave and drum tread pressure, normalised creep at the back end, dummy work at the back end and average dummy work.

It is also a factor in the choice of rope size, tensile grade, breaking strength and mass.

- *Drum diameter and Sheave diameter*
  These parameters determine the D/d ratio and the tread pressure for sheave and drum.
- *Mass of payload*
  This determines the factor of safety, is used to calculate the capacity factor and load range as well as sheave and drum tread pressure, normalised creep at the back end, dummy work at the back end and average dummy work.
- *Mass of conveyance and attachments*
  This determines the factor of safety, is used to calculate the capacity factor and load range as well as sheave and drum tread pressure, normalised creep at the back end, dummy work at the back end and average dummy work.
- *Nominal rope diameter*
  Used for determining D/d ratio, sheave and drum tread pressure. To the extent that rope diameter is determined by end load, factor of safety and length of suspended rope there is a relationship with normalised creep at the back end, dummy work at the back end and average dummy work.
- *Tensile grade*
  This does not have a marked influence on rope performance but is connected with the relationship between rope size and strength.
- *Rope construction*
  Like tensile grade, rope construction does not have a marked influence on performance and has only a slight effect on the relationship between rope size, strength and mass.
- *Rope breaking force*
  Has a direct influence on factor of safety, capacity factor, tread pressure, load range, normalised creep, dummy work at the back end and average dummy work.
- *Rope mass*
  Similar influence as rope breaking force.
- *Rope elastic modulus*
  Has an influence on normalized creep, dummy work at the back end and average dummy work.

Having regard to the above relationships it is still possible to list some of the derived parameters in order of importance.

There are parameters which are directly controlled by some of the choices and so are not listed. The list in order of importance (in the writers' view) is as follows:

- Depth
- Factor of Safety
- D/d ratio
- Tread pressure
- Rope construction
- Tensile grade

Load range is left out of this list because it is considered unimportant, especially for deep winds.

2.1.5 Conclusions

The graphs clearly indicate some of the relationships between rope performance and winder parameters. It is also obvious from some of the graphs that indicate trends contrary to expectations that the interdependence of these parameters makes simple relationships unreliable.

In practice, the life prediction model of the statistical analysis has been shown to be reasonably accurate when used within the parameters used in the study and in some cases has proved to be satisfactory when extrapolating. The graphs give some information on trends, but care must be used in interpreting this information. It is obvious that the life prediction model remains the best approach in evaluating chosen winder parameters.

2.1.6 Recommendations

The statistical model was prepared from the best data available, even though it was somewhat inconsistent. Because it is a valid representation of current practice, this model should be used for the purposes it was designed for.

In order to improve the model, the opportunity must be made to obtain "better" data by having consistent discard criteria and properly documented modes of rope deterioration. When this is available a new model can be prepared.

The graphs clearly illustrate the difficulty of separating individual winder parameters when undertaking a design for a new winder or making modifications to an existing winder. In many ways the old "rules of thumb" are shown to be a satisfactory basis for initial design considerations. These may be listed as follows:

- Winder drum and sheave diameters should be in accordance with the Haggie Rand Ltd formula:

  $$D = Kd(v+9) \times 10^{-1}$$

  where D = sheave or srum diameter (m)
  d = rope diameter (m)
  K = minimum D/d ratio recommended for construction to be used (42 for triangular strand and non-spin ropes)
  v = rope speed (m/s)

- Conveyances should be as light as possible.
- Tread pressure for sheave and drum should not be in excess of 3,2 MPa. However winder capital cost considerations may be an overriding consideration. Kuun's formula should be used for initial evaluation of rope life.
- The lowest allowable factor of safety should be used (with an appropriate margin for fatigue, wear and corrosion in service).

The winder parameters should then be checked by means of the statistical model, developed in the statistical analysis, to establish if appropriate rope performance can be achieved.

2.2 Field studies of rope deterioration

A study programme was proposed in the final report on project GAP054 that entails the following steps:

- Verification of winder parameters to ensure that any changes to the operating conditions since previous investigations will be considered.
- Corroboration of rope maintenance practice to establish rope hygiene practices.

- Winder behaviour measurement to record winder dynamics so that rope forces can be established.
- Rope inspections to note the onset and progression of rope deterioration.
- Evaluation of discarded ropes to allow detailed rope inspections and destructive tests.
- Laboratory work to measure internal rope stresses and contact stresses and to study rope fatigue behaviour and torsional behaviour. Whenever possible, this work should be augmented by mathematical modelling so that universal solutions can be found.

2.2.1 Winder selection

In preparation for the study programme, a preliminary list of winders was selected during the course of project GAP054. These winders were selected on the basis of the reasons for which ropes were discarded. After discussions with the mine engineers, the final list of winders was drawn up as follows:

Winder	Study object
St. Helena No. 4 shaft	Longest rope life
Hartebeestfontein No. 4 shaft	Wear
East Driefontein No. 2 shaft	Broken wires
West Driefontein No. 4 shaft	Wear and broken wires

2.2.2 Observations on site

The selected winders were visited to coincide with rope condition assessments and with rope maintenance procedures. During rope condition assessments, rope diameters and lay lengths were measured independent from the measurements taken by the rope inspectors. Rope surface replicas were made and photographs were taken. In addition, any observations of conditions that could have an effect on rope deterioration were recorded.

Appendix B contains the measurements taken on site as well as an example of the rope surface replicas. The photographs and rope surface replicas are not shown in this appendix. These are being collated for later analysis.

2.2.3 Winder dynamics measurements

The rotation of the drums of each winder was recorded. The instrumentation consisted of a rotary encoder mounted on a wheel that was pressed against the drum. The encoder was connected to a portable computer that recorded the drum position to within 0,2 mm every 100 ms. Two winding cycles (four trips) were recorded on each winder (and on each drum in the case of electrically coupled drums).

The position recordings were then related to linear rope movement by equating the total number of pulses counted to the length of wind. The effect of the increase in effective drum diameter caused by layer cross-overs was neglected. Rope speed and rope accelerations at the drum were calculated from the position recordings.

A computer program was used to calculate the rope forces during each trip. The program solved the equation of motion for a distributed mass system with an attached mass at the one end. The input data consisted of the rope and conveyance mass, the rope stiffness and the winder speed. The output was the rope force at the drum and the conveyance for the duration of the trip.

The following is an example of an input data file. This illustrates the data input requirements of the program.

```
       8.7          { rope mass per unit length}
      122           { elasticity constant k1 [GPa]    (k1 > k2/k3) : stress = K * strain }
       0            { elasticity constant k2 [GPaMPa] (>=0)  : K = k1 - k2/(stress + k3) }
       1            { elasticity constant k3 [MPa]    (>=0) }
      925           { rope area }
      0.02          { damping constant [s] (>=0) : damping force = Area * K(stress=0) *
                      damping constant * d(strain)/dt}
     15136          { conveyance mass including payload [kg] (>0) suspended per rope }
      2103          { initial length of rope from winder to conveyance [m] (>0) }
       1            { "speed factor" (>0) : determines time step selection policy.
                      Increasing speeds up execution and decreases accuracy }
      0.1           { time interval between printed results [s] (>0) : partly determines
                      step size used }
       0 ,0         { time [s] and drum velocity [m/s] coordinates : positive velocity }
.1999969,-7.629511E-05 { start of time and velocity data obtained from winder recordings }
.3999939,-2.288853E-04
```

In this example, the values for a BMR winder are shown. The conveyance mass has been halved. The rope forces calculated by the program are therefore the force acting on each rope.

The following table shows a summary of the input data used:

Winder		StHelena	East Drie	West Drie
Rope Mass (kg/m)		9,3	8,7	9,3
Rope Area (mm^2)		967	925	967
Conveyance Mass (kg)	full	16176	15136	12735
	empty	7186	6511	5017
Skip Position (m from drum*)	top	75	71	76
	bottom	971	2103	1529

* This value includes the length of the catenary.

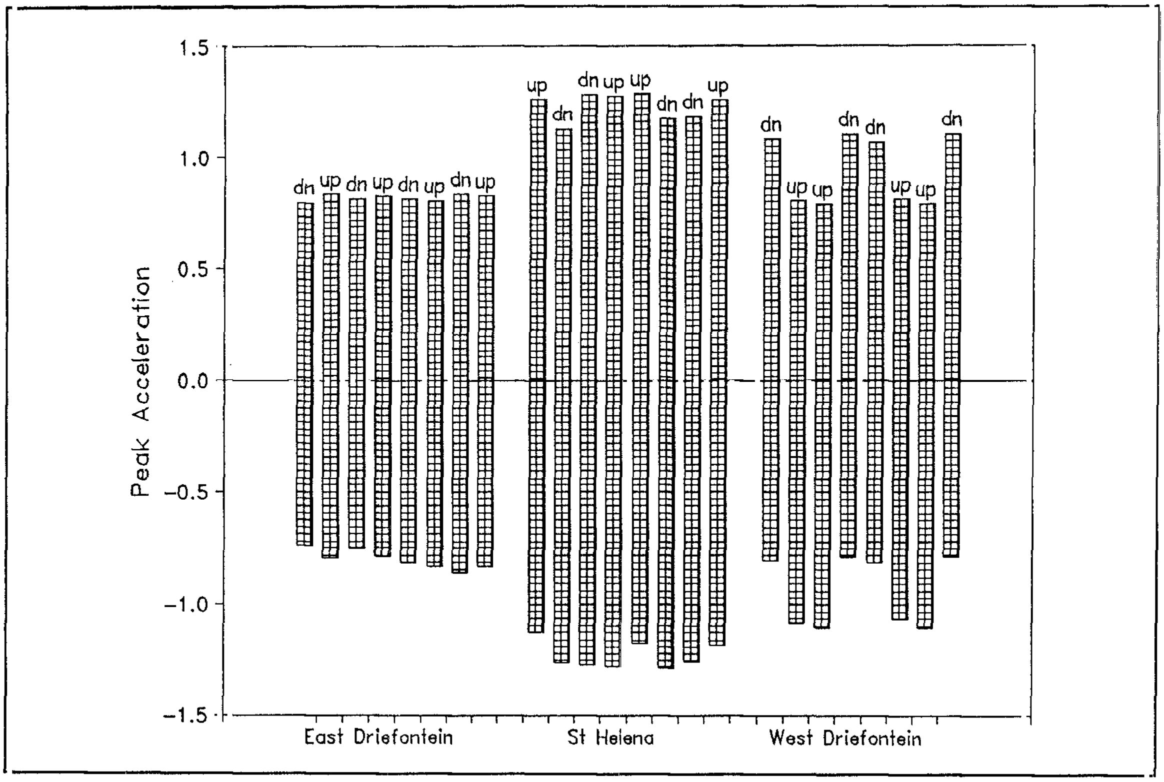
Results

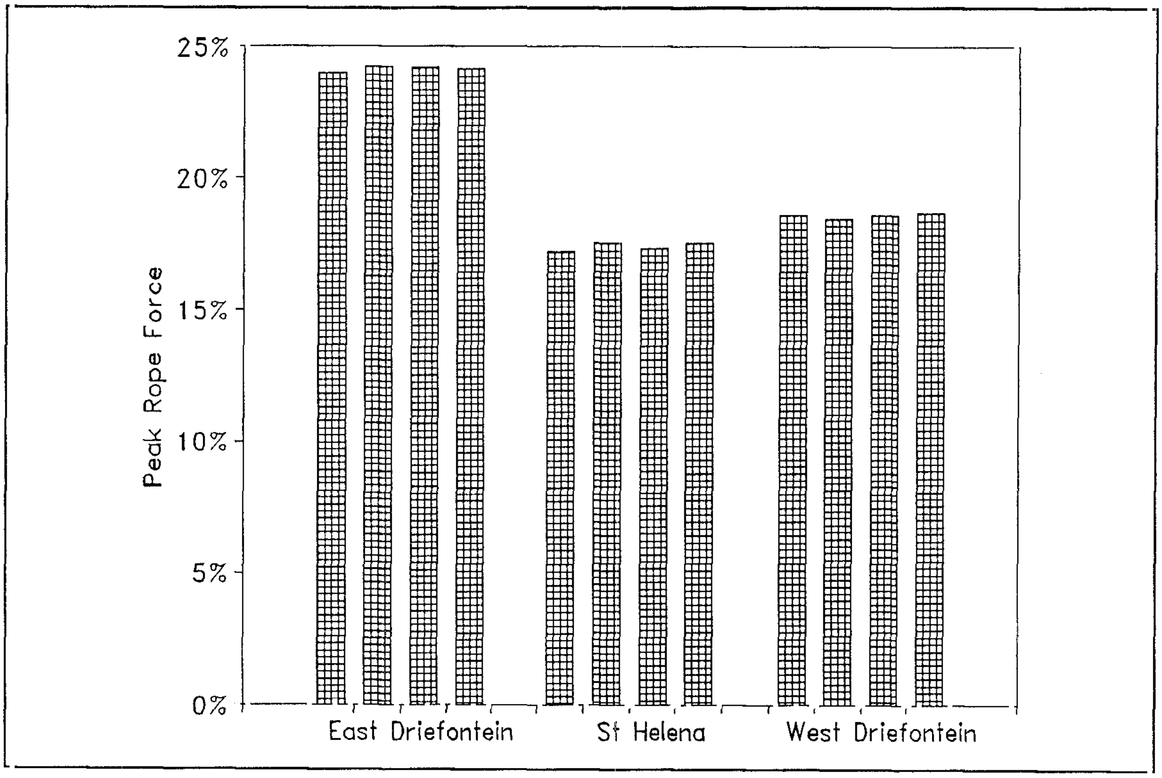
Appendix C shows the results of the winder dynamics measurements and the rope force calculations. The results of the dynamic rope forces are summarised in the graphs that follow.

This graph shows the acceleration peaks and troughs. Note that the West Driefontein winder has the highest values during the deceleration phase.

The peak back end rope forces are very consistent for each winder. The St Helena winder, which has the highest static factor of safety, also has the lowest dynamic rope forces (expressed as a percentage of the rope strength).

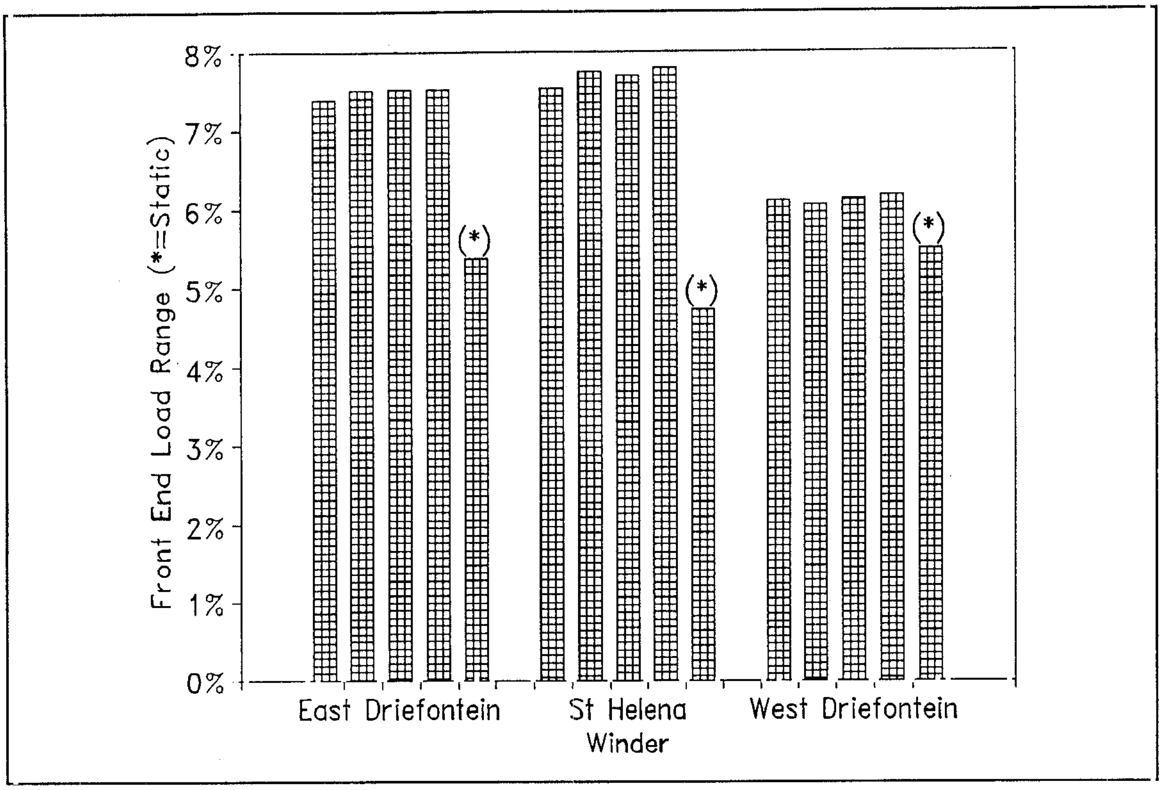
The dynamic load ranges at the front end are the highest at the St Helena winder. The static load range is merely the weight of the payload (expressed as a percentage of the rope strength).





2.2.4 Rope maintenance practice

The only rope maintenance procedure observed was the cutting of front ends an pulling in of back ends at East Driefontein No 2 Shaft on 1996-09-28. Appendix D lists the



steps done and the observations made. Photographs were made of the various steps. They are not included in the report but will serve to make comparisons when conclusions are made regarding the different rope lives obtained on the selected winders.

2.3 Triangular strand rope behaviour in deep shafts

When a triangular strand rope is subjected to pure tension, its helical construction causes it to unlay. Conversely, there is a torsional reaction when the rope is tensioned and prevented from rotating. When such a rope is suspended vertically, therefore, the variation of tensile force along the length of the rope results in a corresponding variation of rope twist: The lay length increases at the back end and decreases at the front end of the rope. This behaviour has led to the following question: What is the maximum depth of a shaft in which a triangular strand rope can be used for hoisting without the danger of excessive deterioration rates or of rope instability?

Members of the GAPEAG requested that tests be done to study the coiling behaviour of triangular strand ropes with very long lay lengths. The following experiment was planned:

- Determine the lay length at of the back end of a triangular strand rope operating in a 3000 metre shaft by means of laboratory tests and calculations.
- Let the spin out of a rope operating on a shallower shaft until the laylength is equal to that determined in the previous step.
- Continue to operate the winder while observing the behaviour of the rope.

Substantial preparation went into this study, but it was difficult to find a mine where such an experiment could be conducted. Concerns were raised about the safety of such an experiment and finally the GAPEAG recommended to suspend this section of the contract.

The following brief report serves to alleviate these concerns:

In April 1987 Haggie Rand supplied a set of 47 mm diameter triangular strand winding ropes for use on the man winder at No. 3 shaft at North Broken Hill Limited in Australia. The mine personnel were requested to double the ropes down the shaft for tensioning at the time of installation. However they declined and proceeded with their normal method, described as follows:

The rope was first coiled onto the winder drum from the rope reel on which the rope was supplied. It was the attached to the conveyance with a swivel connection and the conveyance slowly lowered to the shaft bottom while spin was released from the rope. At the lowest position in the shaft, the conveyance was chaired in the shaft and the rope and swivel disconnected. All the rope was then unwound from the winder drum and accumulated at the bottom of the shaft (i.e. pulled along a driveway be means of a locomotive). After all the rope was uncoiled from the winder drum, it was then recoiled under its own tension and the front end finally connected to the conveyance without the swivel. The rope operated satisfactorily in this condition and was regularly retensioned in the same manner during its life.

Replacement ropes were supplied in 1992 so the operating ropes remain in service until this time and behaved satisfactorily. Mr Duncan MacDonald (Haggie Rand) visited the mine during this period and observed (was struck by) the extremely long rope lay.

Taking this experience into account, it was recommended to resume the investigation. There are incidents in South Africa where a rope needs to be disconnected when the conveyance is at the bottom of the shaft. As soon as the rope is disconnected, it makes hundreds or thousands of turns at the front end. Such an occasion would be ideal to study the rope behaviour when very long lay lengths occur at the front end.

In August 1994 the conveyance on the underlay rope at Loraine No. 3 shaft was detached. The front end of the rope then rotated through approximately 800 turns. This event provided an ideal study object. The report of this study is presented in Volume 2 of this report.

3 Refined discard criteria for winder ropes

The work on refining the discard criteria for winder ropes is a continuation of the work done under GAP054. As before, discarded ropes were collected and tested to determine their strength so that their actual strength could be compared to the condition as assessed by the rope inspectors. Samples of non-spin ropes were used to cut wires before a test to destruction to determine the effect of broken wires on the strength of the ropes

3.1 Tests on discarded ropes

In future, the condition of all winding ropes will have to be assessed in accordance with the Rope Condition Assessment Code of Practice (SABS0293:1996). Destructive strength tests on samples from discarded winder ropes are required to verify the criteria and procedures of the code of practice, and to determine the general state of winder ropes when they are discarded.

The investigation was carried out as part of the SIMRAC project GAP324:1996. The results of tests on samples obtained from winder ropes that were discarded in 1996 are covered.

The majority of rope samples received were of triangular strand construction and from drum winders operating in vertical shafts. The discard criteria for triangular strand ropes are adequate to determine when a rope has lost 10% of its initial strength. The discard criteria for rope diameter changes should be investigated in future.

More Koepe winder head and tail ropes have to be tested before meaningful conclusions on discard criteria for non-spin type rope constructions can be reached. Efforts should also be made to obtain samples from non-spin ropes that operated on drum winders, and from triangular strand ropes that operated on incline winders. The detection, classification, and effects of corrosion on winder ropes have to be studied in greater detail in future.

Quite a number of ropes with unacceptable degrees of strength losses were amongst the samples. The presence of such ropes in service can only be ascribed to poor rope inspection procedures and/or inadequate rope inspection intervals at the shafts concerned. The discard criteria of the code of practice are not at fault.

In future, the information gathered for discarded ropes should include a history of all rope examinations carried out on these ropes. Shafts with poor rope inspection procedures can be then be located, and their inspection procedures can be addressed and improved. Furthermore, information on rope deterioration rates will be acquired.

It is imperative that the collection and testing of samples from discarded winder ropes should continue, but then only if the recommendations are implemented.

3.1.1 Introduction

In future, the condition of all winding ropes will have to be assessed in accordance with the Rope Condition Assessment Code of Practice (SABS0293:1996)[4]. The aim of the prescribed rope discard criteria and prescribed inspection intervals of the code of practice is that a rope will be discarded when it has lost (approximately) 10% of its initial strength.

Destructive strength tests on samples from discarded winder ropes are required for two reasons:

- To verify the accuracy and applicability of the discard criteria of the Code of Practice, and to refine these criteria if necessary.
- To determine the general state of rope discarding in this country, i.e. by how much do ropes actually deteriorate before they are discarded.

An initial investigation into the remaining strength of samples from discarded drum winder ropes (discarded in 1993) was carried out by Borello[5]. The results of samples from ropes discarded in 1994 and 1995 are described in two reports by Wainwright[6,7]. The rope sets of the last two reports included non-spin ropes from Koepe winders.

The results of tests on 52 samples obtained from winder ropes that were discarded in 1996 are described here.

3.1.2 Discard criteria

The rope discard criteria of the Rope Condition Assessment Code of Practice are:

Broken wires

For triangular and round strand ropes, the maximum allowable reduction in steel area due to visible broken wires are:

- 7% if the broken wires is distributed symmetrically in one lay length
  4% if the broken wires are distributed asymmetrically
  Double these amounts are allowed over five lay lengths
- If more than half of the visible broken wires are in two adjacent strands the broken wire distribution will be termed asymmetrical.

A "discard factor" of one (1) is assigned to the allowable discard levels for broken wires. The discard factor for fewer broken wires than the allowable level is calculated proportionally.

The number of visible broken wires in a single strand shall not exceed 40% of the total number of outer wires in the strand. This is applicable to triangular strand, round strand and non-spin type rope constructions.

More elaborate discard criteria for non-spin rope constructions are still in the process of being established. The first series of tests are described in Section 3.2.

Changes in rope diameter

Where there is abrasive wear only, the following reductions in rope diameter (compared to the **nominal** rope diameter) are reason for discard and have a discard factor equal to one:

- Triangular and round strand ropes:
    7% if the wear is symmetrical
    5% if the wear is asymmetrical
- Non-spin ropes (multi-layer strand ropes):
    5% if the wear is symmetrical
    4% if the wear is asymmetrical

Where there is a combination of wear and plastic deformation, the ropes of vertical drum winders generally experience this combined type of surface damage. The following reductions in rope diameter (compared to the **nominal** rope diameter) are reason for discard and have a discard factor equal to one:

- Triangular and round strand ropes:
  - 9% if the wear is symmetrical
  - 7% if the wear is asymmetrical
- Non-spin ropes (Multi-strand layer ropes):
  - 6% if the wear is symmetrical
  - 5% if the wear is asymmetrical

Any localized rope diameter increase of more than 7% shall be reason for discard, and will have a discard factor equal to one.

Combined effects

The discard factors for broken wires and diameter changes are summed to obtain a "total discard factor" for a section of rope. If this combined discard factor is equal to one, the rope shall be discarded.

Corrosion

The loss in rope strength calculated from the steel area loss indication of an electromagnetic instrument shall not exceed 10%.

On visual inspection any corrosion termed as "more than slight" or worse will be reason for discard. The code of practice (SABS0293:1996) contains colour photographs for the different categories of corrosion for visual inspection.

The code of practice is not specific on how the effects of corrosion should be combined with broken wires and rope diameter changes.

Other reasons for discard

Any type of damage to a winding rope that will subsequently lead to an increased rate of deterioration is reason for immediate discard of the rope. These are waves, bends, kinks, rope core failure, and obvious physical damage to the rope. Apart from the latter, all the other factors are defined and specified in the code of practice.

A discard factor does not have to be calculated for any type of damage that calls for the immediate discard of a rope. It is important, however, that these rope sections be tested to establish whether the winders on which the ropes operated were at immediate risk of rope failure while those sections of rope were still in service.

Summary of discard criteria

Rope discard criteria can be divided into three categories:

a. The factors that indicate that a section of rope has lost approximately 10% and more of its initial breaking strength. These are broken wires, loss in steel area (wear, plastic deformation, corrosion), and changes in rope diameter.

b. The factors that indicate that the subsequent rope deterioration at a point on the rope will be at a greater rate than normal. These include rope kinks, waviness, increase in rope diameter, and collapse of the core of the ropes. These call for the immediate discard of the rope.

c. Damage that is such that the rope has obviously lost more than 10% of its strength. Examples are ropes with broken strands; "hourglass" type failures of non-spin ropes; and damage caused by coiling problems or protruding drum sleeve bolts, which result in numerous broken wires and deformation around the circumference of a rope at that specific rope section.

Rope samples that fall into category "a" are required to verify and refine the discard criteria of the code of practice.

Rope samples that fall into categories "b" and "c" are required to determine whether any winding operation was at a risk of rope failure while the damaged sections were still in service.

3.1.3 Discarded rope samples

The 52 rope samples that were received in 1996 can be divided as follows:

25 rope samples for which discard factors could be calculated. (22 from drum winders and 3 from Koepe winders)
7 rope samples with corrosion as reason for discard.
5 rope samples with damage as reason for discard.

1 rope sample with damage, but inadequate information (tested).
1 rope sample with corrosion, but inadequate information (tested).
5 rope samples with no apparent reason for discard and inadequate information (tested).
8 rope samples with inadequate information (these were not tested).

Only the 37 rope samples of which adequate information were obtained are discussed.

It could not be established in all cases that the rope sample received was actually the reason for discard of the rope.

Damaged ropes, and rope samples with corrosion will be discussed separately. For the rest of the ropes, discard factors were calculated for broken wires and diameter changes.

Rope inspectors reports were only available for a few cases. Actual rope diameters (measured on site and in service) were therefore not available for most of the rope samples. For consistency, the discard factors for all the rope samples were calculated on the data obtained from the pre-test inspections. The procedures followed was as follows:

- The number and exact position of broken wires were determined, care being taken to identify any wires broken in more than one place in the sample. The discard factor for broken wires was calculated on the basis of number of broken wires, distribution and steel are of the rope.
- The rope diameter was measured under a 10%-of-breaking-strength pre-load. Based on observations of symmetrical or asymmetrical wear, discard factors were calculated. As prescribed by the Code of Practice, the nominal diameter was used for calculation of the discard factor for diameter changes.

3.1.4 Results of strength tests

Samples with calculated discard factors - Triangular strand rope samples

The discard factors for broken wires and diameter changes were added to obtain a "total discard factor" for every rope sample. Details of the 21 triangular strand rope samples are given in Table A1, Appendix E, together with the calculated discard factors and the results form the strength tests on the samples. In three cases, apart from the rope section that was reason for discard, additional samples were received from the same rope. The additional rope samples were submitted because they had discard factors close to what would have been "reason for discard".

The results of the tests carried out on the triangular strand ropes are summarised in Fig. 3.1.1. The change in rope breaking strength, expressed as a percentage change from the new breaking strength, is shown as a function of the total discard factor calculated for each rope.

Figure 3.1.1 shows that all ropes with discard factors of less than 1,26 (17 ropes) had breaking strength losses of less than 7%. The discard criteria for triangular strand ropes are adequate to determine when a rope has lost 10% of its initial strength.

The indications are that the criteria for rope diameter changes are too strict. The discard factors for diameter changes were calculated on the nominal rope diameters. This aspect should be investigated in future.

The rope with a discard factor of 1,6 and a strength loss of 14% is still tolerable, but the ropes with discard factors greater than 2 are reason for concern. Not enough information was available to determine how these ropes deteriorated to such an extent. Were they perhaps damaged? Were the inspection intervals inadequate? How long before they were discarded were the previous inspections carried out? These questions can only be answered by obtaining more appropriate information on discarded ropes in future. The discard criteria are not at fault here.

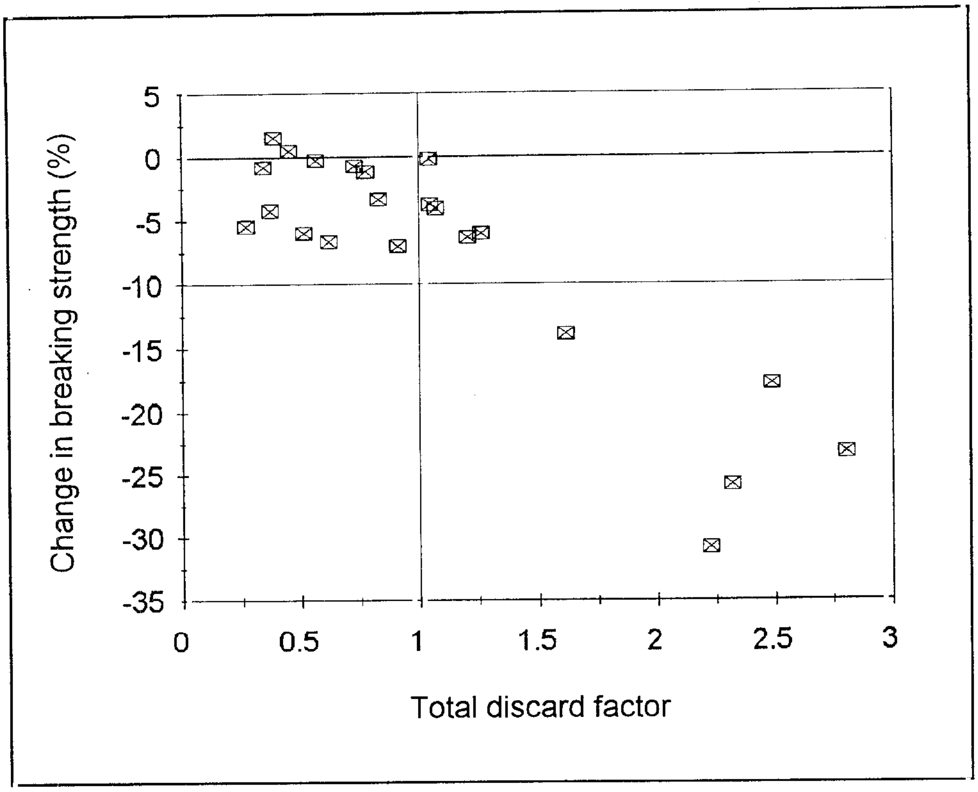


Figure 3.1.1: Triangular strand ropes discarded from drum winders

Samples with calculated discard factors - Samples from Koepe winder ropes

The only guide given by the code of practice for calculating a discard factor for non-spin ropes are diameter reduction and mandatory discard if more than 40% of the outer wires in a single strand is broken. For the purposes of this report, the discard factors for broken wires and diameter changes were based on those of triangular strand ropes. If a rope sample had internal broken wires, they were (and could not) be taken into account.

Samples from two tail ropes and one head rope were received. Details of the ropes are given in Table A2, Appendix A. The results of the strength tests are summarised in Table 3.1.1.

Table 3.1.1: Samples from Koepe winder ropes

Dia. (mm)	Strength change %	Discard factor
32	-8,0	1,42 (1,14 broken wires; 0,28 dia. reduction)
36	0,6	0,06 (diameter increase only)
46	-13,8	1,38 (1,03 broken wires; 0,34 dia. reduction)

The population of samples are too small to derive any meaningful conclusions, apart from that the only sample with a discard factor greater than one had a breaking strength reduction of more than 10%.

Rope samples with corrosion

The details of seven rope samples with different degrees of corrosion are given in Table A3, Appendix A. The results are summarised in Table 3.1.1. In three cases, the strength reductions calculated from the indicated steel area loss obtained from the electro-magnetic instruments were supplied.

Table 3.1.2: Rope samples with corrosion

Winder/ rope type	Dia. (mm)	Wire finish	% change in strength	Degree of corrosion
head rope	44	ungalv.	+2,4	More than slight | EM = 6,5%
drum rope	44	galvanised	+0,5	More than slight
head rope	44	ungalv.	0,1	More than slight | EM = 5%
head rope	29	galvanised	-2,1	More than slight
head rope	44	ungalv.	-9,7	More than slight | EM = 4,6%
head rope	29	galvanised	-13,4	Severe pitting
head rope	44	galvanised	-58,4	Excessive

More rope samples with corrosion and electro-magnetic assessment will be required to make any conclusions of the usefulness or accuracy of such assessments. The results from the three cases in Table 3.1.2 are not very encouraging. Visual "more than slight" corrosion and worse are reasons for discard. Although a visual assessment is not an exact measure, the results in Table 3.1.2 at least show that it is a conservative measure.

One aspect of concern is why the one rope (-58%) was left in service to the point where the visual corrosion was "excessive". Corrosion does not happen overnight.

Damaged ropes

Details of 5 ropes that sustained damage are given in Table A4, Appendix A. The results are summarised in Table 3.1.3.

Table 3.1.3: Samples from ropes that were discarded because of localised damage.

Winder/rope type	Dia. (mm)	Strength change %	Description of damage
stage rope	42	-14,7	6 broken wires in one outer strand
drum rope	55	-19,3	3 broken wires at brazed core
drum rope	40	-26,1	Twisted strand, 13 broken wires in 1 laylength
tail rope	44	-47,7	12 broken wires, severe localised plastic deformation
drum rope	22	-59,0	77 broken wires in 1 laylength

The section of the damaged stage rope (close to the headgear termination) was removed very shortly after the damage occurred. The deterioration at the brazed core damage should have been gradual. The other three ropes are reason for concern. For what reasons were the damaged sections not detected or discovered earlier? Information on the inspection intervals for these ropes were not obtained. This shortcoming must be addressed in future.

Although it is highly undesirable that these ropes were in service with such reduced strengths, it must be said that none of the damaged rope sections would have failed under the rope forces that could have been generated by normal winding and emergency braking operations. The operations were therefore not at an immediate risk of rope failures while these ropes were still in service.

3.1.5 Conclusions and recommendations

The majority of rope samples reported on here, and those tested in the past, were of triangular strand construction and from drum winders operating in vertical shafts. The discard criteria for triangular strand ropes are adequate to determine when a rope has lost 10% of its initial strength. The discard criteria for rope diameter changes should be investigated. Such an investigation should examine the use of measured rope diameters instead of the nominal rope diameters as prescribed by the code of practice.

More rope samples of non-spin type rope constructions are required before any meaningful conclusions can be reached. Koepe winder head and tail ropes have to be obtained. Although only a couple of drum winders in this country use non-spin ropes (those with guide ropes), every effort should be made to obtain samples from such ropes. An effort should also be made to obtain samples of ropes of incline winders.

The efficiency of the rope strength losses caused by corrosion and based on the steel area losses indicated by electro-magnetic rope testing instruments can only be established by obtaining a greater number of samples from such ropes. Visual evaluation of the degree of corrosion still remains an effective tool.

Quite a number of ropes with unacceptable degrees of strength losses were amongst the samples described in this report. The presence of such ropes in service can only be ascribed to poor rope inspection procedures and/or inadequate rope inspection intervals at the shafts concerned. The discard criteria of the code of practice are not at fault.

In future, the information gathered for discarded ropes should include a history of all rope examinations carried out on these ropes. Shafts with poor rope inspection procedures can be then be located, and their inspection procedures can be addressed and improved. Furthermore, information on rope deterioration rates will be acquired.

It is imperative that the collection and testing of samples from discarded winder ropes should continue, but then only if the recommendations are implemented.

3.2 Tests on non-spin ropes with cut wires

Tests on triangular strand ropes were done under project GAP054. The results of these tests proved useful in determining the allowable number of wires before a rope should be discarded. There were several issues relating to non-spin ropes, however:

- The samples of discarded non-spin ropes were scarce and the documentation of the observed rope condition was virtually non-existent.
- While the outer wires normally break on triangular strand ropes, non-spin ropes (at least those operating on Koepe winders) usually display internal broken wires.
- The detection and counting of internal broken wires with magnetic test instruments is difficult if not impossible.

To extend the knowledge on broken wires in non-spin ropes and their effect on the strength of the ropes, a series of tensile tests with broken internal wires was proposed. It was initially intended to subject rope specimens to fatigue loading so that wires would break. The specimens thus treated were then to be tested with a magnetic test head to detect and count broken wires. The advice of Prof C R Chaplin (Reading

University) was sought regarding this approach, and the following problems were identified:

- It is not possible to count the number of internal broken wires using a magnetic test.
- It cannot be predicted which wires will break when a rope is subjected to tensile fatigue loading (as opposed to bending fatigue on a winder).
- Methods of etching or colouring internal wire surfaces (to determine which wires were broken before the tensile test) were considered but no method had been proven reliable.

Because of these problems, the methodology in the SIMRAC contract was not used. The methods used during the test series are described in the sections that follow.

3.2.1 Rope selection

A length of rope was purchased from Messrs Haggie Rand Ltd. This rope had the following construction:

18 Strand Non-spin Fishback / Triangular 12 × 10(8/2)/6 × 29(11/12/6 Δ)/WMC

When the rope arrived, it was noticed that there was corrosion on the outside. Three tensile tests were done on the rope to establish whether the corrosion had led to any reduction in strength. The results of these tests, together with result from the original test when the rope was new, are shown in the following table:

Specimen description	Breaking force (kN)
New rope	1497
Corroded specimen	1532
Uncorroded specimen 1	1544
Uncorroded specimen 2	1542

Although the corroded specimen had a lower strength than the two corroded specimens, the strength was within 1 per cent of the other two results. This is within the scatter of the results that can be expected from tensile tests on steel wire ropes.

It was therefore assumed that the rope was suitable for the tests.

3.2.2 Specimen preparation

The rope was divided into 3,25 test pieces. A tensile test specimen was prepared from each piece. One of the collars usually cast onto a rope when preparing a specimen was made longer so that levers could be clamped to the specimen. After installing the specimen into a tensile test machine, a set of levers was clamped to the longer collar, the machine grips on that end were opened and the rope was twisted by rotating the levers through one turn, thus unlaying the outer rope. In this manner the outer wires of the inner rope could be reached and a number of wires were cut with an angle grinder.

The levers were then rotated back to their original position, thus closing the outer rope again. The specimen was then subjected to 500 load cycles ranging between 5 and 25 per cent of the new rope breaking force.

After preparing each specimen in this fashion, it was subjected to a tensile test. In order to prove that the unlaying of the outer rope did not affect the strength of the specimen in any way, two samples were unlaid and closed again without cutting any wires. Tensile tests were done on these samples without subjecting them to load cycles. The results are shown in the following table:

Specimen description	Breaking force (kN)
Uncorroded specimen 1	1544
Uncorroded specimen 2	1542
Twisted specimen 1	1522
Twisted specimen 2	1533

Although the strength of one specimen was affected by approximately 1,4 per cent, it was concluded from these results that the effect of this preparation procedure on the strength of the rope was negligible.

3.2.3 Test results

The strength loss is the difference between the breaking strength and the average breaking strength of the first two specimens in the following table:

No of cut wires	Breaking strength (kN)	Broken wire area (%)	Strength loss (%)
0	1546	0,00	0,19
0	1552	0,00	-0,19
8	1646	3,86	5,49
8	1484	3,86	4,20
13	1438	6,28	7,17
13	1475	6,28	4,58
13	1487	6,28	4,00
15	1444	7,25	6,78
15	1439	7,25	7,10
15	1430	7,24	7,68
16	1396	7,73	9,88
16	1427	7,73	7,88
16	1365	7,73	11,88
17	1410	8,21	8,97
17	1346	8,21	13,11
17	1359	8,21	12,27

The broken wire area was calculated on the basis that the outer wire of the inner rope has an area of 0,483 per cent of the rope area. Although the table above shows the specimens in an ascending order in the number of cut wires, the specimens were tested in a random sequence.

3.2.4 Interpretation of the results

A non-linear least squares regression analysis was done to determine the coefficients in the relation $Y = X + BX^Q$ with X the broken wire area and Y the strength loss. The least squares process entailed an iteration process that varied the values of B and Q so that, for the n test results, a minimum value of $\sum_{i-1}^{n} (X_i + BX_i^Q - Y_i)^2$ was obtained. The coefficients were thus determined as $B = 1{,}88 \times 10^{-13}$ and $Q = 14{,}5$.

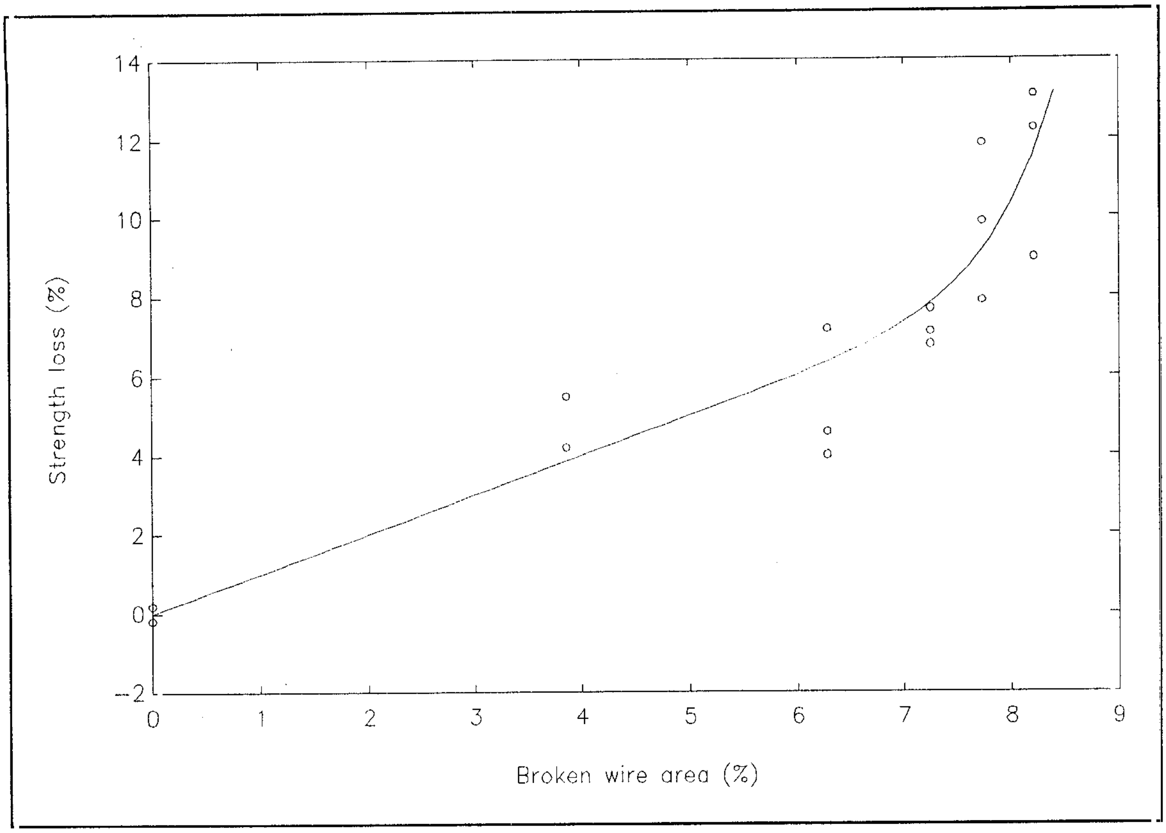


Figure 3.2.2 Regression analysis

The standard deviation was calculated as

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - Y)^2}{n-1}}$$

$$= \mathbf{1{,}48}$$

with n = no of tests

Y_i = individual test results

$Y = X_i + B X_i^Q$

The loss in strength, as calculated by the regression equation, is shown in the following table for discard criteria ranging from 4 to 8 per cent as well as the probability of various losses in rope strength at discard:

These probabilities were calculated based on normal (Gaussian) distribution of deviations of the test results from the regression equation.

Area loss X (%)	Strength loss Y (%)	Probability (%) of loss in strength			
		<3%	>10%	>12%	>15%
4	4,00	24,8			
5	5,00	8,9	<0,1		
6	6,04	2,0	0,4		
7	7,43	0,2	3,6	<0,1	
8	10,34		59,1	13,1	<0,1

3.2.5 *Conclusions*

From the table above, a discard criterion of 7 per cent may be chosen. Based on the test results, this discard criterion will ensure that 96 per cent of non-spin ropes will be discarded at a reduction of breaking strength between 3 and 10 per cent with only a 3,6 per cent probability that strength losses of more than the allowable 10 per cent will occur while less than 0,1 per cent of ropes will be discarded at a strength loss of more than 12 per cent.

This conclusion is based on a limited set of results. The following must be kept in mind:

- **The tests were only done on a non-spin fishback construction. Other constructions may respond differently to broken wires.**
- **The discard criterion only applies to broken outer wires of the inner rope.**
- **It is not a simple matter to count broken inner wires when inspecting a rope.**

A discard criterion to be used in the Code of Practice for Rope Condition Assessment should therefore be selected with circumspect.

It is interesting to note that the standard deviation of 1,48 that was obtained in the regression analysis supports the strategy of discarding a rope at an estimated strength loss of 7 per cent, i.e. approximately two standard deviations from the maximum allowable loss in strength of 10 per cent. For an average strength loss of 7 per cent, the allowable area loss due to broken outer wires of the inner rope is 6,8 per cent.

3.2.6 Recommendations

It is recommended that further work be done on the discard criteria and inspection techniques for non-spin ropes. Such work should involve the following steps:

- Whenever internal broken wires are detected during a magnetic test before a rope is discarded, the magnetic test trace should be inspected carefully and test specimens should be selected. Initially the test specimens should be unlaid to count the broken wires so that a correlation between the magnetic test trace and the broken wires can be obtained.
- Once a pattern of the location of broken wires has been established for a given non-spin rope construction on a given type of winder, similar tests should be done as those described in this section. A test programme on specimens with wires cut from the outer wires can be formulated immediately.

Considering the conclusions drawn from the tests, especially the fact that the results only have limited validity, it is recommended to set the broken wire criterion for non-spin ropes to 6 per cent at this stage.

4 Code of practice for the safe use of kibble and stage winder ropes

The proposed new statutory regulations for drum winder ropes will conceivably allow single lift shafts of as deep as 4 000 m. If such deep shafts have to be sunk in the conventional way, stages and kibbles will be used.

The regulations governing the strength of ropes for stage and kibble winders were investigated. The aim of the stage and kibble winder ropes investigation was to obtain guidelines for drafting a code of practice for sinking winders that operate with lower factors than those required by the current regulations.

The following interim reports were issued during the duration of the project:

- **Van Zyl, M.N.** Overview of the winding rope requirements for deep shaft sinking operations *CSIR Contract Report No. 960158 Ref MC2736, April 1996*
- **Van Zyl, M.N.** Load ranges acting in kibble winder ropes and proposals for new kibble winder rope regulations *CSIR Contract Report No. 960348 Ref MC3127, November 1996*
- **Van Zyl, M.N.** Rope forces generated after brake control failure on kibble winders *CSIR Contract Report No. 960383 Ref MC3127, December 1996*
- **Van Zyl, M.N.** Stage rope factors for deep shaft sinking operations *CSIR Contract Report No. 970003 Ref MC3127, January 1997*

These reports are presented in Volume 2 of this report.

5 Presentations to the Association of Mine Resident Engineers on safety requirements for drum winders

A *Code of Practice for the Performance, Operation, Testing and Maintenance of Drum Winders relating to Rope Safety* was submitted to the South African Bureau of Standards (SABS). It was expected that this document would be circulated in draft form during 1996. It was proposed to make presentations to the parties concerned so that they would be informed on the background of the safety requirements in this code of practice. This would speed up the process of perusing and commenting on the document.

Members of the SABS technical committee, however, did not agree on the requirements in the code of practice and the document was therefore not finalised. Since it was premature to make presentations on the document as it stood, This section of the project was deferred until consensus could be reached and the draft document would be circulated.

References

1. **Hecker, G. F. K. & Van Zyl, M. N. 1994** STATUS REPORT: Safety Standard for the Performance, Operation, Maintenance and Testing of Mine Winding Plant. *CSIR Contract Report No 940248 MST(94)2281*

2. **APCOR** Mine Health & Safety Act, Act 29 of 1996

3. **Van Zyl, M.N. 1991.** A life prediction model from drum winder ropes *CSIR Contract Report MST(91)MC662*

4. **SABS 0293: 1996 South African Standard:** Code of practice: Condition assessment of steel wire ropes on mine winders.

5. **Borello, M:** Results of tests on sections from discarded ropes. *CSIR Contract Report MST(94)MC2122, No. 940126, June 1994*

6. **Wainwright, E J** Discussion of results of tests on discarded ropes - in terms of the draft code of practice on rope condition assessment *CSIR Contract Report MST(95)MC2470, No. 950125, May 1995*

7. **Wainwright, E J** Discussion of results of second series of tests on discarded ropes in terms of the draft code of practice on rope condition assessment *CSIR Contract Report MST(96)MC2887, No. 960167, April 1995*

Appendix A: Results of rope life predictions

A.1 Effect of D/d ratio

The analyses started with the following basic winder parameters:

Length of suspended rope:	1600 m
End Load:	16 t
Pay Load:	9,6 t
Tensile Grade:	1800 MPa
Rope Construction:	6x31(13/12/6+3T)/F

By choosing different rope diameters and varying the drum and sheave diameters, the factor of safety and the D/d ratio could be varied. The results are shown in Fig.A.1 From these rope life comparisons, it can be seen how longer lives are obtained with larger D/d ratios. For each D/d ratio, there seems to be one factor of safety at which a minimum life can be expected. This apparent anomaly illustrates the interdependence

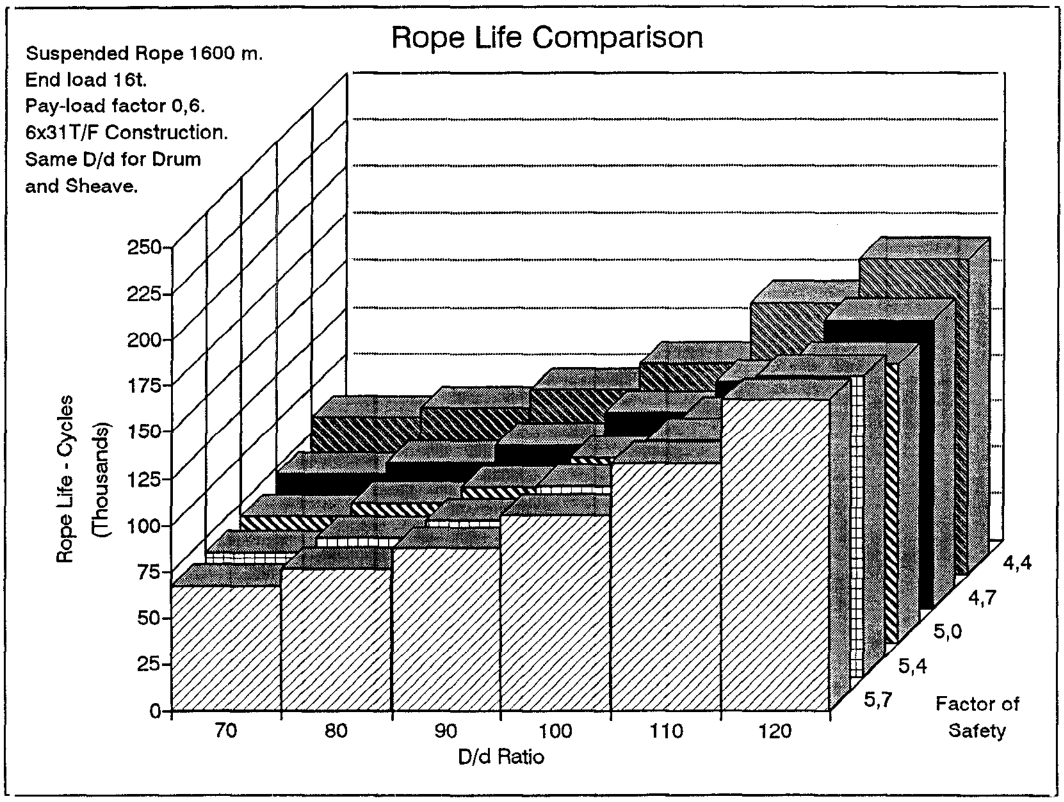


Fig. A.1

of the various winder parameters on rope performance. That is, by varying the D/d ratio the drum and sheave tread pressure is changed and so other important parameters are changed.

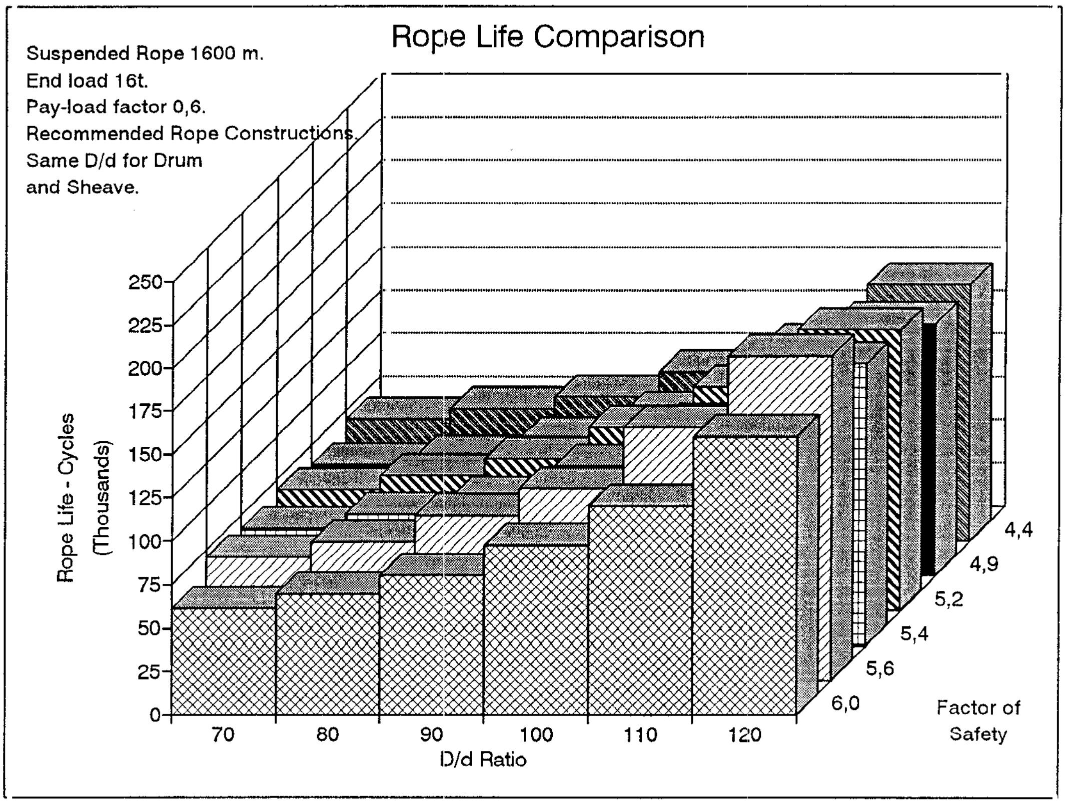


Fig. A.2

This analysis was repeated for those rope constructions recommended by Haggie Rand Ltd for each specific rope diameter. Fig. A.2 shows shorter rope lives for some rope constructions than those in Fig. A.1 , where only the one construction is considered. There is no trend in rope life as a function of factor of safety for the same reason. It must be noted that the chief reason for using different rope constructions for the various rope sizes is the economy that can be achieved by standardisation of the rope outer wire diameters.)

If regression formulae are calculated for rope performance in terms of pay-load tons hoisted for the different factors of safety, the curves are sufficiently close for an average to be taken. This average is represented by the curve in Fig. A.6 for a depth of 1600 m, suspended rope length. Similar curves with lower rope performance figures would apply for greater depths.

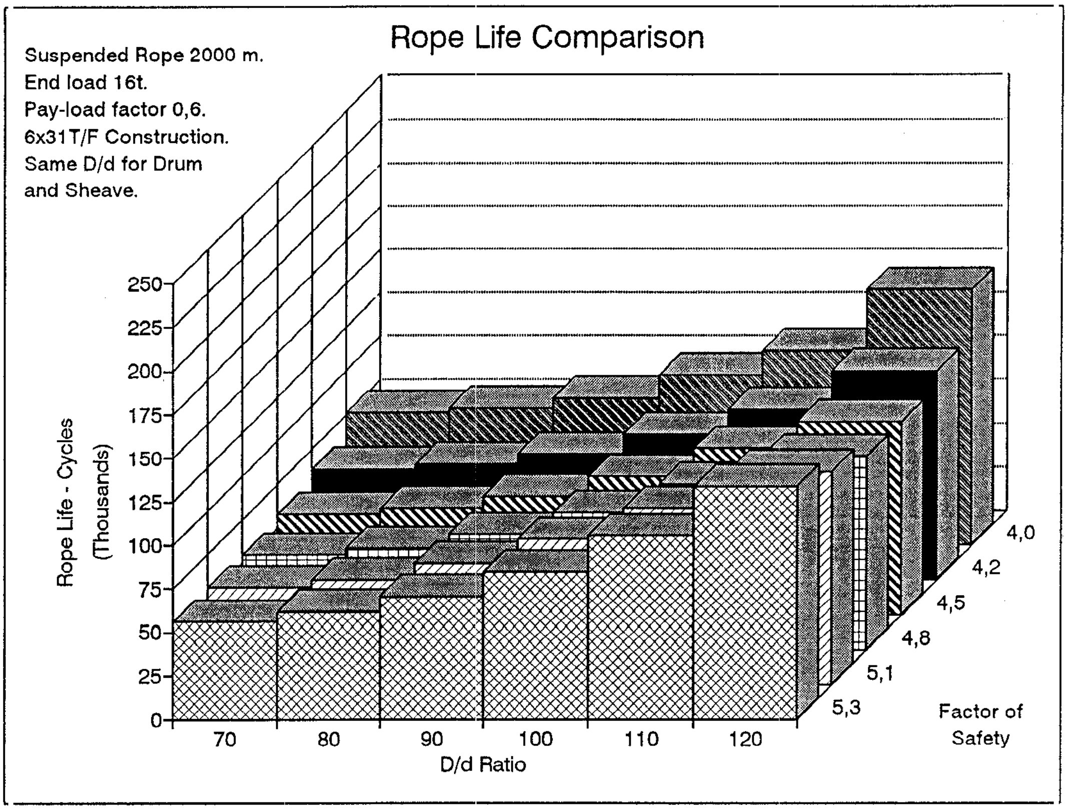

Rope Life Comparison
Suspended Rope 2000 m.
End load 16t.
Pay-load factor 0,6.
6x31T/F Construction.
Same D/d for Drum
and Sheave.
Rope Life - Cycles
(Thousands)
0
25
50
75
100
125
150
175
200
225
250
70
80
90
100
110
120
D/d Ratio
5,3
5,1
4,8
4,5
4,2
4,0
Factor of
Safety

Fig. A.3

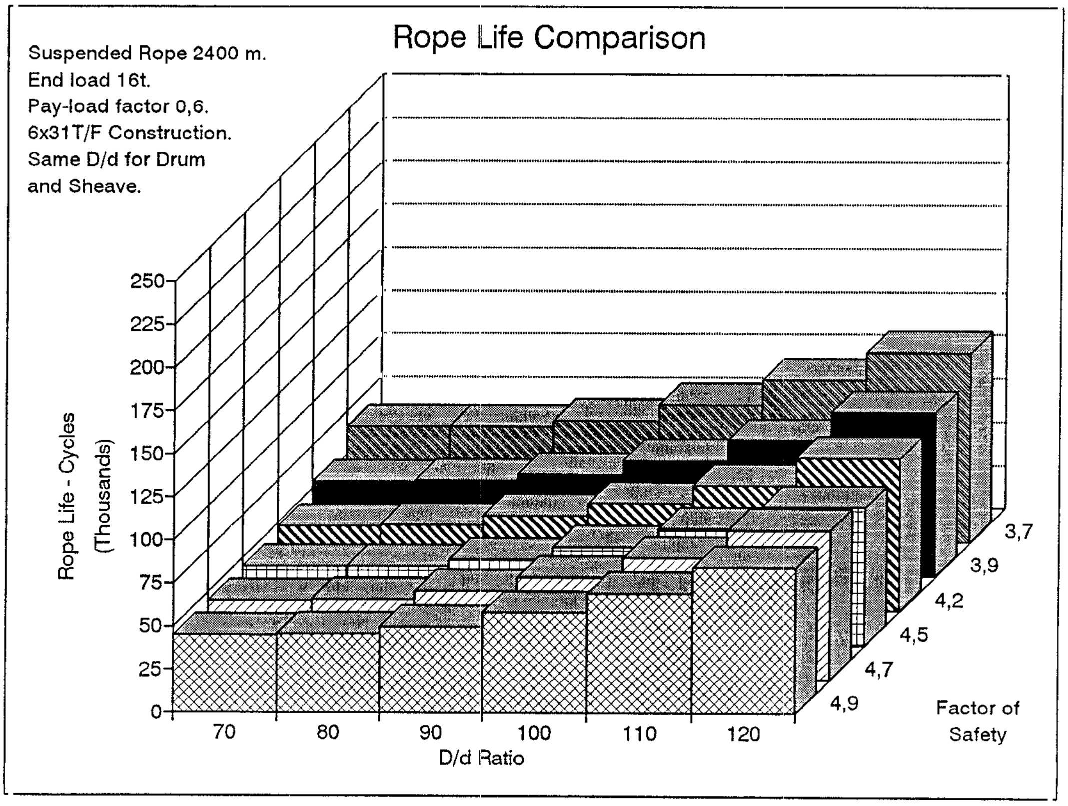

Rope Life Comparison
Suspended Rope 2400 m.
End load 16t.
Pay-load factor 0,6.
6x31T/F Construction.
Same D/d for Drum
and Sheave.
Rope Life - Cycles
(Thousands)
0
25
50
75
100
125
150
175
200
225
250
70
80
90
100
110
120
D/d Ratio
4,9
4,7
4,5
4,2
3,9
3,7
Factor of
Safety

Fig. A.4

Using greater lengths of suspended rope, shorter rope lives are obtained as shown in Figs. A.3 and A.4 (for suspended rope lengths of 2000 m and 2400 m respectively). As the shaft depth increases, lower factors of safety are obtained for a given winder design. There is, however, an overlap and rope lives for a given factor can be compared. At a factor of safety of 4,9 there is a decrease in rope life as the shaft depth increases. Fig. A.4 shows how rope life would be increased with lower factors of safety.

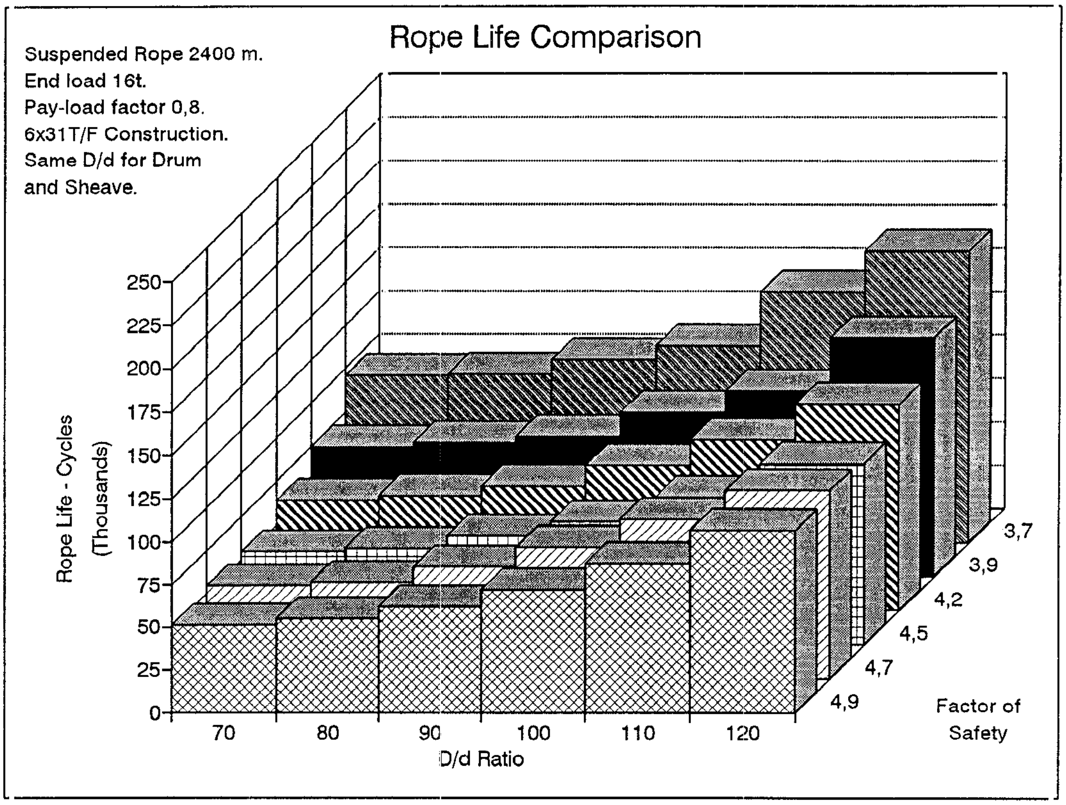


Fig. A.5

Repeating the calculations represented by Fig. A.4, but increasing the pay load to 12,8 t (keeping the end load at 16 t) gives the rope lives shown in Fig. A.4. The results show an overall increase in rope life.

A.2 Effect of shaft depth

Taking the basic parameters used in the beginning of section A.1, the rope life was calculated for different rope diameters and lengths of suspended rope. A factor of safety was calculated for each rope size and an end load of 16 t at a length of

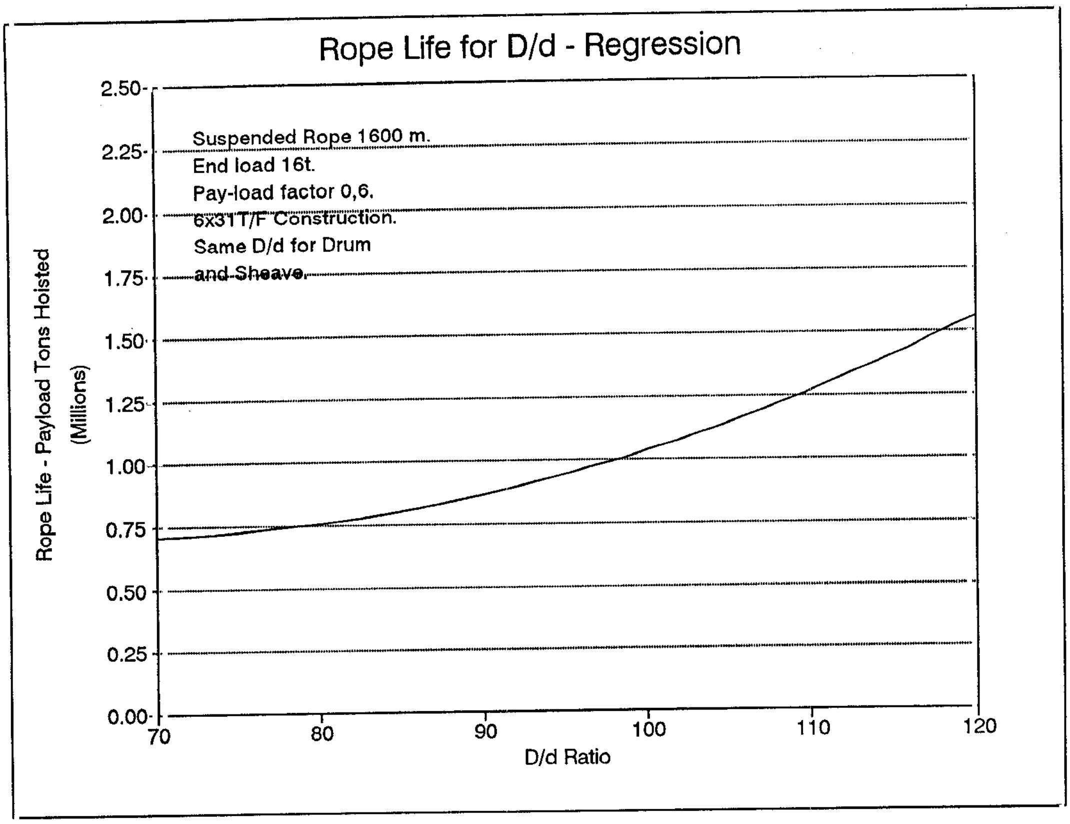


Fig. A.6

suspended rope of 1600 m. The end loads were then varied to give the same factor of safety at different lengths of suspended rope. The D/d ratio was kept constant at 100, for both sheave and drum. The table below shows the changing end load for each depth and rope size.

		Depth (m)											
		400		800		1200		1600		2000		2400	
Dia	FOS	End Load	Life	End Load	Life	End Load	Life	End Load	Life	End Load	Life	End Load	Life
40	4,415	24,23	259000	21,49	215000	18,74	149534	16,00	113000	13,26	101483	10,52	101000
42	4,704	25,24	247141	22,17	165000	19,10	122000	16,00	105150	12,96	96984	9,89	109000
44	4,968	26,11	215000	22,74	149534	13,97	112588	16,00	99000	12,63	98000	9,27	142000
46	5,162	26,85	215000	23,23	150000	19,62	118000	16,00	105551	12,39	109000	8,77	169196
48	5,427	27,93	189435	23,95	143863	19,97	109369	16,00	102872	12,02	119985	8,04	259000
50	5,660	28,97	169196	24,65	134400	20,33	106000	16,00	105614	11,68	147000	7,35	259000
52	5,816	29,74	189435	25,16	143863	20,58	110849	16,00	110918	11,42	169196	6,84	259000
54	6,030	30,87	186737	25,91	138000	20,96	110246	16,00	118843	11,04	232945	6,09	259000
56	6,245	32,21	167719	26,81	126870	21,40	109702	16,00	133270	10,59	259000	5,19	259000

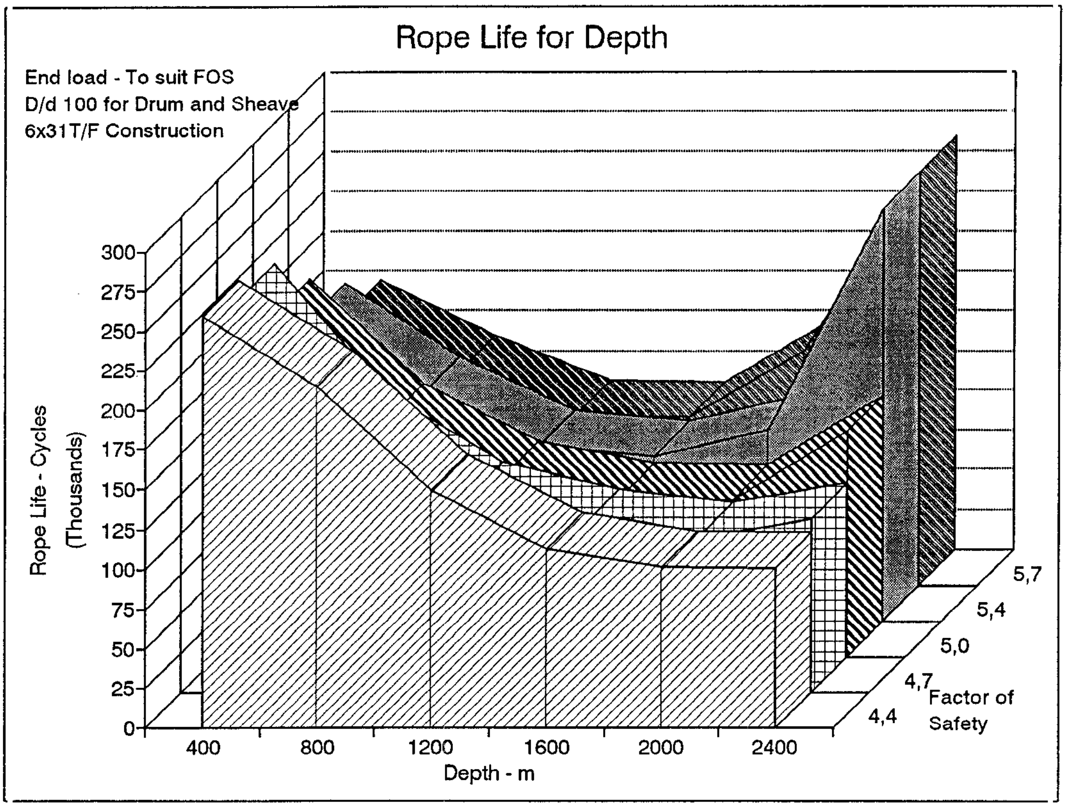

Rope Life for Depth
End load - To suit FOS
D/d 100 for Drum and Sheave
6x31T/F Construction
Rope Life - Cycles
(Thousands)
300
275
250
225
200
175
150
125
100
75
50
25
0
400
800
1200
1600
2000
2400
Depth - m
4,4
4,7
5,0
5,4
5,7
Factor of Safety

Fig. A.7

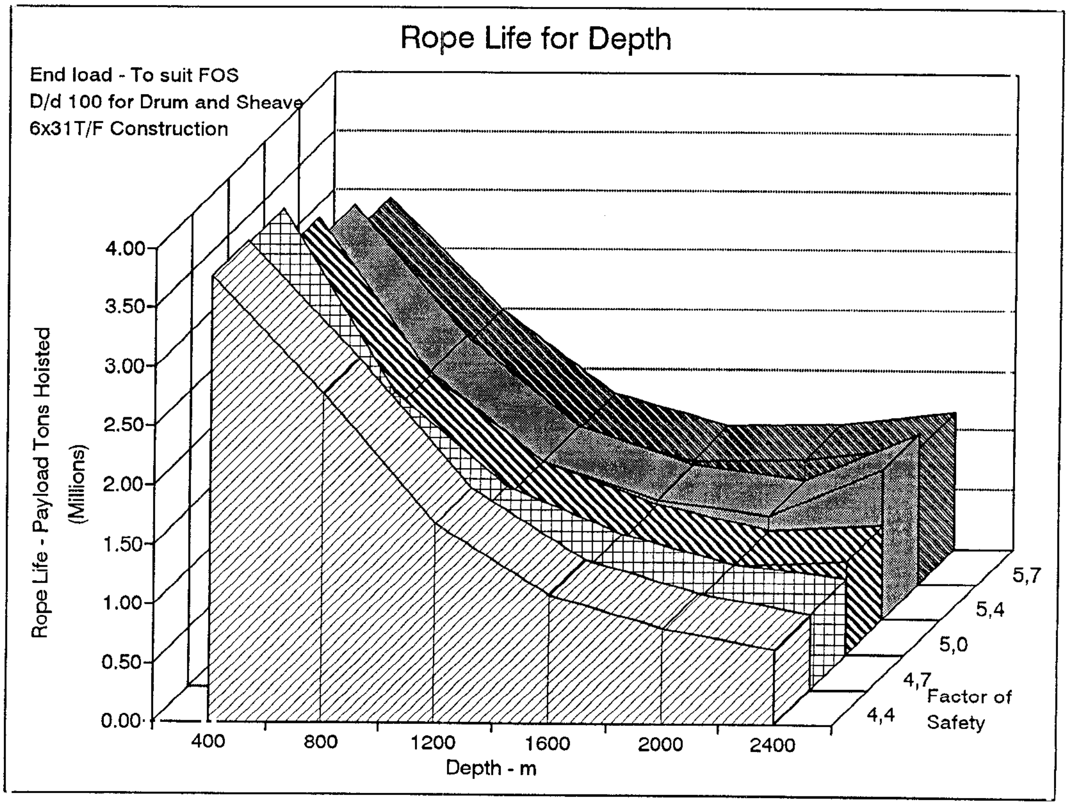

Rope Life for Depth
End load - To suit FOS
D/d 100 for Drum and Sheave
6x31T/F Construction
Rope Life - Payload Tons Hoisted
(Millions)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
400
800
1200
1600
2000
2400
Depth - m
4,4
4,7
5,0
5,4
5,7
Factor of Safety

Fig. A.8

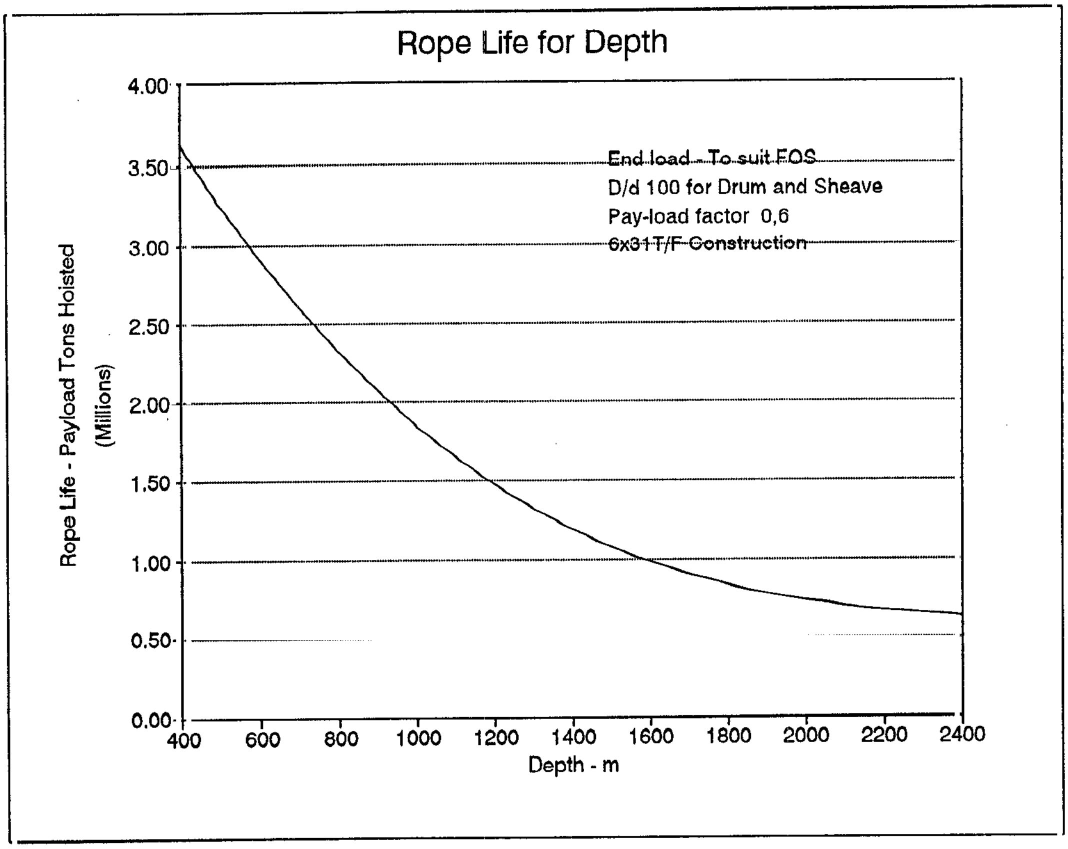


Fig. A.9

These results are shown graphically in Fig. A.7. From this figure it can be seen that, for low factors of safety, the longest rope lives are predicted for shallow depths of wind. For the deepest shafts analyzed, there is a marked increase in rope life with increasing factors of safety. Although this is true in terms of rope life in cycles, a false impression is given. When the varying end load is taken into account and the rope performance in terms of pay-load tons hoisted is plotted, a somewhat different picture is obtained. Fig. A.8 illustrates this aspect. If it is considered that factors of safety in excess of 4,7 are not economically appropriate for depth in excess of 1800 m, a regression can be calculated for the two lower factors of safety. This regression is illustrated in Fig. A.9.

A.3 Effect of static load range

The static load range could be varied by changing the pay-load factor - the ratio between the payload and the total end load. In this way the factor of safety would be constant and only the static load range would vary. The analyses were based on the following winder parameters:

Length of suspended rope: 1600 m

End Load: 16 t

Pay Load: 6,4 to 12,8 t

D/d ratio: 100 for both drum and sheave

Tensile Grade: 1800 MPa

Rope Construction: 6x31(13/12/6+3T)/F

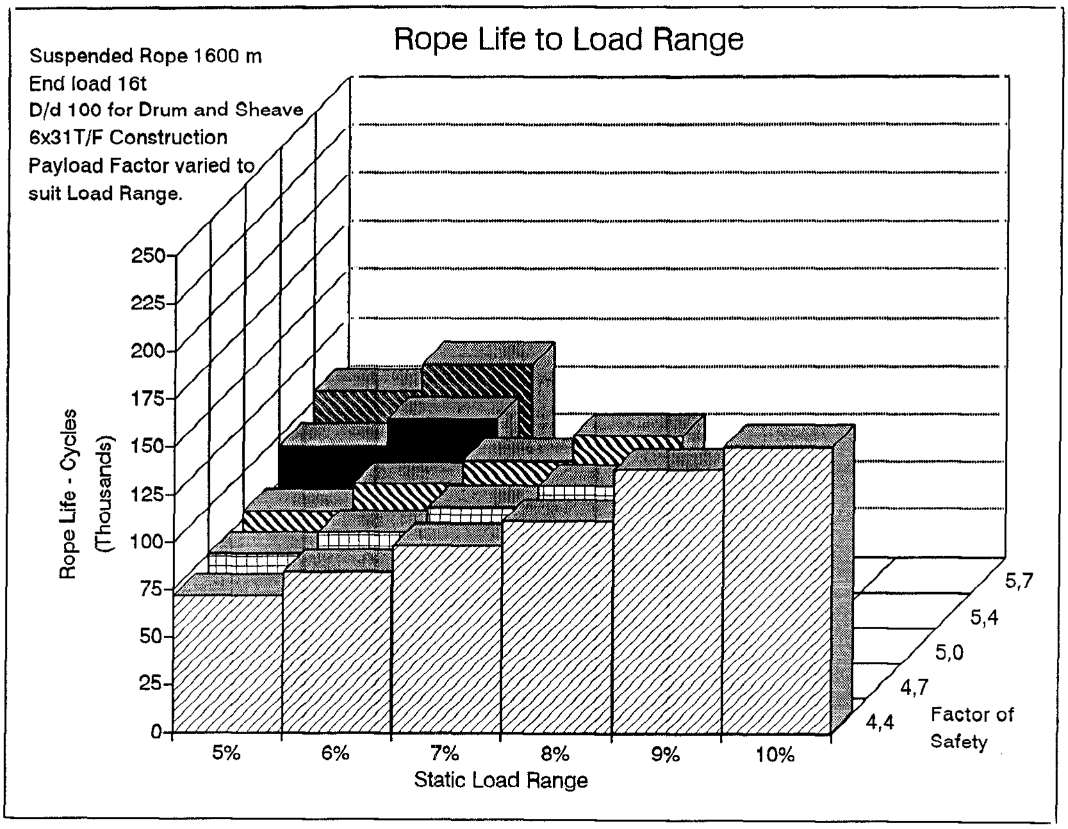


Fig. A.10

The predicted rope lives are shown in Fig. A.10. It can be seen from this figure that the rope lives are dependent on the static load range which is directly determined in this example by the pay-load factor, with the longest rope lives predicted when the load ranges are highest. In preparing the graph, rope performance figures were ignored when the pay-load factor exceeded 0,75, it being unrealistic for the conveyance mass to be less than 0,25 of the end load. The table below lists the calculated rope lives and pay-load factors for the relevant rope sizes and factors of safety.

		Load Range											
		5 %		6 %		7 %		8 %		9 %		10 %	
Dia	FOS	PL Fact	Life	PL Fact	Life	PL Fact	Life	PL Fact	Life	PL Fact	Life	PL Fact	Life
40	4,415	0,37	71581	0,45	84000	0,52	98000	0,60	111000	0,67	138000	0,74	150000
42	4,704	0,42	75000	0,50	86232	0,58	99000	0,66	110918	0,75	133270	0,83	148000
44	4,968	0,46	79000	0,55	93692	0,64	105672	0,73	118843	0,82	142000	0,92	150000
46	5,162	0,49	87000	0,59	102872	0,69	118000	0,79	142000	0,88	154950	0,98	169196
48	5,427	0,54	95148	0,65	109000	0,76	126870	0,87	147000	0,97	162921	1,08	169196
50	5,660	0,59	105150	0,71	118843	0,82	143863	0,94	155671	1,06	169196		
52	5,816	0,62	116516	0,75	145476	0,87	161921	1,00	189435				
54	6,030	0,68	138000	0,81	155671	0,95	186737						
56	6,245	0,73	149534	0,88	169196	1,03	215000						

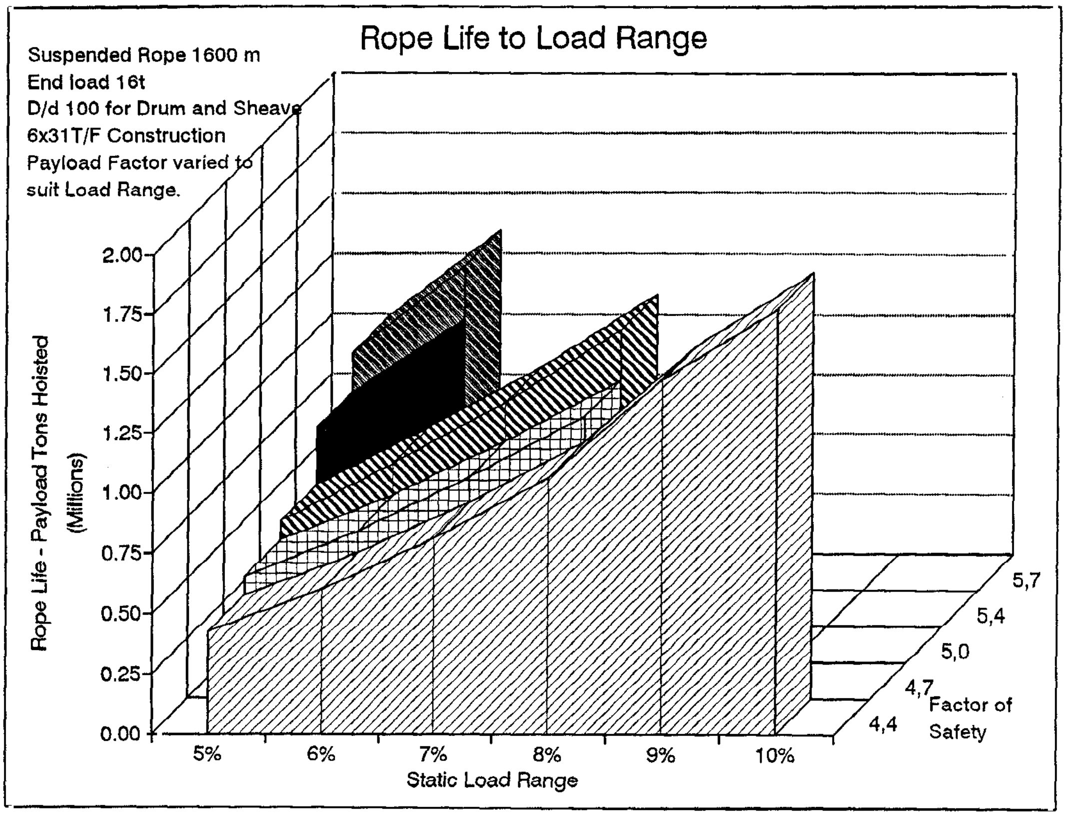


Fig. A.11

As before, because of changes in pay-load, the rope life in cycles is somewhat misleading and it is appropriate to plot life in terms of pay-load tons hoisted. Fig. A.11 is plotted on this basis.

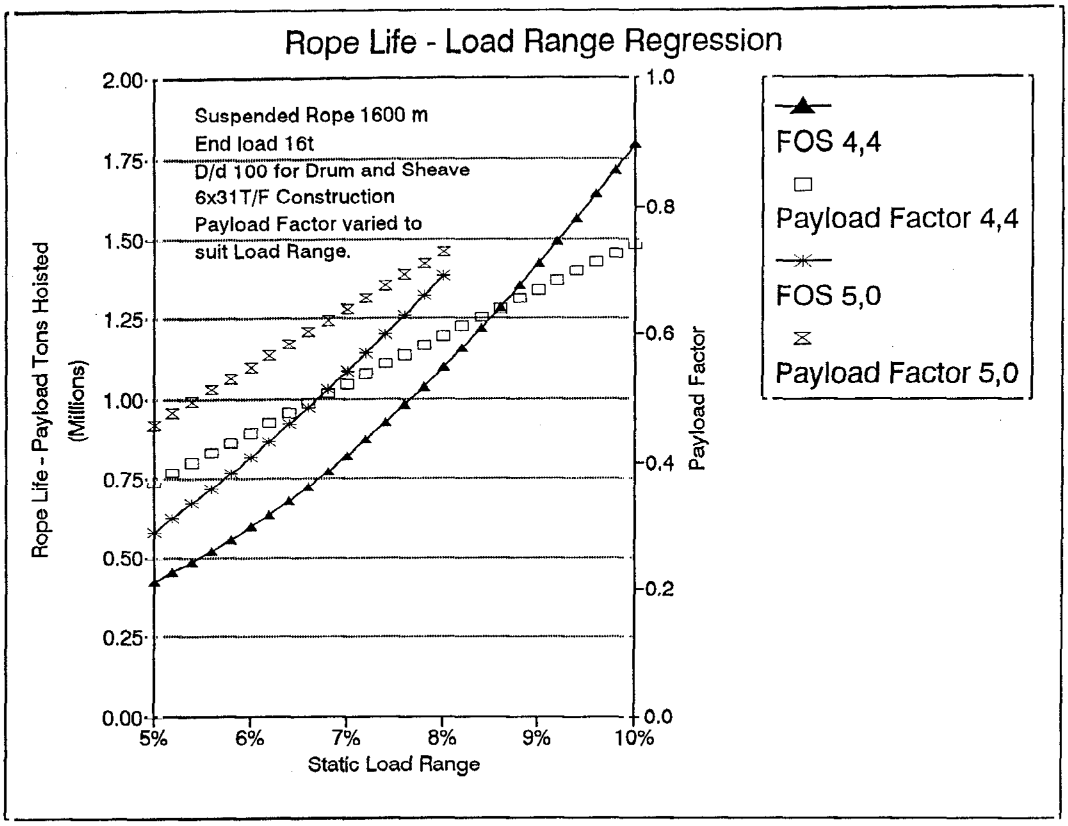


Fig. A.12

Regression formulae have been calculated for factors of safety of 4,4 and 5,0. These formulae are plotted in Fig. A.12 together with relevant information for pay-load factor. The rapidly increasing performance figures with increasing load range suggest the importance of operating with a pay-load factor as high as practicable.

Fig. A.13 shows the load range compared with rope life for the 99 winders of the statistical analysis study. It can be seen that there is no direct correlation. This is to be expected because of the variability of the winder parameters and the interdependence of the effects of these parameters. As far as possible, design parameters in this evaluation have been kept constant, so that it is obvious that the correlation indicated by the model is influenced by the effects of other parameters.

A.4 Effect of drum tread pressure

Taking the basic parameters used in the beginning of section A.1, the rope life was calculated for rope and drum diameters. A factor of safety was calculated for each rope size and an end load of 16 t at a length of suspended rope of 1600 m. The drum diameter was then varied to give the desired tread pressure shown in the following

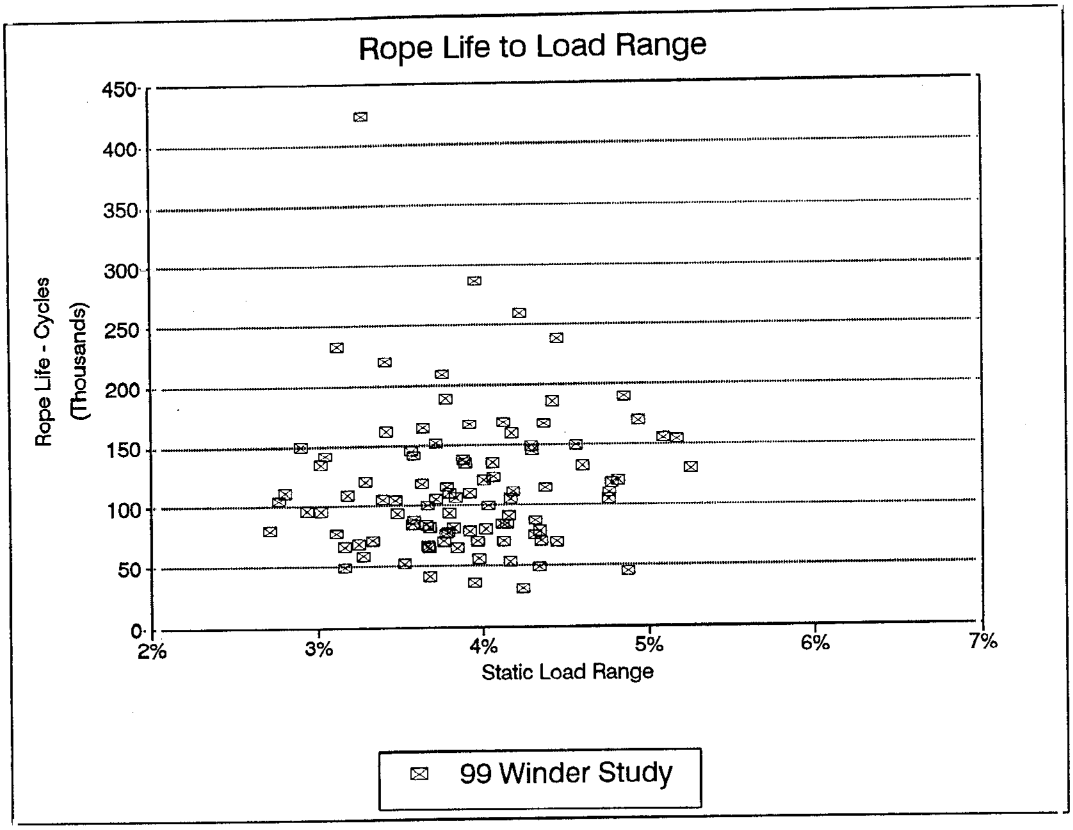


Fig. A.13

table. Also shown are the D/d ratios that follow from each combination of maximum rope force, rope diameter and tread pressure.

		Drum tread pressure (MPa)											
		2,6		2,8		3,0		3,2		3,4		3,6	
Dia	FOS	D/d	Life	D/d	Life	D/d	Life	D/d	Life	D/d	Life	D/d	Life
40	4,415	127,1	215000	118,0	167719	110,1	145891	103,3	120190	97,2	109702	91,8	102872
42	4,704	121,0	161921	112,3	134400	104,8	110246	98,3	99000	92,5	93312	87,4	84000
44	4,968	114,8	138000	106,6	110246	99,5	98000	93,2	88826	87,8	81000	82,9	78027
46	5,162	108,5	120000	100,8	105614	94,1	94658	88,2	83823	83,0	79000	78,4	76000
48	5,427	104,4	109702	96,9	97000	90,5	86232	84,2	79000	79,8	75000	75,4	69300
50	5,660	100,4	105672	93,2	94269	87,0	82871	81,6	78027	76,8	71581	72,5	69186
52	5,816	95,7	105574	88,8	93692	82,9	83594	77,7	78300	73,2	74766	69,1	70251
54	6,030	92,6	105150	86,0	93692	80,3	83751	75,2	78300	70,8	76137	66,9	71581
56	6,245	90,4	105614	84,0	95148	78,4	86232	73,5	80000	69,1	78233	65,3	76000

Fig. A.14 illustrates the effects of varying tread pressure. However, it is not possible to separate tread pressure from other parameters, so that when reducing factor of safety with a constant tread pressure the D/d ratio is reduced and consequently

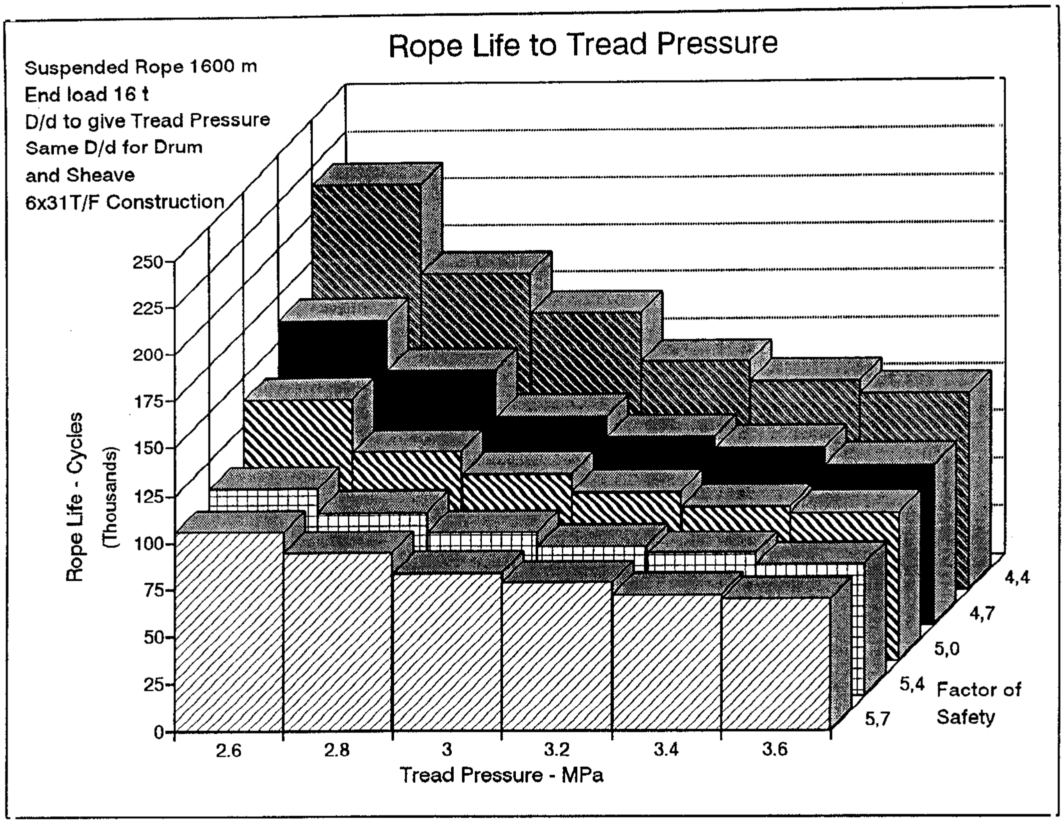


Fig. A.14

bending stresses are increased. This is one of the effects which shows the interdependence of winder parameters which can result in seemingly anomalous results.

The results of regression formulae for life against tread pressure are shown in Fig. A.15. In addition a curve is shown (designated as TCK formula) representing a formula proposed by T C Kuun[1], based on the raw detail of the statistical analysis data. The formula is as follows:

$$\text{Rope life (cycles)} = 503\ 000 \times e^{-0{,}625 \times p}$$

$$\text{where } p = \text{Tread pressure (MPa)}$$

Kuun proposed that, when assessing the effect of tread pressure, this formula be used for factors of safety in excess of 4,5 and a life reduction factor of 0,7 be applied for factors of safety below 4,5.

References:

1. Kuun, T.C. "**Tread Pressure and Rope Life in Winder Design.**" Memorandum prepared in December 1991.

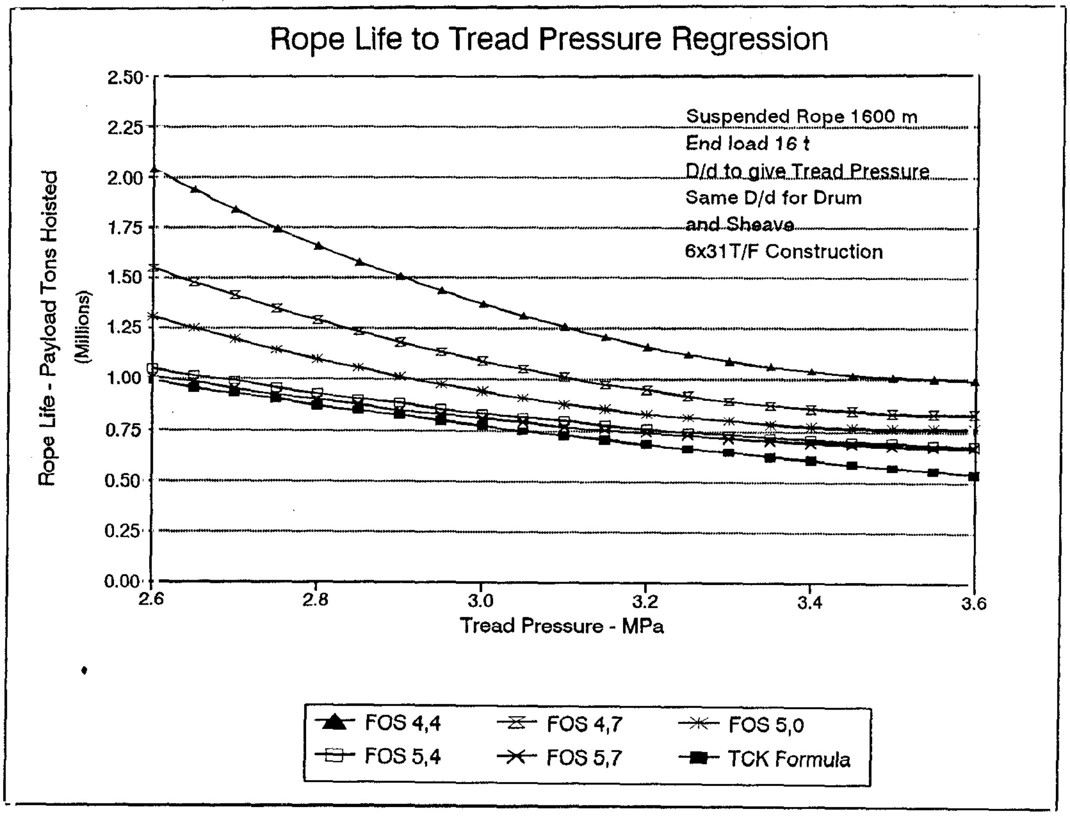

Rope Life to Tread Pressure Regression
Rope Life - Payload Tons Hoisted
(Millions)
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
2.6
2.8
3.0
3.2
3.4
3.6
Tread Pressure - MPa
Suspended Rope 1600 m
End load 16 t
D/d to give Tread Pressure
Same D/d for Drum
and Sheave
6x31T/F Construction
FOS 4,4
FOS 4,7
FOS 5,0
FOS 5,4
FOS 5,7
TCK Formula

Fig. A.15

Appendix B: Site observations during rope deterioration studies

B.1 Hartebeestfontein No 4 Shaft

54 mm 6x33(15/12/6+3T)/F 1800 MPa ungalvanised ropes.

Date installed: 95-09-03

North-west compartment: Coil No 133842002 installed on underlay drum

South-west compartment: Coil No 133842001 installed on overlay drum

1996-09-25	NW Compartment		SW Compartment	
Position	Dia (mm)	LL (mm)	Dia (mm)	LL (mm)
Front	54,5	350	55,0	350
Ref*	52,2	530	53,7	385
Back	52,5	585	52,4	610

* A reference point was chosen at an indication of internal broken wires on the SW compartment approximately 385 m from the skip. Measurements in the NW compartment were taken at the same time

Headgear sheaves examined and found to be in fair condition. There was a slight shoulder on both flanges of each sheave and it was noted that the ropes were rubbing on these shoulders

B.2 West Driefontein No 4 Shaft

46 mm 6x31(13/12/6+3T)/F

Date installed: 96-01-14

North-east compartment: Coil No 122312/001

North-west compartment: Coil No 122312/002

1996-09-17	NE Compartment		NW Compartment	
Position	Dia (mm)	LL (mm)	Dia (mm)	LL (mm)
Front	46,6 46,6/46,5	322	46,2 46,5/46,2	309
Ref*	45,6 45,7/45,6	343	45,7 46,3/45,3	383
Back	45,0 45,1/45,0	401	45,0 44,9/41,1	415

* A reference point was chosen at an indication of internal broken wires on the NW compartment 912 m from the skip. Measurements in the NE compartment were taken at the same time

The rope diameter was measured using a diameter tape. The two further diameter values indicate vernier measurements done to obtain information on the ovality of the rope.

Figure B.1:* *Section of a replica of a wire surface at the reference point on the West Driefontein ropes

Figure B.1 shows a section of a replica made of the surface of a wire at the reference point on the ropes at West Driefontein. The replica is a film of acetate that has been softened with acetone and placed on the wire until it has dried. The acetone film then has the shape of the wire surface and can be photographed. The result is an image that shows the wear on the surface. There are usually two wear striations: One is perpendicular to the rope's axis and originates from the rope entering leaving the sheave. The other is approximately parallel to the rope's axis and is caused by backslip.

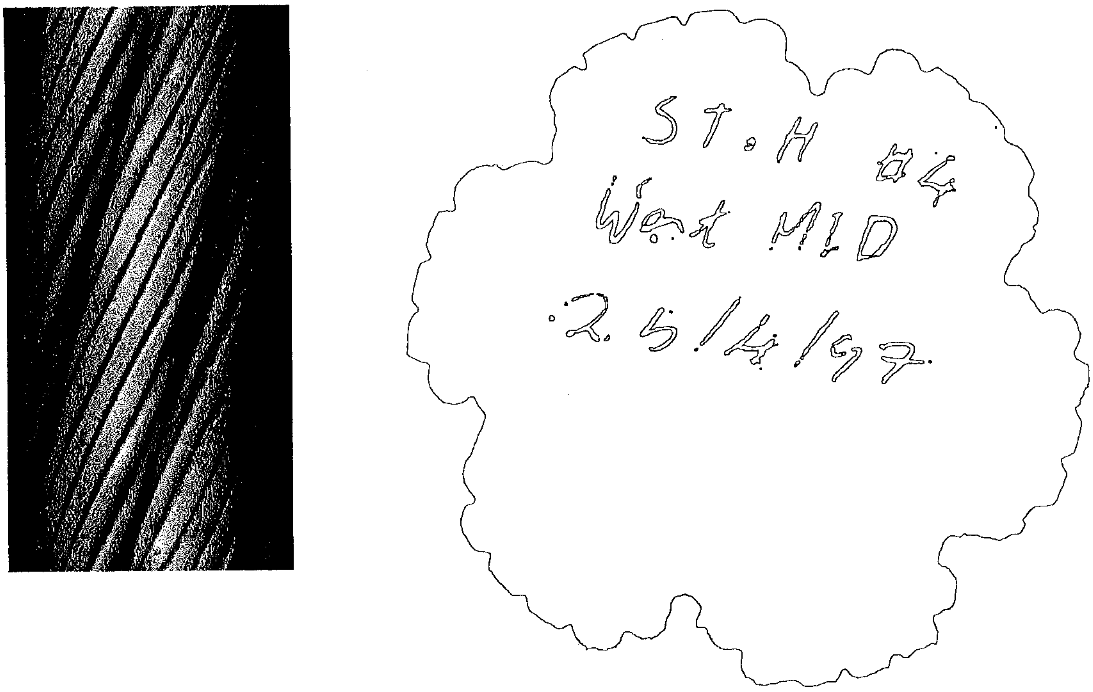


Fig. B.2 **Longitudinal view and cross section of a rope replica**

The above figure shows a photograph of a rope replica and an edge-enhanced image of the outlines of the cross section of a replica respectively.

These replicas are being retained for analysis when the ropes become discarded. Essentially the analyses entail the measurement of the width of the flat sections on the outer wires due to wear. These analyses will form part of project GAP439.

B.3 East Driefontein No 2 Shaft

45 mm 6x33(15/12/6+3T)/F

Date installed: 93-09-19

North West Compartment

1996-08-22	West inner rope (RHL)		West outer rope (LHL)	
Position	Dia (mm)	LL (mm)	Dia (mm)	LL (mm)
Front	45,2 44,7/45,2	305	45,0 45,0/45,0	310
Ref*	44,1 43,8/44,3	370	43,9 43,9/44,2	380
Ref**	44,3 44,2/44,5	320	44,7 44,3/44,9	335
Back	43,7 43,3/44,3	415	43,9 43,7/43,9	430

* Reference point approximately 1239 m from the skip

** Reference point approximately 525 m from the skip

North East Compartment

1996-08-22	East Outer rope (RHL)		East inner rope (LHL)	
Position	Dia (mm)	LL (mm)	Dia (mm)	LL (mm)
Front	45,0 44,6/45,2	305	45,5 45,5/45,5	310
Ref*	43,5 43,2/43,6	405	43,5 43,3/43,5	417
Ref**	44,4 43,8/44,7	340	44,5 44,2/44,7	343
Back	43,6 43,3/43,5	425	43,6 43,5/43,5	445

* Reference point at broken wire approximately 1570 m from the skip

** Reference point at broken wire approximately 75550 m from the skip

The rope diameter was measured using a diameter tape. The two further diameter values indicate vernier measurements done to obtain information on the ovality of the rope.

Headgear sheaves examined and found to be in excellent condition.

B.4 St Helena No 4 Shaft

46 mm 6x31(13/12/6+3T)/F 1800 MPa ungalvanised ropes
Date installed: 90-07-08
No 3 compartment: Coil No 147841 installed on underlay drum
No 4 compartment: Coil No 147842 installed on overlay drum

1996-08-16	No 3 Compartment		No 4 Compartment	
Position	Dia (mm)	LL (mm)	Dia (mm)	LL (mm)
Front	46,5	355	46,7 46,5/46,8	355
Ref*	45,8 45,5/46,2	395	45,6 45,5/45,8	405
Back	45,6 45,5/45,8	445	45,3	440

* A reference point was chosen at an indication of internal broken wires on No 4 compartment approximately 500 m from the skip. Measurements in No 3 compartment were taken at the same time

The rope diameter was measured using a diameter tape. The two further diameter values indicate vernier measurements done to obtain information on the ovality of the rope.

Headgear sheaves examined and found to be in excellent condition.

Appendix C: Results of winder dynamics calculations

The following pages show the results of the calculations in graphic form. The time histories of the rope speed (m/s), rope acceleration at the drum (m/s^2) and the back end and front end rope forces (kN) are plotted for each trip. Two subsequent trips form one cycle.

Note: The gearless Blair winder at East Driefontein No. 2 shaft was treated as two separate single drum winders and the results are presented appropriately.

The winder at Hartebeestfontein No 4 shaft was not available for dynamics measurements. These measurements and the results of the calculations will be presented in the report on project GAP439.

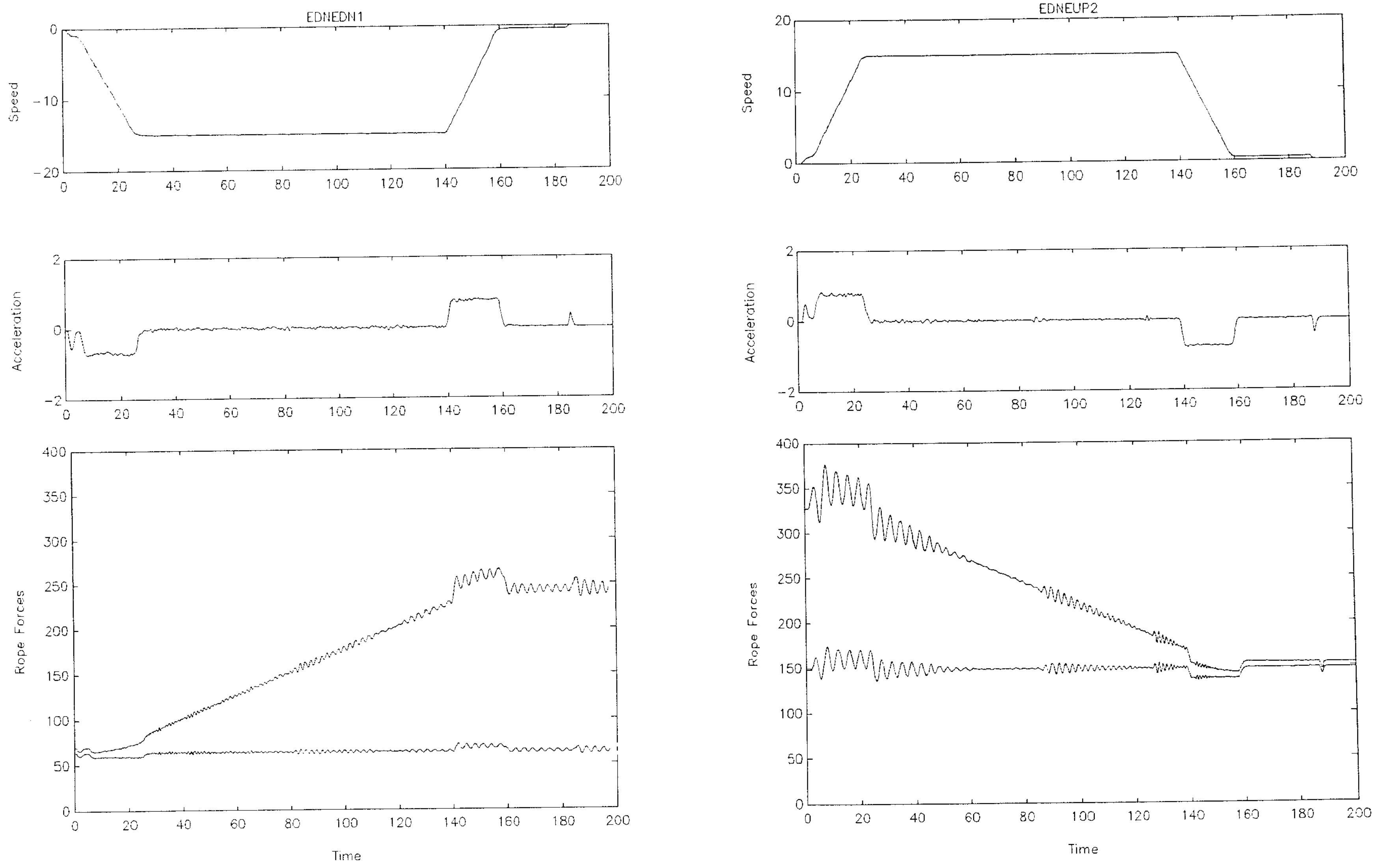


Fig. C.1: East Driefontein North East Compartment: 1st Cycle

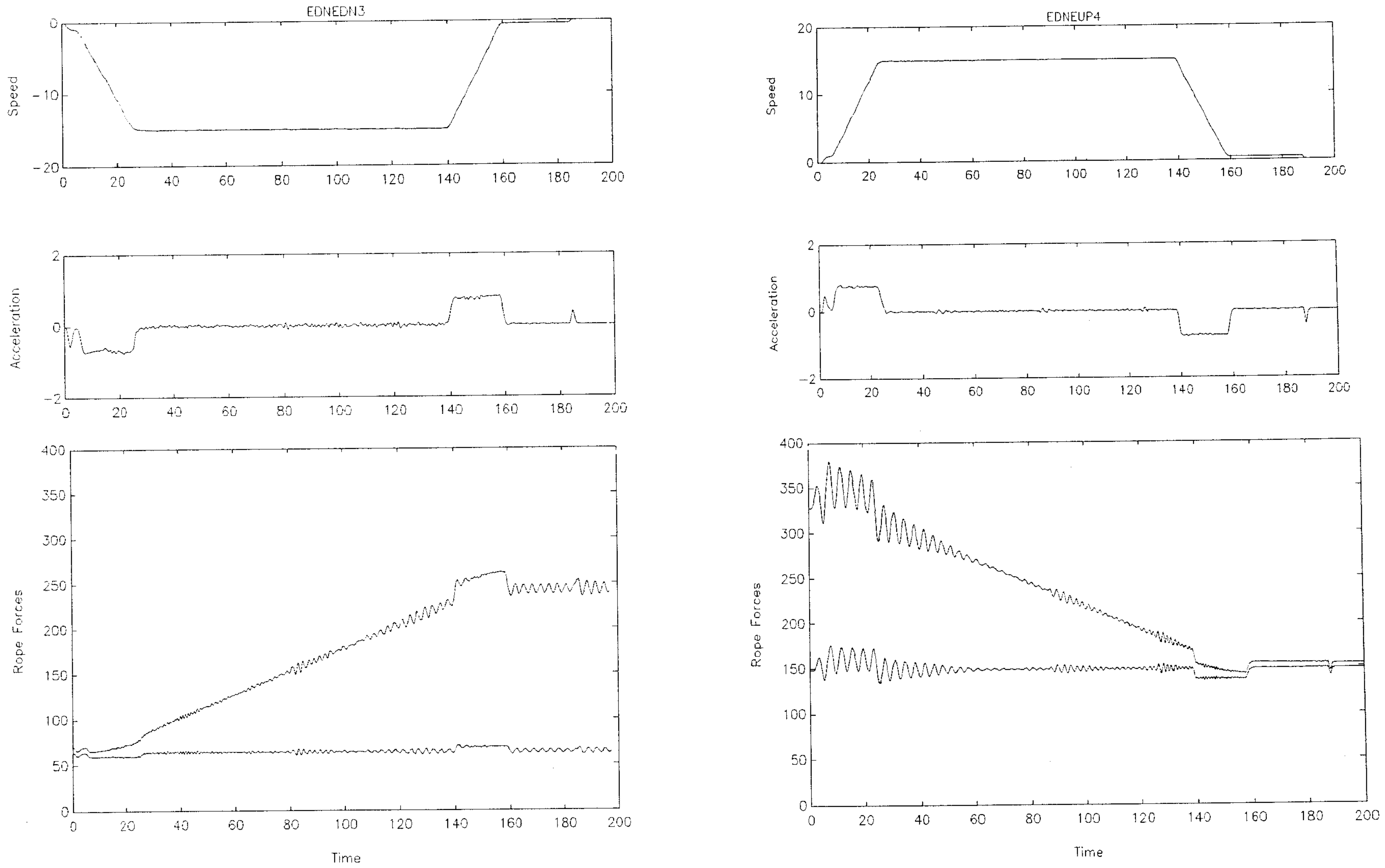


Fig. C.2: East Driefontein North East Compartment: 2^{nd} Cycle

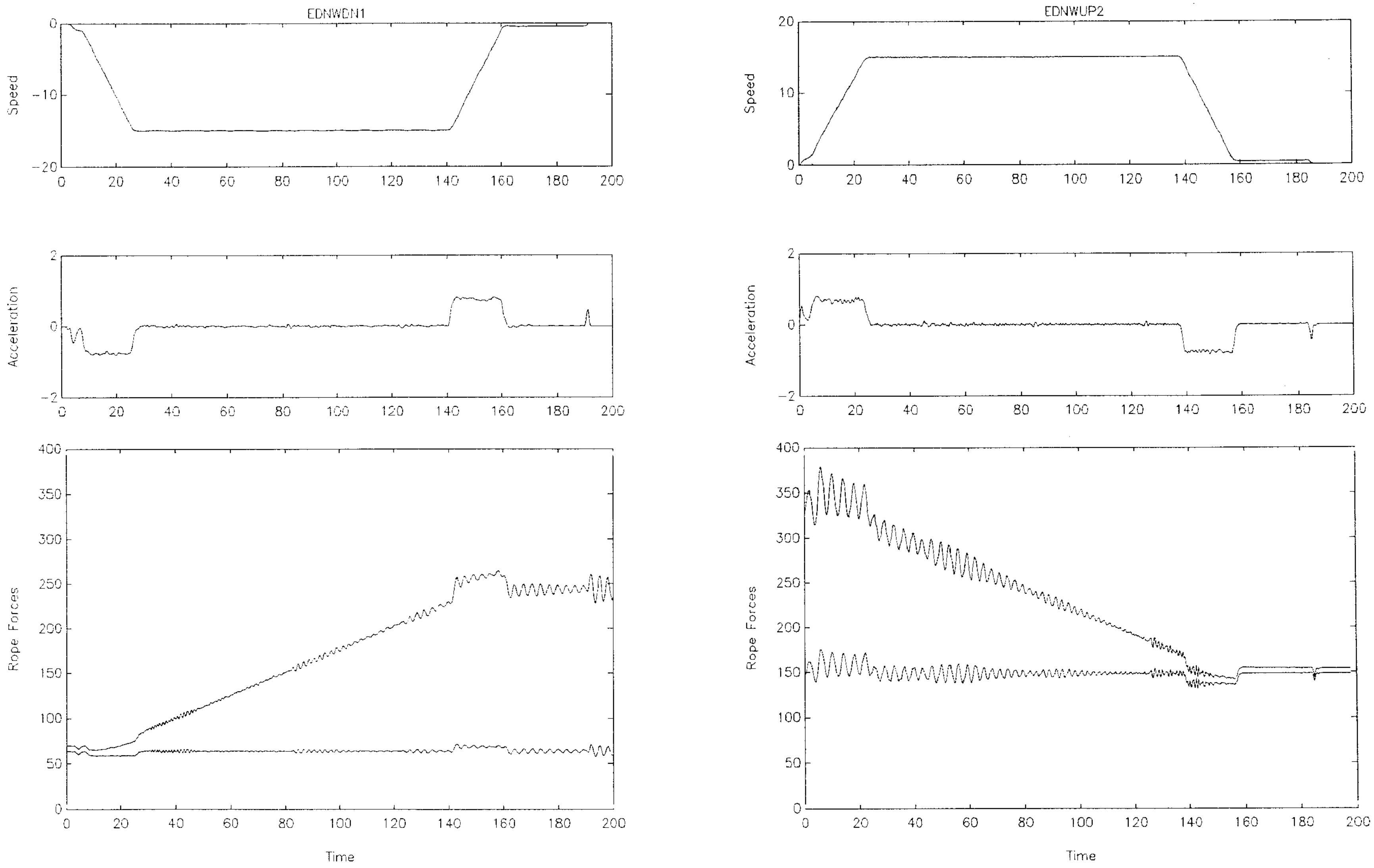


Fig. C.3: East Driefontein North West Compartment: 1st Cycle

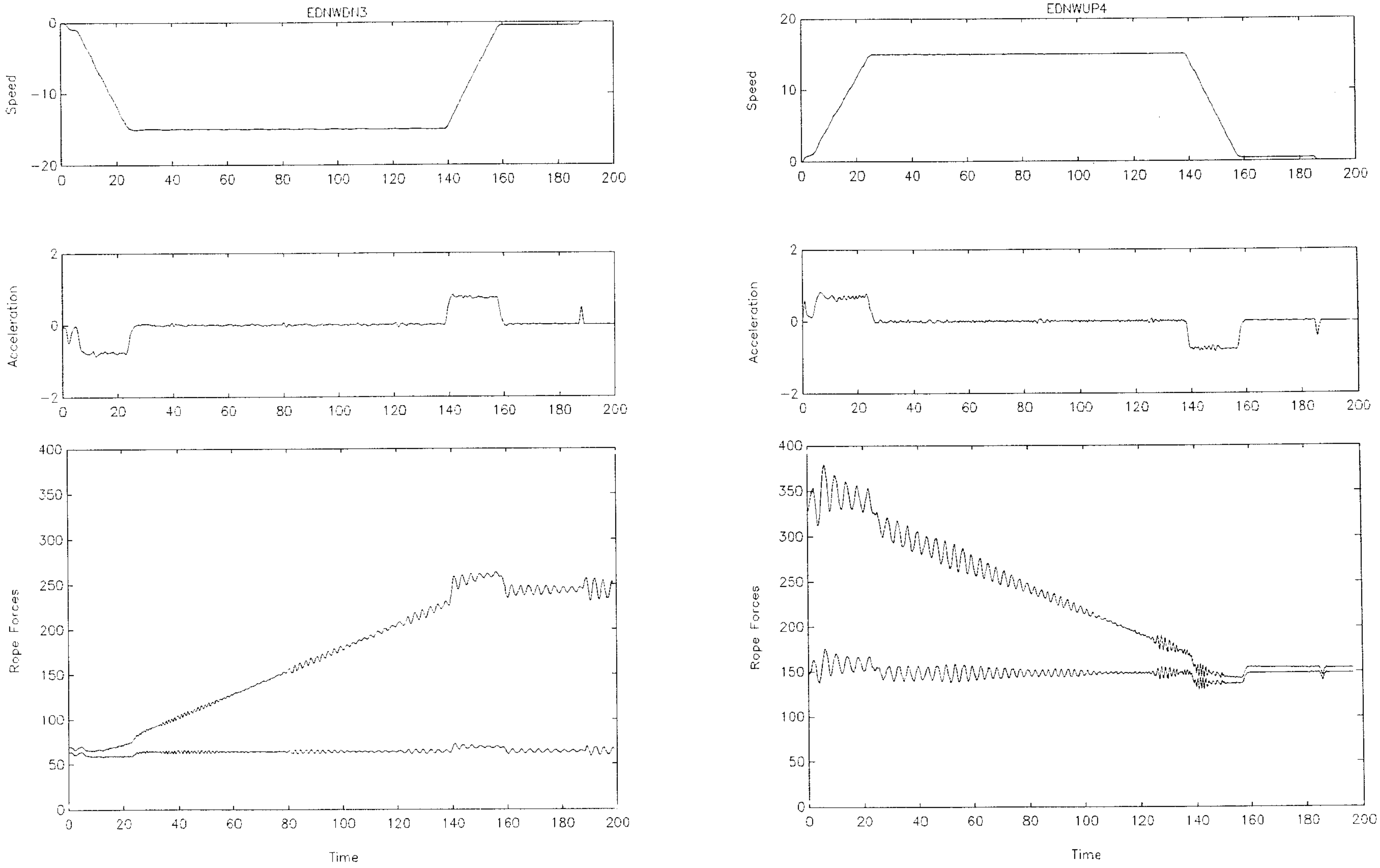


Fig. C.4: East Driefontein North West Compartment: 2nd Cycle

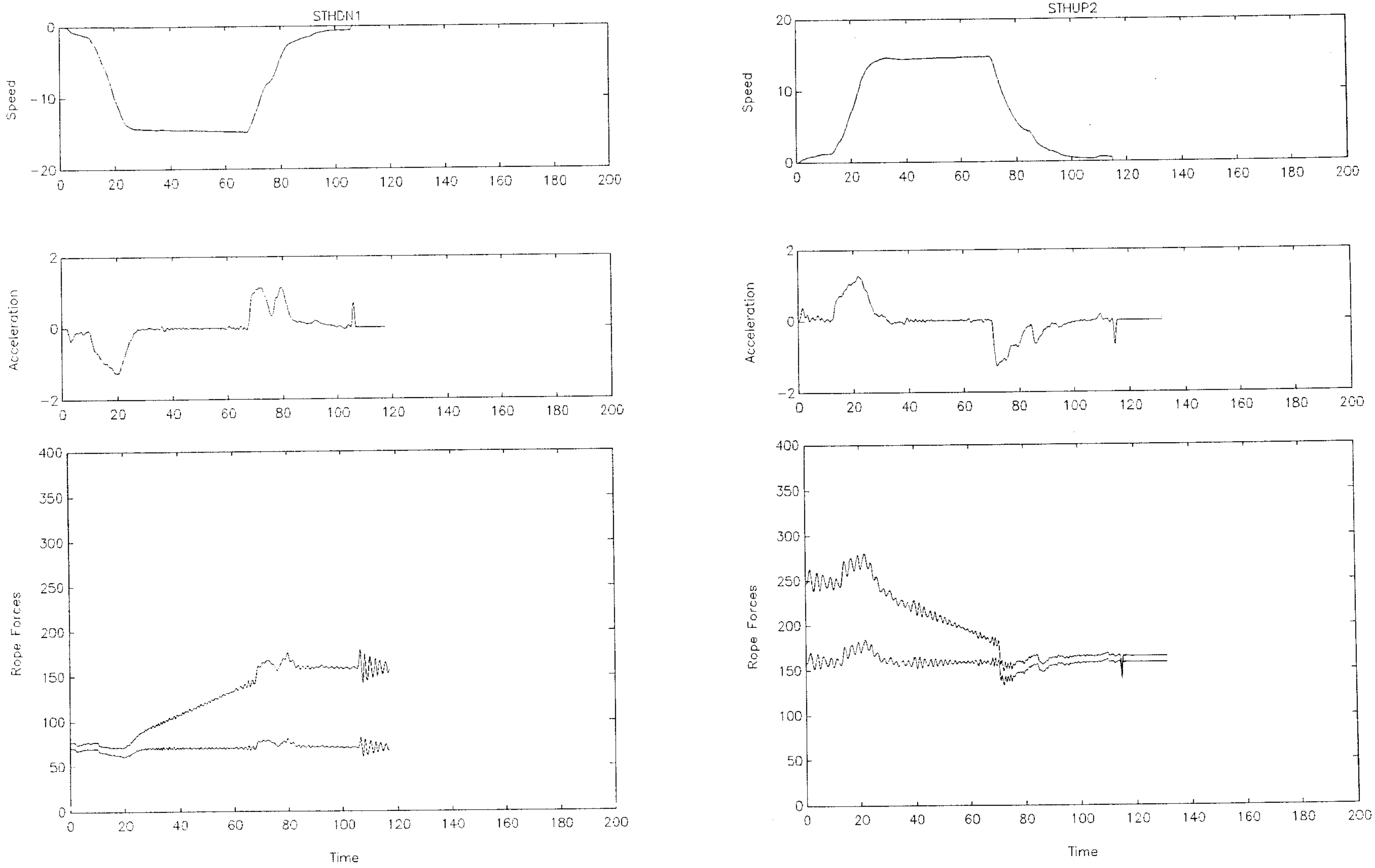


Fig. C.5: St Helena underlay rope: 1st Cycle

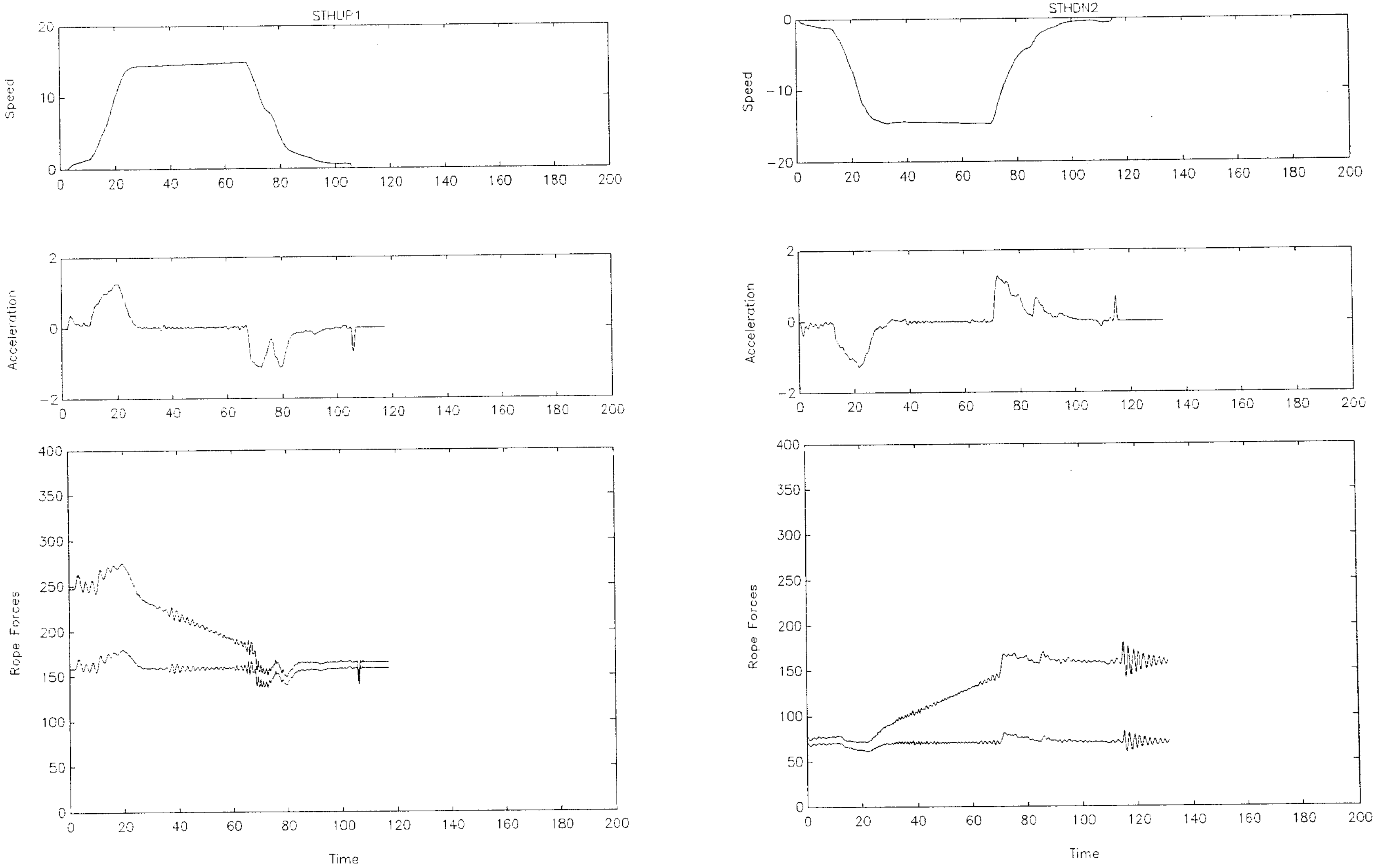


Fig. C.6: St Helena overlay rope: 1st Cycle

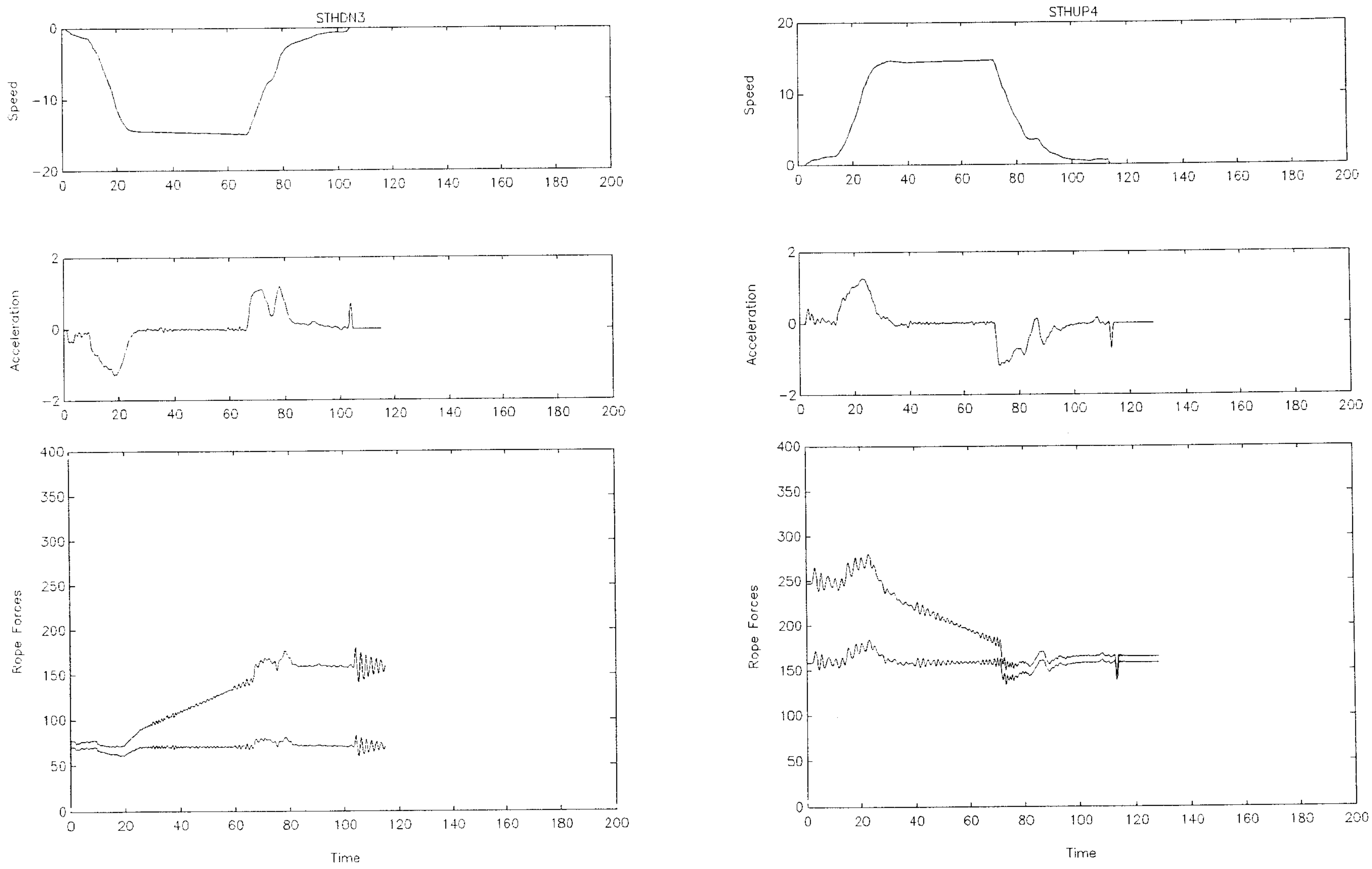


Fig. C.7: St Helena underlay rope: 2^{nd} Cycle

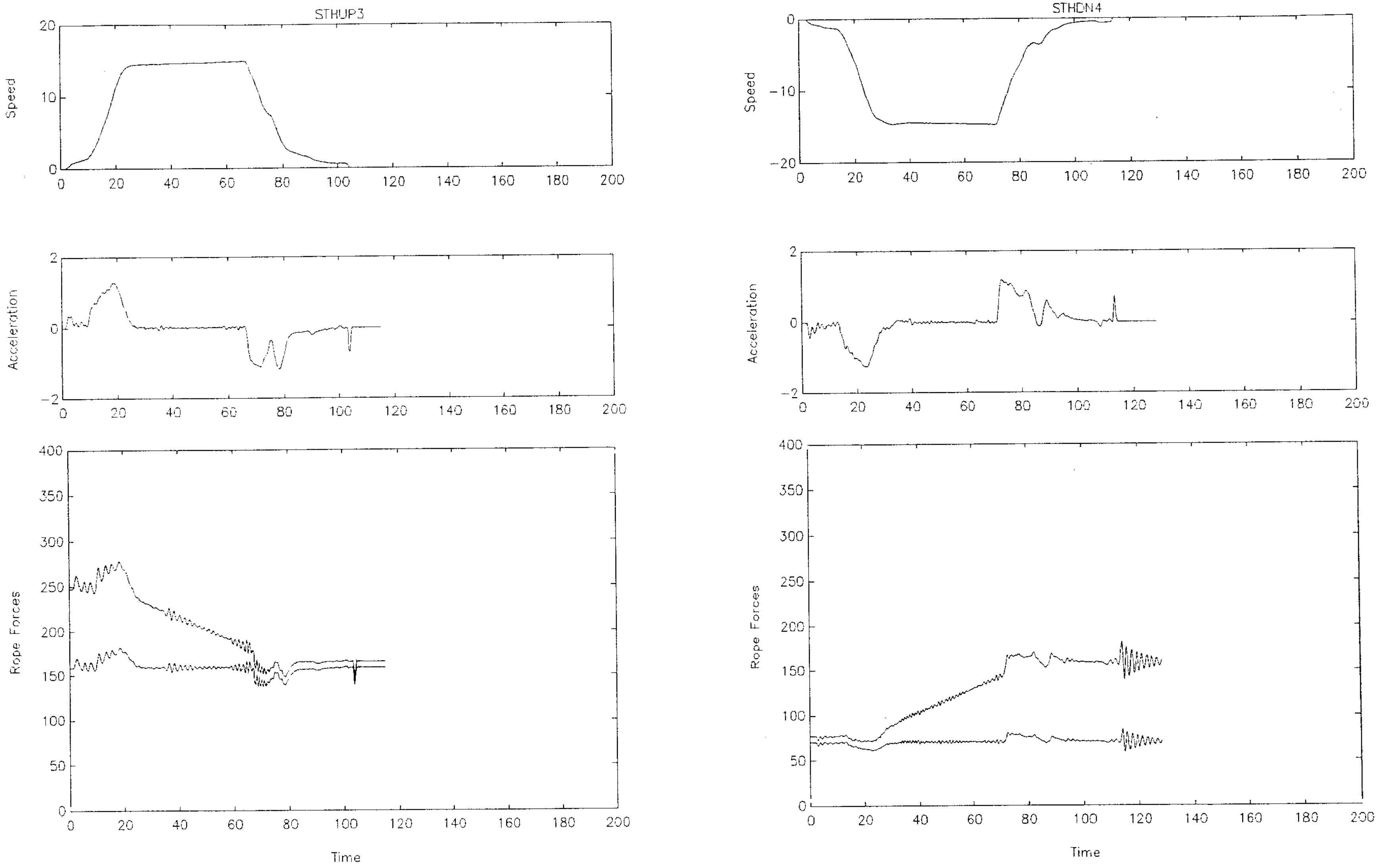


Fig. C.8: St Helena overlay rope: 2nd Cycle

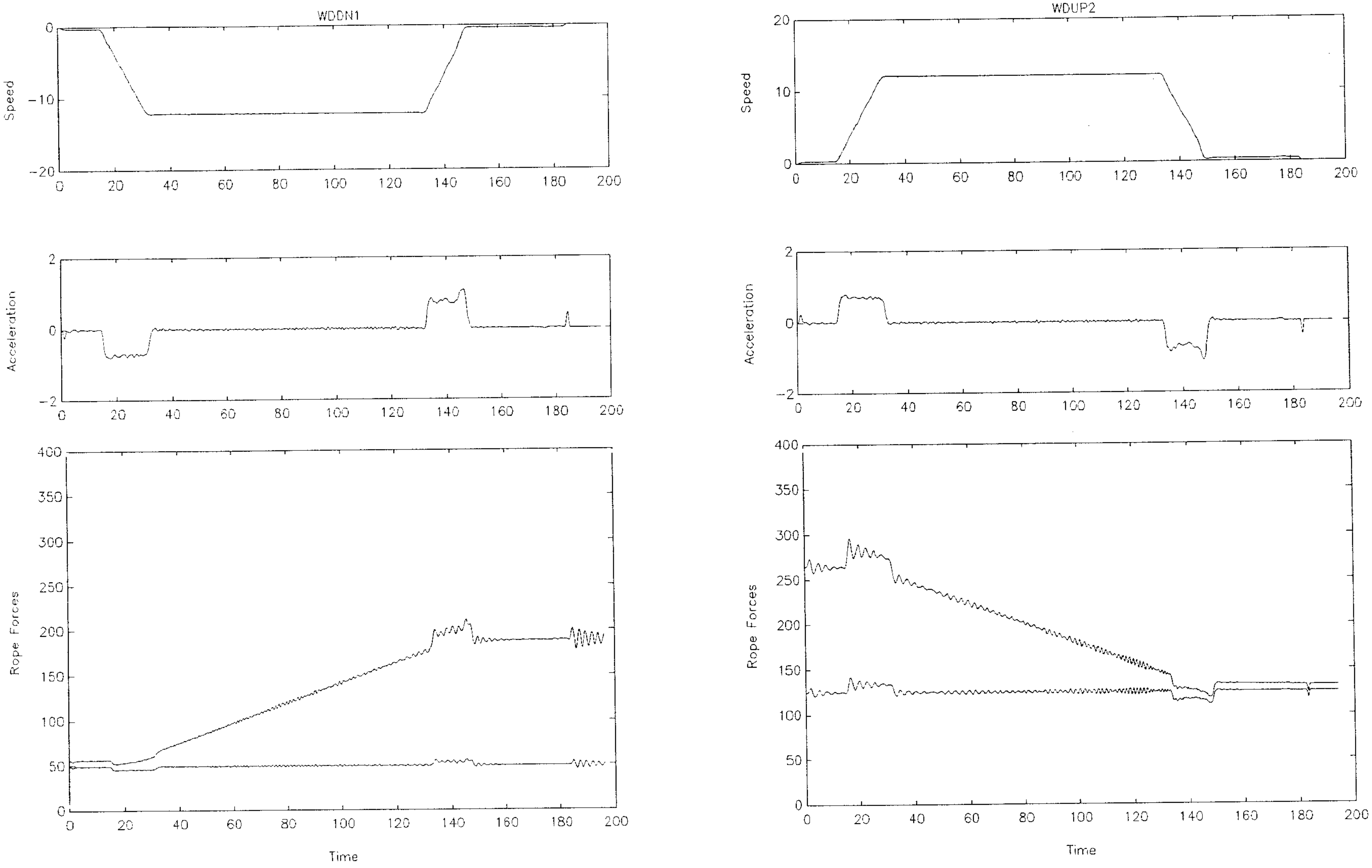


Fig. C.9: West Driefontein overlay rope: 1st Cycle

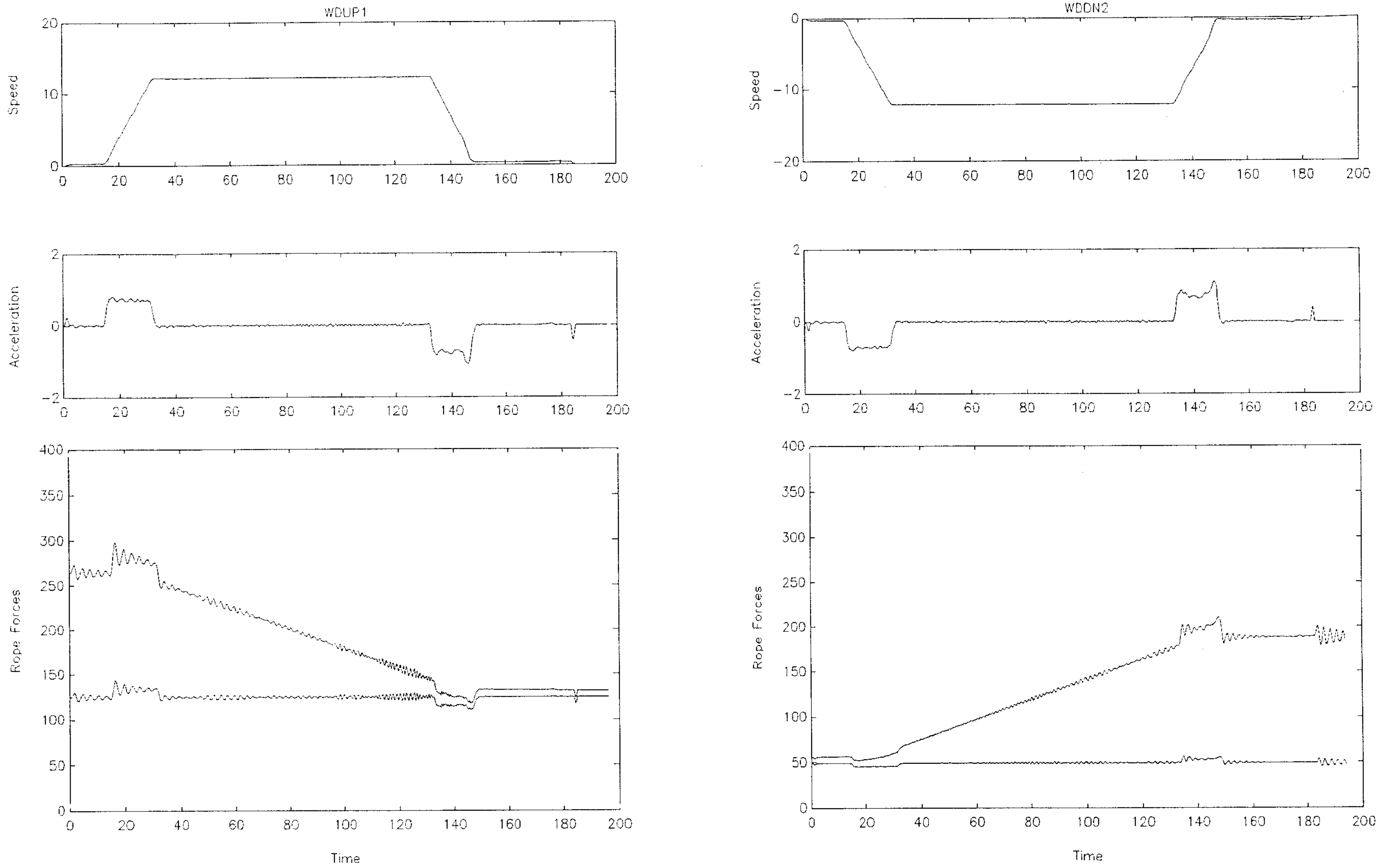


Fig. C.10: West Driefontein underlay rope: 1st Cycle

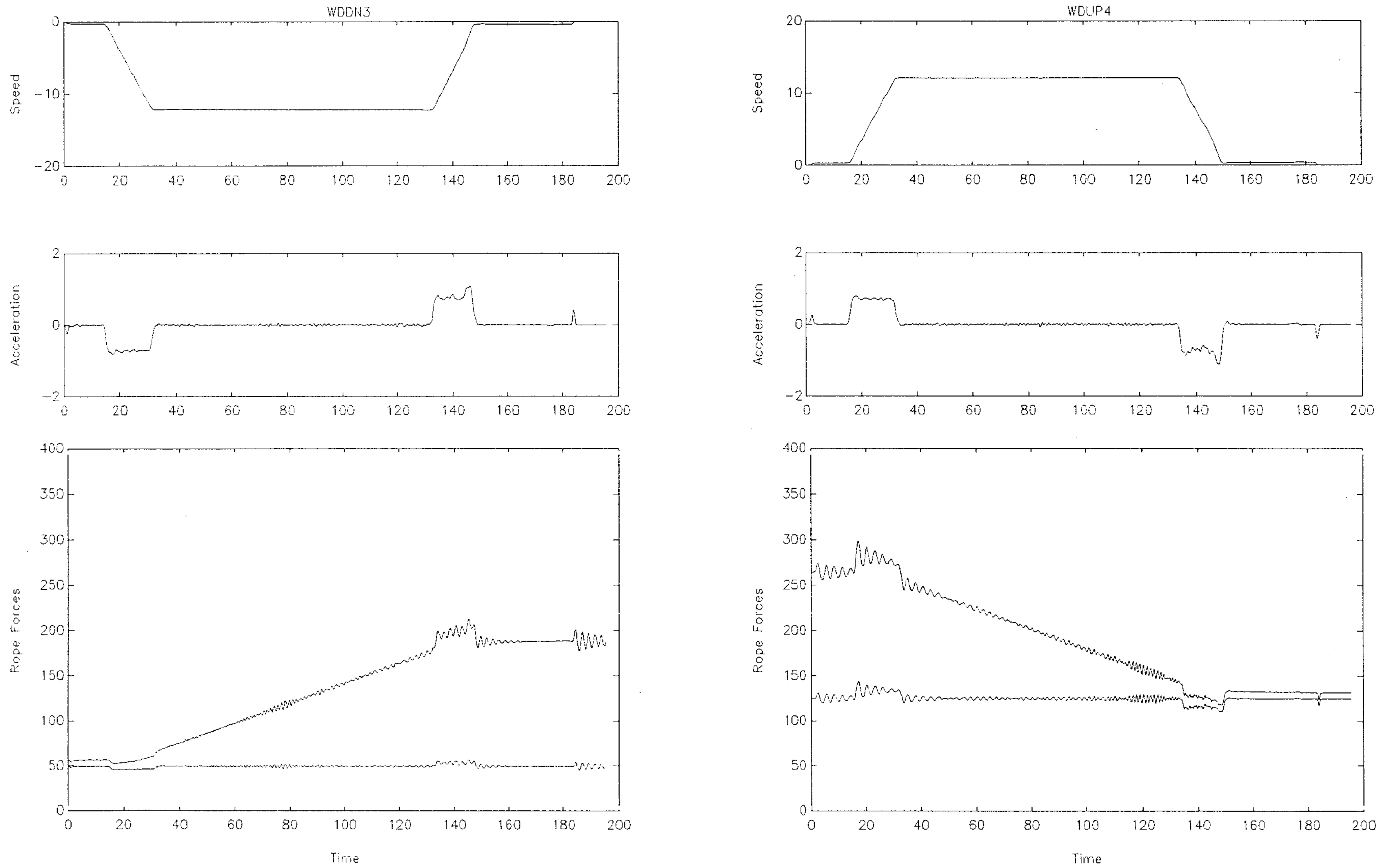


Fig. C.11: West Driefontein overlay rope: 2^nd Cycle

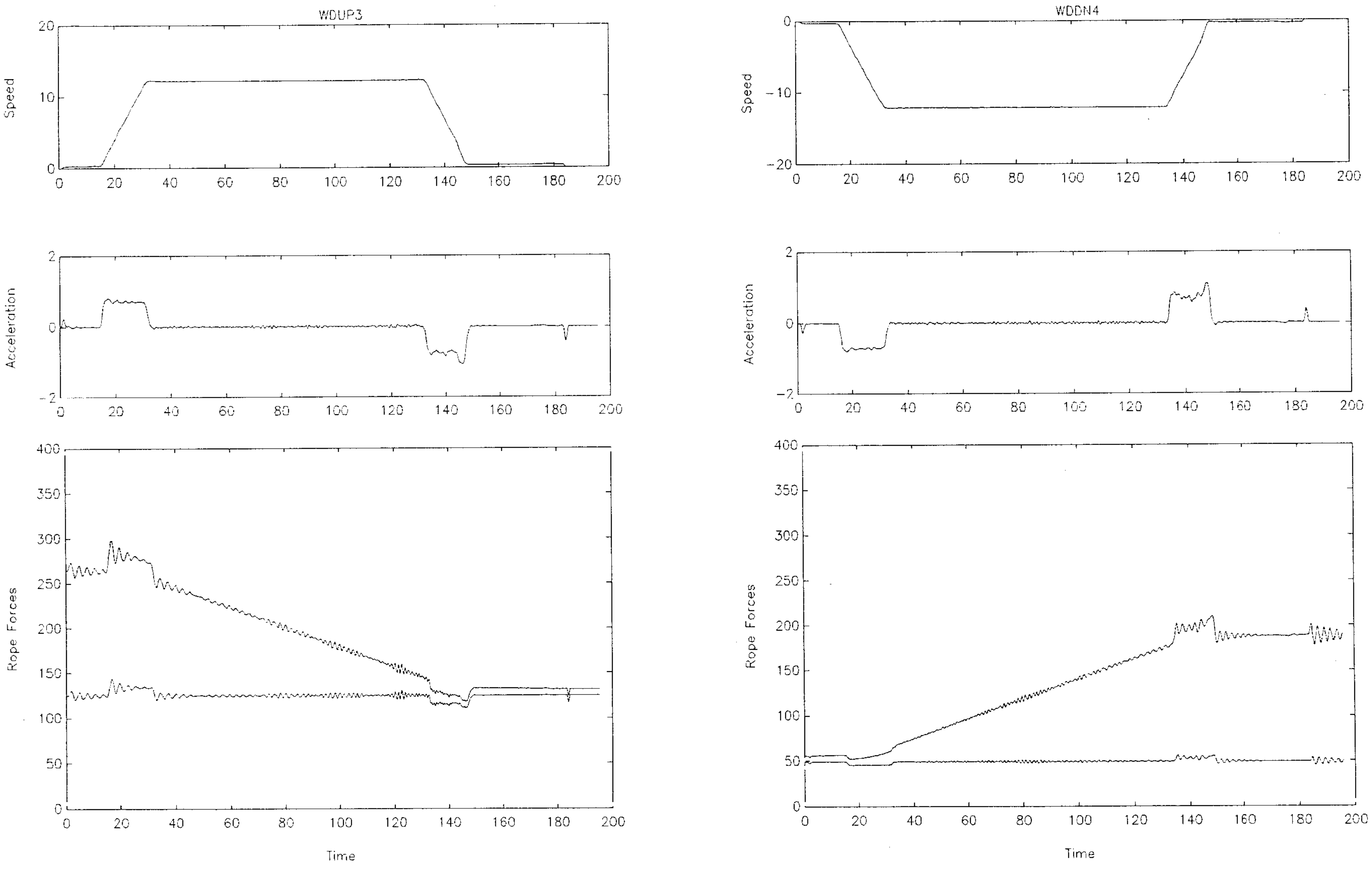


Fig. C.12: West Driefontein underlay rope: 2nd Cycle

Appendix D: Observations of rope maintenance practice at East Driefontein No. 2 shaft

The activities are listed with occasional comments on effectiveness or rope handing problems.

- Both conveyances brought to surface. This is a gearless Blair, but presumably this procedure would be appropriate for mechanically coupled drums as well.
- Clamps attached to both ropes on each conveyance, just adjacent to the equaliser sheave.
- Both skips landed on steel beams placed across the compartments. The bridle crosshead supported on wooden blocks placed on the steel beams.
- Each equaliser sheave disconnected from the bridle crosshead.
- On the NE compartment the equaliser was raised through the crosshead and then lowered to bank level without allowing slack.
- The equaliser attached to a mobile crane hoist.
- A beam for controlling the ropes placed in brackets on the headgear steelwork.
- The equaliser now pulled out of the shaft by the mobile crane while rope payed out from the winder drum. Care was taken to ensure that there was no slack allowed in the ropes which were controlled by radius plates on the beam.
- When about two to three metre of rope had been pulled out of the shaft, the ropes were secured to the radius plates on the control beam by means of U-clamps.
- The ropes were then cut close to the equaliser sheave by means of an oxy-acetylene torch after seizings had been applied to the ropes.
- The equaliser was then removed from the vicinity of the shaft.
- Winch ropes from a winch situated adjacent to the winder house were then attached to the ropes with an intermediate swivel.
- After a slight tension was applied to the winch ropes, the U-clamps were loosened and the ropes allowed to spin (one at a time) under the control of the U-clamp and the swivel. The object of the winch ropes is to maintain the catenary between the headgear sheaves and the drum.

- When all the spin had been released, the ropes were pulled as far as the winch while being payed out from the winder drum.
- Chains were attached to each rope just above the skip and secured to fibre rope attached to the skip (or headgear). This control is required to maintain the catenaries.
- Test pieces were then cut from the ends of each rope and suitably marked to ensure identification.
- One of the ropes was the pulled back towards the shaft so that the free end lay about half way between the winch and the shaft. The end of this rope was then attached to a reconditioned compensator wheel which was placed in position by the mobile crane.
- When the rope had been secured by means of the radial wedges, the compensator sheave was rolled towards the shaft until there were three turns of rope on it. It was then moved away from the shaft by the mobile crane and then again rolled towards the shaft until all the grooves in the compensator were filled with rope.
- The other rope was then attached to the compensator by means of the opposite radial wedge.
- The compensator was then rolled to coil this rope into its correct position, with each rope occupying an equal number of turns.
- The original control clamp was then attached to the ropes to ensure that the ropes were held correctly on the equaliser.
- Connectors for attaching the doubling down sheaves were mounted on the bridle crosshead. The sheaves were then attached with the ropes threaded inside the face plates.
- The equaliser sheave was then lifted by the mobile crane and the ropes were wound onto the winder drum until the equaliser sheave was about two metre from the doubling down sheaves.
- A pennant was attached to the equaliser sheave and the winch rope and the equaliser the raised until it was vertically above the deflection sheaves the supporting the tension due to the catenary.
- The chains and fibre rope maintaining the catenary were then removed.

- The equaliser was then lifted into position at a permanently erected girder by means of the pennant and secured here with an axle mounted in channel supports.
- This procedure was then repeated in the NW compartment.
- Having mounted the equalisers in the headgear, the conveyances were then supported on the doubling down sheaves and the doubled ropes. The supporting beams and wooden blocks were removed.
- Each conveyance, in turn, was the lowered to the full extent of the ropes on the drum, about half a turn only being left on the drum.
- Supporting beams were again placed across the shaft compartments in Reliance taper wedge support glands installed to support the ropes in the shaft while the connections on the drum were being loosened and adjusted.
- With the ropes fully supported in the shaft, fibre rope was attached to each rope near the drum to hold the catenary while the connection on the drum was being adjusted.
- The east drum was turned to remove all the remaining rope.
- A mark was placed on each rope at a predetermined distance from the hawse hole. This was the distance that the rope would be pulled in to move the crossover points.
- The clamps securing the clove hitch round the drum shaft were removed and the rope pulled through the hawse hole to the previously applied mark. This amount of rope was worked through the clove hitch and the clamps reapplied with the required amount of rope being cut off.
- Due to the design of the Lebus shells, a certain amount of welding work was now undertaken to repair cracks in the wedges and distance pieces. The welding was ground smooth by means of a hand held grinding wheel.
- After the examination and repair of this drum, the slack was taken up on the rope and the fibre rope holding the catenary removed.
- Tension was again applied to the rope and the Reliance glands removed, together with the supporting beams.
- The skip was the raised to the surface and supported on steel beams as before.
- The equaliser sheave was then removed from its support steelwork and lowered to bank level.

- With the help of the mobile crane, the pennant was removed from the equaliser sheave, the sheave hoisted into the shaft and lowered into the bridle crosshead.
- The axle and support blocks were then installed on the equaliser sheave and secured to the bridle crosshead.
- The conveyance was then run through the shaft several times and new marks were made to indicate all the appropriate stopping places. The control gear was then adjusted to complete the safety arrangements.
- Because of the time taken and the extra maintenance required on the west drum, a slightly different procedure was followed (compared to the east drum).
- Instead of pulling the rope through the hawse hole by the amount required, all the rope was removed from the drum.
- This drum was then free for detailed inspection and maintenance without the requirement for supervising rope movement.
- When the drum maintenance was completed, the ropes were reinstalled to the marks and the clove hitch remade and clamped. The required amount of rope was cut from the front end.
- The procedure after this was the same as for the east drum.

Appendix E: Detailed information on the rope samples tested to evaluate discard criteria

Table E.1: ***Rope samples from drum winders***

Coil no.	Dia. (mm)	Rope const	Tens. grade (MPa)	New strength (kN)	Actual strength (kN)	Strength change %	Dis-card factor	Reason for discard: broken wires and diameter change
136064/1	26	6x19	1 800 g	435	432	-0,8	0,34	0 BW +0,34 DRs*
133699/1	33	6x26	1 800 u	821	787	-4,2	0,37	0 BW +0,37 DRs
130774/2	38,5	6x28	1 800 u	1 135	786	-30,7	2,22	1,67 BWa+0,55 DRs
129354/1	42	6x30	2 100 u	1 540	1 448	-6,0	1,26	1,02 BWa+0,24 DRa
129353/1	42	6x30	2 100 u	1 530	1 136	-25,7	2,32	2,05 BWa+0,27 DRa
121711/1	44	6x30	1 800 u	1 450	1 402	-3,3	0,83	0,77 BWa+0,06 DRs
129189/1	44	6x31	2 050 u	1 669	1 665	-0,2	0,57	0,47 BWa+0,10 DRs*
129656/1	46	6x31	1 800 u	1 618	1 243	-23,2	2,80	2,27 BWs+0,53 DRs
120995/1	48	6x32	1 900 u	1 770	1 798	+1,6	0,39	0,20 BWa+0,19 DRs
131558/1	48	6x32	1 900 u	1 758	1 662	-6,9	0,91	0,40 BWa+0,51 DRs
131557/2	48	6x32	1 900 u	1 788	1 776	-0,7	0,72	0,40 BWa+0,32 DRs*
131557/2	48	6x32	1 900 u	1 788	1 786	-0,1	1,04	0,69 BWa+0,35 DRs*
131557/2	48	6x32	1 900 u	1 788	1 676	-6,3	1,20	0,81 BWa+0,39 DRs
120995/1	48	6x32	1 900 u	1 770	1 705	-3,7	1,05	0,61 BWa+0,44 DRs
120995/1	48	6x32	1 900 u	1 770	1 750	-1,1	0,77	0,40 BWa+0,37 DRs*
135197/1	49	6x32	1 800 u	1 826	1 836	+0,6	0,45	0 BW +0,45 DRs*
135197/2	49	6x32	1 800 u	1 851	1 594	-13,9	1,61	1,00 BWa+0,61 DRs
132010/1	51	6x32	1 800 u	1 974	1 868	-5,4	0,27	0,20 BWa+0,07 DRs
118789/2	53	6x32	1 800 g	2 130	1 753	-17,7	2,49	2,19 BWa+0,29 DRs
137298/2	62	6x34	1 800 u	2 928	2 736	-6,6	0,62	0,49 BWa+0,13 DIs*
137298/2	62	6x34	1 800 u	2 928	2 811	-4,0	1,07	0,98 BWa+0,09 DRs
137298/2	62	6x34	1 800 u	2 928	2 756	-5,9	0,51	0,49 BWa+0,02 DRs*

Only the first rope sample in the table came from an incline winder. The rest were all from drum winders of vertical shafts. All the ropes in the table were of triangular strand construction.

The "u" or "g" after the tensile grade indicates ungalvanised or galvanised wires.

"BW" indicates broken wires, "DR" rope diameter reductions, and "DI" rope diameter increases.

BWa: Asymmetrical (More than 50% of broken wires in two adjacent strands).
BWs: Symmetrical (Less than 50% of broken wires in two adjacent strands).
DRs: Symmetrical reduction in rope diameter.

The broken wires were in all cases in one lay length of the rope.

In some cases, more than one sample of the same rope was submitted. In other cases, the rope sample submitted was not from the section of rope that was the reason for discard. An "*" after the "reason for discard" indicates that the rope sample was not the reason for discard of the winder rope.

Table E.2: Rope samples from Koepe winders

Coil no.	Dia. (mm)	Rope const	Tensile grade (MPa)	New strength (kN)	Actual strength (kN)	Strength change %	Dis-card factor	Reason for discard: broken wires and diameter change
134040/1	32	15 fb	1 800 u	776	714	-8,0	1,42	1,14 BWa+0,28 DRs
130270/1	36	14 ns	1 600 u	969	975	0,6	0,06	0 BW +0,06 DIs*
150525	46	18 ns	1 600 g	1 280	1 103	-13,8	1,38	1,03 BWa+0,34 DRa

The first sample in the table was from a Koepe head rope (15 strand "fishback"). The other two were 14 and 18 strand non-spin tail ropes.

The "u" or "g" after the tensile grade indicates ungalvanised or galvanised wires.

"BW" indicates broken wires, "DR" rope diameter reductions, and "DI" rope diameter increases.

BWa: Asymmetrical (More than 50% of broken wires in two adjacent strands).
BWs: Symmetrical (Less than 50% of broken wires in two adjacent strands).
DRs: Symmetrical reduction in rope diameter.
DRa: Asymmetrical reduction in rope diameter.

"*" after the "reason for discard" indicates that the rope sample was not that section of rope that was the reason why the winder rope was discarded.

The first and third samples in the table had more than 40% of the broken wires in one strand. The third sample also had localised wear, which indicated that the rope had to have had some type of abnormal deterioration or damage.

Table E.3: ***Samples of ropes discarded because of observed corrosion***

Coil No.	Winder/ rope type	Dia. (mm)	Rope constr.	Tensile grade (MPa)	New strength (kN)	Actual strength (kN)	% change in strength	Degree of corrosion
132506/1	KHR	44	18 fb	1 800 u	1 540	1 577	+2,4	More than slight ¦ EM = 6,5%
014585	DD	44	6x30t	1 750 g	1 470	1 478	+0,5	More than slight
132670/1	KHR	44	18 fb	1 800 u	1 529	1 530	0,1	More than slight ¦ EM = 5%
135015/2	KHR	29	6x25r	1 800 g	573	561	-2,1	More than slight
132670/2	KHR	44	18 fb	1 800 u	1 540	1 390	-9,7	More than slight ¦ EM = 4,6%
135015/1	KHR	29	6x25r	1 800 g	573	496	-13,4	Severe pitting
021879	KHR	44	18 fb	1 800 g	1 610	670	-58,4	Excessive

Winder/rope type: KHR: Koepe head rope
DD: Double drum winder rope

6x30t: A triangular strand rope with a 6x30 construction
6x25r: A round strand rope with a 6x25 construction
18 fs: An 18 strand fishback non-spin rope

"u" or "g" after the tensile grade indicates ungalvanised or galvanised rope wires.

Some of the ropes samples had broken wires as well, but the discard factors for broken wires were never greater than 0,2 for any of the ropes.

The degrees of corrosion shown in the table were taken from the CSIR rope test certificate. The degree of corrosion indicated as "EM =" is a steel area loss as indicated by the electro-magnetic testing instrument.

The last rope in the table (a Koepe head rope) was in operation for approximately 7 years, and was discarded because of excessive corrosion.

Table E.4: Samples from ropes that were discarded because of localised damage.

Coil No.	Winder/rope type	Dia. (mm)	Rope constr.	Tensile grade (MPa)	New strength (kN)	Actual strength (kN)	Strength change %	Description of damage
133974/1	stage	42	15 fb	1 950 u	1 469	1 258	-14,7	6 broken wires in one outer strand[*1]
119819/1	DD	55	6x34t	2 050 u	2 610	2 106	-19,3	3 broken wires at brazed core[*2]
124203/1	DD	40	6x29t	1 800 u	1 220	901	-26,1	Twisted strand, 13 broken wires in 1 laylength
130045/1	KTR	44	18 cp	1 600 u	1 411	738	-47,7	12 broken wires, severe localised plastic deformation[*3]
134298/2	DD	22	6x26t	1 800 u	366	150	-59,0	77 broken wires in 1 laylength[*4]

stage: Stage winder rope
KTR: Koepe tail rope
DD: Double drum winder rope

15 fb: 15 strand "fishback" non-spin rope
6x34t: A triangular strand rope with a 6x34 construction
18 cp: 18 strand compact strand rope

"u" after the tensile grade indicates ungalvanised rope wires.

*1: This stage rope was damaged when the kibble accidentally fell against the rope during tipping. The stage rope was one of the guide ropes for the kibble. The discard factor for the rope, based on the visible broken wires, was only 0,93.

*2: The discard factor for this rope, based on the visible broken wires at the brazed strand core, was only 0,66. The post-tensile test inspection showed that the brazed core had fractured while the rope was in service.

*3: The severe localised wear (some outer wires had a 43% reduction in diameter) indicated that this Koepe tail rope had to have experienced abnormal circumstances in order to have sustained such damage.

*4: The appearance of the damage on this drum winder rope is typical of a bad layer cross-over on the drum or a loose drum coiling sleeve bolt.