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ROPE FORCE MEASUREMENTS DURING SHAFT SINKING OPERATIONS AT VAAL REEFS 11 SHAFT

by

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ROPE FORCE MEASUREMENTS DURING SHAFT SINKING OPERATIONS
AT VAAL REEFS 11 SHAFT

SYNOPSIS

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

The regulations governing the strength of ropes for stage and kibble winders are being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation is 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 the stage winder and two kibble winders at Vaal Reefs 11 Shaft described in this report, forms part of the stage and kibble winder ropes investigation. Such measurements will also be carried out on two further sinking installations.

The rope forces on the winders were monitored over a 24 hour period, together with winder speeds and kibble and stage positions. This report shows the time histories of the measurements. When the measurements were done, the sinking operation at 11 Shaft was nearly complete and station development at shaft bottom was taking place for most of the time. It was not possible to obtain any readings during the normal blast-lash-drill sequence and of rock being hoisted.

The dynamic components of the rope forces measured on the stage winder were small, and the forces can, for all practical purposes, be regarded as static. The stage was found to be substantially heavier than licensed. The measurements on the stage winder showed that manual speed regulation of the winder could result in stage rope force resonance, which is potentially dangerous.

The measurements on the kibble winders included measurements during a number of trip-outs. Nothing that cannot be predicted or calculated were recorded in the 24 hour period of the kibble winder measurements.

Mike van Zyl
December 1995
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1. INTRODUCTION

The proposed new statutory regulations for drum winder ropes1 will conceivably allow single lift shafts of as deep as 4 000 m. These new regulations were formulated after intensive studies into dynamic forces acting on drum winder ropes, and deterioration patterns on discarded ropes. Drum winders that use these regulations will also have to conform to a Code of Practice2. 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 are being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation is 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 the stage and kibble winders at Vaal Reefs 11 Shaft described in this report, forms part of the stage and kibble winder ropes investigation. Such measurements will also be carried out on two further sinking installations.

The sinking operation at Vaal Reefs 11 Shaft was selected for the investigation because:

- The current depth of the shaft of 2 360 m will not be reached by any other sinking operation for at least another year.
- Two double drum kibble winders operate in the shaft, which gives twice the information.
- The one winder is equipped with disc brakes, which is of interest for the performance during emergency braking.

When the measurements were done, the sinking operation at 11 Shaft was nearly complete and station development at shaft bottom was taking place for most of the time. It was not possible to obtain any readings during the normal blast-lash-drill sequence or during transporting jumbo rigs up and down. Jumbo rigs were used for cover drilling only. Hand-drilling was used during the normal sinking process.

Recordings were however made during one stage movement and for a large number of winding cycles during which men and material were transported, and during which water was pumped. Recordings were also made during one (un-planned) trip-out, and during a planned trip-out on each of the two kibble winders with a water loaded kibble on the descending side.

The behaviour of the kibble winders during rock hoisting will be obtained from the next two sinking sites at which the measurements will be carried out.
2. SHAFT LAYOUT, AND WINDER AND ROPE PARAMETERS

The positions of the stage winder and the two kibble winders, relative to the 11 m diameter shaft, are shown in Fig. 1. The two kibble winders were double drum winders, and the stage winder was a two drum friction winder with two ropes. The kibble winders are the permanent winders that will operate in the shaft. They were named "Man winder" and "Rock winder" according to the duties that they will ultimately perform.

![Diagram of shaft layout](image)

**Figure 1:** Layout of the winders relative to the shaft.

The distances from the winders to the centre of the shaft, and the positions of the headgear sheave wheels are shown in Fig. 2.

![Diagram of distances](image)

**Figure 2:** Distances from the winders to the shaft and sheave wheels
At the time of the measurements the shaft was 2 360 m deep (measured from the tip). The winder and rope parameters of the winders are given in Table 1. The stage and kibble masses were obtained from the winder permits, and the rope parameters were obtained from the MD208’s.

### Table 1: Rope and Winder Parameters of Vaal Reefs No 11 Shaft

<table>
<thead>
<tr>
<th>Winder name</th>
<th>Rock winder</th>
<th>Man Winder</th>
<th>Stage winder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permit no.</td>
<td>6636</td>
<td>6635</td>
<td>6634</td>
</tr>
<tr>
<td>Max. length of the suspended rope (note 1)</td>
<td>2 388 m</td>
<td>2 378 m</td>
<td>2 350 m</td>
</tr>
<tr>
<td>Headgear sheave diameter</td>
<td>6,0 m</td>
<td>6,0 m</td>
<td>1,83 m</td>
</tr>
<tr>
<td>Drum diameter</td>
<td>6,0 m</td>
<td>5,4 m</td>
<td>2,0 m/s</td>
</tr>
<tr>
<td>Electrical drive</td>
<td>AC Cyclo</td>
<td>DC Thyristor</td>
<td>AC</td>
</tr>
<tr>
<td>RMS Power</td>
<td>6 953 kW</td>
<td>5 259 kW</td>
<td>1 374 kW</td>
</tr>
<tr>
<td>Brakes</td>
<td>Disk</td>
<td>Drum</td>
<td>Drum</td>
</tr>
<tr>
<td>Brake control</td>
<td>Closed loop</td>
<td>Escort</td>
<td></td>
</tr>
<tr>
<td>Rope speed</td>
<td>15 m/s</td>
<td>15 m/s</td>
<td>0,60 m/s</td>
</tr>
<tr>
<td>Stage speed</td>
<td></td>
<td></td>
<td>0,12 m/s</td>
</tr>
<tr>
<td>Stage mass (note 2)</td>
<td></td>
<td></td>
<td>110 000 kg</td>
</tr>
<tr>
<td>Kibble mass (note 3)</td>
<td>4 240 kg</td>
<td>4 240 kg</td>
<td></td>
</tr>
<tr>
<td>Payload: rock/material (note 4) men</td>
<td>13 000 kg</td>
<td>14 000 kg</td>
<td></td>
</tr>
<tr>
<td>2 100 kg</td>
<td>2 100 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of ropes (falls)</td>
<td></td>
<td>2 x 5</td>
<td></td>
</tr>
<tr>
<td>Rope diameter</td>
<td>54 mm</td>
<td>54 mm</td>
<td>42 mm</td>
</tr>
<tr>
<td>Construction</td>
<td>18 strand non-spin fishback</td>
<td>18 strand non-spin fishback</td>
<td>15 strand non-spin fishback</td>
</tr>
<tr>
<td>Tensile grade</td>
<td>1 900 MPa</td>
<td>1 900 MPa</td>
<td>2 100 MPa</td>
</tr>
<tr>
<td>Mass/length</td>
<td>13,07 kg/m</td>
<td>13,07 kg/m</td>
<td>7,79 kg/m</td>
</tr>
<tr>
<td>Breaking strength (note 5)</td>
<td>2 410 kN</td>
<td>2 430 kN</td>
<td>1 570 kN</td>
</tr>
<tr>
<td>Safety factor (note 6)</td>
<td>4,92</td>
<td>4,88</td>
<td>5,47</td>
</tr>
<tr>
<td>Capacity factor (note 7)</td>
<td>13,12</td>
<td>12,56</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1** The kibble winders and stage winder have their headgear sheaves at different positions (heights) in the headgear. The maximum suspended rope lengths as presented in the table are as they were at the time of the measurements. These lengths will increase until the shaft depth of 2 480 m is reached.

**Note 2** The stage mass is the all up stage mass: 75 340 kg (stage) + 32 000 kg (material) + 2 660 kg (men).

**Note 3** The kibble mass given on a winder permit normally includes the cross-head mass. According to Vaal Reefs personnel, the crosshead mass was 1 500 kg. This leaves 2 740 kg for the kibble only, and it will be assumed that tabled kibble masses do not include the crosshead mass.

**Note 4** The reason for the difference between the rock masses is not known.

**Note 5** The breaking strength is the lowest new rope strength of the two ropes on the winder.

**Note 6** The "safety factor" is the static safety factor at the headsheave for a loaded kibble plus crosshead and a fully payed out rope at the current depth, and calculated on the new rope breaking strength.

**Note 7** The "capacity factor" is the static safety factor at the kibble for a fully loaded kibble.
The layout of the ropes in the shaft are shown in Fig. 3.

**Figure 3:** Layout of the ropes in the shaft.

In Fig. 3, $RW$ refers to the rock winder, and $MW$ refers to the man winder. The north stage rope ran from the winder to $N1$ and down to the stage, up $N2$, down $N3$, up $N4$, and down $N5$ and secured (terminated) at the stage. The south rope followed a similar path. The south stage rope served as guide ropes for the two underlay rope kibles, and the north stage rope served as guide ropes for the two overlay rope kibles. Falls $N5$ and $S3$ are called the dead legs.

With the layout of the stage ropes as shown, the kibble guide rope function is distributed over the total lengths of the two stage ropes, and the dead legs are not used as guide ropes.
3. MEASURING EQUIPMENT AND PROCEDURES

3.1 MEASUREMENTS ON THE STAGE WINDER

The stage was equipped with loadcells in the headgear. These loadcells, one for each stage rope, were used by the mine for monitoring the stage plus stage rope mass, and for the proper balancing of the forces between the two stage ropes. The loadcells measured the rope forces in the headgear between the dead leg and the next rope fall, i.e. between N5 and N4 for the north rope, and between S5 and S4 for the south rope (see Fig. 3, p. 4). The loadcells had readouts at the stage winder foot-plate. The loadcell signals were tapped off at the readout. The readings as shown on the readout were taken as correct.

Winder speed was obtained from the stage winder tacho-generator. Absolute winder movement was obtained by equipment that sensed the passing of the spokes of the stage winder drum. The four stage winder signals were coupled to a data acquisition system which could record each of the signals at 20 samples per second for a twenty four hour period.

3.2 MEASUREMENTS ON THE Kibble WINDERS

The rope forces on the kibble winders could only be measured at the sheave wheels in the headgear. Although the stress variations in the sheave wheel seats were quite low (in the order of 10 MPa), measurable signals were obtained by installing strain gauges. The strain gauge signals were relayed to a data acquisition system in the kibble winder house.

The rotational speed of the winder drums was obtained from the winder drum tacho-generators. Only the signal from the overlay drum of each kibble winder could be made available by the mine at the time of the measurements. The absolute rotation of the kibble winder drums was obtained by equipment that generated two sets of pulses per drum rotation.

The four rope force signals, the four drum position signals, and the two winder speed signals were connected to a data acquisition system in the winder house. Each of the 10 signals could be recorded at 20 samples per second for a twenty four hour period.

3.3 THE RECORDINGS

The signals from the kibble winders were recorded over a 24 hour period while the sinking operation continued normally. The only "abnormal" part of the recordings were two trip-outs, one on each of the kibble winders, that were specially carried out for this investigation.

The intention was to record the signals from the kibble winders and the stage winder at the same time. A malfunction of the stage winder data acquisition system unfortunately delayed the recording of the stage winder parameters to the 24 hour period following the recording period of the kibble winders. The stage winder recordings were carried out in two parts. During the first part, which lasted 22 hours, the stage was stationary. During the second part of the stage winder recordings, the stage was raised by 18 m and lowered again.

As mentioned in the Introduction of this report, station development was taking place at 11 Shaft at the time these measurements were carried out. The kibble winder recordings therefore do not show the normal rock conveying but consist mostly of winding cycles during which men and material were transported, and during which water was pumped.
4. STAGE WINDER MEASUREMENTS

4.1 CONVERSION OF THE STAGE WINDER DATA

The signals that were recorded for the stage winder rope forces were converted by multiplying the mass values of the loadcell readouts by the gravitational acceleration of 9.8 m/s². The tacho signal recorded during raising and lowering of the stage was calibrated using the absolute displacement measured at the stage drum spokes.

During the first part of the recordings on the stage winder, no stage movement took place and the speed signal remained at zero.

4.2 RESULTS OF THE STAGE WINDER MEASUREMENTS

The mass of the stage plus suspended stage ropes was 318 ton compared to the 293 ton calculated from the stage mass on the winder permit and the catalogued stage rope mass. The 25 ton difference constitutes a 23% increase in the stage mass. It is not likely that any increase will come from a rope that is heavier than the catalogued value. According to Haggie Rand, their ropes are never heavier than the catalogued value and can be up to 7% lighter.

The accuracy and calibration of the stage loadcells could not be checked, and the movement of the stage was too small to use the change in rope force during stage raising for checking the loadcells. The loadcell readings therefore had to be assumed as correct.

Figure 4, p. 14, shows 22 hours of stage rope force recordings while the stage was stationary at approximately 2 300 m from the bank. The figure shows the rope forces as percentages of the (new) rope breaking strength of 1 570 kN. The one stage rope was actually slightly stronger and had a new breaking strength of 1 600 kN, but it was decided to use the lower value of the two stage ropes. During this period no stage movement was detected (recorded) from either the tacho-generator or from the stage position indicator. The length of each stage rope fall was approximately 2 350 m at that position.

During the first six hours of the measurements, the average north stage rope force was 323 kN, which is 7% more than the 302 kN of the south rope. On the stage rope breaking strength of 1 570 kN, the difference is 1.3%. This difference remained fairly constant throughout all the stage rope force measurements. From these readings, the safety factor listed in Table 1, p. 3, and calculated using the breaking strength of 1 570 kN, reduces to 4.86 for the north stage rope and 5.20 for the south stage rope.

Figure 4, p. 14, shows that some rope force oscillations occurred at between 12 and 19 hours. When in position, the stage was not slinged but steadied with jacks on swivels that prevented lateral movement but allowed some axial (vertical) movement. The peak-to-peak amplitude of these oscillations was less than 1% of the breaking strength of the stage ropes, and are not significant compared to the oscillations experienced by ropes on drum winders. For the sake of interest, sections of Fig. 4 are shown in greater detail in Fig. 5, p. 15, Fig. 6, p. 16, and Fig. 7, p. 17.

The first natural oscillation period of the suspended stage was calculated by adding one third of the mass of the stage ropes to the stage, and using the formulae for simple harmonic motion of a single degree-of-freedom system. A rope elastic modulus of 120 GPa was assumed. The first
natural period so calculated was 4 seconds. The greater oscillations in Figs. 5 to 7 occurred at that frequency. The origins or causes of these rope force oscillations were not investigated and can unfortunately not be deduced from the operations of the kibble winders, because the measurements on the stage winder were not carried out over the same period as that of the kibble winders for reasons mentioned earlier. They could have been caused by lining or lashing operations. As mentioned before, they are not considered as being significant.

The interesting parts from a further 68 min period during which the stage was raised by 18 m and lowered by 18 m are shown in Fig. 8, p. 18, and Fig. 9, p. 19. The figures show stage displacement, rope speed (which is 5 times greater than the stage speed), and the stage rope forces as percentages of the breaking strength of the ropes. A positive speed corresponds to the stage being raised. The changes in rope forces three minutes after the stage stopped after raising, and six minutes before lowering, were most probably caused by the lifting and placing the kibble crossheads on the stage, and persons getting off and onto the stage. The mean of the measured rope force during raising the stage is less than the static rope force, and during lowering it is higher than the static rope force. This behaviour is attributed to friction in the stage rope system, because the stage loadcells measure the rope forces at the dead legs.

Greater details of the recordings for the periods 5 to 7 min in Fig. 8, and 58 to 60 min in Fig. 9, are shown in Fig. 10, p. 20, and Fig. 11, p. 21, respectively. The recordings during the raising and lowering of the stage again show that the larger oscillations occurred at the first natural period (4 s) of the stage and stage rope system. The peak-to-peak amplitudes of the rope force oscillations are less than those observed when the stage was parked, and are not significant.

A further point of interest is the speed variations recorded when the stage was lowered. Peaks were measured at intervals of between 2.5 s and 3.5 s, and were caused by manual speed regulation by the stage winder driver. Although the rope force oscillations measured when these speed variations occurred were not significant, resonance would have occurred if the speed variations were at the first natural period of 4 s, and large rope force peaks would have resulted. The magnitude of peaks caused by resonance depends on the amount of energy available to be introduced into the system and the amount of energy that can be dissipated by the system.

Resonance can result in rope forces of unacceptable magnitudes, and speed variations as observed should therefore be considered as potentially dangerous.

The observed speed variations would have caused resonance if the stage was at a depth of 1 500 m.
5. ROCK WINDER MEASUREMENTS

5.1 CONVERSION OF THE ROCK WINDER DATA

It was mentioned that only the overlay tacho signals were available on the kibble winders. The overlay kibble position was determined by integrating the overlay speed signal and correcting it every half drum turn from the drum pulses that were recorded. The length of rope per drum turn was taken as constant through the length of the wind. The average diameter of the rope coil on the drum worked out in this way was 6.22 m on the rock winder.

No major clutching operations took place during the 24 hours of the kibble winder recordings. Major meaning more than one or two drum turns from the one drum only. The drum pulses from the underlay rope side could not be interpreted accurately without a tacho (speed) signal on that side of the drum. The underlay rope kibble position therefore could not be derived correctly. The underlay rope kibble position was therefore taken as the inverse of the overlay rope kibble position. The length of suspended rope included the length of rope between the tip and the headgear sheaves.

The rock winder rope forces were calibrated by using the empty kibble after the tip as a reference point and using the rope mass to determine the "slope" of the output curve of each of the two rock winder strain gauge installations. The catalogued rope mass of 13.07 kg/m was used in the rope force calibration. The empty kibble and crosshead plus the length of the suspended rope when the kibles are in the tip weigh 60 kN on the rock winder.

5.2 RESULTS OF THE ROCK WINDER MEASUREMENTS

The measurements on the rock winder for the 24 hour period are shown in Figs 12 to 19 (pages 22 to 29) in 3 hour sections. The graphs show the two kibble positions (actually lengths of suspended rope) on one graph: The thin line for the overlay side (the correct one) and a thicker line for the underlay side (the inverse of the overlay position).

The speed shown is that measured for the overlay drum. Clutching the overlay drum and moving the underlay drum (as during tipping) will therefore not show up in the graphs of either speed or position. A positive speed corresponds to the overlay kibble ascending.

The following general observations were made from the results. Slow drift of the signals occurred during the 24 hours of the measurements. The sheave wheel seats to which the strain gauges were attached were exposed to direct sunlight on the one side. The thermal stresses caused by the differential heating of the seats could have caused the drift in the readings. The drift has an influence on the absolute measurements but not on that of the general behaviour of the winder. It was also found that the underlay rope force measurements displayed a noticeable non-linearity. The non-linearity for the underlay was more profound for the lighter loads and more linear for the larger loads. For this reason the rope force measurement went negative at approximately 5 hours when the kibble was parked on the bank doors.

The kibles were frequently parked on the bank doors. The force in the rope, with the kibble on the bank doors, depends on the amount of slackness in the rope.

The drift in the signals can be observed when the results are checked after every tip. On the underlay rope side, tipping took place at approximately 2¼ hr, 10¾ hr, 12¾ hr, and 18¾ hr.
On the overlay rope side, tipping took place at approximately 3 hr, 4½ hr, 11 hr, 13 hr, 19 hr, 20½ hr and 22½ hr.

The following incidents and/or interesting parts are shown in greater detail in the following figures:

Figure 20, p. 30: 3 hr to 3 hr 20 min (also see Fig. 13, p. 23)
Tipping a near empty kibble on the overlay, some stopping and starting near mid-shaft, and finally parking the overlay kibble on the bank doors. The release and picking up of the crosshead can be seen at the beginning and end of the tipping sections.

Figure 21, p. 31: 7 hr 52 min to 7 hr 57 min (also see Fig. 14, p. 24)
After the underlay rope was filled with water (5 tons) and a further 2 tons of an unidentified substance, the winder was manoeuvred and stopped. This caused the oscillations in the rope force shown in the figure. The period of the underlay oscillations were 3.5 s compared with a calculated period of 3.4 s.

Figure 22, p. 32: 10 hr 30 min to 11 hr (also see Fig. 15, p. 25)
The figure shows water being pumped into the underlay kibble (in the stage) and out of the overlay kibble (in the tip), followed by the a hoisting trip. While water was then pumped into the overlay kibble, water was pumped out of the underlay kibble and then tipped. At the end of the next trip, the water in the overlay kibble was not pumped out, but tipped.

Figure 23, p. 33: 12 hr 15 min to 12 hr 20 min (also see Fig. 16, p. 26)
The figure shows an empty underlay kibble going down and a water-filled overlay kibble coming up. Rope forces from winder acceleration and deceleration, and the effects of drum rope layer cross-overs can be distinguished. The non-linearity of the underlay rope force measurements is also more evident on this graph. Picking up of the crosshead off the stage on the overlay side occurred at 16¾ min, and putting the crosshead down on the stage on the underlay rope occurred at 19½ min.

Figure 24, p. 34: 16 hr 45 min to 17 hr 15 min (also see Fig. 17, p. 27)
The figure shows a water pumping cycle without tipping. Note the change in speed during the middle trip in the figure.

Figure 25, p. 35: 19 hr 56 min to 20 hr 10 min (also see Fig. 18, p. 28)
The figure shows a load of approximately 10 tons lifted on the underlay rope and transported to the bottom. After this load was released, the underlay rope did one complete winding cycle with just the crosshead attached to the rope. This is shown in the next figure.

Figure 26, p. 36: 20 hr 18 min to 20 hr 44 min (also see Fig. 18, p. 28)
The figure shows a complete winding cycle with just the crosshead attached to the underlay rope.

Figure 27, p. 37: 21 hr 52 min to 21 hr 56 min (also see Fig. 19, p. 29)
Emergency braking with the underlay kibble, filled with about 6.5 tons of water, going down at between 1 850 m and 1 900 m. The overlay kibble was empty during the braking. The average deceleration rate was 2.6 m/s².
6. MAN WINDER MEASUREMENTS

6.1 CONVERSION OF THE MAN WINDER DATA

The signals measured on the man winder were converted in exactly the same way as for the rock winder.

The average diameter of the rope coil on the man winder drum was worked out in the same way as for the rock winder, and was 5.73 m.

No major clutching operations took place on the man winder either during the 24 hours of the kibble winder recordings.

The man winder rope forces were also calibrated by using the empty kibble after the tip as a reference point and using the rope mass to determine the “slope” of the output curve of each of the two man winder strain gauge installations. The empty kibble plus crosshead plus the length of the suspended rope when the kibbles are in the tip weigh 58 kN on the man winder.

6.2 RESULTS OF THE MAN WINDER MEASUREMENTS

The measurements on the man winder for the same 24 hour period as for the rock winder are shown in Figs 28 to 35 (pages 38 to 45) in 3 hour sections. The graphs show the two kibble positions (actually lengths of suspended rope) on one graph. As before, the thin line is the overlay kibble and the thicker line for the underlay kibble.

Again, the speed shown is that of the overlay drum. Clutching the overlay drum and moving the underlay drum will therefore not show up in the graphs of either speed or position. A positive speed corresponds to the overlay kibble ascending.

The following general observations were made from the results. The sheave wheel seats of the man winder were not exposed to direct sunlight and very little drifting of the measurements was evident. This can again be checked by comparing the force readings after every tip. On the underlay rope side tipping took place at approximately 7¾ hr, 8 hr, 10½ hr, and 22 hr. On the overlay rope side tipping took place at approximately 10¾ hr, and 16¾ hr.

The repeatability of the measurements on the man winder were estimated to be in the order of ±10 kN. The output from the strain gauge bridges of the man winder also seem to be quite linear. The underlay force measuring strain gauge bridge gave problems at two points. These were cut out from the results shown, and replaced with straight lines. This occurred at 19¾ hr and 23¾ hr.

The following incidents and/or interesting parts are shown in greater detail in the following figures:

Figure 36, p. 46: 0 hr 26 min to 0 hr 42 min (also see Fig. 28, p. 38)
The figure shows one complete winding cycle during which men were conveyed. Rope forces from winder acceleration and deceleration, and the effects of drum rope layer cross-overs can be distinguished.
Figure 37, p. 47: 2 hr 30 min to 2 hr 36 min (also see Fig. 28, p. 38)
The figure shows emergency braking, while conveying men, with the underlay kibble coming up and at a depth (length of suspended rope) of 2 230 m. Just before the trip-out, the winder was still accelerating and at trip-out the speed was 8,9 m/s. At that time, the overlay kibble was going down, of course, and at a depth of 160 m. The (1st) natural period of the rope force oscillations on the underlay rope was measured as 2,8 s, compared to the calculated period of 2,7 s with an attached mass of 5 ton. The average deceleration rate was 2,4 m/s².

Figure 38, p. 48: 7 hr 35 min to 8 hr 10 min (also see Fig. 30, p. 40)
The figure shows a number of water pumping trips, and a tip on the underlay kibble towards the end of the figure.

Figure 39, p. 49: 9 hr 35 min to 10 hr 5 min (also see Fig. 31, p. 41)
The figure shows the rope force behaviour during winder manœuvring with the underlay kibble close to the shaft bottom and the overlay kibble near the bank. The speed graph (of the overlay drum) was enlarged so as to show the slow speeds and speed changes better. Clutching of the overlay side and moving the underlay side only does not show on the speed graph for reasons mentioned earlier. At approximately 45 min (after 9 hr) the overlay kibble was parked on the closed bank doors for a short while.

Figure 40, p. 50: 10 hr 30 min to 11 hr 10 min (also see Fig. 31, p. 41)
The figure shows tipping of the underlay kibble, stopping at midshaft, completing the trip, and tipping of the overlay kibble. Both kibbles carried very light loads before tipping. The latter part of the figure shows a full winding cycle.

Figure 41, p. 51: 13 hr 45 min to 14 hr 25 min (also see Fig. 32, p. 42)
The figure shows the behaviour of the rope forces when the winder was stopped and stated at a number of points in the shaft.

Figure 42, p. 52: 20 hr 20 min to 21 hr (also see Fig. 34, p. 44)
The figure shows two winding trips at maximum speeds of 7,7 m/s and 8,2 m/s. The underlay kibble was filled with water during the first trip, and both kibbles were close to empty during the second trip. The reasons for the slow winding speed during these two trips are not known.

Figure 43, p. 53: 21 hr 44 min to 21 hr 46 min (also see Fig. 35, p. 45)
The figure shows emergency braking with the underlay kibble, filled with about 7,5 tons of water, going down and stopping at 1 900 m. The overlay kibble, which was coming up at the time of the trip-out, had some load in it. The (1st) natural period of the rope force oscillations on the underlay rope was measured as 2,9 s, compared to the calculated period of 2,9 s. The average deceleration rate was 2,5 m/s².
7. DISCUSSION AND RECOMMENDATIONS

The dynamic components of the rope forces measured on the stage winder were small, and the forces can, for all practical purposes, be regarded as static. Apart from accidental damage, and damage from the guide rope function, corrosion may be the only other major factor that can cause stage winder rope deterioration.

It is important to have stage winder rope force loadcells because the stage could be substantially heavier than licensed or planned.

The manual regulation of the stage winder speed could result in stage rope forces of unacceptable magnitudes. Speed variations as observed should therefore be considered as potentially dangerous, and should be avoided.

Rock hoisting was not measured at Vaal Reefs 11 Shaft because of the station building phase that they were busy with. Rock hoisting will be measured at the next sinking site. Apart from the rope force behaviour during rock hoisting, nothing that cannot be predicted or calculated was recorded in the 24 hour period of kibble winder measurements.

Emergency braking on both kibble winders were of the constant deceleration type, and the resultant forces for both the drum type brake and the disk type brake are, as to be expected, the same.

Nothing out of the ordinary happened on either the stage winder or the two kibble winders during the measuring period or during the three weeks that the investigators spent on site at Vaal Reefs 11 Shaft.

The exercise has shown that it is possible to measure the kibble winder rope forces from the stresses in the headgear sheave wheel seats. With extra care, one should be able to eliminate the slow drift that occurred in the measurements. All the measurements shown in this report are stored on computer disks and are available for any further analysis that may be required.

A last point of interest is that the two drum winders at 11 Shaft will be used, with their non-spin ropes, during the sinking of two sub-shafts. This presents an opportunity for deterioration studies of non-spin ropes on drum winders.
8. REFERENCES

1. Hecker, G F K: *Motivation for proposed changes to Chapter 16 of the Minerals Act; Rope safety regulations for drum winders.*

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Figure 34: Rope forces measured on the man winder for the period 18 hr to 21 hr.
Figure 35: Rope forces measured on the man winder for the period 21 hr to 24 hr.

0 Depth in m
1000
2000
21

23

0 Speed in m/s

10

0 -10

500

22

400

300

200

100

0

0.21

UL rope force in KN

22

500

400

300

200

100

0

0.21

0/L rope force in KN

23

23

24

24

Time in hours
Figure 36: Man winder rope forces: One winding cycle during which men were conveyed.
Figure 37: Man winder rope forces: Emergency braking (trip-out) while conveying men. The underlay kibble was just above the stage and coming up, and the winder was still accelerating.
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Figure 42: Man wincher rope forces: Slow speed winding at approximately 8 m/s.
Figure 43: Man winder rope forces: Emergency braking (trip-out). The underlay kibble had a 7.5 ton water load in the kibble and it was going down. The overlay kibble had a small load.
DIVISION OF
MATERIALS SCIENCE AND TECHNOLOGY

ROPE FORCE MEASUREMENTS DURING SHAFT SINKING OPERATIONS AT WEST DRIEFONTEIN 10 SHAFT

by

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This report consists of 62 pages.
ROPE FORCE MEASUREMENTS DURING SHAFT SINKING OPERATIONS
AT WEST DRIEFONTEIN 10 SHAFT

SYNOPSIS

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

The regulations governing the strength of ropes for stage and kibble winders are being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation is 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 the stage winder and kibble winder at West Driefontein 10 Shaft described in this report, forms part of the stage and kibble winder ropes investigation. Such measurements had also been carried out at Vaal Reefs 11 Shaft, and will also be carried out at one other sinking operation.

When the measurements at West Driefontein 10 Shaft were done, the shaft was at a depth of close to 1 400 m and sinking operations were performed normally. During the 28 hours of recording the events, two lash-drill-blast sequences were performed. The rope forces on the stage and kibble winders were recorded, together with winder speeds and kibble and stage positions. The measurements on the kibble winder included measurements during a number of trip-outs. This report shows the time histories of the measurements.

The peak-to-peak dynamic components of the rope forces measured on the stage winder were less than 2% of the rope breaking strength, and the stage rope forces can, for all practical purposes, be regarded as static.

The measuring accuracy of the kibble winder rope forces was good enough to illustrate the behaviour of the kibble winder accurately.

Lifting loaded kibbles and jumbo rigs did not cause large dynamic rope force components because of the low rope speeds applied during these lifts.

All normal sinking operations were performed during the 28 hour recording period. Nothing that cannot be predicted or calculated was recorded during this time on either the kibble or the stage.

Mike van Zyl
January 1996
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1. INTRODUCTION

The proposed new statutory regulations for drum winder ropes\(^1\) will conceivably allow single lift shafts of as deep as 4 000 m. These new regulations were formulated after intensive studies into dynamic forces acting on drum winder ropes, and deterioration patterns on discarded ropes. Drum winders that use these regulations will also have to conform to a Code of Practice\(^2\). 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 are being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation is 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 the stage and kibble winders at West Driefontein 10 Shaft described in this report, forms part of the stage and kibble winder ropes investigation. These measurements had also been carried out at Vaal Reefs 11 Shaft\(^3\), and the results of a further set of measurements at West Driefontein 9 Shaft are still to be reported on.

The sinking operation at West Driefontein 10 Shaft was selected because this shaft, which is a ventilation shaft, might be sunk to a depth of close to 3 000 m. If and when such depths are reached, the installation was to operate either under special dispensation from the Government Mining Engineer, or under new regulations which require the operation to conform to a code of practice. If the envisaged code of practice requires rope force monitoring, this report, and possible further analysis of the results, was to serve as a measure of what can be achieved.

When the measurements were done, the shaft was at a depth of close to 1 400 m and sinking operations were performed normally. During the 28 hours of recording the events, two lash-drill-blast sequences were performed. Drilling was performed with a jumbo rig.

Recordings were also made during one a planned trip-out while a kibble, filled with rock, was descending in the bottom half of the shaft. Trip-outs also occurred during acceleration just after the start of a number of rock winding trips.

Two days before the measurements were carried out at West Driefontein 10 Shaft, new ropes, 3 000 m in length each, were installed on the kibble winder.
2. **SHAFT LAYOUT, AND WINDER AND ROPE PARAMETERS**

The positions of the stage winder and the kibble winder, relative to the 7 m diameter ventilation shaft, are shown in Fig. 1. The kibble winder was a double drum winder, and the stage winder was a two drum friction winder with two ropes.

![Figure 1: Layout of the winders relative to the shaft.](image)

The distances from the winders to the centre of the shaft, and the positions of the headgear sheave wheels are shown in Fig. 2.

![Figure 2: Distances from the winders to the shaft and sheave wheels](image)

The stage ropes entered the headgear approx. 24 m above the bank. The other stage rope sheaves were situated at a level above the kibble winder sheaves.
At the time of the measurements the shaft was 1 389 m deep (measured from the bank). The top of the stage (kibble crosshead release point) was 31 m above shaft bottom. The stage was approximately 17 m in height. The winder and rope parameters of the winders are given in Table 1. The stage and kibble masses were obtained from the winder permits, and the rope parameters were obtained from the MD208’s.

**TABLE 1: ROPE AND WINDER PARAMETERS OF WEST DRIEFONTEIN 10 SHAFT**

<table>
<thead>
<tr>
<th>Winder name</th>
<th>Kibble winder</th>
<th>Stage winder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permit no.</td>
<td>3983A</td>
<td>7595A</td>
</tr>
<tr>
<td>Length of the suspended rope (note 1)</td>
<td>1 389 m</td>
<td>1 358 m</td>
</tr>
<tr>
<td>Headgear sheave diameter</td>
<td>5,5 m</td>
<td>1,8 m</td>
</tr>
<tr>
<td>Drum diameter</td>
<td>5,4 m</td>
<td>2,0 m/s</td>
</tr>
<tr>
<td>Electrical drive</td>
<td>DC</td>
<td>AC</td>
</tr>
<tr>
<td>RMS Power</td>
<td>4 500 kW</td>
<td>675 kW</td>
</tr>
<tr>
<td>Brakes</td>
<td>Drum</td>
<td>Drum</td>
</tr>
<tr>
<td>Brake control</td>
<td>Escort</td>
<td></td>
</tr>
<tr>
<td>Rope speed</td>
<td>15 m/s</td>
<td>0,98 m/s</td>
</tr>
<tr>
<td>Stage speed</td>
<td></td>
<td>0,245 m/s</td>
</tr>
<tr>
<td>Stage mass (note 2)</td>
<td></td>
<td>54 998 kg</td>
</tr>
<tr>
<td>Kibble mass (note 3)</td>
<td>4 400 kg</td>
<td></td>
</tr>
<tr>
<td>Payload: rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>men</td>
<td>1 120 kg</td>
<td></td>
</tr>
<tr>
<td>material</td>
<td>1 500 kg</td>
<td></td>
</tr>
<tr>
<td>Number of ropes (falls)</td>
<td></td>
<td>2 x 4</td>
</tr>
<tr>
<td>Rope diameter</td>
<td>49 mm</td>
<td>42 mm</td>
</tr>
<tr>
<td>Rope construction</td>
<td>15 strand non-spin</td>
<td>15 strand non-spin</td>
</tr>
<tr>
<td></td>
<td>fishback</td>
<td>fishback</td>
</tr>
<tr>
<td>Rope tensile grade</td>
<td>1 800 MPa galv.</td>
<td>1 900 MPa</td>
</tr>
<tr>
<td>Rope mass/length</td>
<td>10,9 kg/m</td>
<td>7,8 kg/m</td>
</tr>
<tr>
<td>Rope breaking strength (note 4)</td>
<td>1 890 kN</td>
<td>1 440 kN</td>
</tr>
<tr>
<td>Safety factor (note 5)</td>
<td>6,27</td>
<td>8,32</td>
</tr>
<tr>
<td>Capacity factor (note 6)</td>
<td>12,69</td>
<td></td>
</tr>
</tbody>
</table>

**note 1** The maximum suspended rope lengths in the table are as they were at the time of the start of the measurements, and as measured from the bank. These lengths will increase until the final shaft depth is reached.

**note 2** The stage mass is the all up stage mass: 45 200 kg (stage) + 6 610 kg (material) + 2 100 kg (men) + 1 088 kg (rock).

**note 3** The kibble mass included the 1 160 kg crosshead. The mass of the jumbo drilling rig was not included on the permit but was estimated as 14 tons from the recorded signals.

**note 4** The breaking strength is the lowest new rope strength of the two ropes on a winder.

**note 5** The kibble winder "safety factor" is the static safety factor at the headsheave for a loaded kibble plus crosshead and a fully payed out rope at the current depth, and calculated on the new rope breaking strength. The stage "safety factor" was calculated using the all up stage mass and the stage length of suspended rope.

**note 6** The "capacity factor" is the static safety factor at the kibble for a fully loaded kibble.
The layout of the ropes in the shaft are shown in Fig. 3.

![Diagram of rope layout](image)

**Figure 3:** Layout of the ropes in the shaft.

In Fig. 3, *O/L* refers to the overlay rope of the kibble winder, and *U/L* refers to the underlay rope. The north stage rope ran from the stage winder to *N1* and down to the stage, up *N2*, down *N3*, and up *N4* and secured (terminated) in the headgear. From *N2* to *N3*, the rope passed over a set of sheaves in the headgear, positioned at a level above the kibble winder sheaves. The south rope followed a similar path. Falls *N4* and *S4* are called the dead legs. Falls *S2* and *S3* of the south stage rope served as guide ropes for the underlay rope kibble, and falls *N3* and *N3* of the north stage rope served as guide ropes for the overlay rope kibble.

With the layout of the stage ropes as shown, the kibble guide rope function is distributed over the greater lengths of the two stage ropes, and the dead legs are not used as guide ropes.
3. MEASURING EQUIPMENT AND PROCEDURES

3.1 THE STAGE WINDER

The dead leg of each stage rope was equipped with a loadcell in the headgear. These loadcells were used by the mine for monitoring the mass of the stage and its suspended ropes, and for the proper balancing of the forces between the two stage ropes. The loadcells had readouts in the headgear and at the stage winder foot-plate. The loadcell signals were tapped off at the stage winder foot-plate. The readings of the stage rope loadcells were assumed to be correct and accurate.

Winder speed was obtained from the stage winder tacho-generator. Absolute winder movement was obtained by equipment that sensed the passing of the spokes of both the stage winder drums. Clutching on the stage winder could therefore be detected. The five stage winder signals were coupled to a data acquisition system in the winder house.

3.2 THE KIBBLE WINDER

The rope forces on the kibble winders could only be measured at the sheave wheels in the headgear. Although the stress variations in the sheave wheel seats were quite low (in the order of 10 MPa), measurable signals were obtained by installing strain gauges. The strain gauge signals were relayed to the data acquisition system in the winder house. Two separate strain gauge bridges were installed on each of the seats of the two kibble winder sheaves. All four the signals (two separate signals per kibble rope) were recorded, but only the best signal on each side was selected for the results shown in this report.

The rotational speed of the winder drums was obtained from a tacho-generator that measured the speed of the winder motor. The absolute rotation of the winder motor was obtained by equipment that generated eight pulses per winder motor rotation. Sensing equipment was also installed to detect clutching operations on the kibble winder.

The four rope force signals, the two clutching signals, the winder motor position signal, and the winder motor speed signal were connected, together with the five stage winder signals, to the data acquisition system in the winder house.

3.3 THE RECORDINGS

The signals from the kibble and stage winders were recorded simultaneously on one data acquisition system, at an average rate of 19,4 samples per second each, over a 28 hour period while the sinking operations continued normally. The signals from the clutching sensors on the kibble winder were only checked once every 1,4 seconds.

During the recording period, two full lashing-drilling-blasting sequences were completed, and more than eighty rock loads and at least ten kibbles of water were transported to the surface. A number of winding trips were carried out with only the crosshead attached to the end of the rope, the jumbo drilling rig was conveyed down and up twice, and the stage was moved before and after each of the two blasts.

The normal sinking operations were only interrupted once when emergency braking was carried out on request with a fully loaded kibble descending at a depth of 1 100 m.
4. MEASUREMENTS ON THE KIBBLE WINDER

4.1 CONVERSION OF THE KIBBLE WINDER DATA

The kibble winder rope forces were calibrated using the empty kibble (plus crosshead) in the tip as one reference point, and the rope, without a kibble attached, at the bottom of the shaft as the second reference point for linear interpolation and extrapolation of the measured signals. The height measured from the bank to the tip was 21 m, and the centres of the headgear sheaves were 37 m above the bank. From the catalogued rope mass of 10,9 kg/m and the kibble plus crosshead mass of 4 400 kg, the rope forces at the reference points (F1 and F2) were calculated as follows:

\[
F1 = \text{weight of kibble} + 21 \text{ m of rope} \\
= (4 400 + 21 \times 10,9 \text{ kg}) \times 9,8 \text{ m/s}^2 \\
= 45 \text{ kN}
\]

\[
F2 = \text{weight of } 1 389 + 37 \text{ m of rope} \\
= 1 426 \times 10,9 \times 9,8 \text{ N} \\
= 152 \text{ kN}
\]

The kibble positions were determined by integrating the speed signal and correcting it with the absolute position measurement. The signals from the clenching operations were used to determine when one drum was stationary and the other moving. The length of rope per drum turn was taken as constant throughout the length of the wind. The kibble positions were calculated and expressed as lengths of suspended rope measured from the headgear sheaves.

During the 28 hour recording period, storage disk problems that occurred on the data acquisition system caused some data to be lost in the following three periods:

- 3 hr 28 min to 4 hr 18 min.
- 7 hr 9 min to 7 hr 38 min.
- 20 hr 32 min to 21 hr 5 min.

The gaps in the data occurred at random intervals and lasted approximately 4 seconds. The gaps were filled in through linear interpolation.

From inspection of the results, the accuracy of the force measurements were estimated to be in the order of ±15 kN. The mentioned disk problems that were experienced caused some difficulty in the calculation of the positions of the kibbles. The accuracy of the kibble positions near shaft bottom is in the order of ±10 m.

4.2 RESULTS OF THE MEASUREMENTS ON THE KIBBLE WINDER

4.2.1 General behaviour

The measurements on the kibble winder for the 28 hour recording period are shown in fourteen 2 hour sections in Figs 4 to 17 (pages 16 to 29). The time scale on these graphs, which is from 0 hr to 28 hr, was used as the reference for any event throughout this report. The stage winder data that will be discussed in the next section of this report also used the same time reference.

In these figures, the two kibble rope positions are shown on one graph: The thin line represents
the length of suspended rope for the overlay side, and the thicker line that of the underlay side. The rope speed shown is the rotational speed of the winder motor converted to linear rope speed. A positive speed corresponds to the overlay kibble ascending. Clutching operations are shown on the rope speed graph as small black rectangles between approximately 12 m/s and 13 m/s on either the positive or negative speed sides. Clutching the overlay drum (overlay drum stationary) is shown on the positive side of the graph, and clutching the underlay drum is shown on the negative side of the graph. The "U/L rope force" is for the underlay side, and the "O/L rope force" is for the overlay side of the kibble winder.

The rope force signals were quite stable and very little zero drift occurred during the recording period. The two headgear sheave wheel seats of the kibble winder were slightly different in construction, and the overlay side produced a larger output (non-linearity) at rope loads less than the weight of an empty kibble. For this reason, the overlay rope signal frequently dips below zero force during tipping. The non-linearity of the underlay rope side is less noticeable. All rope forces greater than 40 kN were assumed to be within the estimated accuracy range of ±15 kN.

The kibble winder either conveyed rock or water to the surface, conveyed the jumbo rig up and down, wended up and down with empty kibbles or with only the crosshead attached to the end of the rope. The allowable (licensed) mass of persons or material in a kibble is so much less than the rock that conveying material or persons in a kibble is comparable to winding an empty kibble.

Not every trip that was recorded and shown Figs 4 to 17 (pages 16 to 29) will be discussed, but some of the mentioned sinking operations occurred at the following times or in the following periods:

- Rock hoisting with both kibbles for approximately the first 6 hours. A rock hoisting cycle normally consisted of winding an empty kibble down to the stage, leaving the crosshead on the stage, placing the empty kibble on the shaft bottom, picking up a loaded kibble, collecting the crosshead while moving through the stage, winding to the tip and tipping the kibble. Note that very little clutching was done during this time.
- The jumbo drilling rig and the crosshead were taken down the shaft on the underlay rope in the time between 6½ hr and 7½ hr. The mass of the jumbo was estimated as 14 ton from the measured rope forces.
- Water pumping took place between 7½ hr and 9 hr. The kibble was positioned in the stage while water was pumped into it, and was positioned near the tip during pumping out.
- At 9½ hr the underlay rope went down with only the crosshead, and at 9¾ hr this was repeated on the overlay rope.
- The jumbo was brought back to surface on the underlay rope at between 9½ hr and 10 hr.
- Just before 10½ hr, the overlay drum was clutched and the underlay kibble was moved to the new stage position. The winder then moved the overlay kibble to the new stage position, while the underlay kibble was brought to the surface and parked on the bank doors.
- From 10½ hr to 14 hr, the stage was moved up 108 m, blasting took place (11 hr 10 min), the stage was moved down again, and finally re-positioned 5 m lower than at the previous position. The results from the measurements on the stage winder are discussed later in this report but, for the sake of direct comparison of the events, the stage movements and forces for the time 10 hr to 14 hr are shown in Figs 48 and 49 (pages 60 and 61) in two 2 hour sections.
- Just before the blast (11 hr 10 min), persons were taken off the stage with the overlay kibble, and were taken down again after the blast. The slight increase in the overlay rope force just before 11½ hr was caused by the kibble taking up the crosshead as the stage was
moved down and away from the kibble. This effect can also be seen as a decrease on the stage winder rope forces (Fig. 48, p. 60).

- Persons and/or material was taken down to the stage in the overlay kibble at around 13 hr, and rock hoisting resumed from 14 hr to 22½ hr.
- Emergency braking with a 14 ton load attached to the overlay rope and **descending**, was carried out just after 19 hr. An empty kibble was attached to the underlay rope at that time.
- The jumbo went down again on the overlay rope at 22¾ hr, and came up again just after 25½ hr.
- Stage movement took place again in the period 26 hr to 28 hr (see Fig. 50, p. 62, for the stage winder events), and blasting took place just after 26¾ hr.

Quite a number of trip-outs occurred at the beginning of rock winding trips, just after the winder started accelerating. These occurred at approximately 54 min (O/L up), 1 hr 13 min (U/L up), 5 hr 7 min (O/L up), 16 hr 58 min (O/L up), 17 hr 30 min (U/L up), 19 hr 24 min (O/L up), 19 hr 36 min (U/L up), and 21 hr 17½ min (O/L up). At 12 hr 56½ min, while the lightly loaded overlay kibble was decelerating at the end of a winding trip near the stage, a trip-out also occurred. An empty kibble was attached to the underlay rope at that time.

### 4.2.2 Details of the measurements on the kibble winder

Greater details of the following incidents and/or interesting parts are shown in the following figures:

**Figure 18, p. 30: 0 hr 50 min to 1 hr 15 min (also see Fig. 4, p. 16)**

Rock hoisting and tipping with both kibbles. Trip-outs occurred at 0 hr 54 min (or 1 hr 6 min) and at 1 hr 13 min. Both trip-outs shown occurred just after the start of the respective winding trips during acceleration. In both cases, a kibble filled with rock was ascending.

**Figure 19, p. 31: 1 hr 10 min to 1 hr 20 min (also see Fig. 4, p. 16)**

The second trip-out of the previous figure is again shown but in greater detail. On the underlay side, the sequence of events shown were: Picking up the loaded kibble (kibble plus payload) at a speed of 0.45 m/s, creeping through the stage at 0.6 m/s and picking up the crosshead, a trip-out during acceleration at a speed of 9 m/s, completing the winding trip, and tipping the payload. The overlay side shows tipping a payload, winding to the stage and slowly through the stage, leaving the crosshead behind on the stage, lifting a weight of approximately 150 kN (kibble plus payload) at a speed of 0.45 m/s, winding through the stage, picking up the crosshead, and accelerating to full speed. The effect of drum layer cross over points on the rope forces can also be seen during the constant speed winding part. The slight reductions in the rope forces after lifting the loaded kibbles were in both cases produced by a short reversal of the travel direction to steady the kibble on the shaft bottom.

**Figure 20, p. 32: 5 hr 2 min to 5 hr 10 min (also see Fig. 6, p. 18)**

The rope speed scale of this figure was enlarged to show the events better. On the overlay side, a loaded kibble was lifted at a rope speed of only 0.2 m/s, and a trip-out occurred during acceleration. The sudden deceleration caused a large negative rope force peak. This large peak was **not** followed by equally large rope force oscillations. Large oscillations were prevented from occurring by the fact that the deceleration stopped (dropped to zero) at the most opportune time. The effect of
layer cross over points on the rope forces can be again visible during the constant speed winding part.

Figure 21, p. 33: 6 hr 40 min to 7 hr 20 min (also see Fig. 7, p. 19)
The figure shows the 14 ton jumbo rig being picked up at the bank together with the crosshead and transported to shaft bottom on the underlay rope. During lifting and releasing the jumbo, the rope speed never exceeded 0.1 m/s and is not visible on the speed trace. The mass of the jumbo rig is comparable to a fully loaded kibble. On the overlay side a loaded kibble was picked up at 0.2 m/s, and after the rock hoisting trip was completed, the empty kibble was parked on the bank doors.

Figure 22, p. 34: 9 hr 27 min to 10 hr (also see Fig. 8, p. 20)
The underlay rope went down to shaft bottom with only the crosshead attached. The jumbo was then picked up, brought to the surface and released. The overlay rope came to surface with and empty or near empty kibble, unhooked it, and went to shaft bottom with only the crosshead attached while the jumbo came up on the underlay rope.

Figure 23, p. 35: 10 hr 25 min to 10 hr 33 min (also see Fig. 9, p. 21)
The scale of the rope speed was greatly enlarged for a better interpretation of the events shown in this figure. During the time shown in the figure, the underlay kibble was manoeuvred to the stage position for blasting. The start-stop events at low speeds generated rope force variations of quite large magnitudes (as much as 170 kN peak-to-peak).

Figure 24, p. 36: 12 hr 54 min to 13 hr (also see Fig. 10, p. 22)
The figure shows a trip-out during the deceleration part of a winding trip. The underlay rope carried an empty kibble and the kibble on the overlay rope carried a light load. The overlay kibble was approaching the stage at the time of the trip-out.

Figure 25, p. 37: 15 hr 3 min to 15 hr 33 min (also see Fig. 11, p. 23)
The figure shows a number of rock hoisting and tipping trips.

Figure 26, p. 38: 16 hr 57 min to 17 hr 3 min (also see Fig. 12, p. 24)
The figure shows another trip-out at the start of the acceleration part of a winding trip. The overlay kibble was loaded with rock at that time, and the trip-out occurred when the winder reached a speed of only 1.5 m/s. The underlay kibble was empty at the time of the trip-out. The latter part of the graph shows tipping of the overlay kibble.

Figure 27, p. 39: 19 hr 1 min to 19 hr 8 min (also see Fig. 13, p. 25)
The figure shows emergency braking (trip-out) that was carried out on request with a loaded kibble descending. The kibble, crosshead and rock load totalled approximately 14 tons. An empty kibble was attached to the underlay rope. The length of the suspended rope on the overlay side was approximately 1100 m at the start of the deceleration, and 1150 m at the end. The average deceleration rate was 2.23 m/s², and the rope force oscillation period after the winder stopped was 2.55 s. The first natural oscillation period of the suspended overlay rope and kibble was calculated by adding one third of the mass of the kibble rope to the loaded kibble mass, and using the formulae for simple harmonic motion of a single degree-of-freedom system. A rope elastic modulus of 120 GPa was assumed. The first natural
period so calculated was 2.4 s compared to the measured 2.55 s. Emergency braking with a fully loaded kibble descending is comparable to what will happen during a trip-out with the jumbo rig descending.

Figure 28, p. 40: 19 hr 20 min to 19 hr 40 min (also see Fig. 13, p. 25)
The figure shows two more trip-outs that occurred at the start of the acceleration parts of the winding trips. At 19 hr 22 min, the overlay rope lifted a fully loaded kibble, put it down, and lifted it again before continuing the winding trip.

Figure 29, p. 41: 21 hr 15 min to 21 hr 45 min (also see Fig. 14, p. 26)
At 21 hr 7½ min, another trip-out occurred when a full kibble on the overlay rope was accelerated. The other events shown for the underlay side are: Winding down with the crosshead only, picking up a full kibble at the bottom, winding to the surface and tipping. The overlay rope shows hoisting the loaded kibble to the surface, and first parking it on the bank doors for a short while before tipping it. The empty kibble was then taken down to shaft bottom.

Figure 30, p. 42: 22 hr 35 min to 23 hr 15 min (also see Fig. 15, p. 27)
The jumbo rig was taken down on the underlay rope, it came back to the surface with the crosshead only, and picked up an empty kibble. During this time a rock hoisting cycle was completed on the overlay rope side.

Figure 31, p. 43: 25 hr 25 min to 25 hr 50 min (also see Fig. 16, p. 28)
The overlay rope descended with the crosshead only and the jumbo was brought back to the bank. On the overlay side, and empty kibble was hoisted to the bank and unhooked. While the jumbo came up on the underlay side, the overlay rope went down with only the crosshead attached.
5. MEASUREMENTS ON THE STAGE WINDER

5.1 CONVERSION OF THE STAGE WINDER DATA

The signals that were recorded for the stage winder rope forces were converted by multiplying the mass values of the loadcell readouts by the gravitational acceleration of 9.8 m/s².

The stage displacement was obtained by counting the stage drum spokes and filtering the resultant signal.

For unknown reasons, the stage winder tacho generator did not function properly when the stage was lowered. It only provided proper signals when the stage was raised. The tacho signal recorded during raising of the stage was calibrated using the absolute displacement measured at the stage winder drum spokes.

A speed signal for the parts where the stage was lowered was obtained by differentiating the stage displacement. This gave a reasonable signal, apart from where the stage lowering speed changed rapidly. This will be pointed out in the results that follow.

5.2 RESULTS OF THE MEASUREMENTS ON THE STAGE WINDER

The licensed full up stage mass was close to 55 tons, and the (catalogued) rope mass for the eight falls of rope at a suspended length of 1384 m was 86 tons. The (theoretical) total suspended mass was therefore 141 tons, giving an average force in each stage rope of 173 kN, which is 12% of the breaking strength of the stage ropes.

During all operations of the stage, except of course when the stage was moved, it was slung from the shaft walls. This was done to steady the stage and to take up some of the rope force variations and displacements during lashing. The measured stage mass can therefore only be compared to the licensed mass when the stage is moved and not slung.

As mentioned before, the same time scale reference was used for both the measurements on the stage winder and the measurements on the kibble winder.

The problems experienced at times with the disk drive of the data acquisition system, as mentioned on page 6, occurred outside the periods of stage movement. No relevant data was therefore lost.

5.2.1 General behaviour

Figure 32, p. 44, shows the recordings of the two stage rope forces, as percentages of the rope breaking strength of 1440 kN, during the complete 28 hr recording period. The stage was moved between 10½ hr and 14 hr, and again between 26 hr and 28 hr. The largest rope force variations were generated during stage movement, and the difference between the largest and the smallest rope force measured was less than 2% of the rope breaking strength.

The rope force variations when the stage was parked and slung, were less than 0.5% of the rope breaking strength, and were caused mainly by lashing operations. During the first part of the measurements the average south rope force was approximately 12.3% of the rope breaking
strength and the average north rope force was around 10.6%. After the first stage movement, these percentages changed to 12.2% and 11% respectively.

The rope force variations caused by lashing while the stage was stationary are shown in greater detail in Figs 33 to 35 (pages 45 to 47). The force scales on the graphs for the two ropes are different to enable a better representation of the data. The rope force variations occurred mainly at frequencies of 1 Hz to 2 Hz and are not considered to be of any significant magnitude.

Figures 36 and 37 (pages 48 and 49) show the rope forces measured during the two periods of stage movement, together with the suspended stage rope length ("stage depth"), and the stage rope speed.

The stage speed was one quarter of the stage rope speed because of the four rope falls of each stage rope. A positive speed corresponded to raising the stage. After analysis of the stage data it was evident that the actual rope speed during the stage movements was one half of that indicated on the control panel of the stage winder. The length of suspended rope ("stage depth") was as measured from the stage rope sheaves in the headgear where the rope entered from the stage winder. Two of the four stage rope falls on each stage rope had suspended lengths of approximately 15 m more, because of having the sheave wheels at the top of the headgear.

During the first stage movement, the stage was raised by 107 m, lowered by 107 m after blasting, and finally parked 5 m lower than the previous parked position. During the second stage movement, the stage was raised by 66 m, and after blasting it was lowered by 61 m. The recording period ended before the stage was manoeuvred to its final position. The average of the north and south rope forces when the stage was not slung and stationary, was never more than 5 kN greater than the calculated theoretical value of 173 kN.

Sudden small increases and decreases of the order of 1.5 kN on the stage rope forces were caused by placing or lifting the 1 160 kg kibble crossheads on and off the stage. Other small changes in the rope forces were caused by personnel and/or material moving between a kibble and the stage, and possibly some friction in the winding system and friction between the stage and the shaft wall.

5.2.2 Details of the first stage movement

The significant parts of the measurements during the first stage movement (Fig. 36, p. 48) are shown in detail in Figs 38 to 40 (pages 50 to 52). Figure 38 shows the stage lifted off the slings and raised by 107 m. The rope forces decreased gradually as the stage was raised and rope was pulled in. Figure 39 shows the stage being lowered by 107 m and some manoeuvring. Figure 40 shows the stage being manoeuvred into its final position, and finally some of the stage weight being taken up by the slings (at 10 hr 36 min).

When the stage was stopped after raising, the rope forces showed an increase of about 5 kN on each rope. The rope forces were measured on the dead legs, and friction in the stage winding system most probably caused the forces at the stage winder to be slightly higher and those at the dead legs to be slightly lower than average during raising of the stage. By the same account, the rope forces measured during lowering of the stage were slightly larger than average.

The part of the recordings around the larger peak that occurred at 10 hr 49 min in Fig. 38 (p. 50), is shown in greater detail in Fig. 41, p. 53. The rope speed graph (on the positive speed side) shows that the rope speed drops quite rapidly when the stage winder is stopped. Although
this rapid reduction of speed also happened on the negative speed side, it cannot be seen on the speed traces because of the filtering that had to be employed in the generation of negative stage speed. Stopping the stage suddenly caused oscillations in the rope forces. The relatively large peak that occurred at 10 hr 49 min was most probably caused by the stage hooking onto something in the shaft. This peak reduced after the stage was lowered a bit.

For the sake of interest, the events for the periods 11 hr 35 min to 11 hr 39 min, and 11 hr 52 min to 12 hr 2 min (see Figs 36 or 39) are shown in greater detail in Fig. 42, p. 54, and Fig. 43, p. 55 respectively.

5.2.3 Details of the second stage movement

The significant parts of the measurements during the second stage movement (Fig. 37, p. 49) are shown in detail in Figs 44 and 45 (pages 56 and 57). Figure 44 shows the stage lifted off the slings and raised by 66 m. Figure 45 shows the stage being lowered by 61 m. As mentioned above, the recording ended before the stage was manoeuvred to its final position.

The behaviour of the stage and the measured stage rope forces during the second stage movement were similar to that of the first stage movement.

The large speed variation that occurred at 26 hr 35 min (see Fig. 45) lasted approximately 20 seconds with peak accelerations of less than 0.15 m/s². The speed variations and accelerations were too slow and too low to cause any significant rope force variations.

For the sake of interest, the events for the period 26 hr 25 min to 26 hr 29 min (see Figs 37 or 44), and for the period 27 hr 5 min to 27 hr 9 min (see Figs 37 or 45) are shown in greater detail in Fig. 46, p. 58, and Fig. 47, p. 59, respectively.

5.2.4 Other comments

The stage rope force oscillations that occurred every time that the stage winder was stopped, had periods of approximately 2.6 s. During raising and lowering the stage the larger rope force oscillations occurred at periods of approximately 2.7 s. The theoretical oscillation period, based on the licensed stage mass and calculated as before, is 2.7 s.

Three extra plots were produced so that simultaneous events on the kibble winder and stage winder can be compared readily. Figs 48 and 49 (pages 60 and 61) shows the first stage movement in two 2 hour sections. These can be compared with the kibble winder events during the same periods shown in Figs 9 and 10 (pages 21 and 22). The second stage movement is shown in Fig. 50, p. 62, in a two hour section, which can be compared with the kibble winder events shown in Fig. 17, p. 29.
6. DISCUSSION AND RECOMMENDATIONS

The peak-to-peak dynamic components of the rope forces measured on the stage winder were less than 2% of the rope breaking strength, and the stage rope forces can, for all practical purposes, be regarded as static. Apart from accidental damage, and damage from the guide rope function, corrosion may be the only other major factor that can cause stage winder rope deterioration.

Accidental hooking of the stage on obstructions in its path may cause higher rope forces than measured. It is therefore important to have loadcells on the stage that measure the stage rope forces.

The measuring accuracy of the kibble winder rope forces was only in the order of 4% of the maximum rope forces, and 14% of maximum kibble payload, but it was better than 1% of the strength of the kibble ropes. Although the measured kibble winder rope forces cannot be used to determine, for example, whether the kibbles were overloaded by 10%, they were good enough to illustrate the behaviour of the kibble winder accurately.

Lifting loaded kibbles and jumbo rigs did not cause large dynamic rope force components because of the low rope speeds applied during these lifts.

Emergency braking on the kibble winders was of the constant deceleration type, and the resultant rope forces were of predictable magnitudes. All the other trip-outs recorded also did not generate any rope forces of alarming magnitudes.

All normal sinking operations were performed during the 28 hour recording period. Nothing that cannot be predicted or calculated was recorded during this time on either the kibble or the stage.

Nothing out of the ordinary happened on either the stage winder or the kibble winder during the recording period or during the two and a half weeks that the investigators spent on site at West Driefontein 10 Shaft.

As at Vaal Reefs 11 Shaft, this exercise has shown that it is possible to measure the kibble winder rope forces from the stresses in the headgear sheave wheel seats. With better practical calibration procedures over the whole rope force range, better accuracy could be achieved.

The data of all the measurements shown in this report are stored on computer disk (80 Mbyte in total) and are available for any further analysis that may be required.
7. REFERENCES


Figure 4: Rope forces measured on the kibble winder for the period 0 hr to 2 hr.
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Figure 50: Special plot: 2nd stage movement, 26 hr to 28 hr. See Fig. 17, p. 29, for kibble winder events during this period.
DIVISION OF
MATERIALS SCIENCE AND TECHNOLOGY

ROPE FORCE MEASUREMENTS DURING
SHAFT SINKING OPERATIONS AT
WEST DRIEFONTEIN 9 SHAFT

by

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This report consists of 42 pages.
ROPE FORCE MEASUREMENTS DURING SHAFT SINKING OPERATIONS
AT WEST DRIEFONTEIN 9 SHAFT

SYNOPSIS

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

The regulations governing the strength of ropes for stage and kibble winders are being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation is 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 the stage winder and kibble winder at West Driefontein 9 Shaft described in this report, forms part of the stage and kibble winder ropes investigation. Such measurements had also been carried out at Vaal Reefs 11 Shaft, and at West Driefontein 10 Shaft. This report completes the experimental phase of the stage and kibble winder investigation.

When the measurements at West Driefontein 9 Shaft were done, the shaft was at a depth of close to 1 900 m and sinking operations were performed normally. During the 26 hours of recording the events, one drill-blast-lash sequence was performed. The rope forces on the stage and kibble winders were recorded, together with winder speeds and kibble and stage positions. The measurements on the kibble winder included measurements during one trip-out. This report shows the time histories of the measurements.

The peak-to-peak dynamic components of the rope forces measured on the stage winder were less than 1.5% of the rope breaking strength, and the stage rope forces can, for all practical purposes, be regarded as static.

The measuring accuracy of the kibble winder rope forces was good enough to illustrate the behaviour of the kibble winder accurately.

Lifting loaded kibbles and jumbo rigs did not cause large dynamic rope force components because of the low rope speeds applied during these lifts.

All normal sinking operations were performed during the 26 hour recording period. Nothing that cannot be predicted or calculated was recorded during this time on either the kibble winder or on the stage winder.

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1. INTRODUCTION

The proposed new statutory regulations for drum winder ropes\(^1\) will conceivably allow single lift shafts of as deep as 4 000 m. These new regulations were formulated after intensive studies into dynamic forces acting on drum winder ropes, and deterioration patterns on discarded ropes. Drum winders that use these regulations will also have to conform to a Code of Practice\(^2\). 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 are being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation is 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 the stage and kibble winders at West Driefontein 9 Shaft described in this report, forms part of the stage and kibble winder ropes investigation. These measurements had also been carried out at Vaal Reefs 11 Shaft\(^3\) and at West Driefontein 10 Shaft\(^4\). At the end of 1995, West Driefontein 9 Shaft was the only suitable site available where the experimental part of the stage and kibble winder investigation could be completed.

When the measurements were done, 9 Shaft was at a depth of close to 1 900 m and although the shaft was nearly completed, sinking operations were still performed normally.

During the 26 hours of recording the events, one drill-blast-lash sequence was performed. Drilling was done with a jumbo rig. Recordings were also made during a planned trip-out while a kibble, filled with rock, was descending in the lower half of the shaft.

The transportation of personnel between the bank and the stage at 9 Shaft was performed by a single drum service winder. No measurements were carried out on the service winder.
2. **SHAFT LAYOUT, AND WINDER AND ROPE PARAMETERS**

The positions of the stage winder, kibble winder and service winder, relative to the 9 m diameter shaft, are shown in Fig. 1. The kibble winder was a double drum winder, the service winder a single drum winder, and the stage winder was a two drum friction winder with two ropes.

![Diagram of shaft layout with winders](image)

**Figure 1:** Layout of the winders relative to the shaft.

The distance from the kibble winder to the centre of the shaft, and the positions of the headgear sheave wheels are shown in Fig. 2.

The stage ropes entered the headgear approx. 51 m above the bank. The service winder rope entered the headgear at tip level.

![Diagram of distances](image)

**Figure 2:** Distances from the winders to the shaft and sheave wheels.
At the time of the measurements the shaft was 1 840 m deep (measured from the bank). The top of the stage (kibble crosshead release point) was approximately 30 m above shaft bottom. The stage was approximately 15 m in height. The winder and rope parameters of the winders are given in Table 1. The stage and kibble masses were obtained from the winder permits, and the rope parameters were obtained from the MD208's.

**TABLE 1: ROPE AND WINDER PARAMETERS OF WEST DRIEFONTEIN 10 SHAFT**

<table>
<thead>
<tr>
<th>Winder name</th>
<th>Kibble winder</th>
<th>Service winder</th>
<th>Stage winder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permit no.</td>
<td>7628</td>
<td>7632</td>
<td>7578B</td>
</tr>
<tr>
<td>Length of the suspended rope (note 1)</td>
<td>1 840 m</td>
<td>1 808 m</td>
<td>1 808 m</td>
</tr>
<tr>
<td>Headgear sheave diameter</td>
<td>5,5 m</td>
<td>-</td>
<td>2,2 m</td>
</tr>
<tr>
<td>Drum diameter</td>
<td>5,5 m</td>
<td>-</td>
<td>2,1 m</td>
</tr>
<tr>
<td>Brakes</td>
<td>Drum</td>
<td>Drum</td>
<td>Drum</td>
</tr>
<tr>
<td>Brake control</td>
<td>Escort</td>
<td>Escort</td>
<td></td>
</tr>
<tr>
<td>Rope speed</td>
<td>15 m/s</td>
<td>15 m/s</td>
<td>0,95 m/s</td>
</tr>
<tr>
<td>Stage speed</td>
<td></td>
<td></td>
<td>0,24 m/s</td>
</tr>
<tr>
<td>Stage mass (note 2)</td>
<td></td>
<td></td>
<td>71 552 kg</td>
</tr>
<tr>
<td>Kibble mass (note 3)</td>
<td>5 260 kg</td>
<td>1 860 kg</td>
<td></td>
</tr>
<tr>
<td>Payload: rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>men</td>
<td>18 000 kg</td>
<td>2 240 kg</td>
<td>840 kg</td>
</tr>
<tr>
<td>material</td>
<td>10 000 kg</td>
<td>1 100 kg</td>
<td></td>
</tr>
<tr>
<td>Number of ropes (falls)</td>
<td></td>
<td></td>
<td>2 x 4</td>
</tr>
<tr>
<td>Rope diameter</td>
<td>54 mm</td>
<td>32 mm</td>
<td>42 mm</td>
</tr>
<tr>
<td>Rope construction</td>
<td>15 strand</td>
<td>15 strand</td>
<td>15 strand</td>
</tr>
<tr>
<td></td>
<td>non-spin</td>
<td>non-spin</td>
<td>non-spin</td>
</tr>
<tr>
<td>Rope tensile grade</td>
<td>1 800 MPa</td>
<td>1 800 MPa</td>
<td>1 950 MPa</td>
</tr>
<tr>
<td>Rope mass/length</td>
<td>13,2 kg/m</td>
<td>4,5 kg/m</td>
<td>7,8 kg/m</td>
</tr>
<tr>
<td>Rope breaking strength (note 4)</td>
<td>2 340 kN</td>
<td>800 kN</td>
<td>1 470 kN</td>
</tr>
<tr>
<td>Safety factor (note 5)</td>
<td>4,94</td>
<td>7,20</td>
<td>6,39</td>
</tr>
<tr>
<td>Capacity factor (note 6)</td>
<td>10,27</td>
<td>27,6</td>
<td></td>
</tr>
</tbody>
</table>

**note 1** The maximum suspended rope lengths in the table are as they were at the time of the start of the measurements, and as measured from the bank. These lengths will increase until the final shaft depth is reached.

**note 2** The stage mass is the all up stage mass: 59 440 kg (stage) + 8 380 kg (material) + 2 100 kg (men) + 1 632 kg (rock).

**note 3** The kibble mass included the 1 600 kg crosshead. The mass of the jumbo drilling rig was estimated as 14 tons from the recorded signals.

**note 4** The breaking strength is the lowest new rope strength of the two ropes on a winder.

**note 5** The kibble winder "safety factor" is the static safety factor at the headsheave for a fully loaded kibble plus crosshead and a fully payed out rope at the current depth, and calculated on the new rope breaking strength. The stage "safety factor" was calculated using the all up stage mass and the length of the suspended stage ropes.

**note 6** The "capacity factor" is the static safety factor at the kibble for a fully loaded kibble plus crosshead.
The layout of the ropes in the shaft are shown in Fig. 3.

![Diagram of rope layout](image)

**Figure 3:** Layout of the ropes in the shaft.

In Fig. 3, O/L refers to the overlay rope of the kibble winder, and U/L refers to the underlay rope. The east stage rope ran from the stage winder to E1 and down to the stage, up E2, down E3, and up E4 and secured (terminated) in the headgear on the same level at which the stage ropes entered the headgear. The west rope followed a similar path. Falls E4 and W4 are called the dead legs.

Falls E1 and W4 (a dead leg) served as guide ropes for the overlay rope kibble, and falls E4 (a dead leg) and W1 served as guide ropes for the underlay rope kibble.

Falls E2 and E3 served as guide ropes for the service winder. The sheave wheel from E2 to E3 was positioned on the same level as the stage rope terminations, while the sheave wheel from W2 to W3 was positioned approximately 20 m above the bank.

The east stage rope was also referred to as the "left" rope, and the west stage rope as the "right" rope. A point of interest is that the lay directions of the two non-spin stage ropes were opposite.
3. MEASURING EQUIPMENT AND PROCEDURES

3.1 THE STAGE WINDER

The dead leg of each stage rope was equipped with a loadcell in the headgear. These loadcells were used by the mine for monitoring the mass of the stage and its suspended ropes, and for the proper balancing of the forces between the two stage ropes. The loadcells had readouts in the headgear and at the stage winder foot-plate. The loadcell signals were tapped off at the stage winder foot-plate. The readings of the stage rope loadcells were assumed to be correct and accurate.

Winder speed was obtained from the stage winder tacho-generator. Absolute winder movement was obtained by equipment that sensed the passing of the spokes of one of the stage winder drums. The four stage winder signals were coupled to a data acquisition system in the stage winder house.

3.2 THE KIBBLE WINDER

The rope forces on the kibble winders could only be measured at the sheave wheels in the headgear. Strain gauges were installed on the sheave wheel seats for the measurement of the rope forces. The magnitude of the strain gauge signals were appreciably lower than those recorded at the previous two sites\(^3\): A maximum variation of 3.5 MPa for the overlay rope, and only 2 MPa for the underlay rope. Meaningful recordings could however be made from these signals. The strain gauge signals were relayed to a data acquisition system in the kibble winder house.

The rotational speed of the winder drums was obtained from a tacho-generator that measured the speed of the winder motor. The absolute rotation of the winder motor was obtained by equipment that generated two pulses per winder motor rotation. Sensing equipment was also installed to detect clutching operations on the kibble winder.

The two rope force signals, the two clutching signals, the winder motor position signal, and the winder motor speed signal were connected to the data acquisition system in the kibble winder house.

3.3 THE RECORDINGS

All the signals from the kibble winder were recorded at an average rate of 21.8 samples per second each, over a 26 hour period while sinking operations continued normally. The signals from the stage winder were recorded at an average rate of 21.95 samples per second each. The stage winder recordings started approximately 10 min after the start of the kibble winder recordings, and continued only for 22 hours because of limited storage capacity on the stage winder data acquisition system.

During the recording period, one drill-blast-lash sequence was completed, and forty seven rock loads and twelve kibbles of water were transported to the surface. The jumbo drilling rig was conveyed up once during the recording period, and the stage was moved before and after the blast.

The normal sinking operations were only interrupted once when emergency braking was carried out on request with a kibble loaded with rock descending at a depth of 1 500 m.
4. MEASUREMENTS ON THE KIBBLE WINDER

4.1 CONVERSION OF THE KIBBLE WINDER DATA

The kibble winder rope forces were calibrated using the empty kibble (plus crosshead) in the tip as one reference point, and the rope, without a kibble attached, at the bottom of the shaft as the second reference point for linear interpolation and extrapolation of the measured signals. The height measured from the bank to the tip was 37 m, and the centres of the headgear sheaves were 59 m above the bank. From the catalogued rope mass of 13.2 kg/m and the kibble plus crosshead mass of 5260 kg, the rope forces at the reference points (F1 and F2) were calculated as follows:

\[
F1 = \text{weight of kibble} + 22 \text{ m of rope} = (5260 + 22 \cdot 13.2 \text{ kg}) \cdot 9.8 \text{ m/s}^2 = 54 \text{ kN}
\]
\[
F2 = \text{weight of} \ 1840 + 59 \text{ m of rope} = 1899 \cdot 13.2 \cdot 9.8 \text{ N} = 246 \text{ kN}
\]

The kibble positions were determined by integrating the speed signal and correcting it with the absolute position measurement. The signals from the clutching operations were used to determine when one drum was stationary and the other moving. The length of rope per drum turn was taken as constant throughout the length of the wind. The kibble positions were calculated and expressed as lengths of suspended rope measured from the headgear sheaves.

The accuracy of the rope force measurements were estimated from inspection of the results. Although the signals from the strain gauges were small by any comparison, the overall accuracy of the force measurements, which included any zero drifting, was better than ±30 kN.

The measured rope force signal from the underlay rope side sometimes showed jumps of the order of +10 kN, which lasted from a number of seconds to as long as one minute. Because the measured signal was so small, these jumps were most probably caused by instability of the analog to digital converter of the data acquisition system and by interference from other electrical equipment.

The accuracy of the kibble position measurements was in the order of ±3 m.

The following approximate static rope force values are given to assist the reader in interpreting the results that follow:

- Empty kibble at bank = 60 kN
- Empty kibble at shaft bottom = 300 kN
- Rope without kibble at shaft bottom = 250 kN
- Fully loaded kibble at shaft bottom = 470 kN

At shaft bottom the kibble minus crosshead (36 kN) was lifted together with the payload, while at the tip, only the payload was tipped. The weight of the crosshead, which is left on the stage when the kibble is moved to shaft bottom, was approximately 15 kN.
4.2 RESULTS OF THE MEASUREMENTS ON THE KIBBLE WINDER

4.2.1 General behaviour

The measurements on the kibble winder for the 26 hour recording period are shown in thirteen 2 hour sections in Figs 4 to 16 (pages 14 to 26). The time scale on these graphs, which is from 0 hr to 26 hr, was used as the reference for any event throughout this report. The stage winder data, which is discussed in the section 5 of this report, also used the same time reference.

In Figs 4 to 16, the two kibble rope positions are shown on one graph: The thin line represents the length of suspended rope for the overlay side, and the thicker line that of the underlay side. The rope speed shown is the rotational speed of the winder motor converted to linear rope speed. A positive speed corresponds to the overlay kibble rope ascending. Clutching operations are shown on the rope speed graph as small black rectangles between approximately 12 m/s and 13 m/s on either the positive or negative speed sides. Clutching the overlay drum (overlay drum stationary) is shown on the positive side of the graph, and clutching the underlay drum is shown on the negative side of the graph. The "U/L rope force" is for the underlay side, and the "O/L rope force" is for the overlay side of the kibble winder.

Although not every trip that was recorded and shown Figs 4 to 16 (pages 14 to 26) will be discussed, the general sinking operations occurred at the following times or in the following periods:

- At the start of the recordings (0 hr), the underlay rope showed a decrease in rope force of 90 kN when it was at the bottom of the shaft. The jumbo rig was most probably put down in two small movements, the first movement should have reduced the rope force by 50 to 60 kN just before the recordings started. During the first hoisting trip shown, both kibble ropes only had their crossheads attached. After the first trip, one rock hoisting trip was carried out on the overlay rope while water was pumped on the underlay rope side.

- Water was hoisted with both kibbles from ½ hr to 5½ hr. A water load was generally in the order of 6 tons.

- Between 5½ hr and 6 hr, the jumbo was transported to the surface on the underlay rope. The mass of the jumbo was estimated as 14 tons from these recordings.

- From 7 hr to just after 8 hr, one water load was pumped into the underlay kibble. After the this kibble was hoisted to the bank, the water was pumped out, and the kibble tipped.

- Between 8½ hr and 9 hr, the overlay kibble was parked on the bank doors. This caused the small reduction in rope force at the end of a trip, and the slight increase when it is picked up just before the next trip.

- Just after 9½ hr the overlay kibble was clutched, and the underlay kibble was moved to the position of the stage for blasting. After completion of the following trip, the overlay kibble was in that position.

- The results from the measurements on the stage winder are discussed later in this report but, for the sake of direct comparison of the events, the stage movements and forces for the time 8 hr to 14 hr are shown in Figs 29 to 31 (pages 40 to 42) in three 2 hour sections.
The stage was raised by 103 m from 9 hr 49 min to 10 hr 17 min. Near the end of stage raising, the stage passed the overlay kibble and the crosshead was lifted. This can be seen as slight reduction in the overlay kibble rope force at 10 hr 7½ min.

The slight increase in the underlay rope force just after 10⅔ hr was caused by the crosshead being picked up at the start of a ascending trip. This corresponds to a drop in the stage rope forces at the same time. The small increase in the overlay rope force just before 10⅔ hr will be discussed later in this report.

Blasting took place at 10 hr 21 min.

The stage was lowered from 11 hr 8 min to 12 hr 2 min and finally positioned 3 m deeper than the previous position.

Rock hoisting with both kibbles took place from 14 hr to 22½ hr. A rock hoisting cycle consisted of winding an empty kibble down to the stage, leaving the crosshead on the stage, placing the empty kibble on the shaft bottom, picking up a loaded kibble, collecting the crosshead while moving through the stage, winding to the tip and tipping the rock load. Note that very little clutching was done during rock hoisting. The kibbles were never loaded to the full (licensed) capacity of 18 tons. The weight of the kibble (36 kN) plus the payload was generally in the order of 160 kN.

Emergency braking with a load of approximately 18 tons attached to the underlay rope and descending, was carried out just after 15¾ hr. An empty kibble was attached to the overlay rope at that time.

Just before 22½ hr, something weighing around 13 tons was lifted off the bank on the underlay rope and replaced again after a while.

Nothing of interest happened for the rest of the recording period.

4.2.2 Details of the measurements on the kibble winder

Greater details of the following incidents and/or interesting parts are shown in the following figures:

Figure 17, p. 28: 0 hr 25 min to 1 hr 5 min (also see Fig. 4, p. 14)
Water pumping on the underlay rope and tipping a relatively small load on the overlay rope. After tipping the overlay kibble was parked on the bank doors, and lifted again at the start of the next winding trip.

Figure 18, p. 29: 5 hr 30 min to 5 hr 56 min (also see Fig. 6, p. 16)
The figure shows the 14 ton jumbo rig being picked up at shaft bottom and transported to the bank on the underlay rope. An empty kibble was attached to the overlay rope during this time. During lifting and releasing the jumbo, the rope speed never exceeded 0,1 m/s and is not visible on the speed trace. The mass of the jumbo rig was less than a fully loaded kibble.

Figure 19, p. 30: 10 hr 6 min to 11 hr 12 min (also see Fig. 9, p. 19, and for the stage events see Fig. 30, p. 41)
The events shown in this figure are purely for the sake of interest. The rope force
variations shown were insignificant compared to other events. The rope speed scale and the rope force scale of this figure was adjusted to show the events better. Full rope speed falls outside the speed graph limits. At the beginning of the figure the overlay rope kibble was positioned at the blasting position of the stage. When the stage passed the kibble during raising, the kibble crosshead was lifted (10 hr 8 min). The increase in overlay rope force at 10 hr 15 min could be from people moving from the stage to the kibble. The next increase (12 hr 17 min) was from lifting the crosshead before the trip to the surface. When the overlay kibble was moved to the surface, the underlay kibble was moved down to the stage and stopped 14 m above the stage. The interesting point to note is the decrease in rope force when the underlay kibble was raised by 3 m at 10 hr 22 min. After the blast and before the next trip, the underlay kibble was lowered by 2.5 m (10 hr 50 min) during which time the rope force increased by 20 kN. Reasons for this unexpected decrease and increase in rope forces are not apparent. The slight increase in the underlay rope force towards the end of the graph was caused by the crosshead being taken of the stage by the stage passing over the kibble during stage lowering.

Figure 20, p. 31: 15 hr 45 min to 15 hr 59 min (also see Fig. 11, p. 21)
The figure shows a rock hoisting cycle of each kibble plus emergency braking with the kibble, crosshead and rock (18 tons total) on the underlay rope descending. An empty kibble was attached to the overlay rope during the emergency braking. The length of the suspended rope on the underlay side was approximately 1450 m at the start of the deceleration, and 1500 m at the end. The average deceleration rate was 2.23 m/s², and the rope force oscillation period after the winder stopped was 3.0 s. The first natural oscillation period of the suspended overlay rope and kibble was calculated by adding one third of the mass of the kibble rope to the loaded kibble mass, and using the formulae for simple harmonic motion of a single degree-of-freedom system. A rope elastic modulus of 120 GPa was assumed. The first natural period so calculated was 2.9 s compared to the measured 3.0 s.

Figure 21, p. 32: 19 hr 1 min to 19 hr 25 min (also see Fig. 13, p. 23)
The figure shows a few rock hoisting cycles. The rope speed during lifting of the loaded kibbles was generally in the order of 0.3 m/s.

Figure 22, p. 33: 20 hr 45 min to 21 hr 15 min (also see Fig. 14, p. 24)
The figure shows more rock hoisting. At 20 hr 49 min, the loaded kibble on the underlay rope was momentarily parked on the shaft bottom again after the initial lift.
5. MEASUREMENTS ON THE STAGE WINDER

5.1 CONVERSION OF THE STAGE WINDER DATA

The signals that were recorded for the stage winder rope forces were converted by multiplying the mass values of the loadcell readouts by the gravitational acceleration of 9,8 m/s².

The stage displacement was obtained by counting the stage drum spokes and applying linear interpolation between the counts.

As was the case with the measurements on the stage winder at West Driefontein 10 Shaft, the stage tacho generator did not function properly. The most probable reason was interference caused by the data acquisition system employed for the measurements. During raising of the stage, an insignificant signal was measured, while lowering of the stage produced a signal that was larger than normal, and which saturated the measuring equipment at full speed.

Stage rope speed signals for the periods where no signals were measured, and for the periods where the measuring equipment was saturated, were reconstructed from differentiating the displacement signal. Although the manufactured speed signal was slightly noisy, it was adequate for the demonstration of the stage winder behaviour.

5.2 RESULTS OF THE MEASUREMENTS ON THE STAGE WINDER

The licensed full-up stage mass was close to 72 tons, and the (catalogued) rope mass for the eight falls of rope at a suspended length of 1 859 m was 116 tons. The (theoretical) total suspended mass was therefore 188 tons, giving an average force in each stage rope of 230 kN, which is 15,6% of the breaking strength of the stage ropes.

During all operations of the stage, except of course when the stage was moved, it was slung from the shaft wall. This was done to steady the stage and to take up some of the rope force variations and displacements during lashing. The measured stage mass could therefore only be compared to the licensed mass during the period when the stage was moved and not slung.

As mentioned before, the same time scale reference was used for both the measurements on the stage winder and the measurements on the kibble winder.

5.2.1 General behaviour

Figure 23, p. 34, shows the recordings of the two stage rope forces, as percentages of the rope breaking strength of 1 470 kN, during the complete 26 hr recording period. The recordings of the stage signals started at 0 hr 10 min and continued until 22 hr. The stage was moved between 9½ hr and 12 hr. The largest rope force variations were generated during stage movement, and the difference between the largest and the smallest rope force measured was less than 1,5% of the rope breaking strength.

The rope force variations when the stage was parked and slung, were in the order of 0,5% of the rope breaking strength, and were caused mainly by lashing operations. During the first part of the measurements the average east rope force was approximately 14% of the rope breaking strength and the average west rope force was approximately 14,9%. After the stage movement, these percentages changed to 14,7% and 15,5% respectively.
5.2.2 Details of the measurements on the stage winder

The rope force variations caused by lashing while the stage was stationary are shown in greater detail in Fig. 24, p. 35. The force scales on the graph for the two ropes are different to enable a better representation of the data. The rope force variations occurred mainly at a frequency in the order of 1 Hz, and are not considered to be of any significant magnitude.

Figures 25 and 26 (pages 36 and 37) show the rope forces measured during the period of stage movement. The forces are shown together with the suspended stage rope length ("stage depth"), and the stage rope speed. The stage speed was one quarter of the stage rope speed because of the four rope falls of each stage rope. A positive speed corresponded to raising the stage. The length of suspended rope ("stage depth") was as measured from the stage rope sheaves in the headgear where the rope entered from the stage winder.

Figure 25, p. 36, shows the stage lifted off the slings (9 hr 49 min) and raised by 103 m. The rope forces decreased gradually as the stage was raised and rope was pulled in. Blasting took place just after 10 hr 21 min. Figure 26, p. 37, shows the stage being lowered to a position 3 m deeper than the previous parked position, and finally some of the stage weight being taken up by the slings (at 12 hr 2 min).

The average of the east and west rope forces when the stage was not slung and stationary, was never more than the calculated theoretical value of 230 kN.

During the time that the stage was not slung, sudden small increases and decreases of the order of 2 kN on the stage rope forces were caused by placing or lifting the 1 600 kg kibble crossheads on and off the stage. Other small changes in the rope forces were caused by personnel and/or material moving onto and off the stage, and possibly some friction in the winding system and friction between the stage and the shaft wall.

Every time the stage was stopped after raising, the average rope forces showed a slight increase on each rope. The rope forces were measured on the dead legs, and friction in the stage winding system most probably caused the forces at the stage winder to be slightly higher and those at the dead legs to be slightly lower than average during raising of the stage. By the same account, the rope forces measured during lowering of the stage were slightly larger than average. The same behaviour was observed during the measurements at the previous two sites.\textsuperscript{3,4}

The rope speed dropped quite rapidly every time that the stage winder was stopped. Stopping the stage so suddenly caused oscillations in the rope forces. These rope force oscillations had periods of approximately 3.4 s. The theoretical oscillation period calculated as before, is 3.0 s.

Three extra plots were produced so that simultaneous events on the kibble winder and stage winder can be compared readily. Figs 29 to 31 (pages 40 to 42) shows the stage movement in three 2 hour sections. These can be compared with the kibble winder events during the same periods shown in Figs 8 to 10 (pages 18 to 20).
6. DISCUSSION AND RECOMMENDATIONS

The peak-to-peak dynamic components of the rope forces measured on the stage winder were less than 1.5% of the rope breaking strength, and the stage rope forces can, for all practical purposes, be regarded as static. Apart from accidental damage, and damage from the guide rope function, corrosion may be the only other major factor that can cause stage winder rope deterioration.

The measuring accuracy of the kibble winder rope forces was only in the order of 6% of the maximum rope forces, and 17% of maximum kibble payload, but it was better than 1.5% of the strength of the kibble ropes. Although the measured kibble winder rope forces cannot be used to determine, for example, whether the kibbles were overloaded by 10%, they were good enough to illustrate the behaviour of the kibble winder accurately.

Lifting loaded kibbles and jumbo rigs did not cause large dynamic rope force components because of the low rope speeds applied during these lifts.

Emergency braking on the kibble winder was of the constant deceleration type, and the resultant rope forces were of predictable magnitudes.

All normal sinking operations were performed during the 26 hour recording period. Nothing that cannot be predicted or calculated was recorded during this time on either the kibble winder or on the stage winder.

Nothing out of the ordinary happened on either the stage winder or the kibble winder during the recording period or during the two weeks that the investigators spent on site at West Driefontein 9 Shaft.

As at the two previous sites,\textsuperscript{3,4} this exercise has shown that it is possible to measure the kibble winder rope forces from the stresses in the headgear sheave wheel seats. It may not be possible to obtain better measuring accuracy when the stresses in the sheave wheel seats are as low as they were for the measurements shown in this report.

The data of all the measurements shown in this report are stored on computer disk (73 Mbyte in total) and are available for any further analysis that may be required.
7. REFERENCES


Figure 4: Rope forces measured on the kibble winder for the period 0 hr to 2 hr.
Figure 5: Rope forces measured on the kibble winder for the period 2 hr to 4 hr.
Figure 6: Rope forces measured on the kibble winder for the period 4 hr to 6 hr.
Figure 7: Rope forces measured on the kibble winder for the period 6 hr to 8 hr.
Figure 8: Rope forces measured on the kibble winder for the period 8 hr to 10 hr. See Fig. 29, p. 40, for the stage winder events during this period.
Figure 9: Rope forces measured on the kibble winder for the period 10 hr to 12 hr. See Fig. 30, p. 41, for the stage winder events during this period.
Figure 10: Rope forces measured on the kibble winder for the period 12 hr to 14 hr.

See Fig. 31, p. 42, for the stage winder events during this period.
Figure 11: Rope forces measured on the kibble winder for the period 14 hr to 16 hr.
Figure 12: Rope forces measured on the kibble winder for the period 16 hr to 18 hr.
Figure 13: Rope forces measured on the kibble winder for the period 18 hr to 20 hr.
Figure 14: Rope forces measured on the kibble winder for the period 20 hr to 22 hr.
Figure 15: Rope forces measured on the kibble winder for the period 22 hr to 24 hr.
Figure 16: Rope forces measured on the kibble winder for the period 24 hr to 26 hr.
Figure 17: Kibble winder rope forces: Water pumping on the underlay rope and tipping on the overlay rope. The overlay kibble was parked on the bank doors between the two winding trips.
Figure 18: Kibble winder rope forces: Transportation of the jumbo drilling rig to the surface on the underlay rope.
Figure 19: Kibble winder rope forces: The behaviour of the kibble ropes just before and after blasting is shown in this figure purely for the sake of interest. See page 8 of the text for an explanation of the events.
Figure 20: Kibble winder rope forces: Rock hoisting with both kibbles, and emergency braking with a loaded kibble on the underlay rope descending.
Figure 21: Kibble winder rope forces: Rock hoisting with both kibbles.
Figure 22: Kibble winder rope forces: Rock hoisting with both kibbles.
Figure 23: Stage rope forces measured for the full 26 hour recording period. The stage was moved between 9½ hr and 12 hr.
Figure 24: Stage rope forces measured during lashing for a 3 min period around 16 hr.
Figure 25: Stage winder rope forces measured while the stage was raised.
Figure 26: Stage winder rope forces measured while the stage was lowered.
Figure 27: Details of stage raising: See Fig. 25 for the broader picture.
Figure 28: Details of stage lowering: See Fig. 26 for the broader picture.
Figure 29: Special plot: Stage movement, 8 hr to 10 hr. See Fig. 8, p. 18, for the kibble winder events during this period.
Figure 30: Special plot: Stage movement, 10 hr to 12 hr. See Fig. 9, p. 19, for the kibble winder events during this period.
Figure 31: Special plot: Stage movement 12 hr to 14 hr. See Fig. 10, p. 20, for the kibble winder events during this period.