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GEOTECHNICAL STUDY FOR IN-PIT COAL REFUSE TAILING CELLS

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ABSTRACT

To address coal refuse tailings storage needs for a mine operation in western Canada, a feasible solution was to convert excavated open pits into tailings cells. A slope stability investigation and design study were completed to determine the necessary width and slope geometry for in-situ native plugs as the impoundment embankment. The native plugs separate the previous open pit from the current active open pit. This configuration allows for the deposition of refuse tailings in the previous pit while allowing mining to safely continue "downstream" of the temporary impoundment. As mining progresses, each subsequent pit will be filled with refuse tailings; thereby, buttressing the upstream slope of the previous native plug. Although these cells are excavated, and the timeframe for downstream exposure is relatively limited, the native plugs are classified as dams and must be designed to meet applicable safety of dam standards since they impound water and tails above mining personnel in the subsequent open pit. The presentation and paper will discuss the investigation and analysis conducted to develop the geotechnical and hydrogeological design recommendations.

INTRODUCTION

Bighorn Mining, Ltd. (Bighorn) operates the Coalspur Mines Operation (Coalspur). The surface coal mine, located east of Hinton, Alberta, Canada; is nearly 300 kilometers west of Edmonton, Alberta (see inset of Figure 1). Coalspur began full time production in 2019 after receiving approval in 2014 and completing site construction. The coal process plant included a plate filter press to dewater the fine coal refuse. The fine refuse could then be placed with coarse coal refuse within a single refuse storage facility. However, the plate filter press did not achieve the dewatering rates necessary to allow for economic and efficient mining production. Coalspur required a solution to properly deposit fine tailings to maximize production. A typical external tailings impoundment had been included in the original mine site plan of operation; it was subsequently eliminated in favor of the filter press approach to manage fine tails. Although an external tailings facility would be a solution, the timeframe to allow for the necessary investigation, design, and permitting process would have adversely impacted the overall mining plan. To address the project timeline concern, Coalspur identified in-pit deposition as an option to impound tails.

Coalspur considered rather than beginning the McPherson Pit 2 as an extension from McPherson Pit 1, instead leave a native plug between the open pits (see Figure 1). The native plug becomes the "embankment" for impounding fine tails deposited in Pit 1 while mining activity excavates Pit 2 downstream of the native plug. The design aspect is concerned with determining the native plug width, height, and upstream and downstream slope angles such that the native plug remains stable from block and slope failure.

The concept of in-pit tails deposition allows for placement to occur within excavated cells below the ground surface rather than to placement within a typical above ground tails facility constructed with earthen embankments. The risk of embankment failure and tails release flowing downstream is mitigated, since a release would be contained within the next open pit. However, seepage from the tails cells into the surrounding formations was identified as a potential concern.

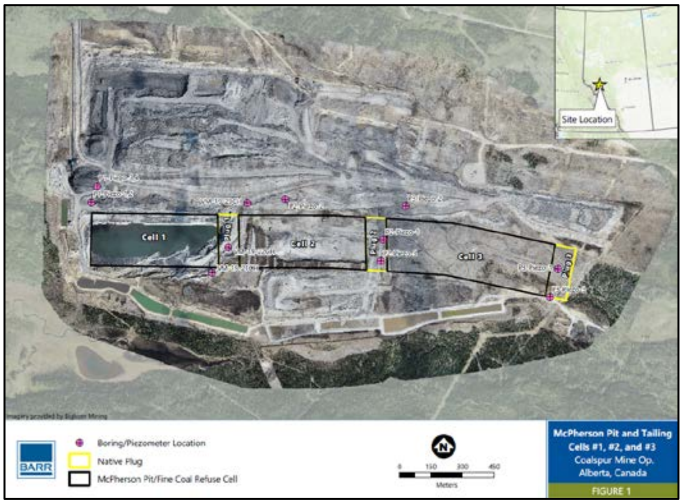

Figure 1. General site overview and locations of McPherson Pits and first three tails cells (aerial imagery April 2020).

Barr worked with Coalspur to develop and execute geotechnical and hydrogeology investigations for the native plugs to develop McPherson Tailing Cells #1, #2, and #3. These included core borings, multi-level vibrating wire piezometer installations, and laboratory test to characterize the native ground and fine tails. The investigation findings were incorporated into the engineering design stability analysis for the native plugs and groundwater model analysis to understand seepage potential.

The design study provided Coalspur with specific native plug geometries based on immediate site conditions that exceeds the minimum factor of safety (FOS) criteria of 1.50 for a static condition (CDA, 2019). To date, Coalspur has successfully deposited tails within Cell #1 and is currently deposited within Cell #2 while mining of Pit #3 (future Cell #3) is underway.

This paper discusses the key aspects of the investigation and analysis to design the native plugs and the assessment of seepage potential into the surrounding formations.

SITE GEOLOGY

The Coalspur Mines Operation site is in the Western Canada Sedimentary Basin on the eastern edge of the Rocky Mountain Foothills (Hamblin, 2004). The area was formed because of the Laramide Orogeny. The geologic setting developed primarily from eroded and transported Canadian Cordillera sediments deposited in fluvial and floodplain environments during the Upper Cretaceous and Paleocene. Two major geology formations are present at the mine site; these are the Paskapoo and Coalspur Formations. The Paskapoo conformably overlies the Coalspur Formation. The surficial geology of the site consists of an upper layer of muskeg underlain by silty, sandy, and clayey glacial till. Although there can be significant granular

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materials near surface, previous hydrology investigations did not identify significant surficial aquifers.

Lithology

Paskapoo Formation. The Paskapoo Formation consists predominantly of fluvially derived sediments forming interbedded mudstones, siltstones, and sandstones (Hamblin, 2004). The primary composition is a thick bedded, massive to cross-bedded, medium to coarse grained, light grey sandstones, with some grey to greenish grey sandy mudstones and siltstones. In the Hinton area there are a few economically significant bituminous coal layers of the Obed Coal Zone (Hamblin, 2004).

Coalspur Formation. The Coalspur Formation consists of fluvially derived sediments that formed varying massive too thin interbedding of sandstone, siltstone, mudstone, and coal with some bentonite (Glass, 1997). The sandstone is largely grey and fine to coarse grained, with greenish grey mudstone and siltstones (Glass, 1997). The Vista Mine extracts coal from six continuous layers in the Coalspur Coal Zone: the Val d'Or, Arbour, McLeod, McPherson, Silkstone, and Mynheer seams. The primary sources of coal are the Val d'Or, McLeod, and McPherson zones. In many of these zones the coal is interbedded with bentonite.

Geotechnical Investigation

Field Investigation. A total of 11 geotechnical borings were completed within the native plugs and area surrounding the tails cells (Figure 1). Obtaining core allowed for visual inspection and characterization of the subsurface geology. Samples collected from the borings were used to characterize the geotechnical properties of the key geology subunits with laboratory testing. The samples were photographed, packaged in plastic, and sealed to preserve in-situ moisture content and material conditions.

Upon completion of drilling each geotechnical boring, multi-level vibrating wire piezometers (VWP) were installed to measure in-situ groundwater levels. The existing groundwater levels are necessary to understand local groundwater flow and provide a basis to analyze future flow regimes around the tailing cells. Furthermore, the VWP installed within the native plugs can be utilized to monitor pore pressures during operations to facilitate comparisons between pre-mining, active mining, post-mining, and tails deposition. All VWP were fully grouted installations to ensure a vertical seal between the multiple observed groundwater levels. Although the exact installation details were specific to each boring, typically they were installed within the overburden Till, the McLeod coal seam, the McPherson coal seam, and foundation below the McPherson coal seam.

Native Plug Geology and Lithology. The detailed, local stratigraphy for the native plugs, as identified in the geotechnical borings, is summarized in Table 1. A simplified cross-section is shown in Figure 2.

Table 1. Summary of Native Plug Geology.

Material	Description
Glacial Till	Weakly cemented silty sand with gravel. Moist, brown.
Sandstone	Massive, medium to coarse grained; gray, RQD is 50%.
Upper mudstone	Overlies the McLeod coal seam, fractured, dark gray, frequent fractures, RQD between 0 – 25%.
McLeod coal	Bituminous, highly fractured, low RQD.
Clay parting	Present in all coal seams, primarily a high plasticity clay (CH) varying in thickness of 0.1 to 0.45 meters. Tan to light brown, massive to fissured with variable strength.
Lower Sandstone	Massive, medium to coarse grained, gray to gray, brown, RQD ranging 50 – 98%.
Lower mudstone	Typically observed two layers, approximately 4 m and 0.5 m respectively, dark gray to gray, brown, RQD between 55 to 90%
McPherson coal	Like McLeod coal.

Laboratory Testing

Core samples collected during the field investigation were tested to determine to characterize the material through index testing and determine mechanical properties. The test program, over the course of the site investigation and supplemental programs, consisted of moisture content, grain-size distribution, Atterberg Limits, organic content, unit weight, unconfined compressive strength (UCS), and direct shear. Additional testing on deposited tails samples was conducted to understand how shear strength and permeability change during consolidation. These included consolidation with ring shear and consolidation with permeability.

Moisture content. Moisture-content testing was performed on samples of from all available material types. The average moisture content of the clay parting is 33.4%, ranging between 14.7% and 43.6%. The average moisture content of the coal is 26.5%.

Unit weight. The average dry unit mass of the clay partings is 12.66 kN/m^3 ranging from 11.19 kN/m^3 to 15.00 kN/m^3.

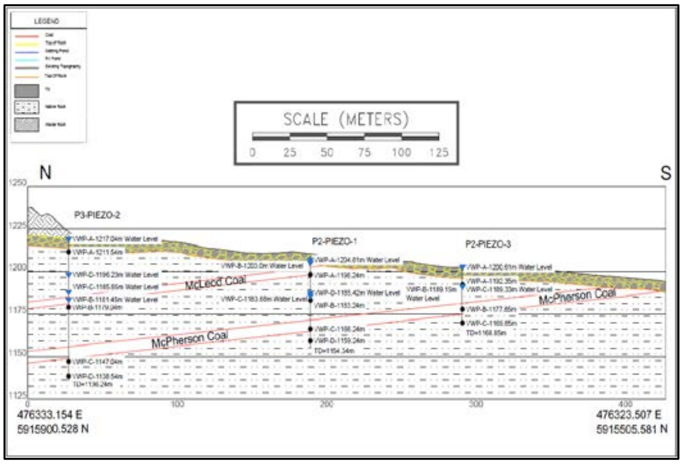

Figure 2. General north-south cross-section through the native plug area for Cell #2.

Grain size analysis. Grain-size analyses, both mechanical (sieve) and hydrometer analyses, were performed on samples of clay parting materials. The mechanical grain-size analysis is used for coarse-grained gravel and sand particles. The hydrometer analysis is used to determine the grain-size distribution of fine-grained silt and clay materials. For the samples identified as clay during core logging, the percentage of sand ranged from 3.9% to 18.8%, with an average of 10.4%. The percentage of silt ranged from 18.7% to 26.5% with an average of 21.8%. The percentage of clay ranged from 54.7% and 75.3% with an average of 67.8%.

Atterberg Limits. Variations in liquid limit (LL) may indicate changes in clay particle characteristics. Larger clay particles tend to have lower aspect ratios than smaller platy-like clay particles. The large aspect ratio of smaller clay particles creates more surface area per volume of the particles. This allows platy-like particles to hold more water, resulting in a higher liquid limit. The liquid limit is the amount of moisture required for a material to act as a liquid. Other parameters associated with Atterberg Limits are the plastic limit (PL) and plasticity index (PI). The plastic limit is the moisture content required for a sample to deform plastically. The plastic index is the difference in moisture content between the liquid limit and plastic limit.

The liquid limit of the clay material ranged from 80% to 213%, with an average of 150%. The plastic limit of the clay material ranged from 44% to 61%, with an average of 48.55%. The resulting plasticity index of the clay material ranged from 36% to 152%; the average plasticity index was 101.45%.

Shear strength testing. Shear strength parameters used in the modeling were estimated based on the laboratory test results from native plug studies and previous works. The parameters have been reviewed and updated, when necessary, as new laboratory results become available. In these analysis materials are typically treated as behaving similarly to soil. A Mohr-Coulomb based failure criterion is applied for both the drained (ESSA) and undrained (USSA) strengths. The undrained strength applies when excess pore-water pressures are present and is normally used when performing highwall analysis, because the active mine pit is only open for a relatively short period of time. The drained strength parameters are used once excess pore-water pressures have reached equilibrium, mobilizing the drained shear strength. Drained strengths are suitable for analyzing slopes when mine operations have been paused for an extended period or the material comprising the slope is granular and the soil drains relatively quickly not allowing excess pore pressure development.

Within the coal seams, zones of massive to fissured stiff clay parting material with high plasticity and liquid limit were observed during the investigation. Fissured material shows signs of shear zones which may have a lower strength (fully softened or residual) relative to its intact strength. Fully softened and residual strengths were estimated based on Atterberg Limits and clay content following Stark and Hussain (2013). Both fully softened and residual strength were considered in analysis in addition to undrained and drained conditions.

The testing methodology includes direct shear tests, UCS tests, and use of material parameters from the previous studies. The undrained strengths determined through testing are generally high. Conservative values were selected for the rock mass incorporated into the stability models represented by cohesion. These values are selected to account for discontinuities and weathering.

DESIGN PARAMETERS

A conservative approach was utilized in defining stability parameters based on the laboratory test results and field logging observations. A standard practice is to use the 33rd percentile for selection of non-liquefiable soil strength parameters and 20th percentile for selection of liquefiable soil strength parameters. To avoid convergence issues in the limit equilibrium analysis cohesive strength values are assigned to the rock units in the model using a lower bound approach. For the contractive clay parting undrained, drained and fully softened strength were considered in the analysis and additional analysis performed based on the residual drained strength for additional check. Also, a zero-strength property (fresh water) was used for the slurry deposit, which is unrealistically conservative, for the stability model evaluations. Supplemental testing on tails samples and CPT data obtained following design completion are now available for the subsequent native plug designs. In practice, a 0.22 undrained shear strength ratio can be assumed for normally to under-consolidated soil. This value can become higher as the mine plans to discharge ponded water above the deposited coal refuse which help accelerating self-consolidation process and matric suction. The coupled consolidation-ring shear test results from the supplemental testing indicate a variable strength with depth and consolidation.

Table 2. Summary of Model Parameters.

Material	Moist Unit Weight (KN/m^3)	Vertical Hydraulic Conductivity (m/s)	Anisotropy (k_y/k_x)	Shear/Normal Function (kPa)					c (kPa)	φ (°)
Overburden Till (Drained/Undrained)	19.8	1.40E-04	0.07	N/A					20	34
Upper Sandstone (Drained/Undrained)	23.0	5.60E-07	0.01						300	0
Lower Sandstone (Drained/Undrained)	23.0	5.60E-07	0.1						950	0
Upper Mudstone (Drained/Undrained)	22.9	1.70E-10	0.1						185	0
Lower Mudstone (Drained/Undrained)	22.9	1.70E-10	0.1						750	0
Coal - Drained	13.6	8.20E-06	0.01						24	31
Coal - Undrained									550	0
Clay Parting - Drained	16.2	8.20E-06	0.01						1	19
Clay Parting - Undrained									60	0
Clay Parting - Fully Softened				(0,0)	(12,4.9)	(50,17.0)	(100,29.4)	(400,95.9)	N/A	
Clay Parting - Residual				(0,0)	(50,6.9)	(100,12.5)	(400,42.9)	(700,59.9)	N/A	
Waste Rock Buttress	23.0	1.00E-03	1.0	N/A					0	38

GROUNDWATER AND SEEPAGE

Groundwater Discussion

The geotechnical borings with the vibrating wire piezometers installations are shown in Figure 1. An example cross-section for the native plug for Cell #2 is shown in Figure 2. The installation location below the ground surface and the corresponding measured groundwater level (as of April 20, 2020) are indicated on the cross-section.

The vibrating wire piezometers installed in the McLeod coal seam are designated as “A,” and measured groundwater level within the coal seam. Based on the observed groundwater measurements, the general gradient was from east to west. VWPs installed in the material separating the McLeod and McPherson coal seams are designated as “B.” The general gradient within this interburden is from north to south and from west to east

VWPs installed in the McPherson coal seams are designated as “C.” The VWPs installed in the foundation, below the McPherson coal, are designated as “D.” Both layers show the general gradient is from north to south.

Seepage Analysis

A series of MODLOW models were developed to evaluate the groundwater gradient during various stages of the tailing cell development and fine coal refuse deposition. The purpose was to evaluate whether preferential groundwater flow was toward the open pits and tailing cells, or outward into the surrounding geology formations. An example of one of the scenarios is shown in Figure 3.

Based on the available information and analysis parameters, the groundwater study identified that the overall flow gradient remains north to south and is toward the Tailing Cells. This means that no significant seepage from the fine coal refuse placed in the tailings cells is expected along or through the McPherson coal seam. Furthermore, including the highwall mining excavations within the McPherson coal seam did not impact the groundwater flow direction as determined by the model.

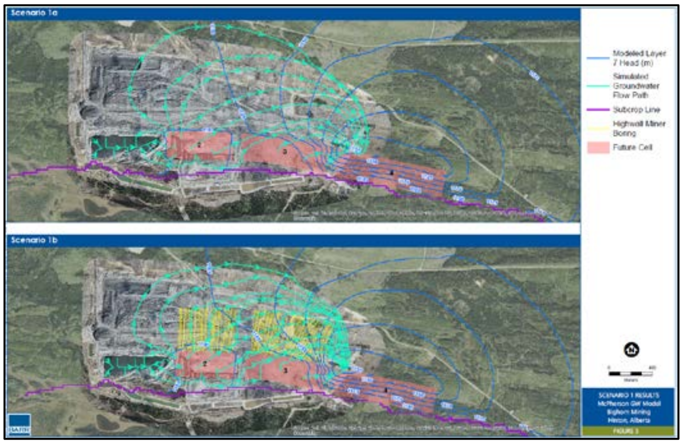

Figure 3. Groundwater flow models for potential seepage from the first three tailing cells; the 4th is modeled as an open pit.

Uplift and Piping Potential

Since the native plugs are structures left in place in its original condition, as opposed to a typical constructed earthen embankment which is built from engineered fill with specific design features requiring different levels of compaction. Therefore, there is minimal disturbance to materials within the native plug footprint. The risk of piping exists when the foundation soil composes of non-cemented to very weakly cemented cohesion soil. The native plugs for these cells have a natural foundation composed of siltstone and sandstone which have relatively high tensile strength and strongly cemented.

Considering such characteristics, and the low potential for seepage flow through the units, the potential for groundwater flow to erode the cemented particles and risking the stability of the structure is not likely. Additionally, the relatively high tensile strength of the siltstone and sandstone will create a high resisting force combined with their inherent mass to prevent any uplift instability. The addition of a downstream toe buttress will also prevent material transport through the coal seam and will provide additional resistance against uplift forces. It is also anticipated that the fine materials deposited in the tailings cell will form a low permeability barrier on the floor and against the slope of each native plugs acting as a clay liner resulting in reduced gradient. This will further mitigate any seep related risk.

NATIVE PLUG DESIGN ANALYSIS

Design Criteria

The main objective of the slope stability analysis was to evaluate the native plugs against downstream failure. The upstream slope stability was also analyzed for the integrity assessment of the plugs. The critical cross-sections for each plug were considered as the scenario where the difference in height between the pit floor and top of the plug is at its maximum, which occurs at the north end of the native plug. A cross-section through the south end of each native plug were analyzed as well to ensure there were no local stability concerns. Coalspur determined that the maximum elevation of the tailing will maintain a minimum of 2 meters below the contact of the till and the bedrock; therefore, the stability of the till overlying the native plugs will not pose any risk to the performance of the plugs for retaining impounded materials.

As fine refuse is deposited within the tail cells, it will provide additional slope stability benefit through the placement of material against the upstream slope. FOS requirement for the designed native plug was selected based on the Canadian Dam Association (CDA) technical bulletin (CDA, 2019). Guidelines list target factors of safety for the slope stability of mining dams: 1.3 during or at end of construction and during full or partial drawdown, and 1.5 during normal operation of the dam and for long term stability and 1.0 for pseudo-static analysis for seismic event. For scenarios where there is a potential loss of stored materials, Barr selected a target factor of safety of 1.5 or greater for static conditions and 1.1 for seismic conditions.

As previously explained, two types of stability analyses for static conditions are typically performed for retaining structures: the undrained strength stability analysis (USSA) which represents the short-term condition and the effective stress stability analysis (ESSA) which represents the long-term condition.

Earthquake Design

The mine facility is in a relatively low seismic area as can be observed on the Canada earthquakes map (NRC 2015). As mentioned above, the McPherson tailings cells should be designed to meet requirements for a “Significant” consequence dam based on the ADCSD (2018) and Canadian Dam Safety Guideline (2013). These guidelines require that the dam is designed for an earthquake with an annual exceedance probability between 1/100 and 1/1000 return period. However, a conservative approach to account for any uncertainties was followed by evaluating the stability of the native plugs for an earthquake with an annual exceedance probability of 1/2475 return period.

This is typically a standard for structural seismic performance assessments when modeling. This equates to the median bedrock peak ground acceleration (PGA) at a probability of exceedance of 2% in 50 years. Based on the earthquake map of Canada (NRC, 2015), a peak ground acceleration (PGA) of 0.128g is justified for the mine site. In the GeoStudio, the SLOPE/W module can be used to perform a pseudo-static analysis by introducing the horizontal and vertical seismic coefficient as the fraction of the PGA. The application of a vertical seismic coefficient often has little impact on the safety factor. It is prudent to use half of the PGA as the horizontal seismic coefficient (Pyke, 1991). Therefore, a horizontal coefficient of 0.065 was used in the pseudo-static analysis for this design.

Slope Stability Modeling

The slope stability analysis was conducted using SEEP/W and SLOPE/W, a computer-modeling program developed by GEO-SLOPE International, Ltd. SEEP/W uses finite-element analysis to compute pore water pressure conditions from boundary conditions to model the piezometric surface of the proposed plug. SLOPE/W uses limit equilibrium (LE) theory to compute a factor of safety for earth and rock slopes. It can use a variety of LE methods to compute a slope’s factor of safety while analyzing complex geometry, stratigraphy, and loading conditions.

A combination of Morgenstern-Price and Spencer’s methods was used as the search technique to determine the FOS for the McPherson Tailing Cells’ native plugs stability analysis. Optimized critical failure surface was allowed for the downstream failure mode when the critical surface wasn’t bounded within the till to allow for failure over bedrock in addition to assumed block failure over underlying sand seam based on the existence and location of the clay parting. A minimum slip surface thickness of 1.0 meter was applied to the stability models. Potential slip surfaces less than 1.0 meter in depth were associated with shallow material raveling and will not risk the integrity of the structure.

The phreatic surface used in SEEP was generated assuming each cell’s respective final fine-coal refuse elevation and hydraulic conductivity properties of the materials applied for the MODFLOW analyses examining seepage.

Model Geometry

The surface and subsurface geometry was based on CAD surfaces from drone surveys provided by Coalspur, as well as results from the stratigraphic interpretation from the drilling investigation. A crest width of minimum 8.5 meter wide, a downstream slope of 45 degrees with a toe buttress of 22- to 11-meter-wide crest, 26 degrees slope with a height of 13 to 7 m which starts from 5 to 4 meter above the contact of the top of McPherson coal seam was considered appropriated for the native plug designs. A schematic cross-section is shown in Figure 4.

A conservative approach was utilized in the modeling for the tails by assuming fresh water instead of coal refuse within each cell. This approach disregards existing strength within the coal refuse due to the presence of solids, as well as the strength gain from the effect of self-consolidation and evaporation and pumping of stagnant process water.

The maximum tails elevation, on the upstream side of the native plug, averaged the 1190 m elevation.

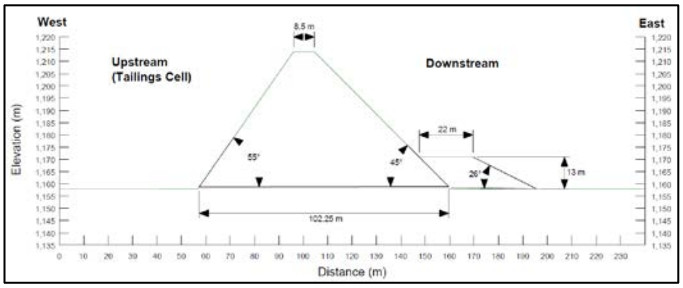

Figure 4. Example native plug cross-section with dimensions. The average tails elevation was 1190 m.

Model Parameters

Barr developed model parameters using field and laboratory data and previous geotechnical studies. Field data includes information from borings logs and E-logs conducted around the proposed plug. Laboratory data used to develop parameters is discussed in previous sections; the material strength properties are summarized in Table 2.

A conservative approach was utilized in defining stability parameters. It is industry practice to use the 33rd percentile for selection of non-liquefiable soil strength parameters and 20th percentile for selection of liquefiable soil strength parameters. To avoid convergence issues in the limit equilibrium analysis cohesive strength values are assigned to the rock units in the model using a lower bound approach. For the contractive clay parting undrained, drained and fully softened strength were considered in the analysis and additional analysis performed based on the residual drained strength for additional check. Also, a zero-strength property (fresh water) was used for the slurry deposit (which is unrealistically conservative). In practice, a 0.22 undrained shear strength ratio can be assumed for normally to under-consolidated soil. This value can get higher as the mine plans to discharge ponded water above the deposited coal refuse which help accelerating self-consolidation process and matric suction.

Table 2. Summary of Cell #2 Native Plug Slope Stability Analysis Results.

Model Scenario	FOS Summary	
	North	South
Full Tailing Cell		
Dr - DS	1.57	1.59
Udr - DS		
Udr-Block-L.C.-DS		
Udr-Block-M.C.-DS		
Udr-Block-U.C.-DS		
Udr-Block-MSt-DS		N/A
FS - DS		1.59
FS-Block-L.C.-DS		
FS-Block-M.C.-DS		
FS-Block-U.C.-DS		
FS-Block-MSt.-DS		N/A
Res-DS		1.61
Udr - US	2.1	1.66
Udr-Block-L.C.-US		
Udr-Block-M.C.-US		
Udr-Block-U.C.-US		
Udr-Block-MSt.-US		N/A
FS - US		1.66
FS-Block-L.C.-US		
FS-Block-M.C.-US		
FS-Block-U.C.-US		
FS-Block-MSt-US		N/A
Udr – DS (Seis)	1.35	1.37
Udr-Block-L.C.-DS (Seis)	1.13	1.36
Udr-Block-M.C.-DS (Seis)	1.10	
Udr-Block-U.C.-DS (Seis)	1.11	
Udr-Block-MSt-DS (Seis)	1.35	N/A
FS – DS (Seis)	1.35	1.37
FS-Block-L.C.-DS (Seis)		1.36
FS-Block-M.C.-DS (Seis)		
FS-Block-U.C.-DS (Seis)		
FS-Block-MSt-DS (Seis)		N/A
Empty Tailing Cell		
FS-Block-L.C.-US	2.10	1.36
FS-Block-M.C.-US		
FS-Block-MSt.-US		
Udr-Block-L.C.-US		
Udr-Block-M.C.-US		
Abbreviation Legend		
Dr	Drained Strength	
Udr	Undrained Strength	
FS	Fully Softened Strength	
Res	Residual Strength	
Block	Block Failure	
L.C.	Lower Coal	
M.C.	Middle Coal	
U.C.	Upper Coal	
MSt	Mudstone	
US	Upstream Slope	
DS	Downstream Slope	
Seis	Pseudo-Static Analysis	

Minimum FOS Search Method

Minimum factors of safety were determined in GeoStudio models by the grid and radius method to review global critical surfaces over probable ranges in the model. Multiple failure modes were analyzed, including undrained scenario, drained scenario, fully softened scenario where the clay parting material was assumed to have reached a fully softened state and residual strength scenario for clay parting Since in Slope/W only circular failure slip surface is considered, optimization of the slip surface and block failure by assigning impenetrable material type to the potential slip plane were incorporated in the analysis.

Stability Analysis Results

Each native plug design analysis required over 70 model scenarios. This approach accounts for evaluating undrained, drained, fully softened, and residual strengths, full and empty tails cells, static and pseudo-static conditions, both the upstream and downstream slopes, and assuming circular and block failure geometries. Since the subsurface geology and native plug dimensions are similar between each location, this paper will only show the results for Tailing Cell #2 within this section. The stability analysis results are summarized in Table 4. The FOS for all the static scenarios is above 1.5.

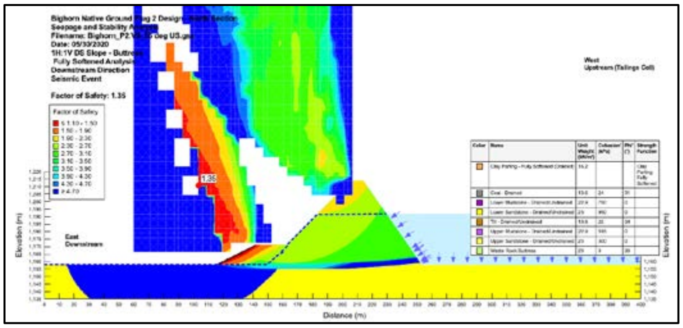

Figure 5. Example slope stability analysis results for Tailing Cell #2; fully softened, downstream, pseudo-static analysis.

Also, all the critical failure surfaces were observed to be limited to the buttress or overburden till neither of which pose a risk to the integrity of the native plug or result in a failure with potential release of materials to the environment. It should be reminded that in the stability analysis, clear water was assumed to be stored in the pond while it will be slurry coal refuse which provides additional stability in upstream direction. Factor of safety for seismic scenarios where the failure mode can intersect through the native block, is above 1.10 for all the cases which exceeds the minimum factor of safety requirement of 1.0.

HAZARD RATING AND CONSEQUENCE CLASSIFICATION

ADCSD (2018) and CDA (2013) guidelines require an evaluation of the potential consequences of failure for a particular dam. A specific set of design criteria can be selected, based on the potential consequences, to incorporate into the design of the impoundment. The location and geometry of the Tailing Cell #2 and Cell #3 to their respective native plugs are key criteria that facilitate the classification. To determine the consequence classification several categories and factors were considered including loss of life, potential damage to environmental and cultural resources, and potential damage to infrastructure economics and other property. The main assumption which relates to the classification is the fact that any potential failure will occur through the east side of the native plugs where the stored material will be released and fully contained within the adjacent pit.

- Population at Risk: As mentioned above, a potential failure will result in contained refuse to displace into the adjacent pit. The geometry and surrounding topography eliminate the potential risk of impact to surrounding mine infrastructure and nearby communities. The potential risk is limited to the people operating mobile equipment working at the bottom of the adjacent pit. This risk is temporary in nature because it requires the production fleet be in operation when adjacent pit bottom is at a depth where a breach of the respective cells native plug will result in the stored materials overtopping the mobile equipment within the pit (e.g., shovel, mine truck). This scenario is further mitigated by the immediate emergency call in place that would notify personnel to quickly begin evacuation of the pit with the mobile equipment.

- Loss of Life: the maximum number of people which work within the pit at a given is 5-6 people based on communications from mine site staff.

- Environmental and Cultural Losses: A potential failure with full release of settled material and fluid from McPherson Tailing Cell #2 or Cell #3 will only result in material loss into an adjacent pit. Due to on-going planned mining activity to the east of the native plug, no fisheries, wildlife, or endangered species will be present in the adjacent pits. Similarly, cultural values are not at risk due to the presence of an active mining pit rather than undisturbed topography.

- Infrastructure, Economics and Other Property: Considering the limited run-out extents associated with a potential loss of material, the economic losses due to a breach in McPherson Tailing Cell #2 or Cell #3 native plugs will be limited to the owner's property. This may involve damage to the equipment, loss of ore reserve or a halt in production. There is no infrastructure, public transportation or services, commercial facilities or other property in the inundation zone which can be affected by any potential dam breach. A formal dam break analysis has not been performed given the incised nature of the storage.

Based on the explanation provided above for each category evaluated to determine the consequence classification with regards to the incremental consequences of failure, the McPherson Tailing Cell is deemed to be of "Significant" consequence facility.

Additional measures of critical controls for mining and operating within McPherson Tailing Cell #2 and Cell #3 will identify changes in condition that could indicate instability prior to a potential hazard. This includes monitoring for changes in seepage through visual observation or installed VWs within each respective native plug. Internal slope movement, particularly in the clay parting layer, can be detected through regular monitoring of inclinometers.

External slope movement of the downstream slope of each cells native plug can be monitored using highwall monitoring systems and daily, monthly, quarterly, and annual visual inspection to the level appropriate for each.

It should be added that the native plugs for McPherson tailings cells will be constructed in a series arrangement meaning that each subsequent cell will contain the preceding cells. Therefore, the "Significant" consequence classification applies only to the external native plug. Any breach through the internal active plugs will only release materials to the subsequent cell without any expected risk. Consequently, it is plausible to reduce the consequence classification to "Low" for any internal plugs. It can be concluded that each preceding native plugs will be assigned a "Low" consequence following construction of the new native plug as mitigation work can be done without any potential risk.

CONCLUSIONS AND RECOMMENDATIONS

A comprehensive slope stability analysis examining undrained, drained and fully softened strength parameters, concluded that the FOS for all credible scenarios of the native ground plugs exceeded the minimum required factor of safety of 1.50. In general, the highwall material is competent and global failures are not anticipated.

In general, for Coalspur's ground and site conditions, the native plugs meet or exceed the FOS requirements with a minimum width of at least 100 meters, a downstream slope angle of 45 degrees and an upstream slope angle of 55 degrees with the maximum tail's elevation maintaining the 2 m freeboard requirement between the pond elevation and the till/bedrock contact. This results in at least several meters of freeboard to the top of the native plug.

An appropriately sized, free drain, toe buttress along the downstream slope and constructed to a height such to cover the McPherson coal seam plus 2 meters is needed to prevent block failure through the weak clay parting layers. A typical buttress of minimum dimensions of 22 m wide, approximately 13 meters high (which also accounts for the minimum achievable with Coalspur's mining equipment), and a 26 degrees downstream slope angle is recommended. The size of the buttress can be reduced towards the south end of the plugs where the tailings become shallower relevant to the native plug height.

Conservative assumptions were applied to the analysis for coal hydraulic conductivity, as well as, assuming clear water as the impounded solution. However, if minor seepage through the native plug should occur, then a drainage ditch downstream of the buttress toe to collect the seepage is recommended.

The groundwater model results indicated that the groundwater gradient is flowing north to south and towards the tailing cells. The gradient does not reverse to allow seepage out of the cells, through the McPherson coal seam.

A comprehensive Operation, Maintenance and Surveillance (OMS) manual is required for the life of the tailing cells. It is key for frequent communications between mine operations and technical services to increase awareness and need for action if changes in conditions are observed. Modifications to the OMS manual and consideration to lower the consequence of each impoundment is recommended as each native plug and tails cell transitions to an internal impoundment as subsequent open pits are excavated.

Based on studies completed to date, Barr expects that future native plug for future tails cells will require geometries like those developed for Cells #1, #2, and #3; however, site specific geotechnical investigations will be necessary to confirm and design for actual subsurface conditions.

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