SLOPE STABILITY ANALYSIS FOR SUNGUN HIGH CENTERLINE TAILINGS DAM

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ABSTRACT

The aim of slope stability analyses is evaluate safety of earth slopes at different conditions of loading and operation. Requirements of these analyses include selection of slope geometry, physical & geotechnical specifications of foundation and slope material as well as the applied loads. Limit equilibrium analysis is carried out based on static equilibrium study of an active soil mass positioning over the slip surface, and as a consequence, safety factor is achieved in the form of ratio of resisting to active forces. Resisting forces are defined as the sum of existing shear strengths on the slip surface, whereas active forces are sum of shear stresses produced on this plane. Slope stability is performed to earth dyke slopes and slope modification scheme of reservoir shores. All the analyses are performed by computer software SLOPE/W, (a part of GEO SLOPE program) according to General Limit Equilibrium (GLE). Analyses were carried out using circular slip planes. Planes in the program are considered such that all slip planes are assumed to have minimum safety factor. For evaluation of seismic stability, pseudo-static method has been used. Seismic coefficients of 0.13 g, 0.20 g and 0.25 g were used in different loading conditions. Results are presented in terms of static and pseudo-static slope stability analyses.

1. INTRODUCTION

The stability of tailings dams has drawn much attention over the past few decades as a significant number of tailings dam failures have been recorded worldwide. Geometric design of tailings dams depends on barrowed materials, subsurface conditions and type of construction. Consequently feasible design can cause significant reduction on construction time, materials and costs. One of the main important factors for the failure of tailings dams is the slope stability analysis in their body and abutments. In order to prevent the dam failure, it is essential to control the stability in the tailings dam.

In this paper, software analysis results consisting of slope stability analysis at different loading conditions of dam performance within its effective life are presented, based on which, geometric design of Sungun high centerline tailings dam parts is performed.

Sungun porphyry copper mine is located 125 km northeast of Tabriz, in north-western Iran (43° 46′ E and 38° 42′ N) (Figure 1). The Sungun high centerline tailings dam is a rockfill dam with a clay core and final crest level is 2275 meters.

Figure 1 : Location of Sungun copper mine in Iran.

In order to identify the dam geometry, the typical cross section of Sungun tailings dam has presented in the Figure 2. According to the geological surveys, alluvial foundation of Sungun tailings dam concluded from coarse-grain (GC, SC and partial SM-SC) and fine-grain materials (CL and partial CL-ML). The dam reservoir (tailings) has concluded from slimes and silicone sands.

Dam crest width is 16-23 and the core width is 5.2 meter.

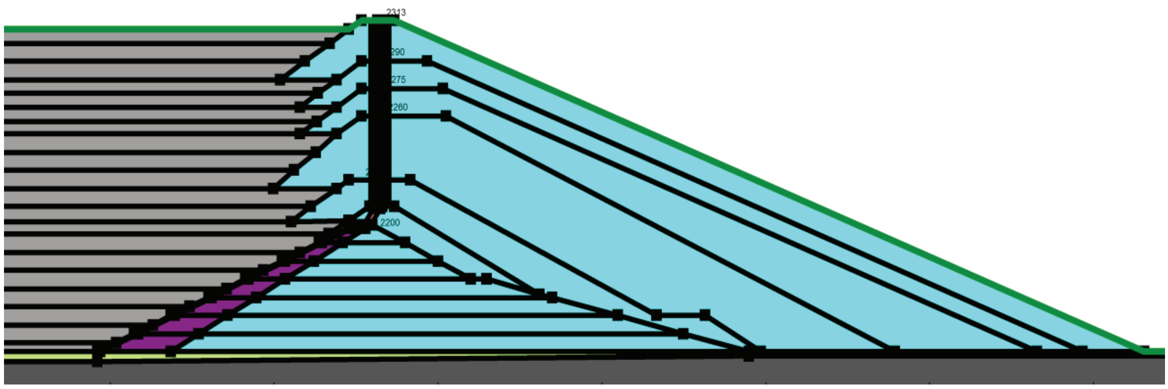

Figure 2 : Sungun tailings dam typical cross section

2. Analysis method

In order to achieve the objectives of this study, Slope/W software (Geo-slope, 2012) is used. This program can calculate the safety factor (FOS) using Bishop (1981), Janbu (1954), Morgenstern-Price (1965), Fellenius (1936) and Spencer (1967) methods. SLOPE/W is one component in a complete suite of geotechnical products called Geo-Slope, one of whose powerful features of the integrated approach is that it opens the door to types of analyses of a much wider and more complex spectrum of problems, including the use of finite element computed pore-water pressures and stresses in a stability analysis. Slope/W can effectively analyze both simple and complex problems for a variety of slip surface shapes, pore-water pressure conditions, soil properties, analysis methods and loading conditions.

Allowable safety factors in the static and pseudo-static analyses has presented based on valid references recommendations (Department of Minerals and Energy Western Australia, 1999 and IRCOLD issue No. 23, 1999) (Table 1) and resulted safety factors in the analyses are in comparison and corresponding to Table (2).

Table 1 : Loading states and minimum of required safety factors (FOS) corresponding to Department of Minerals and Energy Western Australia and IRCOLD issue No. 23.

Loading Conditions	Safety Factor	Shear Strength
Long-term drained	1.5	Effective strength
Short-term undrained (instability can cause to dam failure)	1.5	Consolidated- undrained shear strength
Short-term undrained (There is no probability of the dam failure by instability)	1.3	Consolidated- undrained shear strength
After earthquake	1.2	Drained or undrained shear strength

Table 2 : Considered allowable safety factors (FOS) in slopes stability design.

Raw	Level	Section	Downstream slope	Static safety factor	Pseudo-static safety factor			Pre pressure coefficient
					0.13	0.20	0.25	
1	2275	Maximum	2.45	2.29	1.25	0.99	0.87	Foundation: 0.1
		Right Bank		2.59	1.28	1.00	0.87	Core: 0.05- 0.1

The pseudo-static analysis of slopes stability is performed using a horizontal earthquake coefficient. Earthquake force is considered as the force equivalent to a percentage of the piece weight. To ensure slopes stability under pseudo-static conditions, the earthquake coefficient has been considered based on valid theories of slopes seismic stability.

In the various loading conditions, the earthquake coefficients of 0.13 g, 0.20 g and 0.25 g have been used. These numbers are about half the maximum ground acceleration in the event of an earthquake (DBE, MDE or MCE).

3. SLOPE STABILITY ANALYSIS CALCULATIONS

In order to evaluate slope stability for Sungun tailings dam, Slope/W software is used under the following conditions:

- Drained conditions.
- Undrained conditions.

In general, most of the body of Sungun tailings dam is made of rockfill, which creates a drained conditions for the dam body. But the core, dam reservoir (tailings) and the alluvial foundation are in the undrained conditions, which is considered in the relevant analyzes.

Due to this point which the dam body is constructed using rockfill materials, there is practically no difference between the total stress resistance and the effective stress for these materials, so these materials are in the drained conditions. And considering this point that the tailings are in saturated mode, in all analyzes to ensure the unconsolidated-undrained resistance have been used.

These analyses have done based on geotechnical parameters of dam body, Reservoir (tailings) and alluvial foundation materials (Table 3). Martin et al. (2002) to design and evaluate the tailings dams stability, suggests considering the ratio of undrained shear strength of tailings to effective vertical stress (Su/σv ‘) between 0.2 and 0.3. So in the conservative analyzes, the value of Su/σv’= 0.2 has been chosen.

Table 3 : Geotechnical parameters of dam body and alluvial foundation materials.

Dam Part	Materials Type	CD		CU		UU		γ (Kn/m3)	
		φ	c(KPa)	φ	c(KPa)	φ	c(KPa)	Wet	Saturated
Alluvial Foundation	Fine-Grain	24	10	23.5	63.7	0.4 σv0		-	19
	Coarse-Grain	0	35	Similar to Effective Stress		Similar to Effective Stress		-	20
	Bedrock	28.8	400	Similar to Effective Stress		Similar to Effective Stress		-	
Resrvoir (Tailings)	Slimes	-	-	-	-	0	Su/σ’v0=0.2	-	20
	Sand	37	0	Similar to Effective Stress		Similar to Effective Stress		18.5	19.4
	All-in Tailings	26.9	38.0	19.7	57.8	11	71	19	20
Body	Core	24	10	22.2	53.9	0	100	18.4	19
	Rockfill	Function of Normal Stress		Similar to Effective Stress		Similar to Effective Stress		20	

The varieties of shear strength against the normal stress in the SLOPE/W software have been shown in the Figure 3. Due to the validity of the proposed Leps relations (1970) and the comparison with the newer Barton & Kjærnsli relations that fit well with the Leps relation, the Leps commonly used relation is used to select the parameter of internal friction angle for the Rockefle materials. Barton & Kjarensl's (1981) relation has also been used for better evaluation of the selective friction angle for rockfill materials.

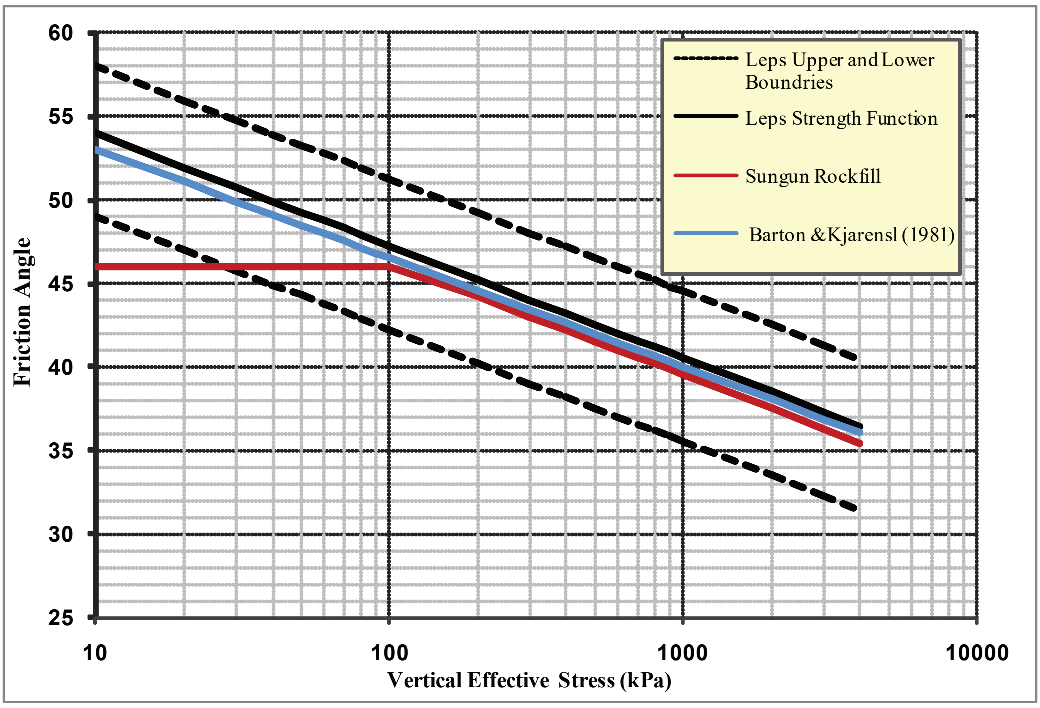

Figure 3 : The varieties of internal friction angle of rockfill materials along with the vertical effective stress increasing

To ensure the stability of the dam slopes, all cross sections along the dam axis (along the river bed and abutments) have been evaluated. Selection of sections is done based on alluvial foundation status. By alluvial foundation study, in the northern bank (abutment) and middle part, the foundation thickness is zero and in some places is insignificant, but in the right bank, the alluvial foundation depth reaches to about 20 meters. Accordingly, the analysis of dam stability has been analyzed in the two sections of maximum and right bank.

The software outputs contain a built-in geometric model and the slip surface with the least safety factor in the downstream slope at static and pseudo-static states has been presented in the maximum cross section and the maximum level (2275 meter) in the Figures (4- 7) and in the right bank and the maximum level (2275 meter) in the Figures (8- 11).

The obtained safety factors indicate that the considered geometrical shape with respect to the information obtained from the foundations and the body materials is sufficiently stable at each level.

It is worth noting in all levels and in all uploading conditions is used from both of Entry & Exit and Grid & Radius methods to determine the failure surfaces and the least safety factor is calculated and presented.

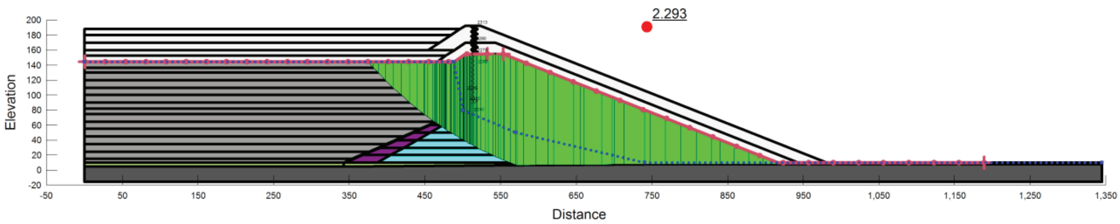

Figure 4 : Downstream failure surface at static state and maximum cross section

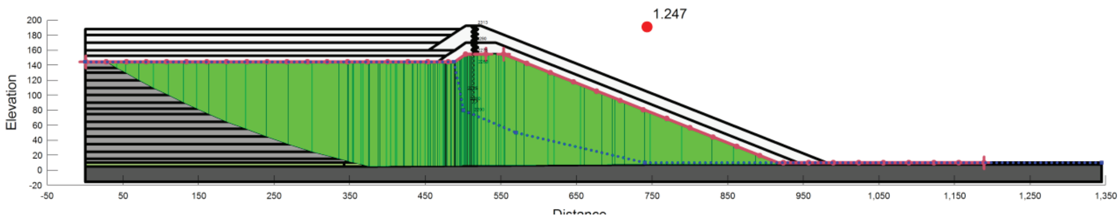

Figure 5 : Downstream failure surface at pseudo-static state and maximum cross section with earthquake acceleration 0.13g (DBE)

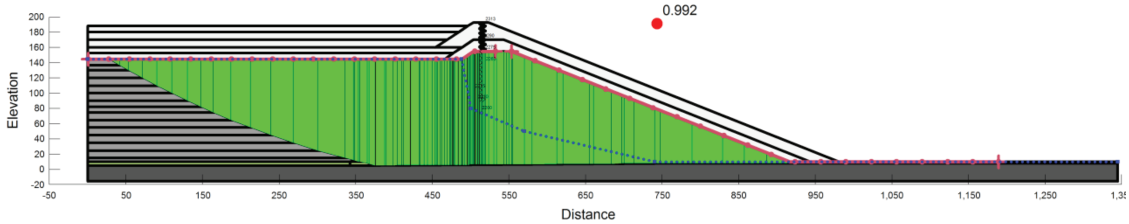

Figure 6 : Downstream failure surface at pseudo-static state and maximum cross section with earthquake acceleration 0.20g (MDE)

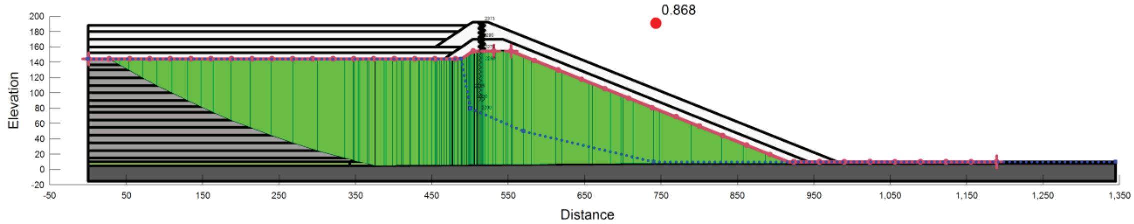

Figure 7 : Downstream failure surface at pseudo-static state and maximum cross section with earthquake acceleration 0.25g (MCE)

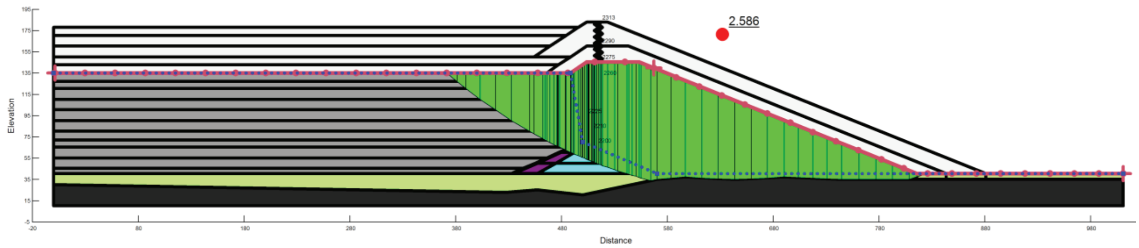

Figure 8 : Downstream failure surface at static state and right bank

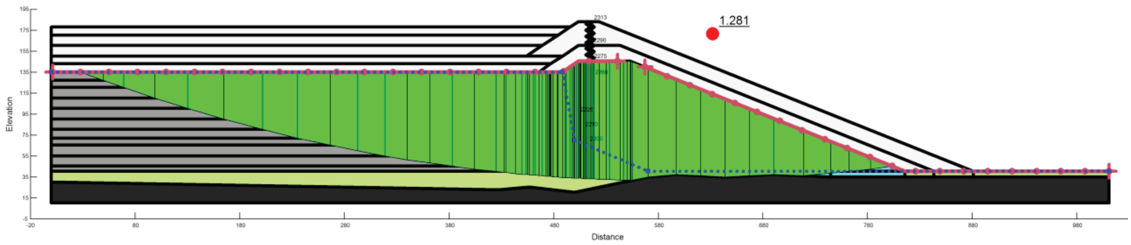

Figure 9 : Downstream failure surface at pseudo-static state and right bank with earthquake acceleration 0.13g (DBE)

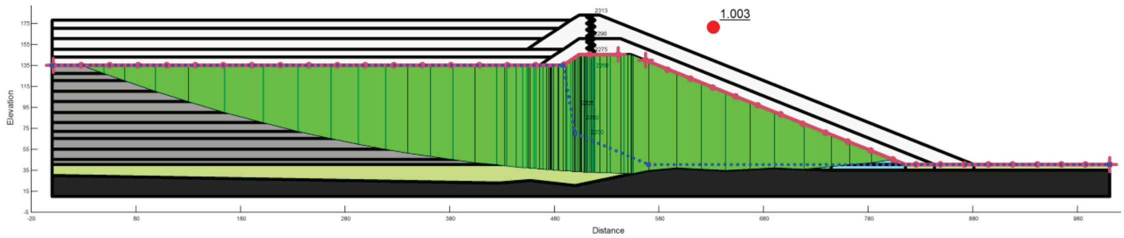

Figure 10 : Downstream failure surface at pseudo-static state and right bank with earthquake acceleration 0.20g (MDE)

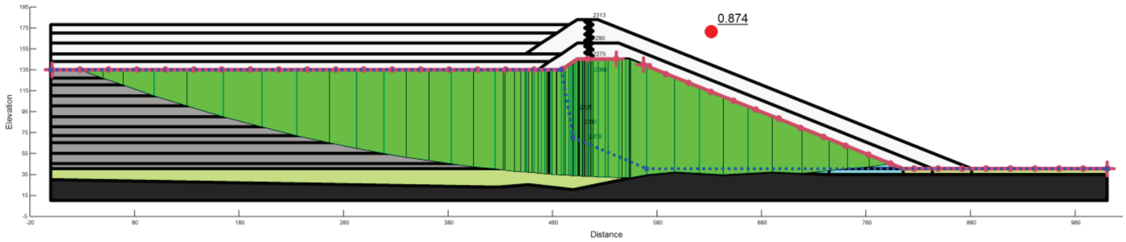

Figure 11 : Downstream failure surface at pseudo-static state and right bank with earthquake acceleration 0.25g (MCE)

4. CONCLUSION

In the present study Slope/W software is used under different conditions to evaluate slope stability. Analyzes for each state and each slope is calculated that the minimum safety factor in each of this method, be considered as a safety factor (FOS) of slope stability. Stability analyses has done based on common finite element method at different loading conditions, and the results showed that dam body has no specific problem in terms of stability.

Based on the results, in general in the performed analyzes, and especially in the final levels, the width of the dam crest and the assumed slopes, provide the required stability for the dam body.

The proposed sections at DBE level have a safety factor more than one in all levels. At the MDE level, the results are nearly one at almost all levels. In general the safety factor of less than one cannot be interpreted as a means of dam instability and failure. Given the nature of the reciprocal earthquake and the assumptions of the pseudo-static analysis method, it is practically conservative to consider a constant seismic coefficient in a horizontal direction and in the cases which the required safety factor is not achieved, the slope does not lose its performance and will only have displacement values; therefore, it is important to evaluate more accurately the performance of the lattice seismic behavior with the help of dynamic analysis.

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