SELATI TAILINGS DAM DECANT FAILURE AND REMEDIAL ACTIONS

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ABSTRACT

On 27th February 2014 solids were noted to be discharging into the Return Water Dam below the Selati Tailings Dam at Foskor in Phalaborwa, indicating a decant failure. All parties involved reacted quickly to curb the discharge of solids and minimize the risk of catastrophic failure of the facility. Within days, a temporary filter was constructed on the outlet, followed by the design and construction of a medium term filter, while a solution is being sought for the permanent sealing of the decant outlet.

1. INTRODUCTION

1.1 Company background

Foskor (Pty) Ltd is a company whose primary focus is the production and marketing of Phosphoric acid and related products, consisting of two divisions situated in Phalaborwa and Richards Bay respectively. Phosphate rock is supplied by Foskor Phalaborwa to Foskor Richards Bay, where Phosphoric Acid and granulated fertilizer is manufactured.

The Phalaborwa division consists of Mining, Communition & Beneficiation, and Tailings management, and the Richards Bay division is divided into Phosphoric Acid, Sulphuric Acid and Granulation production. The Phalaborwa Operation produces approximately 2.1 million tons of phosphate annually. As part of the mining process, approximately 45,000 tons of mine residue need to be disposed daily on mine residue facilities.

The Phalaborwa operations are currently using the Selati and Southern Tailings dams for this purpose. The Selati Tailings Dam (Selati TD) covers approximately 1,110 hectares and the Southern dam (Southern TD) covers about 244 hectares.

Tailings are mainly deposited on the Selati tailings dam with the Southern dam serving as a bypass capacity in case problems are experienced at the Selati Transfer pump station.

Tailings are deposited via 1 m diameter cyclones which are fed from the Tailings Transfer Pump Station by way of 5 feed lines installed to distribute tailings material around the facility.

1.2 Selati Tailings Dam

The Selati TD is located in the south western area of the Foskor industrial complex in Phalaborwa, and south of the Selati River as presented in Figure 1. It functions as the current tailings disposal facility for the mining operations. The Southern TD, located north of the Selati River, was the main disposal facility until about 1987 when the Selati TD was commissioned.

Deposition on the Selati TD has used 1 m diameter cyclones from first commissioning. These are moved around the wall crest on skids to build up the walls in 7 m high lifts. During 2006, deposition over a significant length of the wall was converted to spigoting to improve dust control. In a further effort to control dust, the facility was divided into discreet paddocks in 2008 by cycloning divider walls onto the beach. This strategy was abandoned in 2011 and deposition reverted back to cyclone deposition. The supernatant pond stores approximately 15 Mm^3 of water.

Figure 1 Site Layout

In the early days of operation of the Selati TD, decanting took place via temporary gravity penstocks in the north and east of the facility. The main decant conduit was installed around 1990. This conduit mainly comprises an 864 mm diameter Armco void former encased in reinforced concrete.

It is not general practice to provide a downstream emergency shut-off valve system to stop the decanting of material from the dam in case of a failure.

A layout and schematic sections of the decant system are shown in Figures 2 to 5 below.

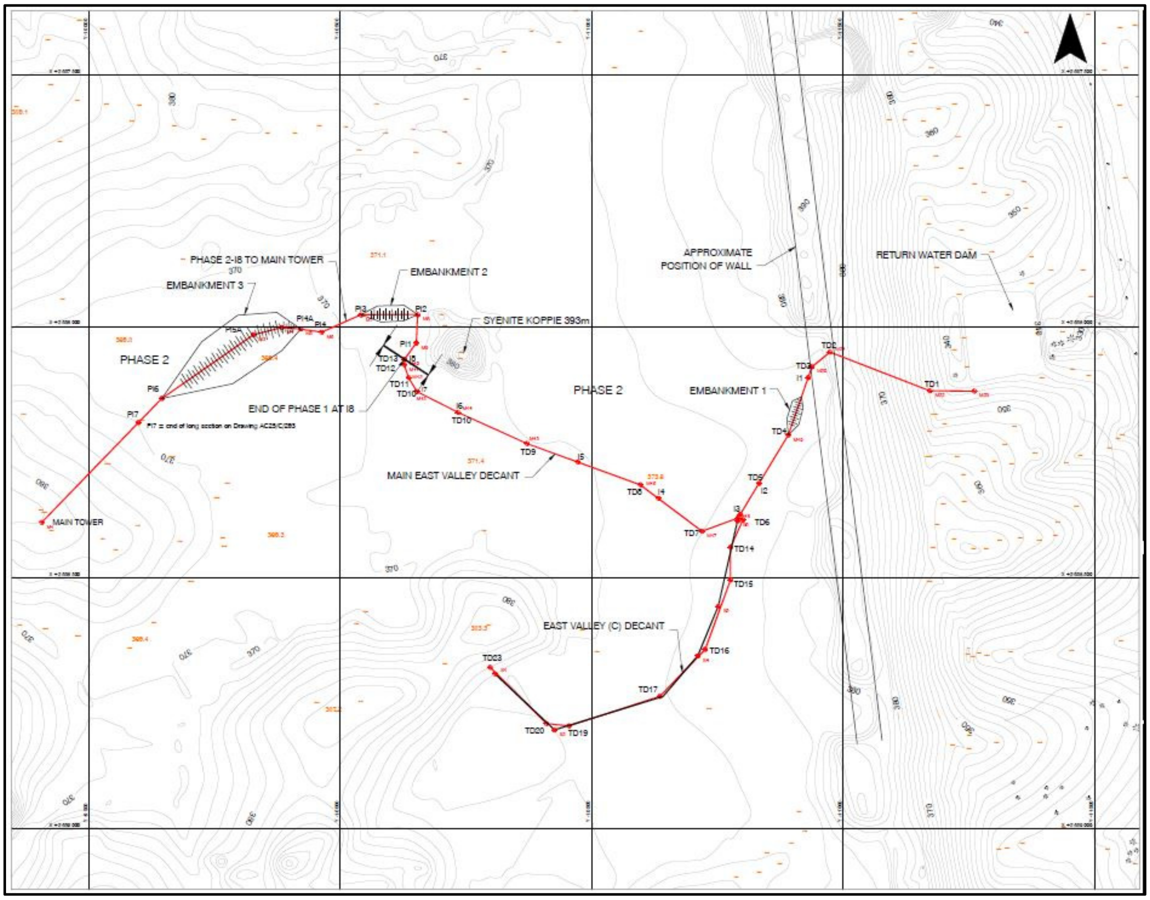

Figure 2 Selati Tailings Dam - Decant system layout

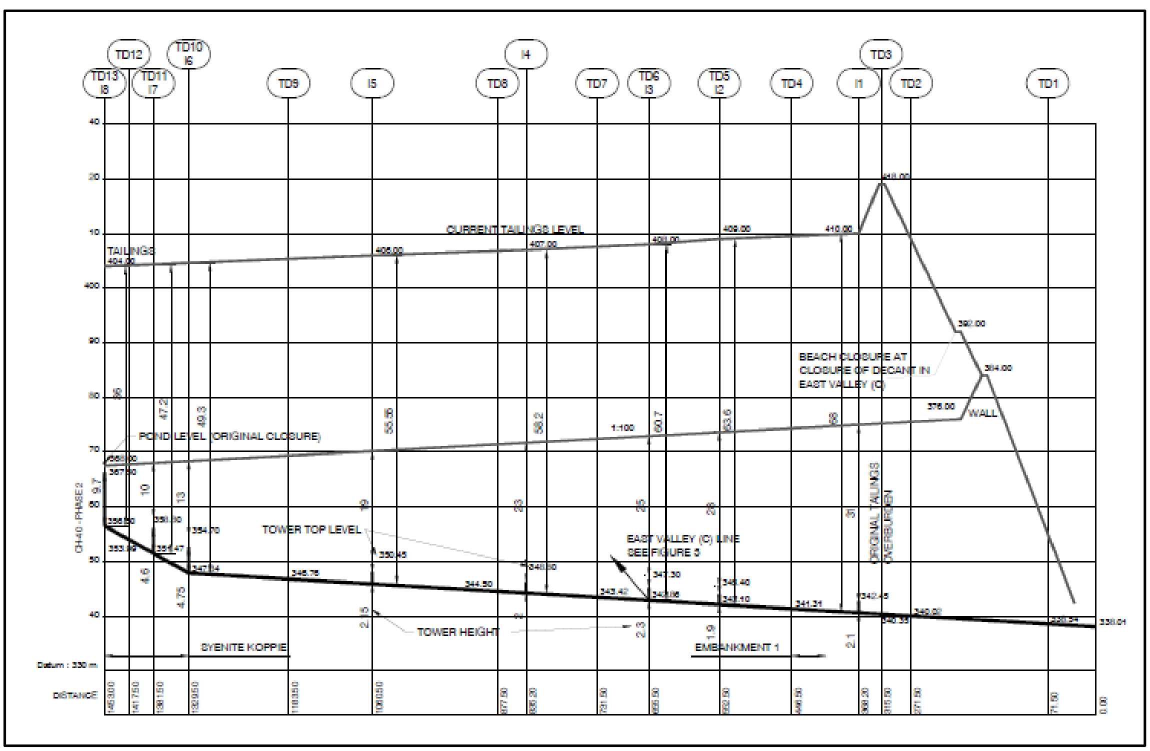

Figure 3 Phase 1: Main East valley decant-long section

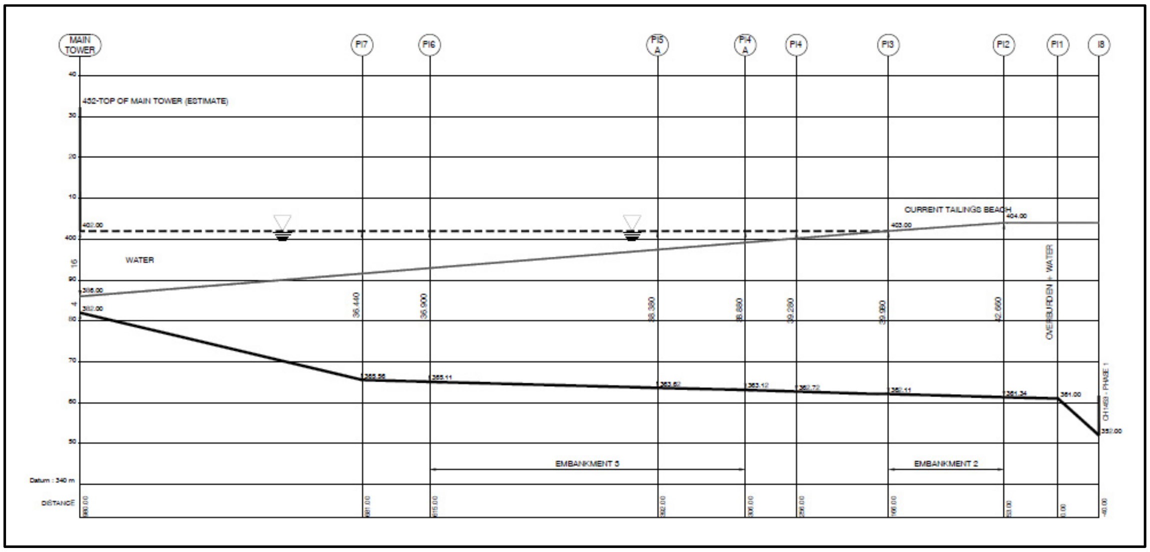

Figure 4 Phase 2: Main East valley decant-long section

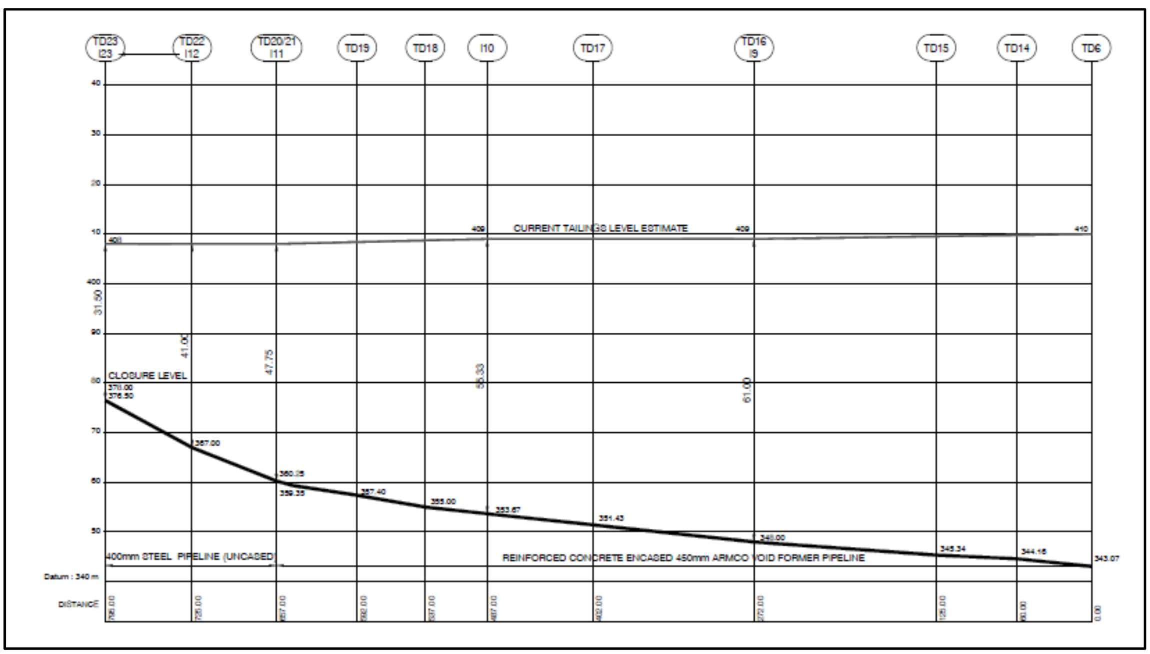

Figure 5 East valley (C) decant-long section

The Main East Valley decant system consists of two pipelines and intermediate inlets, namely the Main East Valley and East Valley (C) Decants. The Main East Valley Decant was built in two phases;

1. Phase 1: designed and built in 1986/7 including part of East Valley (C) decant, and
2. Phase 2: designed in 1991 and built progressively with the Main Tower being commissioned in 2000.

Some of the construction highlights are as follows:

- Main East Valley Decant construction, phase 1:
  - A short length of 900 mm diameter concrete spigot and socket pipes between the RWD and the Selati TD toe
  - 864 mm diameter reinforced concrete encased Armco void former (1 mm thick walls) as the main conduit.
  - A constant grade of 0.74% except for 6.98% at the Syenite Koppie
- East Valley (C) pipeline construction:
  - 450 NB reducing to 400 NB steel pipes
- Main East Valley Decant construction, phase 2:
  - Special bifurcation section (Y joint)
  - 864 mm diameter reinforced concrete encased Armco void former (1 mm thick walls).
  - This section of outfall pipe traverses two valleys where the outfall pipe was laid in a trench excavated into compacted embankment across the valleys.

2. FAILURE EVENT

2.1 Role players

The parties involved at this facility are:

- Foskor - Client
- Knight Piésold (KP) – Professional consultant
- Fraser Alexander Tailings (FAT) – Facility operator

2.2 Failure and initial options considered

On 26th February 2013 it was noted by Foskor that solids were being discharged into the Selati Return Water Dam (RWD) with the supernatant discharge. This was not considered serious at that stage and was not brought to the attention of the consultant. On 27th February the discharge of solids was seen to have increased noticably, and was brought to the attention of both Fraser Alexander and Knight Piésold.

Decanting was immediately ceased and a brainstorming session was held among various highly experienced engineers who have been involved with design, construction and monitoring of the Selati TD over the years as to the best course of action to be taken. The initial brainstorming resulted in the following options being considered:

- Stop water ingress at the inlet
  - Plug the decant tower
  - Stop decanting from the tower
- Seal off the outlet

- Install a blank plate
- Construct a rock fill plug

These options are discussed in more detail in the following sections.

2.2.1 Stop water ingress at the inlet by plugging the decant tower

It was initially thought that the failure had occurred in the decant tower. Sealing off of the tower at its base would therefore prevent any further ingress of water and solids to the decant system. This option was later discarded as a CCTV inspection of the four vertical decant tubes showed that the tower is intact.

2.2.2 Stop water ingress at the inlet by ceasing decanting

Cessation of decanting through the existing decant tower was implemented immediately, but the facility was required to remain in place in case of emergency. Continued flow through the outlet system was expected to wash more solids from the facility and deposit it into the RWD with consequent loss of capacity.

Furthermore, the uncontrolled release of solids could lead to sinkhole formation in the tailings beach. If left uncontrolled, this void can ultimately lead to catastrophic failure of the facility.

2.2.3 Sealing off of the outlet by installation of a blank plate

Foskor personnel who had been involved at the mine from the time of commissioning of the Selati TD reported that a structure had been constructed that would allow for the insertion of a blank plate into the outlet pipe line between the toe of the tailings dam and the discharge point in the RWD. No design or construction drawings of this were available for review at the time, so it was therefore considered inappropriate to attempt such an installation.

The outlet conduit system was designed for gravity flow conditions only. Installation of a blank plate would result in pressure build-up within the outlet conduit system, which could then result in further breaches in the outlet conduit with possibly more severe consequences than that already being experienced.

2.2.4 Sealing off of the outlet by construction of a rock fill plug

The remaining option was to seal off the outlet at the discharge point. As discussed in paragraph 2.2.3, complete sealing could have undesirable consequences. The concept was then further developed to provide a reverse filter, rather than a plug. This concept was recommended as the short term solution and is described in the following two publications:

- International Commission on Large Dams (ICOLD), in their publication entitled “Tailings Dams. Transport Placement and Decantation, Review and Recommendation, Bulletin 101.” Published in 1995, and

- Chamber of Mines of South Africa, in their publication entitled “Guidelines for Environmental Protection – Volume 1/1979”. Published in March 1996.

Once the emergency situation was brought under control, planning then began for the reinstatement of full decanting capacity on the facility.

3. TIMELINE OF EVENTS

3.1 Tuesday, 26th February 2013

Mine personnel noticed solids being discharged into the RWD. They did not judge it to be a serious enough nature to report to FAT or KP.

3.2 Wednesday, 27th February 2013

The annual aerial inspection of the tailings dams took place on the morning of 27th February 2013. Discharge of solids into the RWD which had been noticed the day before was not reported.

The inspection was done by helicopter. Solids being discharged into the RWD was not noticed (it is now thought that flow may have reduced from that observed the day before).

Approximately an hour after the inspection and meeting, FAT and KP were advised that significant volumes of solids were being discharged into the RWD. It was noted that solids were being deposited into the RWD and were settling from the decant outlet in the southern portion of the RWD. Decanting was ceased immediately.

The flow was kept under observation while the way forward was discussed amongst all parties involved. It was noted that a continuous flow remained even after sufficient time had elapsed for all water already in the outlet conduit to have discharged to the RWD. This indicated a fairly large breach somewhere in the outlet system, allowing both water and solids to be pulled into the outlet system.

It was recommended that an internal CCTV inspection of the intake tower be carried out to ascertain whether the leakage into the system is from the tower itself. A reputable Johannesburg based company was contacted who indicated they could mobilize within 2 days.

3.3 Thursday, 28th February 2013

The outlet was inspected again early that morning. It was visually assessed that the flow had increased significantly overnight. At an emergency meeting called to decide on the way forward the following steps were agreed upon:

1. Stop the use of the decant tower completely until further notice
2. Determine a way forward to plug the tower and reduce the flow out of the pipe.
3. Arrange for a CCTV inspection down the tower to search for any evidence of ingress below the current intake level. Foskor made available their corporate aircraft and managed to bring the contractor to site immediately. The CCTV inspection was carried out in the afternoon and found no evidence of any solids ingress below the last operating level.
4. Search for a sinkhole on the beach of the facility
5. Search for any sign of a slip failure on the outer walls of the facility or any other signs of mass movement of the walls.

In line with Step 2 it was decided that a plug of some sort should be built, and planning started for the construction of a reverse filter.

The plant was also stopped for a few days to minimise the risk of overloading any section of the Selati TD while the outlet was still at risk.

The inlet level at the tower was also raised well above the current pool elevation to prevent unwanted inflow into the system.

3.4 Friday, 1st March 2013

It was suggested that rock should be dumped on the outlet in an attempt to curb or at least reduce the flow. A layer of geotextile was placed on the flowing water and rock dumped on top of it. Initial attempts failed due to the high flow rate.

It was assessed that the primary reason for the initial failure was the particle size grading of the material used. The material contained a large proportion of coarse gravel which was washed away by the strong flow. Larger sized rock was then used and a marked reduction in flow was achieved.

3.5 Saturday, 2nd March 2013

3.5.1 Rock fill

On the 2nd March 2013, the site was visited by the team to inspect the performance of the rock fill dumped the day before. It was found that a slip failure occurred over night on the downstream face of the placed rock fill. It is believed that washing out of fine material overnight lead to this failure. The larger rocks were still in place.

The upper cone of the rock fill placed the day before was then dozed into the failed zone to repair the damage. This action resulted in less weight acting on top of the outlet. The path of least resistance for flow then changed from sideways to upward and water started flowing out the top of the flattened rock fill. Additional rock material was then dumped onto the rock fill to increase the weight on the outlet. This was continued until the flow retuned to a horizontal flow path.

3.5.2 Inspections

The facility was inspected from a fixed wing aircraft. The inspection focused on locating a possible sinkhole in the beach and assessing the outer wall for any other signs of weakness. No warning signs were noted.

Similar inspections were carried out on the ground. Again, no evidence was found of additional cause for concern.

Inspection of the beach was also performed via boat, looking for any signs of unnatural movement of material on top of the facility.

The pilot of the rented aircraft flew over the site of his own accord later in the day and reported spotting a sinkhole in the beach. This report was backed up with photographic evidence. Foskor then carried out an inspection via boat and also located the apparent sinkhole in the beach, close to the edge of the pool, above the route of the outlet conduit. This reinforced the suspicion that the failure occurred along the outlet conduit and not in the decant tower itself.

3.5.3 Filter construction

It was acknowledged that a better engineered filter was required to retain solids while allowing the flow of water. This solution is also suggested in the Guidelines for Environmental Protection, as published by the Chamber of Mines of South Africa.

The basic filter principles had to be applied with the material readily available on site at the time. Material containing excessively large rocks was not deemed suitable. The aim was to select a fairly evenly graded material.

Firstly, a layer of geofabric was placed over the rock fill, almost covering the full exposed surface. A layer of fine filter material was then placed over the geofabric and spread evenly. The available quantity of geofabric was insufficient to cover the full rock fill area. Flow was exiting the rock fill in the area where the slippage occurred during the night of 28th February. This is the area not covered completely.

As part of managing the water flow, this area was left undisturbed, while rock fill was again placed onto the filter material layer. The constructed filter is presented graphically in Figure 6.

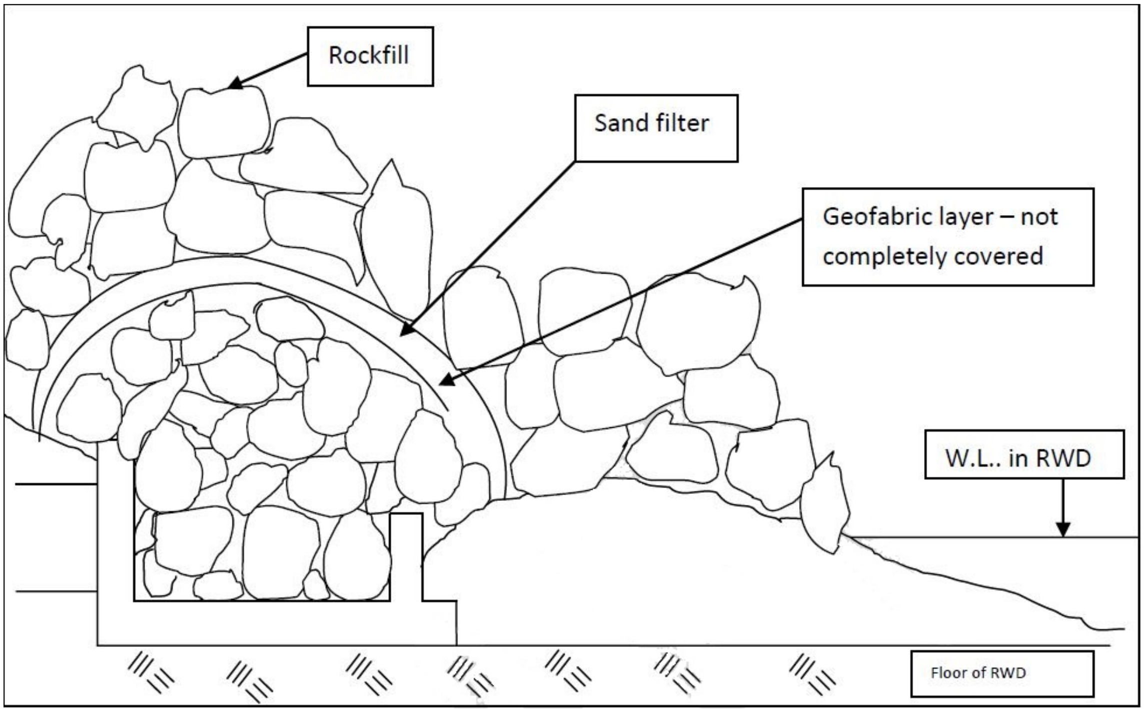

Figure 6 Constructed filter schematic

3.6 Sunday, 3rd March 2013

A site inspection early in the morning showed that he dumped rock had performed much better over night with no visible evidence of any slippage or subsidence.

Discharge of solids had essentially ceased and the flow rate of water had been reduced to a fraction of that seen shortly after decanting was stopped. This suggested that tailings was starting to back up in the decant pipe and the reverse filter was starting to function. However it does mean that the pipe becomes pressurized, albeit that as long as clear flow is occurring, the pressure build up is limited.

4. TECHNICAL DISCUSSION

4.1 Rock fill performance

The recommendation to utilize larger sized rock fill material on the outlet followed from the following technical considerations. The rock fill provides resistance to flow by the following:

1. Weight of the rock fill: The larger the rock the greater the weight, which supports the rock in a static state. This supports the recommendation to use larger sized rock together with the mixed fraction of other coarse material and cobbles already brought to site.
2. Dissipating energy by obstructing the flow path: This would reduce those forces that may mobilize the rock fill material away from the outlet.
3. Providing resistance to movement through interlocking between the rocks to prevent movement: Spherical and rounded rock has a tendency to roll under flowing water. Angular rocks provide resistance through mechanical interlocking action. For the same reason angular rock fill has a steeper angle of repose than rock fill of rounded rocks. Additional resistance is

provided between the interface of the rock fill and the foundation on which it is placed. Tailings would fill the voids between the rocks, helping to dissipate the energy of water flow.

4.2 Conduit design considerations

It must be understood that the outfall conduit was not designed for internal pressure conditions. Therefore if the outlet is sealed by grouting while the dam is still in operation, the outlet pipe will fill with water and full hydrostatic pressure will develop. The current elevation difference between the outlet and the pool surface is approximately 70 m. Current planning is to raise the dam by another 48 m. It is possible that the dam may even be raised beyond this height.

Where the outlet pipe is under the dam, the internal forces due to water pressure will be in balance with the external forces due to the weight of the tailings. This is not the case for the section of pipe from below the dam crest to the outlet. In this section, the internal forces will exceed the external forces. It is possible that the pipe may fail under these conditions, leading to seepage on the outer wall and possible piping.

It is therefore critical that as long a section of the outlet as possible be grouted. This will be a challenging exercise due to the size, length and layout of the outlet conduit.

5. CONCLUSIONS

All parties were able to react immediately to a threatening situation that developed on site. Working as a team Foskor, FAT and KP ensured that the best possible remedial action was taken and implemented in the least possible time.

A rock fill based filter plug was constructed on the outlet into the RWD, serving to keep most of the tailings solids back while allowing the flow of water to continue. The flow rate was significantly reduced from that witnessed shortly after the failure.

Allowing flow to continue, prevents the buildup of pressure in the outlet conduit which is not designed for a pressurized condition.

Keeping back the solids protects the storage capacity of the RWD and prevents the continued growth of the sink hole in the tailings beach.

Access to the outlet has now been lost for regular sealing of the outlet by grouting as would normally be undertaken at the end of life of a decant.

6. RECOMMENDATIONS

The Chamber of Mines Guideline states that:

In the case of a penstock or outfall failure the following possible remedial measures should be considered and the most important selected:

i. The penstock inlet may be raised so that it is no longer possible for water to enter the penstock except during a storm of a defined duration and recurrence interval which it is considered provides a minimum practical probability of overtopping. It is recommended that a storm of 24 hour duration and 100 year recurrence interval be used for design

ii. The penstock pipe may be blocked or closed. This may be effected by plugging the inlet either at the top or at the juncture with the outfall pipe. If the plug is at the bottom of the tower, the backfill of residue should be stabilized by adding Portland cement.

iii. If the tailings are being washed out of an outfall pipe and it is not possible to plug the penstock a reverse filter and buttress may be constructed around and over the penstock outlet.

iv. *Any continued flow of water from a penstock or outfall pipe should be stored in settling and evaporation ponds.*

With respect to Item i, the facility currently has sufficient excess freeboard to contain the run-off resulting from a rain event far in excess of the 1:100 year 24 hour storm.

Item ii will be challenging and costly to implement as access to the tower is only by water on a small barge type boat with very limited carrying capacity. Alternatively, grout pumping infrastructure can be set up on the natural ground on the south of the Selati TD. A floating pipe line of approximately 1,200 m length would be required to convey the grout to the tower.

Item iii has been crudely implemented as emergency response action in limited time with limited access to appropriate materials and design time. A properly engineered filter has now been designed and has been constructed over the temporary filter.

Item iv is provided for as the flow still reports to the RWD which will remain in operation.

Because it is assessed that the breach occurred somewhere along the outlet conduit, sealing of the decant tower alone will not be sufficient to prevent the buildup of hydrostatic pressure in the outlet conduit. Some means should be sought to seal off the outlet conduit as well as the inlet tower.

Plans are in place for the decant system to be replaced. This needs to be implemented as soon as possible. The facility cannot be operated in the long term without being able to recover water from the pool.

7. REFERENCES

Parmar S & Strauss AJ. (2013). Selati Tailings Dam Penstock Outlet Failure: Emergency remedial works and recommendations. *Knight Piésold Report No. 301-00055/50-0001*.

Knight Piésold project archived documentation.