BOOYSENDAL SOUTH ROPECON PROJECT

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SYNOPSIS

The RopeCon conveyor at Booysendal links the Booysendal Central shaft complex with the exiting Booysendal South Concentrator Plant. The RopeCon is a 4.7 km long conveying system, spanning over rough terrain and gaining 500 m of elevation from tail to head. At one of the valley crossings, a massive 800 m span is installed between towers. The project kicked off in 2015 with a proof of concept study where multiple technologies and solutions were evaluated. The RopeCon option was selected and the project received full approval in 2016. Successful commissioning took place in December 2018 and final optimisation settings were being completed in the month of January 2019.

This paper discusses the project from the proof of concept phase, through engineering and design, construction events and commissioning. The last section of the paper will be presented as a case study where theoretically calculated results are compared to actual results obtained in the field.

1. INTRODUCTION

The purpose of this paper is to discuss the selection and implementation of an aerial materials transporting system. Due to terrain, environmental and other operational constraints, conventional conveyors are found to be impractical in linking the mining operations with the concentrator plant. A trade-off and investigative study of available technology around the world led to the selection of a RopeCon.

Northam Platinum is currently expanding the production of the Booysendal mine with the following objectives to be met:

- Increase the output of the Booysendal North (BYN) UG2 mine to 315 ktpm, and transport 127 ktpm to Booysendal South (BYS) for processing at the BYS Concentrator Plant.
- Develop the Booysendal Central (BYC) mine to produce 317 ktpm and transport the ore to the BYS Concentrator Plant.

To achieve the above objectives, an ore transport system must be capable of transporting 127 ktpm from BYN to BYC, and 444 ktpm from BYC to BYS Concentrator Plant. The system must be able to utilise the BYS stockpile facility to allow for maintenance and stoppages at the BYS concentrator plant without affecting mining production from the above-mentioned production areas.

Understanding the workings of a RopeCon is crucial for the interfacing of the technology with the project and include among others; civil design, bulk materials handling simulations and tests. Other project challenges include the import and logistics handling of material, regulatory compliance of the various applicable bodies and the use of specialised equipment.

2. BACKGROUND

2.1. LOCATION

Booysendal Platinum mine is located on the Eastern Limb of South Africa’s platinum region known as the Bushveld Complex.

It is approximately 35 km from the town of Mashishing (formerly Lydenburg), straddling the border of Limpopo and Mpumalanga provinces. The concession hosts both UG2 and Merensky ore bodies.

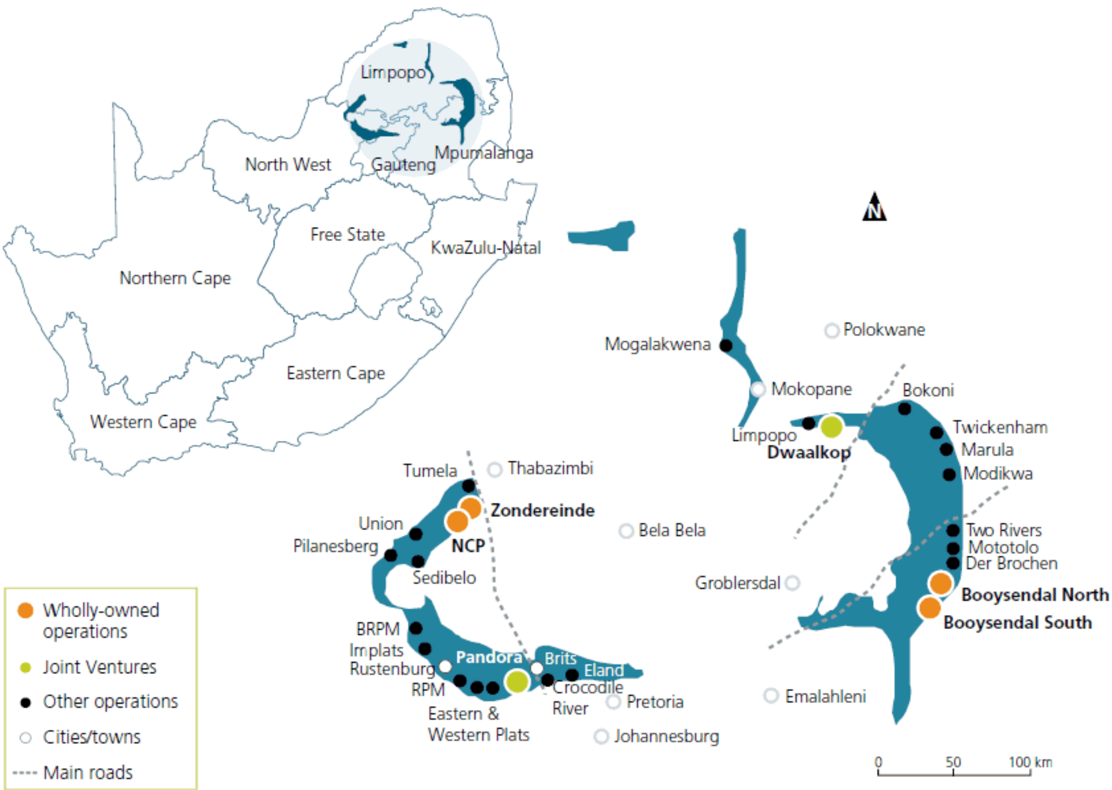

Figure 1: Booysendal mine location.

2.2. BOOYSENDAL AREAS

The Booysendal mine comprises of various operating areas, Figure 2. These are mainly divided into the BYN and BYS areas. BYS itself is then further divided into subareas:

- Booysendal Central
  - BYC Complex; surface mining infrastructure.
  - BS1; underground UG2 mining complex.
  - BS2; underground UG2 mining complex.
  - BS3; future underground UG2 mining complex.
- Booysendal Central Merensky
  - BCM1; surface mining infrastructure and underground Merensky mining complex.
  - BCM2; underground Merensky mining complex.
- Everest
  - BS4; old Everest UG2 mining complex.
- Hoogland
  - Surface ore deposit.
- BYS Concentrator Plant
  - Old Everest UG2 Platinum Concentrator plant.

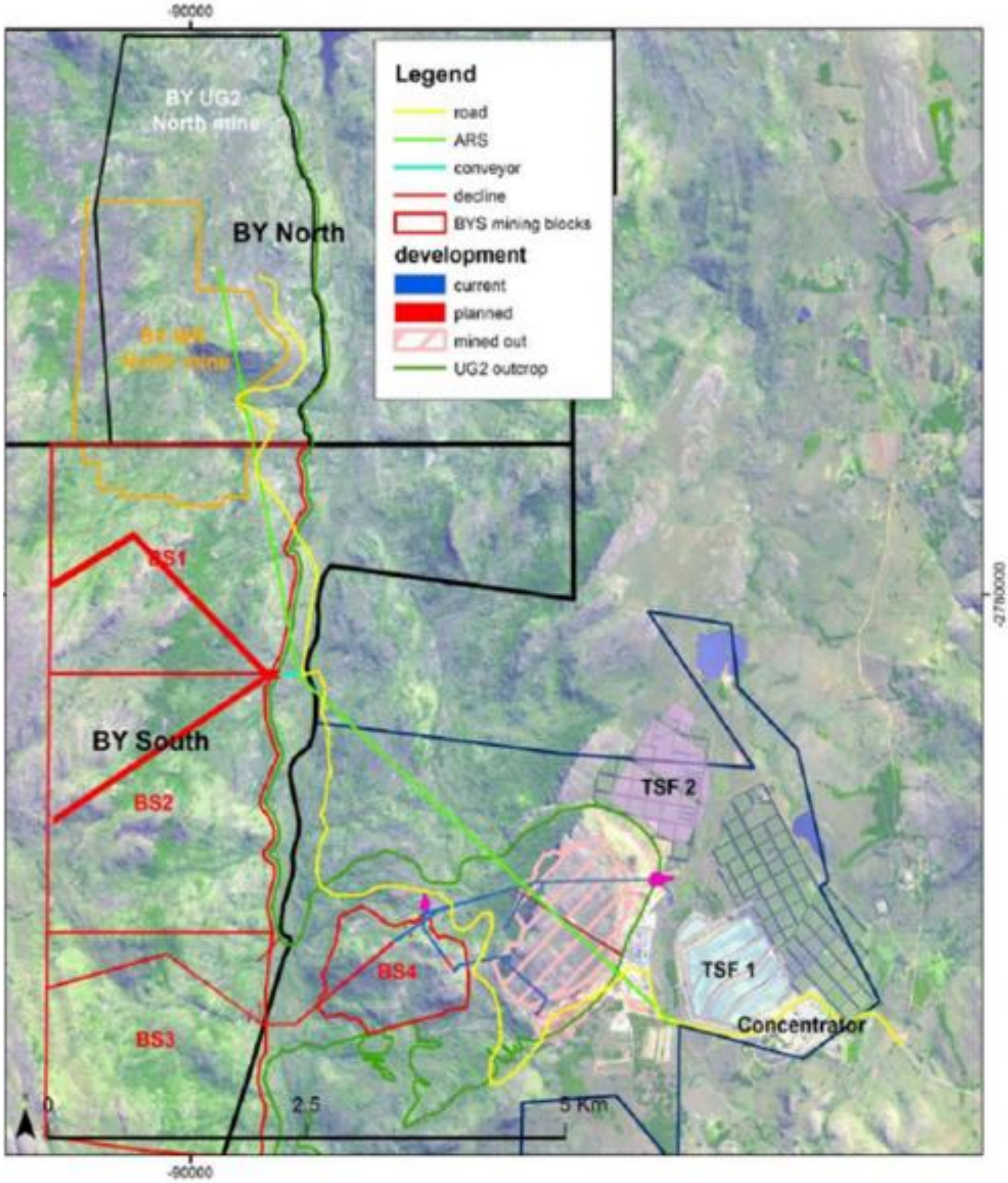

Figure 2: Booysendal areas.

2.3. NEED FOR ORE TRANSPORT

To be able to balance the available mining and concentrator plant capacities, various solutions were investigated. These included expansion of current concentrator plants, moving of ore to available concentrator plants and constructing new concentrator plants. The most feasible solution found is to transport ore to the BYS Concentrator Plant, with the main reasons being:

- Capital spend on procuring BYS property including the existing plant.
- Forecast mining capacity from BS4. This ore body is located close to the plant but not sufficient to maintain plant capacity.

- BYC terrain does not allow construction of concentrator plant, thus ore needs to be transported to a concentrator plant.
- BYN Concentrator Plant expansion life cycle cost is higher than that of transporting solutions investigated. This assumed outcomes from the BYC transport study and thereby connecting BYN with BYC.
- The BYS's current Tailing Storage Facility (TSF) has available capacity with a future dam included in the existing Environmental Impact Assessment. Whereas the BYN TSF has limited expansion capacity and will reach full capacity from the BYN life of mine.

To achieve above objectives, an ore transport system is required of 127 ktpm from BYN to BYC and 444 ktpm from BYC to BYS. The BYS RopeCon addresses the latter.

2.4. TIMELINES

The BYS RopeCon is part of the Greater Booysendal South (GBS) expansion project. The GBS concept study started in 2015 as part of Booysendal's business development plan and the feasibility study was concluded in 2016.

Upon board approval contract negotiations with Doppelmayr commenced. Total construction time for the RopeCon is 22 months of which 10 was for civil and earth works and the remainder for the mechanical installation. Figure 3 gives a summary of the project from inception until final handover.

Description	Start	Finish	2015	2016	2017	2018
Booysendal Concept Study	Mar-15	Jun-15				
Booysendal Feasibility Study	Jun-15	May-16				
RopeCon Design Phase	Sep-16	May-18				
RopeCon Fabrication	Apr-17	Jun-18				
RopeCon Civil Construction	May-17	Feb-18				
RopeCon Mechanical Construction	Jan-18	Dec-18				
RopeCon Commissioning	Oct-18	Dec-18				
RopeCon Performance Test & Handover	Dec-18	Dec-18				

Figure 3: Booysendal South RopeCon schedule summary.

The time management of the BYS RopeCon is considered a success as the project schedule was met with the successful test of completion of the RopeCon on the contractual date of 21 December 2018.

3. PROOF OF CONCEPT

3.1. CONCEPT IDENTIFICATION AND EVALUATION

To be able to make an objective selection for the most feasible ore transporting solution, various technology solutions known at that stage were evaluated. These includes:

- Underground conveying (existing development);

  The further development of the BS4 declines underneath the Groot Dwarsriver could connect the existing conveyor system with the BS1, BS2 and BS3 mining complexes.

- Tunnel boring;

  Development of a tunnel by means of a Tunnel Boring Machine (TBM). This tunnel will connect the BYS Concentrator Plant with the BS1, BS2 and BS3 and will service a dedicated conveyor.

- Haul road

  Construction of a haul road to haul ore by means of trucks. This haul road will mostly be a pass to climb the approximately 500 m.

- Conveyors

  Construction of overland conveyors is an industry norm for the most efficient long-term transport system. However, crossing the mountain, a long series of conveyors is required to zig-zag the mountain. This also requires extensive earthworks.

- Aerial Rope System (ARS)

  A cable way pulling gondola. This will connect the BYS Concentrator Plant directly with BYC.

- Milling and pumping

  Installing a series of parallel small ball mills, either on surface at BYC or in underground mined out areas at BS1 and BS2. The slurry is then to be pumped up the mountain to the concentrator plant.

- Combinations

  Various combinations of above to gain most of each solutions advantage.

A desktop costing study was used to evaluate the various solutions. Input for the costing is based on existing models and designs, layout drawings and data base costs as well as contracts in place.

An ARS was found to be 53 per cent more capital extensive than hauling (lowest capital) and 39 per cent less capital extensive than Tunnel Boring (highest). As the operational costs were found to be highly subjective, its weighting on the evaluation was purposefully limited.

Other aspects that motivated the selection of the ARS for further investigation include:

- Tried and tested engineering.
- Lower capital compared to overland conveyor system due to the longer route and extensive earthworks.
- Higher system availability compared to a series of overland conveyors.
- Lower maintenance requirements compared to a longer overland conveyor system.
- Suited for terrain (mountain and rivers).
- Possible financing solution available for development within South Africa.

- Low environmental foot print.

Other aspects identified for further investigation include:

- As the technology is not commonly used in South Africa, technical suitability and interfacing must be confirmed.
- Due to the unknown technology a premium is expected for life cycle maintenance, that will require management.
- The system may require a surface silo. The original requirement for an underground silo was due to the limited foot print area at BYC and has been eliminated.

3.2. EXISTING TECHNOLOGY / INVESTIGATIVE STUDY

Aerial transporting systems can be differentiated into two main groups:

- Aerial Rope Ways of the gondola / cable car type.
- Rope Conveyors where a conveyor belt type is suspended. Rope Conveyors are further differentiated between various supplier specific technology such as RopeCon, FlyingBelt and others.

Upon identifying an aerial transporting system as the most feasible solution for Booysendal, further investigations were conducted. These include correspondence with various equipment suppliers and site visits for similar installations. Installations visited as part of the investigative study are shown in Table 1. All installations as per Table 1, apart from the Barberton installation, are part of either Doppelmayr Transport Technologies GmbH or Leitner AG. The Barberton installation is of unknown origin and dates from 1939.

Table 1: Installations visited as part of investigative study.

Technology	Location	Material	Length	Lift	Capacity	Installed power
ARS	Barberton South Africa	Gold ore	2 630 m		30 t/hr	22 kW
ARS	Savona Italy	Coal	16 900 m	340 m	400 t/hr	8 x 160 kW
ARS	Bolzano Italy	People	4 500 m	949 m	726 p/hr	900 kW
RopeCon	Zöchling Austria	Gravel	245 m	-78 m	350 t/hr	-75 kW
RopeCon	Lenzing Austria	Wood chips	665 m	32 m	350 t/hr	53 kW
RopeCon	Tüfentobel Switzerland	Inert landfill	1 250 m	45 m	500 t/hr	136 kW
ARS	Kreuzeckbahn Germany	People	2 304 m	875 m	1 400 p/hr	2 x 430 kW

3.3. LEARNING POINTS

Knowledge gained from the investigative study as per Section 3.2 can be summarised as follows:

- **Aerial Ropeway System**
  - Transport capability over long distances.
  - Suitable up to 450 t/hr.
  - Almost vertical inclination.
  - Complex loading and unloading stations and require relatively large footprint.
  - Fixed capacity.
  - Capable of long service life.
  - Low environmental footprint.
- **RopeCon**
  - Simpler system to the ARS.
  - Smaller loading and unloading footprint required.
  - Up to 1 200 t/hr.
  - Maximum inclination equals material angle of repose. A special belt with cleats can reach steeper inclinations.
  - Lower maintenance requirements than an ARS.
  - Extremely narrow line corridor compared to the ARS' feeding and return lines.
  - More flexible system capacity.

Another important aspect from the above technology is that the major equipment suppliers are all European based. This aspect must be considered in design standards, construction methodologies and impact for exchange rates.

Both types of systems are superior to overland conveyors only when the terrain requires such solutions. In the case where no natural obstacles, environmental constraints and/or rural obstacles exist, conventional conveyors should always be evaluated.

3.4. EVALUATION

Evaluation of the technology under investigation involved a cost analysis and final selection by means of a selection matrix.

For the cost selection, capital and operating cost proposals were obtained from both suppliers listed in Section 3.2 and included an ARS and a RopeCon. The costs are based on preliminary process parameters to meet the Booysendal requirements. Table 2 summarises these costs, converted with the exchange rate valid at the time. It should be noted that due to the accuracy level of the study the RopeCon costs are given in a range.

Table 2: Aerial transporting system cost evaluation.

Description	System Type	
	ARS	RopeCon
System supplier	Leitner	Doppelmayr
Scope	Transporting UG2 ore at 400 ktpm for 5.8 km	
Capital cost estimate	R 255 million	R 275 ~ 325 million
Operational cost estimate	R 2.60 /t	R 2.20 /t ~ R 2.54 /t

The estimated life cycle cost for each technology system based on Table 2 input values is shown in Figure 4. Due to the RopeCon costs given in a range, the 'high', 'low' and 'average' are indicated. From Figure 4, it is seen that the ARS is slightly less expensive, with the cut-off point varying for the range of the RopeCon cost. This illustrates that the solution for aerial transport is unique for each project and should be evaluated for each project's specific requirements.

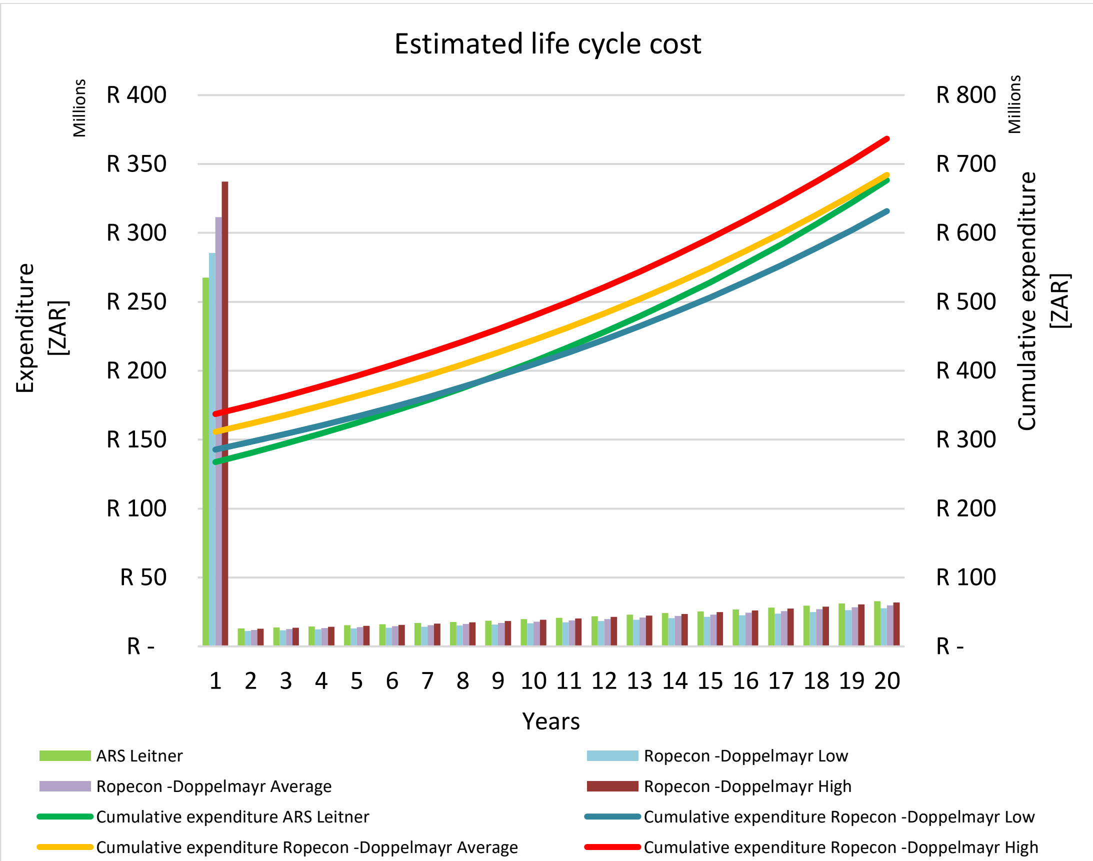

Figure 4: Estimated life cycle cost for each system evaluated.

It was felt that there are more criteria in evaluating the technologies than cost. For this reason, a panel, each member with certain expertise, was called to evaluate various aspects. A selection matrix lists all aspects identified and each is scored. The summary of the selection matrix is summarised in Table 3. Final scores are determined by applying weighting factors with higher scores being better.

Table 3: Summary of final selection matrix.

Category	**System score**	
System Type	ARS	RopeCon
System supplier	Leitner, Doppelmayr	Doppelmayr
Technical	26	46
Costing	23	21
Maintenance requirements	11	24
SHER	14	16
Construction	8	9
Total score	**82**	**116**

Due to the simpler technology of the RopeCon it scored higher in the 'Technical' and 'Construction' areas. Reducing the requirement for maintenance and personnel on the line in an elevated position also gained favour for the RopeCon in 'Maintenance' and 'SHE'. The latter being an important factor due to the fact the uncertainty existed in complying with the Mine Health and Safety Act. As the ARS has a slightly lower life cycle cost it scored higher in 'Cost'.

It should be noted that the original scope for the investigation did not include rope conveyors such as the RopeCon. This technology was only introduced during the site visits as per Table 1. Following this the FlyingBelt was introduced by means of a presentation only. Therefore, the panel could not effectively evaluate the FlyingBelt. However, it was considered and the following noted:

- The utilisation of standard conveyor components indicates a possible capital cost reduction and reduces maintenance complexity. This is also supported in that the FlyingBelt only utilises 4 ropes whereas the RopeCon requires six ropes.
- The above also indicates maintenance requirements similar to conventional conveyors. This maintenance is carried out from an inspection carrier in an elevated position. Due to the unknown factor of system compliance to the MHSA, a risk reduction approach was followed by the panel. Therefore, placing maintenance personnel in an elevated work position, made the FlyingBelt an unfeasible option for Booysendal.
- The Flying Belt has an inherent advantage in that changing from 'flying' to conventional conveyor stringers is simple and do not require any transfers

and/or chutes. The cost advance of overland conveyors can thus be utilised where the terrain allows such.

Based on the above the RopeCon is selected as the most feasible solution to transport ore from BYC to BYS Concentrator Plant.

4. ROPECON DESCRIPTION

4.1. TECHNOLOGY DESCRIPTION

4.1.1. Line structure (Khodadadi, 2018)

As opposed to a conventional conveyor's stringers, gantries and trestles, the RopeCon's line structure is mainly made up of six fully locked steel wire track ropes. Track rope frames are mounted at regular intervals to keep the six ropes in alignment while distributing the forces acting on each rope.

The track ropes are anchored at both ends and tensioned to ensure the desired catenary is obtained throughout. Anchoring is via a separate concrete block or integrated into the end station concrete.

To maintain clearance between the track ropes and the ground, towers are installed underneath the track ropes to guide it over the terrain. Tower types and height are dependent on the terrain and are mainly:

- Tubular shaft A-frame towers. These could be symmetrical or a-symmetrical depending on the terrain.
- Track rope anchoring towers.
- Lattice type towers.

Apart from track rope anchoring towers, towers are hinged at the bottom to allow for movements in the line.

Figure 5: Typical RopeCon line structure; (1)Track ropes, (2)Tower and (3)Track Rope Anchor (Khodadadi, 2018).

4.1.2. Conveyor belt (Khodadadi, 2018)

Material is transported on a continuous cross-reinforced flat belt with corrugated side walls. Depending on project specific requirements, a textile belt or a steel cord belt is used. Corrugated side wall height is determined by the material properties. Generally, the RopeCon can achieve higher inclinations than a conventional conveyor due to the elimination of idlers, but for inclinations higher than the angle of repose, cleats can also be installed on the belt.

The conveyor belt is driven by a drive drum at one end. To maintain the required belt tensions, the drive station is either located at the tail or head end of the RopeCon. Generally, for RopeCon configurations feeding uphill, this will be at the head end, and RopeCon's feeding downhill, this will be at the tail end. Even though it is possible to have two drive pulleys, only one is preferred due to the belt configuration. If required, the pulley is driven by two input shafts with independent drives. The drive system is equipped with two independent mechanical braking systems.

The conveyor belt is tensioned via the tail pulley by means of the hydraulic tensioning equipment. After the tensioning, the tail pulley is clamped onto the track ropes and only released should re-tensioning be required. The RopeCon thus has no active tensioning.

Material from the RopeCon can be discharged onto a stockpile, silo, another RopeCon or conveyor. Project specific chute design is thus required. After unloading of the RopeCon, the belt is turned by 180°. This prevents spillage along the RopeCon track. Before reaching the loading end the belt is turned once more.

Figure 6: Typical RopeCon conveyor belt; (1)Drive pulley, (2)flat belt with corrugated side walls, (3)belt turning and (4)tail or return pulley (Khodadadi, 2018).

Belt guidance (Khodadadi, 2018)

The RopeCon's belt is attached to axles arranged at regular intervals supporting the belt. Polyamide wheels are fitted to each end of the axles. These wheels travel on the track ropes, thereby guiding the conveyor belt. The wheels of the top feed belt travel on the central pair of track ropes and the wheels of the bottom return belt travel on the bottom pair of track ropes. The uppermost track ropes provide additional stability and forms the track for the inspection vehicle if applicable.

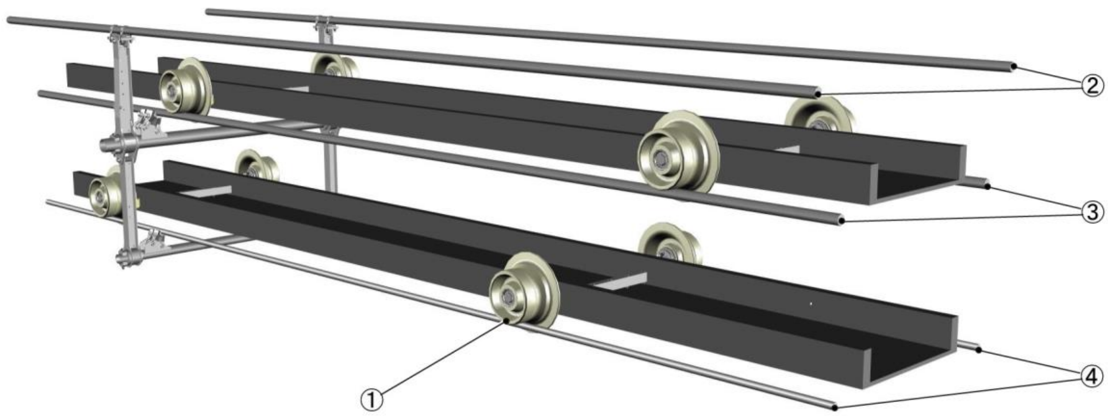

Figure 7: Typical RopeCon belt track; (1)wheel set, (2)upper track ropes, (3)central track ropes and (4)bottom track ropes (Khodadadi, 2018).

4.2. TENSIONING

As opposed to conventional conveyors' dynamic tensioning devices, the RopeCon's belt tension is fixed. This is because the ropes supporting the belt and the belt itself both have the same flexibility in movement. Therefore, both moves in relation to each other with changes in the system due to loading of the belt, temperature variations and other factors that will act on the system.

The RopeCon design complies with DIN 22101:2001-12 which stipulates the required design safety factor. This safety factor is determined from a set of criteria instead of simply recommending a fixed value. For this reason, the safety factor applied to RopeCon design differs from that usually applied to conventional conveyor designs. The primary difference that allows a lower safety factor is that the belt stays flat throughout. In a troughed belt the edges experience increased tensions in the transitions and vertical curves.

The requirement for active tensioning with a take-up/counterweight system as with a conventional conveyor is addressed by pre-tensioning the belt. With the tail pulley clamped to the track ropes, the belt and belt support (track ropes and towers) can then move in unison. It should be noted that the RopeCon belt support moves as opposed to the fixed structure of a conventional conveyor, therefore movement resulting from forces such as an aborted start is absorbed within the RopeCon system. In addition to this, shock loads on the belt from the drive pulley are minimised by controlled start-up and speed-up of the RopeCon with a variable speed drive (VSD).

4.3. MAINTENANCE

Due to the elimination of idlers, the RopeCon does not have any moving parts on the track line apart from the wheels. As these wheels can be maintained when they reach the two end stations, all major maintenance requirements are reduced on the line.

However, the requirement to inspect the track ropes and conduct minor maintenance on instrumentation requires access to tower heads and track ropes and frames. An Inspection Carrier, Figure 8, travels along the RopeCon for this purpose. The Inspection Carrier runs on top of the two track ropes and is push-pulled by a dedicated rope. The relevant European Standards (EN) for aerial people transporting systems are used in designing the Inspection Carrier.

Figure 8: The BYS RopeCon Inspection Carrier with cages for personnel on both side of the RopeCon.

Rope maintenance includes periodic checks as per the rope fabricator's recommendation (Fatzer AG Wire Ropes, 2018). Apart from this any Electromagnetic Testing (EMT) and/or X-ray testing is impractical due to the proximity and amount of structural steel around the track ropes.

The oldest RopeCon inspected at Zöchling, Switzerland is more than 20 years old and has had no belt or rope failure and/or maintenance. The likelihood of this risk occurrence is noted as low and the fabricator, Fatzer AG, periodic checks are thus seen as sufficient maintenance at this stage.

5. PROJECT DETAIL

5.1. PROCESS PARAMETERS

The BYS RopeCon's contractual process parameters are specified as follows:

- Route : BYC Coarse Ore Silo to BYS Concentrator Plant Feed Conveyor (4.7km)
- Material type : UG2 ore

- Material size distribution : -150 mm
- Bulk density : 1.8 t/m^3 to 2.4 t/m^3
- Angle of repose : Static 37°
  : Dynamic 18° (surcharge)
- Moisture by weight : 3 % – 10 %
- Abrasiveness : High
- Adhesiveness : Medium to high
- Capacity : 500 kt/month

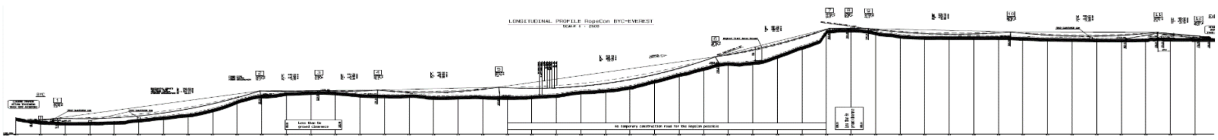

Figure 9: BYS RopeCon profile drawing.

5.2. LOADING STATION

The BYS RopeCon is loaded directly from the BYC Coarse Ore Silo. Similar to a conventional conveyor loading from a silo, two draw points load the RopeCon by means of VSD controlled vibrating feeders. The anchoring of the track ropes is directly behind the silo with the belt turning through the silo opening underneath the loading points.

To minimise spillage at the loading, a small conveyor is installed underneath the belt turning device. With the belt turning, any ore stuck to the belt is likely to dislodge and fall onto the spillage belt. The spillage belt discharges onto a vertical spillage conveyor with cleats to lift the spillage. As the vertical spillage conveyor circles the main RopeCon belt, a knocking device ensures the spillage is dropped onto the main RopeCon belt, Figure 10.

Figure 10: Vertical spillage conveyor circling the RopeCon after the loading points.

A simulation study determined the silo capacity to be 4 200 t, allowing for future expansion and additional surge. As this is not practical in terms of an underground silo, the silo was relocated to surface. Furthermore, the combined forces from the silo and anchoring of the RopeCon dictate that the silo must be footed on bed rock. This means that the silo terrace is lower than the BYC terrace that is engineered in a cut-fill arrangement due to the location on the side of the mountain.

Due to the limited available foot print the main access road runs between the silo and Tower 1. To maintain the 11 m clearance as per specification, the RopeCon must be loaded at an angle. This results in a bottom opening of the silo of 13 m with the total silo height being 33 m.

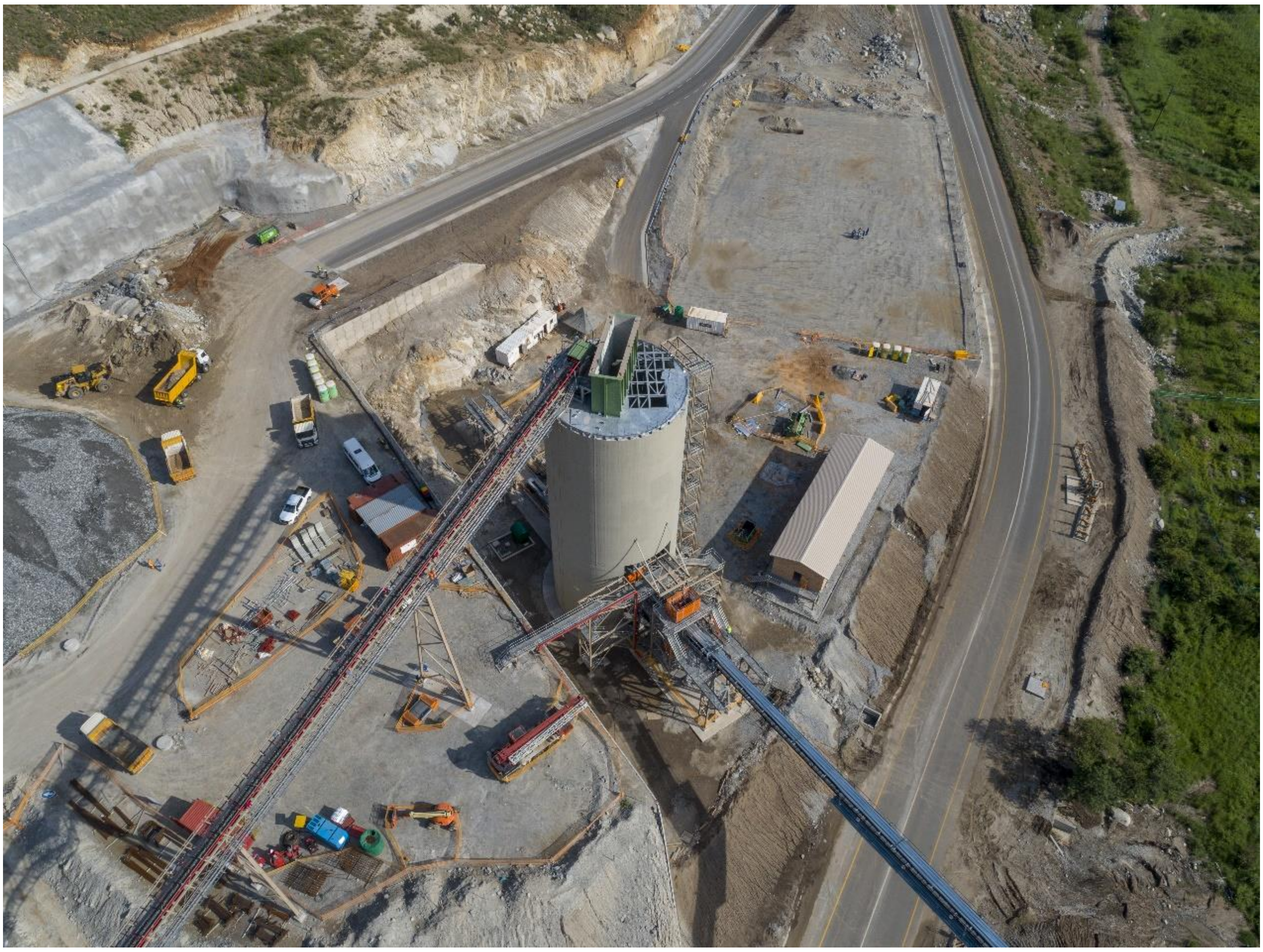

Figure 11: BYC coarse ore silo with the silo feed conveyor coming from the bottom left and the RopeCon leaving to the bottom right. Note the chute on top of the silo for the future BYN RopeCon.

5.3. TOWERS

The BYS RopeCon consists of twelve towers of which ten are symmetrical A-frame towers and two track rope anchoring points. All A-frame towers are hinged just above the civil base to allow movement of the RopeCon during all load cases. Towers 3 and 8 serve as track rope anchors.

Figure 12: Tower 5, a typical A-frame tower.

Construction of A-frame towers requires each leg to be independently assembled and lifted into place. Stay ropes anchored into concrete anchor blocks, hold each leg up at the required angle. With both tower legs up, the tower head is lifted into place and fixed to the tower legs. Once the tower head is clamped to all six track ropes, the stay ropes can be removed and the tower is held upright by the track ropes.

Figure 13: Tower 8, a typical track rope anchor.

Tower 5 is the highest tower at 59 m and the longest span between towers, 878 m, is between Towers 5 and 6. Due to the terrain, the highest point that the RopeCon is from ground level, is 90 m between Tower 6 and 7.

5.4. TRACK LINE EQUIPMENT

Track line equipment consists mainly of the six track ropes, track rope frames and the belt.

The six track ropes maximum rope force is 6 000 kN. Each rope is supplied at the required length plus cut-off as the fully locked ropes cannot be spliced. The installed length of each rope is 4 910 m. Track rope diameters is as follows:

- Two off 52 mm.
- Two off 47 mm.
- Two off 37 mm.

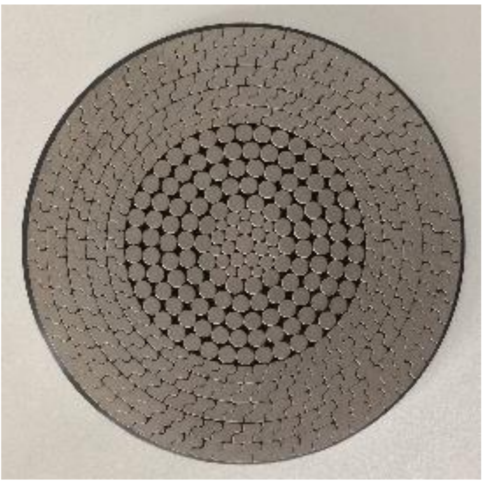

Figure 14: Fully locked steel wire track rope cross section.

To install all track line equipment, the drive and endless steel rope of the inspection carrier was utilised as a winching system, Figure 15. The endless rope connected the main drive station and the loading station with the inspection carrier drive at the main drive station and a return sheave at the loading station.

Figure 15: Inspection Carrier drive used as winch to install track rope line equipment.

Installing the endless rope required a helicopter pulling a specialised nylon rope from the loading station to Tower 7, Figure 16. The steel rope was pulled by hand from the unloading station to Tower 7 and connected to the nylon rope. The steel rope was then winched down to the loading station. This was repeated for the other end of the steel rope whereupon the two ends were spliced at the loading station creating an endless loop.

Figure 16: Helicopter pulling nylon rope up to Tower 7.

With the winch system installed progressively larger steel ropes could be winched in. The track ropes were finally connected to these steel ropes. However, the force required to pull the track ropes is too high for the winches and a specialised rope pulling device is utilised. This rope pulling device shown in Figure 17, pulls the steel rope by a push-pull action. A hydraulic system exerts the required force to pull the track ropes.

Figure 17: Specialised rope push-pull equipment used to pull the track ropes.

To keep the track ropes in position the BYS RopeCon has a total of 315 track rope frames as shown in Figure 18. The average spacing of track rope frames is 15 m.

Figure 18: Installed track rope frame.

The BYS RopeCon belt has the following characteristics:

- Class : ST 5100 10T/7T-Y
- Width : 800 mm
- Sidewall height : 160 mm
- Cleat height : 140 mm and 55 mm
- Belt length : 9 800 m

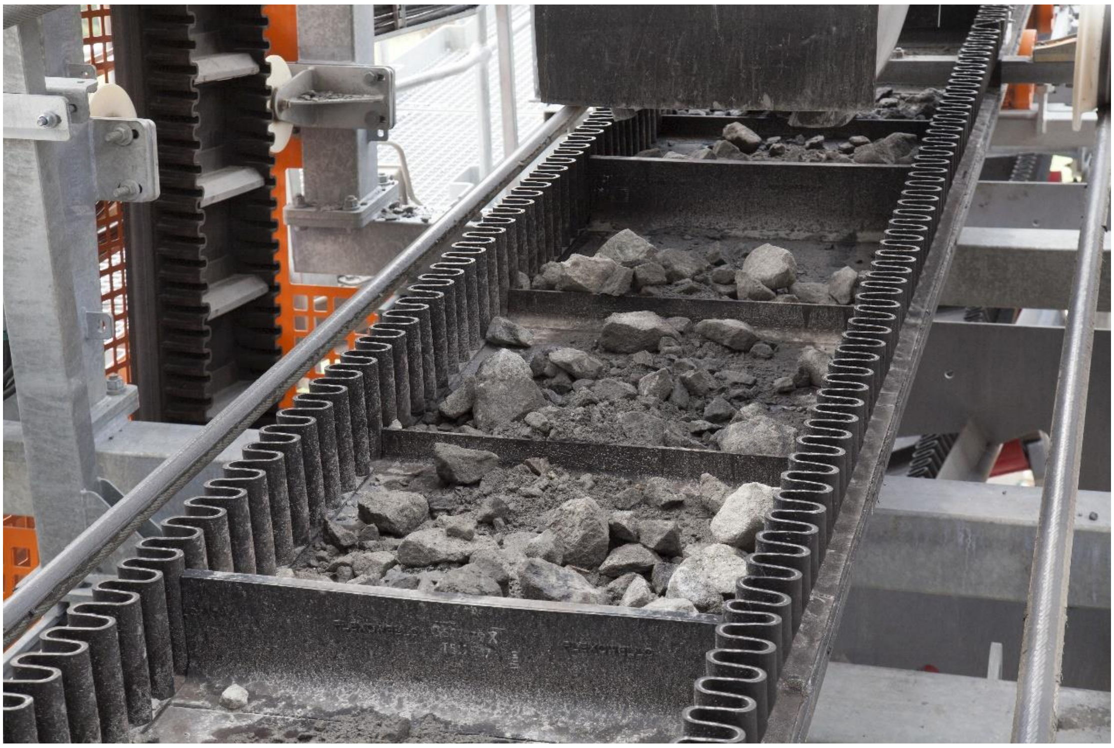

Figure 19: BYS RopeCon belt.

Installation of the belt required an engineered solution. This is due to the belt being packed and transported in 22 individual belt racks as the belt with side walls and cleats cannot be rolled. Furthermore, the installation schedule required that all belt racks' belts be spliced together before belt pulling commenced.

The inherent requirement for the RopeCon meant that the terrain is not sufficiently flat to access and place the belt racks with mobile cranes. 'This area must be on the low side of the profile to pull the belt in a controlled manner up, as opposed to placing the belt on the high side and then prevent the belt running downhill whilst installing. Excessive earthworks would be required to create a terrace and thus further negates the advantage of the RopeCon by increasing the impact on the environment.

To meet the constraints, belts were placed on the main access road at BYC. As this road was at an incline, mobile cranes could not establish on the road and level out. Specialised Omrigs were thus used in tandem to pick-up and transport each belt rack into position.

As the road was not in the centreline of the RopeCon, two belt deflection devices were designed as shown in Figure 20. These devices utilised a set of belt pulleys to turn the belt from horizontal to vertical, change the belt direction and turn it back to horizontal. Civil bases anchored the deflection devices.

Figure 20: Belt deflection device installed.

Figure 21: Belt racks placed in the road with belt deflection devices indicated in red.

The design of the belt splices followed EN ISO 15236-4 for steel cord conveyor belts. The calculations of the belt splices include: cord stress, rubber shear stress for the various layouts and investigated number of steps to ensure competent splice. Finite element analysis was conducted at 50 per cent and 22.5 per cent of nominal breaking force of overall belt.

Figure 22: Splicing station set up between belt racks.

5.5. UNLOADING AND DRIVE STATION

As the unloading station of the RopeCon is the highest point, it is also the drive station. The RopeCon has one drive pulley of 2 330 mm with two drives mounted on either side of the pulley. The total power requirements are:

- Start-up : 3 300 kW
- Operation : 2 400 kW
- Braking : 1 600 kW

Figure 23: RopeCon unloading and drive station feeding unto the existing conveyor infrastructure.

The discharge of the RopeCon, Figure 23, is through a trolley chute on either the existing BYS Concentrator Plant feed conveyors or the Stock Pile Feeder. The Stock Pile Feeder is a short RopeCon with no belt turning and only one tower. This tower is integrated with Tower 11. The head pulley of the Stock Pile Feeder is suspended in an aerial position and clamped to the ropes as seen in Figure 24. This results in the discharge being above the existing stockpile.

Figure 24: Tower 11 (a) and (b) with the Stock Pile Feeder head pulley suspended above the stock pile.

To manage spillage, a horizontal spillage conveyor is located underneath the belt turning which in turn discharges onto the Stock Pile Feeder.

5.6. CIVIL CONSTRUCTION

Contractual battery limit for the RopeCon was in all cases top of concrete. Load cases and civil outline drawings define the civil design and interfacing. Civil work had to meet SANS 1200 Tolerance Accuracy Type II. This required extensive surveying for the various cast-in items. Civil construction quantities are summarised in Table 4. It is to be noted that the drive station plinth is cast in one continuous pour. This plinth constitutes about 10% of the total drive station concrete quantity.

Table 4: Summary of civil construction quantities.

Area	Concrete	Re-bar
Silo and loading station	1 936 m^3	65 t
Towers	2 827 m^3	236 t
Drive and unloading station	1 323 m^3	162 t

Figure 25: Intricate drive station civils cast in one continuous pour.

5.7. BULK MATERIALS HANDLING SIMULATION AND DESIGN

The contractual battery limit of the chutes is within Doppelmayr's scope as these connected directly on to the RopeCon. To ensure effective interfacing and sound Bulk Materials Handling (BMH) designs an iterative design process was followed for the chutes on the RopeCon.

Interfaces that had to be checked were from the vibrating feeders into the RopeCon loading chutes and from the discharge chute onto the existing BYS Concentrator Plant feed conveyor. Each iteration resulted in the final design being more accurate and the time spent during design proved valuable during construction.

As BMH design for chutes falls outside the expertise of Doppelmayr, layouts for all chutes was issued to DRA. These layouts were used to build EDEM models for the various flow conditions of the ore. Based on the simulation results, functional designs were updated to restart the iteration. The integrate trolley chute at the unloading station is identified as the highest risk and various simulations were run, see Figure 26.

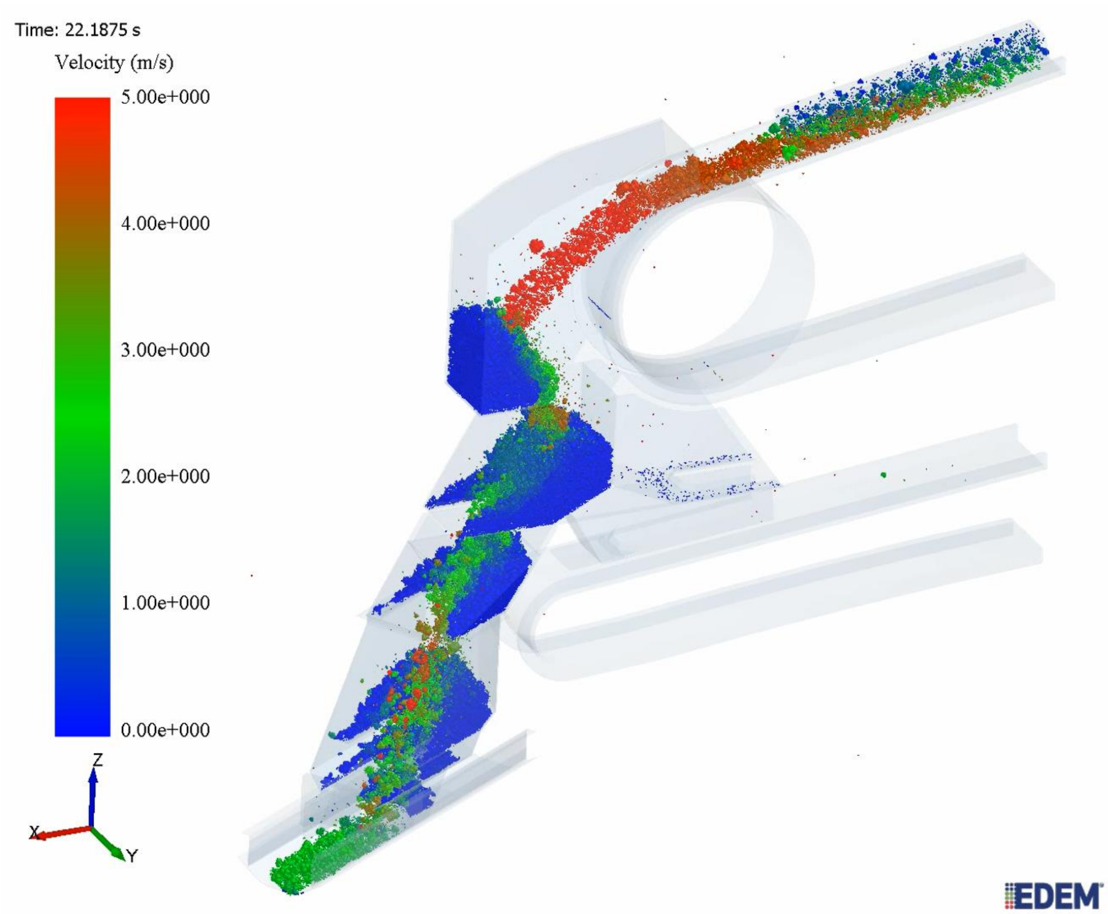

Figure 26: Snap shot of discharge chute BMH simulation (Burger, 2017).

5.8. BELT TESTS

With the exclusion of idlers, Section 4.1.2, it is claimed that the RopeCon can achieve higher incline angles than conventional conveyors. This is because no external equipment such as idlers exert a force on the belt and thereby agitating the material. Therefore, no movement of the material on the belt results in a stable load and increased belt inclination. This was identified as an unproved factor, especially for UG2 ore and contained some project risk as the maximum BYS RopeCon inclination is 30°. Therefore, belt tests were set up to measure the effect.

Two independent tests were conducted; a standard material laboratory test and a RopeCon test bed. Both test facilities were issued with actual UG2 samples from Booysendal. These samples were taken after the BYN primary crusher delivering -150 mm.

The RopeCon test bed, Figure 27, was operated by Doppelmayr and consisted of a piece of belt with the same dimensional parameters as the BYS RopeCon. Tests were conducted for various load cases:

- Belt loading up to 1 150t/hr
- Moisture content 67 % - 80 %

Results from the RopeCon test bed found the material to be stable up to the tested inclination of 40° (Erber, et al., 2016). These results are supported by the laboratory results (Roos, 2016).

Figure 27: RopeCon test bed (Erber, et al., 2016).

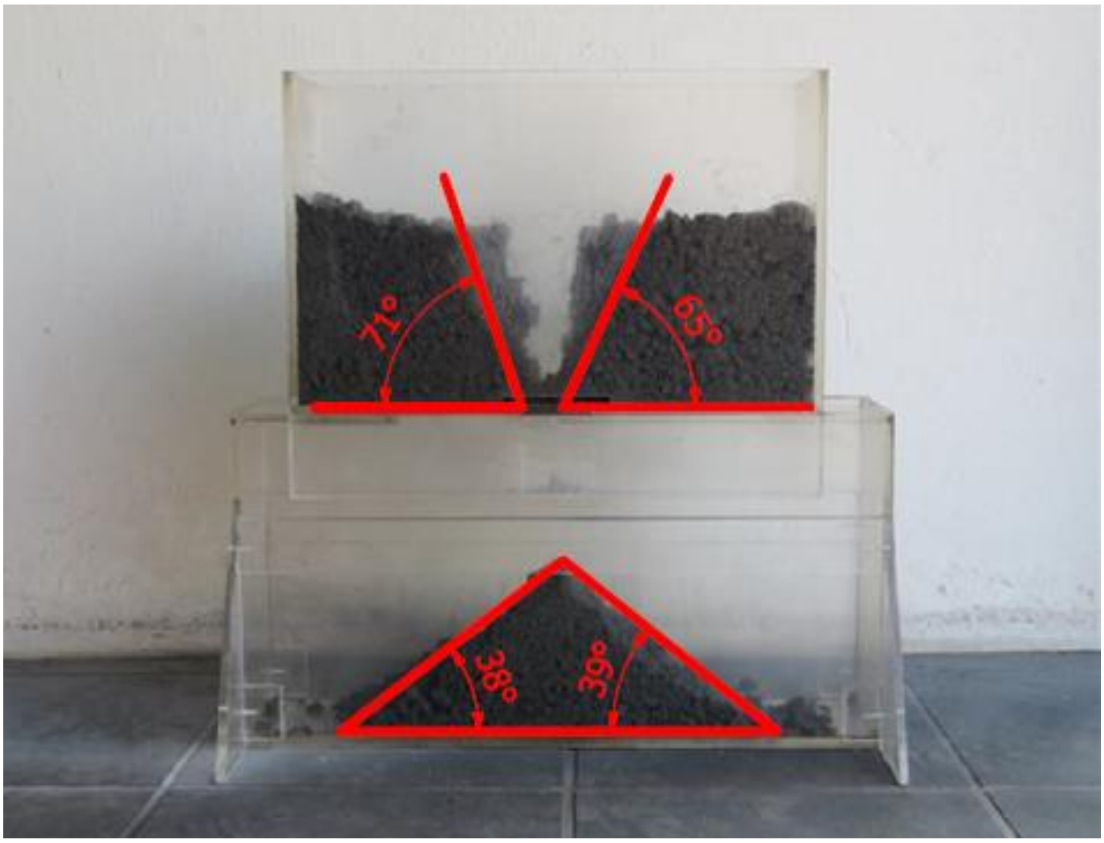

Figure 28: Laboratory test results on actual Booysendal UG2 sample (Roos, 2016).

Slow motion video footage of the material on the BYS RopeCon during commissioning showed limited movement of material. This movement is only seen when the belt crosses over the tower head and thereby confirming the above.

5.9. REGULATORY BODIES

The BYS RopeCon design complies to relevant South African regulations including the MHSA and the Civil Aviation Authority (CAA).

As European machinery regulations vary from that of South Africa, various design modifications have been implemented. These include machine guards and cat ladders among others. Cat ladders require landings, loops and lockable access that require modifications to the standard Doppelmayr tower design, Figure 29.

The RopeCon also falls within the requirements for CAA approval. Design recommendations for tower aviation lighting is included.

Figure 29: MHSA compliant cat ladders.

5.10. SAFETY SYSTEMS

The BYS RopeCon is installed with standard RopeCon safety and control systems to ensure the system operates efficiently within design parameters, such as belt slip devices, derailment sensor etc.

However, the RopeCon is considered a conveyor and therefore typical conveyor safety systems are included in the installation.

These include:

- Sirens for the start-up of the RopeCon including rotation red lights.
- Pull wires and emergency stop bottoms ('E-stops') in areas where the belt and/or track wheels are accessible.
- Machine guarding at any possible pinch point.
- Where the RopeCon crosses a road or pedestrian walkway, covering is added to protect from any possible falling object, Figure 30.
- Fire detection and protection system are similar to all other Booysendal underground conveyors at the loading and unloading stations.

Figure 30: Covering underneath the RopeCon where it crosses a road.

5.11. LOGISTICS

Most of the BYS RopeCon material is imported from Austria and Switzerland. The RopeCon is fabricated in Doppelmayr facilities, not only to protect the design but also to control fabrication quality in-house. This results in a large logistical portion of the project. The total logistical complement includes for 138 shipping containers, 22 specialised belt racks and six rope reels. The latter were transported via abnormal trucks and trailers, Figure 31.

Of the above containers, 36 contained professional tools. These tool containers were imported and returned as Carnet shipments.

Figure 31: Three of the six rope reels being delivered to Booysendal.

5.12. COMMISSIONING

Cold and hot commissioning commenced with the successful construction completion of the RopeCon. Various load cases, operating speeds and all safety systems were tested during these phases.

Hot commissioning was concluded with the test on completion during which the following is achieved:

- Test time of 24 hours and 17 minutes.
- Total capacity transported during test: 22 160t.

6. EVALUATION

To evaluate the engineering accuracy of the BYS RopeCon, the design power requirement can be compared to the actual power drawn during commissioning and testing. Table 5 summarises the design vs. actual power consumption. The actual power consumption of the RopeCon at the contractual operating capacity, 909 t/hr, is within the design range. For all other conditions the actual power is less than the design power consumption.

Table 5: Summary of BYS RopeCon design vs. actual power requirements.

Operating condition	Operating capacity	Power consumption		
		Design	Operating	Variance
Operating	0 t/hr	540 kW	380 kW	-29%
Acceleration	0 t/hr	1 080 kW	780 kW	-27%
Operating	900 t/hr	2 050 kW	2 060 kW	0.5%
Acceleration	900 t/hr	2 720 kW	2 400 kW	-11%

7. LESSONS LEARNED

Some notable lessons learned during the BYS RopeCon project include:

- The complex interfacing between the BYC silo and the RopeCon required extensive design time. This was a requirement, as the terrain does not allow a feed conveyor to the RopeCon. However, where possible this interfacing must be de-coupled by installing a short feed conveyor.
- The extensive design time spent on interfacing checks paid dividends as minimum interface problems were experienced during construction. This ensured effective construction time spent, especially where European rates are applicable.
- Contract negotiations and clear scope definition required various meetings and months of work. This assisted in that all parties clearly understood the

project requirements and timeous evaluation was possible where site conditions required decision making.

- Due to Doppelmayr not having South African exposure, service contracts such as crane hire were excluded from the installation contract. This required additional time spent managing interfaces during construction as day-to-day activities were managed by the Doppelmayr's installation crew, but the contract by DRA.
- Involving logistics from an early study phase until the final delivery was a key factor in ensuring material arrived in time on site and all external aspects and/or stakeholders were managed efficiently.

7. NEXT PHASE

To achieve the 127 ktpm ore transport from BYN to BYC, Section 2.3, a second RopeCon project is underway. The BYN RopeCon will have the following process parameters:

- Material : Merensky Coarse Ore
- Maximum Lump Size : -150 mm
- Capacity
  - Nominal : 320 t/hr
  - Peak : 400 t/hr
- Length: : 2 752 m
- Lift: : -160 m Power regeneration

Figure 32: BYN RopeCon profile.

8. CONCLUSION

The RopeCon is selected as the best solution for Booysendal due to the terrain and minimum environmental impact. The life cycle cost is off set to other more conventional transporting solutions due to the rough terrain.

The BYS RopeCon project is unique in the fact that it addressed a problem in a complete engineering design. This is achieved by evaluating various concepts, selecting the most suitable concept and developing the concept into a design. The design takes all relevant standards and regulations into account and resulted in a product meeting the original Client requirements. A large aspect that resulted in delivering a successful product within the contractual schedule, is the role that each of the various stakeholders performed. This required continuous aligning via meetings and constant communication.

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