DRA-52. SLOPE STABILITY MODELING

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1. STATEMENT OF PROBLEM:

The stability analysis of the generic rock pile requires addressing of the following questions:

- What is the influence of various input parameters on the calculated factor of safety of a rock pile?
- How will the stability of the rock pile change over time?
- When will an internal weak layer pose significant risk to the stability of a waste rock dump?
- How much cohesion is necessary to keep a vertical wall standing?
- What is the effect of Poisson's Ratio on the stability of the rock pile?
- What shear strength properties of the waste rock material are required to produce the type of failure surface noted during trench LG008?
- What probabilistic methodologies can be used to quantify slope stability?

The purpose of this part of the slope stability modeling project was to provide a sensitivity analysis of possible variations in factor of safety over time. The sensitivity analysis shows the influence of various input parameters on the calculated factor of safety.

2. PREVIOUS WORK:

Previous work performed in Phase I of the current study involved the quantification of various model sensitivities using a generic slope and the dynamic programming method of slope stability analysis.

The Phase I study involved the use of two generic 2D models, namely, i) a conceptual waste rock pile, and ii) a conceptual model similar to the Goathill North rock pile. Each model was evaluated in terms of potential shallow, intermediate, or deep-seated slip surfaces.

<u>Summary of Soil Properties</u>

The assessment of soil properties focused on compiling relevant unit weights and effective angles of internal friction from available legacy data and laboratory shear box test results provided by New Mexico Tech and the University of British Columbia, Vancouver, B.C.

Unit weight measurements made in the field by New Mexico Tech showed an average of 17.7 kN/m^3 with a standard deviation of 1.7 kN/m^3. These tests were made on all material types encountered. Ninety-five percent confidence limits are between 14.2 and 21.1 kN/m^3. The influence of this range of unit weights was found to be the least significant variable influencing the factor of safety

Average effective angles of internal friction were measured using a shear box. The results ranged from a minimum of 38 degrees (UBC) up to a maximum of 43 degrees (NMT). Tests previously performed by Norwest showed an average value of 40 degrees and a standard deviation of 2.7 degrees. These results were used in the analyses presented

in this report. The Norwest values for the angle of internal friction were intermediate to the values produced by NMT and UBC.

Conceptual Rock Pile Analysis Results

Analyses were carried out using a homogeneous cross-section as well as a multi-layer cross-section of the generic rock pile. The dynamic programming method was used to calculate results of the conceptual model. From these analyses the following findings are most significant:

SHALLOW

- The relative influence of cohesion and angle of internal friction bear a similarity.
- The infinite slope analysis was highly sensitive to the relative position of the water table.

INTERMEDIATE

- The slope stability analyses showed that an angle of internal friction, ϕ, of 30 degrees and a cohesion of less than about 4 kPa would be required to simulate incipient failure in a homogeneous slope.
- The location of the assumed slip surface significantly influences the resulting factor of safety.
- For a homogeneous slope with cohesion equal to 10 kPa and an angle of internal friction of 34 degrees, it is impossible to find a slip surface with a factor of safety below 1.0.
- The depth of the slip surface and the resulting factor of safety are influenced by Poisson's Ratio. (These analyses are utilizing the stresses computed from a stress analysis with "switched-on" gravity forces being applied). A Poisson's Ratio of 0.48 appears to give results that are most consistent with a traditional limit equilibrium analysis.
- In a weak/strong layered analysis with varying Poisson's Ratio between 0.42 and 0.48, an angle of internal friction between 20 to 30°is required for the weak layer.
- In a weak/strong layered analysis, varying the angle of internal friction for the weak layer will not affect slip surface location. Varying the cohesion of the weak layer will affect the slip surface location.

As a general observation the following points should be noted that are relevant to the present study. These points were confirmed by the analysis of the generic slope when using the SVDynamic software.

- Changing the effective friction angle will cause changes to the computed factor of safety but will not affect the location of the critical slip surface.
- Changing the cohesion will change both the location and the calculated factor of safety. Higher cohesion values will cause the critical slip surface to go deeper into the slope.

Goathill North Rock Pile Analysis Results

Analysis of the geometry extracted from the GHN site provided the following additional insights into circumstances that could potentially lead to failure.

SHALLOW

- In a limit equilibrium analysis of a homogeneous slope, the factor of safety will drop below 1.0 when the angle of internal friction is equal to 36 degrees and cohesion becomes less than 1 kPa. The additional 5 kPa of cohesion will result in lowering the angle of internal friction, ϕ to 33 degrees at the point where the factor of safety becomes 1.0.
- Based on the statistical analysis of a shallow failure the following conclusions can be drawn:
    - The angle of internal friction has the most significant influence on the calculated factor of safety.
    - The influence of unit weight on the computed factor of safety appears negligible.
    - The influence of cohesion on the computed factor of safety is of importance and needs to be further studied.
    - Realistic variance of suctions due to climatic events needs to be determined.
    - Given the present statistical distributions on the field measured soil properties, it appears unlikely that shallow failure conditions will occur if the material is assumed to be homogeneous.

INTERMEDIATE

- Based on the current analyses that have been performed, it appears that a weak layer with an angle of internal friction less than 30° and a cohesion of zero may lead to failure conditions when alternating thin weak and strong layers are considered.
- Statistical analysie applied to the soil properties provide further insight into the potential behavior of the system as noted by the following conclusions:
    - The angle of internal friction within the deep colluvium/rubble zone has a significantly higher influence on the computed factor of safety followed closely by the angle of internal friction of the waste rock zone.
    - The influence of pore-water pressures and cohesion could not be properly quantified as the variance distribution for this data was not available.
    - Given an assumed distribution for the angle of internal friction for the colluvium/rubble zones, it is statistically possible for a failure condition to be triggered by weakness in the rubble or colluvium zones.

3. TECHNICAL APPROACH

A combination of traditional limit equilibrium methods (i.e., methods of slices), as well as newer searching, stress-based methods have been used to analyze multiple conceptual models of Goathill North. Sensitivity analyses have been performed to assist in mapping

the effect of various input parameters on the calculated factors of safety. The sensitivity analyses have been applied to both the deterministic and probabilistic procedures.

The analysis of a waste rock pile presents unique complexities. The system is inherently layered and therefore traditional assumptions regarding circular slip surfaces may or may not be strictly valid. Equally as important as the calculations for the factors of safety are calculations related to the determination of the location of the critical slip surface. It is possible that the critical slip surface may follow a particular weak layer and therefore be non-circular in shape. Analyzing combinations of circular and non-circular shaped slip surfaces using both traditional and stress-based methodologies, as well as advanced algorithms for locating the critical slip surface, are a part of the scope of the current slope stability study.

The proposed analytical approach involves a number of components. It is also noted that there may be significant differences between 2-D and 3-D analyses (e.g., as much as 20 to 50%). Therefore, calculations of the factor of safety will involve a mixture of 2-D and 3-D slope stability analyses. Also, various pore-water pressure possibilities or scenarios from the hydrological analysis will be used in the slope stability analysis.

Following are some of the aspects considered in the technical analyses.

CALCULATIONS: The following methods of calculations are used in the present study. This does not imply that every scenario will be analyzed with all of the following methods. Rather, the appropriate methodology will be selected based on the analysis to be performed.

- Methods of slices
    - Bishop's Simplified
    - Spencer
    - Morgenstern-Price
    - GLE
- Stress-based methods
    - Kulhawy
    - SAFE (dynamic programming)

SEARCHING METHODOLOGIES: The location (and shape) of the critical slip surface is of paramount importance in the present analysis. Methodologies for determining the most reasonable location of the critical slip surface are shown below:

- Circular
    - Grid and radius
    - Entry and exit
    - Auto refine
- Non-circular
    - Greco
    - Dynamic programming

PROBABILITY: A mix of deterministic and probabilistic methodologies have been considered for the slope stability study undertaken.

- Deterministic

- Sensitivity analysis
- Probabilistic
    - Monte Carlo
    - Latin Hypercube
    - APEM

4. CONCEPTUAL MODEL

The slope stability modeling study is performed on the conceptual model presented to the Team (SoilVision Systems Ltd, 2008). This final conceptual model (Figure 2) is based on the overall conceptual model for waste rock systems as presented in Figure 1.

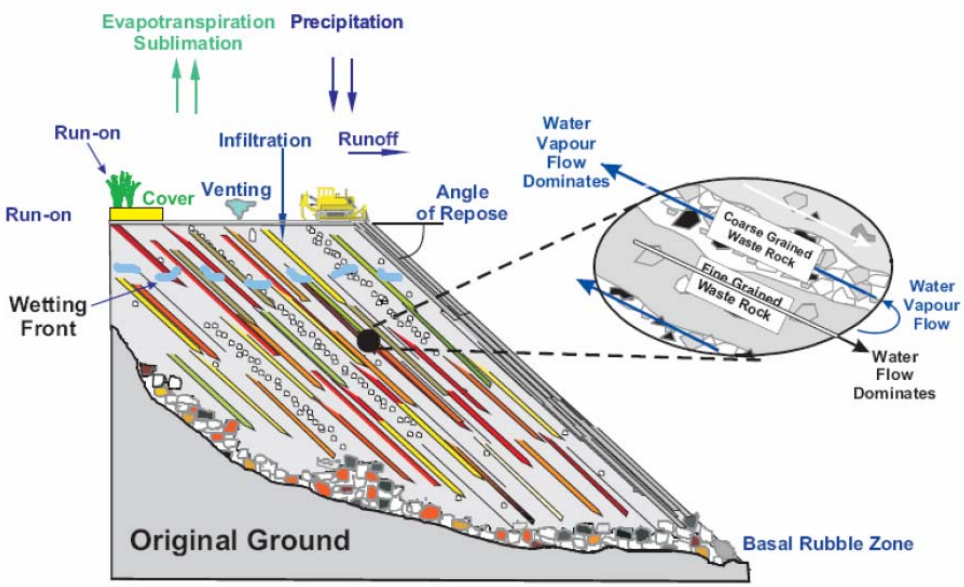

Figure 12: Conceptual model of water flow and vapour transport in a waste rock dump based on observations at Golden Sunlight Mine.

Herasymuik 1996

Figure 1 Generalized waste rock conceptual model (Herasymuik, 1996)

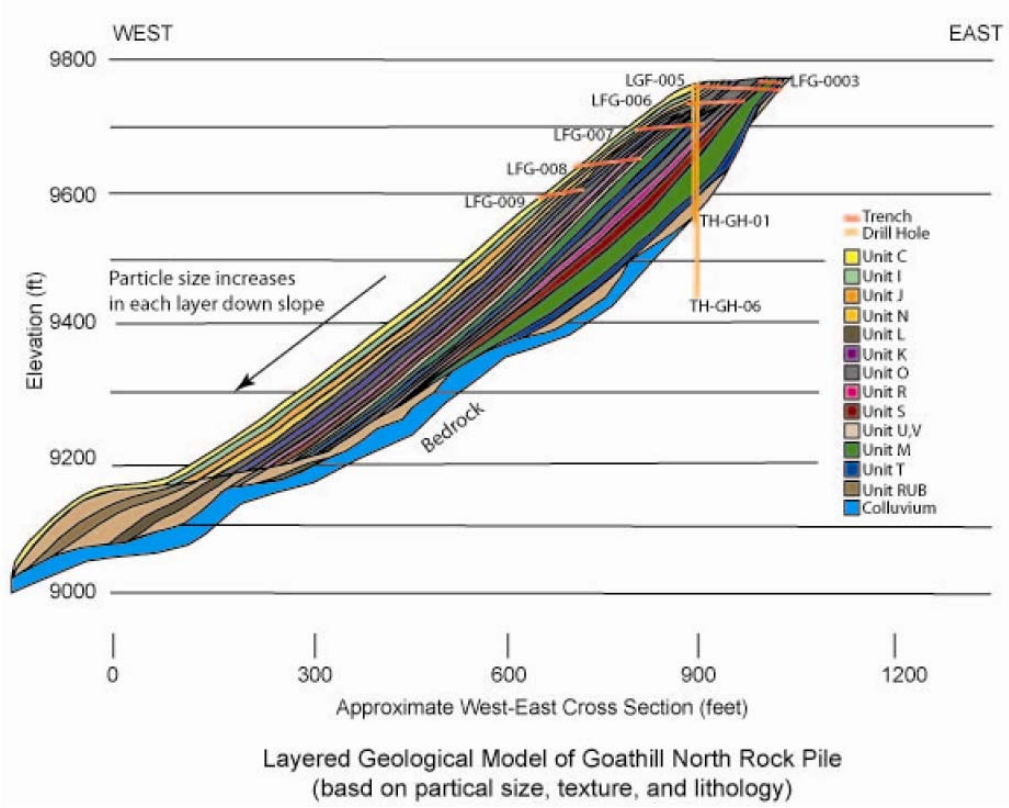

Figure 2 Layered final conceptual model (McLemore, 2007)

The current conceptual model is based on the results of analyses performed in Phase I of the project. Ultimately, a more advanced conceptual model will be developed for the final analysis in Phase II of the project.

The modeling aspects of the current study are later presented as a sensitivity study. A combination of seepage and slope stability models are first used to quantify thr model input parameters. The effect of each model input on the computed factor of safety is then examined.

Given the large number of model input parameters, it is of utmost importance to determine the relative influence of each of the input parameters on the calculated factors of safety. There is a complication that arises when there are many input parameters that may vary. It becomes important to determine the relative influence of each parameter. It is also preferable to assess the relative influence of each model input parameter in a probabilistic manner.

The purpose of the Phase I modeling study of this project was to identify the sensitivity of the parameters on the slope stability calculations. As well, a similar study is required for the seepage modeling portion. Subsequent phases of the project will address the variation of model parameters in a more comprehensive manner.

Failure Zones

In order to identify different potential failure zones and mechanisms, the generalized slope stability model was divided into three potential failure zones; namely, i) shallow, ii) intermediate, iii) and deep. These failure zones are illustrated in Figure 3.

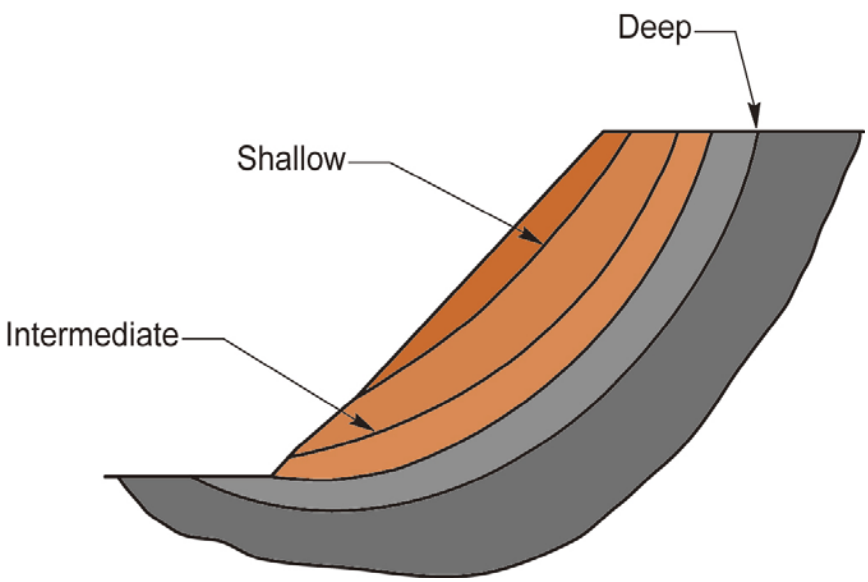

Figure 3 Identification of the three possible failure zones

The failure zones identified are not rigidly bounded but are loosely defined according to the following criteria.

SHALLOW SLIP SURFACE

- Less than about 10 m maximum for the slip surface depth,
- Failures likely caused by the surface slope angles exceeding the angle of internal

friction or the influence of unusual climatic events, and
- Slides are generally of lesser consequence

INTERMEDIATE SLIP SURFACE
- Still located in the waste rock or rubble zone,
- Slip surfaces does not dip into weathered or unweathered bedrock,
- Generally not highly influenced by climatic events, and
- The failure mechanism is most likely due to a weaker layer in the zones above the bedrock.

DEEP
- The failure slip surface would pass through the colluvium or weathered bedrock,
- Deep springs or flow through the fractured bedrock may influence the slip surface, and
- Not currently considered as part of this study

The Phase II modeling program is focused on the evaluation of potential shallow and intermediate slip surfaces. Deep failure surfaces may be considered at a later time or under another study.

5. STATUS OF SLOPE STABILITY MODELING

The purpose of the Phase II modeling study is to more accurately model the layering of fine (i.e., weak) and coarse (i.e., strong) layers. The advanced conceptual model is currently under development. Work to-date has focused on the following aspects of the analysis:

- Back-analysis of the slip surface that developed during the digging of trench LG008
- Literature review into probabilistic slope stability analysis
- Investigation into the effect of Poisson's Ratio on the calculated factor of safety
- Analysis of the cohesion required to keep a vertical slopes stable, and
- The compilation of reasonable soil properties

The specific tasks moving forward are as follows:
- Limit equilibrium forward sensitivity analyses
- Analysis of non-circular failure modes
- Additional back-analysis of existing crack data (i.e., calibration of the model)
- Worst-case scenarios? (i.e., with regard to cohesion, angle of internal friction, weak layers, and suction elimination)
- Sensitivity analysis
- Probabilistic analysis

7. RELIABILITY ANALYSIS

The reliability of the analysis will be evaluated through the application of the: i) Monte Carlo, and ii) APEM methods. Although the analysis is comprehensive, it should be noted that not all uncertainties are considered in the current study. Some of the uncertainties considered are as follows:

- Sampling uncertainty: There is uncertainty related to the ability to minimize the disturbance during the sampling process. It is assumed that this uncertainty is accounted for in the general distribution of sampling results.
- Testing method uncertainty: Testing methos uncertainty accounts for the variation in laboratory and field testing methodologies because of differences in equipment and personnel running the equipment. There is no data on this uncertainty and it will not be included in the analysis.
- Spatial uncertainty: Spatial uncertainty arises from variations in material properties related to spatial location. It is assumed that spatial variations are accounted for in the general testing variations experienced. It is currently difficult to separate spatial variances and sampling variances. An appropriate spatial autocorrelation distance will be assumed.
- Climate uncertainty: Climate uncertainty is accounted for in the slope stability analyses as extreme events.
- Analysis method uncertainty: Different analysis methods as well as different searching methodologies can yield differences in the computed results. These uncertainties are minimized through the application of multiple analysis methodologies.

8. CURRENT CONCLUSIONS

The current Phase II conclusions include the following:

8.1 BACK-ANALYSIS

The back-analysis of the slope failure at Goathill North in October, 2004 indicates that there are two possible modes of failure. These modes of failure are: i) a deep-seated failure through a relatively weak layer of rubble or colluvium layers, or, ii) failure through the waste rock.

Case 1, 3: Deep-seated failure: If the observed failure surface was initiated by a deep weak layer then it is the indication of this analysis that material properties associated with failure conditions are as follows:

LOCATION FIXED:

Friction angle: 22.3 to 23.5 degrees
Cohesion: 25 to 10 kPa.

LOCATION VARIABLE: In this case the waste rock properties are fixed with a friction angle of 36 degrees and cohesion equal to 15 kPa. The properties of the rubble material are as follows:

Friction angle: 24 degrees
Cohesion: 7 kPa

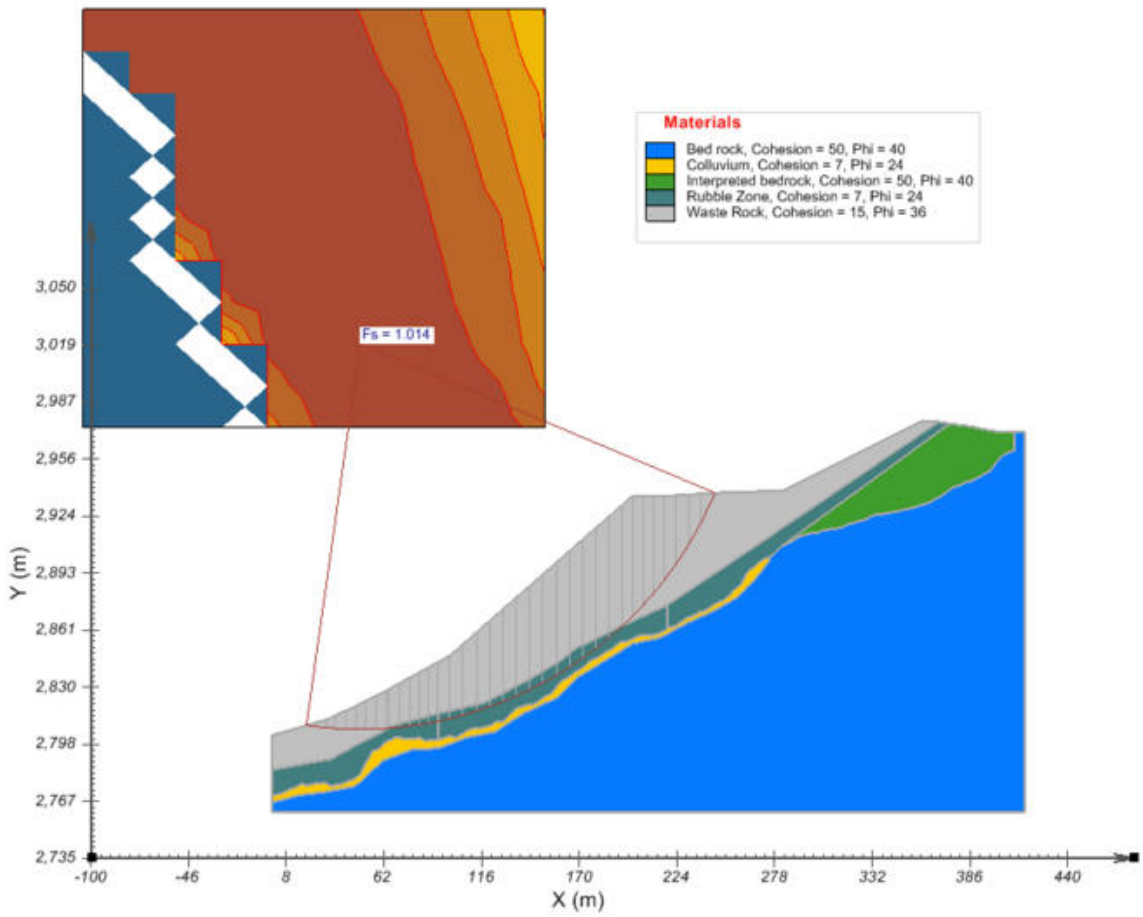

Figure 3 Location of slip surface for the weak rubble scenario

Case 2, 4: Waste rock failure: If the observed failure surface goes entirely through the waste rock then the properties associated with the waste rock at the time of failure are as follows:

LOCATION FIXED:
Friction angle: 29.5 to 31.5 degrees
Cohesion: 25 to 10 kPa.

LOCATION VARIABLE:
Friction angle: 18 degrees
Cohesion: 150 kPa

It is important to note that that the (circular) slip surface ultimately passes through both disturbed and undisturbed material. The center of the crack passed through generally undisturbed material. It is not clear from this analysis whether the values for the angle of internal friction back-calculated from this analysis are comparable to peak or residual shear strength values.

The following points summarize the findings:

- It appears unlikely that the crack observed on October, 2004 was due to a failure plane through waste rock alone. If this were the case, the resulting soil properties back-calculated from the model (i.e., ϕ = 18 degrees, cohesion = 150kPa) differ significantly from the values measured in the *in site* testing program.
- It appears likely that the observed slope failure was the result of sliding along a deep-seated weaker layer beneath the waste rock and above the bedrock layers. When this hypothesis is considered, the resulting material properties needed to produce incipient failure conditions appear to be consistent with existing field observations.

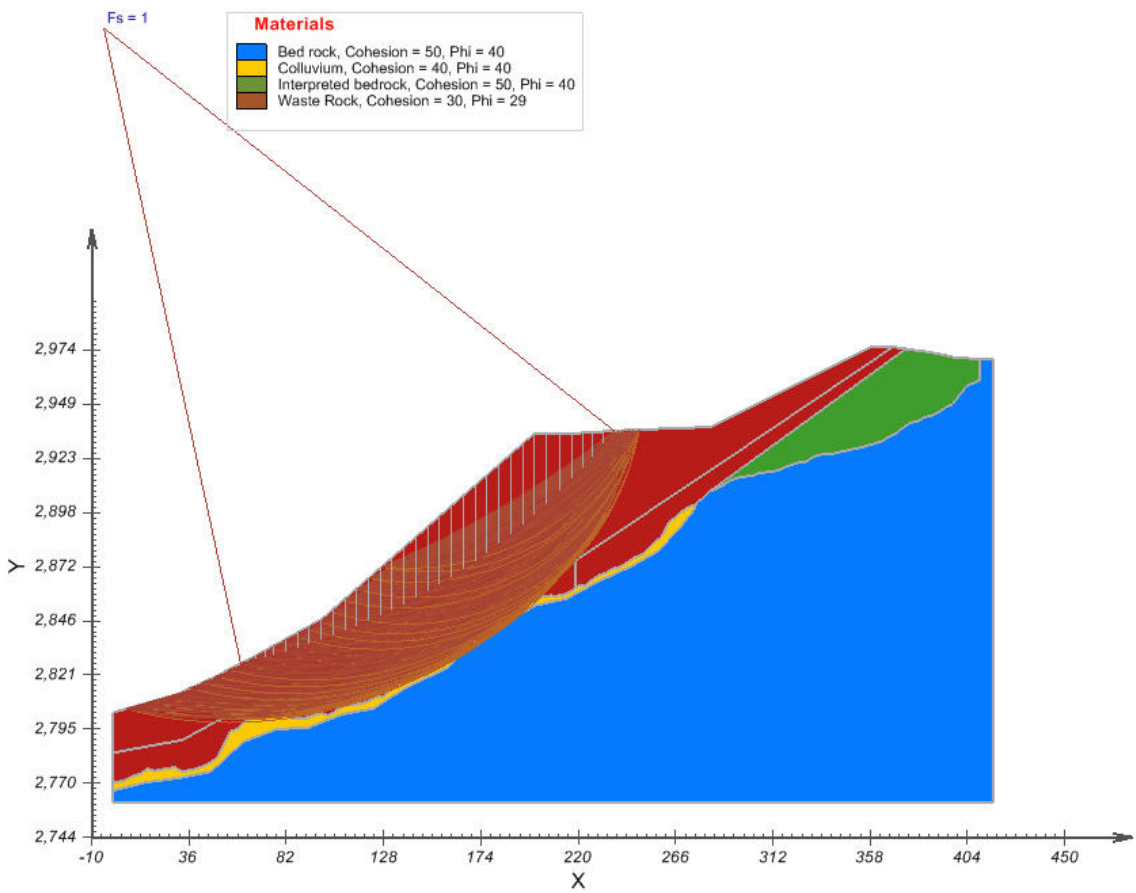

Figure 4 Location of the critical slip surface in the waste rock material

8.2 POISSON'S RATIO ANALYSIS

The location of the critical slip surface selected from the dynamic programming analysis are dependent upon the admissibility criteria used in the analysis. The computer results may become numerically unstable as cohesion becomes zero if adjustments to the kinematic admissibility criteria are not made. Further studies related to the required adjustments for the analysis are ongoing at SoilVision Systems Ltd.

It should be noted that the aforementioned Poisson's ratio effect on the dynamic programming analysis would have an inconsequential effect on the slope stability

analysis performed by SoilVision Systems Ltd during the current study. The reasons the Poisson's ration effect becomes a non-issue in this study is as follows:

1. Dynamic programming is only used in the final report as a backup or an extension of the method of slices analysis method. The method of slices analysis is predominantly used for the current analyses.
2. Almost all material layers in the final analysis have a cohesion value greater than 0.0. Therefore the Poisson's ratio effect is minimized to less than 5%.

8.3 VERTICAL SLOPE ANALYSIS

The cohesion required to maintain stability of a vertical slope is dependent on the height of the slope. A number of computer model runs were performed where the angle of internal friction was keep constant at 36 degrees and the slope height was varied. The cohesion term was changed to bring the computed factor of safety to a value of 1.0. The results of these analyses can be seen in the following figure.

Figure 5 shows that there is a limit to the amount of cohesion required to keep a slope completely vertical. Even with a relatively low friction angle of 20 degrees, it only requires 30 kPa to keep a 10m vertical slope at a factor of safety of 1.0. There is little difference in the relationship between slope height and cohesion when increasing the friction angle beyond 35 degrees.

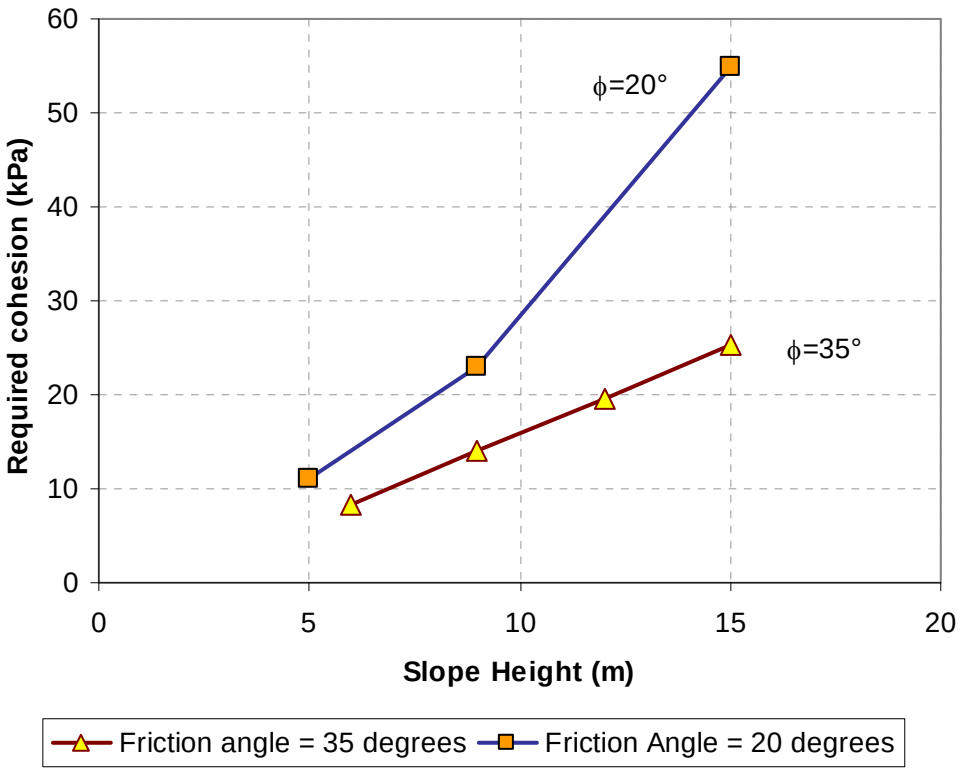

Figure 5 Variation of slope height with the cohesion required for a factor of safety of 1.0

8.4 PROBABILISTIC METHODS LITERATURE REVIEW

From the literature review surrounding the application of various other methods to slope stability analysis, the following conclusions can be drawn:

- The Monte Carlo, Latin Hypercube, and APEM methods are mathematically sound and have significant advantages in quantifying the effect of potential variations in a slope stability analysis.
- The application of these methods to a number of real-world situations is well-documented in the research literature. The application of probabilistic slope stability analysis is documented and encouraged by the US Army Corps of Engineers.
- Difficulties with the selection of autocorrelation distances can be overcome with the estimation of appropriate values.
- If spatial variation of material properties is not included, the analysis might result in an over-estimation of the probability of failure.
- Probabilistic analysis are highly sensitive to whether the analysis is considering a fixed or floating critical slip surface methodology. A floating critical slip surface location improves the ability of the software to identify the true critical slip surface.

8.5 CALIBRATION OF SLOPE STABILITY MODELING

It was considered important in the present slope stability modeling study to provide continuity between new analysis methods and the traditional methods (e.g., the methods of slices). In particular, it was considered important to compare the dynamic programming method to more traditional methods. Two approaches were taken to provide this continuity:

i) The dynamic programming methodology was compared to more classic limit equilibrium methods.

ii) The classic limit equilibrium methods were run on two separate software packages.

It was the intention that this approach would confirm the validity of the dynamic programming method and provide a reference to the more traditional methods.

Both the SVSLOPE (SoilVision Systems Ltd., 2008) and the SLIDE (Rocscience, 2008) software packages were used for this comparison. Over 100 benchmark models were set up in both software packages and run side-by-side. Almost all model comparisons resulted in differences in the calculated factors of safety that were less than a 1% between the software packages. Differences larger than 1% were investigated and were typically due to differences between the searching algorithms and not a reflection on the reliability of the calculations. Many of the models used in the final conceptual model analysis were run on the SLIDE software as well as the SVSLOPE software package. The differences between the two software packages were insignificant. It should also be noted that the probabilistic analyses were also compared between the two software packages and no significant differences were encountered.

Final comparisons between the limit equilibrium method and the dynamic programming method are ongoing.

8.6 PRESENT-DAY 2-D FORWARD ANALYSIS

The following soil properties and geometry was established for the final conceptual model.

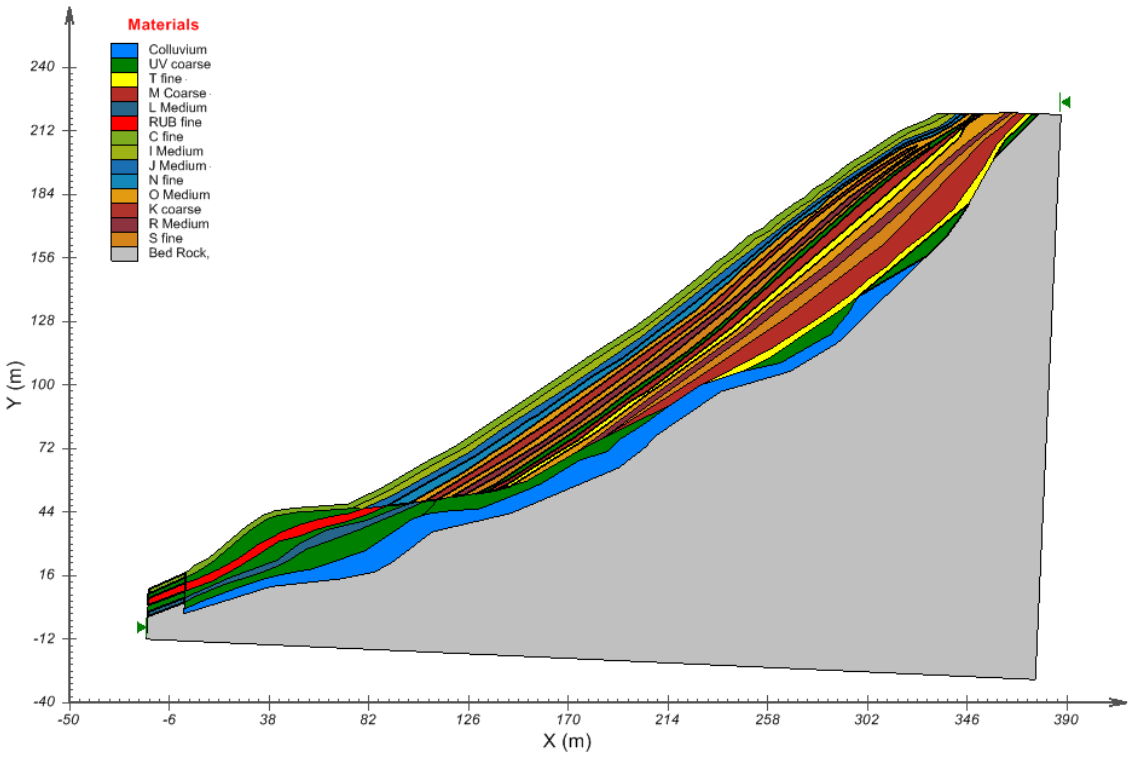

Figure 6 Adjusted final geometry for the slope stability analysis (Slope=35.7 degrees)

Table 1 Peak strength values

		Peak (2 in-dry)											
Layer	Hydrological Mapping	Phi (deg)					Cohesion (kPa)			Pore-water pressures (kPa)			Phi-b
		Average	Minimum	Maximum	COV	SD	Average	Minimum	Maximum	Average	SD	COV	Average
RUB	Fine	**43**	43	43	10%	4.3	0	0	0	12	6	50%	?
UV	Coarse	**41.8**	36.2	46.2	10%	4.18	0	0	0	12	6	50%	?
T	Fine	**37**	37	37	10%	3.7	10	3	17	12	6	50%	?
L	Medium	**40**	40	40	10%	4	5	5	5	12	6	50%	?
Colluvium	Fine	**40.8**	36.9	45.8	10%	4.08	0	0	0	12	6	50%	?
M	Coarse	**42.7**	42.7	42.7	10%	4.27	10	3	17	12	6	50%	?
S	Fine	**43.2**	43.2	43.2	10%	4.32	10	3	17	12	6	50%	?
I	Medium	**38.9**	35.2	41.6	10%	3.89	10	3	17	12	6	50%	?
N	Fine	**42.3**	41.7	43.4	10%	4.23	10	3	17	12	6	50%	?
J	Medium	**43.7**	41.7	44.9	10%	4.37	10	3	17	12	6	50%	?
R	Medium	**42.3**	39.2	45.4	10%	4.23	10	3	17	12	6	50%	?
K	Coarse	**42.3**	36.9	46.9	10%	4.23	10	3	17	12	6	50%	?
O	Medium	**42.3**	36.9	47.8	10%	4.23	10	3	17	12	6	50%	?
C	Fine	**45.7**	45.7	45.7	10%	4.57	10	3	17	12	6	50%	?
AVERAGE		**41.9**											

Table 2 Residual strength values

		Ultimate (2 in - dry)										
Layer	Hydrological Mapping	Phi (deg)					Cohesion (kPa)			Pore-water pressures (kPa)		Phi-b
		Average	Minimum	Maximum	COV	SD	Average	Minimum	Maximum	Average	SD	Average
RUB	Fine	**40**	40	40	10%	4	0	0	0	12	6	?
UV	Coarse	**37**	32.5	41.6	10%	3.7	0	0	0	12	6	?
T	Fine	**33**	33	33	10%	3.3	10	3	17	12	6	?
L	Medium	**37**	37	37	10%	3.7	5	5	5	12	6	?
Colluvium	Fine	**40**	40	40	10%	4	0	0	0	12	6	?
M	Coarse	**40.7**	40.7	40.7	10%	4.07	10	3	17	12	6	?
S	Fine	**39.3**	39.3	39.3	10%	3.93	10	3	17	12	6	?
I	Medium	**34.9**	33.7	35.9	10%	3.49	10	3	17	12	6	?
N	Fine	**38.1**	35.8	39.7	10%	3.81	10	3	17	12	6	?
J	Medium	**36.8**	33.7	37.9	10%	3.68	10	3	17	12	6	?
R	Medium	**37.4**	36.5	38.2	10%	3.74	10	3	17	12	6	?
K	Coarse	**36.8**	35.7	37.5	10%	3.68	10	3	17	12	6	?
O	Medium	**37.2**	30.5	42.1	10%	3.72	10	3	17	12	6	?
C	Fine	**36.6**	36.6	36.6	10%	3.66	10	3	17	12	6	?
AVERAGE		**37.5**										

A classic limit equilibrium analysis (i.e., method of slices) on a 35.7 degree slope yields the factors of safety as presented in the following figure. It should be noted that there is an influence of the slip surface depth. Only circular slip surfaces were considered for this analysis. Pore-water pressures were not considered in this analysis. It is useful to note that both soil suctions and 3-D effects will potentially cause an increase in the calculated factors of safety.

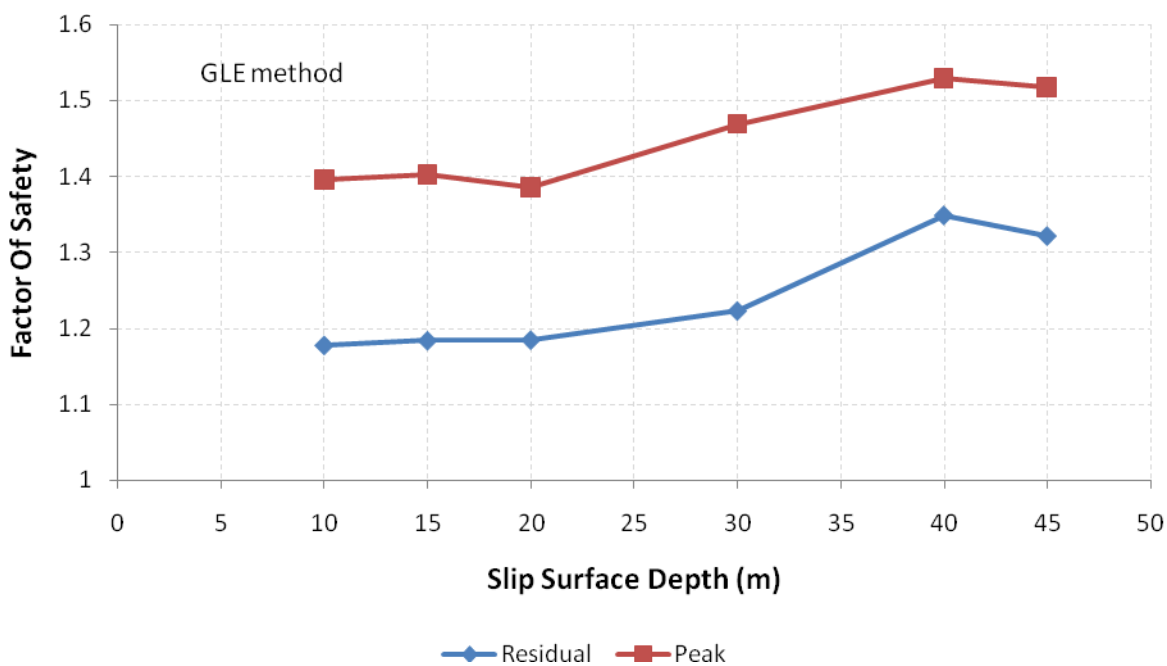

Figure 7 Factors of Safety calculated using the GLE method

During the course of this analysis it was noted that the slope was sensitive to the angle of the upper portion of the slope. In order to quantify this sensitivity, the geometry of the model was rotated through a set of angles and the above analysis repeated. The results may be seen as follows:

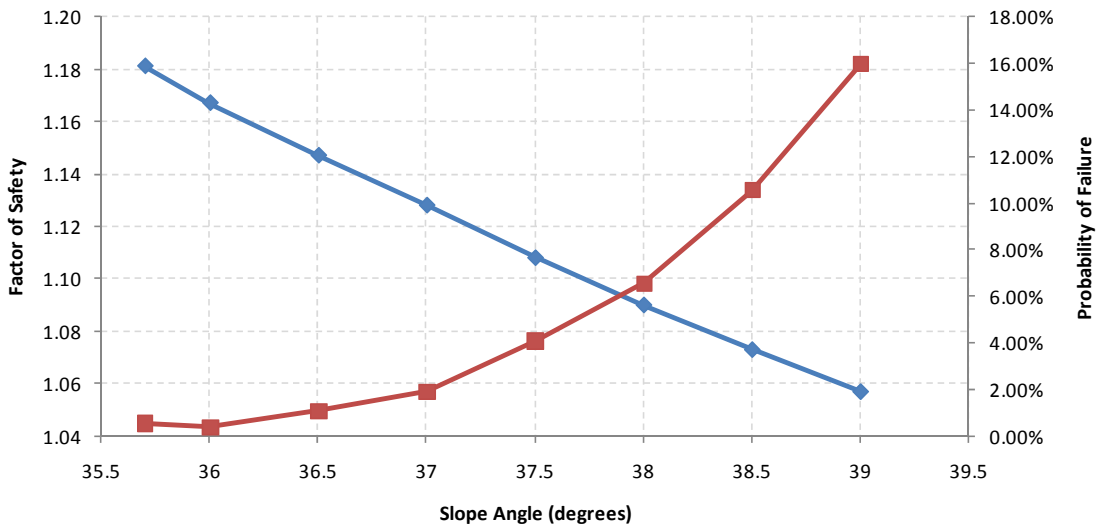

Figure 8 Sensitivity of the factor of safety to the upper portion slope angle

8.7 WEAK LAYER ANALYSIS

A weak layer analysis was performed on the slope in order to determine the extent to which a weak layer with a decrease in shear strength might result in a potential slope failure. The most common failure mechanism was a failure in the upper intermediate zone. In order to identify potential weak layers an APEM statistical analysis was first run on the slope. The tornado diagram produced from the APEM analysis allowed the identification of the soil layers which were most likely to produce failure in the slope. These weaker layers were identified as layer O, K, N, and R.

Individual sensitivity analyses were subsequently performed on each of these layers. The cohesion for each layer was held constant at 10 kPa and the effective friction angle was then decreased until the factor of safety was approximately equal to 1.0. The friction angles needed in order to produce failure conditions can be seen in the following table.

Table 3 Effective friction angles needed to produce failure conditions in respective layers.

Description	Results	
Layer O	20	degrees
Layer K	23-24	degrees
Layer N	22	degrees
Layer R	21	degrees

The location of layers O, K, and N may be seen in the following figure.

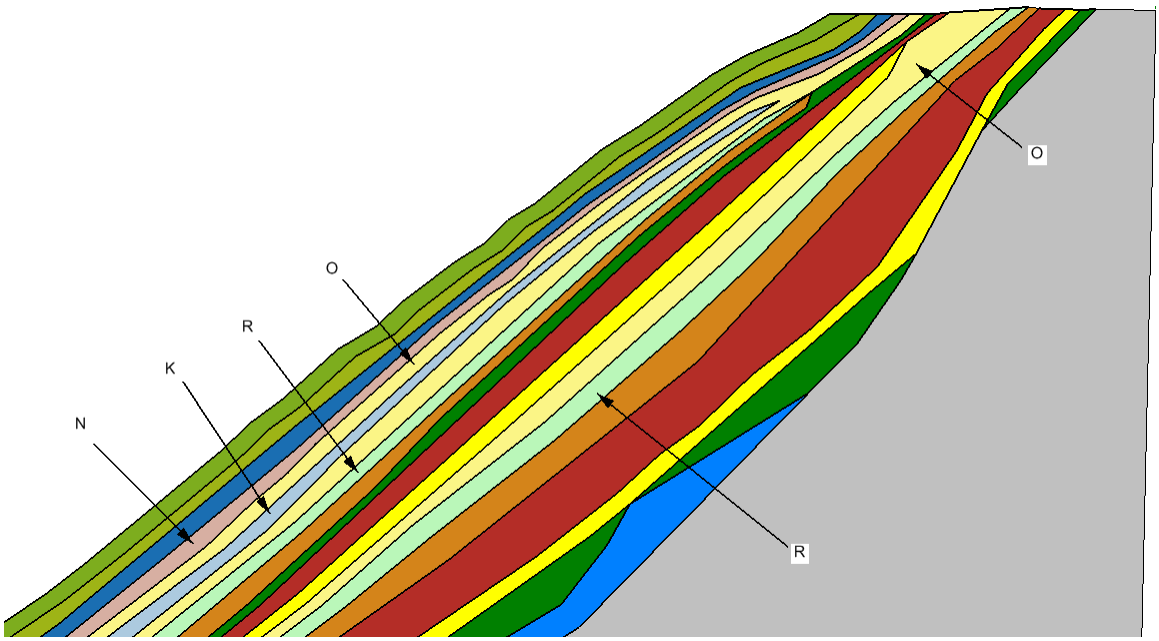

Figure 9 Location of weak layers O, K, and N (colored white)

8.8 FUTURE 2-D ANALYSIS

The present modeling study results were compared to potential scenarios in the future in which the shear strength properties of the material were assumed to change. For the purposes of this analysis future reductions in the shear strength of 3 or 5 degrees were analyzed. Also included in the sensitivity analysis were the scenarios where the cohesion of the waste rock materials was increased. It should be noted that this modeling study does not imply any physical change in material properties but is intended to be a "what if" scenario regarding the potential for change.

The results of the analysis can be seen in the following table. It can be seen that while the factor of safety does not change significantly when the angle of internal friction is reduced, the probability of reaching failure conditions is increased. As a result the probability of failure increases for a 3-degree decrease in the angle of internal friction and dramatically increases for a 5 degree decrease (50%). It is interesting to also note that a reasonably small cohesion increase of 10kPa has a significant ability to decrease the probability of failure in these situations.

It should be further noted that the present analysis is conservative and real-world slope stability factors may actually be significantly higher for the following reasons:

i) The analysis performed was 2-D. The factors of safety produced in a 3-D analysis would be higher, and

ii) This analysis does not include the effect of unsaturated soil suctions which will also have the effect of increasing the factor of safety.

Table 4 Summary of peak and large displacement results for present and future conditions

Condition	Peak Shear Strength		Large Displacement Strength	
	FOS	$p_{f\,(\%)}$	FOS	$p_{f\,(\%)}$
Present Conditions				
Upper Intermediate	1.37	6.4E-07	1.18	0.8%
Lower Intermediate	1.39	1.3E-07	1.19	0.1%
Future Conditions - Upper Intermediate				
3 degree reduction	1.27	0.007	1.08	11.0%
3 degree reduction +10 kPA	1.37	2.75E-10	1.14	0.2%
5 degree reduction	1.19		1.00	50.0%
5 degree reduction +10 kPA	1.29	0	1.06	9.5%
Future Conditions - Lower Intermediate				
3 degree reduction	1.24	0.0035	1.09	4.5%
3 degree reduction +10 kPA	1.29	5.4E-05	1.13	0.3%
5 degree reduction	1.16	0.30	1.00	46.0%
5 degree reduction + 10 kPA	1.21	0.01	1.05	11.3%

8.9 LIKELYHOOD OF SATURATION FAILURE

The type of climatic event which could possibly lead to a potential failure of the slope has been given consideration in this study. One of the potential failure mechanisms is the possibility of a large rainfall or snowmelt event that might cause net percolation of an unnaturally large amount of water into the rock pile which could lead to a potential failure.

This scenario was analyzed in two ways in the current study. In the first scenario presented in this report, a water table is directly placed on the rock pile. This extremely high level of pore-water pressures will significantly change in the calculated factor of safety. In further analyses six different water level conditions were also analyzed. The resulting factors of safety are presented in Table 5.

Table 5 Summary of factors of safety associated with various water levels

Level 1	1.181
Level 2	1.181
Level 3	1.181
Level 4	1.019
Level 5	0.724
Level 6	0.479

A graphical description of the locations of these various water levels can be seen in the following figures. The yellow trapezoids represent the tangent search boxes used for the trial slip surfaces.

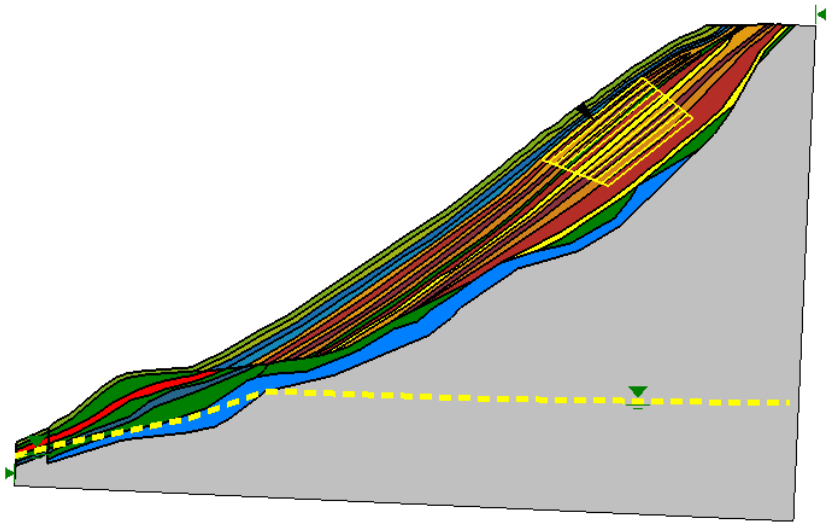

Figure 10 Level 1 water level

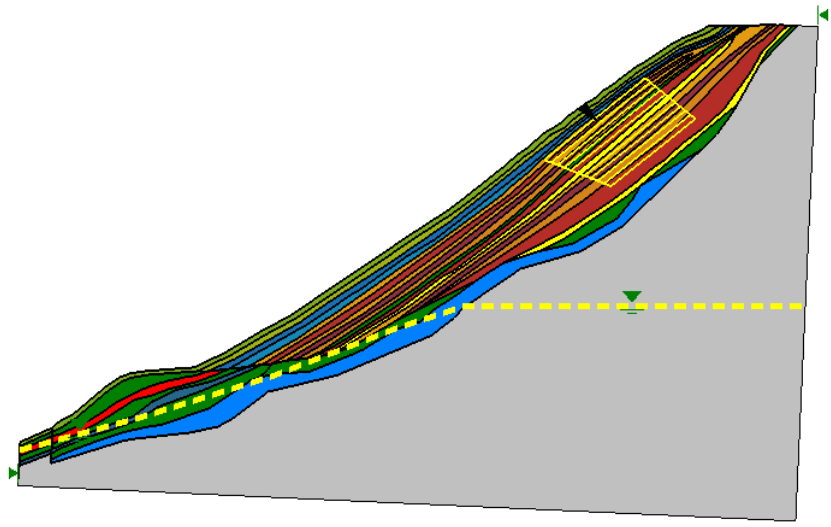

Figure 11 Level 2 water level

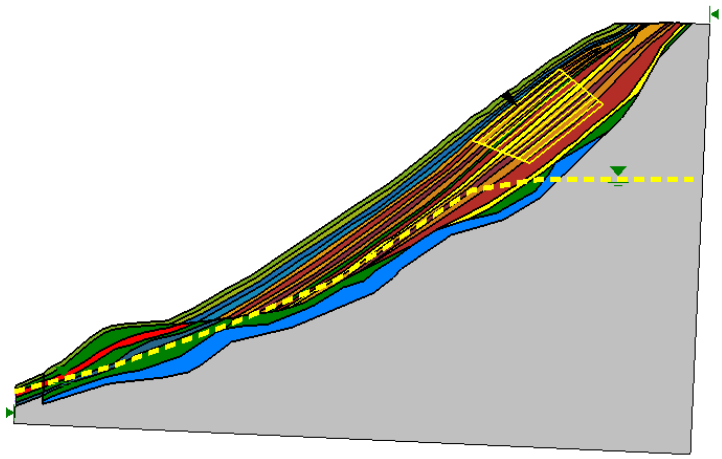

Figure 12 Level 3 water level

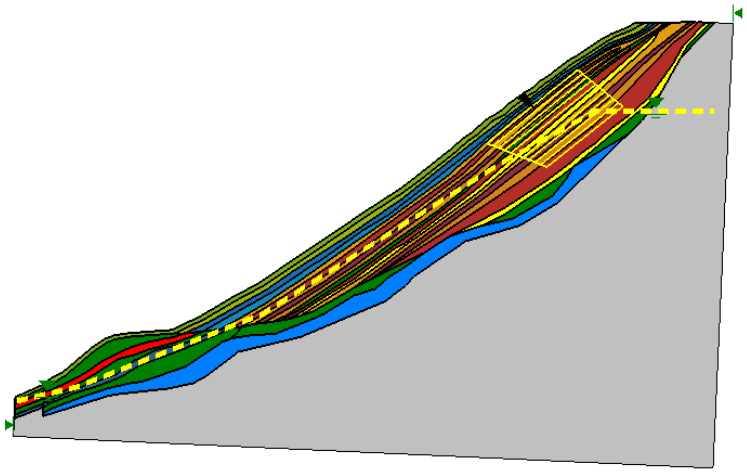

Figure 13 Level 4 water level: Failure conditions reached

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