

**Safety in Mines Research Advisory Committee**

**Final Report**

**Technology transfer of winder ropes research**

**Mike van Zyl**

**Research agency: MIKE VAN ZYL INCORPORATED**  
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# Executive summary

In the early 1980's, winder ropes research in South Africa gained new momentum when it was decided to investigate the validity of the regulations governing the strength of winder ropes. Although knowledge of, and experience with winder systems and winder ropes were available at the time that the research effort started, very little was actually written in the form of reports that could have been used as motivation for changes to the regulations.

Originally the research was sponsored collectively by the mining industry through the Chamber of Mines, and later through government levies raised and administered by the Safety in Mines Research Advisory Committee (SIMRAC). The CSIR (a semi-government organisation) was the initial co-ordinator of the research. Because of their intimate involvement in the project, both the CSIR and Anglo American Corporation also sponsored their own winder ropes related investigations from time to time. The reports on these "privately" sponsored investigations were made available to the research effort.

By the year 2000, more than 100 research reports had been produced. These reports either had some bearing on the new rope load factors that were included in the South African regulations, or were produced as a result of the changes introduced to the regulations. In total, the reports consist of more than 5 900 pages.

The main part of this document describes the events and history that led to the creation of this vast amount of research. The research reports that were produced are listed and a summary of the contents of each report is given in an appendix.

The research described in this report produced and established the following:

- ? New rope load factors and regulations for drum winder ropes were established.
- ? A code of practice for rope condition assessment was produced, rope discard criteria were investigated and magnetic rope testing instruments were evaluated.
- ? The winder code of practice that would allow better utilisation of drum winders as well as deep shaft hoisting was established.
- ? A code of practice for shaft sinking winders was established and used to sink two very deep shafts.
- ? New rope terminations were introduced.
- ? Winder and rope dynamics are now well understood.
- ? Rope deterioration on a drum winder is far better understood.
- ? Uncertainties like winder motor fault torque and slack rope have been investigated.
- ? A large information base on drum winders has been established.

A large part of the SIMRAC investigations were concerned with rope discard and rope deterioration in order to verify and refine the requirements in the mentioned codes of practice. None of the recommendations in the SIMRAC reports has been implemented. This should be followed up.

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## Terminology and abbreviations

**Back end:** The section of rope at and near the drum of the winder when the conveyance is at its lowest point in the shaft.

**Front end:** The section of rope at and near the conveyance end of the rope.

**Initial rope strength:** The strength of a rope when new, and as determined by a tensile test.

**New rope strength:** See "Initial rope strength"

**Capacity factor:** The rope strength divided by the maximum allowable (static) front-end load.

**Safety factor:** (FoS) The rope strength divided by the maximum allowable (static) back end load (calculated at the headsheave for the maximum length of suspended rope). The safety factor will always refer to the static load except if *dynamic* is specifically mentioned.

**Rope load factors:** The capacity factor and the safety factor.

**Dynamic factor:** The dynamic safety factor: The rope strength divided by the maximum rope load that can be generated under a given set of circumstances.

**Installation factors:** Rope load factors calculated by using the initial rope strength. Unless otherwise specified, installation factors are assumed.

**Discard factors:** Rope load factors calculated using the actual or remaining rope strength of a rope, or that strength of the rope at the point that it will be discarded. Discard factors are not used any more.

**Payload factor:** The rope strength divided by the weight of the allowable payload

**Load range:** The difference between the largest and smallest dynamic loads that act on a section of rope in a given period (e.g. one winding cycle). The load range divided by the initial rope strength gives the *load range ratio*, which is generally given as a percentage of the initial strength of the rope.

**Winding cycle:** A round or intermittent winding journey, starting with one conveyance at bank level and ending with that same conveyance returning to the bank level.

**The formula:** The safety factor formula in the "new" regulations:  $FoS = 25\ 000 / (4\ 000 + L)$

**Non-spin rope:** A generic term for a rope consisting of multiple layers of strands in which the strand layers are laid in opposite directions to achieve opposing torques under load; also referred to as a low-rotation rope.

**Low rotation rope:** see Non-spin rope

**BMR:** Blair multi-rope drum winder. These winders have two ropes per drum side.

**UHT:** Ultra-high tensility (of the wires of a winding rope). Generally greater than 1 950 MPa.

**Winder code of practice:** A shorter name for the "Code of practice for the performance, operation, testing and maintenance of drum winders relating to rope safety", SABS0294.

**RCA code of practice:** The rope condition assessment code of practice, SABS0293.

**EMT:** Electro-magnetic rope testing; now only referred to as magnetic testing.

**NDT:** Non-destructive testing.

**CM&EE sub committee:** A Chamber of Mines committee consisting of the Chief Consulting Mechanical and Electrical Engineers of the member mining houses.

**CoMRO:** Chamber of Mines Research Organisation, which was merged with the CSIR in 1993.

**GME:** The Government Mining Engineer of the Department of Minerals and Energy; now called the Chief Director.

**Backslip:** (or slip-back) Unwinding a rope from a drum at a lower load than when it was wound onto the drum will result in a rope section slipping backwards to establish load equilibrium before that section of rope leaves the drum.

# 1 Introduction

In the early 1980's, winder ropes research in South Africa gained new momentum when it was decided to investigate the validity of the regulations governing the strength of winder ropes. Although knowledge of, and experience with winder systems and winder ropes were available at the time that the research effort started, very little was actually written in the form of reports that could have been used as motivation for changes to the regulations.

Originally the research was sponsored collectively by the mining industry through the Chamber of Mines, and later through government levies raised and administered by the Safety in Mines Research Advisory Committee (SIMRAC). The CSIR (a semi-government organisation) was the initial co-ordinator of the research. Because of their intimate involvement in the project, both the CSIR and Anglo American Corporation also sponsored their own winder ropes related investigations from time to time. The reports on these "privately" sponsored investigations were made available to the research effort.

By the year 2000, more than 100 research reports had been produced. These reports either had some bearing on the new rope load factors that were included in the regulations, or were produced as a result of the changes introduced to the regulations. This report summarises the research carried out.

The findings of a large part of the research effort have become common knowledge and for that reason, some of the investigations that were carried out would now seem superfluous or nonessential. To appreciate why different projects were carried out, and why the direction of the research changed course from time to time, the events relating to the research during the period 1982 to 2000 is given in a more-or-less chronological order (the "history").

## 2 Report format

The main section of the report gives the overview of the history of the research effort.

References in this report that are not specifically summarised are listed in Appendix A as "other references" and their references are superscripted with a preceding "o" or "ref. o1" and so forth in this report.

Those reports and papers that were summarised are listed in Appendix B and are referenced with a superscript with a preceding "r" or "ref. r1" and so on.

Summaries of the reports listed in Appendix B are given in Appendix C. In most cases it was possible to fit the summary into a single page. When and where the author of this summary report deemed it necessary, comments on the contents and findings of a report were included.

The contents of the various research reports (that were summarised) were divided into the categories that follow. This should make it easier to find information on a specific subject amongst the large number of reports. An abbreviation was also assigned to each category:

COP:	A code of practice or a draft code of practice.
DEEP:	The behaviour of ropes in (deep) shafts.
DET:	The deterioration mechanisms and deterioration patterns of drum winder ropes, "fatigue", and rope life and rope life predictions.
DYN:	The dynamic behaviour of ropes and winders.
FOS:	Rope safety factors, safety philosophies, proposals for new safety factors, and reviewing of safety factors.
INFO:	Information on winder design, winder drums, headsheaves, winding speeds,

	rope end loads, winder rope properties, rope lives achieved, etc.
MOTOR:	Winder motor fault torque and winder motor behaviour.
RCA:	The condition assessment of winder ropes, discard criteria, and rope conditions assessment instruments (magnetic rope testing instruments).
SINK:	Shaft sinking.
TERM:	Rope front-end terminations.
TRAIN:	Training manuals for incumbent rope inspectors.

In Appendix D, the summarised reports are listed per author in alphabetical order. In the case of more than one author, a report is listed for every one of the authors.

Lastly, the reports are listed under the different categories in Appendix E. The majority of the reports cover more than one category.

## 3 History

### 3.1 Shaft depths

Prospecting for gold in the old Zuid-Afrikaanse Republiek had been in progress for some time prior to April 1886, when the outcrop of the Main Reef Leader was discovered on the farm Langlaagte by George Harrison. By September that year, four shafts had been sunk; the deepest to 20 m. In January 1888, a shaft was sunk at Langlaagte Estates (where the outcrop had been discovered), which was expected to intersect the reef at approximately 90 m deep. In September 1894 the Robinson Deep Ltd was registered and two shafts then being sunk went on to intersect the Main Reef at 570 m and the South Reef at a depth of 730 m.

In 1939 there were fifty four vertical shafts in commission. During the years immediately following, shafts were sunk to depths approaching 2 000 m: Vlakfontein No. 1 shaft at 1 600 m deep, and South Deep Summer and Jack, 1 920 m deep.

Until recently, the deepest single lift winder was Hartebeestfontein Gold Mine No. 6 shaft at 2 490 m deep. Gold mining in South Africa is already done at around 4 000 m below surface, and utilises secondary and tertiary (underground) shafts to exploit the deep ore bodies.

At South Deep of Western Areas/Placer Dome, the Vent Shaft was sunk to 2 760 m and the sinking of the Main Shaft was very recently completed at 2 995 m below surface. Both these shafts were sunk from surface, which makes them the deepest shafts ever sunk "in one go". The permanent winders of the Main Shaft will have suspended rope lengths of just more than 3 000 m.

The rope load factors and code of practice that were used for the stage and kibble winders at South Deep were those developed as part of the research effort described in this report.

Within this year, the longest single lift wind in the world will be at Moab Khotsong of AngloGold. The maximum suspended rope length will be of the order of 3 100 m. The shaft, on which this winder will operate, was sunk in two stages because of changes to the originally planned layout of the mine.

The permanent winding operations at South Deep and Moab Khotsong will use the rope load factors of the new regulations that were developed through the described research, and will have to comply with the specifications of the codes of practice that were developed.

### 3.2 The old regulations

During the first half of the previous century, the regulations required a minimum (static) safety factor of 6 for winder ropes. Later a regulation was introduced that a rope should be discarded when its strength has reduced to 85% of the new rope strength. The 85% was eventually changed to 90%. Although the regulations allowed a rope to have a safety factor of 6, Kinghorn observed that very few winder installations actually operated close to this factor (ref. o1).

The South African regulations for the strength of drum winder ropes that were in use in the nineteen eighties were introduced in the nineteen fifties, but have been used before that time in cases where the authorities gave special dispensation. Those regulations were based largely on recommendations made by Vaughan in 1904 and 1917 (ref. o2 and ref. o3), Dolan and Jackson in 1939 (ref. o4) and Kinghorn in 1949 (ref. o1). However, the numerical values of the safety factors and the capacity factors that were adopted in the regulations were not those actually recommended by the mentioned researchers, and it is not clear how the official values of that time came into being.

The regulations introduced in the nineteen fifties for drum winder ropes operating on vertical shaft required:

Rope discard: *A winding rope, balance rope or tail rope shall not be used if the breaking force at any point is less than nine-tenths of the initial breaking force.*

Conveying persons and material; the greater of:

Capacity factor	= 10	at discard
Safety factor	= 5	at discard

Conveying of mineral (rock or ore); the greater of:

Capacity factor	= 9	at discard
Safety factor	= 4,5	at discard

The safety factor for conveying mineral only could be reduced by 5% if two or more ropes are used (i.e. a BMR winder). The minimum safety factor for a BMR winder was therefore 4,25 at discard.

### **3.3 The initial thrust of the research**

In April 1982, Laubscher of Gold Fields approached Fritz of the CSIR and requested a proposal for an investigation into the validity of the safety regulations for winding ropes, because: "It is considered that the present design procedures laid down by the Mines and Works Act and the regulations concerning the required rope strength on a winder are incorrect and based on unscientific principles."

It was also felt that the regulations of that time were severely restricting the maximum economic depths of single lift shafts and the payloads that could be raised in existing shallow shafts. It was felt that if more information was to be gleaned from research, the factors could be re-evaluated.

The proposal by Fritz (June 1982) included a historical background on South African (drum winder) safety regulations and details of the envisaged research project. The following was extracted from his proposal:

"Vaughan (1904) showed that shorter ropes are more severely loaded than long ropes by an analysis of kinetic shocks induced by instantaneous braking. In all the references studied the winding rope in a shallow shaft is accepted to be more highly stressed than the rope in a deeper shaft, although no experimental evidence for this theory could be found. If technically sound design principles are used to determine the required size of a winding rope, it follows that not only can the section of maximum deterioration in the rope be

predicted but also the expected service life. The service life of winding ropes, dimensioned according to the present statutory regulations, may vary from three months on some deep level Koepe winders to three and even ten years on some drum winders. This can be interpreted or be indicative of the fact that the present design procedures are based on technically unsound principles, otherwise a similar service life could be expected from all ropes on all winders."

Fritz proposed to carry out the required research in three phases as follows:

Phase 1: Determination of the damage distribution in winding ropes.

This phase would illustrate whether the hypotheses upon which the present regulations are based, do correctly predict the "hardest worked" section in the rope, or whether another hypothesis, such as accumulation of fatigue damage accumulation, is more successful in predicting the most severely stressed section of a headrope. It was proposed that ropes from three drum winders of different depths and ropes from one Koepe winder should be investigated.

Phase 2: Safety regulations in other countries.

The factors of safety specified in all the various countries in the world should be studied in depth. Should it be observed that safe winding be carried out in some countries at shallow depths with smaller capacity factors (or safety factors) as compared with South Africa, such a precedent could be used to motivate an interim reduction of statutory factors of safety for new winding installations.

Phase 3: Experimental determination of the in-service loads acting in winding ropes.

In order to motivate and formulate a permanent change in the regulations, this third phase of the project should be completed. The relationship between drum acceleration and deceleration under normal and emergency trip-out conditions as well the effect of loading of the skip on rope stresses will be determined. This investigation would shed more light on the generally accepted theory that the wire ropes on shallow winders are more highly stressed than the ropes in deep shafts.

During the following 18 months Gold Fields approached the other mining houses in South Africa as well as the Chamber of Mines Research Organisation (CoMRO) for assistance in funding a project on winder rope safety regulations.

### **3.4 Formation of the Steering Committee**

The CoMRO Steering Committee on Factors of Safety of Winder Ropes was formed towards the end of 1983 to guide the investigation into the validity of the safety regulations used at that time. The Steering Committee consisted of representatives from the six major South African gold producing mining houses and from CoMRO, and its first meeting was held in November 1983. The six mining houses were Anglo American Corporation (AAC), Anglovaal, Gencor, Gold Fields, JCI, and Rand Mines.

The objectives of the investigation to be covered by the Steering Committee, according to the minutes of the first meeting, were:

"... to examine the legally required factors of safety of winding ropes and to verify the validity, or otherwise, of the relevant design regulations. Depending upon the outcome of the investigation, approaches would be made to the Government Mining Engineer (GME) with a view to amending the present regulations on factors of safety of winder ropes."

The original proposal of the CSIR was tabled at this meeting. It was decided that the CSIR should revise their proposal and that other organisations (SDRC of the USA) should also be approached for proposals because it was felt that the CSIR's estimated 4 to 5 years for completion of the investigation would be too long.

During the first six months of 1984, the CSIR (Fritz), the assistant Government Mining Engineer (Raath) and the winder rope manufacturer, Haggie Rand (Wainwright, EJ), were invited to join the committee. In May 1984, the Steering Committee decided that the CSIR should act as the main co-ordinator of the whole investigation.

### **3.5 Original scope of the work proposed**

The CSIR tabled a revised proposal at a Steering Committee meeting in January 1984. The work envisaged for the revision of the regulations was divided into the following six phases:

1. A critical review of South African and foreign statutory factors of safety.
2. Experimental determination of the damage distribution in winding ropes.
3. Experimental determination of the dynamic loads in winding ropes.
4. Theoretical prediction of the dynamic loads in drum winding ropes.
5. A statistical analysis of the in-service performance of wire ropes.
6. Proposals for the revision (if warranted) of the South African statutory factors of safety.

In April 1984, Kuun (AAC representative on the Steering Committee) produced a report "Notes on design factors for winding ropes" (ref. r1). In the report, the investigations and papers that led to the then current rope load regulations (refs o2, o3 and o4), as well as the regulations themselves are reviewed critically. The following were amongst his recommendations:

"Due to its inherent inflexibility, the capacity factor approach should eventually be abandoned. A factor of safety that varies with depth provides the same safeguards and can easily be fitted to the requirements of the situation.

Selection of ropes on a fatigue basis is the ultimate solution but requires information on rope fatigue behaviour. Selective field trials and simulated service fatigue tests should be added to the programme of work initiated through the Chamber of Mines.

Improved utilisation of ropes requires more than just a review of the Regulations. Simultaneous and renewed attention must also be given to various aspects of the operating environment in order to: Eliminate corrosion of ropes, reduce dynamic loads imposed on the rope, improve sheave contact and drum coiling, and reduce accidental deformation of the rope. There is also a need for improved electromagnetic rope testing equipment and procedures, with immediate follow up of test indications in the field."

In the report, Kuun also proposed a rope load factor for drum winder ropes that decreases with depth. (Of interest is that the shape of the safety factor Kuun proposed was the one that was eventually accepted as the new factor for deep mine operations (the "formula")). Although Kuun gave a copy of his report to Fritz (CSIR), the report was not presented to the Steering Committee and therefore never discussed at that forum. The report is of importance, however, because it paved the way towards field trials at lower safety factors.

Kuun's document showed that the then current regulations were unnecessarily severe on shallow winders; and more restrictive than what was required in 1900. A safety factor that varies with depth (a fatigue approach) was propagated in place of the Capacity Factor. The selection of ropes on a fatigue basis was proposed as the ultimate solution but "required information on rope fatigue behaviour". It was also proposed that selective field trials and simulated service fatigue

tests be added to the programme of work of the Steering Committee. Kuun also wrote that attention should be given to the control of dynamic rope loads and the improvement of magnetic testing of ropes.

### **3.6 Initial direction of the investigation**

The scope of the investigations proposed by the CSIR in January 1984 was accepted by the Steering Committee. Parts 1, 2 and 5 were awarded to the CSIR, while Parts 3 and 4 were to be awarded to SDRC. The majority of the members of the Steering Committee felt that SDRC were better equipped and could carry out the work quicker and better than the CSIR. After much revision of the SDRC proposal, a contract was eventually awarded to them in June 1985.

Although the Steering Committee had decided on the projects to be carried out and the general direction of the total investigation, it did alter the course from time to time. Some of these policy decisions and other events that changed the course were:

- The statistical analysis

Initially it was agreed that the study should be conducted into drum winders and Koepe winders. It was quite early decided to exclude Koepe winders from the study "because of the specific nature of the rope problems associated with their operation." It was also thought that the true factor of safety was better known for Koepe winder ropes. It was also decided to concentrate on rock winders only in order to expedite the collection of data from winders and because a rock winder operated on a repetitive and (mostly) full load cycles.

- Rope load factors

From the chronicles, it also seems that the initial thrust was to revise or to get rid of the Capacity Factor for drum winder ropes. Eventually this receded and the thrust of the work actually shifted towards the Factor of Safety when the importance of deep level single lifts became more prominent.

- Rope fatigue studies

Kuun and most other members of the Steering Committee felt that rope "fatigue" studies should be undertaken both in the laboratory and in the field, but that it would not be possible to obtain useful fatigue data within the timescales envisaged for this project, and with the equipment available.

- What was expected from the statistical analysis

In the beginning both the Steering Committee and the CSIR (who eventually had to propose new rope load factors) had no idea of the philosophy behind and the numerical values of the regulations that they envisaged to propose to the GME. It was thought that rope life and the parameters affecting rope deterioration would emerge from the statistical analysis. It was believed that the statistical analysis would provide the numbers for the new regulations. The statistical analysis received a lot of criticism throughout until it was finally completed in February 1991.

- Rope condition assessment (magnetic non-destructive testing)

Non destructive testing of ropes was placed on the agenda of the Steering Committee (in July 1987) because this subject "would come under close scrutiny if safety factors were reduced." It was reasoned that particular attention would then be given to the instrumentation used for NDT and also to the kind of training provided for the operators.

The Steering Committee agreed that the need existed to optimise the procedures for selecting and training of the operators of NDT instruments, and for awarding a suitable certificate of competency for these operators. Members agreed strongly that a certificate of competency should be issued after a trainee had completed a training course and that only people with the certificate of competency should be allowed to act as NDT testers. Kuun (AAC) commented that the instrument requirements should not be over-emphasised since the quality of the tester was far more important than the quality of the instrument.

One of the mining houses did not support the certification of testers. Their reason was that there were certain differences between the groups on their approaches to NDT and therefore it would be difficult to agree upon a training programme and examination body.

In September 1987 it was recommended at a Steering Committee meeting that tensile tests be carried out on discarded ropes on those sections of ropes identified as being the worst according to the EM tests; the objective of this exercise would be to quantify the EM test results and a body of data would then gradually be built up. This would assist in determining why and how ropes deteriorated. Some of the members indicated that they had started collecting this data already. Although such test became very important in later years, the proposed project never got off the ground.

In November 1987 the CM&EE sub-committee decided there were valid arguments for formalising and standardising the training of rope inspectors, and in addition consideration should also be given to the subject of whether to issue a certificate. In February 1988, however, the CM&EE sub-committee accepted the then current situation that each group carried out its own EM-testing training and there was only limited support on that committee for the introduction of formalised and standardised training. The item "non-destructive testing" was removed from the agenda of the Steering Committee.

#### - General

At a Steering Committee working group meeting in January 1988, on possible new rope load factors to be proposed, it was decided that:

- ? The determination of factors of safety should be based on a reasonable life expectancy (life in terms of winding cycles and not time).
- ? In selecting the factor of safety, no differentiation should be made between man and rock winders.
- ? Rope discard criteria should be a reduction of 10% below new rope breaking force.

The Steering Committee tried to structure its work and investigations in such a way that the final recommendations would be acceptable to the GME (who was represented on the committee by the assistant-GME). Some of the statements and comments made by the assistant GME, which influenced decisions taken by the Steering Committee, are:

1984: The GME was in favour of retaining the 10% deterioration as the criterion for discarding a winder rope. Responsibility for the condition of a rope rested with the engineer at a mine, and a government inspectorate for rope condition monitoring would be undesirable.

1985: The GME said that any comparison between South African and foreign safety factors would not be very valid because it was not known how other countries derived their regulations concerning safety factors and at what factors they actually operate. Foreign regulations should therefore not be used to guide or influence any decisions on possible changes to South African safety factors.

1987: The GME said that the report (SDRC on dynamics) stated that dynamic loads were critical and that these needed to be thoroughly assessed before any conclusion could be

drawn. He felt the work was progressing in the right direction. He also stated that his department did not intend to apply direct control over the training and the issuing of the certificates of competency for rope EM testers. Nevertheless, it was clear that some thought would have to be given to the organisational structure in which the NDT tester worked. He commented that he did not expect his Department to make the certification of EM testers a statutory requirement. Moreover, he doubted that whether his department would be willing to accept responsibility for the certification of testers; instead, this should rather be performed by another body.

1988: Raath was appointed GME. Raath said that if Fritz (CSIR) approved recommendations for the new rope safety regulations, then his decision would be easy. He also indicated that he would not consider changes to the regulations if the motivation for such changes were based on the experience gained from a single winder installation only.

In December 1988, a discussions took place between Laubscher (Chairman of the Steering Committee) and Raath (GME). The GME said that the research and the line of thought for the new regulations were acceptable to him. He requested that special attention be given to the following:

- ? The wording of the regulations would need very serious thought as they would apply throughout the industry and their correct interpretation was essential.
- ? He would request persons outside the industry to review the proposed changes to the Regulations and it was agreed that Fritz would be a member of that group of persons.
- ? He required guidance in the application of different factors for mines that conduct EM testing. This application should not impose additional expertise requirements on his inspectors.

### **3.7 Completion of the initial phases of the investigation**

By September 1988, the following reports had been issued, which completed the first four phases of the proposed investigation:

- ? JTD Fritz: A critical review of South African and foreign factors of safety, specified for mine winding ropes (1985). CSIR, September 1985 (ref. r2).
- ? JTD Fritz: In-service damage accumulated by wire ropes operating on drum winders; Libanon Gold Mine, 1 658 m deep. CSIR, June 1986 (ref. r3).
- ? JTD Fritz: In-service damage accumulated by wire ropes operating on drum winders; Deelkraal Gold Mine, 2 062 m deep. CSIR, August 1986 (ref. r4).
- ? JTD Fritz: In-service damage accumulated by wire ropes operating on drum winders; Premier Diamond Mine, 600 m deep. CSIR, March 1987 (ref. r5).
- ? GFK Hecker: In-service damage accumulated by wire ropes operating on drum winders; Summary and Conclusions. CSIR, February 1988 (ref. r6).
- ? Gareth R Thomas: An investigation into the dynamic rope loads in drum winder systems. SDRC (USA) October 1987 (ref. r7).

The (originally planned) statistical analysis was also completed by the issuing of the following reports:

- ? R Hohendorf: Verified drum winder and discarded wire rope information for 99 rock winders. CSIR, June 1988 (ref. r8).
- ? TC Gilfillan: Report on the analysis of lifetimes of steel ropes in mining headgear. CSIR, August 1988 (ref. r9).
- ? Mike van Zyl: Review of the statistical analysis of the in-service performance of winder ropes. CSIR, September 1988 (ref. r10).

Apart from proposing new winder rope regulations, all the phases of the project, as originally

envisaged, had been completed.

### 3.8 What was found

Apart from analysing the historical background of how the rope load factors of that time came into being, Fritz<sup>2</sup> concluded that "the present South African regulations represent very nearly the upper limit of the range of factors of safety employed in other countries." Based on "rope fatigue principles" a "required shape" of the factor of safety with depth is finally derived in the report (although the only fatigue data available was for a limited number of non-spin ropes that operated on Koepe winders).

On the in-service damage accumulation in drum winder ropes it was concluded that a definite pattern of deterioration could not be established from the investigations carried out, apart from singular points of deterioration like the first layer crossover. The report further concluded that the rope section between the drum and the bank for a fully paid out rope could have significant deterioration, and should therefore be subjected to magnetic testing as well. The magnetic testing of the ropes established the worst deteriorated section of the ropes (greatest reduction in breaking strength). It was also concluded that if the pulling in of the back end of a rope is delayed, the rope could suffer accelerated deterioration at the layer crossovers and in the dead turns on the drum.

The objective of the statistical analysis of the in-service performance of winder ropes was to search for a model that would describe the lifetime of a rope as a function of various operating conditions. It was hoped that the statistical model would identify and quantify those variables that affect the service life of winder ropes.

A paper (ref. o1) was published in 1949 on the statistical selection of winder ropes. It is obvious from this paper that the lack of computing power and the inability to handle the "embarrassingly" large number of variables were serious drawbacks. As far as it could be established, apart from the paper mentioned, the statistical analysis project was the first time such an analysis was attempted anywhere in the world. The level of expertise and experience at the onset of the project was therefore very limited.

Although models were found that fitted the data well, the input data set was not well chosen and the data still contained some errors and irregularities. The models found were not good engineering models. It was concluded that, with the experience gained, a model could be found which would satisfy both statistical and engineering criteria. It was decided to continue with the statistical analysis by verifying the data again and selecting "better" input variables.

The analysis of rope loads carried out at that time was the start of a much better understanding of rope and winder dynamics. Through the measurement of winder rope loads the following points were established (these are at present considered common knowledge, of course):

- ? During normal winding operations, the largest rope loads are caused by emergency braking.
- ? The oscillations in winder rope-attached mass systems occur at the first natural frequency of the system. Oscillations at higher order frequencies are of no significance because of internal rope damping.
- ? The elastic modulus of a winding rope is rope load dependent.
- ? The rope loads generated by accelerating or decelerating a winder are not rope length dependent, but depend only on the total load suspended and the winder acceleration or deceleration.

It was obvious at this point that not enough information was obtained to propose changes to the regulations.

Another Anglo American report of interest (and importance) was produced by Kuun in May 1988:

? TC Kuun: Single lift shafts: Limits of winding rope application. AAC, May 1988 (ref. r11).

In the report Kuun argues that economically viable single lift shaft are limited to 2500 m to 3 000 m under the present regulations. The report shows how rope utilisation can be improved without reducing safety if the rope design factors are based on fatigue. The report shows the derivation of equations for a static factor that decreases with depth, and that would give a constant dynamic load range. It also says that the application of this approach requires reliable information on rope fatigue behaviour, and that existing information on the fatigue behaviour of drum winder ropes is "grossly inadequate". It further states that a full review of the regulations cannot be motivated on the basis of analytical considerations only, but that factual proof and an upgrading of rope surveillance should be essential features in such a review. Negotiating of field trials with lower safety factors, and establishment of a full scale rope fatigue testing facility in order to evaluate the effect of factors of safety and of the other variables on rope life were proposed as being urgent.

It is very interesting to note that the report<sup>r11</sup> was made available by Kuun to the researchers at the CSIR, but that it was never tabled at any Steering Committee meeting. It should be noted that the "formula" adopted in 1993 for the lower factors in the new regulations was effectively derived in Kuun's May 1988 document.<sup>r11</sup>

### **3.9 Second round of investigations**

The following projects were approved by the Steering Committee (for 1989):

- ? Continuation of the statistical analysis of the factors affecting the in-service rope lives.
- ? Dynamic rope load investigation to expand on the findings of the SDRC report and to clear up anomalies discovered in their report.
- ? An investigation into the rope loads generated after the occurrence of slack rope.

A large number of reports on rope dynamics by Anglo American Corporation and two from the Chamber of Mines research organisation are also discussed in.

During 1988, the Steering Committee also initialised a project to study the feasibility of the development of a winder rope fatigue testing facility that would simulate actual winding conditions (as originally proposed by Kuun<sup>r11</sup>). Field trials on actual winders at lower safety factors could be conducted, but these were considered to be very expensive, time consuming, and unexpected rope failures would be disastrous. After proposals from various sources were received, the Steering Committee awarded a contract to Chaplin (Reading University, UK) in September 1988.

#### **3.9.1 Deterioration mechanisms and feasibility study**

Chaplin's study into the feasibility for establishing a testing facility would have comprised of the following three phases:

- ? Collection and evaluation of information and specifications of test parameters.
- ? Development and specification of the test methodology.
- ? Schematic design of the test facility.

After an initial report was submitted by Chaplin, the Steering Committee decided that it would be wise to first analyse the deterioration mechanisms of drum winder ropes. It was reasoned that if these were known, it would be easier to determine whether a particular winding rope testing facility would be able to reproduce the mechanisms (simulation vs. duplication). Prof. Chaplin was therefore requested to shift the emphasis of his project to the determination of the main

deterioration mechanisms of drum winder ropes. The following reports were produced by Chaplin:

- ? Feasibility study - interim report. February 1989 (ref. r12).
- ? Drum winder rope deterioration study - summary report. August 1989 (ref. r13).
- ? Drum winder rope deterioration study: simulation and backslip. March 1990 (ref. r14)
- ? Drum winder rope deterioration study - draft final report. April 1990 (ref. r15).
- ? Backslip: a re-evaluation. July 1990 (ref. r16).

A complete overview and summary of Chaplin's work are found in two papers published by him:

- ? Hoisting ropes for drum winders - mechanics of degradation. 1994 (ref. r17).
- ? Failure mechanisms in wire ropes. 1995 (ref. r18).

Chaplin also instigated some bending-tension fatigue tests that were carried out at NEL (Glasgow):

- ? The bending-tension fatigue testing of four 40 mm diameter steel wire ropes. September 1991 (ref. r19).

The conclusions of Chaplin's work on the deterioration mechanisms of drum winder ropes were:

"There are two major mechanisms of degradation in triangular strand ropes operating on multi-layer drum winders: plastic wear of outer wires and fatigue.

The primary cause of plastic wear is backslip (or creep) of the rope on the drum as the empty conveyance is lowered. The classical analysis of backslip indicates that wear rate would be expected to be a function of tension range alone, but the very high stresses between wires in adjacent layers of rope on the drum give a considerable weight to this parameter. The effect of the plastic wear is to render the wire more susceptible to the initiation of fatigue cracks.

The major fatigue loading component is due to the payload, but with significant enhancement from dynamic factors, especially during acceleration and braking."

Very early in his investigation, Chaplin introduced the concept of "backslip" as the main deterioration mechanism of ropes operating on drum winders. Backslip and frictional work were included as variables in the continuation of the statistical analysis of drum winder ropes.

In March 1990, when most of Chaplin's thoughts on deterioration mechanisms were known, the Steering Committee awarded a contract to the CSIR to investigate the feasibility of designing the drum winder fatigue testing facility.

### **3.9.2 Continuation of the statistical analysis of rope lives**

After the data for the statistical analysis was thoroughly checked again, the model searches were carried out and three reports were produced on behalf of the CSIR by Mike van Zyl.

- ? Information on 99 drum winders and 711 discarded winder ropes. May 1990 (ref. r20).
- ? Relationships and trends of drum winder parameters. November 1990 (ref. r21).
- ? A life prediction model for drum winder ropes. February 1991 (ref. r22).

Although the data in the "information" report were originally collected purely to serve as input for the statistical analysis, the report is a unique collection on, and a reference document for the design of drum winders.

All the parameters and variables used in the statistical model searches are discussed in the "relationships and trends" report. The complexity of the statistical analysis is highlighted in the "relationships" report, because the graphs of winder and derived variables versus cycles to discard for the ropes do not show any direct or straightforward relationships.

The "life prediction" report describes the selection of a model from various models generated by the statistical analysis process. While the "relationships and trends" report showed no significant relationships between the variables used in the statistical analysis and rope life, the statistical model finally selected predicted rope life quite accurately (of the winders in the "information" report).

It was also stated in the "rope life report" that the deterioration mechanisms of drum winder ropes were not yet fully understood and the predicted influence of some of the variables of the model could be contested. The complex way in which the winder and rope parameters interact with the variables of the model created difficulties in isolating their discrete influences. A model with good rope life predictive qualities had been generated, but it is stated that the model should be used with caution, because the influence of some parameters rope life was not fully understood.

The importance of drum winder rope deterioration mechanisms and rope discard criteria were highlighted by the execution of the statistical analysis.

The final result of the statistical analysis was not quite what was expected (or as originally anticipated). This was most probably because deterioration mechanisms of drum winder ropes were not yet understood, and that the input variables for the statistical analysis were therefore not the best selection. Another factors that influence rope lives, and that could not be determined (quantified) for the analysis were rope maintenance (rope lubrication, pulling in of back-ends), and the coiling arrangement on the winder drums (contact stresses: see the GAP501 report, ref. r102).

### **3.9.3 Dynamic rope loads**

The Steering Committee requested further work to clear up some anomalies discovered in the SDRC report (ref. r7). The rope load calculations were done using a computer program developed by SDRC. Three draft reports that were produced were eventually consolidated into one report. The reports were:

- ? Influence of depth on emergency braking; CSIR, February 1989.
- ? Influence of drum acceleration during normal hoisting; CSIR, June 1989.
- ? Rope forces generated by loading the skip; CSIR, June 1989.
  
- ? Mike van Zyl: Drum winder rope forces generated during emergency braking, normal acceleration and skip loading. CSIR, April 1991 (ref. r23).

The mentioned anomalies were cleared up, and the main finding of the reports was (as before) that the ratio of dynamic to static rope forces during emergency braking under instantaneously applied constant decelerations is only dependent on the magnitude of the deceleration and is insensitive to depth or the ratio of the attached mass to the total suspended mass. Vaughan's "critical depth", which was used as a basis for the capacity factor part of the then current regulations, therefore does not exist.

Uncertainties regarding the ability of a numerical method (program ROPE of SDRC) to calculate the rope loads generated after the occurrence of slack rope correctly resulted in a further investigation. An analytical method had to be developed with which slack rope cases could be investigated:

- ? Mike van Zyl: Drum winder rope forces generated by the occurrence of slack rope - a mathematical method. CSIR, September 1991 (ref. r24).

The results of the investigation showed that the severity of slack rope would increase if the values of the Capacity Factor and Safety Factor were reduced.

During this time the Mechanical Engineering Department of Anglo American Corporation also sponsored and produced various reports on rope dynamics. These reports were made available to the Steering Committee and were:

- ? ME Greenway: Dynamic rope loads in winding systems - an analytical approach. February 1989 (ref. r25).
- ? RS Hamilton: Dynamic response of freely suspended skips during ore loading. November 1989 (ref. r26).
- ? RS Hamilton: The use of clamping devices to control the dynamic response of skips during ore loading. February 1990 (ref. r27).
- ? ME Greenway: Dynamic rope loads due to cage loading. June 1990 (ref. r28).
- ? ME Greenway: A simple static and dynamic analysis of coupled extensional-torsional behaviour of winding rope. November 1990 (ref. r29).
- ? ME Greenway: Dynamic rope loads developed in response to instantaneous winder braking. June 1991 (ref. r30).
- ? RS Hamilton and ME Greenway: A finite element study of the coupled extensional-torsional behaviour of winding rope. October 1991 (ref. r31).

Two more reports on the rope dynamics of conveyance friction clamp release were produced by the Chamber of Mines Research Organisation (CoMRO):

- ? A D'Arcy-Evans and RA Backeberg: Dynamic response of conveyances during friction clamp release. June 1992 (ref. r32).
- ? A D'Arcy-Evans and RA Backeberg: Non-dimensional dynamic response of conveyances during friction clamp release. February 1993 (ref. r33).

Details of the above reports and the findings are given in Appendix C. Generally the findings of the reports were in line with those of the earlier mentioned reports on winder dynamics. The report on ore loading showed that the effect of rock loaded from some height above the skip has to be considered. The investigations on the coupled extensional-torsional behaviour showed that the torsional characteristics do not influence the calculation of (tensile) rope loads.

The various reports on clamping devices showed that such devices eliminate the effects of rope stretch during conveyance loading, and the rope dynamics after clamp release can be reduced by controlling the rate at which the clamping force is released. However, the effect of rope dynamics after clamp release is generally overstated, especially in relation to fatigue in the wires of the rope. Rope dynamics due to clamping device release do not have to be any less severe than the dynamics generated by normal winder acceleration. Rope dynamics during normal winder operations will only have an influence on rope life in very deep shafts. The rope load ranges in deep shafts are large enough to cause tension-tension fatigue breaks in the rope wires.

### **3.10 Elandsrand rope trial and more rope deterioration**

The rock-vent shaft at Elandsrand Gold Mine was used exclusively for rock winding. This shaft was therefore considered safe for field trials at lower safety factors. Kuun (AAC) obtained permission from the authorities and from the mine to operate the ropes at a static safety factor of 4,0 (at installation). This was quite a bit lower than the 4,5 (at discard) allowed by the regulations of that time. The headsheaves, drum coiling sleeves and doubling down sheaves had to be

changed, rope load monitoring systems had to be installed, and two new ropes had to be purchased. Funding for these items (around R1 million at that time) was provided by the industry through the Chamber of Mines. The mine agreed to refund the Chamber for the ropes depending on the rope life obtained.

The safety factor was changed from 4,8 to 4,0 by lowering the tensile grade of the ropes from 1 950 MPa to 1 800 MPa, and by reducing the rope diameter from 52 mm to 48 mm. New coiling sleeves and headsheaves had to be installed because of the rope diameter reduction. The responsibility for the field trial rested with AAC, and they provided the required manpower. The field trial at Elandsrand commenced in September 1989.

The Elandsrand field trial, together with earlier work by Chaplin, spawned numerous projects related to the behaviour of ropes on drum winders, the in-service damage accumulated by drum winder ropes, and the deterioration mechanisms of ropes operating on drum winders.

At the request of the Steering Committee, the last set of 52 mm diameter ropes that were discarded from the Elandsrand winder before the field trial commenced were investigated as before. The reason for the investigation was to enable a direct comparison between this rope set and the ropes that would be operating at the lower factor of safety:

- ? M Borello: Fifth report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep. CSIR, September 1990 (ref. r34).

The report showed that the ropes were still in very good condition after 27 months in service, and that neither of the ropes had any singular points of (greater) deterioration. The report does not make mention of the reason why the ropes were discarded other than "policy". Considering the good condition of the ropes, it has to be concluded that the ropes were simply removed so that the lower factor of safety ropes could be installed. Although the ropes were not at the end of their service lives, they were tested very thoroughly. The tests also included tensile modulus tests and torque-tension tests as a start to collecting data of the in-service properties of triangular strand ropes.

The CSIR initiated and funded a tribological study into the wear mechanisms of ropes operating on drum winders. Samples from one of the 52 mm ropes removed from the Elandsrand winder were examined. The investigation was a "first attempt" at describing the observed wear and plastic deformation of the outer rope surfaces of a drum winder rope. The report on the investigation shows numerous interesting photographs of the rope, strands and wires (macroscopic, microscopic, and SEM):

- ? GJ Wright, JJ Pretorius and IL Maarseveen: An assessment of the wear mechanisms of wire ropes removed from the rock winder at Elandsrand Gold Mine. CSIR, October 1990 (ref. r35).

Following the report describing the observed wear<sup>r35</sup>, the CSIR funded a project to investigate the mathematical modelling the wear processes of drum winder ropes. The report on the investigation describes the wear of a rope in terms of adhesion, abrasion and plastic deformation. Although this was an initial investigation, the report concludes that "abrasive and adhesive wear (from "backslip") plays a relatively minor role in relation to plastic deformation" (as a result of multi-layer coiling on a drum).

- ? RA Hunziker and JJ Pretorius: A mathematical model of wear mechanisms in a mine hoisting rope. CSIR, March 1991 (ref. r36).

The first set of 48 mm ropes that operated at a safety factor of 4 at Elandsrand remained in service for 16 months, and was discarded in January 1991. Three reports were produced after this first set of ropes was discarded.

- ? TC Kuun, WP van der Walt and SJ Mostert: Condition assessment of winding ropes operating at a factor of safety of four. AAC, March 1991 (ref. r37).
- ? M Borello: Sixth report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep. CSIR, April 1991 (ref. r38).
- ? RA Hunziker, JJ Pretorius and IL Maarseveen: An assessment of the wear mechanisms of the 48 mm ropes removed from the Siemens double drum rock winder at the Elandsrand Gold Mine in January 1991. CSIR, March 1991 (ref. r39).

The Kuun et al report concluded that "the field trials at Elandsrand indicated that mine winding rope operating at a nominal factor of safety of 4,0 deteriorate in the normal way. Present discard criteria and condition assessment techniques are adequate at these load levels." The other two reports were repeats of earlier investigations (refs 34 and 45).

The tribological approach to the degradation of drum winder ropes was written up for the Steering Committee in a stand-alone report:

- ? RA Hunziker, JJ Pretorius and Mike van Zyl: Wear mechanisms of drum winder ropes. CSIR, June 1992. (ref. r40).

The report on the investigation into the feasibility of designing a drum winder rope fatigue testing facility was also eventually completed. The report includes continuous measurements of rope tensions and rope torques that were carried out in December 1990 while the first set of 48 mm ropes operated on the Elandsrand winder. The feasibility study on a drum winder rope test facility addresses the issues of rope behaviour on drum winders, the ability to duplicate winder behaviour on a test facility, and the estimated cost to build and operate such a facility.

- ? GFK Hecker and Mike van Zyl: Drum winder rope test facility: A feasibility study. CSIR, January 1993 (ref. 41).

As a continuation of the field trials at Elandsrand, AAC planned to reduce the safety factor of the ropes even further: from 4,0 to 3,5 by changing the rope diameter from 48 mm to 43 mm. While waiting for the final preparations to be completed for this next phase of the field trial, the 48 mm ropes in operation (the second set that operated at a safety factor of 4) reached the end of their service lives. The ropes were in service for just more than two years, and completed 78 000 winding cycles. This was more cycles than any of the previous sets of ropes used on the winder. After discard the ropes were tested in the same way as the previous two sets:

- ? M Borello: Seventh report on the in-service damage accumulated by wire ropes operating on drum winders (Elandsrand Gold Mine, 2204 m deep). CSIR, September 1993 (ref. 42).

The above was the last of the very exhaustive type of tests carried out on discarded ropes.

### **3.11 Towards new winder rope regulations**

A working group to guide the drawing up of new regulations was formed in the beginning of 1988. The members of the working group were from the Steering Committee. The first report for this working group was produced in September 1989, and the last one in November 1992.

All the reports written towards the new winder rope regulations are summarised in detail in the report summary section (Appendix C). It may not make much sense to the reader if the events and decisions regarding the different reports are not describes as well, and these are therefore given both here in the main section of the report and in Appendix C. For some of the reports, the Steering Committee asked for the opinions of other parties (especially that of Chaplin of Reading University). Such comments were reproduced where applicable.

### 3.11.1 Initial reports

A working document (Pro-forma 1) and its revision (Pro-forma 2) were produced to lay down the basic concepts for the recommendations to the authorities for new safety regulations for drum winder ropes.

- ? Mike van Zyl, GFK Hecker and JTD Fritz: Factors of safety of winder ropes; recommendations towards new regulations for drum winders; notes for discussion. CSIR, September 1989 (ref. r43).
- ? Mike van Zyl: Factors of safety of winder ropes; recommendations towards new regulations for drum winders; notes for discussion. CSIR, October 1989 (ref. r44).

It was proposed to limit the maximum rope loads generated during winding and to limit the static load range. Chaplin also agreed with the concept of the proposed factors, but suggested that the actual (dynamic) load range be used instead of the static value.

March 1990: Some members on the working group were of the opinion that some dispensation should be provided for EM-testing, while others did not agree that EM testing should be included in the new regulations. A suggestion was made that this particular clause (in the pro-forma recommendations) be removed so that the work on the recommendations could continue, allowing the uncertainty regarding the EM testing to be clarified at a later stage. An industry working group (outside CoMRO) was formed to study rope condition assessment.

### 3.11.2 More information

In June 1990 Anglo American Corporation produced a report which reviewed the depth and hoisting capacity limits of conventional winding in very deep single lift shafts, and with the rope regulations of the day.

- ? ME Greenway: An engineering evaluation of the limits to hoisting from great depth. AAC, June 1990 (ref. 45).

In the end the report ranks "the parameters that influence depth of wind and hoisting capacity from those that have most impact to those that have least", with the most influential one being rope safety factors.

### 3.11.3 Proposing regulations

In August 1990 the Steering Committee decided to base the new drum winder rope regulations on the limits of the then current knowledge of dynamic peak loads and dynamic load ranges. As a second phase, the regulations would be revised again in future once further knowledge and understanding on the remaining strength of ropes have been gained (assessing the condition of the rope accurately).

In September 1990, Pro-forma 3 was tabled:

- ? GFK Hecker: Pro-forma 3: Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. CSIR, September 1990 (ref. 46).

Pro-forma 3 suggested that the "old" regulations (as for rock winding) be retained and that the new dynamic factors be added to the regulations. This would have catered for (existing) winders without load measuring devices. A 10% allowable deterioration was to be retained, and a dynamic factor and a dynamic load range were to be added. It was stated that a detailed investigation into the actual dynamic rope loads was required before a final dynamic factor of

safety could be recommended. A more detailed investigation was also suggested for the dynamic load ranges in order to recommend a value for the allowable load range.

After these recommendations were discussed at working group meetings, the industry members rejected the proposals on the basis that it would be too difficult to measure the actual rope forces and requested the CSIR to recommend static factors that would ensure that the dynamic factors were kept within limits. The working group also gave consideration to a code of practice for EM-testing, and additions to the regulations that would allow some dispensation for winders where EM-testing was performed.

Note of interest: The current codes of practice for permanent winding installations and for sinking winders (that operate at the new lower rope factors) require the "actual rope forces" to be measured. Rope load monitoring is already done successfully at a number of winding installations.

Much turmoil followed the decision by industry that rope load measurement would be "too difficult". Throughout the following two years, Hecker (CSIR) tried various ways specifying static factors to curb rope dynamics. Although he informed the Steering Committee on numerous occasions that that it was not possible to attain a dynamic factor of safety without specifying one, the situation remained much the same. The reports that were produced during that period showed various attempts at the unattainable. Details of all these reports are given in Appendix C:

- ? GFK Hecker: Pro-forma 4; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. CSIR, January 1991 (ref. 47).
- ? GFK Hecker: Pro-forma 5; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. CSIR, April 1991 (ref. 48).
- ? GFK Hecker: Proposed changes to rope safety regulations (draft). CSIR, January 1992 (ref. 49).
- ? GFK Hecker: Proposed changes to rope safety regulations (2nd draft). CSIR, March 1992 (ref. 50).
- ? GFK Hecker: Rope forces during dynamic brake tests. CSIR, July 1992 (ref. 51).
- ? GFK Hecker: Proposed changes to rope safety regulations (final draft). CSIR, August 1992 (ref. 52).
- ? GFK Hecker: Proposed changes to rope safety regulations (for consideration by the CM&EE sub-committee). CSIR, September 1992 (ref. 53).

The regulations that were finally proposed<sup>53</sup> were based on the levels of operation of that time, with dispensation allowed for rope condition assessment (RCA), and further dispensation allowed for controlled dynamic rope loads. In summary the proposals were:

Payload factor = 14  
Capacity factor = 7  
Static factor = 5

Dynamic factor = 3

For the dynamic factor, a winder installation had to show that the peak conveyance acceleration under trip-out conditions was within prescribed limits. A grandfather clause was included that would allow the continued operation of all existing systems.

Using an accepted or approved Code of Practice for rope condition assessment would give a 5% reduction in the above factors except for the Capacity Factor.

A new and different set of regulations ("phase 2") was envisaged for the future where winder installations have to conform to a winder code of practice. The dynamic factors suggested were 2,5 for RCA and 2,8 for all other installations.

At this stage the load range investigation<sup>r54</sup> was still under way, and the proposed payload factor was therefore not yet finalised. After the "load range" investigation was completed, the recommendation of a "payload factor" of 14 was amended to 12,5.

? Mike van Zyl: Load ranges experienced by drum winder ropes. CSIR, November 1992 (ref. 54).

At this point, the "phase 1" investigation of the CSIR into new rope factors for the regulations was actually concluded. The anticipated "phase 2", with the "winder code of practice", would have required rope dynamics to be controlled and/or measured, and would have effectively allowed lower static rope factors than that of "phase 1".

### **3.12 Code of practice for rope condition assessment**

It was mentioned earlier that an industry working group was formed to further the study of rope condition assessment. Certain of the Steering Committee members expressed a desire that some dispensation should be allowed for the rope factors of winders of mines that do proper EM testing of their ropes.

Because the CSIR was part of this working group, it initiated and funded the following project in order to develop expertise on the subject of non-destructive testing of winder ropes within the CSIR:

? C O'Conner: Non-destructive testing of wire rope in the RSA. CSIR, November 1990 (ref. r55).

The report presented the results of a survey conducted into the equipment and personnel involved in electromagnetic (EM) non-destructive testing of wire ropes in the mining industry in South Africa, and a comparison between the current status of EM testing in South Africa and international trends.

In the beginning of 1991, rope condition assessment (RCA) was put back on the agenda of the Steering Committee in order to produce a code of practice which would be used to obtain further reductions on the new (proposed) rope load factors. The CM&EE sub-committee decided to place RCA under the control of the Steering Committee so that information (and rope discard criteria) of the various mining houses could be shared for the purposes of the envisaged code of practice.

In 1991, the GME also said that he would not consider allowing lower winding rope installation factors if the person doing the rope inspection was not accredited.

Anglo American Corporation tabled their discard criteria at a Steering Committee meeting in August 1991. The discard criteria finally adopted in SABS0293 (Condition assessment of steel wire ropes on mine winders) were virtually the same as those proposed in this document:

? T C Kuun: Condition assessment of winding ropes; discard criteria for 6/F triangular strand ropes. AAC, July 1991 (ref. 56).

Using the Kuun document<sup>r56</sup> as a start, the CSIR had to produce the Code of Practice with the help of an industry working group. By May 1992 a draft of the code of practice was issued for comment. This draft code of practice contained nearly all the items and elements of the final version of SABS0293 (issued in 1996).

? Code of practice for rope condition assessment (2nd draft). CSIR, May 1992 (ref. 57).

Because rope inspectors had to be "accredited" in future, a number of training modules were planned and prepared for this purpose. The initial titles were: Wire rope technology; magnetic testing of ropes; legal knowledge; and rope destructive testing. Funding was provided for the rope technology and destructive testing modules. (These two modules were eventually included in SIMRAC report GAP054, together with five other training modules.)

Although the "code of practice" was being developed at that time, the discard criteria (of AAC) were not totally acceptable to the Genmin and Gold Fields. It was therefore decided that an "abridged code of practice" would be written for each of the winding houses, each with its own discard criteria. They would then each use their own "codes" until agreement could be reached. (This actually never happened because of eventualities during the first part of 1993.)

### **3.13 Rope terminations**

It was after a splice of a rope on a drum winder failed that the GME requested mines to submit splices for tensile testing. This was the beginning of the investigations on winder rope terminations sponsored and carried out by the CSIR.

After the report on the results of the tensile tests on the submitted splices, the CSIR funded a comprehensive investigation into the strength of rope splices in 1991. The report was issued in 1992 and distributed to the members of the Steering Committee.

- ? M Borello: A survey of results of tests on rope terminations. CSIR, May 1991 (ref. 58).
- ? M Borello: A comprehensive study of the factors affecting splice efficiencies. CSIR, April 1992 (ref. 59).

The Steering Committee then requested further research in this area to establish the performance of other types of terminations, and to identify safe rope terminations that were less dependent on artisan skill (compared to splices). Consequently an industry funded laboratory investigation was carried out to determine the fatigue and tensile strength of resin socketed terminations. The first report on this investigation was issued at the end of 1992.

- ? M Borello: Laboratory axial fatigue tests of resin cappings for use as winder rope terminations. CSIR, December 1992 (ref. 60).

The results of the test on these resin cappings were so good (all terminations remained stronger than the rope) that the industry requested further laboratory test before commencing with any field trials. The investigations were continued with SIMRAC funding.

### **3.14 A new direction**

Not only did the political climate in South Africa change in 1992, but several other events led to drastic changes in the direction and contents of ropes research carried out, and the proposals for new rope load regulations.

Funding for the most of the research described so far in this report was provided by the mining houses through CoMRO, the research arm of the Chamber of Mines. It was decided by the Chamber of Mines that CoMRO would be merged into the CSIR in March 1993, to become the Division of Mining Technology (Miningtek).

Legislation promulgated in 1992 provided for the mines to be levied based on safety risk to "refund research and surveys for the promotion of industrial safety and health." Funds so obtained were to be administered through the Safety in Mines Research Advisory Committee (SIMRAC). To a certain degree, SIMRAC funding replaced CoMRO funding, but only for "health

and safety" research approved by SIMRAC.

CoMRO/Miningtek secured a three-year SIMRAC contract (GAP054 for 1993, '94 and '95) to continue with winder ropes related research that was deemed essential at the end of 1992. Funding was obtained for:

- ? Verification and calibration of the discard criteria used for the rope condition assessment code of practice.
- ? Rope terminations.
- ? Development of a code of practice for the performance and maintenance of rope winding systems. This is the code that was envisaged in the proposed regulations as a "phase 2 reduction of the factors". Recommendations for further changes in rope safety regulations were part of the original work plan.

Apart from the anticipated political changes in South Africa, it was anticipated then that government policy towards the mining industry might also come under scrutiny in the not-so-distant future.

Section 3.11.3 on "proposing new regulations" showed that it was difficult to establish consensus amongst the representatives from the different mining houses, while at the same time maintaining general guidelines set out from time to time by the GME. Towards the end of 1992 some of the mining houses also indicated that they were likely to reject the CSIR proposals<sup>r53</sup> if a static (installation) safety factor of "5" instead of "4,5" was to be proposed. The Steering Committee therefore instructed the CSIR to expand the dynamic factor analysis so that the proposed static factors could be re-evaluated.

However, during these times of relative uncertainty and uncompromising attitudes, Anglo American Corporation decided to pre-empt the situation and approached the deputy GME with a set of proposed regulations for consideration.

The then deputy Government Mining Engineer (Burger) delivered a paper titled "Safety philosophy and statutory requirements for the operation of winding plants" on 17 March 1993 at the seminar "Recent developments in the mining industry in the testing monitoring and design of mine shaft and winder related systems". In his address, Burger, amongst other things, mentioned the following probable changes to the regulations:

- ? The strength of a winding rope, balance rope or tail rope shall be assessed in accordance with an accepted code of practice.
- ? A capacity factor at installation of 9 and a factor of safety at installation of 4,5 for both rock and men for drum winders.
- ? Provided that a mine complies with an approved code of practice for operating the winding plant, the factor of safety shall have a value of no less than  $25\ 000/(4\ 000 + L)$ , where  $L$  is the maximum length of suspended rope in metres.

Subsequently, at a Steering Committee meeting, Burger informed the meeting that the policy, based on the earlier directives given by the GME, had changed. He also indicated that the "code of practice" for rope condition assessment would include magnetic testing of the ropes. Magnetic testing of ropes would therefore become mandatory for all winding ropes. The proposals by Burger therefore were:

RCA will be mandatory and the following installation factors will be required:

Capacity Factor = 9,0  
Safety Factor = 4,5

If the winder conforms to an approved code of practice for winder operation (the contents

of which was not specified), then:

$$\text{Safety Factor} = 25\,000 / (4\,000 + L) \quad L = \text{suspended rope length in metres}$$

Note: The static factor "formula" above is a special case of the derivations given in the Kuun document of May 1988 (ref. r11). The formula would ensure that the (dynamic) load range of a rope is limited to 15% of the (new) rope breaking strength if the accelerations and decelerations of the winder during normal winding do not exceed 1 m/s<sup>2</sup>, the rope has a tensile grade of not more than 2 000 MPa, and if the payload is not greater than 70% of the total attached mass.

After the proposals by Burger and those of the CSIR were compared and discussed by the Steering Committee's working group, the following decisions and course of action was eventually endorsed:

- ? It was accepted that rope condition assessment in accordance with a code of practice would become compulsory. One code of practice would therefore be required (and it would be applicable to all winding ropes). The code that had been drawn up (initially) only considered triangular strand ropes.
- ? For compulsory rope condition assessment, the capacity factor and safety factor as proposed by the GME in essence did not differ by much from factors proposed earlier by the CSIR. The GME's factors were acceptable to the industry and should therefore be pursued.
- ? The original thrust of the research was to investigate reducing the capacity factor. The proposals from the GME only provided for future deep shafts. Enough evidence was available to propose a capacity factor of 8 instead of 9.
- ? The proposed "formula" required a code of practice to be drawn up. A "bottom limit" to the proposed formula for deep mines would be included in the code of practice, and would be a dynamic safety factor of 2,5 (maximum rope load of 40% of the new rope breaking strength).
- ? The CSIR would produce a new report motivating the final proposals, which were:

RCA will be mandatory and the following installation factors will be required:

$$\begin{aligned} \text{Capacity Factor} &= 8,0 \\ \text{Safety Factor} &= 4,5 \end{aligned}$$

If the winder conforms to an approved code of practice for winder operation (the contents still to be determined), then:

$$\text{Safety Factor} = 25\,000 / (4\,000 + L) \quad L = \text{suspended rope length in metres}$$

A dynamic safety factor of 2,5 would also apply.

In June 1993, the CSIR issued a report that substantiated the proposed new drum winder rope regulations

- ? GFK Hecker: Motivation for proposed changes to Chapter 16 of the minerals act: Rope safety regulations for drum winders. CSIR, June 1993 (ref. 61).

The amendments to the regulations that were proposed in the report was accepted by the industry and the GME, but the code of practice for rope condition assessment and the "winder code of practice" still had to be produced. The greater part of the original scope of the GAP054 project was therefore still appropriate, and the research that would be required specifically in drawing up the codes of practice could therefore be funded through GAP054.

The South African Bureau of Standards (SABS) established a technical committee that would be responsible for the two codes of practice. The scope of this committee (TC 801.19 Wire Ropes) was: "Standardisation in the field of design, operation and maintenance of mine winding systems

to promote the safe use of winding ropes, including the standardisation of the examinations and discarding criteria of wire rope." This technical committee already had its first meeting in June 1993. Two working groups were established by the committee to draw up the required codes of practice.

After these events the CM&EE Sub-Committee, at a request from the Chamber of Mines Research Advisor, disbanded the Safety of Winder Ropes Steering Committee. Future ropes related research, sponsored through SIMRAC, would be reviewed by an Engineering Advisory Group (EAG) reporting to the SIMRAC Gold & Platinum Sub-Committee (SIMGAP). The EAG held its first meeting in September 1993.

## **3.15 The SIMRAC era**

Rope safety investigations sponsored through SIMRAC and covered in this summary report are GAP054 (1993, '94, '95), GAP324 (1996), GAP418 and GAP439 (1997), and GAP501, GAP502 and GAP503 (1998). The last report was produced at the end of 2000 (GAP 501), which is also the last of the reports covered in this summary document. This summary document was, of course, also funded through SIMRAC.

### **3.15.1 GAP054: The safe use of mine winding ropes**

The SIMGAP Engineering Advisory Group changed the title of the GAP054 project to "The safe use of mine winding ropes" and added some new parts to the scope of the work during the time that the project was carried out.

The final report on GAP054 actually consists of 30 individual reports, and covers more than 1 500 pages. The different reports of GAP054 are discussed separately in Appendix C. Volume 1 of the report is an "Executive summary" with the rest of the reports divided into a further six volumes. Apart from listing all the reports contained in GAP054, Volume 1 also discusses the scope and findings of all the different individual projects that were undertaken. For most readers the information contained in this "executive summary" will be of sufficient detail as opposed to studying the specific individual reports.

? GFK Hecker: GAP054: The safe use of mine winding ropes; Volume 1: Executive summary. CSIR, April 1996 (ref. 62).

#### **3.15.1.1 Recommendations for changes in rope safety factors**

A report mentioned earlier, and produced by the CSIR in June 1993, "Motivation for proposed changes to Chapter 16 of the minerals act: rope safety regulations for drum winders" (ref. 61) was started as part of a Steering Committee project and finalised with SIMRAC funding. It was therefore included in the GAP054 report (Volume 2). This is the report that substantiated the proposed new drum winder rope regulations.

#### **3.15.1.2 Winder code of practice: SABS0294**

The term "winder code of practice" is a shorter name for the "Code of practice for the performance, operation, testing and maintenance of drum winders relating to rope safety". This code of practice was eventually issued by the South African Bureau of Standards as SABS0294. The working group that drafted the winder code of practice identified its scope of work on the basis that safe winding was mainly dependent on the effective condition assessment of the rope. A code of practice for drum winders was nevertheless required that would prevent abnormal and accidental rope deterioration. The working group proceeded to draft a code of practice that would fulfil the following requirements:

- ? The rate of rope deterioration should be limited so that excessive deterioration could not occur from one rope inspection to the next.
- ? The peak dynamic loads acting in the rope should not cause permanent damage to the rope.
- ? No foreseeable condition should lead to failure of the rope.

Although quite a few investigations on the mechanisms of rope deterioration had been carried out previously, and although the deterioration mechanism of drum winder ropes had been identified in general, attempts at quantifying the mechanisms had not been successful to date. The contents of the winder code of practice therefore were largely based on "current best practices" employed at drum winder installations (e.g. ratio between rope diameter and drum and headsheave diameters). However, some investigations on (dynamic) rope loads that could be generated on a winder were still required in order to include proper prescriptions in the code.

For the code of practice, it was decided that the rope loads that could be generated during controlled emergency braking events should not exceed 40% of the initial strength of the rope. It was also realised that mechanical winder brake systems could fail, and that such an event could lead to uncontrolled braking, and possibly very high rope loads. The concern was that ropes with relatively low static safety factors could then also have dangerously low dynamic safety factors. The rope loads that could be generated after brake control failure were therefore investigated. The findings of the report led to the inclusion of a specification in the "winder code of practice" that the brakes of a drum winder will be designed such that the rope loads will not exceed 60% of the rope breaking strength when brake control failure occurred. This would ensure that winder brakes are not over-designed.

- ? J Kroonstuiwer: Investigation into rope forces generated during emergency braking events. CSIR, September 1994 (ref. 63).

An investigation was also carried out to determine whether it would be necessary to measure rope loads at the headgear sheave or at the conveyance when the dynamic factor of safety of the rope is being established. The investigation was an extension of earlier work.<sup>r51</sup>

- ? GFK Hecker: Rope force measurements during emergency braking; CSIR, September 1994 (ref. 64).

A concern was also expressed that winder motor faults could lead to abnormal rope loads. Some preliminary information on the magnitude and duration of motor torque pulses resulting from short circuits was obtained from a winder motor manufacturer. Rope loads were calculated using these fault torque pulse data:

- ? J Kroonstuiwer: Investigation of forces in a 4 000 m mine winding rope resulting from a motor fault torque. CSIR, September 1994 (ref. 65).

Although the initial calculations showed rope loads that were not excessive, different combinations of pulse duration and torque magnitude could result in higher rope loads. A more thorough investigation was therefore recommended. On behalf of SIMRAC, Anglo American Corporation carried out such an investigation in collaboration with CEGELEC (now called Alstom) and Siemens. In that investigation the interaction between motor mechanicals and electricals as well as the entire dynamic system up to, and including, the conveyances were taken into account.

- ? RS Hamilton: A study of the transient torques produced by winder motors under fault conditions and the implications concerning the safety of the winding system. AAC, March 1997 (ref. 66).

Note: Because the final version of the above report was not ready at the time that the GAP054

report was issued, it could not be included in GAP054. However, the report will be made available by SIMRAC.

A first version of the "winder code of practice" was produced in November 1994:

- ? GFK Hecker and Mike van Zyl: Status report: Safety standard for the performance, operation, maintenance and testing of mine winding plant. CSIR, November 1994 (ref. r67).

The code of practice required continuous rope load monitoring, from which, amongst other things, the rope load range had to be determined. Because the code allowed rope loads to be measured at either the headsheave or at the conveyance, it also had to provide the algorithms for the calculation of load range for rope loads measured at the conveyance.

- ? J Kroonstuiver: Load ranges during a normal winding cycle. CSIR, June 1995 (ref. 68).

The "draft winder code of practice" was produced in April 1996 and delivered to the SABS Technical Committee. With this document the working group (established for drawing up the code) completed its part of the project.

- ? Code of practice: Performance, operation, testing and maintenance of drum winders relating to rope safety. Draft prepared by working group. April 1996 (ref. 69).

The SABS circulated the draft for comments in June 1996. From information and queries received through the SABS, Hecker (CSIR) updated the document a number of times until it was submitted to SABS in October 1988 for the final time.

### **3.15.1.3 Rope deterioration**

Most of the requirements proposed in the draft of the winder code of practice were based on the collective experience of members of the working group and task groups that prepared the code. However, there were still many unknowns regarding rope deterioration, and with more knowledge available, some of the requirements in the winder code of practice could be changed to be less restrictive or to be less damaging to a winding rope. It was therefore considered to study how different winder parameters and operating conditions influence the degradation of winder ropes. Such a study was outside the scope of the GAP054 contract, but the requirements for such a study and a programme of work were drawn up. Funding for most of the investigations recommended were eventually carried out as part of GAP324 (1996), GAP439 (1997), and GAP501 (1998).

- ? GFK Hecker: Rope deterioration: Field study requirements and recommendations. CSIR, March 1995 (ref. r70).

### **3.15.1.4 Code of practice for rope condition assessment: SABS0293**

The SABS Technical Committee on "wire ropes" was responsible for the establishment of the code of practice for Rope Condition Assessment (RCA). A working made up from knowledgeable persons from industry was set up to draft the code. The "2nd draft" of the code of practice issued in May 1992 (see section 3.12 and ref. r57) was used as the starting point. A further draft of the code was issued in April 1994 by the SABS and the actual code in 1996.

Various SIMRAC funded investigations were carried out as part of GAP054 to refine the code. One of the investigations were to establish what the situation was in other countries regarding the use of magnetic rope testing instruments:

- ? A James: A literature review of the use of magnetic testing of steel wire rope, with particular regard to rope discard criteria. CSIR, May 1995 (ref. r71).

The draft code of practice already contained discard criteria for broken wires in triangular and round strand ropes. These discard criteria were based on work carried out in the late fifties by Harvey and Kruger (ref. o5). Some of the findings and results of Harvey and Kruger were questionable, and more tests on triangular strand ropes with induced defects (broken wires) were carried out to verify and refine the discard criteria. The recommendations from the two reports below were adopted in the RCA code of practice.

- ? M Borello and TC Kuun: The effect of cut wires on the strength of winding ropes. CSIR, December 1994 (ref. r72).
- ? GFK Hecker and TC Kuun: Further tests to study the effect of cut wires on the strength of winding ropes. CSIR, April 1996 (ref. r73).

Rope inspectors and mine engineers were requested to submit sections of discarded ropes to the CSIR for destructive tests. The researchers were interested in the physical condition of the ropes and the loss in strength compared to the strength of the rope when new. Of particular interest was the samples cut from a rope section that was the actual reason for discarding the rope. The results of the tests were to be used to verify and/or refine the discard criteria, and would indicate how well the prescriptions of the draft code were implemented by industry and rope inspectors.

- ? M Borello: Results of tests on sections of discarded ropes. CSIR, June 1994 (ref. r74).
- ? EJ Wainwright: Discussion of results of tests on discarded ropes in terms of the draft code of practice for rope condition assessment. CSIR, May 1995 (ref. r75).
- ? EJ Wainwright: Discussion of results of second series of tests on discarded ropes in terms of the draft code of practice for rope condition assessment. CSIR, April 1996 (ref. r76).

The general conclusions from these tests were:

- ? The discard criteria of the "draft code of practice" were generally satisfactory for broken wires in round strand and triangular strand ropes.
- ? The degree of corrosion was grossly underestimated in most cases and is a very serious problem (excessive strength losses were recorded).
- ? Discard factors calculated using the nominal diameter of the rope as the initial value in stead of a value measured soon after rope installation lead to errors.
- ? Not all ropes were assessed and discarded according to the draft code of practice, i.e the code was still not used properly or was not yet implemented widely.

Seven self-study-training manuals were developed for the accreditation of rope inspectors. These manuals were included in Volume 5 of GAP054 and were:

- ? Module 1: Study guide for wire rope inspectors. (by EJ Wainwright) (ref. r77)
- ? Module 2: An introduction to mine winders. (by EJ Wainwright) (ref. r78)
- ? Module 3: Technology of wire ropes for mine winding in South Africa. (by EJ Wainwright) (ref. r79)
- ? Module 4: Magnetic rope testing instruments. (by TC Kuun) (ref. r80)
- ? Module 5: Practical aspects of rope inspection. (by TC Kuun) (ref. r81)
- ? Module 6: Destructive testing of wire ropes. (by M Borello) (ref. r82)
- ? Module 7: Rope deterioration field guide. (by M Borello and GFK Hecker) (ref. r83)

The refinement of the discard criteria of the RCA code of practice continued in GAP324, GAP439 and GAP502.

### **3.15.1.5 Rope terminations**

Earlier work on rope terminations is discussed in section 3.13. A comprehensive study was carried out on various types of rope terminations with the goal to provide guidelines for the

selection and maintenance of rope terminations. The following reports were produced:

- ? M Borello: Laboratory evaluation of white metal and resin cappings for use as winder rope terminations. CSIR, November 1993 (ref. r84).
- ? M Borello: Performance of resin filled sockets prepared by the mining industry. CSIR, November 1994 (ref. r85).
- ? M Borello: Performance evaluation of resin filled sockets used at Premier Diamond Mine. CSIR, December 1994 (ref. r86).
- ? Mike van Zyl: An investigation into the behaviour and deterioration of winding rope tangent points on conveyance mounted compensating sheaves. CSIR, May 1995 (ref. r87).
- ? M Borello: Splicing techniques for mine winder ropes. CSIR, October 1994 (ref. r88).
- ? EJ Wainwright and M Borello: Rope terminations for mine hoisting applications. CSIR, March 1995 (ref. r89).

The investigations into using sockets as rope end terminations led to the conclusion that resin-filled sockets (as well as white metal filled sockets) were suitable replacements for splices as terminations for winder ropes operating in vertical shafts. Resin-filled sockets are now used widely by the mining industry, and are the preferred rope termination for drum winder ropes.

The "BMR compensating sheave tangent point" investigation concluded that 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. It was also concluded that the longer a tangent point is left in service on a winder, the greater the chance becomes for a tangent point to deteriorate to an unacceptable degree. It was therefore recommended that regular inspection of the condition of the tangent points was the only proper action that would ensure safety. The new mine winder regulations now require that conveyance mounted compensating sheaves rope terminations are remade every three months (instead of every six months previously).

The investigations listed above concluded the SIMRAC work on rope terminations.

### **3.15.1.6 Shaft sinking**

The new statutory regulations that were proposed for drum winders would 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 therefore investigated. The aim of the stage and kibble winder ropes investigation was to obtain guidelines for drafting a code of practice for the ropes and winders of deep shaft sinking operations.

The measurement of the rope forces on the stage winders and kibble winders at three shafts formed the first part of the investigation. The stage rope forces were measured during all types of sinking and stage operations, i.e. during blasting, lashing, stage raising and lowering, kibble crosshead interactions, and water hoisting. The kibble winder rope forces were measured during all types of normal sinking operations, which are hoisting of loaded kibbles and tipping, hoisting water, transporting personnel and material, transporting jumbo drill rigs, running the winder with only the crosshead attached at the rope end, and emergency braking with loaded kibbles, both ascending and descending, near the bottom of the shaft.

- ? Mike van Zyl: Rope force measurements during shaft sinking operations at Vaal Reefs 11 Shaft. CSIR December 1995 (ref. r90).
- ? Mike van Zyl: Rope force measurements during shaft sinking operations at West Driefontein 10 Shaft. CSIR January 1996 (ref. r91).
- ? Mike van Zyl: Rope force measurements during shaft sinking operations at West Driefontein 9 Shaft. CSIR February 1996 (ref. r92).

The shaft sinking investigations continued as part of SIMRAC project GAP324. SIMRAC project GAP418 produced the envisaged code of practice.

### 3.15.2 GAP324: Deterioration and discard of mine winder ropes

Investigations into verifying and refining the discard criteria proposed for the code of practice for rope condition assessment were described in the previous section on GAP054. These investigations continued as part of SIMRAC project GAP324. The year of this SIMRAC project (1996) was also the year that the rope condition assessment code of practice was issued for the first time as SABS0293.

In GAP054 "field study requirements" were explored and recommendations for investigations to substantiate and/or improve the requirements proposed for the winder code of practice were put forward. Most of the requirements in the winder code of practice were based on experience and there were still many unknowns regarding rope deterioration. A number of winders were identified on which rope life and rope deterioration could be studied. These investigations commenced as part of GAP324.

The report on GAP324 was divided into two volumes:

- ? Hecker, et al: GAP324, Volume 1: Deterioration and discard of mine winder ropes. CSIR, September 1997 (ref. 93).
- ? Mike van Zyl: GAP324, Volume 2: Deterioration and discard of mine winder ropes. CSIR, September 1997 (ref. 94).

The first volume detailed the "relationship between winder parameters and rope life" investigation as well as the part on "refined discard criteria for winder ropes". The second volume contains five individual reports:

- ? Mike van Zyl: Overview of the winding rope requirements for deep shaft sinking operations. CSIR, April 1996 (ref. 95).
- ? Mike van Zyl: Load ranges acting in kibble winder ropes and proposals for new kibble winder rope regulations. CSIR, November 1996 (ref. 96).
- ? Mike van Zyl: Rope forces generated after brake control failure on kibble winders. CSIR, December 1996 (ref. 97).
- ? Mike van Zyl: Stage rope factors for deep shaft sinking operations. CSIR, January 1997 (ref. 98).
- ? Mike van Zyl: Triangular strand rope for deep shaft operations – an initial study. CSIR, September 1997 (ref. 99).

The studies towards drafting a code of practice for sinking winders continued under GAP324 as is evident from the first four reports listed above. A further report on the behaviour of triangular strand ropes in deep shafts was also completed.

Because of the torque generated by a triangular strand rope when loaded, such a rope operating in a very deep shaft will have a back-end laylength substantially longer than ropes operating in shallower shafts. There was a concern regarding the behaviour of the longer laylength when subjected to multi-layer coiling on winder drums. Initially funding was made available to investigate coiling with longer back-end laylengths, but because a suitable winder installation could not be located for the practical part of the work, the project was suspended. Fortuitously it was reported to the researchers that one of the triangular strand ropes of a drum winder accidentally lost around 800 turns when the front of the rope was released from the conveyance at shaft bottom. This event provided an ideal study object. The original scope of this part of the investigation was altered to "triangular strand rope behaviour in deep shafts".

The investigations on the deterioration and discard of mine winder ropes continued in GAP439 (1997) because conclusions could not yet be derived from the work carried out under GAP324. The drafting of a code of practice for deep shaft sinking winders continued as GAP418. The report on "triangular strand ropes for deep shaft operations" was the only report commissioned by SIMRAC on the subject of suitable rope constructions for very deep shafts.

### **3.15.3 GAP418: Ropes and winders of deep shaft sinking operations**

The objective of this project was to establish a code of practice for the ropes of deep shaft sinking winders. The major difference between the sinking of a shallow and a very deep shaft (with a stage and kibbles) is the load in the winder ropes. During earlier investigations (ref. r94) the rope loads that could be generated in very deep shafts during shaft sinking operations were calculated. Appropriate rope safety factors were then proposed and motivated. The final part of the work was drafting the actual code of practice (this project, GAP418).

In essence, the code of practice for sinking winders was written for the shaft sinking operations at the twin shafts at South Deep (Western Areas, Placer Dome Joint Venture). The planned shaft depths were approximately 2 800 m and 3 000 m.

Very few ultra deep shafts will be sunk in the near future. If the sinking of a very deep shaft is started now, the shaft depth could only reach the "code of practice values" three years from now. On the other hand, permanent winder operations on relatively shallow shafts may make use of the lower rope safety factors of the winder code of practice (SABS0294).

Because the envisaged infrequent use of the code of practice for sinking winders, it was decided by the industry and the Department of Minerals and Energy that it was not necessary to create another Bureau of Standards (SABS) document (at that stage). It was decided that the code of practice would be a "set of rules" mutually agreed upon by the authorities and the industry, and that exemption will be granted to a mine to use the rope load factors in the code if it abides by the specifications in the code ("catalogue of best practices").

? Mike van Zyl and Frieder Hecker: GAP418: Catalogue of best practices for the ropes and winders of deep shaft sinking operations. CSIR, November 1998 (ref. r100).

In April 2002, the sinking parts of both shafts at South Deep were complete. The code of practice can be improved from the experience gained at South Deep.

### **3.15.4 GAP439: Deterioration of mine winder ropes**

The purpose of the "drum winder rope deterioration study" was to verify some of the specifications included in the winder code of practice. When the requirements for the investigation were tabled as part of the GAP054 report, it was known that such a project would not be completed within one year, but it was agreed that the project would be divided into one year contracts. The project started as part of GAP324 (1996), and continued as GAP439 (1997).

Funds were available to carry out tensile tests on the ropes discarded from one of the winders under observation (as part of the deterioration studies). Because no discarded ropes became available for such tests, the funds were re-allocated to carry out more cut-wire tests on non-spin ropes. GAP439 also provided for further tests on discarded winder ropes for the verification of the discard criteria of SABS0293. No clear conclusions could be reached from the investigations carried out for GAP439. In 1998 the winder rope deterioration studies and the rope discard criteria investigations continued as two separate projects (GAP501 and GAP502).

- ? GFK Hecker, EJ Wainwright, CHeydenrych: GAP439: Deterioration of mine winder ropes. CSIR, July 1998 (ref. 101).

### **3.15.5 GAP501: Deterioration mechanisms of drum winder ropes**

It was generally accepted that the pure tensile load variations that occur on drum winders (up to 15% load range) were too small to result in the generation of fatigue failures (broken wires). Because drum winder ropes develop broken wires in service, it was believed that there had to be some "fatiguing" mechanism present in drum winder systems. It was therefore reasoned that, excluding environmental and accidental damage, fatiguing of drum winder ropes could be the result of one or a combination of the following (in order of perceived importance):

- ? The plastic wear that flattens the outer wires of all drum winder ropes with usage could make the rope wires more susceptible to crack initiation. Broken wires would therefore be produced at lower load ranges.
- ? The bending of a rope over a headsheave and on the drum could result in stresses that lead to broken wires.
- ? The repeated contact stresses experienced by the rope when coiled onto a winder drum could produce broken wires.

Apart from continuing with the "field observations" of GAP324 and GAP439, the primary objectives of the GAP501 project were the investigation of the mentioned deterioration mechanisms. Fatigue performance of triangular strand ropes was obtained from literature and fatigue tests were carried out on sections of used triangular strand rope. The bending stresses in the wires of a winding rope were calculated and measured (with strain gauges) while a rope was wound on and off a winder drum at various speeds. The contact stresses were calculated for multi-layer coiling on drums, and from observed rope surface conditions. Changes to the regulations and the winder code of practice (SABS0294) are recommended in the GAP501 report.

- ? Mike van Zyl: GAP501: Deterioration mechanisms of drum winder ropes. MvZ INC, September 2000 (ref. r102).

This was the final SIMRAC sponsored investigation into the deterioration mechanisms of drum winder ropes.

### **3.13.6 GAP502: Discard criteria for mine winder ropes**

The objectives of the GAP502 investigation were the same as those of previous SIMRAC projects, i.e. to verify, and possibly refine the discard criteria of SABS0293. For the GAP502 investigation, special emphasis had to be placed on non-spin ropes, because the discard criteria for non-spin ropes were not yet well defined in SABS0293. The possible use of non-spin ropes in future deep shaft operations required the situation to be addressed. The majority of (drum) winder ropes are discarded because of broken wires. The discard criteria for broken wires were therefore the focus of the investigation. More cut-wire tests were carried out on non-spin ropes as part of this project. The results obtained were evaluated together with the cut-wire results of GAP324 and GAP439 in order to establish and propose proper discard criteria for broken wires in non-spin ropes.

- ? Mike van Zyl: GAP502: Discard criteria for mine winder ropes. MvZ INC, September 2000 (ref. 103).

However, the report concluded that the premise of a rope having lost 10% of its original strength, used previously for establishing discard criteria for broken wires in ropes, does not exist if different lengths of rope are considered. It was further concluded that this basis for establishing

discard criteria had to be reconsidered. No further SIMRAC investigations on discard criteria were scheduled for 1999 and 2000.

### **3.15.7 GAP503: An evaluation of magnetic rope testing instruments**

Because of the possibility that non-spin ropes (low rotation, multi-layer ropes) would be used in future deep shaft, this SIMRAC project was initiated to evaluate the abilities of available magnetic rope testing instruments in assessing the condition of a non-spin rope.

The scope of the original project (GAP503) on the detection of internal broken wires in a rope was extended to include the evaluation of a corroded non-spin rope as well (GAP535).

? Martin Dohm: GAP503 and GAP535: An evaluation of international and local magnetic rope testing instrument defect detection capabilities and resolution, particularly in respect of low rotation, multi-layer rope constructions. AAC, May 1999 (ref. r104).

This investigation was the first venture into assessing the abilities of different rope testing instruments. Eight different organisations participated in this investigation. The participants had to evaluate the number of broken wires in one non-spin rope section, and the amount of corrosion (loss of metallic steel area) in another section of non-spin rope. After the evaluations of the participants were completed, the corroded rope was tensile tested to destruction, and the rope with broken wires was destrandred to count the broken wires manually.

The report is quite critical on the ability of the instruments (and the users of the instruments) to detect the number of internal broken wires accurately in a non-spin rope, and to assess the amount of corrosion in a non-spin rope. However, it should be kept in mind that both the rope sections evaluated were way beyond discard: The corroded rope section had a strength loss of 48%, and the sample with broken wires contained as many as 24 wire breaks per a 100 mm length of rope.

Nevertheless, the situation is not as "bad" any more because the drum winders that will come into operation in 2002 and 2003 in two ultra deep shafts (3 000 m and 3 100 m) will be using triangular strand ropes.

## **3.16 And then?**

Apart from this report (GAP637), ropes related research was not sponsored by SIMRAC for 1999 and 2000.

Although the regulations and the codes of practice (to sink deep shafts and to operated permanently from these depths) were all in place in 2000, there was still some uncertainty regarding the most suitable rope constructions for sinking and for permanent winding.

Kibble winders for conventional shaft sinking require non-spin ropes. On two shafts that were sunk beyond 2500 m (and to nearly 3000 m) poor rope lives were experienced. The kibble winders performed around 1 000 to 1 200 winding cycles per month, and rope lives were less than 10 000 winding cycles. Rope lives as little as 5 000 winding cycles were experienced. The average rope life for a triangular strand rope on a permanent drum winder is around 80 000 winding cycles.

For permanent operations on deep shafts using drum winders, Anglo continued with field trials at Elandsrand and at Moab Khotsong. Later AngloGold and Placer Dome-Western Areas clubbed together with Haggie (the rope manufacturer) to continue the research into the most suitable rope construction for permanent deep shaft operations. Their findings are their intellectual property.

## 4 Conclusions and recommendations

Various aspects of mine winding and winding ropes were investigated. Drum winding and triangular strand ropes were mostly considered, but not exclusively.

The research described in this report produced and established the following:

- ? New rope load factors and regulations for drum winder ropes were established.
- ? A code of practice for rope condition assessment was produced, rope discard criteria were investigated and magnetic rope testing instruments were evaluated.
- ? The winder code of practice that would allow better utilisation of drum winders as well as deep shaft hoisting was established.
- ? A code of practice for shaft sinking winders was established and used to sink two very deep shafts.
- ? New rope terminations were introduced.
- ? Winder and rope dynamics are well understood.
- ? Rope deterioration on a drum winder is far better understood.
- ? Uncertainties like winder motor fault torque and slack rope have been investigated.
- ? A large information base has been established.

A large part of the SIMRAC investigations were concerned with rope discard and rope deterioration in order to verify and refine the requirements in the mentioned codes of practice. None of the recommendations in the SIMRAC reports has been implemented. This should be followed up.

## Appendix A: Other references

- o1. WM Kinghorn: A statistical approach to the selection and performance of vertical winding ropes. Journal of the South African Institution of Engineers, March 1949.
- o2. JA Vaughan: An investigation regarding the effect of kinetic shocks on winding ropes in vertical shafts. Journal of the South African Association of Engineers, March 1904.
- o3. JA Vaughan: The factor of safety of wire ropes used for winding in mine shafts. Journal of the South African Institution of Engineers, Vol. XVI, No. 4, 1917.
- o4. JJP Dolan and WG Jackson: An investigation into the permissible load carrying capacity of steel wire ropes for hoisting, with special reference to deep level winding on the Witwatersrand Gold Fields. Journal of the South African Institution of Engineers, November 1939.
- o5. T Harvey and HW Kruger: The theory and practice of electronic testing of winding ropes. Trans. Inst. Elect. Eng., June 1959.
- o6. TC Kuun: Low rotation winding ropes for long lift drum winders. May 1993.

## Appendix B: Research reports references

Full details (such as report numbers or where published) are given in the Appendix C where all the report listed here are summarised.

The reports are also listed in alphabetical order of the authors in Appendix D, and by the "research category" in Appendix E. Research categories are given with the report summaries in Appendix C.

- r1 TC Kuun: Notes on the design factors for winding ropes; AAC April 1984.
- r2 JTD Fritz: A critical review of South African and foreign factors of safety, specified for mine winding ropes (1985); NMERI, CSIR, September 1985.
- r3 JTD Fritz: In-service damage accumulated by wire ropes operating on drum winders; Libanon Gold Mine, 1 658 m deep. NMERI, CSIR, June 1986.
- r4 JTD Fritz: In-service damage accumulated by wire ropes operating on drum winders; Deelkraal Gold Mine, 2 062 m deep. NMERI, CSIR, August 1986.
- r5 JTD Fritz: In-service damage accumulated by wire ropes operating on drum winders; Premier Diamond Mine, 600 m deep. NMERI, CSIR, March 1987.
- r6 GFK Hecker: In-service damage accumulated by wire ropes operating on drum winders; Summary and Conclusions. NMERI, CSIR, February 1988.
- r7 Gareth R Thomas: An investigation into the dynamic rope loads in drum winder systems. SDRC (USA), October 1987.
- r8 R Hohendorf: Verified drum winder and discarded wire rope information for 99 rock winders. NMERI, CSIR, June 1988.
- r9 TC Gilfillan: Report on the analysis of lifetimes of steel ropes in mining headgear. CACDS, CSIR, August 1988.
- r10 Mike van Zyl: Review of the statistical analysis of the in-service performance of winder ropes. NMERI, CSIR, September 1988.
- r11 TC Kuun: Single lift shafts: Limits of winding rope application. AAC, May 1988.
- r12 CR Chaplin: Feasibility study - interim report. February 1989.
- r13 CR Chaplin: Drum winder rope deterioration study - summary report. August 1989.
- r14 CR Chaplin: Drum winder rope deterioration study: simulation and backslip. March 1990.
- r15 CR Chaplin: Drum winder rope deterioration study - draft final report. April 1990.
- r16 CR Chaplin: Backslip: a re-evaluation. July 1990.
- r17 CR Chaplin: Hoisting ropes for drum winders - mechanics of degradation. Paper published in 1994.
- r18 CR Chaplin: Failure mechanisms in wire ropes. Paper published in 1995.
- r19 N Casey: The bending-tension fatigue testing of four 40 mm diameter steel wire ropes. NEL Glasgow, September 1991.
- r20 Mike van Zyl: Information on 99 drum winders and 711 discarded winder ropes. CSIR, May 1990.
- r21 Mike van Zyl: Relationships and trends of drum winder parameters. CSIR, November 1990.
- r22 Mike van Zyl: A life prediction model for drum winder ropes. CSIR, February 1991.
- r23 Mike van Zyl: Drum winder rope forces generated during emergency braking, normal acceleration and skip loading. CSIR, April 1991.
- r24 Mike van Zyl: Drum winder rope forces generated by the occurrence of slack rope - a mathematical method. CSIR, September 1991.
- r25 ME Greenway: Dynamic rope loads in winding systems - an analytical approach. AAC, February 1989.
- r26 RS Hamilton: Dynamic response of freely suspended skips during ore loading. AAC, November 1989.
- r27 RS Hamilton: The use of clamping devices to control the dynamic response of skips during ore loading. AAC, February 1990.
- r28 ME Greenway: Dynamic rope loads due to cage loading. AAC, June 1990.
- r29 ME Greenway: A simple static and dynamic analysis of coupled extensional-torsional

- behaviour of winding rope. AAC, November 1990.
- r30 ME Greenway: Dynamic rope loads developed in response to instantaneous winder braking. AAC, June 1991.
- r31 RS Hamilton and ME Greenway: A finite element study of the coupled extensional-torsional behaviour of winding rope. AAC, October 1991.
- r32 A D'Arcy-Evans and RA Backeberg: Dynamic response of conveyances during friction clamp release. COMRO, June 1992.
- r33 A D'Arcy-Evans and RA Backeberg: Non-dimensional dynamic response of conveyances during friction clamp release. COMRO, February 1993.
- r34 M Borello: Fifth report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep. CSIR, September 1990.
- r35 GJ Wright, JJ Pretorius and IL Maarseveen: An assessment of the wear mechanisms of wire ropes removed from the rock winder at Elandsrand Gold Mine, CSIR, October 1990.
- r36 RA Hunziker and JJ Pretorius: A mathematical model of wear mechanisms in a mine hoisting rope. CSIR, March 1991.
- r37 TC Kuun, WP van der Walt and SJ Mostert: Condition assessment of winding ropes operating at a factor of safety of four. AAC, March 1991.
- r38 M Borello: Sixth report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep. CSIR, April 1991.
- r39 RA Hunziker, JJ Pretorius and IL Maarseveen: An assessment of the wear mechanisms of the 48 mm ropes removed from the Siemens double drum rock winder at the Elandsrand Gold Mine in January 1991. CSIR, March 1991.
- r40 RA Hunziker, JJ Pretorius and Mike van Zyl: Wear mechanisms of drum winder ropes. CSIR, June 1992.
- r41 GFK Hecker and Mike van Zyl: Drum winder rope test facility: A feasibility study. CSIR, January 1993.
- r42 M Borello: Seventh report on the in-service damage accumulated by wire ropes operating on drum winders (Elandsrand Gold Mine, 2 204 m deep). CSIR, September 1993.
- r43 Mike van Zyl, GFK Hecker and JTD Fritz: Factors of safety of winder ropes; recommendations towards new regulations for drum winders; notes for discussion. CSIR, September 1989.
- r44 Mike van Zyl: Factors of safety of winder ropes; recommendations towards new regulations for drum winders; notes for discussion. CSIR, October 1989.
- r45 ME Greenway: An engineering evaluation of the limits to hoisting from great depth. AAC, June 1990.
- r46 GFK Hecker: Pro-forma 3: Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. CSIR, September 1990.
- r47 GFK Hecker: Pro-forma 4; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. CSIR, January 1991.
- r48 GFK Hecker: Pro-forma 5; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. CSIR, April 1991.
- r49 GFK Hecker: Proposed changes to rope safety regulations (draft). CSIR, January 1992.
- r50 GFK Hecker: Proposed changes to rope safety regulations (second draft). CSIR, March 1992.
- r51 GFK Hecker: Rope forces during dynamic brake tests. CSIR, July 1992.
- r52 GFK Hecker: Proposed changes to rope safety regulations (final draft). CSIR, August 1992.
- r53 GFK Hecker: Proposed changes to rope safety regulations (for consideration by the CM&EE sub-committee). CSIR, September 1992.
- r54 Mike van Zyl: Load ranges experienced by drum winder ropes. CSIR, November 1992.
- r55 C O'Conner: Non-destructive testing of wire rope in the RSA. CSIR, November 1990.
- r56 TC Kuun: Condition assessment of winding ropes: Discard criteria for 6/F triangular strand ropes. AAC, July 1991.
- r57 Code of practice for rope condition assessment (2nd draft). CSIR, May 1992.
- r58 M Borello: A survey of results of tests on rope terminations. CSIR, May 1991.
- r59 M Borello: A comprehensive study of the factors affecting splice efficiencies. CSIR, April

- 1992.
- r60 M Borello: Laboratory axial fatigue tests of resin cappings for use as winder rope terminations. CSIR, December 1992.
  - r61 GFK Hecker: Motivation for proposed changes to Chapter 16 of the minerals act: Rope safety regulations for drum winders. CSIR, June 1993.
  - r62 GFK Hecker: GAP054: The safe use of mine winding ropes; Volume 1: Executive summary. CSIR, April 1996.
  - r63 J Kroonstuiwer: Investigation into rope forces generated during emergency braking events. CSIR, September 1994.
  - r64 GFK Hecker: Rope force measurements during emergency braking; CSIR, September 1994.
  - r65 J Kroonstuiwer: Investigation of forces in a 4000 m mine winding rope resulting from a motor fault torque. CSIR, September 1994.
  - r66 RS Hamilton: A study of the transient torques produced by winder motors under fault conditions and the implications concerning the safety of the winding system. AAC, March 1997.
  - r67 GFK Hecker and Mike van Zyl: Status report: Safety standard for the performance, operation, maintenance and testing of mine winding plant. CSIR, November 1994.
  - r68 J Kroonstuiwer: Load ranges during a normal winding cycle. CSIR, June 1995.
  - r69 Code of practice: Performance, operation, testing and maintenance of drum winders relating to rope safety. Draft prepared by working group. April 1996.
  - r70 GFK Hecker: Rope deterioration: Field study requirements and recommendations. CSIR, March 1995.
  - r71 A James: A literature review of the use of magnetic testing of steel wire rope, with particular regard to rope discard criteria. CSIR, May 1995.
  - r72 M Borello and TC Kuun: The effect of cut wires on the strength of winding ropes. CSIR, December 1994.
  - r73 GFK Hecker and TC Kuun: Further tests to study the effect of cut wires on the strength of winding ropes. CSIR, April 1996.
  - r74 M Borello: Results of tests on sections of discarded ropes. CSIR, June 1994.
  - r75 EJ Wainwright: Discussion of results of tests on discarded ropes in terms of the draft code of practice for rope condition assessment. CSIR, May 1995.
  - r76 EJ Wainwright: Discussion of results of second series of tests on discarded ropes in terms of the draft code of practice for rope condition assessment. CSIR, April 1996.
  - r77 EJ Wainwright: Module 1: Study guide for wire rope inspectors. GAP054, April 1996.
  - r78 EJ Wainwright: Module 2: An introduction to mine winders. GAP054, April 1996.
  - r79 EJ Wainwright: Module 3: Technology of wire ropes for mine winding in South Africa. GAP054, April 1996.
  - r80 TC Kuun: Module 4: Magnetic rope testing instruments. GAP054, April 1996.
  - r81 TC Kuun: Module 5: Practical aspects of rope inspection. GAP054, April 1996.
  - r82 M Borello: Module 6: Destructive testing of wire ropes. GAP054, April 1996.
  - r83 M Borello & GFK Hecker: Module 7: Rope deterioration field guide. GAP054, April 1996.
  - r84 M Borello: Laboratory evaluation of white metal and resin cappings for use as winder rope terminations. CSIR, November 1993.
  - r85 M Borello: Performance of resin filled sockets prepared by the mining industry. CSIR, November 1994.
  - r86 M Borello: Performance evaluation of resin filled sockets used at Premier Diamond Mine. CSIR, December 1994.
  - r87 Mike van Zyl: An investigation into the behaviour and deterioration of winding rope tangent points on conveyance mounted compensating sheaves. CSIR, May 1995.
  - r88 M Borello: Splicing techniques for mine winder ropes. CSIR, October 1994.
  - r89 EJ Wainwright and MBorello: Rope terminations for mine hoisting applications. CSIR, March 1995.
  - r90 Mike van Zyl: Rope force measurements during shaft sinking operations at Vaal Reefs 11 Shaft. CSIR, December 1995.

- r91 Mike van Zyl: Rope force measurements during shaft sinking operations at West Driefontein 10 Shaft. CSIR, January 1996.
- r92 Mike van Zyl: Rope force measurements during shaft sinking operations at West Driefontein 9 Shaft. CSIR, February 1996.
- r93 GFK Hecker, EJ Wainwright, P Goosen, C Heydenrych: GAP324, Vol. 1: Deterioration and discard of mine winder ropes. CSIR, September 1997.
- r94 Mike van Zyl: GAP324, Volume 2: Deterioration and discard of mine winder ropes. CSIR, September 1997.
- r95 Mike van Zyl: Overview of the winding rope requirements for deep shaft sinking operations. CSIR, April 1996.
- r96 Mike van Zyl: Load ranges acting in kibble winder ropes and proposals for new kibble winder rope regulations. CSIR, November 1996.
- r97 Mike van Zyl: Rope forces generated after brake control failure on kibble winders. CSIR, December 1996.
- r98 Mike van Zyl: Stage rope factors for deep shaft sinking operations. CSIR, January 1997.
- r99 Mike van Zyl: Triangular strand ropes for deep shaft operations – an initial study. CSIR, September 1997.
- r100 Mike van Zyl and Frieder Hecker: GAP418: Catalogue of best practices for the ropes and winders of deep shaft sinking operations. CSIR, November 1998.
- r101 GFK Hecker, EJ Wainwright, C Heydenrych: GAP439: Deterioration of mine winder ropes. CSIR, July 1998.
- r102 Mike van Zyl: GAP501: Deterioration mechanisms of drum winder ropes. MvZ INC, September 2000.
- r103 Mike van Zyl: GAP502: Discard criteria for mine winder ropes. MvZ INC, September 2000.
- r104 Martin Dohm: GAP503 and GAP535: An evaluation of international and local magnetic rope testing instrument defect detection capabilities and resolution, particularly in respect of low rotation, multi-layer rope constructions. AAC, May 1999.

# Appendix C: Research report summaries

Full details and summaries of the research reports are given in this section.

When and where the author of this summary report deemed it necessary, comments on the contents and findings of a report were included.

The meaning of the "research categories" included with the headings of the reports are:

COP:	A code of practice or a draft code of practice.
DEEP:	The behaviour of ropes in (deep) shafts,
DET:	The deterioration mechanisms and deterioration patterns of drum winder ropes; "fatigue", rope life and rope life predictions.
DYN:	The dynamic behaviour of ropes and winders.
FOS:	Rope safety factors, safety philosophies, proposals for new safety factors, and reviewing of safety factors.
INFO:	Information on winder design, winder drums, headsheaves, winding speeds, rope end loads, winder rope properties, rope lives achieved, etc.
MOTOR:	Winder motor fault torque and winder motor behaviour.
RCA:	The condition assessment of winder ropes, discard criteria, and rope condition assessment instruments (magnetic rope testing instruments).
SINK:	Shaft sinking.
TERM:	Rope front-end terminations.
TRAIN:	Training manuals for incumbent rope inspectors.

A category listed with a report means that some aspects of the given category are addressed in the specific report.

Appendix E lists all the reports by "research category".

## **Notes on the design factors for winding ropes**

TC Kuun

Report ME/TCK/IS/6446 SP1, Mechanical Engineering Department, AAC, April 1984

Sponsor: Anglo American Corporation .....46 pages

### **From the synopsis of the report**

"In the first section of this note a rope constant is developed to assist in the quantitative illustration of rope factor implications. Subsequent sections deal with proposals made by Vaughan in 1917 and by Dolan and Jackson in 1939 regarding factors of safety and capacity factors for winding ropes. Existing regulations are reviewed and the use of UHT ropes in terms of these requirements is explored. Emphasis is placed on rope deterioration and rope examination as the basis for future rope design factor legislation."

### **Summary**

The contribution of various authors to the rope regulations that were in force in the nineteen eighties are discussed critically in the report. The origin of these regulations are outlined and discussed. It is reasoned that very little of the actual recommendations of these authors found their way into the regulations. In effect it is reasoned that the regulations did not have a sound scientific basis.

It was further reasoned that the capacity factor concept "has outlived its usefulness" and that it could be replaced by a "factor of safety that varies with depth". From a "simplified fatigue analysis" it is shown that the factor of safety should decrease with depth for drum winders, and increase with depth for Koepe winders.

Of interest: The shape of the rope safety factor finally adopted in the new regulations for drum winders (the "formula") was already proposed in this document.

### **Recommendations (from the report)**

- ? As an immediate need, the present dispensation of Regulation 16.37 for Blair rock winders should apply to (the) capacity factor as well.
- ? Due to its inherent inflexibility, the capacity factor approach should eventually be abandoned. A factor of safety that varies with depth provides the same safeguards and can easily be fitted to the requirements of the situation.
- ? Selection of ropes on a fatigue basis is the ultimate solution but requires information on rope fatigue behaviour. Selective field trials and simulated service fatigue tests should be added to the programme of work initiated through the Chamber of Mines.
- ? Improved utilisation of ropes requires more than just a review of the Regulations. Simultaneous and renewed attention must also be given to various aspects of the operating environment in order to
  - eliminate corrosion of ropes,
  - reduce dynamic loads imposed on the rope,
  - improve sheave contact and drum coiling, and
  - reduce accidental deformation of the rope.
- ? There is also a need for improved electromagnetic rope testing equipment and procedures, with immediate follow up of test indications in the field.

Reference: r2 ..... FOS, DET  
**A critical review of South African and foreign factors of safety, specified for mine winding ropes (1985).**  
JTD Fritz  
Report ME1925, Mine Hoisting Research Unit, NMERI, CSIR, September 1985.  
Sponsor: Chamber of Mines .....60 pages

### **From the synopsis of the report**

"The current South African regulations concerning allowable load levels in mine winding ropes were adopted approximately forty years ago. Since the introduction of the present regulations a significant amount of experience has been gained with the winding at various depths up to the present maximum of 2 490 m (Hartebeestfontein No. 6 Shaft).

Several members of the South African mining industry requested a re-evaluation of the validity of the South African regulations in the light of more recent experience and the availability of modern analytical tools. In response to this requirement, the Mine Hoisting Research Unit formulated a comprehensive research project, which was approved and financed by the South African Chamber of Mines. This report documents the results of a comparative study of South African and foreign regulations as specified at present.

### **Summary of the contents of the report**

The report gives a historical background as to how the regulations in force at that time came into being. It shows that the Capacity Factor was introduced to allow factors of safety of less than six in deeper shafts. Although the introduction of the Capacity Factor would require higher factors on shallow shafts (than those required at the turn of the century) no shallow shaft winders actually operated at the minimum safety factor of six. The introduction of the Capacity Factor was therefore not restrictive on shallow shafts. The report comes to the same conclusion reached by Kuun<sup>r1</sup> that the "actual factors finally adopted... were chosen rather arbitrarily and not entirely in the accordance with the recommendations" of various authors.

The report compares the South African regulations with those of most other mining countries (the 1985 situation), and concludes that "... the present South African regulations represent very nearly the upper limit of the range of factors of safety employed in other countries." The report also compares prescribed rope design and installation requirements, prescribed rope inspection and maintenance requirements, and prescribed rope discard criteria included in the regulations of the different countries.

The report analyses the accumulation of winding cycles and "fatigue damage" using different rope load factors. The concept of "slipback" was also first mentioned in this report. The report highlights the point that very little quantitative data on tension-tension fatigue properties of wire ropes could be located. Nevertheless, with data available for non-spin ropes that operated on Koepe winders (friction winders), a "required shape" of the factor of safety with depth is finally derived in the report based on "rope fatigue principles".

The report concluded: "It is evident that the current factor of safety specifications for the RSA are based on a technique which yielded a factor of safety that decreased with increasing depth of wind (Capacity Factor), and minimum and maximum values which were deduced from local and overseas winding experience. However, the current RSA specifications appear to be unduly cautious when compared to the practice in other countries, especially at intermediate depths of wind. It can therefore be tentatively concluded that the present research project covering a thorough re-evaluation of the current RSA specifications is fully warranted."

References: r3, r4, r5, r6..... DET  
The following reports on **the in-service accumulation of damage** are summarised together.

JTD Fritz: Second report on: In-service damage accumulated by wire ropes operating on drum winders; Libanon Gold Mine, 1658 m deep. Report ME1985, Mine Hoisting Research Unit, NMERI, CSIR, June 1986.....60 pages

JTD Fritz: Third report on: In-service damage accumulated by wire ropes operating on drum winders; Deelkraal Gold Mine, 2062 m deep. Report ME1986, Mine Hoisting Research Unit, NMERI, CSIR, August 1986. ....57 pages

JTD Fritz: Fourth report on: In-service damage accumulated by wire ropes operating on drum winders; Premier Diamond Mine, 600 m deep. Report ME2024, Mine Hoisting Research Unit, NMERI, CSIR, March 1987.....50 pages

GFK Hecker: In-service damage accumulated by wire ropes operating on drum winders; Summary and Conclusions. Report ME2062, Mine Hoisting Research Unit, NMERI, CSIR, February 1988. ....16 pages

Sponsor: Chamber of Mines

Note: There was actually a "first" report on this subject on two ropes discarded from the Unisel mine. Because coiling problems were experienced on this winder, it was reasoned that the in-service damage was not representative of that of a "normal" winder. The findings of that report were therefore disregarded.

### **Summary of the findings of the four reports**

The damage distribution in ropes discarded from the three mines was determined experimentally. Different sections of the ropes were investigated mainly for reduction in breaking strength. Other issues investigated were the strength of the individual roping wires, changes in rope diameter, laylength, strain energy to failure, and torsions to failure of individual wires. Mainly because so little was known at that stage, all these additional tests were carried out, i.e. maximise the information that could be gained.

Large reductions in the breaking strengths of the ropes were not found and the results from tests other than the breaking strength tests were not very significant. During later repetitions of this type of investigation, only the breaking strength of rope samples was considered important.

All the rope sections referred to in what follows are for fully paid out ropes (when the conveyances were at their lowest positions in the shaft).

#### Premier mine, 600 m deep

At installation the capacity factor of the set of ropes was 8,7 and the safety factor was 6,8 (the winder was operating below the required factors with special dispensation from the authorities). The rope set was discarded after 249 days and 87 043 winding cycles in service. The reason for discard was "numerous broken wires".

The back ends of the ropes were pulled in at 12 week intervals (approximately every 30 000 winding cycles). The winder operated with only one and a half rope layers on each drum, and rope was therefore not wound over the dead turns on the drums. Samples from the dead turns therefore showed very little deterioration.

The "worst" section of the overlay rope, in the portion between the conveyance and the bank, was determined by magnetic testing of the rope. This section was near the rope layer crossover

point (on the drum) and gave a reduction in breaking strength of 6%. On the overlay rope, the section next to the headsheave showed a reduction in breaking strength of 6%, and a sample from the centre of the catenary gave a reduction in strength of 9%. The breaking strengths of the rest of the samples from these ropes were all within  $\pm 2\%$  of the new rope strengths.

The deterioration of the ropes on this winder was attributed to a poor layer crossover point and to poor coiling on the drums.

#### Libanon mine, 1 658 m deep

At installation the capacity factor of the set of ropes was 12,3 and the safety factor was 5,6. The rope set was discarded after 931 days and 79 136 winding cycles in service, which represented the shortest rope life to that date for a rope set on the winder.

The back ends of the ropes were pulled in at after 147 days (12 500 cycles), 665 days (56 000 cycles) and after 847 days (72 000 cycles). The drums contained four rope layers at installation.

The "worst" deteriorated rope sections of both ropes in the sections between the bank and the conveyance were determined through magnetic testing of the ropes, and were in the vicinity of the original first layer crossover points. The overlay rope showed a strength reduction of 10% and the underlay rope 17%. It was reasoned that the damage at the original first layer crossover points might have been less severe if the first pulling in of the back ends was done earlier. The dead turns of the overlay rope reduction in breaking strengths of 11% and 14% as opposed to 5% of the underlay rope. The breaking strengths of the rest of the samples from these ropes were all within  $\pm 2\%$  of the new rope strengths.

#### Deelkraal mine, 2 062 m deep

At installation the capacity factor of the set of ropes was 10,1 and the safety factor was 5,0. The two overlay ropes of this Blair winder were investigated. The ropes were discarded after 420 days (53 774 cycles) and 539 days (69 708 cycles). A decision by the mine to retain the two underlay ropes as spares influenced the preparation for the investigation. The rope that remained in service for 539 days was not tested magnetically. The "worst" section on this rope could therefore not be located, and the first layer crossover point was also not marked.

The back ends of the ropes were pulled in at intervals of 6 weeks (approximately every 5 400 winding cycles). The drums contained four rope layers at installation.

The "worst" deteriorated rope section of the rope that remained in service for 420 days was determined by magnetic testing, and was again in the vicinity of the first layer crossover point. The strength reduction at that point was 5%. The greatest reduction in strength of the rest of this rope was 4% at a point next to the headsheave.

The other rope (which was not subjected to a magnetic test) showed a strength reduction of 10% halfway down the shaft, and 12% next to the sheave. In general, this rope showed greater deterioration and a larger scatter in the strength test results compared to the other rope over the whole length of the ropes.

Other than a slightly longer service life, no further reasons were offered for the difference between the ropes.

#### Summary of the in-service damage

The report, which summarised the findings of the above three report concluded that "a definite pattern of deterioration could not be established from the investigations carried out, apart from singular points of deterioration like the first layer crossover."

The report further concluded that the rope section between the drum and the bank (for a fully paid out rope) could have significant deterioration, and should therefore be subjected to magnetic testing as well. The magnetic testing of the ropes established the worst deteriorated section of the ropes in all cases. If the pulling in of the back end of a rope is delayed, the rope could suffer accelerated deterioration at the layer crossovers and in the dead turns on the drum.

**Comment:**

Keep in mind that the investigations described above were the first endeavour into understanding what happens to ropes operating on drum winders. Information on the exact damage (number of broken wires for example) of the "worst" rope sections identified are not given in the reports. This was not an oversight by the investigators but simply that the importance of such information had not yet been realised. Nevertheless, from that time onwards the loss in breaking strength of a standard length rope sample remained the only parameter with which the effect of observed damage to a rope was represented.

## **An investigation into the dynamic rope loads in drum winder systems**

Gareth R Thomas

SDRC Project No. 11845 Structural Dynamics Research Corporation, San Diego, California (USA), October 1987.

Sponsor: Chamber of Mines .....215 pages

### **Summary**

The investigation included the experimental and theoretical determination of dynamic rope loads, as well as a parametric study to determine the influence of depth on dynamic rope loads.

The experimental work was carried out at three mines with different depths of wind, namely Premier (600 m), Libanon (1 658 m) and Deelkraal (2 062 m). These were the same three mines from which discarded ropes were obtained for the investigation of the in-service accumulation of damage (refs r3, r4, r5, r6). The analytical analysis used the parameters of these three mines so that the experimental and analytical results could be compared.

### Experimental determination of dynamic rope loads

The parameters that were recorded were acceleration and rope load at the conveyance, rope load at the headsheave, and winding speed. These were recorded during normal winding operations (loading, off-loading, acceleration and deceleration) and during emergency braking at various positions in the shaft, from various speeds, ascending and descending, and empty and loaded skips.

Although the actual values measured at that time are of lesser importance now, the following was established through the measurements:

- ? The peak rope loads generated by skip loading could be as large as those generated while the loaded skip was accelerated.
- ? The largest rope loads were caused by emergency braking.
- ? The oscillations in winder rope-attached mass systems took place at the first natural frequency of the system. Higher order frequencies had no significant amplitudes.
- ? The measurements showed that the elastic modulus of a winding rope was rope load dependent.
- ? The order of magnitude of internal rope damping was established.

### Theoretical evaluation of dynamic rope loads

For the theoretical analysis of the rope loads, SDRC developed a one-dimensional finite element based computer program. The program calculated rope loads and conveyance accelerations, velocities and displacements for a given time-dependent acceleration applied at the winder drum, or for a time dependent force applied at the conveyance (loading). Rope damping was included as viscous damping on each rope element. The actual rope length was not shortened during a wind, but this was not of great consequence because the program was used to study what happened immediately after the winder accelerated a loaded conveyance and for calculating the rope loads immediately after emergency braking.

The parameters and measured winder accelerations of the three winders of the experimental analysis were used to check the accuracy of the computer simulations. SDRC reported that the comparisons were acceptable.

The computer program was then used to examine the effect of winding depth on rope loads (to study the "critical depth" postulated by Vaughan). They reported that the peak rope load generated by accelerating or decelerating a winder was not rope length dependent, but was only

a function of the total load suspended and the winder acceleration or deceleration.

**Comment:**

An anomaly was discovered in the SDRC report regarding some calculations on a BMR winder. The situation was rectified by another investigation commissioned by the Steering Committee (see ref. r23).

References: r8, r9, r10.....INFO, DET  
The following reports on **the statistical analysis of the in-service performance of winder ropes** are summarised together.

R Hohendorf: Verified drum winder and discarded wire rope information for 99 rock winders (draft report). NMERI, CSIR June 1988. ....230 pages  
TC Gilfillan: Report on the analysis of lifetimes of steel ropes in mining headgear. Report CKOMP 88/18, CACDS, CSIR, August 1988. ....126 pages  
Mike van Zyl: Review of the statistical analysis of the in-service performance of winder ropes. NMERI, CSIR September 1988. ....22 pages

Sponsor: Chamber of mines

The following was extracted and concluded from the reports:

The distribution-free Cox proportional hazards regression model was used for the statistical analysis. This model is explained in the "lifetimes" report. The process selects all the variables from an input data set that have significant influence and also assigns values to the proportions of the individual influences. The process could also take lifetimes of ropes into account that were discarded while still in good working order. The outcome of an analysis would be the probability that a rope will be discarded after a given number of winding cycles, given that the rope was still in service. Once a statistical model is established, the influence of the significant variables on the discard probability for a given lifetime can be calculated (or the influence on the lifetime for a given discard probability can be calculated). If, for argument's sake, there was only one real significant variable in the input data set for the statistical analysis, then this variable would be retained by the process and all the other variables would be left out. A relationship between that variable, lifetime of the rope and the discard probability would be established by the model produced.

The first attempt at the statistical analysis used a relatively small data set (TC Gilfillan: Lifetime model for wire ropes; December 1986). Acceptable models (in the statistical sense) could not be found using the given input. It was also later found that the input set contained some errors. There were, however, indications that good statistical models could be found if the input data set could be enlarged.

The statistical analysis project was then extended to include a comprehensive verified data set. A considerable effort was made to collect and verify the relevant information on 710 ropes discarded from 99 rock winders. The winders all operated on vertical shafts and were either double drum or BMR winders. Rock winders were selected because they operate on well defined and repetitive working cycles.

The statistical analysis carried out on the enlarged data set yielded a large number of statistical models that all fitted the input data well (67 in total). The most appropriate model could not be selected statistically, but can only be selected on its usefulness in making predictions that could be interpreted in the engineering sense. The models generated were found not to be good engineering models.

The outcome of a statistical analysis is totally dependent on the selected input. A problem with the statistical analysis was that the large number of variables used could have been "confusing" to the procedure in that unrelated variables could have had coincidental relationships that were significant enough so that they were retained at the expense of other variables that were more interpretable in the engineering sense.

Apart from the establishment of a large verified data set on rock winders, invaluable knowledge and experience on the application of the employed statistical method were gained. It was reasoned that if the statistical analysis was to be pursued further, great care should be exercised

in the selection of the input variables, especially the "derived variables" (e.g. tread pressure, safety factor). Care should also be exercised to guard against biasing the statistical analysis, i.e. selecting only safety factor as a derived variable containing the breaking strength and the working load of the rope instead of for example, selecting safety factor, capacity factor and tread pressure as input and letting the statistical process decide which ones were significant and what the magnitude of that significance was. Care should also be taken against including insignificant variables as input, e.g. the ratio between maximum acceleration and deceleration of the winder drum.

It was concluded that, with the experience gained, a model could be found which would satisfy both statistical and engineering criteria.

During the execution of the "review", errors were discovered in the "number of cycles to discard" and these would have to be verified again before the start of a new analysis.

## **Single lift shafts: Limits of winding rope application**

TC Kuun

May 1988

Sponsor: Anglo American Corporation .....22 pages

### **Summary and recommendations from the report:**

"Rope factor of safety has the most important single influence on the limits of winding rope application. Present legal requirements place a limit of about 2500 m to 3000 m on economically viable single lifts. Lower factors based on fatigue considerations could possibly extend this limit to 4 000 m and beyond. In addition, special measures are required on deep shafts to counteract unsafe conditions resulting from existing legal requirements.

The issue at stake here is not simply a reduction in factors of safety: it is instead a matter of improved rope utilisation with no reduction in safety. This objective can be achieved as shown in this report. However, a full review of the present regulations cannot be motivated based on analytical considerations only. Factual proof and an upgrading of rope surveillance are essential features in such a review. The following action is required on an urgent basis.

- ? Negotiation of field trials with lower factors for selected existing or new shafts where the safety of people cannot be jeopardised by rope failure. This is an extension of the initiative taken at Vaal Reefs and at Elandsrand and will yield hard evidence.
- ? Establishment of a full-scale rope fatigue testing facility in order to evaluate the effect of factors of safety and of the other variables on rope life. This is also an important requirement for the development and successful application of improved ropes.
- ? Development and implementation of
  - reliable rope load monitoring systems
  - improved rope condition monitoring facilities
  - improved winder control systems
  - improved conveyance design concepts."

### **Rope safety factors and rope fatigue**

The report contains an appendix on "rope design factors based on fatigue". An equation for a shaft depth dependent rope safety factor is derived in that appendix.

Using a rope tensile grade of 2 000 MPa, a winder acceleration and deceleration of 1 m/s<sup>2</sup> (bang-bang applied), and assuming that the payload will be 70% of the total attached load, the equation given in the appendix for the factor of safety (FoS) yielded:

$$\text{FoS} = 26\,800 / (4\,300 + L)$$

where L is the maximum suspended rope length in metres.

The above formula gives safety factors of 6,23 at zero depth and 3,23 at a depth of 4 000 m.

Kuun wrote in his report: "No useful information is available regarding the fatigue behaviour of triangular strand ropes on drum winders." To illustrate how his design factors operated he wrote: "Information for Koepe winders will be used here. In spite of major differences in rope construction, interaction with the drum, mean load and torsional deformation, the following relationship could well be a conservative lower limit for triangular strand drum winder ropes:

Load range of 12,7%: 200 000 winding cycles

Load range of 15,2%: 100 000 winding cycles  
Load range of 17,7%: 50 000 winding cycles"

Kuun continued "Fatigue strength properties used in this analysis yield a rope life that is very sensitive to factor of safety, particularly in deeper shafts. Availability of reliable fatigue data for our drum winder ropes is therefore of crucial importance in application of the fatigue approach to deep level winding."

In the main part of the report Kuun wrote on past field trials: "Vaal Reefs management obtained the approval of the Government Mining Engineer's office during 1976 to lower the Capacity Factor on the Vaal Reefs no. 8 Shaft BMR winder to 8,3. Six sets of 1 800 MPa ropes have since been used on this winder with an average life in excess of 90 000 cycles. There is agreement that the reduced capacity factor had no effect on rope life." He also mentioned "Elandsrand BMR operating 1 800 MPa ropes at the legal limit for factor of safety with equally good results." Kuun concludes that "neither of these cases is in the fatigue regime and that lower factors could be feasible."

**Comment:**

The "formula" that was finally adopted (in 1993) for the new regulations of

$$\text{FoS} = 25\,000 / (4\,000 + L)$$

gives 6,25 at zero depth and 3,13 at a depth of 4 000 m.

The only small difference between the adopted "formula" and the one of this report is that the dynamic components of the rope loads were calculated differently. The formula given in the report discussed here (ref. r11) is again a further derivation of a concept originally given in 1984 by Kuun (ref. r1).

Fatigue tests on (used) triangular strand ropes were eventually carried out eleven years later in 1999 (see SIMRAC report GAP501; ref. r102). The results of these tests showed that a load range of 10% was outside the "fatigue regime", but that fatigue breaks develop at a load range of 15%. However, the GAP501 report concluded that rope service lives of 100 000 winding cycles (on a drum winder) would be achievable at a dynamic rope load range of 15%.

References: r12, r13, r14, r15, r16, r17, r18, r19.....DET  
The following reports on Chaplin's **Feasibility study and drum winder rope deterioration studies** are summarised together.

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Reports by CR Chaplin, Department of Engineering, University of Reading, UK:

r12	Feasibility study - interim report. February 1989 .....	9 pages
r13	Drum winder rope deterioration study - summary report. August 1989.....	11 pages
r14	Drum winder rope deterioration study: simulation and backslip. March 1990.....	6 pages
r15	Drum winder rope deterioration study - draft final report. April 1990.....	14 pages
r16	Backslip: a re-evaluation. July 1990.....	6 pages

The papers published by Chaplin on the subject:

- r17 Hoisting ropes for drum winders - the mechanics of degradation, *J. Inst. Min. Elect. Mech. Engrs.*, Vol. 76, 1994.
- r18 Failure mechanisms in wire ropes, *Engineering failure analysis*, Vol. 2, 1995.

The fatigue tests carried out for Chaplin:

- r19 N Casey: The bending-tension fatigue testing of four 40 mm diameter steel wire ropes. Report no. 179/91, NEL, Glasgow, September 1991 .....6 pages

#### **Feasibility study - interim report**, February 1989 (ref. r12)

The interim report discussed possible deterioration mechanisms on drum winder ropes, namely: compression in dead turns, corrosion, wear/plastic deformation, crossover damage (at layers and turns), and fatigue (bend-over-sheave and tension-tension). A possible simulator arrangement is also shown and discussed.

#### **Drum winder rope deterioration study (summary report)**, August 1989 (ref. r13)

The primary objective of the study had been to determine the feasibility of modelling experimentally the processes of normal degradation in mine hoisting ropes. Therefore, no special attention had been given to corrosion and abnormal damage. Damage to dead turns was also considered as secondary because it was understood and it could be controlled.

Plastic wear (a combination of plastic deformation and wear) and tension-tension fatigue were identified as the main deterioration mechanisms of drum winder ropes. It was also reasoned that "backslip" was the main contributor to plastic wear. Plastic wear would produce flattened wire surfaces with a "ragged feather edge". It was further reasoned that this edge increased the susceptibility of the wire to crack initiation, and that broken wires would therefore occur at load ranges lower than that of new ropes under tension-tension fatigue loading.

The report recommended that:

- ? actual backslip should be measured on (rock) drum winders,
- ? some bending-tension fatigue tests be carried out (to verify whether bending in conjunction with tensile fatigue results in shorter rope life, and that bending with fluctuating loads produces locations for early fatigue crack initiation),
- ? perform tension-tension fatigue tests
- ? develop the design of a full-scale testing rig to simulate the identified rope deterioration mechanisms.

The Steering Committee requested bending-tension fatigue tests to be carried out. These tests were done <sup>r19</sup> at the National Engineering Laboratory (NEL) in Glasgow. After analysis of the specimens, Chaplin concluded that the NEL tests did not simulate the damaging mechanisms experienced during normal drum winding operations.

#### **Drum winder rope deterioration study: simulation and backslip, March 1990 (ref. r14)**

From the introduction of the report the following:

"The rope degradation process in drum winders is thought to involve a number of features which act in combination. These operational characteristics which must all be incorporated in an attempt to simulate deterioration, include:

- ? tensile load fluctuation -essentially determined in magnitude by the skip payload with some amplification due to accelerations;
- ? bending fatigue from wrapping and unwrapping on the drum - with some local accentuation from crossovers;
- ? slip of rope on the drum as the unwinding rope recovers in length from the stretched, higher tension, condition in which it was wound onto the drum (slipback).

These operational characteristics must all be incorporated in any attempt to simulate deterioration."

Slipback is then quantified by deriving an equation for slipback in terms of rope tensions, drum diameter, rope stiffness and friction.

From measurements carried out on a drum winder, it is calculated in the report that slipback will take place over a drum angle of 284°. It is then concluded that a testing facility with sheaves only (180° wrap) will not be able to duplicate the wrap angle realistically - drums will be required to give at least 1,5 turns of contact.

#### **Drum winder rope deterioration study - draft final report, April 1990 (ref. r15)**

The report is a collection and expansion of the preceding reports. The following extracts from the report:

"The investigation set out with two main objectives:

- ? to investigate the primary mechanisms of rope degradation in drum winders, developing an understanding of the extent to which mechanisms were independent or interactive;
- ? to establish the feasibility of simulating the winding rope degradation process, identifying the essential features of any test facility and outlining the test procedure."

The report contained the following on "the rope degradation process":

"The rope degradation process in drum winders has been found to involve a number of operational characteristics acting in combination which include:

- ? tensile load fluctuation - essentially determined in magnitude by the skip payload with some amplification due to accelerations;
- ? bending fatigue from wrapping and unwrapping on the drum - with some local accentuation in cross-over (turn and layer) regions, combined with bending over the sheave;
- ? slip of rope over rope on the drum as the unwinding rope recovers in length from the stretched, higher tension, condition in which it was wound onto the drum (slipback).

Thus the essential components are winding on and off at different tensions leading to slip

(which causes *plastic wear*), combined with bending and tensile fatigue. The plastic wear results from the *slipback* of the rope on the drum, and induces a flattening of the wire with a ragged feather-edge. Fatigue cracks in the wire initiate from this feather-edge under the influence of bending and tensile load fluctuations. Previous simulations have not attempted to model this action which is seen as vital to achieve any realism."

An equation for slipback is given, showing that the amount of slipback is greater for the rope front end compared to the back end. The report also gives an equation for the "friction work" associated with frictional slipping of rope on rope on the drum. It is shown that the friction work increases towards the drum end of the rope. Drum winder rope deterioration is also always greater towards the drum end of a rope.

On "simulation" the report continues that the features that are essential to any simulation are:

- ? rope wrapped around a cylinder of conventional diameter;
- ? tensions which can be controlled between winding on and off;
- ? contact angle which is in excess of one and a half full turns;
- ? motion on and off the cylinder of at least one and a half full turns;
- ? rope bearing onto rope on the cylinder with the provision for running with and without crossover geometry.

The report continues that "Only one configuration appears to offer a realistic means of achieving these requirements: effectively a drum winder and return sheave with displacement system to control tension levels." The report further outlines testing system specifications and a test programme.

The report concludes "that simulation of the winding rope degradation is feasible and can be achieved by means of a test facility which incorporates the slipback plastic wear process with associated fatigue loads."

### **Backslip: a re-evaluation, July 1990 (ref. r16)**

The equation for the "friction work" associated with frictional slipping of rope on rope on the drum derived in the report "Drum winder rope deterioration study - draft final report" was found to have a slight error. The corrected term is given in the "re-evaluation" report.

Where frictional work was previously shown to increase towards the back end of the rope, the new equation gives a constant value along the length of the rope (if winder dynamics are not considered). However, it is argued that the simplicity of the equation could be misleading, and that it would be naive to assume that plastic wear is a simple function of frictional work. The report maintains that backslip is the major contributor to plastic wear and therefore rope degradation.

### **Papers subsequently published by Chaplin**

The complete content of the drum winder deterioration mechanisms derived by Chaplin is given in two published papers listed at the beginning of this section.

On the friction work during slipback the first of the papers states: "To assume that the plastic wear of the rope is a simple function of this friction term alone would be naive. Wear of steel on steel is regarded as a highly complex process for which there is no simple predictive analysis. The backslip work is certainly relevant, and an essential part of the mechanism, but a moment's reflection of loading extremes will demonstrate that other factors will compound to influence any relationship between frictional shear work and wear." The second paper indicates that winder dynamics and contact stresses between rope layers on the drum will influence the *plastic wear* as well.

The first paper concludes:

"There are two major mechanisms of degradation in triangular strand ropes operating on multi-layer drum winders: plastic wear of outer wires and fatigue.

The primary cause of plastic wear is backslip (or creep) of the rope on the drum as the empty conveyance is lowered. The classical analysis of backslip indicates that wear rate would be expected to be a function of tension range alone, but the very high stresses between wires in adjacent layers of rope on the drum give a considerable weight to this parameter. The effect of the plastic wear is to render the wire more susceptible to the initiation of fatigue cracks.

The major fatigue loading component is due to the payload, but with significant enhancement from dynamic factors, especially during acceleration and braking."

References: r20, r21, r22.....INFO, DET  
The following reports on **the continuation of the statistical analysis of the in-service performance of winder ropes** are summarised together.

Van Zyl, Mike: Information on 99 drum winders and 711 discarded winder ropes. CSIR Contract report MST(90)MHT3, May 1990. ....	133 pages
Van Zyl, Mike: Relationships and trends of drum winder parameters. CSIR Contract report MST(90)MHT10, November 1990. ....	128 pages
Van Zyl, Mike: A life prediction model for drum winder ropes. CSIR Contract report MST(91)MC662, February 1991. ....	129 pages

Sponsor: Chamber of Mines

## Summary

The aim of the statistical analysis was to model the life of a rope, expressed in "cycles to discard" as a dependent variable in terms of the winder and rope specifications and other variables. The model would therefore determine the factors that influence the service lives of ropes on drum winders, and how rope lives would be affected if these factors were changed.

Rock winders were selected for the study because they operate on a fairly well-defined and repetitive working cycle.

The "information" report contains the principal winder parameters, the rope parameters and the service lives achieved for 99 winders. On average, the service lives of three ropes sets per winder are given in the report.

The statistical analysis of the in-service performance of winder ropes, which used the described data set as input, had to distinguish between ropes that were discarded because they had reached the end of their useful lives, and ropes that were discarded while still in good working order. This "censoring" of rope lifetimes is explained in the report.

Although the data in the "information" report were originally collected purely to serve as input for the statistical analysis, the report is a unique collection on, and a reference document for the design of drum winders.

All the parameters and variables used in the statistical model searches are discussed in the "relationships and trends" report. The report also expanded on the "information" report by the tabulation of most of the data in categories (instead of by winder) and by showing the distribution of the data in the form of histograms. Graphs of winder and rope parameters as functions of winding (shaft) depth and cycles to discard are also shown. The derivation of all the variables used in the statistical model searches are shown in the report, and are included in the tables, histograms and graphs.

The complexity of the statistical analysis is highlighted in the "relationships" report, because the graphs of winder and derived variables versus cycles to discard do not show any direct or straightforward relationships.

The "life prediction" report describes the selection of a model from various models generated by the statistical analysis process (the distribution-free Cox proportional hazards regression model). The statistical analysis technique is not discussed in detail on the report, but the variables used for the model searches are discussed. The usefulness of a selected model depends on its ability to make sound predictions. The final selection of an appropriate model was not based on statistical considerations only, but models were evaluated by considering how they could be interpreted in an engineering sense.

While the "relationships and trends" report showed no significant relationships between the variables used in the statistical analysis and rope life, the model finally selected predicted rope life quite accurately (of the winders in the "information" report).

The report also states that the deterioration mechanisms of drum winder ropes were not yet fully understood and the predicted influence of some of the variables of the model could be contested. The complex way in which the winder and rope parameters interact with the variables of the model created difficulties in isolating their discrete influences.

The report gives recommendations on how model searches should be conducted if a statistical analysis of rope service lives is ever attempted again.

The report concludes that a model, based on the most important parameters of a winder installation and with good rope life predictive qualities had been generated, but that the model should be used with caution, as the influence of some of the winder parameters on rope life is not fully understood.

The importance of drum winder rope deterioration mechanisms and rope discard criteria were highlighted by the execution of the statistical analysis.

**Comment:**

The final result of the statistical analysis was not quite what was expected (or as originally anticipated). This was most probably because deterioration mechanisms of drum winder ropes were not yet understood, and that the input variables for the statistical analysis were therefore not the best selection. Other factors that influence rope lives, and that could not be determined (quantified) for the analysis were rope maintenance (rope lubrication, pulling in of back-ends), and the coiling arrangement on the winder drums (contact stresses: see the GAP501 report, ref. r102).

Reference: r23 ..... DYN  
**Drum winder rope forces generated during emergency braking, normal acceleration and skip loading.**  
Mike van Zyl  
CSIR Contract report MST(91)MC714, April 1991.  
Sponsor: Chamber of Mines .....91 pages

The findings were originally published in three draft reports, and it was later decided to consolidate the findings into the one report mentioned above. The tasks originally undertaken and the draft reports by Nicola De Veredicis and Mike van Zyl were:

- ? The calculation of rope loads generated on a drum winder during emergency braking under constant deceleration rates. Draft report: Dynamic behaviour of winder systems: Influence of depth on emergency braking; February 1989.
- ? The rope loads generated during normal accelerations and decelerations of a winder. Draft report:: Dynamic behaviour of winder systems: Influence of drum acceleration during normal hoisting; June 1989.
- ? The rope loads generated during loading of the skip at different loading rate. Draft report: Dynamic behaviour of winder systems: Rope forces generated by loading the skip; June 1989.

### **Summary of the final report**

The theoretical prediction and experimental determination of the rope forces of drum winders were two of the original projects undertaken for studying the validity of the current safety regulations in South Africa. The work was carried out by SDRC (USA), and their report<sup>7</sup> describes:

- ? Experimental rope force measurements on three winders;
- ? a finite element based computer program for the calculation of rope forces generated during different operating conditions (program ROPE); and
- ? a theoretical study of the influence of depth on rope forces during emergency braking.

The Steering Committee requested the CSIR to expand on the theoretical study of SDRC and to include:

- ? The influence of depth and total attached mass on the rope loads during emergency braking under constant decelerations;
- ? the influence of different shaped accelerations on rope loads during normal hoisting; and
- ? the effect of different skip loading rates on rope loads generated.

All the calculations of rope forces in the CSIR report were done with program ROPE developed by SDRC. A constant rope stiffness (not varying with applied tension) was used, and the winder ropes were given some internal damping.

The results of the investigation showed that, whenever the winding rope was given some damping, the skip-rope system behaved like a spring-mass system with a single degree-of-freedom, even for very small values of internal rope damping (of the order of that of solid steel). Simple relationships could therefore be derived with which the maximum rope loads could be approximated for the different winder operations.

The results also showed that the value of the elastic modulus of the rope does not have an influence on rope forces during constant accelerations and decelerations (but it has an influence on the natural frequency of the system of course).

It is further shown that the ratio of dynamic to static rope forces during emergency braking under

instantaneously applied constant decelerations is only dependent on the magnitude of the deceleration and is insensitive to depth or the ratio of the attached mass to the total suspended mass. A "critical depth", as proposed by Vaughan, which was used as a basis for the capacity factor part of the current regulations, does not exist, because the ratio of the dynamic to static rope force is not sensitive to depth.

The report shows that maximum rope load generated by accelerations or decelerations applied to a rope-mass system can be approximated by the following equation:

$$\frac{\text{Maximum rope load}}{\text{Static rope load}} = 1 + \frac{2a}{g}$$

where  $a$  = constant acceleration or deceleration  
 $g$  = gravitational acceleration

The "2a" term in the above equation represents a "100% dynamic overshoot".

The maximum rope load will be reached if the constant acceleration or deceleration is maintained for at least one half the (first) natural period of the system. Gradually applied (ramped) accelerations reduce the "dynamic overshoot". If the time of the ramp equal the first natural period of the system, dynamic components of the rope loads can be eliminated.

Attaching a load instantaneously to the end of the rope will cause a "100% overshoot" of the load. More gradual loading will reduce the overshoot.

**Comment:**

Loading (gradually) from some height above the skip was not considered. The momentum of the rock falling into the skip would increase maximum rope loads. More gradual loading will also reduce these maximum loads.

Hamilton (ref. r26) did more work on the loading of rock.

Reference: r24 ..... DYN  
**Drum winder rope forces generated by the occurrence of slack rope - a mathematical method**  
Mike van Zyl  
CSIR Report MST(91)MC867, September 1991.  
Sponsor: Chamber of Mines .....93 pages

**Summary**

A theoretical analysis of the rope forces generated after the occurrence of slack rope on drum winders was requested by the Steering Committee.

The report shows the full derivation of a mathematical model that was developed for the calculation of the rope forces in the rope-conveyance systems after the occurrence of a slack rope condition. The model used a rope elastic modulus that did not vary with applied rope tension, and internal rope damping was included.

The rope forces were determined for a number of different winder installations to establish the general behaviour of rope-conveyance systems when subjected to a slack rope condition. The effect of changes to the current winder rope safety regulations on the generated rope forces was also analysed.

The results of the investigation showed that the severity of slack rope would increase if the values of Capacity Factor and Safety Factor were reduced.

**Comment:**

The report is also of interest from a mathematical and stress analysis viewpoint, because it contains the full derivation of the mathematical model (with and without rope damping).

Reference: r25 ..... DYN  
**Dynamic rope loads in winding systems - an analytical approach**  
ME Greenway  
Mechanical Engineering Department, Anglo American Corporation, February 1989  
Sponsor: AAC .....52 pages

In October 1989, a note on corrections and an additional appendix to the report was issued.

### From the summary of the report

"In reviewing the philosophy of factors of safety of winding ropes, and winding rope selection strategy it is necessary to determine, by analytical and experimental means, the peak dynamic loads that are developed under all possible operating and emergency conditions. This determination needs to be as comprehensive as possible and needs to confidently allow extrapolations of design parameters beyond the domain of current practice into domains of possible future practice.

This report offers an analytical approach to the determination of peak winder loads that are developed in response to winding drum accelerations. Undamped solutions are developed, but these are later refined to include the effects of damping. The contributions of the various modes of vibration to the peak dynamic loads are discussed. The ratio of rope mass to attached mass ( $\mu$ ) is one of the design parameters which affect the peak loads, and its effect on peak loads is analysed for a wide range of  $\mu$  values from 0,05 to 20. The limiting cases of  $\mu = 0$  and  $\mu = \infty$  are also reviewed.

The values of peak dynamic load as a function of damping and rope mass ratio are used to develop plots of the ratio of *dynamic* to *static* factors of safety. With the inclusion of damping, the results bear a close correspondence to curves produced by Kuun<sup>r11</sup> which were obtained empirically from various published experimental and analytical material. Hence, a purely analytical basis is established confirming Kuun's conclusions that the dynamic factor of safety is only a weak function of shaft depth and rope selection strategy. This conclusion is of major significance in the CoMRO review of winding rope factors of safety, winding rope selection criteria, and winding rope utilisation.

Finally, the influence of the winder's acceleration-time profile on peak dynamic rope loads is reviewed and it is shown that suitable acceleration/deceleration control techniques could be used to limit peak dynamic rope loads."

### Comment:

The report does not contain a full derivation of the analytical technique used; the reader is referred to one of the references. The report is therefore only useful for its results and conclusions.

The report confirmed that rope loads generated when a winder is accelerated or decelerated is not dependent on shaft depth (i.e. the ratio between the rope mass and the attached mass).

The report finds that the maximum rope loads are weakly dependent on shaft depth: 100% "overshoot" at shallow depth and 83% for very deep shafts. The "overshoot" values depend, of course, on the damping coefficient used, and how damping was incorporated into the calculations. A shallow shaft could also give an 83% overshoot instead of 100% if the rope damping is incorporated differently (see ref. r96).

Reference: r26 ..... DYN  
**Dynamic response of freely suspended skips during ore loading**  
RS Hamilton  
Mechanical Engineering Department, Anglo American Corporation, November 1989  
Sponsor: AAC .....20 pages

**From the summary of the report**

"When ore is loaded into a freely suspended skip, the resulting forces cause a lowering in the static position of the skip (typically 2 to 3 metres) as well as harmonic oscillations. Adverse effects of these motions include spillage of ore as well as increased dynamic forces and fatigue in the rope. After loading, the residual oscillations of the skip can add to the peak dynamic rope loads experienced during the acceleration period of the winding cycle, depending on chance phasing between the oscillation and the start of acceleration.

This report seeks to model the dynamic behaviour of the skip in order to be able to predict and minimise the oscillations.

An equation of motion describing the motion of the skip is presented. A routine to solve the equation numerically is developed and used to model the behaviour of skips at Vaal Reefs No. 9 shaft and a proposed deep single lift shaft. The influence of various loading parameters such as loading time, impact velocity and total load is examined in more detail. An appropriate empirical formula is developed which can be used to calculate the optimum loading time of the skip."

**Comment:**

The rope-attached mass system is approximated as a single degree of freedom system with one third of the rope mass added to the attached mass. The results were much the same as those of an earlier report<sup>r23</sup> for which a finite element based numerical solution was used.

"Optimum" loading times calculated are dependent on the rope stiffness used, but errors in rope stiffness of 20% will only give a 10% error in a calculated optimum loading time.

What is of importance in this report is that the concept of the rock load "hitting" the skip at a certain velocity is introduced. If the loading time is not the optimum then the generated rope loads could be significantly higher than the static loads. The higher the impact velocity, the higher the generated rope loads, of course.

Reference: r27 ..... DYN  
**The use of clamping devices to control the dynamic response of skips during ore loading**  
RS Hamilton  
Report no. 90-T-4, Mech. Eng. Dept., Anglo American Corporation, February 1990  
Sponsor: AAC .....20 pages

**From the summary of the report**

"This report assesses a method of loading a skip with ore where the skip is clamped in the loading station using friction clamps acting on rails attached to the skip. By releasing the clamping pressure in an exponentially decaying manner, the load is gradually applied to the rope with minimum dynamic response."

**Summary**

The report describes the development of a mathematical model to simulate the behaviour of the skip when the clamps are released, thereby providing a tool for predicting and optimising the skip's dynamic response

An equation of motion that takes into account friction at the clamping surface was developed. A numerical solution was presented and used to model the behaviour of a skip at Vaal Reefs No. 9 shaft. The influences of various parameters such as friction coefficients, release rate and payload mass were examined in detail to provide guidelines for the design of such systems.

**Comment:**

The report notes that the dynamic and static rope stretch is as much a problem in long ropes as dynamic rope loads. Rope stretch will cause operating problems during loading (spilling).

From a mathematical viewpoint: The rope-attached mass system was modelled as a simple (single degree-of-freedom) spring-mass system with coulomb damper and one third of the rope mass added to the conveyance to obtain an approximate correct frequency of oscillation. Rope elasticity is based on a rope modulus of 110 GPa and the value for the damping incorporated in the mathematical model was not given.

Although calculated peak rope loads are dependent on the damping used, and the frequency response of the rope-attached mass system is dependent on the selected rope stiffness, the calculated responses of the report should still be of the correct order for practical considerations.

Reference: r28 ..... DYN  
**Dynamic rope loads due to cage loading**  
ME Greenway  
Report no. 90-T-09, Mech. Eng. Dept., Anglo American Corporation, June 1990  
Sponsor: AAC .....42 pages

### **From the summary of the report**

"In reviewing the philosophy of factors of safety for winding ropes, and winding rope selection strategy it is necessary to determine, by analytical and experimental means, the peak dynamic loads that are developed under all possible operating and emergency conditions. The determination needs to be as comprehensive as possible and needs to confidently allow extrapolations of design parameters beyond the domain of current practice into domains of possible future practice. This report offers an analytical approach to the determination of peak rope loads that are developed during cage loading.

Relationships for the dynamic magnification factors and the ratio of peak dynamic rope load to static load at the upper end and lower end of the rope due to suddenly applied loads are obtained. Deep shafts are found to be relatively safer than shallow ones. The loading of material cars and the sudden release of hydraulic kepping clamps can be regarded as suddenly applied loads.

If, during release of keps, the load can be applied progressively at a controlled rate then dynamic rope loads can be reduced. Linearly ramped and exponentially applied loads are examples of controlled load application. Dynamic response solutions are also given for these loading functions and optimum parameters are derived."

### **Comment:**

Cage loading refers to the loading of men, material and material in cars, as opposed to skip loading, which is the loading of rock (ore).

Essentially, optimum releasing parameters were sought through the investigation in order to minimise dynamic responses.

The report does not consider the use of "stiff" keps as holding devices during loading.

From a mathematical viewpoint: full mathematical derivations of the equations are not given in the report. The analytical approach to the problem consists of a rope with evenly distributed mass and a cage attached at the end of the rope. Additional load is added to the cage as a function of time.

The response of an undamped system is also included in the report, but it should be remembered that such a response is totally unrealistic because all winder ropes have damping properties.

However, the analysis shows that the peak effect of a suddenly applied load is twice the weight of the load added, and that this effect can be reduced by kepping and releasing the keps in a controlled manner.

Optimum release rates depend, of course, on the actual rope stiffness and internal rope damping which could be different to that used in the analysis of the report.

Reference: r29 .....DYN, DEEP  
**A simple static and dynamic analysis of coupled extensional-torsional behaviour of winding rope**  
ME Greenway  
Report no. 90-T-22, Mech. Eng. Dept., Anglo American Corporation, November 1990  
Sponsor: AAC .....22 pages

### **From the summary of the report**

"Triangular strand rope is known to respond quite strongly in torsion to applied axial loads. The influence of this torsional response on the natural frequencies and dynamic response of a heavy rope/end mass system has not previously been adequately established. To assess this problem, the lowest natural frequency of coupled extensional-torsional vibration is determined using the Rayleigh method.

This is based on the assumption that the dynamic deflected shape is the same as the static one. Hence, initially, the static axial displacement and rotation of a vertically hanging rope with end load is established.

This is also used to determine the elastic laylength changes in the rope. For triangular strand rope, there are significant laylength changes and it turns out that essentially the same parameters that affect these laylength changes also influence the lowest natural frequency of coupled extensional-torsional vibration.

To obtain accurate results from the analysis, improved test data specifying the extensional-torsional response of commonly used rope construction (triangular strand and non-spin ropes) are required. Experimental methods for establishing this information are discussed."

### **Comment:**

The report found that the "curves for the frequency of coupled extension-torsional vibration differ strongly from the curves for extensional only vibration. The large difference between the natural frequency for coupled extensional-torsional vibration and extensional only vibration was not expected before this analysis was undertaken. It was hoped that the Rayleigh method would justify, by means of straightforward physical reasoning, other author's claims that the coupled extensional-torsional vibration has no significant influence on the dynamic response of a rope and end mass system. Faced with this contradictory result, it is essential that more detailed analysis of the coupled extensional-torsional vibration problem should be carried out."

In a footnote added in the report, Greenway states that "initial numerical analysis based on the finite element method, and yet to be reported, shows that mode shapes and frequencies are indeed influenced by the extensional-torsional coupling but this does not significantly influence the rope's dynamic response to transient loading events." (See ref. r31 as well.)

The erroneous results of the report described could have resulted from assuming incorrect torque-tension properties for ropes, incorrectly assuming that "when the rope and end mass system vibrates at its lowest natural frequency, it vibrates in a mode shape equal to the static deflected shape" (in extension as well as torsion), and not taking the extensional as well as torsional damping of a triangular strand rope into account.

However, the report shows a different method for calculating the torque-tension response of ropes, and drawing attention to possible effects of the coupling of extensional and torsional behaviour.

Reference: r30 ..... DYN  
**Dynamic rope loads developed in response to instantaneous winder braking**  
ME Greenway  
Report no. 91-T-11, Mech. Eng. Dept., Anglo American Corporation, June 1991  
Sponsor: AAC .....43 pages

### **From the summary of the report**

"Although brake engines on winders cannot develop sufficient retardation torque to stop a winder from full speed instantaneously, this load case did form the basis of a modal problem studied by JA Vaughan in the early part of this century. As Chief Inspector of Machinery at the time, he was particularly instrumental in formulating the rope factor of safety legislation that has prevailed since then.

In this report the instantaneous winder braking load case is revisited. Early solutions are studied parametrically with the benefit of modern computational and plotting facilities. Alternative mathematical solutions are developed which allow the influence of damping to be studied. The bases for Vaughan's thinking - namely the use of a capacity factor which provides for a reducing effective factor of safety as depth increases and then a constant factor of safety beyond the "critical depth" - is brought out in the analysis and graphical plots. However, the rationale is wide open to the criticism of instantaneous braking from full winding speed being impractical.

The load case analysed is equally applicable to instantaneous changes in winding speed and is thus judged to be realistic in the case of final clamping of a winder drum from creep speed on terminal braking, and also to the very abrupt change of winding rope speed that occur during layer cross over. In these two practical situations the amplitude of the dynamic rope loads are much smaller than the instantaneous braking from full speed because the change of winding speed is much less than full winding speed (about 10%)."

### **Comment:**

For academic interest: The report gives the partial derivation and the results of analytical solutions for the undamped and damped rope of a heavy rope-attached mass system. The analytical solutions are not given in full - the reader is referred to literature.

The results shown for an undamped rope in the report is purely academic and unrealistic. Only the results for the damped case are relevant.

Reference: r31 .....DYN, DEEP  
**A finite element study of the coupled extensional-torsional behaviour of winding rope**  
RS Hamilton and ME Greenway  
Report no. 91-T-16, Mech. Eng. Dept., Anglo American Corporation, October 1991  
Sponsor: AAC .....50 pages

### **From the summary of the report**

"Triangular strand winding rope is known to be strongly torsional in its response to axial loading. Concern has arisen over the suitability of such ropes for use in future deep shafts since changes in lay length increase with depth and also since previous studies of the dynamic extensional-torsional behaviour of heavy rope/end mass systems have been inconclusive. (ref. r29)

A finite element approach is pursued in order to assess the influence of extensional-torsional coupling on winder dynamics. The model assumes the behaviour of the rope to be linear and elastic and the effects of damping are ignored. The results of tests carried out by the CSIR on a sample of triangular strand rope have been studied to obtain the constants for the linear elastic model.

The normal mode method is used to analyse the finite element model. Using this approach, natural frequencies and mode shapes are easily determined. The response of a rope and conveyance system to typical forms of dynamic loading is investigated using mode superposition techniques.

Extensional-torsional coupling is found to strongly influence the natural frequencies and mode shapes of a rope and conveyance system."

### **From the conclusions and recommendations of the report**

"Although the mode shapes of a system with extensional-torsional coupling differ significantly from an equivalent system where these terms are ignored, the fundamental extensional mode has been shown to dominate the response to typical dynamic loading events in both cases. The frequency of this mode is increased only slightly by the introduction of the coupling terms.

Axial rope forces, which are of primary concern in assessing the response of a winding system, are not significantly affected by the introduction of extensional-torsional coupling. It can therefore be concluded that models that only take account of the extensional behaviour of a rope are, in most cases, adequate for analysing dynamic winder behaviour."

### **Comment:**

With the shape of the torque-tension properties of the rope that was assumed for the calculations in the report, there should not have been any tendency of the rope to rotate when loaded or when subjected to extensional dynamics (once the rope has assumed its changed laylength state in the shaft). The validity of the assumed expressions relating rope load and rope torque to axial and angular strain of the report are therefore questionable. These expressions formed the basis of the analysis in the report.

Reference: r32 ..... DYN  
**Dynamic response of conveyances during friction clamp release**  
A D'Arcy-Evans and R A Backeberg  
Chamber of Mines Research Organisation, June 1992  
Sponsor: Chamber of Mines .....28 pages

### **From the abstract of the report**

"Over the years the increasing depth of South African gold mines and the quest for ever increasing payloads has highlighted problems related to winder rope stretch. Typically, the loading of a conveyance can cause the rope to stretch in the order of 2 metres. The high stresses arising from the resultant dynamic motion contribute to the fatigue life of the winder rope.

This report presents a theoretical analysis of a conveyance being held and then released under friction control. The release rate that results in minimum dynamic loading of the rope is derived. Various simulations of conveyance release using the ideal release curve are presented in order to observe the effect of the various parameters. Simulations with non-ideal release curves are also presented to highlight problems associated with present practice.

Simulations showed that using the ideal release rate results in very low acceleration values (0,2 m/s<sup>2</sup>). For non-ideal release rates, the acceleration was in the range of 1 to 2 m/s<sup>2</sup>. Parameter studies indicated that the higher the difference between the static and kinetic friction coefficients, the higher the resulting maximum acceleration. Further studies indicated that it is better to design a friction controlled device for the greatest envisaged depth and payload, and to operate it at lower depths and payloads than vice versa."

### **Comment:**

The rope-attached mass system was approximated as a single degree of freedom system (a spring with an attached mass). Internal rope damping was not included because it was reasoned that the "damping effect" of the friction clamps would far outweigh the effects of internal rope damping.

The responses calculated are dependent on the static and dynamic friction coefficients, and on the rope elasticity (which is actually rope stress dependent). The trends of the simulations in the report are therefore of value, but actual response times and rope loads can only approximate.

The reports on the same subject by Hamilton and Greenway (refs r27 and r28) studied the effect of exponential clamping force release, whereas the report here also included an "ideal release" and a linear release curve.

For academic interest:: The report gives details of the Newmark integration scheme that was used for the numerical solution of the equations of motion. A listing or a flowchart of the computer program used for the calculations is not given.

Reference: r33 ..... DYN  
**Non-dimensional dynamic response of conveyances during friction clamp release**  
A D'Arcy-Evans and R A Backeberg  
Chamber of Mines Research Organisation, February 1993  
Sponsor: Chamber of Mines ..... 15 pages

### **From the abstract of the report**

"Over the years the increasing depth of South African gold mines and the quest for ever increasing payloads has highlighted problems related to winder rope stretch. Typically, the loading of a conveyance can cause the rope to stretch in the order of 2 metres. The high stresses arising from the resultant dynamic motion contribute to the fatigue life of the winder rope.

The report begins by commenting on the use and effectiveness of a commercially available system to counter the rope stretch problem - the Levelok clamping system. Current practice is reviewed and its performance in terms of loading time and control of dynamic loads is assessed. Maintenance issues are commented on. It is concluded that the Levelok system goes a long way in solving the rope stretch problem.

The report then presents a theoretical analysis of a conveyance being released under friction control. The equations are non-dimensionalised, allowing solution of a general class of problems and not just specific cases. The conveyance response to an exponentially reducing clamp force is investigated and optimum parameter values determined. Minimum release times and maximum accelerations are presented in graphical form."

### **From the report**

"A previous report by the authors (ref. r32) modelled the response of a conveyance being held and then released under friction control. The report had certain limitations, firstly the shape of the clamp release curve chosen was somewhat impractical and secondly the equations were presented in dimensional format, thereby allowing solution for only specific cases. This report also presents a theoretical analysis of a conveyance being released under friction control. The equations are non-dimensionalised, allowing solution of a general class of problems and not just specific cases. The conveyance response to an exponentially reducing clamp force is investigated and optimum parameter values determined. Finally, conclusions are drawn and recommendations given as to future direction."

### **Comment:**

The equations of motion are given in the report, but the MATLAB procedures used for the calculations are not. The dimensionless approach of the analysis makes it more difficult to interpret the results (directly) than for specific case studies.

Nevertheless, the conclusions of the report remain valid: Clamping devices eliminate the effects of rope stretch during conveyance loading, and the rope dynamics after clamp release can be reduced by controlling the rate at which the clamping force is released.

However, the effect of rope dynamics is generally overstated, especially in relation to fatigue in the wires of the rope. Rope dynamics due to clamping device release do not have to be any less severe than that generated by normal winder acceleration. Furthermore, only the ropes operating in very deep shaft are subjected to load ranges large enough to cause tension-tension fatigue breaks in the rope wires.

Reference: r34 .....DET, INFO  
**Fifth report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep.**  
M Borello  
CSIR Contract Report MST(90)MHT5, September 1990  
Sponsor: Chamber of Mines .....230 pages

## Summary

The last set of 52 mm diameter ropes that were discarded from the Elandsrand winder was investigated as before. The reason for the investigation was to enable a direct comparison between this rope set and the subsequent rope set which operated at a lower factor of safety of 4,0 as part of a field trial.

The ropes were removed after 27 months in service and during which time they performed 77 000 winding cycles. The largest reductions in breaking strength, determined by the tensile tests carried out on specimens cut from the full lengths of both ropes, were 2% for the overlay rope and 3,5% for the underlay rope. The magnetic tests (non-destructive tests) carried out on the ropes before they were discarded did not detect any singular points of deterioration, nor did the tensile tests.

The report concluded that the good condition of the ropes and the absence of singular points of deterioration could be attributed to good coiling of the ropes on the drums and the relatively short intervals between pulling in back-ends (approximately every three months from the time that the ropes were installed).

Elastic modulus tests were carried out on specimens of the discarded ropes. It was found that the modulus values increased with increasing rope loads: approximately 60 GPa at 4% of breaking strength to 135 GPa at 40% of breaking strength (elastic modulus values were based on the cross-sectional steel area of the ropes). The modulus values obtained from samples cut from the front end and from back end of the rope gave very much the same values.

Torque-tension-twist tests were also carried out on front end, mid-shaft, and back end sections of one of the ropes. These tests were done to start collecting data and information on the possible change in the torque-tension behaviour with usage of triangular strand ropes in vertical shafts. Unfortunately the torque-tension testing machine on which the tests were carried out could not return the front end and back end samples to their in-service lay- lengths (measured just prior to removal of the ropes from service). Nevertheless, the report contains information that could be useful for future research into the torque-tension behaviour of triangular strand ropes.

## Comment:

It was not reported whether any broken wires were present in the rope specimens that returned the lowest breaking strengths.

The ropes were not at the end of their service lives when they were discarded and were still in relatively good conditions. The ropes were most probably only discarded so that the rope trial at the safety factor of four could commence.

Reference: r35 ..... DET  
**An assessment of the wear mechanisms of wire ropes removed from the rock winder at Elandsrand Gold Mine**  
GJ Wright, JJ Pretorius, IL Maarseveen  
Internal Report MST(90)TR36, Tribology and Surface Engineering Programme, MATTEK, CSIR, October 1990  
Sponsor: CSIR .....42 pages

### **Summary**

An investigation into the dominant wear processes and mechanisms of a wire rope that operated on a drum winder was carried out. The report details the results of an examination into the wear processes of individual wires and strands of a 52 mm diameter rope removed from a double drum winder at Elandsrand Gold Mine (ref. r34).

The investigation was carried out as part of a study to evaluate the feasibility of simulating fatigue and wear of steel wire ropes in a laboratory. Rope sections from the front end, middle and back end of the rope were examined.

The described investigation was a "first attempt" at describing the observed wear and plastic deformation of the outer rope surfaces. The intention of the investigation was to provide a foundation on which to build subsequent investigations.

The report shows numerous interesting photographs of the rope, strands and wires (macroscopic, microscopic, and SEM).

Reference: r36 ..... DET

**A mathematical model of wear mechanisms in a mine hoisting rope**

RA Hunziker, JJ Pretorius

Internal Report MST(91)TR16, Tribology and Surface Engineering Programme, MATTEK, CSIR, March 1991

Sponsor: CSIR .....49 pages

**Summary**

The previous tribology report (ref. r35) was used as a basis for the development of a mathematical model, simulating the primary degradation mechanisms of a wire rope operating on a drum winder. Adhesion, abrasion and plastic deformation were the wear types concentrated on, since evidence for these wear types had been found on a discarded drum winder rope. It was believed that a mathematical model could help explain the effect of the different winder and rope parameters have on the degradation of a rope.

The report noted that previous models that were developed ("slipback", see refs. r15 and r16) did not explain the degradation that increases towards the back end of the rope satisfactory, and that these models were rather "contradictory"; i.e. actually predicted more wear towards the front end.

Models for adhesive wear and abrasive wear were derived. A plastic deformation model based on contact stresses was also derived. Because the greatest degradation of a drum winder rope occurs towards the back-end, the report concluded that the contribution of adhesion and abrasion had to be minor, as these wear models predict more wear towards the front end. The report further concluded that plastic deformation (as a result of multi-layer coiling on a drum) "may be the critical criteria because it follows the same trend as the wear in the rope."

Both the adhesive and the abrasive wear models required relative movement between the rope and another surface, which would be "slipback". It was therefore found that "slipback" was not the main contributor to drum winder rope degradation.

**Comment:**

The findings of this report were finally corroborated by the report on GAP501 (ref. r102).

Reference: r37 .....RCA  
**Condition assessment of winding ropes operating at a factor of safety of four**  
TC Kuun, WP van der Walt and SJ Mostert  
Anglo American Corporation, March 1991  
Sponsor: AAC and Chamber of Mines .....21 pages

**From the summary of the report**

"Field trials at Elandsrand indicated that mine winding rope operating at a nominal factor of safety of 4,0 deteriorate in the normal way. Present discard criteria and condition assessment techniques are adequate at these load levels."

**From the contents of the report**

The report compares the condition of the ropes (during the service life period) to that of the previous set of 52 mm ropes and also to that of the 48 mm ropes of the BMR winder operating in the same shaft. The comparison included total number of broken wires, rope diameter, rope laylength, and the results of statutory front-end rope tests carried out at various times during the service lives of the ropes.

The report mentioned that "except for a more rapid increase in the number of broken wires the lower factor ropes behaved normally."

The ropes were removed from service after 16 months, in which 56 000 winding cycles were completed. The ropes were discarded because of "a combination of broken wires and rope diameter reduction" of the overlay rope. It was estimated that the underlay rope could "probably have lasted another three or four months."

Two locations were identified on the overlay rope that was reason for discard. At the one location there were three broken wires in one strand, and at the second location there were two broken wires in one strand and a "creeping wire" in an adjacent strand. Breaking strength tests carried out on rope samples that included these locations returned strength reductions of 5,7% and 6%.

The report also concluded that "rope life can be extended by regular pulling in of the back end". (The back ends were pulled in every two months until the ropes were discarded.)

**Comment:**

Also see the report on the detailed discarded rope tests on the two 48 mm ropes (ref. 38).

Reference: r38 .....DET, INFO  
**Sixth report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep.**  
M Borello  
CSIR Contract Report MST(91)MC702, April 1991  
Sponsor: Chamber of Mines .....214 pages

## Summary

This "sixth report" describes details of tensile tests carried out on samples taken from the whole length of each of two 48 mm ropes that were discarded from the Elandsrand winder. The ropes were the first ropes to operate at a safety factor of 4 as part of a field trial carried out with special permission from the authorities.

In addition, modulus of elasticity and torque-tension tests were carried out to determine whether and by how much these rope characteristics varied from the front to the back in a used rope and by how much the characteristics changed from those of a new rope. The total cross-sectional area of a couple of samples were also determined in order to obtain a measure of the actual loss of material as opposed to pure plastic deformation on the outer wires of the ropes. (The tests carried in this report were the same as that described in the "fifth report".)

The ropes were removed from service after 16 months, in which 56 000 winding cycles were completed. The back-ends of the rope were pulled in every two months.

The lowest breaking strengths were 6,3% less than new for the overlay rope, and 1,6% less than new for the underlay rope.

The back-end of a rope on a drum winder always shows the greatest amount of visible degradation, which is mainly plastic deformation of the outer wires. One section of rope was selected from the back end of the underlay rope and one section from the front end of the rope for the cross-sectional area tests. The reference cross-sectional area was determined from a section of the "stock" sample of the rope that was kept by the rope manufacturer. The back-end section had an area loss of 1,8% compared to the 0,5% of the front end.

During the torque-tension tests the back end rope sample could be returned to its in-service laylength (measured just prior to removal of the ropes from service), but the front end sample could not be returned to the in-service laylength because of the limitations of the testing machine. Nevertheless, and as was the case for the information of the "fifth report" (ref. 34), the information in the report will be useful for future research into the torque-tension behaviour of triangular strand ropes.

## Comment:

Also see ref. r37.

The diameter of the headsheaves of the winder is incorrectly given as 4,88 m in the report. The headsheaves were changed to 5,54 m diameter when the first set of 48 mm ropes was installed on the winder.

Reference: r39 ..... DET  
**An assessment of the wear mechanisms of the 48 mm ropes removed from the Siemens double drum rock winder at the Elandsrand Gold Mine in January 1991**  
RA Hunziker, JJ Pretorius, IL Maarseveen  
CSIR Internal Report MST(91)TR20, October 1991  
Sponsor: CSIR .....36 pages

## Summary

The rope sections that were investigated were from the same ropes described in the Kuun report<sup>r37</sup> and the "Sixth report" by Borello<sup>r38</sup>. The investigation on the 48 mm ropes was a continuation of the first investigation (on the 52 mm ropes) described in ref. 35 and was carried out to "built on the information provided in the initial study."

The two focus areas of the report were cross-sectional area measurements of the wires, and the examination and classification of surfaces exhibiting wear.

The report contains numerous interesting photographs and micrographs of the surfaces of the wires of the ropes.

It was reported that the results of the investigation were very similar to those of the previous report (ref. r35). It was concluded that the plastic deformation of the outer wires was more pronounced at the back end of the rope, and that the amount of abrasion was greatest at the front end of the rope. The area measurements showed that the percentage volume removed from the wires increased from the front to the back end section.

Reference: r40 ..... DET  
**Wear mechanisms of drum winder ropes**  
RA Hunziker, JJ Pretorius, and Mike van Zyl  
CSIR Contract Report MST(92)MC1109, June 1992  
Sponsor: Chamber of Mines .....32 pages

### **Summary**

In this report the models for adhesion, abrasion and plastic deformation of an earlier internal CSIR investigation (ref. 36) were developed further, and written in terms of the radial rope loads exerted by a rope on a winder drum, and in terms of the backslip of the rope on the drum.

Although the report was based largely on the previous investigation, it is a standalone document that incorporated the wear observed on discarded drum winder ropes.

All three models indicate that wear takes place primarily on the drum, and that plastic deformation is the dominating deterioration mechanism. According to the models, the wear caused by slip-back of the rope on the drum is of minor importance.

The report further concluded that "if the predictions of the wear models are correct, then the ropes on a counterweight drum winder should show wear patterns comparable to that of rock winders subjected to equivalent maximum rope loads". (A counterweight rope does not experience slip-back on the drum.)

The report therefore recommended an investigation of the deterioration of the ropes on a counterweight drum winder.

### **Comment:**

Appendix B of the report has a typing error: Page 31 equation B4: delete the "4" in the equation.

It is worthwhile to note that the "counterweight drum winder investigation" was eventually done as part of the SIMRAC investigation GAP501 (1998) (ref. r102), and that the conclusions of the "wear model" report were corroborated by that investigation.

### **From the executive summary of the report**

"Newly proposed safety regulations for drum winder ropes were based on current drum winder hoisting experience. In his proposals (for new rope regulations, ref. r53) Hecker showed that safety would not be compromised if the peak rope loads are controlled and if the remaining strength of ropes in service is not allowed to decrease beyond a given limit.

Although higher (static) rope loads will be attainable if the proposed regulations are accepted, a further clause in the proposals will limit the load range that drum winder ropes may experience. This load range limit is based on current winder practice and was incorporated as an attempt to restrict the rate of deterioration of these ropes. The rate at which ropes will deteriorate at higher mean loads and higher load ranges is currently not known. Changes to the safety regulations beyond the proposed limits without compromising safety will only be possible if the deterioration mechanisms of drum winder ropes are verified for higher rope duties.

Attempts at quantifying rope deterioration as observed on drum winders and predicting operating lives for ropes have, to date, been unsuccessful. Most of the problems experienced during these earlier studies resulted from the fact that the level of knowledge on the behaviour of drum winder ropes was always overestimated. The indications are that the calculation of rope deterioration will still not be possible in the near future. Deterioration studies for drum winder ropes at higher rope duties must therefore be done experimentally. If the behaviour of ropes on drum winders is not properly understood, laboratory simulations will not provide reliable results. Two alternatives therefore remain in order to achieve a set of regulations based on true safety:

- ? Change the operating parameters on selected winders to move into the unknown territory gradually (as is currently being done by Anglo American with the field trial at the Elandsrand winder), or
- ? Built a test facility on which the behaviour of ropes on drum winders can be duplicated.

This feasibility study on a drum winder rope test facility addresses the issues of rope behaviour on drum winders, the ability to duplicate winder behaviour on a test facility, and the estimated cost to build and operate such a facility.

It is concluded that a test facility that **will** duplicate the behaviour of drum winder ropes can be built. It should be cautioned that the capabilities of such a machine will have to be verified once it is constructed, **even** after further detailed design verification and rope behaviour studies."

### **Notes on the contents of the report**

Rope elongation and slipback as a function of a rope elastic modulus that varies (increases) with rope tension is calculated in the report. The torque-tension-twisting behaviour of a triangular strand rope in a vertical shaft is also derived and calculated.

The report also shows continuous recordings carried out on the Elandsrand drum winder. The rope loads at both headsheaves were measured together with the rope load and torque at the underlay skip (front-end load). The displacement/speed/acceleration of the winder drum was also recorded. The report shows all of these measurements for ten consecutive winding cycles.

Discrete measurements of slipback on the drum and rope rotation while the rope moves through the catenary are also described for the Elandsrand winder ropes. Having described the interaction between a winding rope and its environment, the report investigated a number of concepts for the simulation and/or duplication of the degradation of drum winder ropes.

**Comment:**

On what constituted the major deterioration mechanism for drum winder ropes, the report "hovers" between Chaplin's "backslip" (see ref. r16) and the findings of the "wear mechanisms" report (ref. r40).

The above and the effect of the assumed stress variations produced by bending of the rope over a sheave of this "feasibility report" have to be compared to the findings and conclusions reached in the GAP501 report (ref. r102).

Reference: r42 ..... DET  
**Seventh report on the in-service damage accumulated by wire ropes operating on drum winders: Elandsrand Gold Mine, 2 204 m deep.**  
M Borello  
CSIR Contract Report MST(93)MC1665, September 1993  
Sponsor: Chamber of Mines .....111 pages

### **Summary**

These 48 mm diameter ropes of this report operated at Elandsrand at a safety factor of 4. The intention of AAC was to reduce the safety factor from 4 to 3,5. While waiting for the final preparations to be completed for this next phase of the field trial on this winder, this second rope set operating at a factor of safety of 4,0 reached the end of its service life.

Sections of the discarded ropes were selected as before, and mainly for tensile tests. Elastic modulus tests were also carried out on samples from the front, middle and back-end of the two ropes.

The overlay rope was in service for approximately 25 months during which time it completed 78 972 winding cycles. The underlay rope started its service 11 days after the overlay rope, and completed 77 981 winding cycles. The original underlay rope was removed from service because of some manufacturing defects. As before, the back end of these ropes were pulled in every two months.

According to the report, the rope samples that showed the lowest breaking strengths during the tensile tests for both the overlay and the underlay ropes were in each case the rope sections that were identified by the rope inspectors as being the weakest part of the rope. The "weakest section" of the overlay rope had two broken wires "prior to the test", and the strength reduction was 4,5% compared to the new rope breaking strength. The "weakest section" of the underlay rope had two broken wires and a strength reduction of 1,5% compared to the new rope breaking strength.

### **Comment:**

The diameter of the headsheaves of the winder is incorrectly given as 4,88 m in the report. The headsheaves were changed to 5,54 m diameter when the first set of 48 mm ropes was installed on the winder.

References: r43, r44 .....FOS  
The following **initial reports written towards new regulations** are summarised together in this section.

Mike van Zyl, JTD Fritz and GFK Hecker: Pro-forma 1: Factors of safety of winder ropes; Recommendations towards new regulations for drum winders; Notes for discussion, September 1989. Mine Hoisting Technology, CSIR, September 1989. ....15 pages  
Mike van Zyl Pro-forma 2: Factors of safety of winder ropes; Recommendations towards new regulations for drum winders; Notes for discussion, October 1989. Mine Hoisting Technology, CSIR, October 1989. ....22 pages

Sponsor: Chamber of Mines

## Summary

Pro-forma 1 introduced the concepts on which the recommended regulations would be based. The proposed regulations aimed to keep the maximum rope load and the remaining rope strength safely apart. This would give true reserve or safety margin for a winder installation. The true reserve has to cater for abnormal or unexpected events. The 10% allowable deterioration was retained because of the general belief that the rate of deterioration of the rope increases rapidly after this level was reached. It was proposed to limit the maximum rope loads generated during winding, loading and emergency braking to a given number (later described as the dynamic factor). It was also proposed to limit the static load range of a winder (or also later called the payload factor) otherwise shallow winders would be able to increase their load ranges too drastically if a "flat" dynamic factor would be used. Pro-forma 2 was produced in October 1989 and was essentially the same as Pro-forma 1. The following set of regulations was used as an illustration of the concepts of the proposed regulations:

The regulations would specify installation factors; men and rock winders were considered the same; and multi-rope winders would not get special considerations. If EM testing were not done, then the factors should be higher.

Dynamic factor = 2,5 (40% of initial breaking strength)  
Payload factor = 12,5 (8% static load range)  
Discard at 10% reduction in rope strength

Dynamic factor = the dynamic safety factor (rope breaking strength divided by the maximum dynamic rope load)

Payload factor = the breaking strength of the rope divided by the static weight of the payload, which is also equal to the static rope load range.

The proposed basis for the regulations was accepted by the Steering Committee. At the request of the Steering Committee, Chaplin (Reading University) also responded to the pro-forma proposals in December 1989. Chaplin agreed with the concept of the proposed factors. He suggested that the actual (dynamic) load range be used instead of the static value. He also expressed the opinion that our "true reserve" was more related to the effectiveness of inspection procedures and frequency of inspection in terms of anticipated rates of deterioration.

## Comment:

It is of interest that the new regulations that were finally adopted effectively included a dynamic load range (of 15%) and a dynamic factor of 2,5; which is much the same as that proposed above.

Reference: r45 ..... FOS, INFO, DEEP  
**An engineering evaluation of the limits to hoisting from great depth**  
ME Greenway  
Report no. 90-T-08, Mech. Eng. Dept., Anglo American Corporation, June 1990  
Sponsor: AAC.....55 pages

### **From the summary of the report**

"This report reviews the depth and hoisting capacity of conventional winding in deep single lift shafts. This is motivated by the existence of new ore bodies at depths in excess of 3 000 m. The economic development of these ore bodies would be greatly facilitated by the use of single lift shafts rather than the conventional main and sub shaft systems which have the penalties of requiring additional capital resources and a longer development period before mining can take place. A parametric study of the factors affecting winding depth and hoisting capacity limits is pursued. Parameters having the most impact on the extension of depth limits are identified. The engineering consequences of non-standard parameters are assessed. Model winder duty cycles for great depths are developed and achievable depths of wind established.

New gold fields are being explored where the depth of the ore body lies between 3 000 m and 4 000 m. Unlike current mines where some reef could be assessed relatively early on in the development of the mine by a single lift shaft system of say 2 000 m depth, the new mines, if based on conventional main and sub shaft systems, will require major capital intensive development with the discouraging prospect of very late return on investment.

This motivates a review of the depth and hoisting capacity limits of conventional winding in deep single lift shafts. A systematic parametric study of the factors influencing depth of wind and hoisting capacity is described in the report, and the factors are ranked in order of the potential for extending limiting depths.

Model winder duty cycles are developed for winding depths of 3 000, 3 500 and 4 000 m by varying some of the winder design parameters away from conventional practice. The engineering consequences of these changes are discussed and realistic achievable depths of wind established. It is concluded that there is considerable scope to extend the depth limits of rope hoisting in single lift shafts to at least 4 000 m."

### **From the contents of the report**

The report ranks "the parameters that influence depth of wind and hoisting capacity from those that have most impact (top of the list) to those that have least:

1. Rope safety factor
2. Rope tensility
3. Scale of design (increase rope carrying capacity by increase in number of ropes and rope diameter)
4. Winder utilisation
5. Winding speed
6. Ratio of payload mass to skip mass
7. Winding cycle acceleration and deceleration
8. Other winding cycle parameters (loading time, etc.)

The report therefore concludes that changes to "rope factor of safety" will give the greatest improvements on winding depths and hoisting capacity.

The following **reports written towards proposing new regulations** are summarised together in this section.

GFK Hecker: Pro-forma 3; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. Mine Hoisting Technology, CSIR, Sept. 1990 (r46). .....	28 pages
GFK Hecker: Pro-forma 4; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. Mine Hoisting Technology, CSIR, January 1991 (r47). .....	34 pages
GFK Hecker: Pro-forma 5; Factors of safety of winder ropes; Recommendations towards new regulations for drum winders. Mine Hoisting Technology, CSIR, April 1991 (r48). .....	41 pages
GFK Hecker: Proposed changes to rope safety regulations (draft). CSIR Contract Report MST(92)MC977, January 1992 (r49).....	57 pages
GFK Hecker: Proposed changes to rope safety regulations (second draft). CSIR Contract Report MST(92)MC1052, March 1992 (r50). .....	62 pages
GFK Hecker: Rope forces during dynamic brake tests. CSIR Contract Report MST(92)MC1220, July 1992 (r51). .....	12 pages
GFK Hecker: Proposed changes to rope safety regulations (final draft). CSIR Contract Report MST(92)MC1303, August 1992 (r52).....	73 pages
GFK Hecker: Proposed changes to rope safety regulations (for consideration by the CM&EE sub-committee). CSIR Contract Report MST(92)MC1303, September 1992 (r53). .....	74 pages
Mike van Zyl: Load ranges experienced by drum winder ropes. CSIR Contract Report MST(92)MC996, November 1992 (r54). .....	171 pages

Sponsor: Chamber of Mines

### Report summaries and comments

Comments on the events and decisions surrounding the different reports are given in this section because it would not make much sense otherwise (also see refs 43 and 44 on the initial reports).

March 1990: Some members on the working group were of the opinion that some dispensation should be provided for EM-testing, while others did not agree that EM testing should be included in the new regulations. A suggestion was made that this particular clause (in the pro-forma recommendations) be removed so that the work on the recommendations could continue, allowing the uncertainty regarding the EM testing to be clarified at a later stage. An industry working group (outside CoMRO) was formed to study rope condition assessment. (See section 3.12 in the main part of this report).

In August 1990 the Steering Committee decided to base the new drum winder rope regulations on the limits of the then current knowledge of dynamic peak loads and dynamic load ranges. As a second phase, the regulations would be revised again in future once further knowledge and understanding on the remaining strength of ropes have been gained (assessing the condition of the rope accurately).

In September 1990, Pro-forma 3<sup>r46</sup> was tabled. In the document it was suggested that the "old" regulations (as for rock winding) be retained and that the new dynamic factors be added to the regulations. This would have catered for (existing) winders without load measuring devices. A 10% allowable deterioration was to be retained, and a dynamic factor and a dynamic load range were to be added. A dynamic factor of 2,8 (37,5%) and a dynamic load range of 1/9 (11.1%) were suggested based on the initial breaking strength of the rope (installation factors). It was further stated that a detailed investigation into the actual dynamic rope loads were required before a final dynamic factor of safety could be recommended. A more detailed investigation was also suggested for the dynamic load ranges in order to recommend a value for the allowable load range.

Pro-forma 3 was discussed at working group meetings in October and November 1990. Industry members rejected these proposals on the basis that it would be too difficult to measure the actual rope forces and requested the CSIR to recommend static factors that would ensure that the dynamic factors were kept within limits. The working group also gave consideration to a code of practice for EM-testing, and additions to the regulations that would allow some dispensation for winders where EM-testing was performed.

Note of interest: The current codes of practice for permanent winding installations and for sinking winders (that operate at the new lower rope factors) require the "actual rope forces" to be measured. Rope load monitoring is already done successfully at a number of winding installations. The "turmoil" that followed the recommendations throughout the following two years was a direct result of the decision of the working group that it would be "too difficult" to measure rope loads.

In January 1991, Pro-forma 4<sup>r47</sup> was produced. The basis of Pro-forma 4 was still a limit to the dynamic factor and to limit the dynamic load range, but explored the possibility of an approach towards regulations that would limit the dynamic load range and peak dynamic loads without specifying "elaborate" measuring techniques. The proposals were to be based on the dynamic loads that ropes actually experienced under the old regulations. Pro-forma 4 introduced the "payload factor" and reintroduced dispensation for RCA. The following from that document:

"Representatives of the gold mining industry indicated that it would be impractical to have rope force measurements or acceleration measurements enforced by a regulation. The only parameter that remains to be addressed, therefore, is the static factor of safety."

An attempt was therefore made to specify a static factor that would guarantee a minimum dynamic factor of safety. From emergency braking data available it was shown that, if the lowest dynamic factor was adopted as the limit, a static factor of 5,2 had to be specified to ensure that any winder installation would conform to the adopted (lowest) dynamic factor. This static factor was however higher than what the present regulations allowed. The report therefore concluded that there was no case for proposing a static factor of safety with a value lower than the present one.

To overcome the problem, a code of practice was proposed that would allow static rope forces higher than those allowed by the then present regulations. It was argued that a limit to the peak winder acceleration would limit dynamic rope forces and therefore would allow lower static factors.

Pro-forma 4 also suggested the following set of regulations:

Payload factor of 14  
Static factor of 5

If the mine complies with a Code of Practice for rope condition assessment (RCA) then the applicable factors would be 0,9 times the above.

Payload factor of 12,6            (for RCA)  
Static factor of 4,5            (for RCA)

Pro-forma 4 also asked that the allowable rates of retardation under emergency situations be reconsidered so that lower static factors could be recommended, and suggested that a Code of Practice should be adopted that would allow further reduction of the factors without impeding safety. After pro-forma 4 was produced, proposals were submitted for a more accurate determination of the rope loads acting on drum winders, and rope condition assessment was back "on board" again.

The Steering Committee thought that the document (Pro-forma 4<sup>r47</sup>) was now suitable to be discussed with the GME. The GME had to be familiarised with the work and invited to make comments after which the CSIR would produce a final document.

14 March 1991: Comments was received from Chaplin on Pro-forma 4<sup>r47</sup>: He agreed that one should move away from load definitions in "nominal" terms. He further said that several levels of regulation could apply according to circumstances. Regulations should be framed to ensure safe operation of the hoisting rope (not necessarily long life) and should essentially maintain an adequate margin between peak forces and actual strength. It is largely the business of the mine to establish its own maintenance procedures and operating practice to give economic rope utilisation, within the regulations. However, the regulatory function in respect of safety does require consideration of the rate of deterioration. Whatever the initial strength of the rope in relation to normal operating loads, it will gradually deteriorate, slowly at first and more rapidly towards the end of its life, and unless removed will fail in service. This is prevented by requiring an examination (inspection and testing) procedure that leads to removal of the rope when there is an unacceptable risk of the rope deteriorating to a condition such that failure is a significant possibility before the next inspection. Because of this time lapse between detailed examinations, the regulatory authority does have a duty to frame regulations that limit the rate of deterioration. However, it is right and proper to vary those regulations to take account of different levels of effectiveness, and even frequency, of an examination system.

In April 1991, Pro-forma 5<sup>r48</sup> was produced. It was a stand-alone document that included all the relevant information given in the previous pro-formas. The following factors were included in the document:

payload factor	14	
static factor	5	these factors reduced to 0,9 of the value for RCA CoP

Code of Practice for winder control will allow lower factors. The following minimum allowable dynamic factors were suggested:

dynamic factor = 2,5	for RCA CoP
dynamic factor = 2,8	for all other operations

A detailed analysis of winders with high payload factors was suggested before the actual value would be proposed.

The industry was concerned that the proposed regulations would outlaw winders that (at that time of discard factors) installed their ropes just above the discard safety factor of 4,5. For BMR winders, this discard level is 4,275.

The Steering Committee stated that the proposed regulations should specify rope factors at installation rather than at discard; be based on present practice and the knowledge gained to date; be based on dynamic rope force considerations but should not specify any requirements that limit dynamic forces, i.e. only static factors were to be specified. A second phase of the regulations could entail recommendations based on additional research into areas such as winder control and simulated rope fatigue testing.

After the CSIR reiterated that it was not possible to attain a dynamic factor of safety by means of a regulation without specifying one, the Steering Committee finally agreed that the CSIR should investigate whether it was feasible to specify a single value of maximum drum deceleration which would ensure that installation factors of 4,5 could be safely implemented on winders which did not decelerate faster than that maximum.

In July 1991, the Steering Committee decided on the following course of action: The first phase of the proposed regulations must be formulated and documented. The degree to which the

effectiveness of rope NDE can be quantified must be evaluated (Phase 2). It was agreed that the production of a Code of Practice on rope condition assessment (Phase 2) should proceed in parallel with the (Phase 1) recommendations. At this stage the GME also wished to see proof that NDT of winder ropes actually achieved what it set out to do. Kuun (AAC) also supplied his discard criteria for triangular strand ropes<sup>r56</sup> to the Steering Committee as a starting point for creating a code of practice for rope condition assessment (see section 3.12).

For the next draft of the proposals, the capacity factor was reintroduced by the CSIR for front-end protection (rope terminations) and for counterweight winders. It was also decided to include controlling of the brake deceleration rate in the proposals, as well as the Code of Practice for Rope Condition Assessment. The draft proposed regulations<sup>r49</sup> report was produced in January 1992. The report was a complete document with references, justifications, implications, and even the wording for the new regulations. The factors proposed were all installation factors (based on the initial rope strength) and were:

Payload factor = 14  
Capacity factor = 7  
Static factor = 5

Presuming that the deceleration rate of the drum under trip-out conditions can be effectively used to determine the peak dynamic force that will occur in a rope, then for a drum deceleration rate that will not exceed 3 m/s<sup>2</sup>:

Static factor = 4,5

Accepted or approved Code of Practice for rope condition assessment will reduce the factors by 10%, therefore:

Payload factor = 12,6  
Capacity factor = 6,3  
Static factor = 4,5

Code of practice for controlling mine winders: reduced factors (not specified) could be allowed. Dynamic factor values of 2,5 for RCA and 2,8 for all other installations were envisaged.

For Blair winders with rope load compensation at the headsheaves a further 5% reduction would be allowed on the static factor:

BMR static factor = 4,75      and      4,275 (for RCA)

The payload factor and brake deceleration after trip-outs were still under investigation.

The second draft of the proposed regulations<sup>r50</sup> was produced in March 1992. This was again a complete standalone document. The payload factor and dynamic factor (brake deceleration) were still being investigated. Everything was basically the same as in the previous document, except that the proposed regulations specified that the "winder code of practice" were to be used in conjunction with the "rope condition assessment code of practice".

In April 1992, the CSIR informed the Steering Committee that it was not possible to obtain the required dynamic factor by specifying either a peak or average drum deceleration rate. The dynamic factor could however be obtained by one of the following four alternatives: Measurement of drum dynamics; measurement of the rope force at the sheave or at the conveyance, and measurement of the conveyance dynamics (acceleration).

In May 1992, a draft of the rope condition assessment code of practice was tabled<sup>r57</sup>.

In June 1992, the GME informed all of those concerned that the target date for the revision of Chapter 16 of the regulations was October 1992. This was part of the revision of the whole Health and Safety Act. This prompted a programme to be set up with the view to complete the proposed changes to the regulations before that time. The proposals had to be approved by the CM&EE sub-committee before it could be sent to the GME.

After the work on the rope forces generated during emergency braking<sup>r51</sup> was completed in July 1992, a dynamic factor of 3,0 was proposed for inclusion in the regulations. The report<sup>r51</sup> shows the calculation of the dynamic safety factors for fifteen rock winders. The rope forces generated during emergency braking were calculated for these winders from recorded drum speed traces. Static safety factors were compared to the dynamic factors, and the dynamic factors were also compared to dynamic factors estimated from peak conveyance accelerations.

The final draft report on the proposed new regulations<sup>r52</sup> was issued in August 1992, and after some corrections a report on the proposed changes for consideration by the CM&EE sub-committee<sup>r53</sup> was issued in September 1992. From the executive summary of this document:

"Current South African regulations for sizing of mine winder ropes were introduced during 1956, based mainly on circumstantial evidence. A more rational approach is now required to meet the demands for improved guarantees of safety and more economical winding operations. Investigations in this regard are undertaken by the CSIR under the auspices of the Chamber of Mines.

This document contains a summary of the background studies carried out to date and makes the following initial proposals with regard to rope safety regulations:

In order to align the regulations with commonly accepted engineering practice, it is proposed that they should specify the rope strength at installation and not at discard.

Considering the fact that man winders seldom operate with the full licensed payload and that their rate of winding cycle accumulation is relatively slow, the rate at which their ropes deteriorate is lower than that of rock winders. It is therefore proposed to apply the same regulations to man and material winders as those that apply for rock winders.

The present capacity factor regulation limits the mass that may be suspended from the end of a rope. Since the regulation limits hoisting capacity, there has been a move to lighter conveyances, which, in turn, has resulted in higher rope load ranges. It is considered that the load range (and not the static load) has an influence on rope life and it is therefore suggested to introduce a payload factor of 14 at installation for rock and men. The payload factor is the strength of the rope divided by the weight of the payload. This regulation would limit the load range more effectively than the present capacity factor regulation. Realising that the rope termination is often weaker than the rest of the rope, it is not considered justified doing away with the capacity factor altogether. It is therefore proposed to reduce the capacity factor from 9 for rock and 10 for men at discard to 7 for rock and men at installation.

Many ways were considered in which a more rational approach towards the static factor regulation could be obtained. At present there is no justification to reduce the minimum static factor and it is proposed to replace the static factor at discard of 4,5 for rock and 5 for men with a static factor at installation of 5 for both rock and men.

The present statutory rope discard criterion is considered valid. It is proposed to retain the amount of deterioration (10% down from the initial breaking strength) that a rope may have before it must be discarded.

If the above regulations were to be adopted, there would be some winders which would operate outside the regulations, namely those at which the present installation factor is lower than 5. After analysing peak dynamic rope loads on these winders, it was found that they do not necessarily impose high rope loads during emergency braking. For these winders, a dynamic factor of 3 is proposed instead of a static factor. The winder brakes should then be controlled in such a way that the dynamic factor is maintained.

In summary, the document shows that, while safety would be enhanced by introduction of the proposed regulations, the payload and the maximum hoisting depth would be increased.

The document also indicates the direction in which future research could go. Anticipating the results of this work, proposals are made to allow lower factors in special cases where a code of practice for rope condition assessment is applied. Further work is proposed to investigate the minimum allowable dynamic factor.

The proposed regulations<sup>r53</sup> were based on the current levels of operation, with dispensation for rope condition assessment, and dispensation for controlled dynamic rope loads. In summary they were:

Payload factor = 14  
Capacity factor = 7  
Static factor = 5

Dynamic factor = 3      A grandfather clause that would allow the continued operation of all existing systems was also included.

For the dynamic factor, a winder installation had to show that the peak conveyance acceleration under trip-out conditions was within prescribed limits.

Using an accepted or approved Code of Practice for rope condition assessment would give a 5% reduction in the above factors except for the Capacity Factor. (An ultimate dispensation of 10% for RCA was envisaged once the accuracy of EM-testing had been proven.)

Payload factor = 13,3  
Capacity factor = 7,0  
Static factor = 4,75

Dynamic factor = 2,85

Blair winders with compensation at the headsheaves would get a further 5% reduction of the static factors:

Static factor = 4,75 and 4,5 (for RCA)

A new and different set of regulations was envisaged for the future where winder installations have to conform to a "winder code of practice". The following dynamic factors were suggested: 2,5 for RCA and 2,8 for all other installations.

At this stage the load range investigation<sup>r54</sup> was still under way, and the proposed payload factor was therefore not yet finalised.

The primary objective of the load range investigation was to determine how well the actual load ranges can be controlled by the proposed "payload factor". The load ranges of 18 rock winders were determined. The report on the load range investigation<sup>r54</sup> was completed in November

1992:

The rope forces generated during skip loading were determined from rope strains that were recorded during loading of the skips. Rope elastic modulus values were determined from tests on 41 rope samples so that the measured rope strains could be converted to rope loads. The elastic modulus tests are described in the report, and a simple equation was derived for the calculation of the rope stress dependent rope elastic modulus.

The rope loads generated during a normal winding cycle at each of the 18 winders were determined from recordings that were made of the drum speed at each of the winders.

The dynamic load ranges for loading were up to 60% greater than the static load ranges. The dynamic load ranges for winding were as much as 90% greater than the static load ranges. The dynamic load ranges for winding were always greater than those generated during loading. The highest dynamic load ranges were generated by the winders that had the highest static load ranges. The highest static load range was just less than 8% of the rope breaking strength, and the same winder produced the highest dynamic load range of just below 15% of the rope breaking strength.

A minimum "payload factor" of 12,5 for drum winder ropes was recommend by the report (as opposed to 14 in the last "proposals" report<sup>53</sup>). A payload factor of 12,5 would limit the static load range to 8% of the rope breaking strength.

Reference: r55 .....RCA  
**Non-destructive testing of wire rope in the RSA**  
C O'Conner  
CSIR Internal Report MST(90)SM151, Speciality Metals, MATTEK, CSIR, November 1990.  
Sponsor: CSIR .....41 pages

**Summary**

The report presents the results of a survey conducted into the equipment and personnel involved in electromagnetic (EM) non-destructive testing (NDT) of wire ropes in the mining industry in South Africa. In addition, a comparison was made between the status of EM testing in South Africa and international trends.

The aim of the survey was to develop experience within the CSIR to enable them to identify appropriate research projects in order to quantify EM testing, and to standardise personnel training and certification, and equipment calibration and test procedures.

The report discusses equipment used by the various mining groups, as well as discard criteria of that time ("retirement standards"). Proposals for the qualification and training of personnel by the ASTM (obtained through Anglo American Corporation) were also included and discussed in the report.

Reference: r56 .....RCA, COP  
**Condition assessment of winding ropes: Discard criteria for 6/F triangular strand ropes**  
TC Kuun  
Mechanical Engineering Department, Anglo American Corporation, July 1991.  
Sponsor: AAC.....9 pages

### **From the introduction of the report**

"A code of practice for the condition assessment of winding ropes must address the following issues in the order shown:

- ? Discard criteria
- ? Condition assessment techniques and procedures
- ? Specification, calibration and certification of equipment
- ? Selection, training and certification of personnel

This note deals with the discard criteria for triangular strand winding ropes commonly used on SA mines. Relatively few round strand winding ropes are in service locally. Until further notice, the criteria presented here can be used for the latter ropes as well. The clauses on corrosion, distortion of rope, heat damage, short rope, combined effects and economic considerations apply equally well to multi layer stranded ropes used on friction winders and on drum winders.

Recommendations presented here are based on:

- ? Experience with winding ropes on local mines
- ? Analysis of test results for new ropes with broken wires obtained from Mr EJ Wainwright
- ? BS 6570:1986 - British Standard Code of practice for the selection, care and maintenance of steel wire ropes
- ? ISO/DIS 4309:1987 - Wire ropes for lifting appliances - Code of practice for examination and discard.

Some of the views recently expressed by overseas instrument developers regarding loss of metal area and loss of breaking strength can lead to potentially unsafe conclusions and must be treated with a great deal of caution.

With existing factors of safety and also with lower factors, the discard criteria presented here will promote safe and economical use of winding ropes."

### **From the contents of the report**

The discard criteria for triangular strand winding ropes on drum winders were given in terms of:

- ? Broken wires; Reduction in rope diameter; Corrosion; Distortion; Fibre core defects
- ? Change in laylength; Heat damage; Mechanical properties; Short rope
- ? Combined effects; Economical considerations.

### **Comment:**

The discard criteria finally adopted in SABS0293 (Condition assessment of steel wire ropes on mine winders) were virtually the same as proposed in this document.

Reference: r57 .....RCA, COP  
**Code of practice for rope condition assessment (2nd draft)**  
RCA working group  
CSIR Contract Report MST(92)MC1178, May 1992  
Sponsor: Chamber of Mines .....44 pages

## Summary

This document eventually became the first draft of SABS0293:

SABS0293:1996  
South African Standard  
Code of Practice  
Condition assessment of steel wire ropes on mine winders

The South African Bureau of Standards

It contained sections on:

- ? Discard criteria for triangular strand ropes
- ? Techniques and procedures
- ? Equipment specifications
- ? Selection, progression and general responsibilities of staff
  
- ? and an appendix on the classification of degrees of corrosion by visual comparison

Reference: r58 ..... TERM

**A survey of results of tests on rope terminations**

M Borello

CSIR Internal Report MST(91)MC745, May 1991

Sponsor: CSIR .....43 pages

**Summary**

After a splice failed in service, the CSIR carried out a detailed investigation on the failed splice. It was concluded that the splice failed "because of progressive brittle failure of individual wires due to bending fatigue". It was further concluded that "had regular inspections of the termination been carried out, the broken wires on the splice should have been noted".

After this incident, and at a request of the Government Mining Engineer, the mines sent rope terminations to the CSIR for destructive testing. The 110 samples received in the period April 1990 to March 1991 were mostly rope splices, but included other types of terminations as well.

The splices tested broke at loads that varied between 67% and 98% of their new rope strengths, and approximately two thirds of the splices had strengths of less than 90% of their new rope strengths.

It was concluded that it was not possible to identify the factors that affected the strengths of the splices because of the large number of rope and splice variables, and unknown service conditions.

Reference: r59 ..... TERM  
**A comprehensive study of the factors affecting splice efficiencies**  
M Borello  
CSIR Internal Report MST(92)MC1117, April 1992  
Sponsor: CSIR .....107 pages

### **From the summary of the report**

"Failure of wire rope terminations over the past few years has caused the mining industry and governing bodies to be concerned and in April 1990, at the request of the Government Mining Engineer, many mines started sending splices and other terminations to the CSIR for testing. It was not possible, from the results obtained from those tests, to establish the causes for the loss in efficiency of the splice in particular. In April 1991, the CSIR initiated this project which investigated the possible causes for the loss in efficiency of a splice. The effects of human workmanship, rope and splice construction, rope diameter, rope tensile grade, fatigue loads, corrosion and corrosion fatigue on the splice were investigated. It was also initially intended to test wedge-type cappels, but that part of the project was temporarily abandoned and the testing of ropes on compensating sheaves produced a null result and was prematurely ended.

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 the rope diameter and it was found that splice efficiency is adversely affected by the increase in rope diameter. 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. Tapered splices outperformed parallel splices during the fatigue tests 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 (less than 44 mm). For the larger 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."

### **Contents**

The report also contained a section dealing with ropes terminated at conveyance mounted compensating sheaves of Blair multi-rope drum winders (BMR's), and one on wedge type cappels. It concluded that the severe deterioration experienced sometimes by the ropes at the conveyance-mounted compensators could not be duplicated in the laboratory. It also concluded that (the strength of) wedge type cappels were no better than that of splices.

Reference: r60 ..... TERM  
**Laboratory axial fatigue tests of resin cappings for use as winder rope terminations**  
M Borello  
Contract Report MST(92)MC1432, Mine Hoisting, CSIR, December 1992  
Sponsor: Chamber of Mines .....35 pages

**From the summary of the report**

"Previous work which was carried out on splices clearly 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 a less labour intensive and skill dependent termination with better efficiencies. The work carried out here was aimed at verifying the applicability of resin cappings as rope terminations on South African mines.

Ten resin socketed terminations were tensile tested in this program, two immediately after the resin has cured and the other eight after having been fatigue tested at different load ranges for various number of cycles (10% load range for 30 000 cycles being the most "severe" loading).

All the specimens tested failed clear of the resin socket, which demonstrated that this type of termination has an efficiency of 100%. It was therefore concluded that the resin cappings are suitable for a series of field trials at this stage."

Reference: r61 .....FOS  
**Motivation for proposed changes to Chapter 16 of the Minerals Act: Rope safety regulations for drum winders**  
GFK Hecker  
Contract Report MST(93)MC1674, Mine Hoisting, CSIR, June 1993.  
Also part of SIMRAC report GAP054, Volume 2.  
Sponsor: Chamber of Mines / SIMRAC .....13 pages

**From the introduction of the report**

"The Steering Committee on Factors of Safety of Winder Ropes has appointed a working group to draw up a set of proposals for changing the regulations governing the required rope strength in the Minerals Act. Certain research projects have been conducted in order to substantiate the recommendations. The results of these projects have shown that a new set of regulations could be recommended for drum winder ropes even though detailed knowledge on rope deterioration was still lacking. The regulations should effectively limit the dynamic load range and the peak dynamic forces. It was requested that static factors be specified in the regulations, however, and to make provision for dynamic behaviour in a code of practice."

**Contents**

The rope load factors that are proposed in the report are:

RCA will be mandatory and the following installation factors will be required:

Capacity Factor = 8,0  
Safety Factor = 4,5

If the winder conforms to an approved code of practice for winder operation (the contents still to be determined), then:

$$\text{Safety Factor} = 25\,000 / (4\,000 + L) \qquad L = \text{suspended rope length in metres}$$

A dynamic safety factor of 2,5 would also apply.

The derivation of the static factor "formula" above was included in the report. It is shown that the formula would ensure that the (dynamic) load range of a rope is limited to 15% of the (new) rope breaking strength if the acceleration and deceleration of the winder during normal winding do not exceed 1 m/s<sup>2</sup>, the rope has a tensile grade of not more than 2 000 MPa, and if the payload is not greater than 70% of the total attached mass.

The motivation for a capacity factor of 8,0 was also included in the report.

**Comment:**

The derivation of the static factor "formula" above was based on rope dynamics and load range calculations by Kuun<sup>r11</sup>, and included a number of approximations and assumptions. The "formula" is quite rigid, and will not give the full benefit to an installation that uses lower winder accelerations and favourable winder control strategies. The winder code of practice require all winders that use the "formula" to have continuous rope load monitoring systems and to calculate the load range for every winding cycle. The 15% load range is the actual crux of the matter, and should take preference over the "formula".

Also see the recommendations of GAP501 (ref. r102) on the 15% load range.

Reference: r62 .....all categories: see individual reports

**GAP054: The safe use of mine winding ropes**

**Volume 1: Executive summary**

GFK Hecker

SIMRAC report GAP054, Volume 1. Mine Hoisting Technology, CSIR, April 1996

Sponsor: SIMRAC .....18 pages

**Summary**

The GAP054 report consists of seven volumes and just more than 1 500 pages. This document (Volume 1) presents an overview of the entire project, and lists the individual reports contained in the other volumes.

The scope and detailed findings of the reports of the other volumes are discussed under the following headings:

- ? Changes in rope factors of safety (Volume 2)
- ? Guidelines for design and maintenance of rope terminations (Volume 3)
- ? Studies towards a code of practice for rope condition assessment (Volume 4) and training manuals for incumbent rope inspectors (Volume 5)
- ? Code of practice for the performance, operation, testing and maintenance of drum winders: background investigations (Volume 6)
- ? The safety of stage and kibble winder ropes (Volume 7).

**Comment:**

Section 5.3 on page 14 of the "executive summary" deals with "dynamic rope forces resulting from motor fault torques". When the GAP054 report was produced, the final report on motor torque faults had not been issued yet, and could therefore not be included in GAP054. See ref. 66 for the details and a summary of that report.

Reference: r63 ..... DYN  
**Investigation into rope forces generated during emergency braking events**  
J Kroonstuiver  
SIMRAC report GAP054, Volume 6, April 1996  
First issued in September 1994 as a CSIR Contract report MST(94)MC2208 No.940189.  
Sponsor: SIMRAC ..... 19 pages

### **From the synopsis of the report**

"This study was commissioned to determine the maximum rope force in the rope of a mine winding system subsequent to a brake control failure. Four different winders were evaluated: a 4 000 m Blair multi-rope system, a 2 300 m Blair multi-rope system, a 2 500 m double drum system, and a 1 800 m double drum system"

The deeper shaft systems exhibited higher rope forces than the shallower systems. The 4 000 m system had the highest rope force as a fraction of the rope breaking strength. A rope force of 60% of the rope breaking strength was calculated for this system. The lower static factors of the deeper winds resulted in the higher rope forces calculated for these winding systems.

Slack rope occurred in the 4 000 m mine winding system after the occurrence of a brake control system failure. Slack rope could be prevented and the maximum rope force in the system could be reduced by increasing the number of independent brake systems on a winder."

### **Comment:**

There are a number of mistakes in the report. The effect of these on the conclusions of the report could not be established because the calculations were done with the aid of a (mathematical) software package. Examples of the mistakes are:

- ? The report is not quite clear on how the maximum brake capacity was established, and does not mention the "twice unclutched out-of-balance per brake" that is the current design norm. The indications are that the maximum brake capacity selected could have been too little.
- ? Although the report indicated that a 4 000 m BMR was analysed, it assigned only two brakes to the winder. A BMR winder will always have at least four brakes in total (two per drum).
- ? The findings of the report led to the inclusion of a specification in the "winder code of practice" that the brakes of a drum winder will be designed such that the rope loads will not exceed 60% of the rope breaking strength when brake control failure occurs.

Reference: r64 ..... DYN  
**Rope force measurements during emergency braking**  
GFK Hecker  
SIMRAC report GAP054, Volume 6, April 1996  
First issued in September 1994 as a CSIR Contract report MST(94)MC2208 No.940190.  
Sponsor: SIMRAC .....8 pages

### Summary

The investigation was carried out to determine whether it would be necessary to measure rope loads at the headgear sheave or whether measurements at the conveyance would be adequate when the dynamic factor of safety of the rope on a winder is being established. The code of practice requires the "dynamic factor" to be determined. The investigation was an extension of earlier work carried out (see ref. r51).

Dynamic rope loads were calculated using the drum speed traces obtained from several winders during emergency brake tests. A simple method was devised with which the dynamic factor could be established (from rope front-end measurements).

The following were concluded:

- ? The peak back-end rope forces that occur during emergency braking can be estimated from front-end rope load measurements, or from conveyance acceleration measurements. It is therefore possible to measure the rope forces either at the front-end or at the back-end to obtain the peak dynamic rope load.
- ? The accuracy of the estimated back-end rope loads (from measured front-end rope loads) is within a few percent when the peak drum accelerations are low.
- ? With higher drum accelerations, the estimate becomes less accurate. However, this is not of concern because the result is conservative: the actual dynamic rope loads are lower than the estimated ones.

### Comment:

Using accelerations to determine rope loads assume, of course, that the attached masses are correct, i.e. that the conveyance is always loaded with the "licensed" mass, and never overloaded.

Reference: r65 ..... DYN, MOTOR, DEEP  
**Investigation of forces in a 4 000 m mine winding rope resulting from a motor fault torque**  
J Kroonstuiver  
SIMRAC report GAP054, Volume 6, April 1996  
First issued in September 1994 as a CSIR Contract report MST(94)MC2208 No.940192.  
Sponsor: SIMRAC .....25 pages

## Summary

Flashover or short circuits in winder motors could give torque pulses. Calculations of the rope loads generated by these torque pulses were carried out to determine whether such occurrences should be of concern to rope safety,

A "hypothetical" winder for a 4 000 m deep shaft was "designed" for the rope load calculations.

## From the conclusions of the report

"The maximum force obtained in the ropes as a result of the short circuit was dependent on the impulse duration. At a duration of 200 ms, 40% of the rope breaking strength was achieved. This relatively short impulse duration indicates that careful consideration has to be given to the allowable flashover impulse duration in (drum) winder systems. For the hypothetical 4000 m winding system, a limit of 200 ms would have to be placed on the impulse duration (for an overload torque of 10 times the imbalance torque).

Altering the shape of the impulse torque while maintaining a constant impulse magnitude did not have a large influence on the maximum force in the rope. Altering the impulse duration while maintaining a constant impulse magnitude, changed the maximum rope forces significantly. The impulse duration has a large influence on the maximum force obtained in the rope.

An increase of 10% for the maximum rope force was obtained when the sheave wheels were included in the simulation."

## Comment:

From the information supplied in the report it seems as if the base calculations were done using a torque pulse duration of 200 ms and a torque magnitude of three times the maximum (clutched) out-of-balance of the winder. This does not tie up with the "10 times" mentioned in the conclusions.

The influence of the headgear sheave could have been overstated because the inertia value of the sheave used seemed a bit on the high side.

The rope loads can, of course, only be calculated accurately if the exact duration and magnitude of the torque impulse is known.

Reference: r66 ..... DYN, MOTOR, DEEP  
**A study of the transient torques produced by winder motors under fault conditions and the implications concerning the safety of the winding system**  
R S Hamilton  
Report No. 96-T-15 (issue 1b), Mechanical Engineering, Central Technical Office, Anglo American Corporation, March 1997.  
Sponsor: SIMRAC .....101 pages

**From the summary of the report**

"A fault occurring on a winder motor can produce transient torques far in excess of the peak torque developed during normal winding. The forces induced in the winding ropes by such torques are of particular concern. The proposed revision to the regulations covering the factor of safety in the winding rope and the possibility of very deep winds in the future has heightened this concern. The move from traditional DC winder motors to cyclo-converter fed AC motors has further increased the uncertainty regarding the nature and consequences of faults.

A computer simulation model of a double drum winder has been developed, as well as models of DC, induction and synchronous motors. These have been used to predict the torque produced by the winder motor under various fault conditions and to determine the likelihood of this transient torque inducing dangerously high stresses in the winding rope and thereby compromising the safety of the winding system.

The simulations indicate that the peak forces induced in the winding ropes never approach the breaking strength of the rope. This applies to all of the drive types. No special requirements need to be placed on deep winders and/or winders designed to the proposed new rope factor of safety formula in order to protect them from transient torques resulting from short circuit type faults."

**Comment:**

According to the report, the transient torques that can be produced by winder motors are four times the rated torque for DC motors and 7,5 times rated torque for AC motors. The DC motor torque can be present for several seconds while the AC motor torque is in the form of a pulse lasting around 80 ms.

The highest rope load obtained during the simulations was 49% of the breaking strength of the rope for a winder with a 4000 m long rope suspended from the drum of a winder with a DC motor.

The report should have been part of GAP054 (Volume 6) but was not yet finalised when GAP054 was produced. This report will be made available by SIMRAC.

Reference: r67 ..... COP  
**Status report: Safety standard for the performance, operation, maintenance and testing of mine winding plant**  
GFK Hecker and Mike van Zyl  
CSIR Contract report No. 940248, November 1994  
Sponsor: SIMRAC .....115 pages

## Summary

The purpose of this report was to present the status of the code of practice to the SABS working group and the SABS Technical Committee.

This was the very first version of the document that ultimately became "SABS0294: Code of practice: The performance, operation, testing and maintenance of drum winders relating to rope safety."

The report briefly describes the contents of the "winder code of practice" and lists items that still needed to be addressed at that time. Because the proposed new drum winder rope regulations referred to a "safety standard" and not a "code of practice", the same name was adopted for the document in preparation.

The report contains two appendices. The first is a *working document* that includes motivations for, and group deliberations on the different requirements in the code of practice. The second reflects the actual status of the code of practice at that time. It is a duplication of the *working document* but stripped of all the supporting text and empty sections.

## Comment:

The *working document* of the report is the only document that was "officially" issued on the motivations for the inclusion of items in, and exclusion of items from the code. Because this was not the final version of the working document, the motivations of this report may not reflect the concluding decisions.

**Load ranges during a normal winding cycle**

J Kroonstuiwer

SIMRAC report GAP054, Volume 6, April 1996

First issued in June 1995 as a CSIR Contract report MST(95)MC2573 No.950189.

Sponsor: SIMRAC .....56 pages

**Summary**

The load range acting in a drum winder is the difference between the maximum and minimum tension that any part of the rope experiences during a winding cycle. The "winder code of practice" requires that the load range at any point in the rope is not to exceed 15% of the (initial) rope breaking strength more than once in every ten winding cycles.

Measuring the rope loads at the headsheaves makes the calculation of load range a very simple matter, but it is more complicated when rope loads measured at the conveyance is used. Apart for measurements at the headsheave, the report describes three other methods for calculating the rope load range using rope loads and/or accelerations measured at the conveyance end of the rope. For rock winders and measurements at the front end, the report cautions that skip loading dynamics will not be taken into account by the proposed methods.

It was shown that it is possible to calculate load ranges acting in the winding rope from measurements obtained from a conveyance-mounted load cell.

In the report the methods of calculating the load range in a winding rope were verified by calculating the load from data measured from rock and man winder cycles. Actual recorded data from a South African rock winder was used while hypothetical data created with a numerical simulation was used for a man winder.

**Comment:**

Since some methods were considered too complicated to be included in the code of practice, only the two more elementary ones were included in the code. The code of practice makes provision for any proven method of obtaining the load range.

Very few, if any drum winder installation at that time had systems for the continuous measurement of rope loads at the headsheaves that operated 100% successfully. The situation is now different and continuous rope load monitoring at the headsheaves is now done with ease and with great accuracy. All winder systems that will require rope load monitoring in future will have headsheave measuring systems.

Although some of the assumptions and derivations in the report are not entirely correct, the errors from using the methods given will be on the conservative side if conveyance measurements are used to estimate headsheave loads (and not vice verse). The findings of the report should only be used after careful consideration.

The part of the winder code of practice dealing with the measurement of rope loads and the determination of the rope load range should be revised.

Reference: r69 ..... COP  
**Code of practice: Performance, operation, maintenance and testing of drum winders relating to rope safety. Draft prepared by working group.**  
By GFK Hecker on behalf of Working Group 2 of the SABS Technical Committee on wire ropes.  
Submitted to the SABS in April 1996.  
SIMRAC report GAP054, Volume 2, April 1996  
Sponsor: SIMRAC .....62 pages

## Summary

This was the draft code of practice that ultimately became "SABS0294: Code of practice: The performance, operation, testing and maintenance of drum winders relating to rope safety."

The document does not contain the parts that motivated the different requirements in the code (see ref. r67). The requirements and specifications in the code are divided into the following sections (as given in the executive summary of GAP054 (Volume 1) (ref. r62)):

Rope selection: This section contains allowed rope constructions, rope quality requirements, mechanical properties and tolerances.

Design considerations: This is the largest section in the document. All fixed parameters of the winding plant are included in this section, for example: Winding plant layout, D/d ratios, fleet angles, emergency brake capacity, rope terminations, conveyances, etc. With the information under this section and the "rope selection" section, the basic winder can be designed. The section also contains some requirements for design analyses that need to be made to ensure that excessive rope forces are avoided. Reference is also made to appendices that contain recommendations or more detailed information.

Feedback and control systems: This section contains the measurement and feedback requirements for the control of the winder.

Performance: This section covers the performance specifications of the winding installation, for example: Load range and peak rope load limits, and alarm and fault detection systems. It includes required automatic winder operations and conditions under which the winder speed is to be reduced to creep speed or those conditions under which the winder should lock-out at the end of a wind.

Operation: This section contains the requirements for the continued safe operation of a winder. Certain operations need to be done at installation or when a malfunction of a winding system component is detected. These do not include any operations covered by the automatic winder control.

Inspection, testing and maintenance: The intervals at which various checks and tests are to be made are given in this section.

## Comment:

This draft document was still revised a few times afterwards, but never "officially" published or issued again.

**Rope deterioration: Field study requirements and recommendations**

GFK Hecker

SIMRAC report GAP054, Volume 6, April 1996

First issued in March 1995 as a CSIR Contract report MST(95)MC2450 No.950107

Sponsor: SIMRAC .....21 pages

**Summary**

The new safety factor equation in the regulations of  $25\,000/(4\,000+L)$  had been motivated on the basis that the load range acting in the rope was the only parameter that required a limit. However, a statistical analysis (refs r20, r21, r22) on rope lives obtained on 99 winders has shown that there are many more parameters that influence rope life. Unfortunately, the results of the statistical analysis were very much affected by a lack of proper rope discard criteria. Nonetheless, there was still a lack of understanding of how various operating conditions affect rope deterioration. Consequently, the need for a test facility was expressed to study simulated in-service rope deterioration. A feasibility study (ref. r41) showed that there was not sufficient information available to compile adequate design specifications for such a test facility. It was concluded that further information on rope behaviour on winders was required before it could be assessed whether a test facility could be realised.

A different proposed strategy was to study rope deterioration on selected winders and to correlate the results of this study with the operating conditions of the rope. The main advantages of such an approach were that no large capital expenditure was necessary and that several tests could be conducted concurrently. The major disadvantages were, of course, that the range of operating conditions would be limited to those set by the winder installations available, and that extrapolations would have to be done with circumspection.

The report describes the preliminary work done to identify winders on which rope deterioration could be studied.

The following study programme was also proposed:

- ? 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.

Reference: r71 .....RCA  
**A literature review of the use of magnetic testing of steel wire rope, with particular regard to rope discard criteria**  
A James  
SIMRAC report GAP054, Volume 4, April 1996  
First issued in May 1995 as a CSIR Contract report MST(95)MC2487 No.950131  
Sponsor: SIMRAC .....25 pages

**From the summary of the report**

"Over 100 papers and publications relating to the magnetic testing of steel wire ropes and rope discard criteria have been studied for the purpose of this literature review.

To date, only the Canadians have included statutory magnetic testing in the safety and inspection regulations and have stipulated a loss in breaking strength related to the results of such tests.

Much work has been done over the years in order to achieve accurate predictions of loss of breaking strength, but this work was largely without success. Only Aimone in the USA has developed a technique, which includes the measurement of localised metal loss due to corrosion pitting, and which gives a more realistic figure.

The information in the literature review does not give any guidelines that relate the loss in rope strength to the results of magnetic testing. Furthermore, a comprehensive set of discard criteria could not be found in the publications consulted."

**Comment:**

The papers reviewed are all listed in the reference section of the report.

The part of the report on the "review of electromagnetic testing" gives a concise and interesting chronological review of the development of instruments.

Reference: r72 .....RCA

**The effect of cut wires on the strength of winding ropes**

M Borello and T C Kuun

SIMRAC report GAP054, Volume 4, April 1996

First issued in December 1994 as a CSIR Contract report MST(94)MC2333 No.940286

Sponsor: SIMRAC .....24 pages

**Summary**

The draft code of practice for rope condition assessment contained discard criteria for broken wires in triangular and round strand ropes. These discard criteria were based on work carried out in the late fifties by Harvey and Kruger (ref. o5). Some of the findings and results of Harvey and Kruger were questionable, and more tests on triangular strand ropes with induced defects (broken wires) were carried out to verify and refine the discard criteria.

The report gives the tensile test results of 46 rope specimens of 48 mm diameter and different configurations and number of broken wires (manually cut wires). The report also lists the results of tensile tests of three 63 mm diameter rope specimens with broken wires all in one strand in each case.

These results, together with some of the results obtained by Harvey and Kruger, were used to define a new distinction between a symmetrical and an asymmetrical distribution of broken wires in a rope. A corresponding new set of discard criteria for triangular strand ropes is also proposed.

The report also recommends further work to investigate the effect of rope size (diameter) and rope tensile grade.

Reference: r73 .....RCA

**Further tests to study the effect of cut wires on the strength of winding ropes**

GFK Hecker and TC Kuun

SIMRAC report GAP054, Volume 4, April 1996

First issued in April 1996 as a CSIR Contract report MST(96)MC2333 No.960171

Sponsor: SIMRAC .....14 pages

**Summary**

The tests described in this report were as recommended in a previous report by Borello and Kuun (ref. r72). The tensile tests on triangular strand rope samples with manually cut "broken wires" were divided into the following three categories:

- ? An assortment of samples with different tensile grades, diameters, and constructions (28 tests).
- ? A length of discarded 62 mm diameter rope (20 tests).
- ? A length of a new 41 mm diameter rope (22 tests).

The wires cut were in all cases in only one of the six rope strands.

After the results of the tests were analysed thoroughly and compared to that of previous investigations and reports, it was concluded that there was "no reason to deviate from the 1994 recommendation (ref. r72) that loss in rope area due to broken wires in one strand over one lay length of the rope must not exceed 4%".

**Comment:**

The recommended value of 4% was included in SABS0293, the rope condition assessment code of practice.

Reference: r74 .....RCA

## **Results of tests on sections of discarded ropes**

M Borello

SIMRAC report GAP054, Volume 4, April 1996

First issued in June 1994 as a CSIR Contract report MST(94)MC2122 No.940126

Sponsor: SIMRAC .....78 pages

### **Summary**

Rope inspectors and mine engineers were requested to submit sections of discarded ropes to the CSIR for destructive tests. The results of the tests were required to verify and/or refine the discard criteria proposed for the rope condition assessment code of practice. It would also indicate how well the prescriptions of the draft code were implemented by industry and rope inspectors.

In the introduction of the report is an interesting section in which steel wire rope discard criteria obtained from "The Ropeman's Handbook", ISO 4309, DIN 15020 (1954 and 1974) and BS 6570 are given and compared. The report also contains a short section on the history of the rope condition assessment code of practice (which eventually become SABS0293).

The main part of the report describes the physical appearance and results of destructive tensile tests on 63 rope specimens obtained from ropes discarded from mine winders. The report also describes the results of five laboratory prepared specimens with two wires arc welded together on each rope, and six specimens that were exposed to an oxy-acetylene flame to simulate "heat damage". From the conclusions of the report, the following:

- ? The most common reason for discard was "broken wires".
- ? The discard criteria for broken wires in one strand should be revised.
- ? The importance of multiplication factors for evaluating the actual rope steel area loss due to corrosion cannot be over-emphasised.
- ? The reference rope diameter at various points along the length of the rope (for the calculation of rope diameter effects) must be determined once a rope has been in service for a certain amount of time (a few weeks maximum).
- ? One half of the ropes for which proper "discard factors" could be calculated were found to have been discarded too late. The code of practice therefore has not been implemented or explained to all rope inspectors and mine engineers.

Details of each of the 63 rope specimens tested are given in a 30-page appendix.

### **Comment:**

The report mentions that it "is important in future that the reference rope diameter is determined once the rope has been in service for a certain amount of time (a few weeks maximum). If this is not done it will be difficult to discard a rope based on rope diameter reduction. It must be remembered that new rope diameter variations can range from 0% to 5% larger than nominal. A rope that is 5% oversize can lose 14% of its actual diameter before the code recommends discard if the diameter reduction is based on nominal diameter" (and not the initial in-service measured diameter).

This comment was still valid in 2002.

Reference: r75 .....RCA  
**Discussion of results of tests on discarded ropes in terms of the draft code of practice for rope condition assessment**  
E J Wainwright  
SIMRAC report GAP054, Volume 4, April 1996  
First issued in May 1995 as a CSIR Contract report MST(95)MC2470 No.950125  
Sponsor: SIMRAC .....130 pages

## Summary

The investigation described in this report was a continuation of the initial study of the strength of discarded ropes (ref. r74).

A further 45 rope specimens were obtained and tested, and the results are given together with the results of the 63 specimens tested during the initial investigation (ref. r74). Details of all 108 specimens and the results of the tensile tests are given in a 108-page appendix to the report. The results of all 108 specimens are discussed together.

From the conclusions and recommendations of the report, the following:

- ? The discard criteria of the "draft code of practice" are generally satisfactory for round strand and triangular strand ropes.
- ? The discard criteria are completely inappropriate for assessing non-spin ropes, especially those used on Koepe winders. Requirements for Koepe ropes should be different to those for non-spin ropes operating on drum winders.
- ? Further work is required in clarifying how corrosion is assessed.
- ? Not all ropes were assessed and discarded according to the draft code of practice.

The report mentions that, in calculating the discard factors, the actual rope diameter measured on site was used if the value was supplied. Otherwise, the diameter measured at the start of the tensile test was used. This diameter was measured at a tensile load of 10% of the new rope breaking strength. In the absence of diameter measurements taken soon after the ropes were installed, the nominal rope diameter had to be used as the initial rope diameter in the calculations of the discard factors.

## Comments:

Greater detail on reasons for larger-than-expected strength losses for some of the rope specimens of the initial study (ref. 74) is given in the report<sup>r74</sup> on the initial study. Not all of those details are given in the report under discussion, and some of the results could therefore be misleading.

Two of the non-spin ropes tested were discarded because of corrosion and had breaking strength losses of 34% and 46%. The degree of corrosion was grossly underestimated in both cases by the rope inspector in combination with his rope-testing instrument. The conclusion made in the report that the discard criteria are "completely inappropriate for non-spin ropes" is therefore somewhat harsh.

Another serious problem is that calculated discard factors were skewed because rope diameter variations could not be referred to initial rope diameters measured in service. A 1-mm diameter difference between the rope front-end and back-end of a rope directly after installation is not uncommon.

Reference: r76 .....RCA  
**Discussion of results of second series of tests on discarded ropes in terms of the draft code of practice for rope condition assessment**  
E J Wainwright  
SIMRAC report GAP054, Volume 4, April 1996  
First issued in April 1996 as a CSIR Contract report MST(96)MC2887 No.960167  
Sponsor: SIMRAC .....66 pages

### **Summary**

In the introduction of the report it is mentioned that no formal instructions had been proposed or circulated in response to the recommendations made in the previous report (ref. r75) on the testing of discarded ropes. Consequently, discarded ropes submitted for testing were addressed in the same manner as before.

The report discusses tensile tests on 50 samples obtained from 33 discarded winder ropes. Details of each of the 50 specimens tested are given in a 50-page appendix.

The results were much the same as that of the previous report (ref. r75), and the conclusions were therefore the same as before.

### **Comments:**

Only in isolated cases were strength reductions of more than 20% found for ropes with broken wires only. In most of these cases, there were secondary reasons for the "excessive" strength loss like martensite formed on the surface from the rope rubbing against an object.

However, corrosion, and especially corrosion of Koepe winder head and tail ropes gave strength losses generally of the order of 30%, but also as much as 50%.

Reference: r77 .....TRAIN, INFO, RCA

**Training manuals for rope inspectors:**

**Module 1: Study guide for wire rope inspectors.**

E J Wainwright

SIMRAC report GAP054, Volume 5, April 1996

Sponsor: SIMRAC .....50 pages

**Summary**

The study guide provides the syllabus of the required theoretical and practical training for both "Level 1 and Level 2" examinations. It also gives a list of recommended visits to various institutions and sites as part of the practical training.

One objective of this "study guide for wire rope inspectors" is to provide an overview of the training modules and to identify the most important features of winder operation and rope inspection.

The guide provides an overview of the following training manuals:

- ? An introduction to mine winders.
- ? Technology of wire ropes for mine winding in South Africa.
- ? Destructive testing of wire ropes
- ? Practical aspects of rope inspection.
- ? Magnetic rope testing instruments.

A short description is given on the content of each of the mentioned training manuals together with the "table of contents" of each of the manuals.

Rope inspectors and the ropes they inspect are subjected to certain legal requirements. The study guide therefore also contains a section on "legal knowledge" in which the numbers of relevant chapters and sections of the "minerals act" and "regulations" are listed.

The guide also contains an 18 page general index on the keywords of the five training manuals that were discussed (those listed above).

**Comment:**

The Mine Health and Safety Act (1997) now contains the relevant sections and regulations pertaining to safety that were previously part of the Minerals Act (1991). The training manuals therefore require a review and update.

The study guide also does not mention a further training module contained in Volume 5 of GAP054: *Rope deterioration reference book*. (ref. r83)

Reference: r78 .....TRAIN, INFO

**Training manuals for rope inspectors:**

**Module 2: An introduction to mine winders.**

E J Wainwright

SIMRAC report GAP054, Volume 5, April 1996

Sponsor: SIMRAC .....67 pages

**Summary**

This module gives an overview of mine hoisting practice in South Africa. All types of winders used in South Africa are described, and include drum winders, double drum winders, multi-rope drum winders (BMR's), sinking winders (kibble winders and stage winders), Koepe friction winders and lifts.

Each winder system is discussed in terms of its components, e.g. drums, brakes, headsheaves, ropes, fleet angles and protection devices.

Reference: r79 .....TRAIN, INFO

**Training manuals for rope inspectors:**

**Module 3: The technology of wire rope for mine winding in South Africa.**

E J Wainwright

SIMRAC report GAP054, Volume 5, April 1996

Sponsor: SIMRAC .....154 pages

**Summary**

The four chapters of this extensive document are:

Chapter 1: Introduction to rope and rope technology.

The different parts of a wire rope are described: strands, the rope core and the wires. Details of single strand ropes, round strand ropes and shaped strand ropes are given to illustrate the types of steel wire rope. The properties of ropes are discussed in terms of breaking strength, mass, elongation, rope lay, rope torque, flexibility, and so forth.

Chapter 2: Manufacture of high tensile wire for use in wire ropes.

All aspects of the processing of wire for steel wire ropes are covered; from rolling to patenting, cleaning, drawing, galvanising and testing.

Chapter 3: Rope manufacture.

The principles of operation of various strand manufacturing and rope closing machines are discussed, as well as the rope making processes, and inspection and testing for the acceptance and rejection of wire, strand and ropes.

Chapter 4: Recommendations for use of ropes in various hoisting applications.

The characteristics of different rope types/constructions are discussed in terms of strength, flexibility, wear resistance, fatigue performance, lay, torque, resistance to crushing, corrosion, stability, and reserve strength. The selection of rope types for all the different drum and friction winders in use in South Africa are discussed in detail.

The document also contains an eight-page glossary of wire rope and related terms, and a six-page list of international and local standards related to the manufacture, testing and use of wire ropes.

**Comment:**

The document requires some revision because of changes to the statutory regulations and to take cognisance of the contents of research reports and codes of practice that were produced since this training manual was written.

Reference: r80 ..... TRAIN, RCA  
**Training manuals for rope inspectors:**  
**Module 4: Magnetic rope testing instruments.**  
TC Kuun  
SIMRAC report GAP054, Volume 5, April 1996  
Sponsor: SIMRAC .....22 pages

## Summary

From the introduction of the manual:

"Many different types of magnetic rope testing instruments are now available from local and overseas suppliers. These instruments have different characteristics. To use any one of them properly, it is necessary to know how it works and how to set it up. These matters are explained in this training module."

The manual contains two and a half pages of definitions of the terms commonly used with magnetic rope testing instruments.

The basic principles of operation is discussed in terms of magnetism, magnetisation of ropes (with AC, DC and permanent magnet systems), and signal generation devices or sensors (coils, Hall sensors, flux gate sensors, and magnetoresistors).

The manual further argues that, because "all magnetic rope testing (MRT) instruments currently available are based on some combination of rope magnetisation and magnetic flux sensing, proper use of an instrument requires detailed knowledge of the characteristics of the particular combination of devices built into the machine." The characteristics of AC electromagnetic, DC electromagnetic, and permanent magnet instruments are therefore discussed in detail. The superiority of permanent magnet instruments is evident from the detailed discussions.

The "requirements for instruments" are discussed in terms of specification, evaluation, certification and maintenance. The last section of the module "use of MRT instruments" elaborates on the magnetic conditioning of ropes, setting up of instruments, and operation of instruments.

Analysis and application of the results (traces) obtained from rope testing instruments are covered in the training manual on "practical aspects of rope inspection" (ref. r81).

## Comment:

The "basic requirements" and specification of magnetic rope testing instruments are given in both SABS0293 and this training module. The two documents have to remain compatible.

Reference: r81 ..... TRAIN, RCA  
**Training manuals for rope inspectors:**  
**Module 5: Practical aspects of rope inspection.**  
T C Kuun  
SIMRAC report GAP054, Volume 5, April 1996  
Sponsor: SIMRAC .....45 pages

## **Summary**

This training module covers all the aspects of inspection (and not only that of magnetic rope testing).

The defects that could be present in new ropes (and while in storage) and in ropes in-service are detailed. The occurrence of abnormal rope damage and normal rope deterioration are discussed in detail. The module further elaborates on the differences in types of defects that can occur in ropes used on drum winders, on Koepe headropes, Koepe tailropes, stage winder ropes, kibble winder ropes, and elevator ropes.

The types of rope testing equipment that are discussed include magnetic rope testing instruments, rope diameter tapes, rope vernier callipers, rope laylength rules, straight-edges, and groove diameter gauges.

A separate section is included on the planning of inspections for the ropes of different types of winders, as well as a section on magnetic tests.

The positions in the rope that requires physical inspection are given, and the actual physical inspection is specified in detail. The section on the evaluation of results details the rope discard criteria and gives detailed examples of calculations related to the discard criteria.

The module also has a seven-page appendix that details the discard criteria of SABS0293.

Analysis and application of the test results obtained from magnetic rope testing instruments are covered in this training manual.

## **Comment:**

This module was completed before the first edition of SABS0293 was finalised. The contents of this module have to remain compatible with SABS0293.

This module requires some updating.

Reference: r82 ..... TRAIN  
**Training manuals for rope inspectors:**  
**Module 6: Destructive testing of wire ropes.**  
M Borello  
SIMRAC report GAP054, Volume 5, April 1996  
Sponsor: SIMRAC .....57 pages

**From the executive summary of the document**

"This document has been compiled to serve as a self-study course for Rope Condition Assessment Technicians. It serves as a guide for the interpretation of data given on the certificate of test conducted on a wire rope specimen. It also gives guidelines as to how rope specimens should be prepared in the field and explains the importance thereof."

**Contents**

The various terms used on the certificates are explained. The remarks made on test certificates are explained in more detail and the possible reasons for defects are given. Photographs illustrating the different types of wire breaks, levels of corrosion and condition of the lubricant have been included. The document also gives details on how the various values given on the load-elongation diagrams are calculated and their significance is discussed.

**Comment:**

With all the accompanying photographs, this module is far more than a document on the destructive testing of wire ropes.

The photographs on the different degrees of corrosion are the same as those included in SABS0293.

The quality of the photographs of this training manual on the SIMRAC CD (volume 1) could be improved.

Reference: r83 .....TRAIN, DET

**Training manuals for rope inspectors:**

**Module 7: Rope deterioration reference book.**

M Borello and GFK Hecker

SIMRAC report GAP054, Volume 5, April 1996

Sponsor: SIMRAC .....41 pages

**From the executive summary of the document**

"It has been found in the past that the terminology used by the CSIR (e.g. levels of corrosion, amounts of lubrication, etc.) in the rope test certificates which are issued for each rope test are not fully understood. The CSIR has already produced a document in the form of a self study module for the Chamber of Mines which describes the rope testing procedure and the interpretation of the results. The module is to be used for the training of Rope Inspectors.

This reference booklet does not contain the same detailed amount of information as the training module but does concentrate on providing illustrations of terms relating to ropes. This booklet is aimed at assisting personnel on mines who are involved with ropes in interpreting the information on a rope test certificate and the meanings of different terms used by the CSIR, rope manufacturers and other institutions in South Africa. This booklet should be used as a quick reference guide for mine personnel."

**Comment:**

This "reference book" contains photographs not present in the other manuals or modules that were produced. These are on different types and degrees of wear, waviness, birdcage, kink, and extrusion of a steel core.

The other photographs are the same as those of training module 6: "Destructive testing of wire ropes" (ref. r82).

The quality of the photographs of this training manual on the SIMRAC CD (volume 1) could be improved.

Reference: r84 ..... TERM  
**Laboratory evaluation of white metal and resin cappings for use as winder rope terminations**  
M Borello  
SIMRAC report GAP054, Volume 3, April 1996  
First issued in November 1993 as a CSIR Contract Report MST(93)MC1838 no. 930031  
Sponsor: SIMRAC .....48 pages

## Summary

The comprehensive introduction of the report describes all the earlier work on rope terminations (refs. r58, r59). The report also contains "all the information and results of the first report produced by the CSIR on resin cappings (ref. 60) and the material is dealt with as if it was part of this investigation." The contents of the previous report were included to form one consolidated report. The results of previous work on white metal cappings were also included in this report.

Previous work carried out on splices demonstrated that the efficiency of this type of termination was sensitive to both rigger skill and operating loads. A less labour intensive, less skill dependent termination with better efficiencies was required. The use of resin and white metal cappings as rope terminations was investigated.

The efficiencies of the socketed rope terminations (resin and white metal) directly after preparation and also after having been subjected to "fatigue" loading at different load ranges and up to 30 000 load cycles. All the specimens tested failed clear of the sockets, which demonstrated the terminations were stronger than the rope i.e. had efficiencies of 100%.

Poor preparation of a termination was addressed by testing terminations of which the wire bushes were only wiped clean prior to casting, and in other cases not cleaned at all before casting. All the poorly prepared resin sockets failed clear of the termination. While for the poorly prepared white metal ones the ropes pulled out of the sockets at between 72% and 92% of the rope strength.

The effect of not heating the (white metal) socket to the specified temperature, as well as overheating the white metal was also investigated. In all cases 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. Resin is a more suitable capping material compared to white metal because of its insensitivity to the cleanliness of the brush and its ease of preparation.

It was recommended to investigate 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.

Reference: r85 ..... TERM

## **Performance of resin filled sockets prepared by the mining industry**

M Borello

SIMRAC report GAP054, Volume 3, April 1996

First issued in November 1994 as a CSIR Contract Report MST(94)MC2166 no. 940155

Sponsor: SIMRAC .....35 pages

### **Summary**

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 exist 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 a 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."

The report also contains an appendix with the "Notes of guidance for resin capping of wire ropes" obtained from the National Coal Board (UK).

Reference: r86 ..... TERM  
**Performance evaluation of resin filled sockets used at Premier Diamond Mine**  
M Borello  
SIMRAC report GAP054, Volume 3, April 1996  
First issued in December 1994 as a CSIR Contract Report MST(94)MC2264 no. 940226  
Sponsor: SIMRAC ..... 13 pages

### **Summary**

The report describes the performance of two resin-capped sockets that were used as the front-end rope terminations of a drum winder. The sockets remained in service for six months and completed nearly 35 000 winding cycles. After removal, the front ends of the ropes with the sockets were tensile tested (to destruction).

The terminations did not show any in-service deterioration.

The report concluded that "resin sockets are suitable replacements as winder rope terminations for rope splices operating in vertical shafts".

Reference: r87 ..... TERM  
**An investigation into the behaviour and deterioration of winding rope tangent points on conveyance mounted compensating sheaves**  
Mike van Zyl  
SIMRAC report GAP054, Volume 3, April 1996  
First issued in May 1995 as a CSIR Contract Report MST(95)MC2491 no. 950132  
Sponsor: SIMRAC .....65 pages

### **From the synopsis of the report**

"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 results of a large number of tensile tests on tangent point samples are given in the report.

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 (with accelerometers), stresses on the outer rope wires (with strain gauges on the wires of the ropes), and the dynamic behaviour of the winder drum during normal rock hoisting. All the measured quantities are shown in graphs as functions of time.

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."

Reference: r88 ..... TERM

**Splicing techniques for mine winder ropes**

M Borello

SIMRAC report GAP054, Volume 3, April 1996

First issued in October 1994 as a CSIR Contract Report MST(94)MC2260 no. 940225

Sponsor: SIMRAC .....19 pages

**Summary**

Splicing: Securing the ends of a rope into its own part by inter-weaving the strands.

The report describes the procedures for making the following splices in detail:

- ? Cross-lay or Admiralty splice on a six strand rope
- ? Liverpool slice on a six strand rope
- ? Cross-tuck slice on a 17x7 non-spin rope
- ? Cross-tuck splice on a 34x7 non spin rope

The information in this report was also included in the report on "Rope terminations for mine hoisting applications" (ref. 89).

Reference: r89 ..... TERM

## **Rope terminations for mine hoisting applications**

E J Wainwright and M Borello

SIMRAC report GAP054, Volume 3, April 1996

First issued in March 1995 as a CSIR Contract Report MST(94)MC2260 no. 940236

Sponsor: SIMRAC .....68 pages

### **Summary**

Rope terminations for the following winder applications are discussed:

- ? Drum winders
- ? Multi-rope drum winders (BMR's)
- ? Stage winders for shaft sinking
- ? Headropes of Koepe winders
- ? Tail ropes of Koepe winders

The report has a section on the inspection and maintenance of the types of terminations discussed, and has a section on terminations for slings

Detailed instructions for the preparation of capels, sockets, and splices for six strand and multi-layer stranded ropes are given in a 30-page appendix:

The advantages and disadvantages of various end connections for triangular strand winding ropes are listed in a separate appendix. Thimble splices, sockets, wedge capels, and thimble capels (or pear shaped capels) are discussed.

Reference: r90, r91, 92 .....SINK, DYN  
Reports on **Rope force measurements during shaft sinking operations**  
Mike van Zyl  
SIMRAC report GAP054, Volume 7, April 1996  
Sponsor: SIMRAC .....163 pages

The objective of the three investigations was to determine what was happening to the winding ropes during shaft sinking operations; therefore, only one summary.

**Rope force measurements during shaft sinking operations at Vaal Reefs 11 Shaft**

First issued in December 1995 as a CSIR Contract Report MST(95)MC2736 no. 950373

**Rope force measurements during shaft sinking operations at West Driefontein 10 Shaft**

First issued in January 1996 as a CSIR Contract Report MST(95)MC2736 no. 950374

**Rope force measurements during shaft sinking operations at West Driefontein 9 Shaft**

First issued in February 1996 as a CSIR Contract Report MST(95)MC2736 no. 950375

**Summary**

The new statutory regulations that were proposed for drum winders would 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 therefore investigated. The aim of the stage and kibble winder ropes investigation was to obtain guidelines for drafting a code of practice for deep shaft sinking winders.

The measurement of the rope forces on the stage winders and kibble winders at three shafts formed the first part of the investigation. The stage rope forces were measured during all types of sinking and stage operations, i.e. during blasting, lashing, stage raising and lowering, kibble crosshead interactions, and water hoisting. The kibble winder rope forces were measured during all types of normal sinking operations, which are hoisting of loaded kibbles and tipping, hoisting water, transporting personnel and material, transporting jumbo drill rigs, running the winder with only the crosshead attached at the rope end, and emergency braking with loaded kibbles, both ascending and descending, near the bottom of the shaft. On each shaft, recordings were made continuously for at least a 24-hour period.

The dynamic rope components measured during lifting of loaded kibbles and jumbo drill rigs were insignificant because of the slow winder speeds employed during these operations. Tipping and hoisting water also did not generate rope dynamics of any significance. The only event, apart from emergency braking (trip-outs), that produced any significant rope dynamics was acceleration of the winder. The dynamic rope forces generated by kibble winders are less severe than those of permanent drum winders because of the absence of skip loading dynamics. For the rest of the operation of kibble winders, the dynamics are the same as that of permanent drum winders.

The peak-to-peak magnitudes of the dynamic components of the stage rope forces measured during any stage operation were never greater than 2% of the breaking strength of the ropes. The rope forces can therefore be regarded as static. The rope dynamics measured during stage movements, expressed as percentages of the rope breaking strengths, were less for the deeper shafts compared to those at the shallower shaft.

Reference: r93 ..... RCA, DET  
**GAP324 Volume 1: Deterioration and discard of mine winder ropes**  
GFK Hecker, EJ Wainwright, P Goosen, C Heydenrych  
SIMRAC report GAP324, Volume 1. CSIR, September 1997.  
Sponsor: SIMRAC .....78 pages

## Summary

The report is divided into four main sections, each with its own introduction and conclusions.

### 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 the winder code of practice required by the proposed new drum winder rope regulations. The requirements in this code 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 also be possible that they are too stringent.

Therefore, to establish how winder design parameters affect rope life and safety, the interrelation between rope operating parameters and rope life/rope deterioration was studied through the following:

- ? Re-work the earlier statistical rope life model (ref. r22) to illustrate clearly 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.

### Statistical evaluation of rope lives on drum winders:

The report shows graphs of rope life as functions of various winder and operating parameters. It is concluded (as earlier) that simple relationships cannot be established because of the interdependence of most of the winder parameters. It is also concluded that the model can only be improved if "better" data are obtained, i.e. consistent rope maintenance procedures and consistent rope discard criteria.

### Field studies of rope deterioration: The programme proposed in the GAP054 report:

- ? Verification of winder parameters.
- ? Corroboration of rope maintenance practice.
- ? Winder behaviour measurement to record winder dynamics.
- ? 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.

GAP324 provided funding for the above, but excluded the laboratory work (which was eventually done later as part of SIMRAC project GAP501<sup>r102</sup>). The report gives the verified winder parameters and the rope loads calculated from the measured winder dynamics. The maintenance practice of one of the winders was observed and listed. The data obtained during the rope inspections are also given.

The report further elaborates on how the "triangular strand rope behaviour in deep shafts" part of the project evolved. The findings of this project is discussed separately (ref. r99).

### **Refined discard criteria for winder ropes:**

The work on discard criteria was a continuation of the work started as part of GAP054. During the time that this project was carried out the "Code of Practice: Condition assessment of steel wire ropes on mine winders" was also issued for the first time (SABS0293:1996).

Destructive strength tests on samples obtained from ropes discarded from mine winders were 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 report includes a summary of the discard criteria of SABS0293.

The results of tests carried out on 52 rope samples are described in the report. The majority of the samples were triangular strand ropes discarded from drum winders, but there were also non-spin rope samples from Koepe winders and seven samples with various degrees of corrosion. The report concluded that the discard criteria for broken wires in triangular strand ropes are adequate, but that the criteria for diameter changes should be investigated further. The report mentioned that more non-spin rope samples were required before meaningful conclusions can be reached. More samples with corrosion were also required to verify the indications of steel area losses obtained with magnetic rope testing instruments.

The GAP054 report describes tests on triangular strand rope samples with laboratory induced defects (i.e. wires were cut to simulate broken wires). The usefulness of these cut wire tests prompted similar tests to be carried out on non-spin ropes so that more appropriate discard criteria could be established for non-spin ropes. Fourteen samples of an 18-strand fishback rope were prepared. The cut wires were all in the inner part of the rope (inner broken wires), and ranged from eight to seventeen in total. The report notes that the "counting" of inner broken wires in a non-spin rope (with the aid of magnetic testing) is not a simple matter, and still needs to be investigated and verified.

All cut-wire tests on samples from non-spin ropes are discussed in detail in the report on SIMRAC project GAP502 (ref. r103).

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

The aim of the stage and kibble winder rope investigation was to obtain guidelines for drafting a code of practice for sinking winders on very deep shafts. The detailed investigations carried out are described in Volume 2 of GAP324 (ref. r94).

### **Presentations to the Association of Mine Resident Engineers**

The draft code of practice for the "performance, operation, testing and maintenance of drum winders relating to rope safety" was submitted to the SABS, and it was expected that the draft would be circulated for comment in 1996. Some funding as part of GAP324 was available to make presentations to the parties concerned so that they would be informed on the background of the safety requirements in the code. However, members of the SABS technical committee could not agree on the contents of the code and the document was not finalised. The "presentations" section of the project was therefore deferred.

Reference: r94 ..... see individual reports  
**GAP324 Volume 2: Deterioration and discard of mine winder ropes**  
Mike van Zyl  
SIMRAC report GAP324, Volume 2. CSIR, September 1997.  
Sponsor: SIMRAC .....176 pages

## Summary

The reports contained in Volume 2 of GAP324 are mentioned in Volume 1. Volume 2 was made up from four interim reports on the sinking winder investigations and the one on the behaviour of triangular strand ropes in deep shafts:

Overview of the winding rope requirements for deep shaft sinking operations. April 1996.<sup>r95</sup>  
Load ranges acting in kibble winder ropes and proposals for new kibble winder rope regulations. November 1996.<sup>r96</sup>  
Rope forces generated after brake control failure on kibble winders. December 1996.<sup>r97</sup>  
Stage rope factors for deep shaft sinking operations. January 1997.<sup>r98</sup>  
Triangular strand rope for deep shaft operations – an initial study. September 1997.<sup>r99</sup>

The main part of the GAP324 Volume 2 report consists of the executive summaries of the above reports. The reports themselves are given complete in separate appendices. The five reports are summarised individually under their separate references.

The aim of the stage and kibble winder ropes investigation was to obtain appropriate rope load factors (safety factors) for deep shaft sinking operations, and to obtain guidelines for drafting a code of practice for deep shaft sinking operations. These reports completed the required investigations, and proposed and motivated appropriate safety factors for the ropes. The measurement of the rope loads on stage and kibble winders had been carried out at three shafts as the initial part of the investigation (see GAP054, Volume 7) (refs r90, r91, r92).

The report on "triangular strand ropes for deep shaft operations" was the only report commissioned by SIMRAC on the subject of suitable rope constructions for very deep shafts.

Reference: r95 .....SINK, FOS  
**Overview of the winding rope requirements for deep shaft sinking operations**  
Mike van Zyl  
First issued in April 1996 as a CSIR Contract Report MST MC. No. 960158  
Part of SIMRAC report GAP324, Volume 2. CSIR, September 1997.  
Sponsor: SIMRAC .....22 pages

**From the synopsis of the report**

"The proposed new statutory regulations for drum winder ropes will conceivably allow single lift shafts of as deep as 4000 m. If such deep shafts have to be sunk in the conventional way, stages and kibbles will be used.

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 measurement of the rope forces on stage and kibble winders had been carried out at three shafts as the first part of the investigation. This report explores the requirements for safe winding rope operation, the regulations that govern the strength of sinking ropes, examples of deep sinking installations, and the applicability of the rope condition assessment code of practice (SABS0293) and the (draft) winder code of practice (SABS0294) on sinking ropes.

It is possible to sink shafts with stage and kibbles winders in the conventional way to depths of 4000 m provided that appropriate rope regulations for such operations are instituted.

The views expressed in this report were largely influenced by the interviews that the author conducted with members of the shaft sinking industry, visits to shaft sinking operations and observations while the field measurements were carried out.

Details of the scope of further work on the requirements for the safe use of stage and kibble winder ropes are also outlined."

**Comment:**

The original report contained an 18-page appendix listing the (new) regulations (of Chapter 16 of the relevant Act) that were applicable to shaft sinking operations. This appendix was not included in Volume 2 of GAP324.

Reference: r96 ..... SINK, DYN, FOS  
**Load ranges acting in kibble winder ropes and proposals for new kibble winder rope regulations**  
Mike van Zyl  
First issued in November 1996 as a CSIR Contract Report MST MC. No. 960348  
Part of SIMRAC report GAP324, Volume 2. CSIR, September 1997.  
Sponsor: SIMRAC .....56 pages

### **From the synopsis of the report**

"In this report, the load ranges of kibble winder ropes are analysed to obtain a basis for regulations that will allow the sinking of deep shafts with kibble winders. From this analysis, regulations for kibble winders are proposed, both for installations that will have to, and will not have to, comply with the requirements of a code of practice.

It is shown that the proposed rope regulations for drum winders that do not have to comply with the requirements of a code of practice are suitable and sufficient for kibble winder operations. These are a capacity factor of 8 and a safety factor of 4,5.

It is further proposed that kibble winders should only have to comply with the requirements of a code of practice once a depth is reached at which the rope safety factor is less than 4,5. The safety factor formula for the ropes of such kibble winder installations should be a capacity factor of 8. One of the requirements of the code of practice for sinking winders will have to be a limit of 15% for the load range ratio of the winder rope."

### **Contents**

The report has a section that elaborates on the "purpose of winder rope regulations", and substantiates and motivates the proposed rope safety factors.

The report also has a very detailed appendix on winder rope dynamics, which includes the effects of rope damping and rope elasticity as well as the influence of the shape of a winder acceleration profile on rope loads generated.

Reference: r97 ..... SINK, DYN, INFO  
**Rope forces generated after brake control failure on kibble winders**  
Mike van Zyl  
First issued in December 1996 as a CSIR Contract Report MST MC. No. 960383  
Part of SIMRAC report GAP324, Volume 2. CSIR, September 1997.  
Sponsor: SIMRAC .....50 pages

### **From the synopsis of the report**

"Permanent drum winders that will (eventually) operate on a shaft are often used for the sinking of the shaft as well. The winding duties during shaft sinking could be lighter than the permanent shaft duty. The investigation described in this report was carried out to determine whether these different winding duties could result in significantly different rope forces after brake control failure.

A further objective of this report was to determine what winder brake requirements have to be included in the code of practice for sinking winders other than those of the draft "winder code of practice". The findings in this report are applicable to kibble winders as well as permanent drum winders.

This report shows that, if current drum winder brake design criteria are employed, rope forces in excess of 60% of the breaking strength of the rope after brake control failure will only be generated under very special circumstances.

It is further shown that slack rope can occur after brake control failure on all drum winders currently in operation, whether they are used for permanent winding duties or for shaft sinking. Double drum winders with two brakes are the most susceptible. Other than disregarding brake control failures completely or reducing the brake capacity of a two-brake double drum winder to the extent that the winder will not be able to stop on one brake only, there does not seem to be an obvious solution to prevent the occurrence of slack rope after brake control failure on such winders. If brake control failures can occur, and if slack at the front end of kibble winder ropes is undesirable, this matter should be investigated further.

On new winder designs, slack rope after the occurrence of brake control failures can be prevented if the regulations governing drum winder brakes are revised to allow rational disc brake configurations. It is recommended that the regulations governing drum winder brakes should be revised.

After brake control failure, excessive rope forces will not be generated and nothing can be done (at present) to prevent the occurrence of slack rope on existing drum winders. Currently, there is very little on brake control failure that can be included in a code of practice."

### **Contents**

The report also contains information on the inertias of winder drums, winder motors and headsheaves.

Information on winder brake regulations, design capacities, brake control systems, uncontrolled braking, and multiple brake systems are contained in a separate appendix.

Reference: r98 .....SINK, DYN, FOS, DEEP  
**Stage rope factors for deep shaft sinking operations**  
Mike van Zyl  
First issued in January 1997 as a CSIR Contract Report MST MC. No. 970003  
SIMRAC report GAP324, Volume 2. CSIR, September 1997.  
Sponsor: SIMRAC .....19 pages

### **From the synopsis of the report**

"The winder rope regulations governing the strength of stage winder ropes do not allow for realistic stage winder configurations for shaft depths greater than 2 500 m to 3 000 m. The mining industry in South Africa need regulations that will allow safe sinking operations with stages and kibles to depths of 4 000 m.

The safety factors for stage winder ropes are analysed in this report. It is shown that a rope safety factor of 3 is required to operate a rationally sized stage at a depth of 4 000 m. It is further demonstrated that a rope safety factor of 3 is acceptable for such operations.

For stage winder operations that comply with the requirements of a code of practice, a rope safety factor of 3 is recommended."

### **Contents**

The rope loads generated in the remaining stage rope(s) after the failure of one stage rope are also shown in the report.

Reference: r99 .....DEEP, DET  
**Triangular strand ropes for deep shaft operations – an initial study**  
Mike van Zyl  
First issued in September 1997  
Part of SIMRAC report GAP324, Volume 2. CSIR, September 1997.  
Sponsor: SIMRAC .....34 pages

### **From the synopsis of the report**

"Nearly all permanent drum winders in this country use triangular strand ropes. The torque-tension characteristics of triangular strand ropes cause laylength changes in the rope when installed in a shaft, and cause torque to be generated at the fixed rope ends. The general belief of the mining industry is that the laylength changes and the generated torque will limit the depth at which triangular strand ropes can be used. Suitable alternative rope constructions for permanent drum winder operations have not yet been established.

In this initial study, the possibility of using triangular strand ropes at shaft depths greater than current experience is investigated. The report examines how triangular strand ropes could behave in ultra deep shafts, and analyses potential problems that could be experienced under such operating conditions.

The investigation was based on an experience at Loraine Gold Mine where a triangular strand rope lost spin by accident to create a (back-end) rope laylength much longer than as-manufactured. The rope had operated satisfactorily for three years in that condition and was still in service at the time of the writing of this report.

It is concluded that there is very little reason why triangular strand ropes will not operate satisfactorily at shaft depths of at least 3200 m. It is further concluded that it is very possible that triangular strand ropes could be used at shaft depths of 4 000 m. It is further shown that the overall laylength situation of triangular strand ropes in deep shafts can be improved by manufacturing ropes with longer laylengths than current practice.

Although SIMRAC decided not to sponsor continued research in this field, recommendations for future research are given."

### **Comment:**

This report on "triangular strand ropes for deep shaft operations" was the only investigation commissioned by SIMRAC on the subject of suitable ropes for very deep shafts.

Reference: r100 ..... SINK, COP, FOS  
**Catalogue of best practices for the ropes and winders of deep shaft sinking operations**  
Mike van Zyl and Frieder Hecker  
SIMRAC report GAP418. CSIR, November 1998  
Sponsor: SIMRAC .....58 pages

## Summary

The statutory rope strength requirements in South Africa limit shaft sinking depths with conventional methods to approximately 3 000 m. Deeper shafts can only be sunk if an exemption is granted by the Department of Minerals and Energy.

If a shaft sinking operation adheres to the specifications in this "shaft sinking code of practice", exemption will be granted by the Department.

The minimum static rope load factors allowed by the Regulations are:

Stage winder ropes: A safety factor of 4,5

Kibble winder ropes: A capacity factor of 8  
A safety factor of 4,5

The minimum rope load factors that will be allowed by an exemption:

Stage winder ropes: A safety factor of 3

Kibble winder ropes: A capacity factor of 8  
A dynamic safety factor of 2,5

The primary purpose of the "catalogue of best practices" is to ensure the safety of the winding ropes. It therefore addresses aspects that will influence rope loads, rope strength, rope deterioration and the condition assessment of the winding ropes. Other aspects of the stage and kibble winders that could influence the safety of personnel conveyed in kibles and personnel working on the stage are included, e.g. the required braking capacities of winders.

The actual code of practice is included as an addendum to the GAP418 report.

Reference: r101 ..... DET, RCA  
**GAP439: Deterioration of mine winder ropes**  
GFK Hecker, EJ Wainwright, C Heydenrych  
SIMRAC report GAP439. CSIR, July 1998.  
Sponsor: SIMRAC .....47 pages

### **From the executive summary of the report**

"The objective of the research project was to determine how winder design parameters affect the safe working life of a rope operating of drum winders with the view to refine requirements in the code of practice for the performance, operation, maintenance and testing of such winders. The major part of the work was the inspection of ropes on selected winders to establish the progress of rope deterioration.

Unfortunately, the only set of ropes that was discarded during the period under review was not made available for subsequent investigation. After consultation with the SIMGAP Engineering Advisory Group, the amount budgeted for this investigation was allocated for tests to obtain discard criteria for non-spin ropes with outer broken wires. The work was a continuation of work done during 1996 and it is continued during 1998. The report therefore mainly describes the results obtained during 1997.

The tests to obtain discard criteria for non-spin ropes with outer broken wires have suggested that a ribbon strand non-spin rope should be discarded when the area of the broken outer wires exceeds eight per cent.

Tests on discarded triangular strand ropes have shown that the discard criteria for such rope constructions are suitable. It is recommended, however, that reductions in rope diameter be measured rather than comparing the rope diameter with the nominal diameter.

Tests on discarded non-spin rope specimens have led to a recommendation for a stricter discard criterion that should be applied until a proper set of discard criteria is found."

### **Contents**

The report gives results from the measurements on the "observed winders", but could not yet come to any conclusions regarding rope deterioration.

The report discusses the problems associated with rope diameter discard criteria in detail, and, as in all previous report, recommends that this issue should be addressed.

The results of the "cut-wire" tests carried out on ribbon strand (non-spin) ropes actually led to more questions than answers, and further tests were recommended.

### **Comment:**

The results of all the "cut-wire" tests carried out during this investigation are included and discussed in detail in the GAP502 report (ref. 103).

### **From the executive summary of the report**

"Deep shaft drum winder operations will be allowed if such winder installations comply with the requirements of a code of practice (SABS0294). The specifications of the "winder code of practice" were largely based on experience, but some uncertainty existed regarding the effectiveness of some of the specifications in the code. These were drum and headsheave sizes, rope layers, and the maximum dynamic rope load range allowed. The objectives of the investigations described in this report were to determine the effectiveness of the specifications regarding the mentioned uncertainties. The investigations of this report generally only considered triangular strand ropes.

Rope fatigue studies and tests were carried out, bending stresses in wire ropes were analysed and measured, contact stresses on ropes were investigated, and drum winders in service were observed to meet the objectives of the project. The more prominent findings of this report are:

- ? Future deep shaft drum winders will operate at rope load ranges of close to 15% of the breaking strengths of the ropes. Under such circumstances, broken wires will be generated by the tension-tension fatigue loading of the ropes. However, rope service lives of 100 000 winding cycles will be achievable for triangular strand ropes if the lubrication of a rope is maintained to minimise the effects of fretting fatigue.
- ? The most surprising result is that surface degradation (or the plastic deformation) of the crown wires of the strands of triangular strand ropes does not increase the susceptibility of wires to fatigue crack initiation.
- ? Contact stress experienced during multi-layer coiling on a winder drum is the primary cause for the plastic deformation or degradation of the crown wires of the rope strands. Although it has been found that this surface degradation will not increase the susceptibility of wires to fatigue crack initiation, it is postulated that high contact stresses will generate their own problems (like split wires) if left unchecked. An alternative approach to the pulling in of back ends is proposed in the section on contact stresses to minimise their adverse effects; i.e. pull in back ends much more frequently in the beginning of the service life of a rope.
- ? The analysis and measurement of bending stresses in triangular strand ropes show that the bending of ropes is still not entirely comprehended, but that the bending stresses for drum-to-rope diameter ratios currently employed will be considerably lower than the stresses generated by the tensile loading of a rope.

Although the findings of this report were different from what was expected or believed earlier. they were not alarming to any extent to warrant immediate changes to the specifications of SABS0294. However, the current specifications in SABS0294 were arrived at after working group discussions over quite a lengthy period, and by giving due consideration to operational and manufacturing constraints and possible impacts on the economics of winding. It is therefore recommended that a working group should consider the recommendations included in this report for possible modifications to the regulations and SABS0294.

The different parts of the project are quite diverse. For that reason, each part is discussed

in detail in separate appendices. The main part of this report is a summary of the findings of the different parts of the investigation."

## **Contents**

The report recommends changes to the regulations and SABS0294 in the following areas:

- ? Preference to the allowable 15% dynamic load range instead of the "formula in the regulations.
- ? Maximum allowable rope loads should be 45% of rope breaking strength instead of 40%.
- ? The maximum D/d ratio required should be 100 instead of 140.
- ? Include specifications in the code for more frequent pulling in of the back end in the beginning of the life of a rope.
- ? The tread pressure recommendation in the code should be scrapped.

Reference: r103 ..... RCA, FOS  
**GAP502: Discard criteria for mine winder ropes**  
Mike van Zyl  
SIMRAC report GAP502. MIKE VAN ZYL INCORPORATED, September 2000  
Sponsor: SIMRAC .....73 pages

### **From the executive summary of the report**

"Various SIMRAC projects have been carried out over the past seven years to verify and refine the discard criteria of SABS0293: The South African Bureau of Standards Code of Practice for the Condition Assessment of Steel Wire Ropes on Mine Winders.

The objectives of the investigation described in this report (GAP502) were the same as those of the previous SIMRAC projects, i.e. to verify, and possibly refine the discard criteria of SABS0293. For this investigation special emphasis had to be placed on non-spin ropes, because the discard criteria for non-spin ropes were not yet well defined in SABS0293, and the possible use of non-spin ropes in future deep shaft operations required the situation to be addressed. The majority of (drum) winder ropes are discarded because of broken wires. The discard criteria for broken wires were therefore the focus of this investigation.

The samples collected and tested from discarded ropes included samples with broken wires, corrosion, substantial plastic deformation, and ropes that had sustained abnormal damage. However, the most important finding of this report ensued from a thorough analysis of "cut-wire" tests.

Very few rope samples from discarded non-spin ropes were, or could be, obtained for the establishment and verification of the discard criteria for non-spin ropes. The effects of broken wires in non-spin ropes were therefore simulated by testing laboratory prepared specimens with selected wires cut in the outer and inner strands. These tests were a continuation of work carried in two previous SIMRAC projects: GAP324 and GAP439. Although not part of the scope of GAP502 (this investigation), the author of this report decided that all cut-wire tests on non-spin ropes of the previous investigations had to be evaluated together with those of GAP502 to be able to establish and propose proper discard criteria for broken wires in non-spin ropes.

The discard criteria for broken wires in SABS0293 were based on a 10% reduction in strength of a rope. An expectation was therefore created that by complying with these discard criteria, a rope would not fail as long as the rope loads did not exceed 90% of the new rope breaking strength.

However, it is shown in this report that rope strands with "allowable" broken wires could fail at loads considerably lower than 90% of new rope breaking strengths. An example: A rope sample from a discarded fishback rope that operated on a drum winder had four broken wires in one outer rope strand. Although the broken wires only made up 1,5% of the total cross-sectional steel area of the rope, that rope strand failed at a load that was 16% lower than the new rope strength, while the remainder of the rope broke at more than 95% of the new rope strength. A thorough analysis of the results of the cut-wire tests of GAP439 further substantiated that weakened rope strands fail at rope loads far lower than originally anticipated.

A theoretical failure analysis of stranded ropes was then performed to explain how and why weakened strands could fail at relatively low rope loads. The failure analysis was not part of the scope of GAP502 but was considered essential, otherwise the apparent anomalies in the results of cut-wire tests would have remained unexplained.

The failure analysis further showed that the load at which a weakened strand in a rope specimen would fail depended on the length of the rope specimen tested. It was also shown that the length of a strand affected by broken or cut wires was the most probable reason for relatively large

scatter in breaking strengths observed in the past for identical specimens.

Friction between a weakened outer strand of a non-spin rope and the rest of the rope was not sufficient to prevent the weakened strand from failing. Although inner rope strands of non-spin ropes would probably be assisted to some extent by inter strand friction, there is very little reason why the strands of triangular strand ropes would not behave the same as the outer strands of non-spin ropes.

Therefore, if the cut-wire and discarded rope tests of triangular strand ropes were carried out on longer specimen lengths, previous researchers would have obtained different results, and would have established different discard criteria.

It was concluded that the concept of a rope having lost 10% of its original strength was only valid for broken wires, damage or corrosion distributed absolutely evenly throughout all the strands of a rope, and then also only valid for ropes of which all strands were identical. It is therefore not possible to establish a general relationship between the reduction in steel area in a stranded rope from broken and cut wires, and the loss in rope strength.

The premise of a rope having lost 10% of its original strength, used previously for establishing discard criteria for broken wires in ropes, does not exist if different lengths of rope are considered. It is therefore required that the basis for establishing discard criteria is reconsidered, especially for broken wires, and therefore what is to be expected if such discard criteria are applied.

It is further recommended that tests be carried out on laboratory prepared specimens to verify the suggested failure behaviour of stranded ropes (fishback, ribbon strand and triangular strand ropes).

Irrespective of how the conclusions and findings in this report are interpreted, winder ropes still have to be inspected and discarded according to the current specifications of SABS0293. The discard criterion that the number of broken wires in a single strand may not exceed 40% of the number of wires in the strand will, at least for the near future, ensure that non-spin ropes with outer strand damage do not remain in service too long.

A major part of this report was done at the cost of the research agency. The findings in this report could not have been anticipated beforehand. Without the additional effort, the larger part of the results obtained from the investigation would have been meaningless."

Reference: r104 .....RCA  
**GAP503 and GAP535: An evaluation of international and local magnetic rope testing instrument defect detection capabilities and resolution, particularly in respect of low rotation, multi-layer rope constructions**  
Martin Dohm  
SIMRAC report GAP503 and GAP535. Anglo American Technical Services, AAC, May 1999.  
Sponsor: SIMRAC ..... 68 pages plus 72 pages in appendices

On the SIMRAC CD Vol 2 and Vol 3, the appendices of the report are not included.

## Summary

Note: The term "non-spin rope" is a generic term for a rope that generates relatively low torque when tensile loaded and that is made up of strands in multiple layers.

Six strand triangular strand ropes, which are used on nearly all permanent drum winder installation in South Africa, have fibre cores, and broken wires that are generated in service are nearly exclusively outer strand wires on the outside of the rope.

All rope testing instruments can detect broken wires on the outer surfaces of a rope, but it is the internal broken wires in a non-spin rope that makes them "difficult to inspect".

The summary that follows was extracted from the contents of the report. The motivation for the execution of the project come from the following two statements from the report:

"Research has indicated that six stranded rope constructions, so commonly used in South Africa, may not be suitable for hoisting from great depths and that multi-layer, low rotation ropes may be required for this application."

"Since non-spin ropes are difficult to inspect and likely to be used more frequently in the future a SIMRAC project was initiated to evaluate the abilities of available magnetic rope testing instruments in assessing the condition of a non-spin rope."

Two lengths of non-spin rope, each approximately 20 m long, were available for comparing the abilities of rope testing instruments. The one rope had a 3,5-m long corroded section while the rest of the rope was still in a good condition and without any broken wires. The other rope sample was cut from a rope that had operated on a permanent drum winder installation until discard, and had a large number of internal broken wires.

The eight organisations that participated in the evaluation of their instruments were:

NORANDA (Canada)	Lloyds Beal (UK)
DMT (Germany)	NDT Technologies (USA)
Universitat Stuttgart (Germany)	AATS (South Africa)
Merastar (Poland)	Rotesco (Canada).

Corroded rope:

The test on the rope sample with the corroded section was relatively simple because the corroded part could be compared directly to the good part of the rope sample. Instruments could be calibrated on the good part of the rope. The tensile test carried out subsequently on the corroded part of the rope showed a strength loss of 48% compared to the new rope strength. The report gives the results and comments of each of the participants. The participants were also asked to estimate the remaining strength of the corroded part, and to comment on the use of "loss of breaking strength" (LBS) as a discard criterion.

## Broken wires:

In December 1990, Anglo American Corporation installed four non-spin ropes on a drum winder (BMR) as part of field trials to determine the suitability of non-spin ropes for permanent drum winder operations. When the ropes were discarded in 1993, a detailed investigation was carried out on sections of the ropes (ref. o6). One of the rope sections was kept in storage "for future instrument evaluation and development work". From the investigation that was carried out (by Kuun at that time), it was known that this sample had a large number of internal broken wires. This specific rope section was used for the comparative instrument evaluation (detection of broken wires) described in the GAP503 report.

The participants were required to assess the number of broken wires in an 8-m long part of the rope section. After the tests the rope was de-stranded and the number of broken wires in the 8-m long section were counted. More than 600 broken wires were identified with as many as 24 per 100-mm length at the "worst spot". It is also reported that the distance between the two faces of a wire break ranged from zero to 3 mm (wire break gaps).

The report shows the findings of each of the participants in graphical form and compares these findings with the actual number of broken wires counted. The number of broken wires identified by the participants ranged from zero to 750 in total. Only two of the participants could identify the broken wires to some degree of adequacy.

The report comments that the large number of broken wires contained in the rope probably made the examination and analysis of the rope condition more difficult than having fewer broken wires.

Some of the conclusions on the detection of broken wires from the report are:

- ? Magnetic rope test instruments are not able to identify each wire break within multi-layer, low rotation ropes.
- ? From the material presented by the rope inspectors, it is obvious that it is not possible to ascertain the radial position of the broken wires within multi-layer, low rotation ropes.
- ? Given the above, it must be concluded that it is not feasible to implement discard criteria for multi-layer, low rotation ropes based on the premise that the accurate identification of the axial and radial position of wire breaks within the rope by means of magnetic NDE is possible. This casts doubt on the applicability and usefulness of the discard criteria derived in GAP502.
- ? The investigations indicate that rope NDE in practice is not as advanced as claimed in the literature.

## Comment:

The investigation described above was the first venture into assessing the abilities of different rope testing instruments. The comments that follow should therefore be seen as constructive criticism, and aimed at improving rope safety in future.

One of the training modules for incumbent rope inspectors discusses magnetic rope testing instrument (ref. r80). The manual describes the abilities of AC, DC, and permanent magnet instruments, as well as the detecting capabilities of sensors such as coils and Hall-effect sensors. The conclusion obtained from this manual is that only a permanent magnet instrument with Hall-effect sensors can execute the required task. The GAP503 report does not list the basic operation of any of the instruments evaluated, and only gives the model numbers of the instruments used in three cases. The performance of the different instruments could therefore not be reviewed in terms of what was written in the training module.

On the corroded rope sample tests:

The report laments the poor results obtained and the large scatter of the estimated remaining rope strength. The report is unduly critical of the results because of the following:

- ? The rope sample was way beyond discard. All participants agreed that the rope should have been discarded. The actual percentage loss in breaking strength (LBS) was therefore of lesser importance. If the sample had, say, 15% loss in strength, the actual results would have been more meaningful.
- ? The calculation of the loss in breaking strength should be a simple matter. The instrument is calibrated to give a value for loss of metallic area (LMA) compared to a good section of the rope. The LMA is then multiplied by a "conversion factor" to obtain LBS.
- ? SABS0293 (RCA CoP) requires a specific "conversion factor" for each combination of instrument and rope construction. The code does not give any further information on the conversion factor except that , in deriving this factor, the code requires "great care to be exercised".
- ? It was therefore unfair to require the non-South African participants to estimate the loss in breaking strength of the corroded sample. It would have been more meaningful to ask for an estimate of loss of metallic area.

The report states that "the code of practice provides good guidelines for establishing the condition of corroded ropes by means of NDE, even though it is a time consuming process" and further concludes that "the guidelines for assessing the condition of corroded ropes as contained in the SABS0293 document are adequate and should remain in their present format". The code does not give any more information on the "conversion factor" than what is given in the third bullet above, and it does not even give an indication of the order of magnitude of the conversion factor. The code could at least have included something like "a conversion factor of 2 shall be used in cases where an actual conversion factor has not been established".

The report criticises "proprietary algorithms" built into instruments because it leads to a "black box" approach, and that the user of an instrument then does not understand the reason for rope discard. By not at least including some (maximum) value for the "conversion factor" in the SABS code, a "black box" approach is being created: The "proprietary algorithm" is then built into the user or into a specific group of users.

On the rope sample with broken wires:

As with the corroded rope sample, the report unduly sketches a too grim picture of the state of affairs. The following has to be taken into account when evaluating the findings and conclusions of the report on the detection of broken wires:

- ? The rope trial that produced the broken wire sample was carried out to establish the suitability of non-spin ropes for the use on drum winders. The report produced by Kuun (ref. o6) and the results of the actual rope tests were not made available for general consumption. Nevertheless, the Kuun report concluded that the rope used was not the most suitable for the given application. The damage and extent of the damage was therefore abnormal.
- ? The "AAC second RAU" instrument was not available from the beginning of the mentioned rope trial. The internal broken wires were interpreted as corrosion until the RAU instrument became available. It was then realised that the internal anomalies were broken wires and the ropes were discarded.
- ? From the Kuun report, it was known that the rope had such a large number of broken wires that it was way beyond discard.
- ? For a rope with such a large number of broken wires it should not be possible to detect each broken wire, especially if some of the wire break gaps was of zero length. A zero length wire break is not detected by magnetic test instruments.
- ? The statement in the report that "the condition of the ropes could not be assessed accurately

on the basis on non-destructive, magnetic rope tests" is therefore misleading.

- ? Tests on ropes with far fewer broken wires are required before such definitive statements on the state of the art can be made.

On the conclusion in the report that "it must be concluded that it is not feasible to implement discard criteria for multi-layer, low rotation ropes based on the premise that the accurate identification of the axial and radial position of wire breaks within the rope by means of magnetic NDE is possible" and "this casts doubt on the applicability and usefulness of the discard criteria derived in GAP502" the following:

- ? The GAP502 report was not available yet when the GAP503 report was issued. The author of GAP503 rightly assumed that the discard criteria in GAP502 would have been given in terms of number of broken wires. GAP502 gives reasons why discard criteria could not yet be derived for non-spin ropes. The conclusion of GAP503 should therefore have been that "this casts doubt on the applicability and usefulness of the discard criteria for internal broken wires in non-spin ropes given in terms of an allowable number of broken wires".
- ? Specifying broken wire discard criteria in any other terms but broken wires **is** moving towards a "black box approach". (The GAP503 report actually cautions against moving towards black box approaches). The user of an instrument has to know the limitations of the instrument and assess the number of broken wires accordingly.

Nevertheless, the drum winders that will come into operation in 2002 and 2003 in two ultra deep shafts (3 000 m and 3 100 m) will be using triangular strand ropes.

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- ? Working group: Code of practice: Performance, operation, testing and maintenance of drum winders relating to rope safety. Draft prepared by working group. April 1996 (ref. r69).

# Appendix E: Report references by category

The meaning of the "research categories" under which the reports are listed are:

COP:	A code of practice or a draft code of practice.
DEEP:	The behaviour of ropes in (deep) shafts,
DET:	The deterioration mechanisms and deterioration patterns of drum winder ropes; "fatigue", rope life and rope life predictions.
DYN:	The dynamic behaviour of ropes and winders.
FOS:	Rope safety factors, safety philosophies, proposals for new safety factors, and reviewing of safety factors.
INFO:	Information on winder design, winder drums, headsheaves, winding speeds, rope end loads, winder rope properties, rope lives achieved, etc.
MOTOR:	Winder motor fault torque and winder motor behaviour.
RCA:	The condition assessment of winder ropes, discard criteria, and rope condition assessment instruments (magnetic rope testing instruments).
SINK:	Shaft sinking.
TERM:	Rope front-end terminations.
TRAIN:	Training manuals for incumbent rope inspectors.

A category listed with a report means that some aspects of the given category are addressed in the report.

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