NSW Resources Regulator

Workers trapped in shaft winder

Causal investigation

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Executive summary

Two workers at Tahmoor Colliery became trapped in the No. 3 shaft friction winder,162 metres below ground on 5 September 2018, when the electrical protection operated in response to a significant disturbance in the alignment of the balance ropes. This disturbance was later found to be caused by a collision between the winder counterweight and the side wall of the shaft. This interaction resulted in damage to a water ring 240 metres below the surface, which dislodged and became wrapped around shaft services, winder head ropes and balance ropes.

The mine emergency management system was activated, and the two workers were rescued from the cage and brought to the surface with the help of NSW Emergency Services.

Following the incident and preliminary investigation, the Resources Regulator decided to undertake a causal investigation to better understand the causes of the incident and publish lessons learnt.

A causal investigation team comprising representatives from Tahmoor Colliery, Shipping, Infrastructure, Mining, Energy and Commodities (SIMEC), the Construction, Forestry, Maritime, Mining and Energy Union (CFMEU) and the Resources Regulator was established to investigate and identify the factors that led to the incident. The investigation identified that the most likely scenario was that the counterweight was misaligned, which caused it to strike the water ring, ripping it from the shaft wall, pulling the guide, head and balance ropes out of alignment, which tripped the winder protection circuit.

The following matters were found to be contributing causal factors:

- Uneven head rope tensions induced rotation on the counterweight resulting in misalignment that reduced clearance between the counterweight, cage and shaft wall.
- The maintenance and inspection scheme did not recognise the necessity of head rope tension.
- Soft signals were not recognised and properly communicated to senior personnel to action.

The following factors were also considered significant but did not directly contribute to the incident:

- Guide rope tension was critical in maintaining counterweight and conveyance alignment.
- Winder duty changes impact the mean time to failure for safety critical components and tolerances.
- Shaft and structure alignment confirmation at the time of commissioning and maintenance throughout the life of the plant.
- Optimisation of operating clearances between the conveyance and other components at time of design to reduce the reliance upon other control measures to maintain a safe operating state.
- Maintenance activities identified during operational and design risk assessments that are critical in maintaining a safe operating state.
- Monitoring of maintenance and inspection schemes for quality assurance.

Contents

Causal investigation

A preliminary investigation and assessment of the incident was carried out by the regulator which did not identify any material breaches of the work health and safety laws. Following this assessment the regulator determined that an investigation under the regulator's causal investigation policy was the most appropriate way forward to enable the quick and full understanding of the causes of the incident and publication of the corresponding lessons to reduce the likelihood of recurrence.

Notably, a causal investigation is an investigation into a safety incident notified to the regulator under the work health and safety laws, not to obtain evidence for a prosecution but rather to identify the causal factors of safety incidents, the effectiveness of the controls being used and what factors may have contributed to the failure of the controls. Timely communication helps ensure that duty holders under the work health and safety laws can better understand the risks they must manage, and the necessary controls to prevent reoccurrences of similar safety incidents.

The Resources Regulator invited relevant stakeholders to participate in the causal investigation process. An investigation team comprising of representatives from Tahmoor Colliery, SIMEC, the CMFEU and the Resources Regulator was established.

1.1. Preliminary report

A preliminary incident report was issued within 14 days of the incident, consistent with the existing causal investigation policy. The report made the following recommendations based on the information known at the time of publishing.

> …mine operators should review their safety management systems, particularly focusing on:
>
> → the implementation of change management processes in relation to significant changes in winder demand, including loading and frequency of operation
>
> → maintenance of control measures required to maintain the safety of shafts and winding systems
>
> → the identification of critical controls and verification activities required to maintain the safety of shafts and winding systems
>
> → the integrity of maintenance and inspection work order systems for shaft and winding systems
>
> → the triggers for response actions, with respect to observed abnormal conditions for shafts and winding systems
>
> → existing safety audits for winding systems and ensure the hierarchy of controls have been applied to identified non-conformances to the required standards or guidelines.

The causal investigation preliminary report can be downloaded from the Resources Regulator website, www.resourcesregulator.nsw.gov.au

1.2. Mine operator

Tahmoor Coking Coal is an underground coal mine that began operations in 1979. The mine has approval to produce up to three million tonnes of run of mine (ROM) coal per annum.

Coal is mined from within the Bulli seam, producing hard coking coal for steel production and minor thermal coal. Product coal is transported via rail to Port Kembla for both Australian customers and export customers. The mining operations, in the Tahmoor North lease area, are forecasted to continue until 2021, when the mining operations is expected to move to a new mining Domain (Tahmoor South) at Bargo.

Tahmoor Coking Coal employed about 380 employees and contractors at the time of writing. The operation supports many local and regional businesses and services.[1]

2. The incident

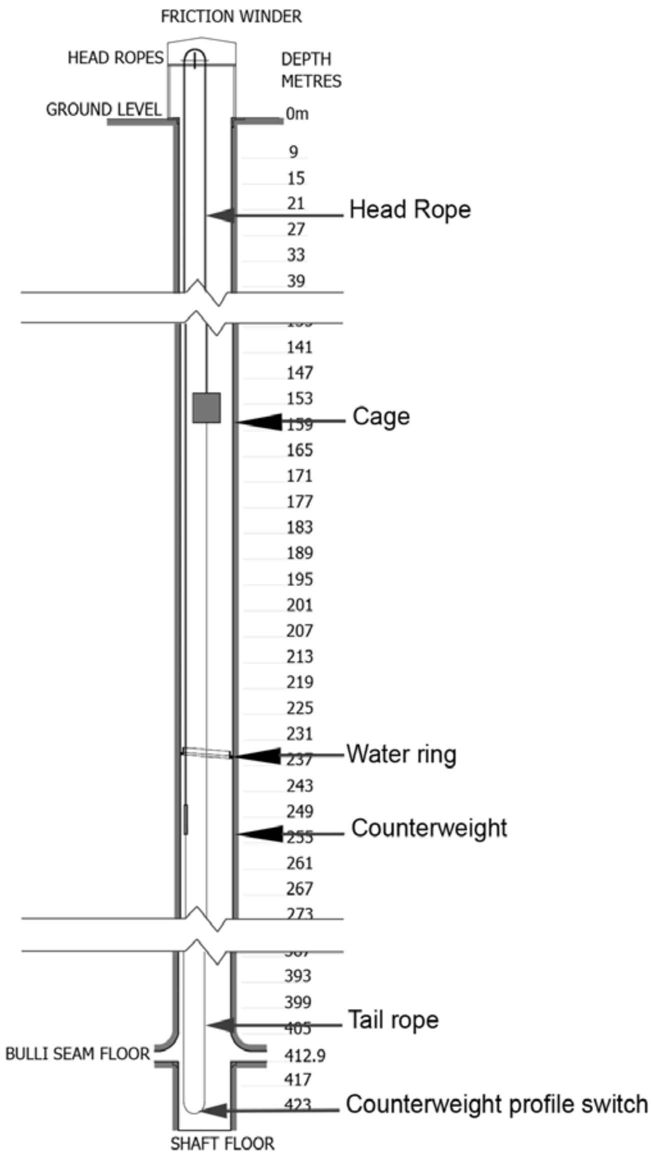
On 5 September 2018 at 3.25pm, two workers at Tahmoor Colliery became trapped in the No. 3 shaft conveyance when the electrical protection operated in response to a significant disturbance in the alignment of the balance ropes. This disturbance in the alignment of the balance ropes was later found to be caused by a collision between the counterweight and the side wall of the shaft. This resulted in damage to the number 4 water ring at the 240-metre mark, which dislodged and became wrapped around shaft services, head ropes and balance ropes.

The final position of the cage conveyance was at the 162-metre mark. This is depicted in figure 1.

Two workers were travelling in the cage at the time of the incident. The mine emergency management system was activated, and the two workers were rescued from the cage to the surface with the assistance of NSW Emergency Services about nine hours later.

[1] SIMEC Mining Tahmoor Coking Coal (2018) Longwall 32 Resident Information Pack p1

Figure 1: Annotated shaft profile drawing.



2.1. People involved

Investigators interviewed and took statements from people involved in the incident, recovery, inspection and maintenance activities leading up to the event. This included the two trapped workers, surface mechanical maintenance personnel and statutory personnel involved in inspection and maintenance of the shaft.

2.2. Equipment specification

The Tahmoor Colliery No. 3 shaft winder head frame and winder drum were originally supplied to Clutha Development by General Electric Company (GEC) in the late 1970s. At that time, the winding system was approved and designed capable of transporting 80 people or 12 tonnes payload. The winding system, originally planned for installation at Tahmoor No. 2 shaft, was eventually installed onto the Nattai Bulli No. 3 shaft as a personnel and supplies winder for the Nattai Bulli No. 2 mine.

Ownership of the GEC winding system and Nattai No. 3 shaft changed in the early 1990s to Oakdale Colliery following underground connection of Oakdale and Nattai Bulli mines. The winder system continued in service at the Oakdale No. 3 shaft for 12 years, serving the mine as its principal transport as well as providing access for the mine’s heavy equipment transport needs, including the initial transport of the longwall roof supports, which weighed more than 15 tonnes.

The Oakdale shaft was of near-identical dimension to that of the Tahmoor No. 3 shaft, differing in that its vertical depth measured at 430 metres as opposed to the 409 metres for the Tahmoor No. 3 shaft.

In 2012, Australian Winch and Haulage (AWH) won the tender for a turn key project designing, installing and commissioning a new shaft winder on the Tahmoor No. 3 down cast shaft. The mine proposed to rehabilitate and reuse some components from the Oakdale winder, which had previously been mothballed due to the closure of the Oakdale Colliery in 1999. This included the head frame. Other components for the winder were either manufactured by AWH (such as the cage) or retrofitted from other used components (such as the counterweight and winder drum, which originally were used at Teralba Colliery, NSW). Figures 2 and 3 are drawings of the cage manufactured by AWH for use in the Tahmoor No. 3 shaft and the retrofitted counterweight (originally from Teralba Colliery). Table 1 identifies components in use in the No. 3 shaft winding system.

Figure 2. No.3 shaft counterweight

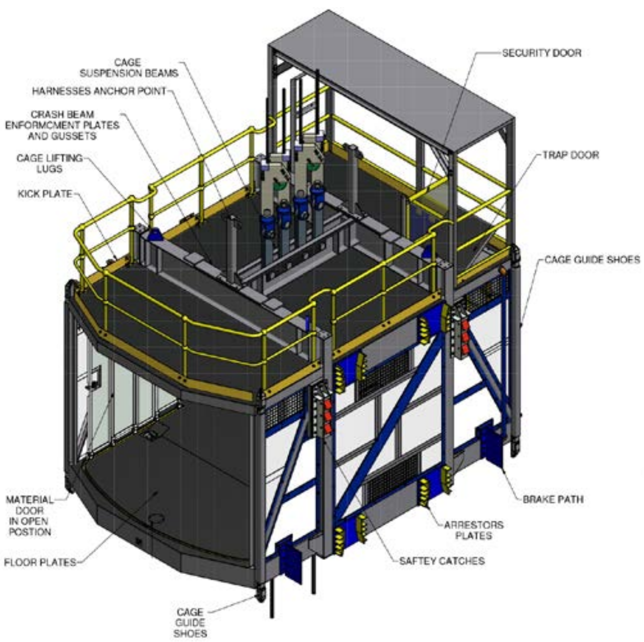


Figure 3. No.3 shaft counterweight.

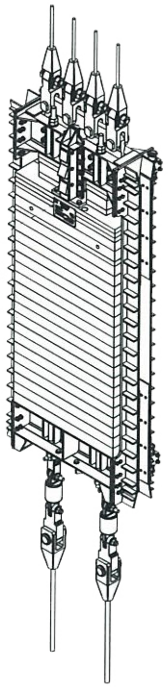


Table 1. The No. 3 shaft winder design parameters.

Parameter	Notes
Manufacturers	Australian Winch and Haulage (mechanical winding system) Rockwell Automation (controller) Siemag Tecberg (brake hydraulics)
Max rated materials payload	10 tonnes De-rated from originally specified 12 tonnes material payload by Tahmoor Coal.
Max rated man riding payload	80 people
Operating speed	5.5 metres per second (Note: speed limited to 3.0 metres per second at time of incident) 1.0 metres per second creep speed and maintenance speed
Shaft depth	409 metres

Drum assembly	Head rope pitch diameter 2.59 metres Main shaft supported by two SKF SD3060 plumber blocks containing 23060CCK W33 spherical roller bearings on OH 3060H sleeves. Becorit K25 rope groove liners
Motor	Toshiba SB170-KCKM, DC motor Shunt wound, externally excited, 600 rpm base speed Rated output power 375 kilowatts
Gearbox	Brevini PLC50-R11-V24-28.4-Z1 Continuous thermal rating (with fan cooling) 429 kilowatts ref [3g] Bevel-helical 3 stage 28.37: 1 ratio
Head ropes	4 ropes refs [5d] [5e] 30 millimetres diameter 2 ropes RHLL, 2 ropes LHLL Wire grade 1960 megapascal, galvanised Minimum break load 790 kilonewton
Balance ropes	2 ropes ref [5f] 44 millimetres diameter 2 ropes RHO lay, steel core Wire grade 1570 megapascal, galvanised Minimum break load 1090 kilonewton
Guide ropes	Cage 4 ropes 38 millimetres diameter Half locked coil, preformed, RH lay Wire grade 900 megapascal, galvanised Minimum break load 756 kilonewton

	Counterweight 2 ropes Same rope type as for cage Note: Guide ropes are restrained by spherically seated, wedge suspension glands at winder deck level and sump level. There was no dynamic tensioning system installed and commissioned on the guide ropes at the time of the incident.
Cage	Men and materials cage with shaft inspection upper deck 12 tonnes empty mass (refer to figure 2)
Counterweight	18.7 tonnes[2] reported by Australian Winch and Haulage 17.1 tonnes[3] weight used by mechanical design verifier due to documents ambiguity of counterweight mass. (refer to figure 3)

At the time of the incident the No. 3 shaft winding system cage and counterweight guide ropes were fixed with a static tensioning system depicted in figure 4.

[2] Australian Winch and Haulage (2013) J5609-Tahmoor Friction Winder – Shaft 3 Issue 7 p4
[3] Advitech (2015) Verification report Mechanical Design Tahmoor No.3 Shaft Friction Winding System Rev 0 (final) p14

Figure 4. Guide rope tensioning system for cage guide ropes 1 and 2.

2.2.1. Seam profile switch

Following an incident in 2015, (see section 2.6.2) the mine developed a unique winder trip switch that was located just above the counterweight seam docking spears. Its purpose was to prevent the counterweight entering the seam level docking infrastructure out of alignment. At the time of this incident, the seam profile switch tripped the winder when the balance ropes were forced out of their normal alignment.

2.3. Operating environment

2.3.1. Physical environment

On 5 September 2018, conditions in the shaft were considered normal. The No. 3 ventilation shaft was delivering 127 metres^3 per second fresh air to the mine at the time of the incident. Maximum temperature variances in the shaft were estimated at ±15ºC and the estimated temperatures on the night of the incident were between 5ºC and 10ºC. Water make in the shaft was via underground aquifers and influenced by local rainfall. Water was collected in the shaft via a series of gutters (known as water rings) and transferred to the base of the shaft through a series of downpipes, where it was pumped from the mine. Figure 5 depicts a water ring fixed in the No. 3 shaft at Tahmoor Colliery.

Figure 5. A water ring fixed in vent shaft No. 3 at Tahmoor Colliery.

The No. 3 vent shaft is 409 metres deep and has a measured deviation of 211 millimetres to the North East in the last one quarter of the shaft.

2.3.2. Winder duty

The No. 3 shaft friction winder was designed for 12 tonne maximum payloads but was reduced to a maximum 10 tonne payload due to a discrepancy between recorded counterweight masses in various design documents. This led to the system being verified and design registered for a lesser load capacity. The design registered system caters for 80 people assessed at 120 kilograms per person.[4]

The winder was designed for 264,000 cycles over a 40-year life. This equates to approximately 36 one-way trips per day, which is medium duty[5]. In the week preceding the incident, the winder was averaging about 100 cycles per day, although still considered as medium duty. This was an approximate 550 percent increase on the historical duty of the winder at Tahmoor.

2.4. Maintenance plan and procedures

Maintenance tasks and scheduling was informed by a design failure modes effects analysis (DFMEA) and risk assessment that was carried out at the time of construction. Table 2 describes the maintenance regime managed by a work order system that was intended to ensure that the winding system continued to operate as designed.

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[4] Tahmoor Underground Glencore (undated) Tahmoor No. 3 shaft friction winder design winding loads and speeds p2

[5] Resource Regulator MDG33/1 *Guideline for design, commissioning and maintenance of drum winders* p52

Table 2. schedule of planned maintenance and inspection work orders for the No. 3 shaft.

Name	Period	Relevant details of workorder	Workgroup responsible
No. 3 shaft winder daily mech exam and test	daily	Visually check the regrooving level floor below the winder for foreign materials. Visually inspect entire length of head ropes. Visually inspect entire length of tail ropes. Visually inspect entire length of guide ropes.	Mechanical trades
No. 3 shaft 2 weekly cleaning	fortnightly	Clean shaft of iron oxide growth on shaft walls and water rings.	Operator
No. 3 winder attachments monthly mech exam/test	monthly	Cleaning and close inspection of head rope and tail rope attachments on cage and counterweight.	Mechanical trades
No. 3 shaft winder 3-month mech offline exam/test	3 monthly	Complete collar to collar test. **Limits -** ropes must be aligned within 25 mm.	Mechanical trades
No. 3 winder balance ropes 6 monthly NDT	6 monthly	Carry out non-destructive testing of winder balance ropes.	Expert consultant

In addition to the inspections identified in table 2, the shaft (including water ring) and the winding system were inspected daily by a statutory mining official.

The requirement to record and trend inspection results was not identified as a predictive tool for the identification of unsafe conditions. Therefore, data obtained from routine maintenance activities was not recorded in a format that facilitated trending and analysis.

Due to other labour demands on site, in the weeks leading up to the incident, there were several maintenance and inspection work orders for the winder, closed but not completed. The mine had not identified those work orders that were critical to maintaining a safe operating state or a system to escalate those work orders or stop the winder if they were incomplete.

Two inspection tasks that were relevant to this incident were the rebound test and the collar-to-collar test. The rebound test was an indicator of rope tension variation across the four head ropes. This test was introduced in November 2016 after an issue was identified with drum liner wear. At the time of the incident, the rebound test was not scheduled in the work order system, rather it was used on an ad hoc basis to identify head rope tension variation. There was no recording or analysis of the of the rebound test results. The second inspection task was the three-monthly, collar-to-collar test that was an indicator of rope slip. This test was completed one week before the incident. There was no recording or analysis of the collar-to-collar test results before the incident.

2.5. Organisation

The mine's engineering department oversaw scheduling, inspection and maintenance tasks for the No. 3 shaft winder. A specific surface coordination and maintenance team was in place to service all surface infrastructure such as the gas drainage plant, the water recycling plant and all winding systems. The team consisted of a maintenance superintendent, maintenance planner, maintenance scheduler, electrical and mechanical coordinators, supervisors and trades. Maintenance priorities were influenced by the business needs at the time.

2.6. Events leadings up to the incident

2.6.1. Design and construction

In 2012, AWH commenced design and construction on the No. 3 shaft friction winder using existing components from other mines within the parent company. Due to reasons outside the scope of this investigation, AWH did not complete the project and on September 2015 Tahmoor took control of the project. Initially, failure modes effects and criticality analysis (FMECA) and risk assessments were undertaken without AWH personnel. However, a subsequent FMECA was undertaken with the original designer, which nominated a collar-to-collar test as a control for monitoring head rope tension variation. A collar-to-collar test measures differences in head rope length by identifying and measuring rope slip over the head drum.

Commissioning of the No. 3 winding system was completed on November 2015, after an incident occurred involving the docking of the counterweight at seam level.

2.6.2. Counterweight docking incident

On 18 March 2015, during commissioning an incident occurred that resulted in the counterweight failing to dock at shaft bottom. The counterweight was not captured by the fixed guides and impacted on the steelwork at shaft bottom. The incident investigation determined that a maintenance task put the counterweight into an abnormal oscillation at midshaft immediately before winding the cage to surface. The mine commissioned Jacobs Group (Australia) Pty Ltd to undertake computational modelling of the shaft winding system, with emphasis on rope guides and displacement of the balance ropes. The main conclusions of this report are reproduced below:

1. The guide rope tensions and guide rope size are considered adequate to control clearances during hoisting.
2. The guide rope tensioning system is sensitive to temperature changes – significant tension may be lost if the rope temperature increases. One way to manage this is to set up the rope loads in the most optimum way for the temperature at the time and then continuously monitor the load in one rope using a loadcell.
3. The counterweight is particularly sensitive to any loss in tension of the guide ropes.

4. The counterweight is susceptible to rotation effects caused by head rope torque imbalances. The capacity of the fixed guides to capture rotated counterweigh is marginal.
5. The adoption of more rotation-resistant head ropes would reduce the risk of the counterweight not engaging in the fixed guides, in situations where the head rope loads are not well balanced.
6. The risk of the counterweight not engaging in the fixed guides can be reduced if the counterweight guide ropes are tensioned more highly.
7. Guide rope systems in general are sensitive to abnormal disturbance of the conveyances. Simulations of the type of disturbance that may have occurred during commissioning indicate that the disturbance could have caused the counterweight to miss the fixed guides.
8. The shaft barrel may not be straight. This could significantly affect the operating clearances around the conveyances during normal hoisting and should be investigated further.[6]

The mine undertook the following work and analysis to address the recommendations identified above:

1. Seam level fixed guides were redesigned and manufactured to provide increased capture tolerance on entry.
2. A counterweight profile switch was incorporated into the safety circuit. The switch activates the safety stop circuit if the counterweight is misaligned before docking.
3. Cage, counterweight and shaft wall clearances were reviewed and verified as part of the design registration process.
4. The cage seam level docking brakes (Keps) were removed which allowed for greater tolerances to minimise binding.
5. A scheduled greasing program was put in place to minimise binding.
6. Pressure gauges were installed on each guide rope tensioning device to provide accurate measurement of tension.
7. A daily inspection process was implemented to monitor and, when required, manually adjust guide rope tensions to maintain the required operating tension.
8. Review maintenance and operating procedures with a view to minimising the risk of causing abnormal disturbances during maintenance.
9. Investigate the straightness of the shaft and potential impact this may have on clearances during normal hoisting. This recommendation was implemented. Whisker test was conducted during the commissioning process. The whisker test results confirmed that there were no major deviations due to shaft alignment.

On 9 November 2015, Tahmoor Colliery applied for design registration. The No.,3 shaft friction winder was design registered by the Department of Industry, Skills and Regional development on 30 November 2015.

2.6.3. Rope slip event

In September 2016, workers reported shuddering and unusual conveyance travel in the No. 3 shaft. This was coupled with drive vibration that was subsequently found to be caused by significant variance in head rope tension. The mine began investigation of the issue and identified that the winder was running with significant uneven head rope tensions and drum liner wear. As part of the 2016 rope slip event investigation a rope tension test (rebound test) and regrooving procedure was developed. The procedure

[6] Grobler S (28 April 2015) Rope Guide Simulation, Jacobs Group (Australia) Pty Ltd p5

for rope tension testing was in line with rebound testing that was occurring at other operations that used a friction winder. The rebound test was not incorporated into the maintenance management system following this incident.

2.6.4. Drift conveyor maintenance

In the weeks before 5 September 2018, Tahmoor Colliery had begun a programmed conveyor belt replacement on its main drift conveyor. The programmed conveyor belt replacement led to restricted access to the drift, resulting in the No. 3 shaft winder being the primary means for worker transportation into the mine. This change resulted in an increase in the use of No. 3 shaft winder.

2.7. Events on the day of the incident

Mining supervisor travels down shaft and conducts shaft inspection

A shift deputy began his daily shaft inspection at 2.27pm. The deputy noted that at mid-shaft, where the counterweight and man riding conveyance pass, the counterweight appeared misaligned. While still in the shaft, the deputy contacted the control room operator via the DAC system to advise of the potential issue, then continued with his shaft inspection until he reached pit bottom.

Following the deputy's call to the control room, engineers were informed of the misalignment of the counterweight. A mechanical engineer attended the shaft winder to investigate the deputy's observations.

Mining supervisor and eight-hour crew travel to surface

While the mechanical engineer was investigating the issue on the surface of the shaft, a work crew and the deputy, who had recently completed the shaft inspection, travelled to the surface using the winder without encountering any problems. Once at the surface, the deputy discussed his observations in relation to the misaligned counterweight with the mechanical engineer.

Two workers use shaft conveyance

At 2.47pm, two workers who were underground at the bottom of the shaft called the cage down and travelled to the surface without problems. During inquiries following the incident, one of the workers reported that he may have heard a noise as the conveyance travelled to pit bottom.

Afternoon shift crew travel to pit bottom

At 3.20pm, about 60 afternoon shift workers entered the conveyance at the surface and travelled to the pit bottom. Workers in the conveyance felt vibration and heard noises as they travelled down the shaft. A shift deputy who was in the conveyance during the trip contacted the control room immediately after alighting from the conveyance to report the unusual vibration and noises.

Two workers enter conveyance at pit bottom and begin to travel to the surface

At 3.26pm, two workers entered the No. 3 shaft conveyance and began to travel to the surface. This occurred while the deputy was on the phone to the control room. During the wind to the surface, the winder tripped on a seam profile switch. Preceding the winder trip, workers on the surface noticed unusual noises and excessive vibration of the head ropes. The two workers in the shaft cage reported hearing loud crashing noises and suspected that the cage had made contact with the counterweight.

3. Incident outcome

Post incident inspection identified an apparent collision between the counterweight and the shaft water ring, which resulted in the water ring being dislodged from its concrete pocket as visible in figure 6. The water ring, remained secured to the shaft wall at one point and collapsed around the head, guide and balance ropes pulling them out of their normal alignment. The reticulated services including air, water and drainage pipes were also pulled from the shaft wall. Figures 6 and 7 depict the damaged shaft wall and water ring in its final resting position following the incident.

Figure 6: Shaft water ring mounting bracket and original position.

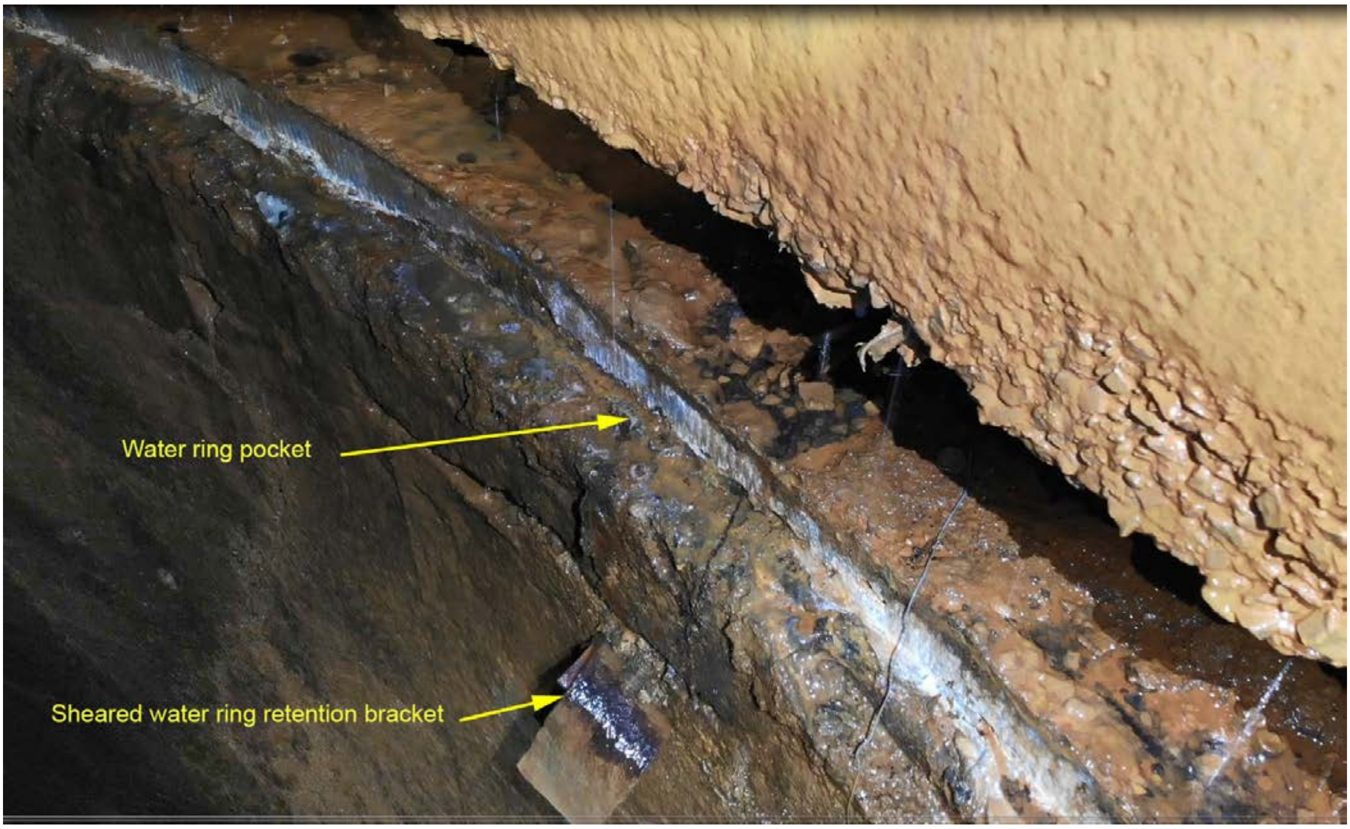
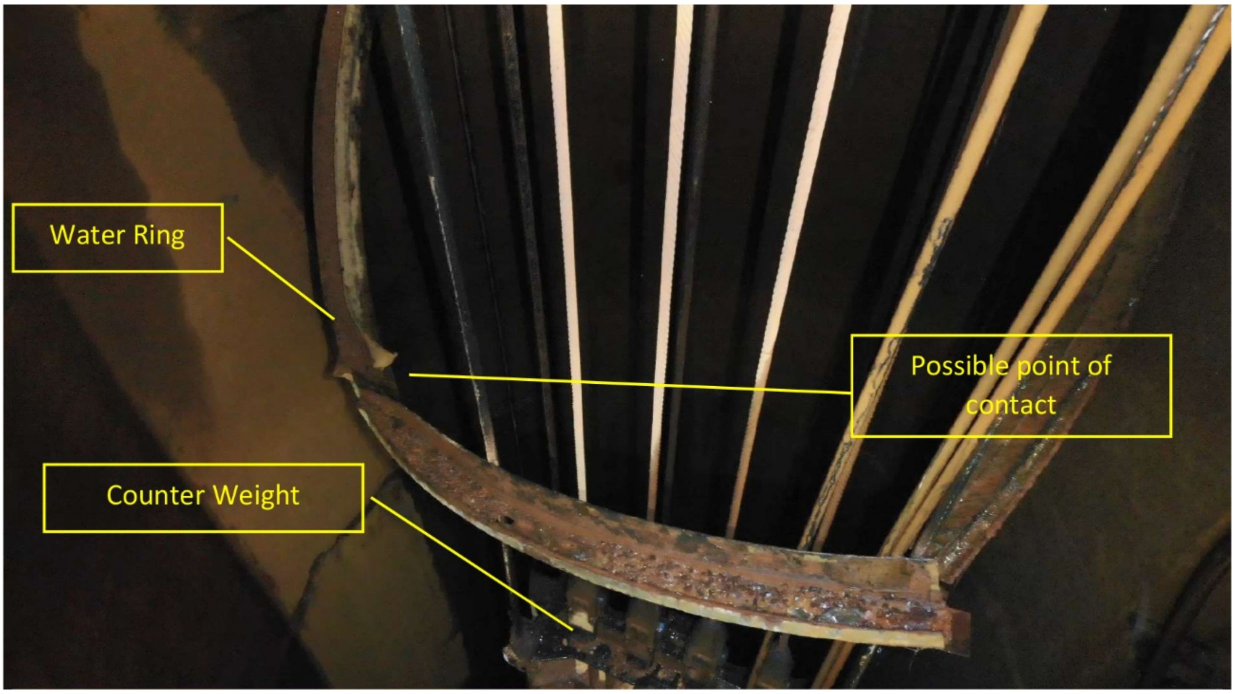


Figure 7: Shaft water ring wrapped around counterweight head ropes and shaft services.



4. Remedial action by the mine

Following the incident of the two trapped workers, the mine operator was given a section 195 prohibition notice under the *Work Health & Safety Act 2011*. The notice stated that the winder was not to be operated while workers were in or on the conveyance or within the confines of the tower or shaft. Over a period of weeks, the mine progressively developed and implemented a plan for the remote removal of the damaged water ring within the shaft and controls to prevent the incident from reoccurring. A summary of works is provided below:

- Sent camera down to assess situation (found water ring dislodged at counterweight location).
- Installed object fall barrier (beams) at bottom of shaft.
- Removed water ring in four sections from shaft using camera directed slings and winches.
- Brought conveyance to surface for examination using auxiliary hydraulic drive.
- Non-destructive testing (NDT) of cage head rope attachments and associated structure on conveyance.
- Removed object fall barrier (beams) from the bottom of shaft.
- Measured and reset rope insert groove depths on winder drum.
- Adjusted winder encoder parameters following insert groove depth adjustment.
- Adjusted mechanical hunting tooth parameters following insert groove depth adjustment.
- NDT of head ropes.
- Inspected counterweight when brought to the surface.

- NDT of counterweight head rope attachment and associated structure.
- NDT of underside of conveyance at pit bottom (balance rope attachments and associated structure).
- NDT of underside of counterweight at pit bottom (balance rope attachments and associated structure).
- Fitted camera to counterweight and verified passing of cage and counterweight and counterweight to wall clearances.
- NDT of balance ropes.
- Shaft inspection by mine official and engineering team.
- Cage and counterweight clearance measurements to water rings in unloaded state.
- Cage and counterweight clearance measurements to closest water ring in loaded states.
- Collar-to-collar tests conducted.
- Head rope rebound tests conducted.
- Test runs at various speeds.
- Completed mechanical maintenance monthly inspections and recommissioning inspections.
- Shortened head rope No. 3 to further balance head rope tensions and improve cage to counterweight clearances.

4.1.1. Rope drum groove depths

Head rope insert groove measurements were taken after the incident with a variance between the largest to smallest being 4.5 millimetres. Over the depth of 414.7 metres, the 4.5 millimetre variance in rope groove depth will result in a 1.456 metres difference in rope travel between the rope on the largest drum insert diameter and the rope on the smallest drum insert diameter. This was not acceptable. Machining of the grooves was completed and deviation in drum groove depths was confirmed to be within 0.4 millimetres.

4.1.2. Head rope rebound tests

After the regroove and shortening of ropes, head rope rebound tests were completed over seven cycles. This was completed with the counterweight at pit bottom. Two tests were completed for repeatability. Final measured variances were within an appropriate range indicating equal head rope tensions as far as reasonably practicable.

4.1.3. Collar-to-collar tests

Following drum liner regroove, shortening ropes and rebound tests, a collar-to-collar test was performed. The method used by the mine was as per the *Rope Man's Handbook* published by the National Coal Board (Great Britain). Results were repeatable and demonstrated no significant variance in rope length.

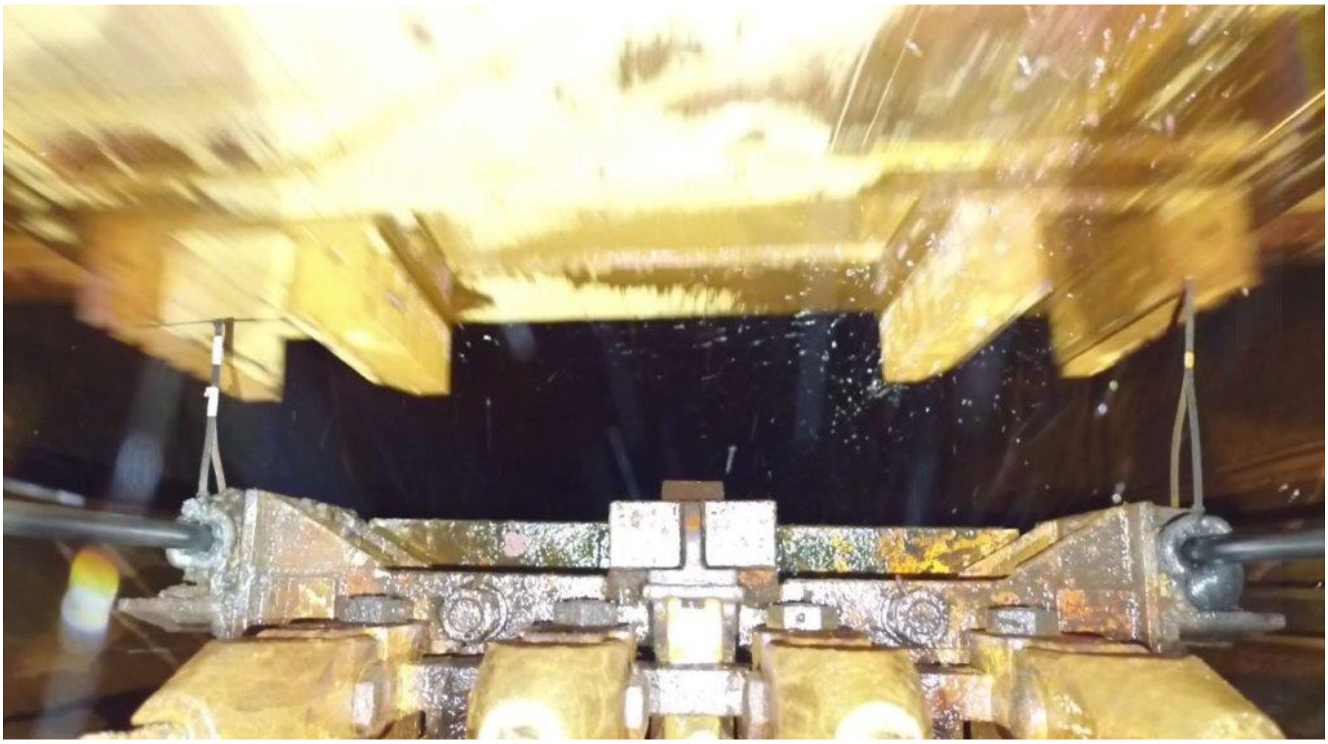
4.1.4. Counterweight clearance measurements

Before personnel riding, a camera run was completed showing the counterweight with whiskers at differing lengths to visually check the clearance between the counterweight to the wall and counterweight to the cage. A photo of the counterweight with whiskers attached can be seen in figures 8 and 9 below.

Once whisker tests showed acceptable clearances physical measurements between counterweight and cage were undertaken to verify clearances.

Figure 8: Counterweight to wall clearance showing clearance at a water ring inside the No. 3 shaft.

Figure 9: Counterweight to cage clearance.



4.1.5. Guide rope tensioning

At the time of the incident, the mine had not commissioned an active monitoring system on its static head rope tensioning system. Although not considered causal in this incident, the mine completed commissioning of the guide rope tensioning system to include active monitoring with trigger points set to alarm or shut down the winder if the tensions deviated from set points.

4.1.6. Additional controls

On 11 October 2018, following completion of all works identified above the Resources Regulator removed its prohibition notice and No. 3 shaft friction winder was put back into full service with a series of additional controls that were implemented before the winder was returned to full service:

1. Develop a rebound test procedure that includes clearly defined tolerances and parameters, instructions on how to perform the test, escalation processes where deviation is identified and tolerance parameters with graduated levels of response.
2. Develop a training package for the rebound test procedure.
3. Include training in the rebound test procedure in the training needs analysis for surface mechanical tradesmen.
4. Train surface mechanical tradesmen and assess competence in performing the rebound test to the required standard.
5. Schedule rebound tests to be completed daily as a critical work order in maintenance work order system (SAP - manual document to be used until published).
6. Develop a collar-to-collar test procedure that includes clearly defined tolerances and parameters verified by a third party consultant, instructions on how to perform the test, escalation processes where deviation is identified and tolerance parameters with graduated levels of response.
7. Develop training package for the collar-to-collar test procedure.
8. Include training in the collar-to-collar test procedure in the training needs analysis for surface mechanical tradesmen.
9. Train surface mechanical tradesmen and assess competence in performing the collar-to-collar test to the required standard.
10. Schedule collar-to-collar tests to be completed weekly – as a critical work order in SAP (manual document to be used until published).
11. Review the maintenance management plan to define the system requirements, reporting and governance processes.
12. Review the SAP reporting to clearly define completion of tasks by hierarchy and implement targets and reporting.
13. Implement scheduled audits of SAP to confirm completion of critical tasks to ensure they are completed in full and to requirements.
14. Review and update deputies' shaft inspection procedure to include clearly defined tolerances and parameters, instructions on how to perform the test, incorporating requirement to travel at full speed as well as inspection mode and requirements to measure counterweight alignment,

escalation processes where deviation is identified, tolerance parameters with graduated levels of response and process for recording results on deputies' report.

15. Develop training package for the deputies' shaft inspection.
16. Include training in the deputies' shaft inspection in the training needs analysis for deputies.
17. Train deputies and assess competence in performing the deputies' shaft inspection to the required standard.
18. Schedule deputies' shaft inspection to be completed daily – as a critical work order in SAP (manual document to be used until published).
19. Review and update the risk management procedure and management of change procedure to ensure that short term operational changes are defined as a trigger point.
20. Amend the process for the use of shims as a control measure to mitigate a failure of the guide rope tensioning system and include the shim distance which accounts for temperature variations.
21. Review maximum/minimum limits for guide rope tension to determine that they consider temperature variations.
22. Review and update the risk management procedure and management of change procedure to ensure that short term operational changes are defined as a trigger point.
23. Review alternate drum liner materials that provide design friction levels and improve wear characteristics and life-cycle.
24. Implement a training and awareness program to improve risk awareness and hazard identification and reporting requirements.
25. Refresher training for workers in the use of hazard reports when they find a situation that is not normal and is out of their control to rectify. An example for the winder would be experiencing a 'rougher than normal ride' or 'noisier than normal docking'.
26. Source deflection tensiometer to reliably and accurately measure head rope tensions.

5. Incident analysis

Possible scenarios leading to the counterweight/water ring collision include:

1. minor contact between the cage and counterweight at mid shaft, due to misaligned counterweight, which caused it to deflect off the cage and collide with the water ring
2. no contact between the cage and counterweight at mid shaft, however, misaligned counterweight contacted the water ring
3. a rope slip event occurred that induced movement in the counterweight that caused a collision with the water ring.

5.1.1. Scenario 1

Rotational torque applied to the counterweight was not pivoted centrally, rather off axis due to the imbalance on head rope three. This compromised clearance between the counterweight and the cage, leading to contact between the counterweight and cage. This is supported by correlation between time stamped CCTV footage recording the rope disturbances and mine SCADA system data, which records conveyance, position, speed and motor torque. Witness statements also corroborate a collision between the conveyance and the counterweight. However, there was no identified physical evidence of a collision between the cage and the counterweight.

5.1.2. Scenario 2

Rotational torque applied to the counterweight was not pivoted centrally, rather, off axis due to the imbalance on head rope three. This compromised clearance between the counterweight and the shaft wall. It was determined that it was possible for the cage and counterweight to pass at mid shaft and then make collision with the water ring.

5.1.3. Scenario 3

Rope slip events due to uneven head rope tensions may introduce disturbances into winder head ropes, which may be reflected into rotational forces in shaft conveyances and counterweights. There is some evidence to suggest rope slip events were occurring in the lead-up to the incident, however there was no evidence to confirm that a rope slip event occurred at the time of the incident.

Available monitoring evidence and examinations were unable to rule out any of the possible scenarios, however, significant weight was given to scenario 2 because there was a lack of physical evidence demonstrating contact between the cage and counterweight. Scenario 1 cannot be proven nor ruled out. This is due to some circumstantial evidence that suggests that there was identified movement of the head ropes at the exact time the cage and counterweight passed and that witness statements corroborated a cage and counterweight collision.

In all scenarios it should be acknowledged that the influence of the guide ropes in maintaining counterweight and conveyance alignment was at its least at the mid shaft position.

5.1.4. Other factors considered

Dynamic external forces such as mine airflow and buffering were considered negligible. It was noted that in all three scenarios as the cage and counterweight approached the mid shaft position the restraining influence of guide rope tensions was at its minimum.

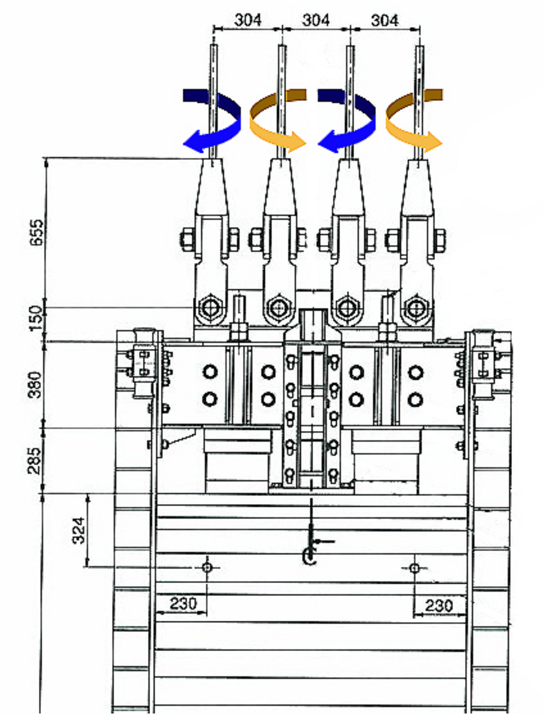
6. Significant causal factors

The following causal factors were relevant to the causal pathway of this incident for all scenarios above. Causal factors were identified following a 5-Why analysis of key timeline events. This was consistent with the ICAM methodology used for this investigation.

6.1.1. Uneven head rope tensions

Witness evidence provided by the dayshift deputy indicated that the counterweight had rotated outside of its usual axis. The most reasonable explanation for this rotation was uneven head rope tensions. The four head ropes used on the No. 3 shaft winder were 30 millimetre diameter, 1960 megapascals, galvanised 790 kilonewton ropes. Ropes 1 and 3 were right hand langs lay and ropes 2 and 4 were left hand langs lay. Langs lay ropes have a known rotational torque when a vertical load is applied. This is demonstrated in figure 10 below.

Figure 10: The Tahmoor No. 3 shaft counterweight depicting rotational torque applied to the capels from the head ropes.



Theoretically, when all four ropes are of equal tension, the net torque on the counterweight is zero. However, each rope will have minor variances in rope rotational torque for any given load. When head rope tensions are out of balance (i.e. do not have the same load applied) a net rotational torque will be applied to the counterweight. This torque will influence the axis on which the counterweight sits and possibly rotate outside of its operating profile.

The investigation process determined that a significant cause of the incident was uneven head rope tensions, combined with drum liner wear, which allowed the counterweight to rotate outside of its normal operating profile. The rotation of the counterweight meant that is was possible for the counterweight to make contact with the number four water ring as the cage conveyance transported two workers to the surface of the mine.

Conveyance clearances in the shaft were compliant to known standards at the time of design. Of note, however, was the fact that the clearances between the cage and the shaft wall and the counterweight and the shaft wall were relatively small in comparison to other similar winders. This meant that it was critical that the mine ensured that the shaft winder continued to meet design parameters during the lifetime of its operation (lifecycle management).

Lifecycle management was considered during preliminary risk assessments and two separate design failure mode effect analysis (DFMEA). The DFMEA or risk assessments did not consider holistic maintenance issues, such as head rope tension monitoring in relation to cage counterweight clearance issues, as it met current standard during design. The impact of uneven head rope tensions on the maintenance of the clearances was not recognised at the time of assessment.

The FMECA proposed collar-to-collar checks to potentially identify a failure mode of rope groove liners due to uneven rope tensions. Collar-to-collar checks do not directly measure rope tension. A collar-to-collar check is an indirect form of measurement that correlates rope slip to out of balance rope tension. A week before the incident a collar-to-collar test was performed that did not alert the mine to any significant variation in head rope tension. On the same day as the collar-to-collar test it was noted that the deputy did not raise an issue with unusual counterweight clearances.

Following the drum liner wear/rope slip event in 2016, rope tension checks were not routinely conducted using an industry benchmark test known as a rebound test. Rebound tests were undertaken on an ad hoc basis and subsequently failed to highlight the criticality of the excessive tension variation prevailing before the incident.

6.1.2. Rope tensioning

The only way of adjusting rope tensions is by adjusting rope length. Small variations in rope manufacturing will result in uneven rope stretch across all four ropes, especially during the early stages of operation. The maintenance of rope tensions was not clearly identified during design and commissioning even though it was reasonable to expect ropes would require routine length adjustments to maintain equal rope tension.

6.1.3. Reporting

Verbal reporting to the control room or non-reporting of shaft travelling issues by workers meant that soft signals such as rough docking or minor rope slip did not receive critical review or escalation at the earliest possible opportunity.

7. Other relevant factors considered not causal

The following factors were considered significant but did not directly contribute to the incident. Commentary on these factors is included to provide industry with information in relation to these known issues that may be relevant to their winding systems.

7.1.1. Guide rope tensioning

Guide rope tensioning was static hydraulic instead of dynamic suspended loads (cheese weights). This unusual form of tensioning was implemented in the No. 3 shaft because of the significantly small area below the seam to install appropriate cheese weights. The static hydraulic rope tensioning system used at the mine is not preferred because it introduces failure modes such as reliance on a hydraulic system.

The 2015 Jacobs report commissioned by the mine demonstrates that guide rope tensioning was critical to ensure that shaft counterweights maintained their designed path of travel. The ability for a guide rope to maintain an out of balance counterweight was at its minimum at mid shaft.

The No. 3 shaft counterweight guide ropes were identified to be tensioned to the designed parameters. As the guide ropes were tensioned as designed and were, in fact, a latent secondary control, only called upon when the primary control of even head rope tensioning fails, this factor was considered significant but not a cause of the incident.

The mine considered this issue in remediation and implemented an automatic guide rope tensioning system including real time monitoring and alarm and shutdown parameters.

7.1.2. Winder duty at time of the incident.

At the time of the incident, the winder was operating at a significantly higher duty than usual. This was because the usual primary access to the mine, the drift dolly car, was on limited use due to work being undertaken in the drift. The duty, although significantly higher was still considered medium duty and well within the design operating parameters for the winder. The winder was operating within designed operating parameters, which meant that the mine did not consider risks arising from changed management. Trouble shooting and identification of the cause of the 2016 rope slip event occurred over a longer period than was available to the mine during this incident. This was because the duty on the winder during the most recent incident was far greater than the 2016 incident. Increased duty may have accelerated the wear of the drum liners to the ultimate failure mode faster in the latter incident and not provided the mine with an adequate amount of time to identify and control the failure.

7.1.3. Shaft alignment (drum alignment, verticality of guide ropes)

Following the incident, the shaft was surveyed and was identified to be out of alignment by 211 millimetres vertical to the north east. The cage guide ropes were 54 millimetres out of parallel. It is not considered that this issue was causal.

7.1.4. Clearance of moving shaft conveyances and obstructions such as shaft walls

Operating clearances of conveyances should be considered with respect to head rope and guide rope tensions during both design and ongoing maintenance practices. Cage and counterweight clearance was by design and was within known standards at time of design. Even though clearances complied at the time of design, the clearance was relatively small compared to other similar winders. The design increased the criticality of maintaining the designed state because small variances in head rope tension could lead to the small clearances falling outside of parameter without notice.

Variations in the head rope tensions are critical in the management of safe operating clearances when these clearances are already minimal.

7.1.5. Shaft inspection and maintenance

There was no evidence structural defects or movement of the water ring caused the incident. This means that even though some inspections and maintenance may have been missed it did not directly contribute to the causal pathway.

7.1.6. Balance rope selection and configuration

Balance rope swivels and tail rope uneven forces were non-contributing.

8. Recommendations

Recommendations published in Information Release IIR18-09 on 27 September 2018 and republished in paragraph 1.1 of this report should be considered relevant and commensurate to the recommendations published below.

Mine operators should review their safety management systems relating to shaft winding systems and:

1. Consult with appropriately skilled people to identify the control measures that are critical to maintaining designed clearances and safe operating limits. This is including, but not limited to, the design specification and maintenance of head and guide rope tensions.
2. Develop or review defect reporting systems to include subjective and verbal comments by the workforce. Consider written hazard reporting so that potential defects are managed appropriately in the mine safety management systems.
3. Maintain accurate records for all baseline data, including and, not limited to, clearances, alignments, rope tensions and weights.
4. Challenge the clarity and effectiveness of maintenance tasks to ensure they provide consistent outcomes that are designed to maintain safe operating states. For example, measurable, repeatable results that clearly identify a deviation that requires escalation and/or isolation of equipment.
5. Identify the critical tasks in the maintenance management system that are required to maintain the system in a safe state and a response plan if those tasks are not completed.
6. Consider a change of duty (load or frequency of operation) that should trigger a review of the maintenance schedule.