Geotechnical Evaluations of a Tailings Dam for Use by a Molybdenum and Copper Mine Project in Southern Idaho

Thomas Robbins, BSCE, Graduate Student, Boise State University; and
Bhaskar C. S. Chittoori, Ph.D., P.E., Assistant Professor, Boise State University

Abstract-- A proposed mining project in Boise County, Idaho for the extraction of copper, molybdenum, and silver deposits, required investigations into a possible tailings dam construction that will be built using the processed material from the mine. The mine is located southwest of Lowman Idaho, northeast of Pioneerville Idaho, and directly north of Jackson Peak Mountain. The total area for the proposed project is approximately 12 square kilometers and the estimated material to be excavated is about 1.99 billion cubic meters (BCM) (USDA 2013). Typical investigations into the construction of a tailings dam consist of identifying the types of ore contained within the mine, identifying a suitable location for the dam based on topography, and conducting an analysis of the geotechnical aspects of constructing the dam. In this project, construction of the tailings dam will adequately model a cut and fill operation where the excavated waste material will be used to construct the tailings dam. Construction of the tailings dam will happen in stages, with a starter dam followed by successive additions to accommodate the need for reservoir capacity. Several aspects such as excavation depth, the types of excavated soil and rock, the ore processing methods, and mechanical properties of the waste material, have been considered for properly conducting an analysis of the tailings dam. Also, aspects including the slope stability of the tailings dam, seepage velocities through the tailings dam, and slope stability after a seismic event have also be studied. This paper discusses the geotechnical aspects of the tailings dam construction including the stability of the dam under both hydrological and seismic conditions.

I. INTRODUCTION

A feasibility study has been conducted for a proposed mining project for the extraction of copper and molybdenum ores in Boise County, Idaho. Topographical layout of the project site encompasses several hills, valleys, creeks, and roads. The elevation of the mine pit is 2,346 m. The highest point on the mine site is Jackson Peak, which is located approximately 600 m just south of the mine with an elevation of 2,476 m. The low points along the valleys are about 1,524 m in altitude. Historical drilling between 1964 and 1981 concluded that there are significant deposits of silver, copper, and molybdenum mixed within various types of granite (Mosquito et al. 2015). Also, the borehole drilling performed by Holgren and Giroux (2009) provided sufficient data to determine that the molybdenum located at this site is one of the largest known deposits in the world.

Due to the quantity of valuable material, this project has the potential to have significant environmental, social, and economic impacts in the Boise area. As a part of the senior design project, undergraduate students at Boise State University have evaluated various aspects of this project including, economic feasibility, environmental impacts, and geotechnical design. This paper discusses the geotechnical aspects of the tailings dam to be constructed as part of the feasibility study for the proposed mine project.

By industry standards, tailings dams are constructed to be impervious, earthen dams, which grow in height as the mine grows in depth. Height growth of the dam is due to the construction materials obtained from waste produced during mine excavation and ore processing. By use of x-ray sorting techniques, there will be two types of waste material, processed slurry, and non-contaminated waste rock. From the processing operations, the waste slurry is pumped to the upstream side of the tailings dam to create a pond where the waste material settles out of the slurry. Slurry production and dumping are modeled as a closed loop system, where the fluid from the slurry is collected at the far end of the pond once the material has settled out. Fluid is then captured and reintegrated into the processing plant for further use (Giroux et al. 2015). Non-contaminated waste material collected during the sorting stage is crushed and cycloned into finer particles which are used to construct the downstream slope of the tailings dam. Prior to any material or slurry being contained by the tailings dam, a starter dam must be constructed (Hamade 2013).

For this project, the starter dam will be constructed using overburden soil and rock as well as excavated material from the mine. Starter dam geometry will be typical of industry standards, where the slope will have a ratio of 2.5 horizontal to 1 vertical. The height of the starter dam is determined from slope stability and seepage velocity calculations as well as assumed soil properties of excavated material. The internal geometry of the starter dam will consist of a porous layer, located vertically along the centerline of the dam and horizontally across the downstream slope at the base of the dam to direct fluid flow and lower the

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phreatic surface. A geotextile will be utilized next to the porous layer to prevent internal erosion, piping, or liquefaction caused by fluid flows exceeding maximum allowable velocities. Dam construction will be done on top of a high-density polyethylene layer to prevent seepage into the groundwater below the dam. Upon completion of the starter dam, processed material and slurry can be contained within the pond. As the slurry is pumped into the tailings pond, the larger particles settle out of the slurry first and close in proximity to the tailings dam. Finer particles then settle out of the slurry further away from the dam creating a semi-impervious layer. The settlement of the material out of the slurry effectively creates a base layer to construct another phase of the tailings dam (Hamade 2013).

One of the important considerations to ensure tailings containment is the location of the dam. Locations that are most likely for the tailings dam are south of the mine. Depending on the site chosen for the dam, construction will consist of one of three methods. The first method is the downstream method. The downstream method is where the downstream side is built up to allow for more storage capacity of the tailings pond. Next is the centerline method, which is where the construction of each additional section of the mine is built directly on top of the starter dam. The third method for construction is the upstream method. This method uses the tailings settled from the waste slurry to be used as the foundation for the next level of dam construction. The upstream method is identified as the most cost efficient and low risk for seismic areas. This method allows for the coarser material that settled out of the slurry to be used as a foundation material, and the fines to act as their own impervious layer for the next level of the dam. The upstream method is the most frequently used construction method; although, due to topography it may not be the most probable method for construction at the proposed mine site in Idaho. For the project in Idaho, the most probable dam construction method is the downstream method, which would ensure a sufficient reservoir storage capacity to hold all the waste slurry produced from mining operations with an increase in construction cost. For the purpose of the analysis presented in this paper, it is assumed that the downstream method will be utilized due to the benefit of an increased storage capacity in the tailings pond reservoir.

Each of the dam construction methods discussed depend on the starter dam, which needs to be analyzed for slope stability, seepage velocities, and its ability to withstand seismic loading. Commenrcially available software, GeoStudio, was used to conduct the required analyses for the starter dam. This software allows for the specific input of the material properties, slope, phreatic surface, surcharge, slip surface, hydraulic, and peak horizontal acceleration to model realistic earthquakes (GEO-SLOPE International Ltd, Calgary, Alberta 2000). Use of the software assisted in determining the maximum height of the dam with the predetermined 2.5 horizontal to 1 vertical slope requirements, maximum allowable seepage velocity to prevent internal failure, as well as a quake analysis to ensure stability before and after a seismic event.

The design of the tailings dam is most dependent upon the soil properties of the material used to construct the dam. Five types of rock that dominate the geological features of the area are quartz monzonite, rhyolite porphyry, lamprophyre, and dacite (R.M. et al. 2009). After extraction of metals from ore, the mentioned geological rock will make up the bulk of what is used for the tailings dam. Geotechnical properties are known for this material only in rock form, as well as through research on other mines that contain similar material. Due to not having physical samples of the waste material, assumptions were made of the actual mechanical properties of the soil to be used in the tailings dam. Considering the prominent ore to be excavated from the mine will be copper and molybdenum, estimations of copper tailings will be used. Approximations for the material properties will be made from previous research on copper mine tailings conducted by Bhanbhro (2014). The assumption can be made that the mechanical properties will model material properties from other copper mines. This is due to the higher quantity of copper than any other material contained within the mine. Bhanbhro (2014) determined that the dry densities in case of copper mine tailings range from 1400 to $1700\mathrm{kg/m^3}$ for copper sands, and from 1100 to $1400\mathrm{kg/m^3}$ for copper slimes. Dam design also relies on the friction angle (Φ') of the soil. The average values were obtained by Bhanbhro (2014) to range from 37° to 42° for a drained condition and a confining pressure of 40 to 300kPa. For an undrained condition, the friction angle (Φ) ranges from 40° to 43° with a confining pressure of 90 to 170kPa.

With the previously mentioned values, it is possible to obtain design parameters of the tailings dam. Mechanical properties of the construction material, internal material layout along with dam geometry consisting of slope ratios of 2.5 horizontal to 1 vertical can be used as input data into the software. An analysis of the stability of the dam with the given parameters will output a factor of safety needed to ensure slope stabilization as well as assist in determining dam height. A typical factor of safety of 1.5 would be satisfactory for standard earthen dams, considering Idaho may be subject to periodic seismic loading it was decided to target a factor of safety of 2 for this project (GEO-SLOPE International Ltd, Calgary, Alberta 2000). The results of these analyses are presented in this paper.

II. TAILINGS DAM OF CUMO MINE

Geotechnical aspects of the CuMo mine project include the excavation of the mine pit, processing of ore, and the tailings dam constructed using waste material from the mine. The total volume of the excavated mine pit was estimated to be 1.99 billion cubic meters (BCM) based on the geometry of the proposed mine pit (USDA 2013). Excavated material will then be processed to extract the sought-after ores including, copper, molybdenum, and silver. Industry standards to extract ore have been researched, and the method of ore extraction has been determined. This method will include rock excavation, then pulverization of rock to a workable material with a diameter of approximately 2.5 to 10 centimeters. The material is then passed through an x-ray sorting system which identifies and separates rocks that contain the desired ore. Waste material that does not contain ore is then separated and used for the construction of a tailings dam, or placed in an overburden fill site while material that does contain ore will be sent to processing for ore extraction (Mosquito et al. 2015). This methodology of separating rock material that contains ore, from a material that does not contain ore reduces the amount of processed rock material which indirectly reduces the required volume for tailings pond storage.

Material that is retained for further ore extraction is then pulverized so that the material is fine enough to pass a #200 sieve (0.074mm). The solids are then saturated and mixed into a slurry to facilitate chemical extraction or ore. Upon completion of ore extraction a slurry mixture of chemicals, water, and solid waste material, is pumped to a tailings pond to allow the settling of solids. At the opposite end of the pond from where the slurry is dumped, the liquid is collected and syphoned back into the processing plant. The tailings pond is designed to be a closed loop system where all infiltrated water is contained and utilized within the processing operations.

A. Construction Method

Typical of industry standards, tailings dams are constructed to be impervious earthen dams, which grow in height as the mine grows in depth. The tailings dam is constructed using both the contaminated and uncontaminated waste material from the mining process. As the material filling the reservoir in the tailings pond is coming from the excavated material from the mine, the tailings dam is constructed in stages. The first stage of the construction will consist of building a starter dam to contain the first throughput of processed material. Construction material for the starter dam will consist of the overburden rock that is excavated from the mine. The starter dam geometry will have slopes that are 2.5 horizontal to 1 vertical as per industry standard (Hamade 2013), with a 10m roadway on the top to allow for any vehicles to maneuver on top of the dam. The actual height of the started dam will depend on the material type used in the construction of the starter dam. Stability analyses were performed using various possible material types that could be yielded from the CUMO mine and based on this analysis the starter dam height was determined.

There are three methods of construction for tailings dams, the upstream, centerline, and downstream methods (Hamade 2013). The downstream method will be used for the construction of the tailings dam, see Figure 1 below, (Holmqvist and Gunnteg 2014). Although this is the most expensive method of dam construction, the downstream method ensures that the reservoir capacity is large enough to hold all the waste material. The downstream method consists of adding several additional dams, built on top of one another by using the previous dam as the base. Upstream slope of the dam is built by the settling of fine particles out of the waste slurry, and the downstream slope being constructed from uncontaminated waste from mining operations. The centerline of the dam moves down stream with each consecutive addition to the dam. The length of the tailings dam is approximately one mile. The final maximum height of the tailings dam is modeled to be a total of 250m, which will hold all the projected mine tailings along with any infiltration from natural water sources. Material settlement on the upstream side of the dam effectively creates an impervious layer. This is due to the fine particles with a diameter small enough that the porosity and hydraulic conductivity is essentially zero.

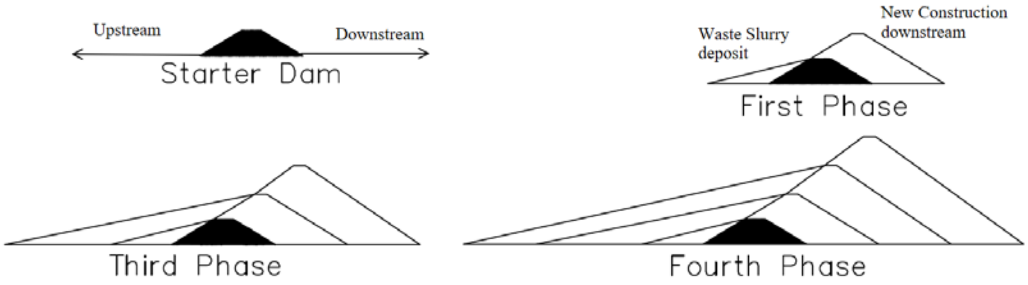

Figure 1: Downstream method of construction (modified from (Holmqvist and Gunnteg 2014))

With the height of the dam growing with each additional phase, the slope of the upstream side grows to be more horizontal. Once the tailings dam reaches the final design height, the slope of the upstream side of the tailings dam is projected to be five horizontal to one vertical. With the gradual slope, and controlled seepage through the dam, the possibility of catastrophic failure in the lifetime of the dam is negligible.

B. *Construction Materials*

The internal geometry of the dam is split into three sections, the upstream side, the downstream side, and the porous layer. Waste slurry from processing is pumped to the downstream site, and the unprocessed waste material is trucked to the upstream side. The porous layer consists of coarse gravel excavated from the mine that does not contain any ore. Porous layer mechanical properties will be similar to the coarse material used for the dam, although it will be the larger size of approximately 2.5 to 5 cm in diameter with a high porosity. As stated by Richards (2012), approximately 50 percent of all dam failures occur due to uncontrolled seepage (Richards 2012). A geotextile layer will be used to protect the porous layer from internal erosion due to uncontrolled seepage and stop coarse material from being washed out of the dam. Geotextile properties have been modeled such that the control of the phreatic surface and water flow prevent piping, internal erosion, liquefaction, or any other seepage failure throughout the dam. Permeability through the geotextile was assumed to be 1×10^{-8} mm/s. To prevent seepage of waste into the ground water table, the starter dam will be constructed on top of a high strength synthetic material such as 30 mil polyvinyl chloride (PVC) or high-density polyethylene (HDPE) 60 mil liner (Rohe 2017). The synthetic layer has been modeled to be impervious. Research conducted by Bhatia (1996) identified several specific attributes that occur at the interface between the soil layer and the geomembrane liner. Attributes such as:

- Friction angle increases with particle size at the interface
- Friction angle increases with increase of flexibility of geomembrane
- Friction angle is higher with PVC than with smooth HDPE

Consideration of these attributes establishes a preference for the geomembrane liner. Preference for the geomembrane liner is to be PVC, over the HDPE. This recommendation is to conform to the studies conducted by Bhatia (1996), where the results of the research concluded that the friction between sand and the PVC liner is greater than that of the sand and HDPE liner (Bhatia 1996).

Materials that are used to construct the tailings dam will consist of the previously mentioned waste from processing operations. From ore processing, the maximum and minimum diameter of the tailings particles are estimated to be 0.82 mm 0.03 mm respectively. Research done on the mechanical properties of copper tailings conducted by various researchers allowed for the estimations on the tailings produced by the mine (Bhanbhro 2014; Holmqvist and Gunnteg 2014; Hu et al. 2016). Values obtained from the research were used as the upper and lower limits for computational analysis. It was assumed that the properties were normally distributed between these upper and lower limits. The purpose of using researched data was to design the dam using materials that have been tested and their mechanical properties verified, which ensures that the results are realistic. Assigning a distribution to the given values allowed for a statistical variance to be modeled within the software given variation in actual material properties. Values obtained from research such as void ratio, natural moisture content, unit weight and hydraulic conductivity are shown in Table I.

TABLE I
Geotechnical properties of soil used for construction of tailings dam

Soil	Particle Size (mm)	Unit Weight (kN/m^3)	Hydraulic conductivity m/s	φ'	MC%	Poisson's Ratio	Damping Ratio	D10	D60	LL	e
Course	0.82	23.544	0.11178253	42	67	0.45	0.1	0.0650	0.140	NA	0.840
Fine	0.03	17.69	5.6997E-05	32	39	0.334	0.3	0.015	0.09	23.33	0.9983

III. NUMERICAL ANALYSIS OF THE TAILINGS DAM

Numerical analysis of the tailings dam was performed using a commercially available software package, GeoStudio. This software package included several applications to analyze slope stability, seepage, finite element slope stability and quake analysis. Three different types of analyses were performed on the tailings dams; a) Seepage analysis, b) Slope Stability analysis, c) Seismic analysis. The following sub-sections present the details of these analyses.

A. Tailings dam model

Location of the tailings dam has been assumed to be approximately two kilometers south of the proposed mine. Dam location was determined based off proximity to the mine, as well as reservoir capacity. The dam will run north to south and enclose a small valley surrounded by two mountains, Jackson Peak, and Wilson Peak, as shown in Figure 2. Waste slurry from the mine was assumed to flow from the dam to fill the reservoir at an elevation of approximately 1798 m and fill the contours of the valley absorbing Clear Creek and Middle North Fork Creek. The length and final height of the dam were determined by the valley contours, elevations, and reservoir capacity needed to contain all waste material produced from mining operations. For the mentioned requirements, the final dam height was calculated to be 230 meters. To account for error in computations, and variances in assumptions of dam location and valley topography, the final height for the model was set at 250 meters. The final height of the dam is considering the lowest portion of the valley, to the top of the dam. Analysis of the tailings dam is considered at this location within the dam, as it is modeling the worst-case scenario.

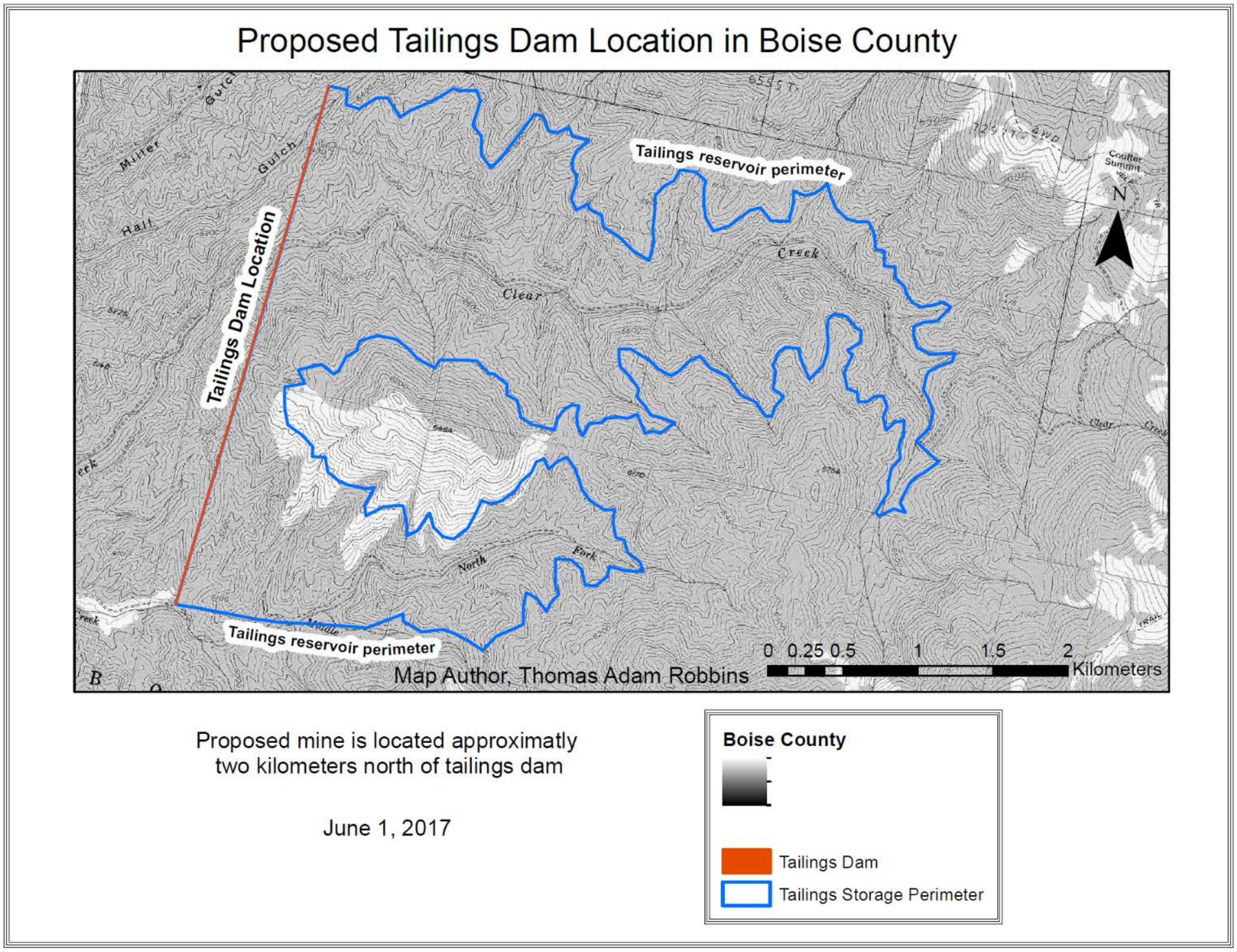

Figure 2: Map of proposed tailings dam and reservoir locations.

From analyzing slope stability with the slope of 2.5 horizontal to 1 vertical, the initial height of the starter dam was determined to be 15 meters. Accounting for a roadway on top of the dam, a 10 m path was drawn in the model. External geometry of the tailings dam model consisted of being 15 meters in height, and 80 meters in width. Geological features in the area researched from the USGS, bedrock is typically within 5 meters of the ground surface (Anderson 1947). An assumption was made to place a generalized bedrock layer 3 meters below the surface. The base material between the bedrock and the dam was modeled as sand. Base material and bedrock were extended beyond the toe of the dam to ensure the seepage, and slope stability calculations were not hindered by incorrect model boundaries. The boundary conditions were extended to 50 meters beyond the toe of the dam. 50 meters was determined by analyzing boundary conditions at various locations from the toe of the dam, to find if any impact on seepage velocity or a factor of safety calculations occurred. The model was drawn within the software to mimic a starter dam, with the fine sand on the left side of the dam, and the coarse sand on the right. A porous layer and PE liner were drawn in the model and colored differently to differentiate each material from one another, see Figure 3.

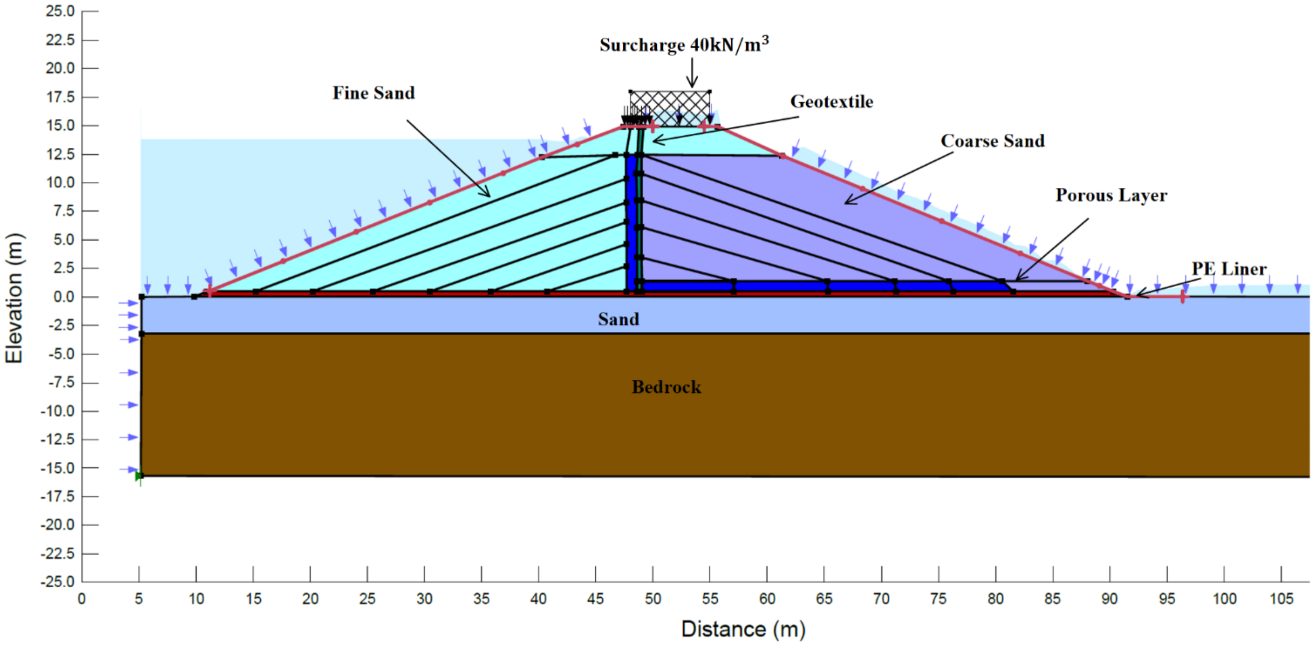

Figure 3: Starter dam geometry and internal material layout.

B. Seepage analysis

After drawing the model, the first step in the computational analysis was to determine the natural forming phreatic surface through the dam. In order to establish this natural free flowing surface, a steady state seepage analysis was performed. Unsaturated material properties are determined from existing reports, while the saturated properties were estimated by use of functions provided by the software. To model for worst case scenario, an assumption was made that the fluid moving through the dam was water, with a viscosity value of 1.0×10^{-6} m^2/s. From the material properties that are shown in Table I, the hydraulic conductivity, particle size, and natural moisture content were used to create variable functions within the software.

Maximum allowable seepage velocity was computed by multiplying the critical hydraulic gradient to the porosity of the course material. This gives the largest possible seepage velocity allowable to prevent piping or internal erosion through the dam. Given the material properties, the maximum allowable velocity of the seepage through the tailings dam is 4 mm/s. Maximum seepage velocity computed from the model was to be 0.005 mm/s. Seepage through the dam model is determined safe, as it is less than maximum allowable velocity. The highest seepage velocity is located at the toe of the tailings dam, which is expected due to that location being modeled as the exit for the porous layer, see Figure 4. Results from the analysis of the seepage through the dam were then used as a parent analysis for all other applications. This further aided the realistic computations for slope stability, and quake analysis.

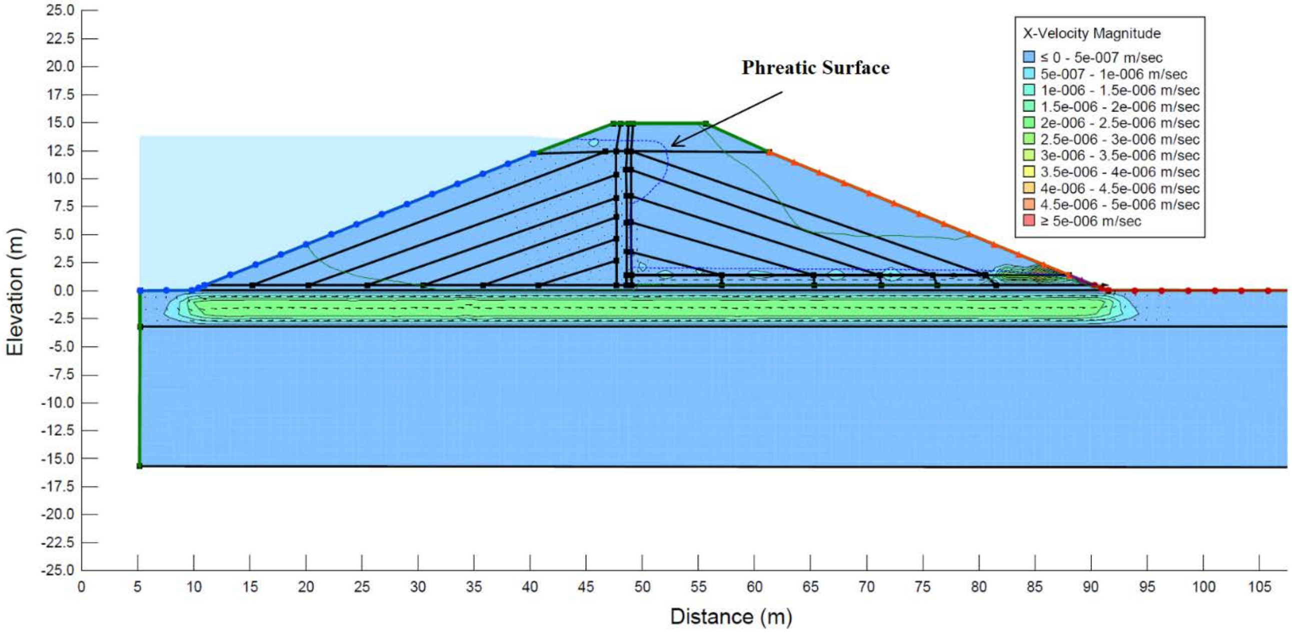

Figure 4: Seepage through starter dam.

C. Slope Stability Analysis

After the seepage analysis, the initial slope stability was determined by use of the software. This application considers Mohr-Coulomb association for mechanical properties of the material such as unit weight (γ), and internal friction angle (ϕ'). Material properties were set using probabilistic parameters by the Monte-Carlo simulation method. This method was used to show the highest probability of failure along with the factor of safety. Monte-Carlo simulation method enabled the material to be variable and normally distributed between two boundary conditions. Upper and lower limits for the boundary conditions are shown in Table I. For the probability function, the analysis ran 2,000 computations from the given boundary conditions, and determined a normal distribution of factors of safety given a zero probability of failure. This shows a range of needed factors of safety to reduce the probability of failure to zero. From the first slope stability computations, the standard deviation was 0.0092, and the mean factor of safety was 3.931, with the minimum and maximum being 3.8633 and 3.9548 respectfully see Figure 5. For the second slope stability analysis, the standard deviation was 0.0026, and the mean factor of safety was 2.5622, with a minimum and maximum of 2.5424 and 2.5889 respectfully, see Figure 6.

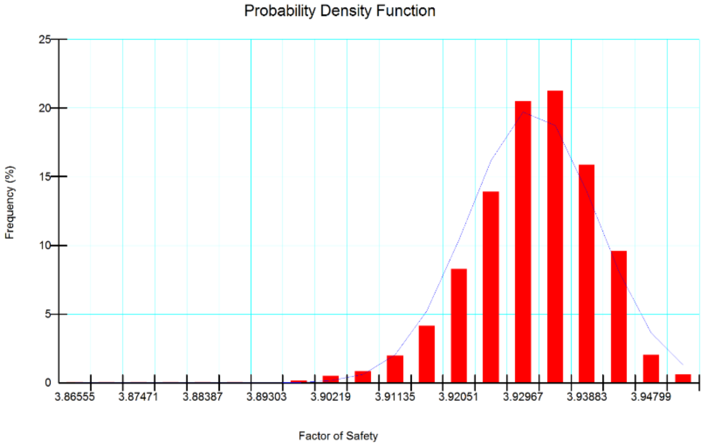

Figure 5: Factor of safety vs. Frequency of failure graph for the first slope stability analysis

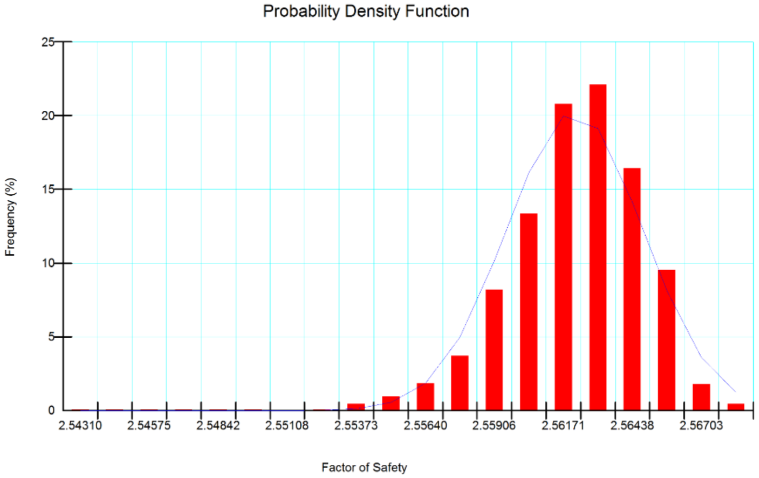

Figure 6: Factor of safety vs. Frequency of failure graph for the second slope stability analysis

To ensure that the dam was sufficiently stable during construction and use of the tailings pond, a surcharge of 40 $\mathrm{kN/m^3}$ was applied to the top of the dam to simulate a large truck that would drive on the dam. Bishop's method of slices was used to determine the slope stability. Bishop's method takes sections of the surface being analyzed down to the known phreatic surface obtained from the previous analysis. To simplify computations, the model for the slices was analyzed without considering a tension crack at the top of the slip surface. Forces and moments acting on each individual slice are balanced to find the resulting force (Budhu 2011). After each slice is analyzed, a factor of safety can be determined by dividing the available shear strength of the soil by the minimum shear strength to maintain stability (Budhu 2011), see Equation 1

$$FS = \frac{\Sigma W_j \tan(\phi')_j m_j}{\Sigma W_j \sin\theta_j} \tag{1}$$

Through research, it has been recommended that for earthen dams the factor of safety for slope stability to be 1.5 or larger. Due to the location of the dam being within a seismic zone, it is recommended to maintain a factor of safety of 2.0 or larger (Hamade 2013). The suggested minimum dictated a target factor of safety of 2.0. However, a factor of safety that fell below 2.0 does not necessarily constitute a catastrophic failure. From initial static slope analysis, the slope stability was computed to be 2.085, which is above the suggested minimum. As shown in Figure 5, the slip surface was taken from the top of the dam where the surcharge is applied to a location midway down the downstream side. This area also shows the critical failure region with the individual slices used for computation shown in green.

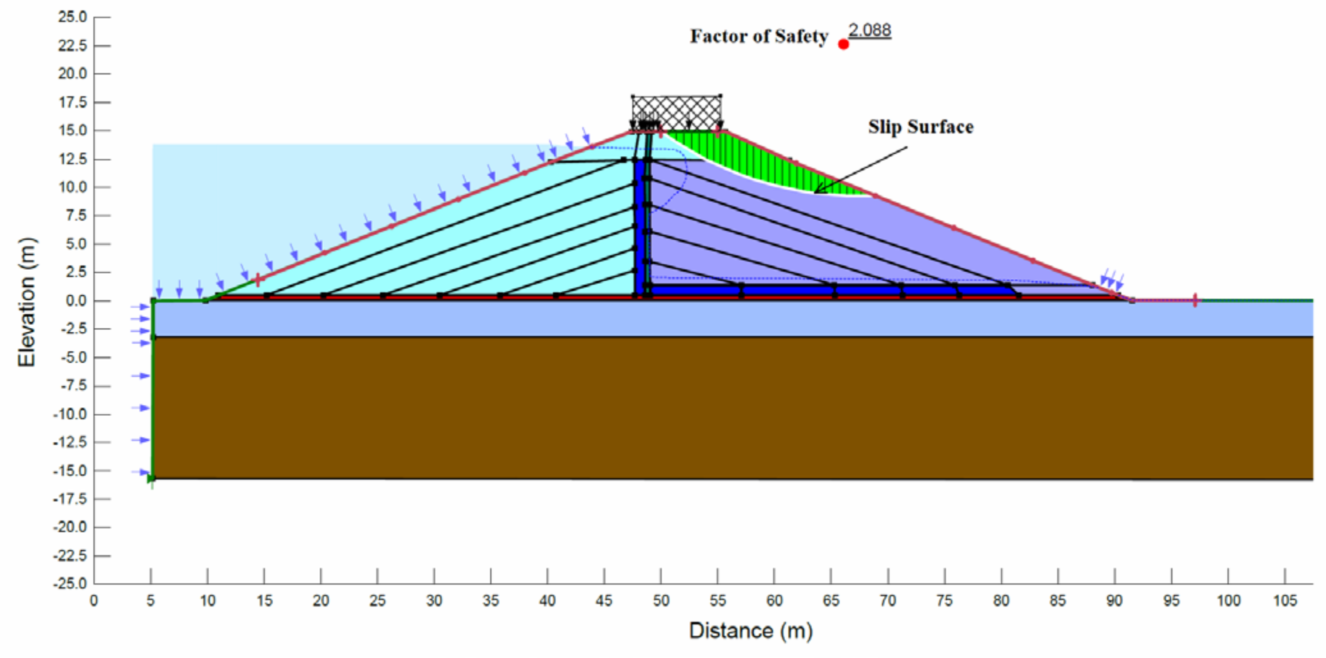

Figure 7: Initial slope stability analysis, taken from GeoStudio software.

D. Seismic Analysis

Once the initial parameters of the starter dam were modeled, the next analysis was to ensure dam safety after a seismic event. The same material properties for the previous computations were used for the quake analysis. To simplify computations, the material was modeled as linear elastic. Modeling this way allowed for simplifications that neglected extraneous work to be done in calculations and data collection that would only come from direct testing of the proposed material. Due to not having the material on hand, linear elastic assumptions are sufficient to obtain generalized results.

Other needed aspects of material properties to determine stability during a seismic event were obtained, such as Poisson's ratio, dampening ratio, and pore water pressure. The pore water pressure was input as a time-based function using results from the seep analysis. From the given material properties the dampening ratio and Poisson's ratio were both inputted into the software as constants.

Proper analysis of seismic activity required the input of an earthquake that simulated a realistic event that would occur in Boise County. This required obtaining the peak horizontal acceleration for seismic activity for the area. From the United States Geological Survey (USGS), peak horizontal acceleration was determined to be 0.4 g, (Survey 2007). With the information obtained from the USGS, a magnitude 5 earthquake could be modeled in the software. Duration of the seismic activity lasted 10 seconds, with alterations in the horizontal acceleration occurring every one thousandth of a second. During the quake analysis, the phreatic surface changed with time through the dam. This modeled the unsaturated soil in the downstream side of the dam becoming saturated and the horizontal forces creating access stress throughout the dam. A significant change in the vertical effective stress occurred throughout the dam as shown in Figure 6.

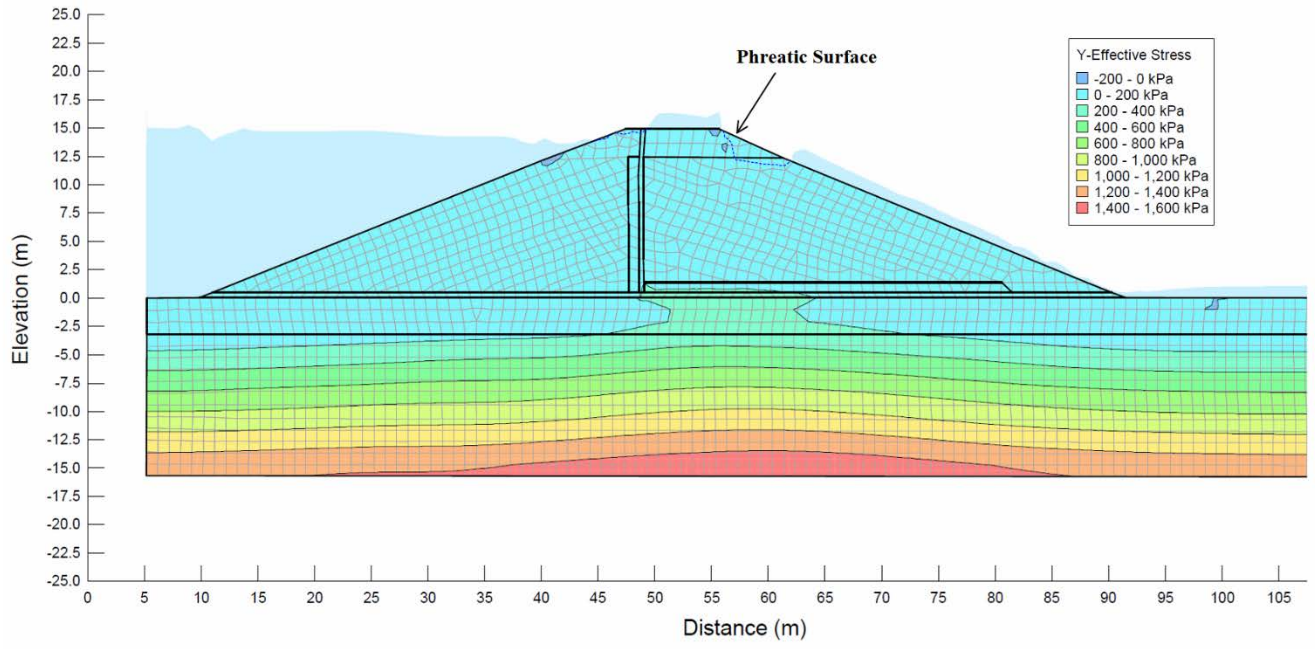

Figure 8: Vertical stress distribution after QUAKE/W analysis.

After the quake analysis, another seepage analysis was conducted. This was to determine the maximum velocity of water through the dam after the seismic event. If the velocity of seepage exceeded 4 mm/s then the potential for internal erosion could occur within the dam. From the seepage analysis after the seismic event, the max velocity of seepage through the dam was determined to be 0.18 mm/s, which is well below the maximum, see Figure 7.

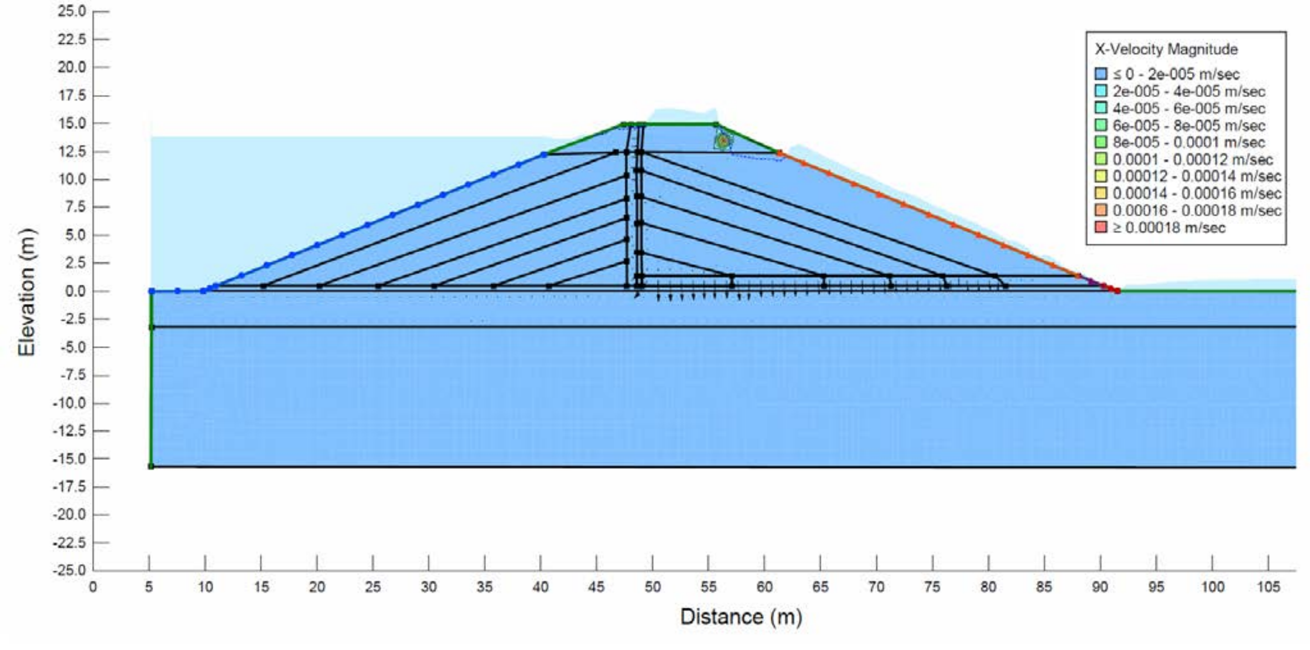

Figure 9: Seepage results computed after quake analysis.

Given the results from the seep analysis an assumption can be made that even though there is seepage occurring through the dam, the potential for internal erosion is negligible. After the seepage analysis, a slope stability analysis was performed to ensure the dam did not undergo catastrophic failure due to the seismic event. The results from the second slope stability analysis showed that the factor of safety was 1.276 as shown in Figure 8. This is less than the recommended factor of safety for tailings dams in seismic areas. The change in the phreatic surface, and the increase of both pore water pressure and vertical effective stress after the quake analysis forced seepage through the downstream face of the dam. By use of the models, the critical point of failure was identified along the surface. It was determined that neither the seepage nor the reduction in the factor of safety was significant enough to cause an entire dam failure but only necessary to warrant re-stabilization of the downstream slope after a seismic event. It is recommended that in the event of an earthquake, the downstream slope be inspected and re-stabilized to prevent further piping or internal erosion and to increase the factor of safety above 2.0.

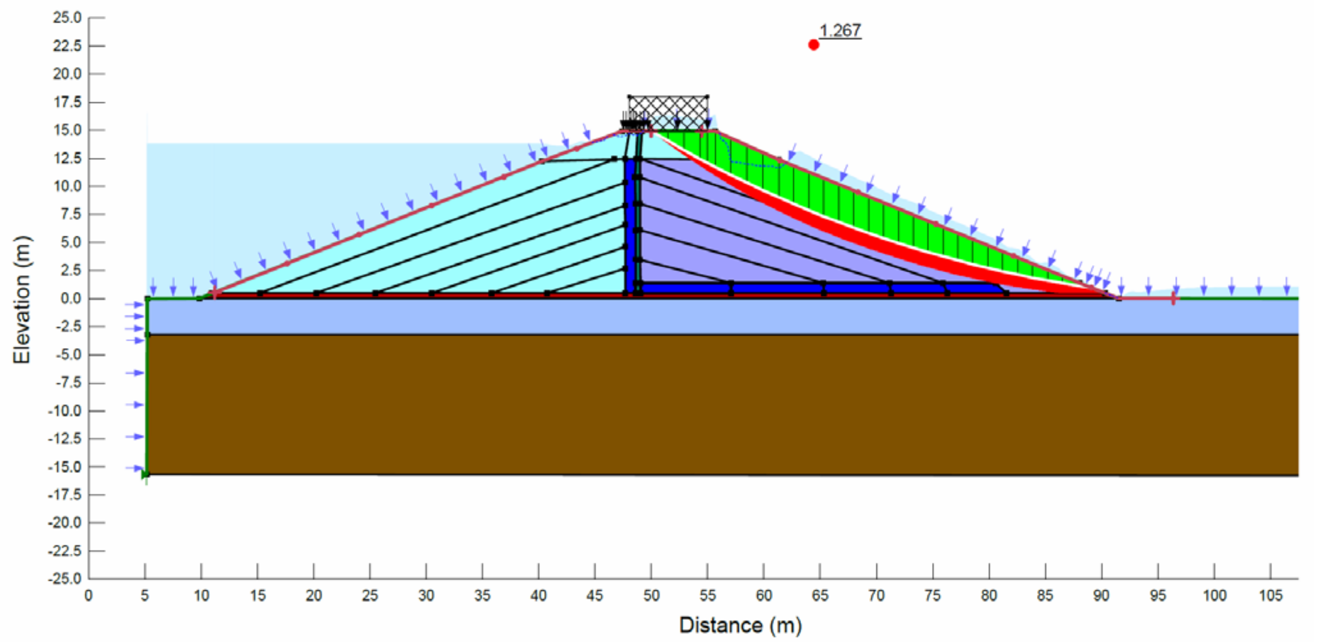

Figure 10: Slope stability analysis, taken after the quake and second seepage analysis.

E. *Other Analysis*

Mechanisms that could be potential failures were analyzed. Consideration was made for a scenario of water overtopping the dam but was not researched further due to the minimal potential of such event. The risk of water overtopping the dam is considered minimal since the tailings pond elevation is strictly controlled by the ore processing and water infiltration has been anticipated.

Further analysis was conducted on additional phases of the tailings dam. Two other models were analyzed using similar material properties, geometry, and seismic properties as the starter dam. With the addition of each phase the dam elevation grows approximately 15 m. All factors such as the factor of safety, flow through the dam and stability for both slope and seismic activity were all determined to be within tolerance with the rise in dam height. A model was constructed to show the final height of the dam, which is 250 m. The final elevation dam also showed comparable results as the previous models. The factors of safety for each phase, as well as the final height of the tailings dam all, fell within minimum acceptable. The seepage flow through the dam at each additional phase was below maximum allowable.

With all considerations analyzed for the starter dam, phased dam, and the final height, it has been determined that the potential for failure is minimal. The models along with the research and assumptions on material properties were all done to ensure that the construction of the tailings dam will contain a reservoir full of potentially hazardous material without failure. The severity of such work is to protect not only the environment, but to protect damage to property, livestock, and human life, all of which are located below the tailings dam in the town Pioneerville. Further research is recommended on actual material properties to validate assumptions made within this analysis.

IV. SUMMARY

As a part of a civil engineering capstone project at Boise State University, a feasibility study was performed on a proposed molybdenum and copper mine in Boise County, Idaho. This paper presented the geotechnical aspects of this feasibility study. As a part of this study, the historical and environmental background of the property was researched, and the location and size of the molybdenum deposit were determined. The estimated excavation volume was calculated to be approximately 1.99 billion cubic meters (BCM). Geotechnical analyses to verify the seepage, stability and seismic aspects of the tailings dam were performed using a commercially available software package. The mechanical properties of typical copper tailings of various gradations were used to model the different layers in the tailings dam. The maximum height and slope of the dam were determined using a reasonable factor of safety (FS = 2). The maximum height of the starter dam was determined to be

15 m at a slope of 2.5H:1V. Subsequent phases of the dam were also modeled to ensure the minimum FS values were maintained at each additional phase to a total height of 250 m.

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I. AUTHOR BIOGRAPHIES

Thomas Adam Robbins BSCE EIT
Graduate Research Assistant
Boise State University, Civil Engineering
1910 W. University Dr.
Boise, Idaho, 83725-2060

Thomas Robbins is from Boise Idaho and graduated high school in 1999. After high school, Thomas worked and traveled the northwest. In June of 2003, he joined the United States Marine Corps and served until 2010. During that time, he obtained the rank of Sergeant and completed two combat tours in Iraq. After his discharge in 2010, Thomas enrolled at the College of Western Idaho, and received his associate's degree with the honor of Summa Cum Laude. Thomas then transferred to Boise State university and enrolled in the civil engineering program. There he graduated with his bachelors of science, with the honor of Cum Laude in spring of 2017. Thomas is an active member of Tau Beta Pi, founder of an honor society for civil engineering at Boise State University, and actively involved with volunteer work with the local civil engineering club, and alumni associations. Thomas is currently a graduate student in the civil engineering program at Boise State University, and as a graduate student researching resiliency and sustainability in geotechnical systems.

Bhaskar Chittoori, Ph.D., P.E.
Assistant Professor
Boise State University, Civil Engineering
1910 University Drive
Boise, Idaho 83725-2060

Dr. Bhaskar Chittoori received his bachelor's degree from Jawaharlal Nehru Technological University, Kakinada, India in 2002 and master's degree from National Institute of Technology Karnataka, Surathkal, India in 2004. He received his Ph.D. degree in 2008 from the University of Texas at Arlington. After his Ph.D. he worked at Parsons Brinckerhoff, a well renowned civil engineering design firm, in their Dallas office. Dr. Chittoori joined as Assistant Professor in Geotechnical Engineering area of the Civil Engineering Department of Boise State University in the fall of 2013. His research interests are clay mineral quantification, sustainability assessment, advanced soil testing and interpretation, soil stabilization, soil reinforcement, pavement materials characterization along with finite element modeling of soil systems. He is a licensed civil engineer in the state of Texas and a member of Chi Epsilon and Tau Beta Pi honor societies.