

Northam Platinum Zondereinde Mine—UG2 as Backfill Product

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ABSTRACT

The Northam Platinum Zondereinde mine is performing multi-reef mining by exploiting two types of platinum bearing reef, known as the Merensky and UG2 reefs, each with differing ore characteristics and resulting tailings properties. The mine has been using uncemented hydraulic backfill for primary as well as regional support since the start of the mining operations in 1993. Historically, the backfill material comprised of classified Merensky and, to a lesser extent, development waste tailings. Northam Platinum Zondereinde mine is now investigating the use of UG2 tailings as backfill material should the availability of Merensky tailings not meet the required future volumetric placement demands.

The suitability of UG2 tailings as backfill material was investigated through benchtop tests, followed by a full-scale test paddock on surface. The test paddock was equipped with total earth pressure cells and piezometers to assess the stress build up in the backfill during and after placement as well as the drainage potential of the material in the paddock. In addition, different geotextiles were trialled to optimise the volume of drainage water, while limiting the amount of solids released from the trial paddock.

During the field trials, slumping events were witnessed inside the test paddock which resulted in increased loading conditions on the fill fence. This paper presents the backfill system, test setup and results from the field trials as well as a discussion, and probable causes, of the slumping events that were witnessed during the field trials.

INTRODUCTION

Northam Platinum Zondereinde mine is located in the Northern portion of the Western limb of the Bushveld Igneous Complex. The mine is located approximately 100 km North of Rustenburg, in the Limpopo Province of South Africa (Figure 1) and is the deepest active platinum mine in the world.

Northam Platinum Zondereinde mine can be classified as a deep tabular hard rock mine, using scattered breast mining techniques. Like many deep mines in South Africa, uncemented hydraulic backfill is used as primary and regional support. Historically, the backfill material comprised of classified Merensky tailings and, to a lesser extent, development waste tailings. Northam Platinum Zondereinde mine is now investigating the use of UG2 tailings as backfill material should the availability of Merensky tailings not meet the required future volumetric placement demands.

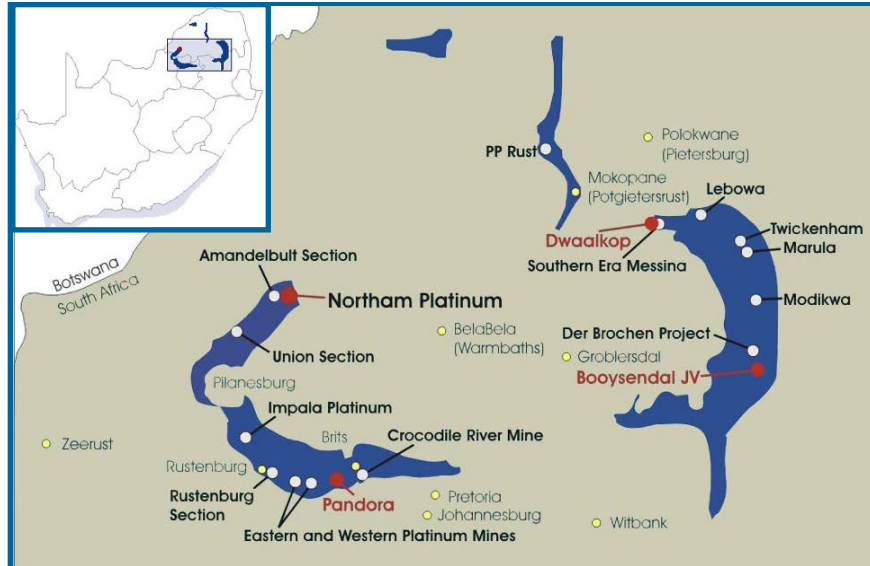


Figure 1. Locality map

Northam Platinum Zondereinde mine initiated a benchtop test campaign in June 2014 to assess the suitability of using classified UG2 tailings as backfill material and to establish a baseline for future decision making.

Following the initial laboratory bench top tests, a decision was made to construct a fully instrumented test paddock on surface for trial purposes to confirm the drainage potential and earth pressure if classified UG2 tailings is used as backfill medium instead of Merensky tailings.

MATERIAL PROPERTIES

The material properties of the Merensky and UG2 tailings samples used for the study are presented in Table 1 below.

Table 1. Material properties

Material Property	Merensky Tailings	UG2 Tailings
Specific Gravity	3 193 kg/m ³	3 858 kg/m ³
d ₉₀ particle size	181 µm	174 µm
d ₅₀ particle size	90 µm	91 µm
d ₁₀ particle size	40 µm	40 µm
Freely settled bed packing conc., C _b free	49.4%v or 76.1%m	45.4%v or 76.3%m
Maximum settled bed packing conc., C _b max	51.1%v or 77.3%m	48.3%v or 78.4%m
Coefficient of uniformity (d ₆₀ /d ₁₀)	2.55	2.62
Permeability	2.87x10 ⁻³ cm/s	3.23x10 ⁻³ cm/s
Backfill Friction Angle (φ')	34.3°	33.3°
Backfill / Geotextile Friction Angle (φ')	26.9°	28.2°

The particle size distribution of the two tailings samples is graphically presented in Figure 2.

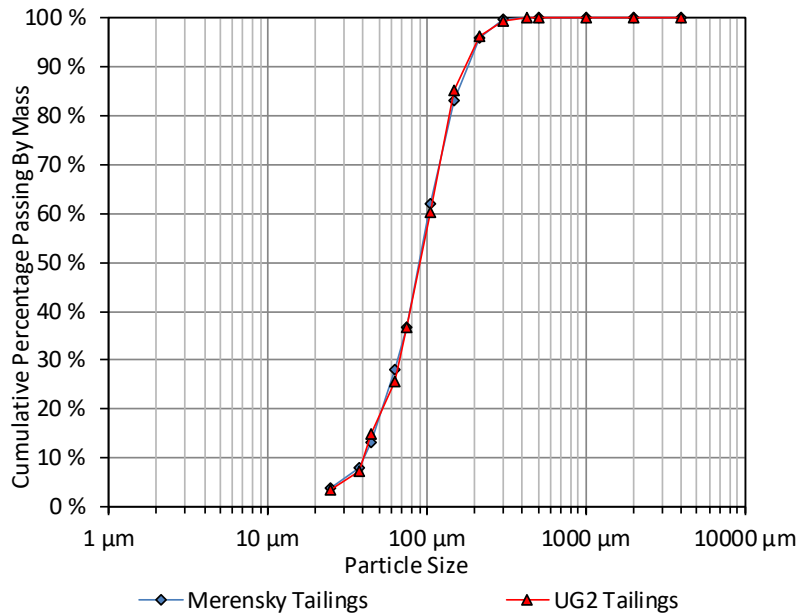


Figure 2. Particle size distributions

TEST SETUP

Surface Test Paddock

A full size test paddock, shown in Figure 3, was constructed in order to eliminate scaling effects and to simulate underground conditions as closely as possible. The primary dimensions of the surface paddock are as follows:

- Angle with the horizon – 20 degrees
- Height (perpendicular to dip) – 1.2 m
- Width (along strike) – 1.5 m
- Length (perpendicular to strike) – 19.5 m

A drainage system forms part of the field setup to collect run-off water and fines released during testing. The hanging wall, foot wall and one side panel are closed. Steps and a walk way on the open side of the paddock provide easy and safe access to monitor the backfill behaviour during field trials.



Figure 3. Side view of surface test paddock

Instrumentation

The following geotechnical instrumentation was used for the field trials:

- Total earth pressure cells (TEPC) (x3)
- Piezometers to measure pore water pressure (x2)

The total earth pressure cells manufactured for the field trials are 225 mm in diameter and ± 9 mm thick, providing a high aspect ratio to minimise inclusion effects. Vibrating wire technology was selected for both the total earth pressure cells and piezometers with independent temperature monitoring on each instrument.

The earth pressure cells and one of the piezometers are mounted inside a steel cage to provide for a robust installation to protect the instruments during filling. In order to measure horizontal and vertical pressures the steel cage has adjustable locators for levelling and is located approximately 1.5 m behind the bulk head.

The second piezometer was placed approximately half way up the paddock in order to determine the hydraulic grade line through the backfill. Refer to Figure 4 for a schematic layout of the instrumentation setup that shows the three total earth pressure cells and the two piezometers.

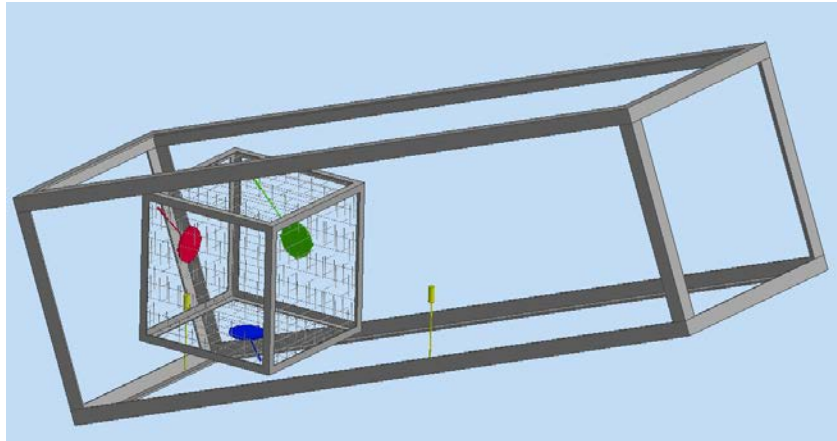


Figure 4. Schematic layout of instrumentation setup

TEST PROCEDURE

Backfill material was produced at the concentrator plant and pumped to the test paddock. The backfill material was discharged into the paddock via an open ended pipe. A perforated plastic sleeve was attached to the open ended pipe which extends all the way to the bottom of the paddock. As the backfill level start to rise, the perforated sleeve splits open to ensure an even spread of fill material.

The feed parameters were monitored and recorded during the trials to ensure actual underground filling conditions are simulated with the field tests. The following parameters were monitored:

- Backfill density (t/m^3)
- Feed rate (m^3/h)
- Date and time

The target feed rate was $\pm 50 m^3/h$ and the target backfill densities were $1.8 t/m^3$ and $2.0 t/m^3$ for the Merensky and UG2 tailings respectively.

FIELD OBSERVATIONS AND TEST RESULTS

The field monitoring data can be divided as follows:

- Data of individual trials measured during the filling phase
- Data of individual trials measured for the total duration of the field trial (filling and post filling)

Filling Phase

Random pressure spikes were noticeable in the data for all six trials during the filling phase. These pressure spikes were caused by slumping of the backfill that took place during the filling phase. This was only confirmed during the last trial when visual monitoring was done inside the backfill bag while filling and intermittent slumping was seen. This is discussed in more detail in subsequent sections.

Total Duration

Cyclical pressure measurements for the total earth pressure cells (EPC) were seen with a repeat period of 24 hours. Field trial 2 was monitored for 8 days. The data of the EPC measurements and the temperature recorded at the data logger is presented in Figure 5.

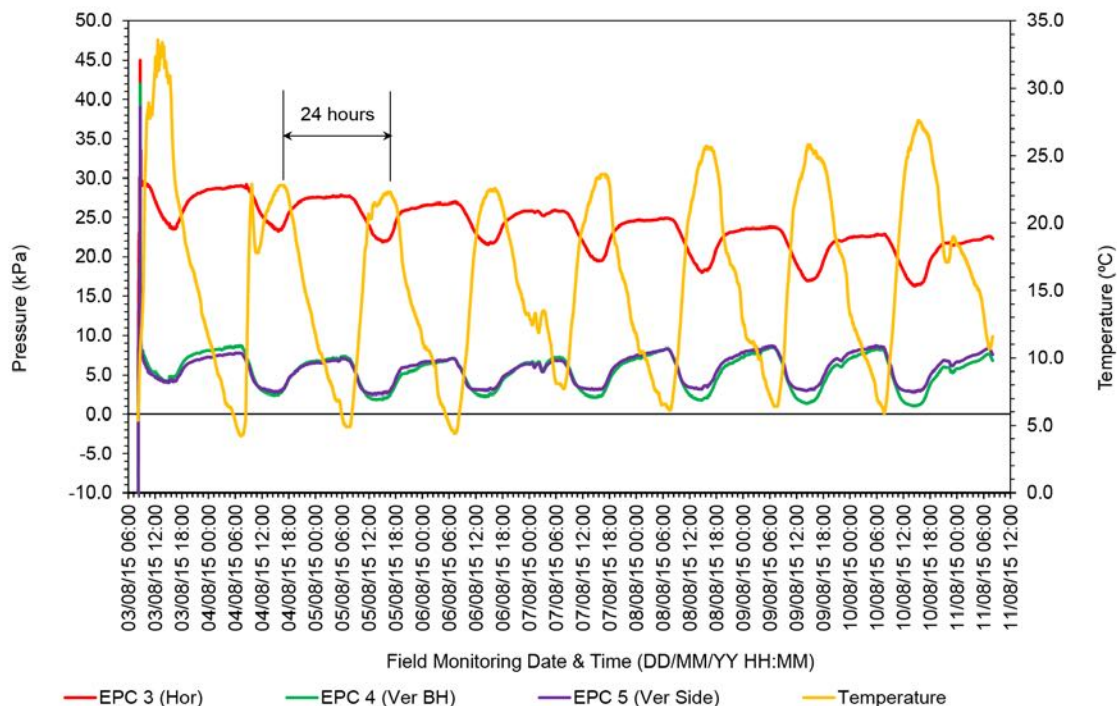


Figure 5. Total earth pressure vs temperature (field trial 2)

From the results presented in Figure 5 it is concluded that the cyclic pressure measurements are directly related to the variation in temperature over a 24-hour period.

Fill Fence Failure

Figure 6 presents the field trial data of field trial 5. During field trial 5 at around 9h18 (approximately 40 minutes from commencement of filling) the fill fence failed. From the results presented in Figure 6 it can be seen that a pressure spike was recorded around the same time that the fill fence failure

occurred. The pressure spike recorded can either be contributed to the fill fence failure or another factor which caused the fill fence to fail.

It was therefore decided to perform a visual inspection inside the backfill bag during trial 6 to see if the cause of the pressure spikes can be identified. During field trial 6 a total of seven surface waves formed inside the bag – Refer to Figure 7. The waves dissipated just as quickly as they formed and the time was recorded whenever a wave formed. It was confirmed after completing field trial 6 that there is a direct correlation between the time when a wave was witnessed and the pressure spikes (Figure 9).

A set of pressure readings was recorded at a sampling rate of 1 set of readings per 10-second interval (the fastest recording speed of the data logger). The pressure spikes witnessed were seen to be virtually instantaneous, however due to the recording sampling rate, the actual peak pressures may be higher than those recorded.

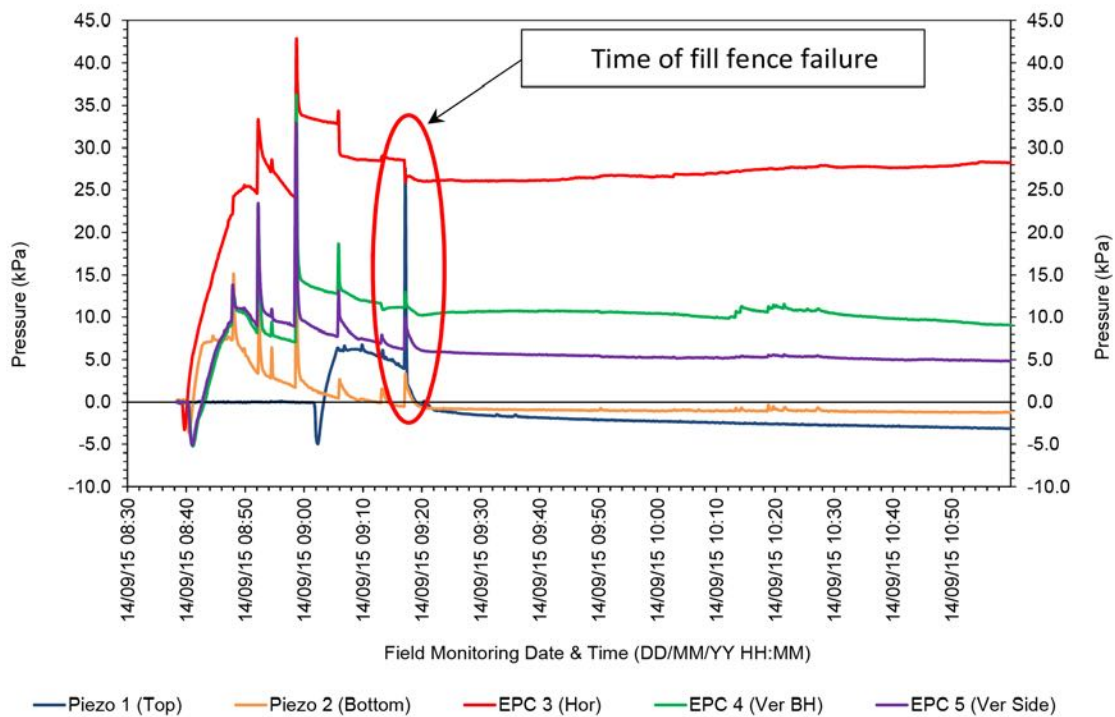


Figure 6. Field trial 5 – gauge pressures during filling



Figure 7. Wave formation while filling (field trial 6)

ANALYSIS

A force diagram was prepared based on the trial paddock dimensions (Blight, 2010) followed by a stability analysis as shown in Figure 8.

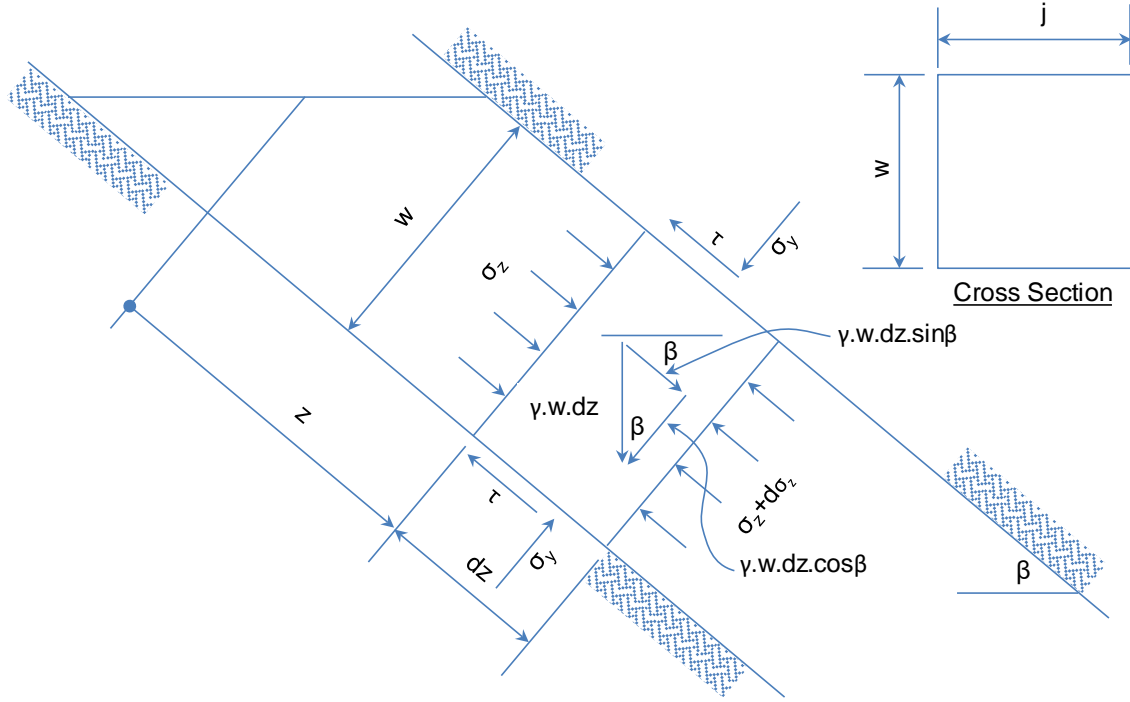


Figure 8. Forces acting on element of backfill in inclined stope

For equilibrium of the element in the z-direction

$$j \cdot w \cdot \sigma_z + \gamma \cdot j \cdot w \cdot dz \cdot \sin \beta = j \cdot w (\sigma_z + d\sigma_z) + 2 \cdot (w + j) \cdot \tau \cdot dz \quad (1)$$

So that

$$d\sigma_z = \left(\gamma \cdot \sin \beta - \frac{2(w + j) \cdot \tau}{w \cdot j} \right) \cdot dz \quad (2)$$

From the Mohr-Coulomb model

$$\tau = c' + \sigma'_y \cdot \tan \varphi' \quad (3)$$

From Terzaghi's Effective Stress Concept

$$\sigma = \sigma' + u \quad (4)$$

In Zondereinde mine's case no binder is added to the backfill therefore the cohesion (c') equals zero. The shear stress can then be expressed as:

$$\tau = (\sigma_y - u) \cdot \frac{\tan \varphi'}{F} \quad (5)$$

Where $\tan\phi'$ is the angle of shear resistance of the fill and F is the factor of safety against shearing through the fill. If the fill is perfectly stable and at rest, σ'_y would relate to σ'_z as follows:

$$\sigma'_y = K \cdot \sigma'_z \quad (6)$$

Where K would approximate to K_o , the coefficient of earth pressure at rest. Combining equation (5) and (6)

$$\tau = K \cdot (\sigma_z - u) \cdot \frac{\tan \phi'}{F} \quad (7)$$

And substituting τ in equation (2) with equation (7)

$$d\sigma_z = \left(\gamma \cdot \sin \beta - \frac{2 \cdot (w + j) \cdot K \cdot (\sigma_z - u) \cdot \tan \phi'}{w \cdot j \cdot F} \right) \cdot dz \quad (8)$$

For a perfectly stable fill:

$$\frac{d\sigma_z}{dz} = 0 \quad (9)$$

The factor of safety against shear can be determined from equation (8)

$$F = \frac{2 \cdot (w + j) \cdot K \cdot (\sigma_z - u) \cdot \tan \phi'}{w \cdot j \cdot \gamma \cdot \sin \beta} \quad (10)$$

Equation 10 was applied to the last set of test data to establish the factor of safety against shear during the filling procedure. The results are presented in Figure 9. (Note the FOS is referenced to the secondary axis).

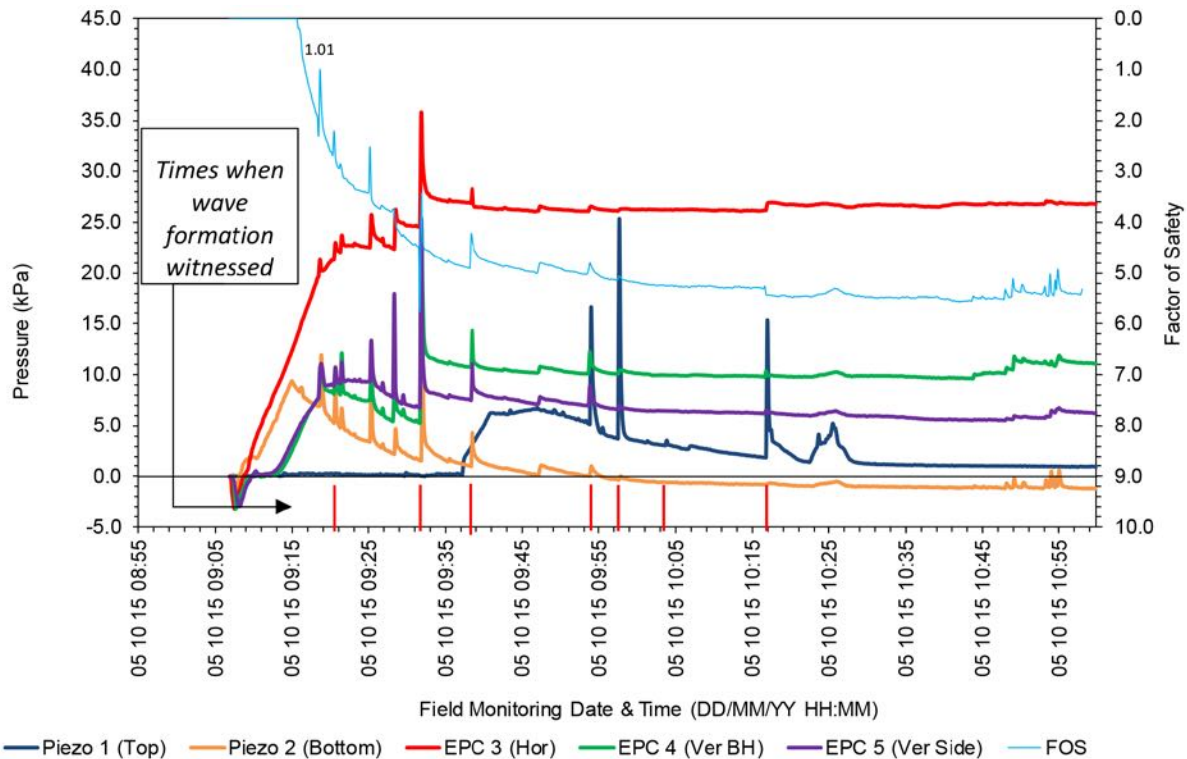


Figure 9. Field trial 6 – gauge pressures during filling

(Note: The instrumentation orientation was not aligned with the force diagram presented in Figure 8 and the measured pressures had to be divided into vectors as shown for the weight component). Also equation (8) must be integrated in order to calculate the vertical and lateral stresses in the column of fill.

From the results presented in Figure 9, it can be seen that the FOS is close to 1 (near failure) at the same time when the first pressure spike was recorded. Closer inspection of the test data indicates that the FOS reduced seconds before the pressure spike was recorded which suggests that the backfill failed in shear causing the slump, which in turn caused the pressure spike. The FOS is calculated using the internal friction angle of the backfill and geotextile interface.

From Figure 9 it can be seen that the FOS steadily increase as the trial stope is filled and the backfill consolidates while the pore pressure dissipates. It should also be noted that it is common backfill practice on Zondereinde to “poke” the bag on the outside while backfilling is taking place to facilitate tight filling. This practice potentially contributes to the slumping which causes the wave formation.

Figure 10 presents a photo of a backfill column which separated during the initial laboratory trials due to consolidation. A number of times during the initial laboratory trials, the top portion of the backfill column dislodged which caused a sudden release of fines and water.



Figure 10. Backfill column separation

LITERATURE REVIEW

A literature review was undertaken to determine whether similar behaviour has been reported on other hydraulic fill operations. The following three papers indicate similar results:

- Fourie A.B. et al (1994) Optimization of the as placed properties of hydraulic backfill.
- Ilgner, H. J. (2007) Sudden slumping of hydraulic fills inside geotextile bags.
- Streuders, S.B. (2011) Rock engineering related experiences with the use of backfill on the deepest platinum mine.

Ilgner (2007) identified the following factors that influenced the backfill behaviour:

- Filling rate (rate of rise) – a lower rate of rise yielded more favourable results when compared to a higher rate of rise.
- Backfill density – a higher backfill density yielded more favourable results when compared to a lower density.
- Less ultra-fines improve permeability.
- Geotextiles with different aperture sizes – Geotextiles with a wider aperture spacing results in faster drainage with higher solids loss.

Streuders (2011) indicates that a pressure ‘spike’ was observed each time the backfill bag ‘settles’ during filling which resulted in a slump and his pressure measurements indicate the same trend as observed at Zondereinde.

KEY STUDY FINDINGS

The study confirmed the following:

- The particle size distributions of the Merensky and UG2 tailings prepared for the field trials were similar (Figure 2) and the two fill types exhibited similar behaviour.
- The UG2 tailings did not perform well with the geotextile used with the Merensky tailings as a significant amount of fines drained through the geotextile. The use of a slightly denser geotextile yielded much better results.
- The pressure measurements (post filling phase) for the two fill types were similar in magnitude and no significant increase in pressure was observed when comparing the results of the two fill materials. The pressures measured post filling for the UG2 and Merensky material are similar ranging between 25 kPa and 30 kPa on the horizontal plane and 5 kPa to 10 kPa in the vertical planes.
- Pressure spikes were witnessed during all the field trials while filling, with the fill fence failing during trial 5. During trial 6 a visual inspection inside the backfill bag indicated that slumping is taking place, resulting in a sudden rise in pore pressures to such an extent that the fill liquefied.

CONCLUSIONS

The use of geotechnical instruments to monitor the performance of backfill provides valuable information to understand and explain certain backfill behaviour. During a series of surface field trials at Northam Platinum Zondereinde mine, to evaluate the performance of UG2 tailings as backfill material, slumping events occurred resulting in pressure spikes which led to a fill fence failure in the paddock.

The data obtained during the field trials as well as visual observations were used to perform a stability analysis. The results of the analysis suggest that shear failures are taking place, resulting in slumping events which causes a sudden rise in pore pressures. This was also observed during benchtop laboratory trials.

The pressure spike caused by the slumping is very short lived as indicated by Ilgner (2007) making it difficult to confirm the peak pressures. In order to confirm this, a high speed data logger and pressure transmitter should be used to ensure the peak pressure is captured.

Fill fences should be designed taking cognizance of the sudden rise in pressure that occurs as a result of slumping events while filling.

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