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Open cast mining pit rehabilitation incorporating the use of soil reinforcement geo-synthetic material

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Abstract

An old open cast chrome pit required rehabilitation to allow for the expansion on an existing tailings storage facility over the rehabilitated pit. The pit was partially backfilled with tailings and a pool is constantly recharged from groundwater. Backfill was done primarily with G4 material placed in compacted layers. To account for differential settlement and the risk of damaging of the expansion Tailings Storage Facility (TSF) basin barrier system, a soil reinforcement system using geogrids was incorporated into the backfill.

Keywords: *Geosythetics, Geotech, Soil reinforcement, settlement, Geogrid*

1 Introduction

The mine will be planning to perform a plant upgrade for an additional 100 kt/pm. This will require a Tailings Storage Facility (TSF) extension to accommodate the increased tailings tonnage. The TSF extension will be constructed over an existing open cast pit which is located to the west of the existing TSF. The previous owner had commenced rehabilitation of the pit by backfilling with their Jig tailings, but was not completed before the pit changed in ownership. The full rehabilitation of the existing pit will be required before the TSF expansion can be constructed. After the pit has been backfilled, the area will then be used for the TSF extension.

1.1 Site Description

The pit site covers an area of approximately 4.7 ha and has an excavation depth of approximately 7 m below the natural surface level, with near-vertical pit wall sides. The southern portion of the pit has a current depth of 5 m from surface level due to the deposited tailings material, whereas the northern portion has a depth of 3 m.

1.2 Pit investigation

The pit investigation included the investigation of Jig tailings that were previously deposited into the pit. Various sources of potential backfill material were investigated which included a slag material, overburden material and waste rock.

Figure 1 indicates the location of the Jig tailings pit.

Figure 1. Jig Tailings Pit

1.3 Backfill Material Investigations

The Slag material was combined with the overburden material and mixed in the laboratory for testing. The test results indicated that a G4 quality material could be achieved from a combination of mixes. However, a commitment to use this material combination as backfilling of the pit was not supported during the Environmental Impact Assessment (EIA) and was not recommended.

The waste rock material was also tested in the lab producing a G5 quality material however if the big rock aggregate was crushed, a G4 quality material could be achieved. The laboratory tests indicated that the material was relatively well graded and had a fines content of below 5% on average. The samples' Maximum Dry Densities ranged between 2 322 kg/m^3 and 2 372 kg/m^3 and an Optimum Moisture Content of between 4 and 7%.

Layer-Works

The rehabilitation of the pit was designed in a way that the loading from the New TSF could be supported while the tailings inside the pit are consolidated over time.

The waste rock material would be placed, spread and compacted into the tailings beach using a heavy vibratory roller, to create a working platform for commencement of the primary backfill. The backfill was designed to be placed in layers not exceeding 200 mm at a minimum compaction of 98% modified AASHTO maximum dry density. The backfill will have a domed overfill of 500 mm beyond the stripped natural ground level (NGL) and will extend to the NGL for approximately 10 m from the edge of the pit.

Consolidation Settlement

The Jig tailings in the pit would continue to consolidate over time due to the backfill load as well as the dynamic, long term loading from the tailings deposition. A finite element analysis was conducted using empirical methods in order to determine the overall consolidation settlement for the Jig tailings inside the pit. The results obtained were compared to a Sigma model in the Geo-Studio Sigma program that was utilised for the comparison.

Laboratory consolidation tests were carried out for the purpose of calculating the field consolidation at the pit. Various loading scenarios between 10 kPa and 1 600 kPa were investigated. The results indicated that the consolidation of the tailings at 800 kPa to be in the range of 270 mm on the northern section of the pit and 250 mm in the southern section.

1.4 Empirical Methods

The Empirical Method utilised for the consolidation settlement, calculates one-dimensional vertical settlement of the tailings. The method was conducted as documented in Craig's Soil Mechanics[1]

An assumption was made that the tailings inside of the pit was founded on an impermeable layer and the backfill on top of the tailings was determined to be equal to the thickness of the tailings layer as recommended by the method. This would define the depth of the longest seepage path within the tailings layer and it was determined to be equal to the thickness of the tailings layer. Loading due to the backfill and the tailings were assumed to have a uniform stress distribution over the tailings layer.

The initial effective stresses were assumed to be only the stresses due to pit backfill materials and were calculated to be in the order of 105 kPa and 152 kPa in the northern and southern portions of the pit respectively. The final effective stresses were defined as the stresses due to the backfill material plus tailings at the final phase of the TSF extension at an elevation of 1 170 mamsl and were determined to be in the order of 755 kPa and 502 kPa in the northern and southern portions respectively. The instantaneous consolidation settlement during and after the mine life are presented in Figure 2 and Figure 3 for the northern and southern portions respectively. From these figures, it is noted that the final consolidation settlement occurs beyond the operational life of the TSF extension and were determined to be 363 mm after 2000 years in the northern section and 370 mm after 400 years in the southern section of the pit.

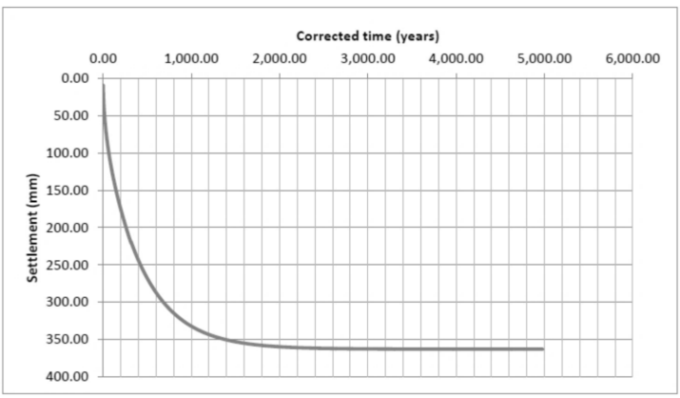

Figure 2. Instantaneous consolidation settlement at the northern portion

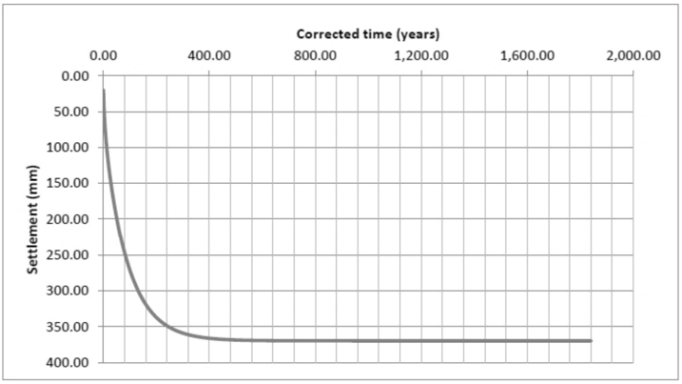

Figure 3. Instantaneous consolidation settlement at the southern portion

Sigma Analysis

The potential consolidation of the tailings within the pit was determined using the Geo-studio Sigma/w finite element analysis software to perform the required stress deformation analysis.

The model was set up with depth of tailings of 4 m at the North and 2 m at the South of the pit. The waste rock pioneer layer was modelled to be 1.5 m deep and the G5 backfill material was modelled as the differential between the waste rock and 8.25 m above datum level. This resulted in a G5 material with a thickness of 2.75 m at the North and 4.75 m at the South. The tailings layer was modelled as two separate materials with higher void ratios and clay content at the South where it is currently saturated. The model is presented in Figure 4.

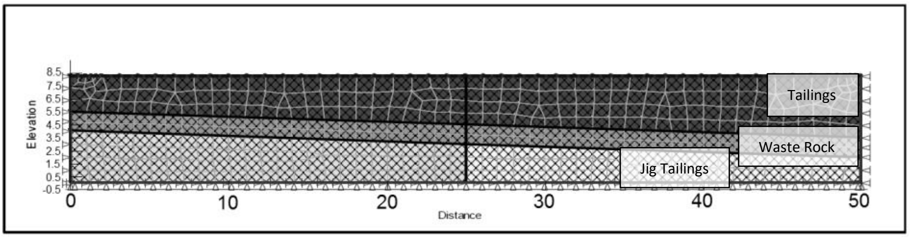

Figure 4 Model Setup

The stress distribution under self-weight of the material or the in-situ stress of the pit was determined using Sigma/w with the phreatic surface located at 8.25 m above the datum level. This represents the worst case scenario for the dissipation of pore pressures under load. The resultant in-situ stress distribution is shown in Figure 5. The bottom of the pit boundary was restrained in the x and y axes while the sides of the pit was restrained in the x direction.

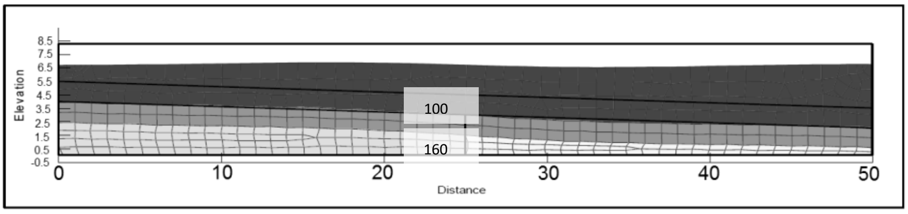

Figure 5 In-situ stress distributions

Modified Cam Clay (MCC) material modelling was performed on the clayey silt tailings. The values of the material properties were determined from the laboratory tests and the porosity was determined from the initial void ratio. The over consolidation ratios used are conservative. The material modelling for the waste rock and G5 material used was effective drained linear elastic.

A Geotechnical investigation was conducted in which Dynamic Probe Light (DPL) tests were conducted on 6 undisturbed samples, in order to determine the penetration resistance of soil. The test results indicated soft or loose consistencies in the drier northern area, while it becomes very soft / loose where the soil is saturated in the southern portion of the pit. DPL sample numbers 1 and 5 were used for the southern and northern sides of the pits respectively. Table 1 to Table 3 indicate the material properties and the inputs for the volumetric water content and hydraulic conductivity function.

Table 1 Material Properties (MCC)

Material	Over consolidation ratio	Dry density (kg/m3)	Bulk density (kg/m3)	Initial void ratio	Poisson's ratio	Lambda	Kappa	Friction angle (°)
DPL 1 (North)	1	18,400	1,791	0.78	0.4	0.0622	0.0175	25
DPL 5 (South)	1	1,288	1,989	1.38	0.4	0.137	0.0287	20

Table 2 Inputs for Volumetric water content and Hydraulic conductivity function

Material	Permeability (m/s^2)	Porosity	Residual water content (m^3/m^3)	Coefficient of volume change (mV) (m^2/kN) @ 800 kPa
DPL 1 (North)	8.50E-05	0.44	0.05	8.50E-05
DPL 5 (South)	1.50E-05	0.58	0.1	1.50E-05

Table 3 Material properties (Effective drained linear elastic)

Material	Young's Modulus (MPa)	Dry density (kg/m^3)	Poisson's ratio
Waste Rock	800	2,700	0.334
G5	150	2,347	0.15

The pressure of the tailings overburden above the pit was modelled with a pressure boundary condition which increases over time up to 23 years, after which it remains constant (aligned with the life of the TSF). The pressure increases from 0 kPa to 700 kPa. The sides of the pit were assigned a boundary condition of a potential seepage face. This will allow the tailings to drain through the sides of the pit only. The total settlements in the pit are shown below in Figure 6 as the exaggerated deformed model.

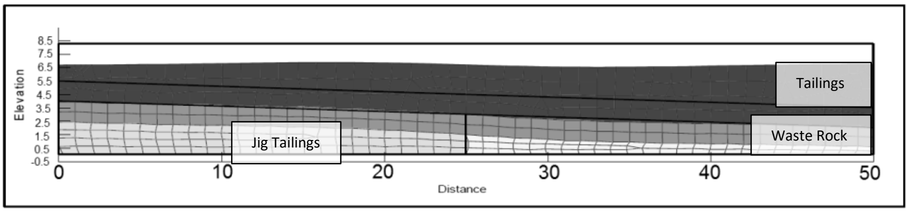

Figure 6 Model showing exaggerated deformation

Figure 7 shows the displacement versus time graph of settlement above the tailings layer and the total settlement for the North while Figure 8 shows the same graph for the South. Figure 9 shows the excess pore water pressures with time of points below the tailings layer near the centre of the model. This represents the worst case scenario with the longest drainage path. In this case, excess pore water pressure is dissipated and therefore maximum settlement achieved.

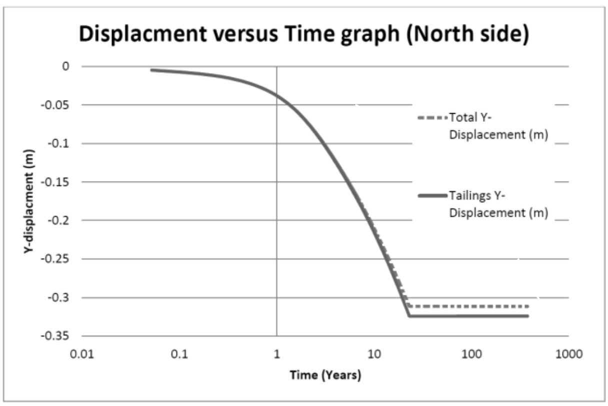

Figure 7 Time versus displacement on the North

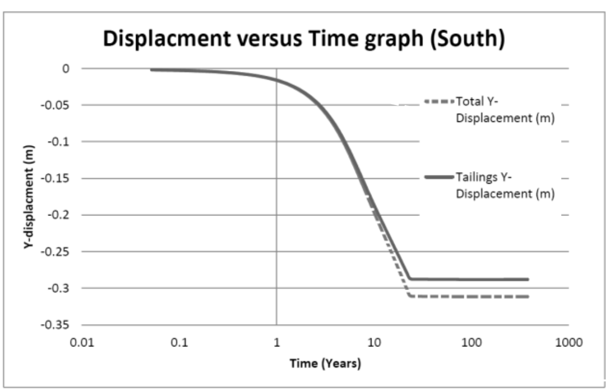

Figure 8 Time versus displacement on the South

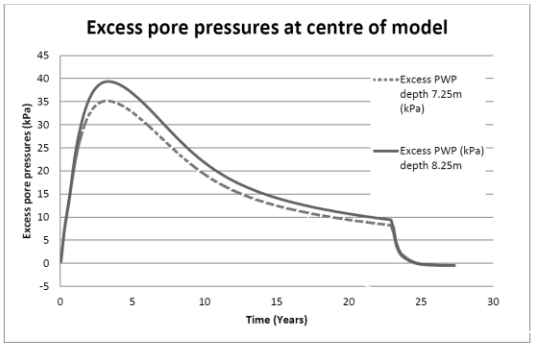

Figure 9 Excess pore pressures at centre of model

The analysis shows that the settlement values of the pit vary along the length. The northern side with a 4 m depth of tailings develops a settlement of 324 mm, while the settlement at the southern side at 2 m depth of tailings is 312 mm. These settlement values include the elastic deformation of the waste rock and G5 materials used to fill in the pit.

1.5 Geogrid reinforcement

The Open pit is susceptible to vertical differential settlement along the perimeter edges. Inclusion of a geosynthetic soil reinforcement material (geogrid) along the edges would minimise or eliminate the differential settlement.

The software Plaxis was used to determine the suitable geogrid to be used for the reinforcement. The software is a numerical simulation package that uses finite element analysis to predict the settlement and the corresponding strain/stress in the system. Supplier input was incorporated into the model to analyse the tensile stresses and strains when using geogrid along the edge of the pit.

In the numerical simulations, only the area close to the intersection between natural soil and the backfilled pit was numerically modelled. For the sake of simplicity, the predicted settlements due to consolidation (50cm) were directly applied as a predefined settlement profile to the surface of deposited tailings in the pit. The schematic shape of the simulated system and the profile of predefined consolidation settlement are shown in Figure 10 and 11. Due to the fact that the ground surface will be levelled at the end of backfilling of the pit, the deformations due to the backfilling process and dome construction were reset to zero before installation of the liner system which forms the basin of the TSF expansion facility.

In the numerical simulations, to prevent inducing excessive restrictions to the system and to allow consolidations settlements in the pit, a very soft interface was defined between the backfill materials and the vertical wall of the pit. To counteract the settlements due to consolidation in the deposited tailings, a dome with a thickness of 50cm was constructed in order to compensate for the consolidation settlements.

Three phases of the numerical model was included in the calculations:

1. Initiation of geostatic stress in the system
2. Backfilling the pit and the dome construction
3. TSF construction (85 m height) an application of predefined consolidation settlement

(As large strains with sharp curves were expected in the geogrid layers, the calculations in the last phase is based on updated mesh to consider the influence of drifted loads)

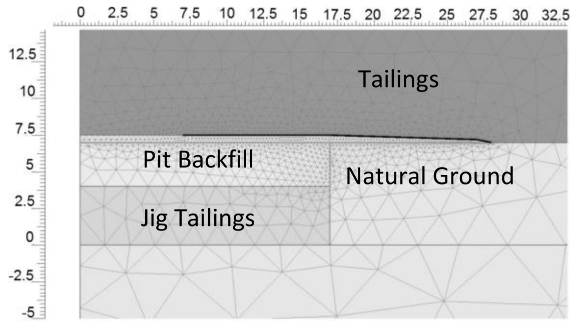

Figure 10 The schematic shape of the model

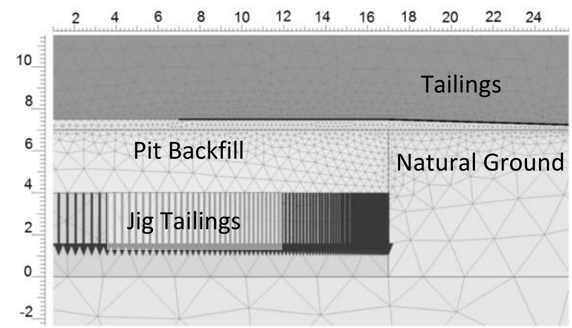

Figure 11 Predefined settlements to simulate the consolidation settlement in the deposited tailings

1.6 Numerical Results

The deformations in the reinforced system due to construction of TSF with 85 m height are shown in Figure 12

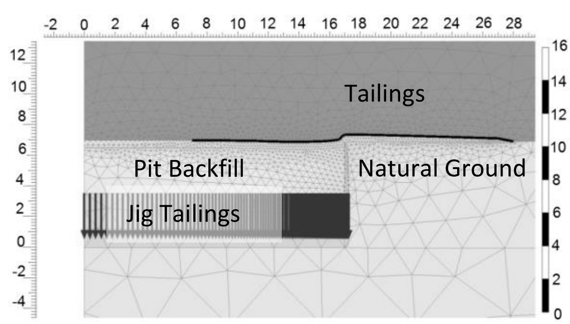

Figure 12 Deformations and differential settlements in the system

As indicated in Figure 13, a maximum unfactored tensile force of 163.5 kN/m was generated in the reinforcement layer and the maximum tensile force occurred in approximately 2 m length of the geogrid.

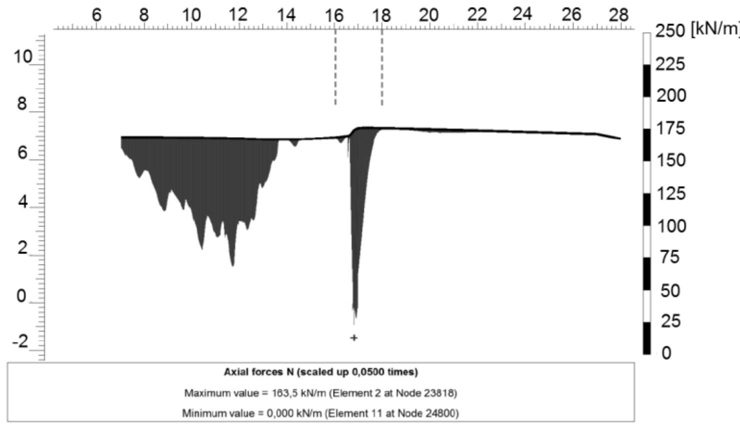

Figure 13 Tensile forces in the geogrid layer

Based on the model, the highest tensile stress generated at the geogrid layer occurs along the edge of the pit and was determined to be 163.50 kN/m because of the weight of tailings above it. The analysis shows that a geogrid with a characteristic short term ultimate tensile strength of 400.00 kN/m has a design stress of 170.55 kN/m considering the applicable reduction factors and partial safety factor, which is greater than 163.50 kN/m and thus acceptable.

The forces developed in the geogrid layer at the end of the TSF construction and in conjunction with the consolidation settlement is shown in Figure 14. To better study the strains in the reinforcement, the zone where the maximum tensile force occurs is zoomed in. Numerical results reveal that the strain this zone is about 10%. Therefore, the conventional Class C liner that was to be used for the TSF (TSF expansion basin which would be constructed over the domed backfill) could not withstand such a high strain and a more in detail design was required to propose a sealing system solution around the perimeter of the pit in the footprint of TSF. A Geosynthetic clay liner which can keep its sealing properties under strains of up to 10% was recommended. Figure 15 indicates the complete solution for the system.

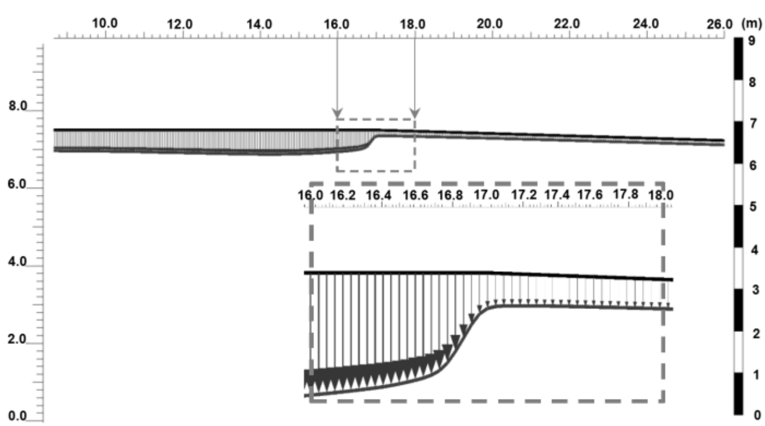

Figure 14 Deformations in the geogrid reinforcement layer

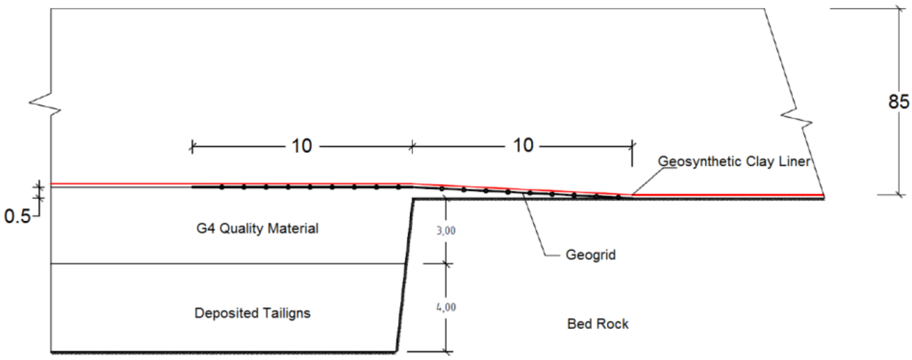

Figure 15 Complete solution for the system

1.5 Conclusion

Due to the plant upgrade, the mine required an extension of the existing TSF. The only area available to the mine for additional tailings storage contained a large open pit. This area could be utilised for tailings storage provided that the pit be backfilled. The pit however contained Jig tailings which are still consolidating. This would mean that even with the pit backfilled there would still be a vertical settlement of the backfill material over time and this movement would negatively impact the TSF extension over the pit area. Incorporating a geogrid into the pit backfill design successfully allows the pit area to be utilised for the tailings deposition, at the same time decreasing the axial forces at the edge of the pit and providing the support required as the backfill/tailings material in the pit consolidates. Without the geogrid to provide the added support, the interface between backfill and the pit wall would undergo axial stress along the entire wall boundary potentially creating a depression within the tailings facility extension and the potential for operational and safety issues to arise and posing risk to the integrity of the TSF basin liner system

Acknowledgement
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