Assessment of Design and Operating Practices on the Risks Associated with Waste Rock Stockpiles

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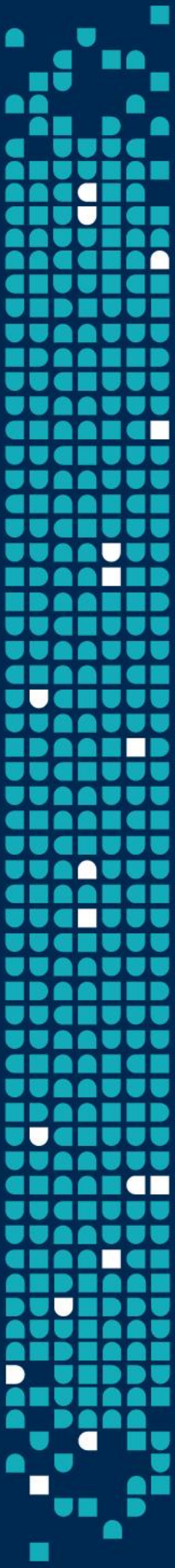

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Executive Summary

The risks associated with the construction, operation and closure of a Waste Rock Facility (WRF) can be significant. This paper demonstrates the impacts that design, construction and operation can have on the overall risk associated with such facilities. This paper first looks at a facility and its current ongoing operation. This is followed by an evaluation of risk for the proposed LOM configuration, with and without mitigating measures with respect to design, construction and operation. The risks associated with current operations as well as the configuration at closure carried with it a level of risk which the operator found inappropriate. Design, construction and operating recommendations were which reduced risks to acceptable levels. This paper relates the findings of this case study.

- Note that this white paper was presented at the Tailings and Mine Waste'18 Conference in Colorado State University.

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Introduction

The construction of waste rock facilities (WRF) is a requirement for most mines and they should provide adequate capacity for the waste rock storage over the life of the mine (LOM). As such, WRFs can be classified as high risk due to deficient design criteria, uncontrolled construction and operating techniques. In order for WRFs to be safely managed both during operations and at closure, risk-based design, carefully planned construction and operating practices are necessary. Risk-based design and assessment are also fundamental managing tools for mine operators used to estimate the likelihood of slope instability in waste rock piles and to account for the multiple variables associated with large mining operations. This paper presents the risk assessment and classification of ten (10) waste rock piles of a large WRF using the Commonwealth Scientific and Industrial Research Organization-CSIRO (Hawley et al., 2017).

In the CISRO method, a series of multi-factor matrices and ratings are applied to the regional parameters, the state of the foundations, the quality of the deposited materials, the mass and the geometry, the analysis of stability, the construction and the performance of each waste rock pile. The evaluations of these factors yield two indices: the Engineering Geology Index (EGI) and the Design and Performance Index (DPI). The combination of these two indices leads to different risk levels that range from very low to very high.

The CISRO method was applied to current and at closure configurations of waste rock piles as they were proposed by the mine operators. Then, a second risk classification of the waste rock piles was conducted assuming the implementation of the design, construction and operational recommendations provided by the authors. The results of the comparative classification and the recommendations for the proposed configuration are presented in this paper.

Methodology

CSIRO Mine Waste Rock Classification Method

The risk assessment and classification of a WRF was conducted following the CSIRO Mine Waste Rock Classification Method (Hawley et al, 2017). This classification is based on the assessment and scoring of twenty two (22) factors such as seismicity, chemical stability

of the waste rock and the height of the dumps. The factors are divided into seven (7) groupings, namely the regional parameters, the state of the foundations, the quality of the deposited materials, the mass and the geometry, stability analysis, construction method and the waste stockpile performance. Each factor is assigned a rating (numerical value) and each rating has qualitative and quantitative ranges pertaining specific constituents and analyses of the waste rock pile. The weight allocated for the ratings of each factor yields two indices: the Engineering Geology Index (EGI) and the Design Performance Index (DPI).

The EGI is the sum of the scores of factors of three groups: regional setting, foundation conditions, and material quality. The DPI is the sum of the factors of four groups: geometry and mass, stability analysis, construction and performance. The sum of the numerical values of EGI DPI results in the Waste and Stockpile Stability Rating (WSR). The WSR is a value ranging between 0 and 100. A pile with a rating WRS of 100 will be considered very low risk while a WRS of less than 20 is associated with a very high risk. The WSR score is then assigned a Waste Hazard Class (WHC). The WHC range from class I to class V. For example, Class I represents a waste rock pile with very low hazard, class III represents a moderate hazard and class V is a waste rock pile with very high hazard. The risk level can also be represented graphically in the form of a matrix whose input parameters are the EGI and DPI indexes as shown in table 1.

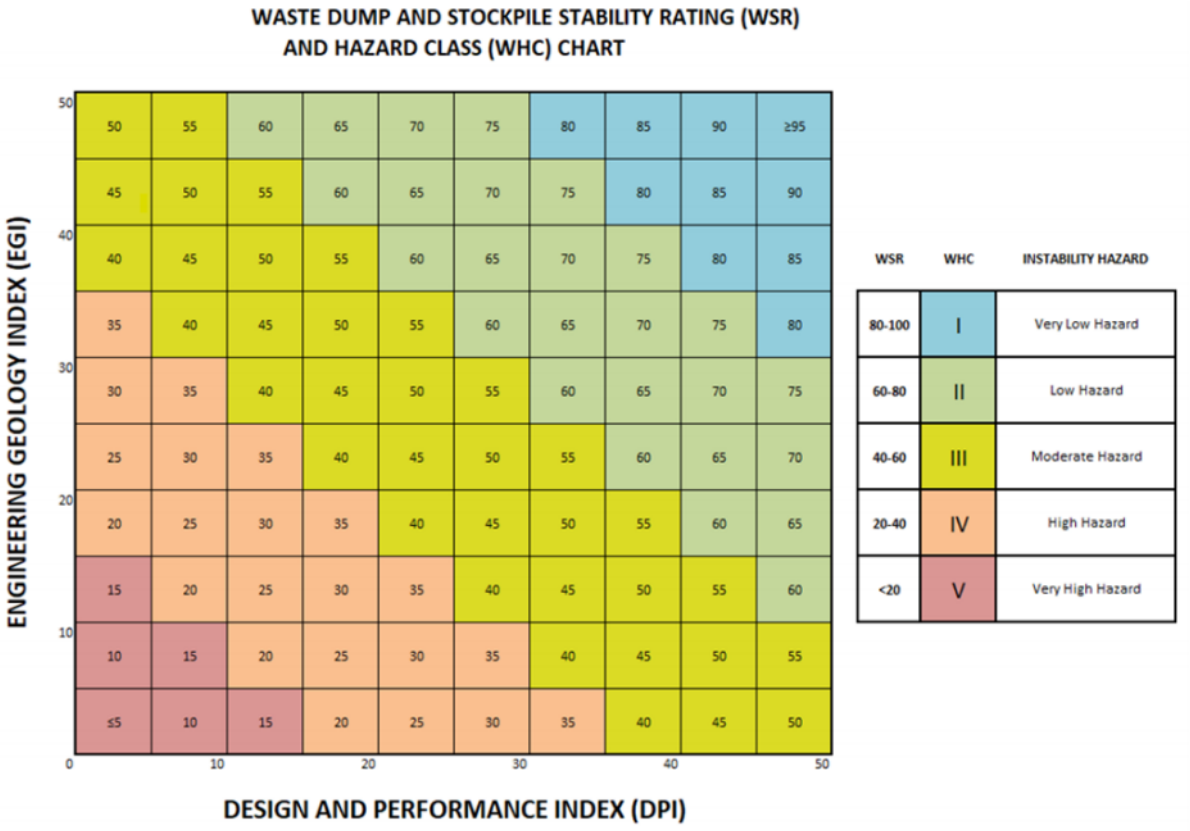

Figure 1: Classification Matrix and Rating System CSIRO method Hawley et al., (2017).

Risk classification method for current and LOM configurations

The CSIRO waste rock pile risk classification method was applied to 10 waste rock piles of a large WRF. The ratings of all factors were based on detailed analysis of existing data for each waste rock pile. The data analyzed included site topography and regional setting assessment, the waste rock piles volume according to mine plan, the gradation and material quality (coarse, fine, mixed), the waste rock piles geometry (overall and benches slopes and heights), geotechnical reports, and field observations. The method of construction, operation and management practices of the WRF were also analyzed. The rating classification also took into consideration the results of 2D and 3D static and

pseudo static slope stability analyses of current and LOM configurations of the WRF assuming that the volumes, geometries and the operation and construction practices of the waste rock piles remained unchanged throughout the LOM and followed the mine plan (Piciacchia et al., 2018)

The results of the EGI and the DPI for current and LOM of each waste rock pile for the current and LOM configurations are presented in table 1. The results of WSR and WHC of each waste rock pile are presented in table 2.

Table 1. EGI and the DPI of current and LOM configurations of proposed by the mine operators.

Waste rock pile ID	Current Configuration	EGI LOM Configuration	Current Configuration	DPI LOM Configuration
WRP6	31	31	-0.5	-1
WRP13	31	31	3.5	2.5
WRP15	31	31	18.5	19
WRP18	31	31	19.5	20.5
WRP19	32.5	32.5	26	25
WRP24	32.5	32.5	25	25
WRP42	31	31	21.5	20.5
WRP53	31	31	2.5	3
WRP54	31	31	25	24
WRP60	31	31	22.5	21.5

Table 2. Waste rock pile stability rating (WSR) and waste rock hazard class.

Waste rock pile ID	Current Configuration	WSR LOM Configuration	Current Configuration	WHC LOM Configuration	Current Configuration	Risk Level LOM Configuration
WRP6	30.5	30	IV	IV	High	High
WRP13	34.5	33.5	IV	IV	High	High
WRP15	49.5	50	III	III	Moderate	Moderate
WRP18	50.5	51.5	III	III	Moderate	Moderate
WRP19	58.5	57.5	III	III	Moderate	Moderate
WRP24	57.5	57.5	III	III	Moderate	Moderate
WRP42	52.5	51.5	III	III	Moderate	Moderate
WRP53	33.5	34	IV	IV	High	High
WRP54	56	55	III	III	Moderate	Moderate
WRP60	53.5	52.5	III	III	Moderate	Moderate

As shown in table 1, the minimum and maximum EGI are respectively 31 and 32.5 on a maximum possible 50 points. The EGI is primarily influenced by factors that are common to the entire site such as precipitation, groundwater level, and chemical stability of the materials. The difference between the EGI is therefore mainly due to the slope and the

shape of the foundation, which explains the small variation between the EGI of the piles studied.

The design performance index (DPI) varied significantly between waste rock piles. The DPI ranges between -0.5 and 26 for the current configuration and between -1 and 24 for the LOM configuration. The variations are largely attributable to the Stability Performance factor, the bench heights and overall slope associated with each waste rock pile. Overall, risk can be mitigated by focusing on DPI more so than EGI where little design or operation control is possible. Good operating practices and approaches as proposed by Vides et al., (2018), can be used to positively affect DPI and therefore reduce risk.

As shown in table 2, seven (7) waste rock piles obtained a moderate risk level classification for current conditions and at closure. A moderate risk classification generally indicates that one or more variables could cause failure if not carefully controlled. A high risk level classification was obtained for three (3) rock piles, namely, WRP6, WRP13 and WRP53 for current conditions and at closure. The waste rock piles with high risk level also represent piles that had experienced failures in the past or that have geometry concerns such as steep overall slopes and poor drainage behavior due to the type of waste rock with which they were constructed. In general, waste rock piles that experience failures, obtain low rating in the Stability Performance factor (ranges from -15 to 15 or very poor to very good, respectively). The Stability Performance factor has a very important relative weight in the overall classification, and waste rock piles with a history of failures are strongly penalized.

Risk classification method for the proposed configuration

In order to assess the impact of implementing design, construction and operational modifications on the risk classification of the to the current and LOM configurations, a third classification procedure was conducted on idealized waste rock piles that were are assumed to follow specific design, construction and operational criteria and recommendations.

Design criteria for the proposed configuration

The main design criteria for the proposed configuration were the (local-individual benches) and at closure (global) factors of safety (FS) required by the regulation. According to common regulations, the factor of safety for individual benches should

equal to or greater than 1.2. The FS for the closure configuration should be equal to or greater than 1.5.

The factor of safety of a waste rock pile depends on the material of construction (coarse vs. fine waste rock piles), the geometry of the pile and the angle of repose of the material that makes up the pile. According to Piciacchia et al. (2018), the overall angle of deposition (β) of a waste rock pile (constructed in descending fashion) is equal to the angle of internal friction (φ) of the material. As such, the factor of safety (FS) of waste rock piles is in equilibrium (FS=1). The current and LOM configurations of the case study showed overall angles β of 35 to 37 degrees for coarse grain waste rock piles and 30-32 degrees for fine grain waste rock.

In order to increase the minimum local and at closure factors of safety, it became necessary to design the waste rock pile with a flatter overall slopes. In the case of coarse waste rock piles, the final overall slope was determined to be 26 degrees, Piciacchia et al., (2018). In the case of fine waste rock piles, the overall slope angle was set to 22 degrees rather than 30-32 degrees for the current configuration.

Another design recommendation was the construction of a stabilization buttress at the foot of the existing waste rock piles. The stabilization buttress was designed to have one to three benches, depending on topography and waste rock pile height. The stabilization buttress was designed to have bench widths of 35m and the heights of 50m. The internal slopes of the buttress were similar to those observed in existing waste rock piles 1.3H: 1V. Its construction was recommended to be carried in a combination of ascending and free dumping construction techniques. Static and pseudo-static slope stability analyses (3D and 2D) were conducted on the proposed configuration and compliance of the regulations for operational and long term factors of safety was achieved.

Construction and operational recommendations for the proposed configuration

The main construction and operational recommendations made for the proposed configuration were: material segregation during operation, assessment of the advancement rate, preparation of deposition plans, and elaboration of an operation, maintenance and safety manual, Vides et al, (2018), Piciacchia et al., (2018).

Material segregation during operation

Material types entering the WRF can vary over time. Given the marked difference between the angle of internal friction of fine and coarse waste rock, it was recommended to deposit these materials in separate stockpiles. Experience has shown that at times (i.e. during a push-back on a pit wall) larger quantities of fine grained waste will likely be generated. If these materials are placed over the face of a coarse grained waste, which are also free draining, water levels within the stockpile will rise. The rising water levels can initiate a failure, particularly in the finer material. From a design point of view designing a facility with and angle of internal friction of 38 degrees is far different than with one at 30 degrees. In order to properly design a WRF and ensure reliability of such as design it is far better to reduce material property variability, which would be accomplished by separating the coarse and fine fractions.

Rate of advancement

The stability of a waste rock pile is influenced by several parameters such as the geometry of the pile, the quality of the materials, the climatic conditions and the materials of the foundations. However, several cases of historical failures show that they are closely related to the height and rate of advance of the pile. During deposition of waste rock, it is important to evenly distribute the materials on the ridge, which allows to reduce the pressure on the materials constituting the heap already in place and to reduce the risks of instabilities. Controlling this parameter reduces short term or operational risk of instability. In general, rates of advancement 1 and 3m per meter of crest per day were recommended based on the height of each waste rock pile at the time of the deposition and on the geotechnical properties of the foundation and the size distribution of the waste rock, Vides et at. (2018).

Deposition plans

WRF are complex structures whose operating criteria change over time, including the quantity and quantity of materials to be managed at a specific time. In addition, the construction of these complex structures must be harmonized with all other mining and engineering activities. As such, waste rock deposition plans are essential management tools that help mining operators evaluate and prioritize, in a predetermined frequency, the construction needs according to the waste rock piles exploitation rates and the mine plan. It was recommended to the mine operators to prepare three series waste

rock deposition plans for the short (year 1 and 2), medium (year 5), long term (year 10, and mine life) planning of the WRF. The deposition plans must respect the wastewater management plan and be adjusted according to changes and operational requirements.

Operation and Management and Safety Manual

The Operation and Management and Safety (OMS) manual allows for the clarification of individual responsibilities, decision-making processes, guidelines for design and possible modifications, instrumentation, monitoring and the development of environmental protection measures and emergency plans for the WRF. Operational guidelines must take into account both longterm and short-term operational needs. The operating manual is a master document that standardizes the operating procedures at the mine and should be updated to include any changes in the operation. Although the OMS manual does not have an impact on the IDP rating by itself, it is the good practices documented in it that will have a direct impact in the overall performance of the WRF overtime.

Result and discussion

The results of the risk classification for the proposed configuration are presented in tables 3 to 5.

Table 3. Comparison of EGI and DPI for all configurations.

Waste rock pile ID	Current Configuration	EGI LOM Configuration	Proposed Configuration	Current Configuration	DPI LOM Configuration	Proposed Configuration
WRP6	31	31	32.5	-0.5	-1	25
WRP13	31	31	32.5	3.5	2.5	24
WRP15	31	31	34	18.5	19	26
WRP18	31	31	32.5	19.5	20.5	28.5
WRP19	32.5	32.5	34	26	25	26.5
WRP24	32.5	32.5	34	25	25	30
WRP42	31	31	32.5	21.5	20.5	25
WRP53	31	31	32.5	2.5	3	25
WRP54	31	31	32.5	25	24	30
WRP60	31	31	34	22.5	21.5	24.5

Table 4. Comparison of WSR and waste rock hazard class for all configurations.

Waste rock pile ID	Current Configuration	WSR LOM Configuration	Proposed Configuration	Current Configuration	WHC LOM Configuration	Proposed Configuration
WRP6	30.5	30	57.5	IV	IV	III
WRP13	34.5	33.5	56.5	IV	IV	III
WRP15	49.5	50	60	III	III	II
WRP18	50.5	51.5	61	III	III	II
WRP19	58.5	57.5	60.5	III	III	II
WRP24	57.5	57.5	64	III	III	II
WRP42	52.5	51.5	57.5	III	III	III
WRP53	33.5	34	57.5	IV	IV	III
WRP54	56	55	62.5	III	III	II
WRP60	53.5	52.5	58.5	III	III	III

Table 5. Comparison of Risk Level Classification for all configurations.

Waste rock pile ID	LOM Configuration	DPI Proposed Configuration	LOM Configuration	Risk Level Proposed Configuration
WRP6	-1	25	High	Moderate
WRP13	2.5	24	High	Moderate
WRP15	19	26	Moderate	Low
WRP18	20.5	28.5	Moderate	Low
WRP19	25	26.5	Moderate	Low
WRP24	25	30	Moderate	Low
WRP42	20.5	25	Moderate	Moderate
WRP53	3	25	High	Moderate
WRP54	24	30	Moderate	Low
WRP60	21.5	24.5	Moderate	Moderate

As shown in table 3, the EGI is slightly modified with values varying between 32.5 and 34. The improvement in EGI is attributed to an increase in the rating of material quality, associated to the recommendation of segregation of materials.

The DPI is the index with the greatest variation from current and LOM configuration. As shown in tables 4 and 5, the geometry modifications, the flattening of the waste rock pile overall slope and the increase in local and global factors of safety from 1 to 1.2 and 1.5, as well as the operating and construction recommendations are attributed to the increase in the DPI which varies between 24 and 30, and represents an average increase of 8 points compared to current operations. Three factors directly impacting DPI rating were analyzed for the waste rock piles for the LOM and Proposed configurations; the results of the comparison are presented in figures 2 and 3.

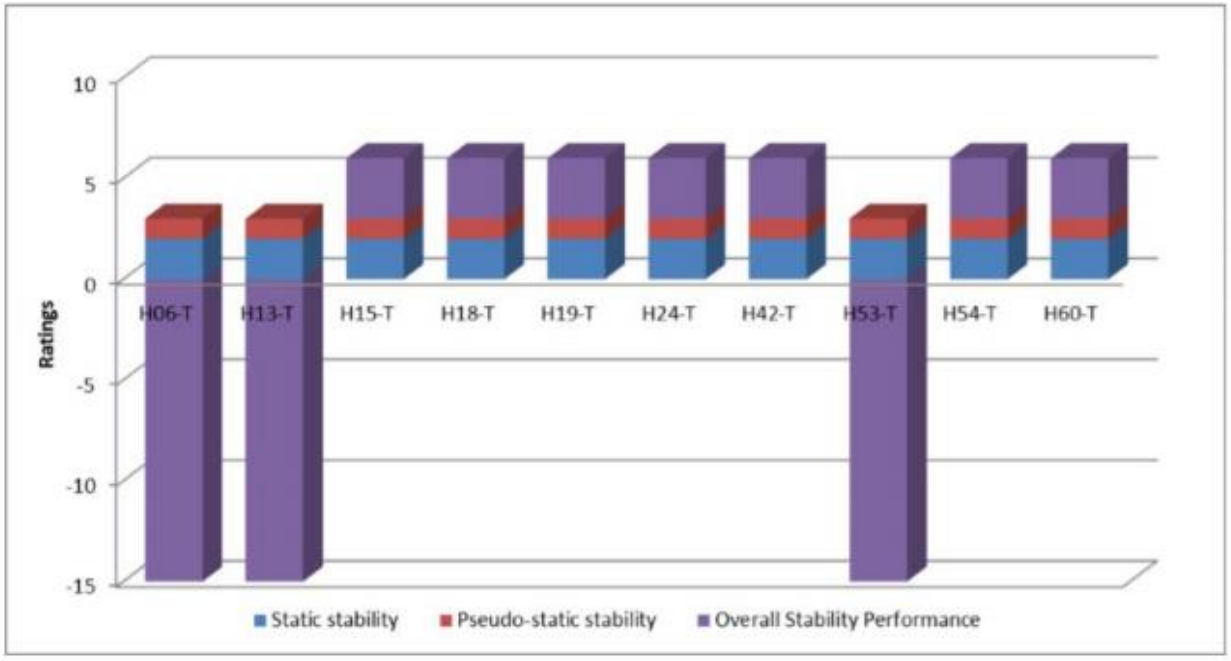

Figure 2: Rating of Design Performance Index Factors - Life of Mine Configuration.

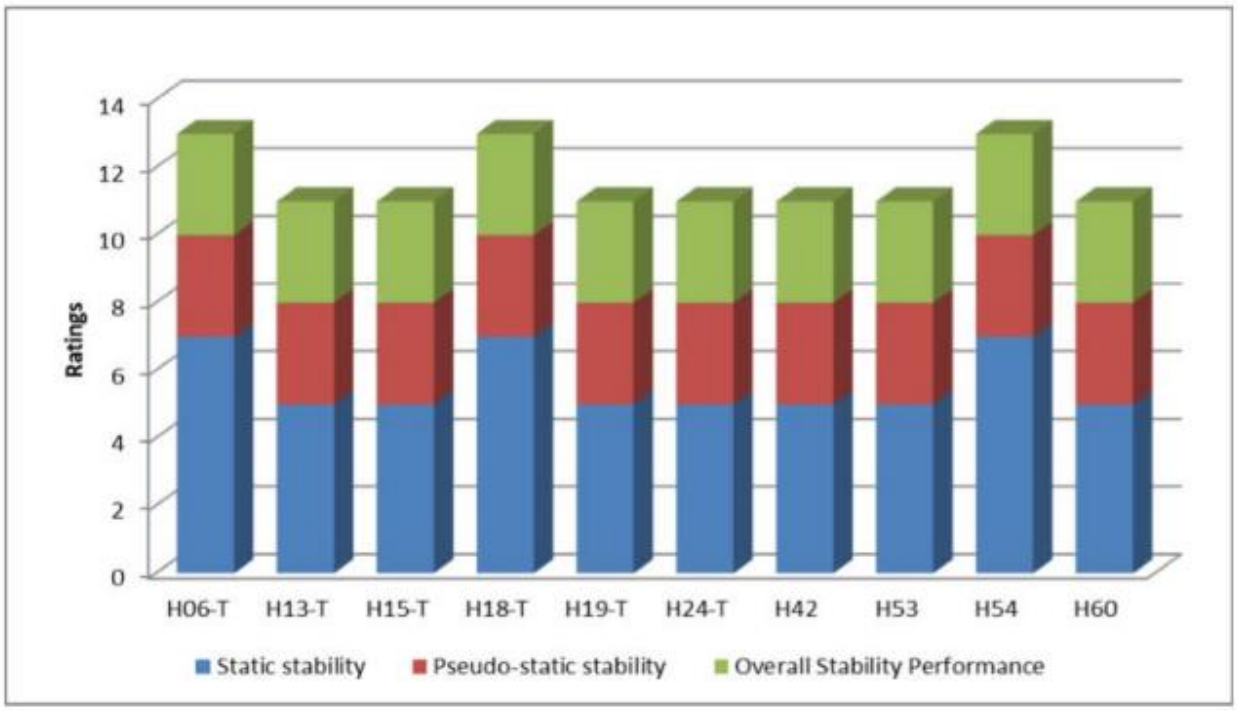

Figure 3: Rating of Design Performance Index Factors – Proposed Configuration.

As shown in the two figures, three waste rock piles, namely, WRP6, WRP13 and WRP53 went from High risk to Moderate risk which is a significant gain. Waste rock piles WRP42 and WRP60 remained in the moderate risk category which is explained by the fact that the stability rating of current and LOM configurations is on average 51 and therefore would require an average increase of 9 points in order to access the category at low risk (60 to 80 points). This is an increase that is too large to be fully met by improvements in geometric factors, stability analysis and construction.

Conclusions

The CSIRO Mine Waste Rock Classification Methodology was selected and adapted for application to 10 waste rock piles of a large WRF. While the initial configuration proposed by the mine operators would contain more than 30% of the waste rock piles in high risk category, the proposed configuration would ensure that none of the piles would be classified as such. In addition, if the recommendations are followed, 50% of stockpiles would be classified as low risk. It has been demonstrated that the implementation of the design, construction and operation recommendations in the current and LOM configurations of the WRF would result in reduced risk in 80% of waste rock piles and compliance with the regulations.

References

1. Hawley, M. Cunning, J. 2017. Guidelines for Mine Waste Dump and Stockpile Design.
2. Piciacchia, L., Marefat, V., and Mosquera, J., 2018. The use of 3D models and analysis in support of waste stockpile design and operations. BBA Inc., Montreal, Quebec, Canada.
3. Piciacchia, L., Marefat, V., and Vides J.A. 2018. Practical Nomograms for Waste Rock Piles Design on Competent Foundations. BBA Inc., Montreal, Quebec, Canada.
4. Piciacchia, L., Vides. J.A., and Mosquera, J., 2018. Mine Waste rock design, construction, and operation as engineered structures.
5. Vides, J.A, Piciacchia, L., and Marefat, V. 2018. Guidance for the safe and optimized operation of waste rock facilities. BBA Inc., Montreal, Quebec, Canada

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Dr. Luciano Piciacchia, P.Eng., Ph.D., is an experienced mining engineer with 30 years of solid geotechnical and environmental experience. He has worked on numerous site characterisation and decontamination projects as well as mine tailings impoundment design and waste management. He has been responsible for the planning, execution or supervision of laboratory and field investigations. Dr. Piciacchia has further been involved in numerous complex decontamination projects requiring specialised methods such as the requirement for sheet piling, bacteriological remediation and on-site encapsulation. His involvement has extended to tailings impoundment planning from the standpoint of scoping, pre-feasibility and feasibility perspectives. He has been involved in the design, site supervision and project management for earthworks, roads and dams for a number of mining sites including Bloom Lake, Mont Wright, Kearl, Mine Aurizon to mention some of the more recent assignments.

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Dr. Bouazza is a senior hydrology/hydraulics engineer holding a Masters and a Ph. D. in civil engineering. With more than 27 years of experience as a water resources specialist, he has developed a particular expertise in analysis and numerical modelling of hydraulic systems: watersheds, rivers, estuaries, lakes, reservoirs and storm drains. His professional experience covers design of hydraulic structures; development and implementation of hydrometeorological information systems; development and implementation of hydrological models; risk assessment of floods, erosion and sediment transport as well as environmental impact assessment of climate change. He has good knowledge of dam safety issues, water management plans and Emergency Preparedness Plans. Dr. Bouazza's specific background covers meteorology, climatology, permafrost, hydrology, hydraulics and numerical and statistical modelling. As a former university professor, he has also developed specific skills in training, project management, supervision and management of project teams.

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