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Slope Stability Analysis of the 3rd Kuhrang Tunnel Portal

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Abstract

Green marls located in the slope of reservoir dam in the 3rd Kuhrang tunnel have considerable swelling behavior, which may fail after filling the reservoir with water. Slope collapse of the 3rd Kuhrang tunnel in big volume may cause the closure of the portal and bring the transportation of the water supply to an end. This study investigates the slope stability of the 3rd Kuhrang tunnel based on different tests of marl. In this investigation, equilibrium methods which are very important in empirical studies are used.

Keywords: Slope stability, marl, portal, rock properties

1 Introduction

Kuhrang water supply project or the third Kuhrang tunnel and dam project, which transfers Kuhrang springs water to Zainderood river. Available systems to exploit Kuhrang water consist of the first Kuhrang tunnel and dam project, second Kuhrang tunnel, and dam project that conveys part of water basin to Zainderood river. The third Kuhrang tunnel and dam are located in Chaharmahal and Bakhtiari province, central Iran, which connects to Zainderood river with 23 km length.

2 Geological and Geotechnical Conditions

Third Kuhrang portal trench and parts of the portal tunnel are located in marine marl formations of Quaternary age. Based on geophysical surveys mainly seismology it is specified that the portal parts are similar to dam site. It is observed the clastic sedimentary formations in portal consist of mudstone, marl, sand, gravel, clay, silt. The above mentioned formations generally maintain initial, horizontal situations and have the least effect on structural events. The marls in the most geological reports are predominant formation known as green marls and generally limestone compounds, which are originated from high mountains located around. The green marls generally result from

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fine sands, silt, clay and are capable of liquefaction, dispersion and swelling. Shear strength of these soils, parts of which are not saturated, such as the marly sediments of the portal, mostly formed of fine sands, silt reduces in fully saturated conditions such as submerge in water. The induced pseudo-cohesion can prevent failure of vertical sections in fine sands or damp silts. This type of cohesion are generally above water table and does not disappear due to heavy atmosphere falls, but when this formation is submerged in water, failure in soil happens. The filling of water dam reservoir may cause big earthquakes, and also reservoir leakage from channels without lining. And the vicinity of portal may undergo failure by internal erosion or piping.

3 The Portal Slope Stability Assessment

From engineering point of view the reasons for the failures are : slope geometry or changes in total stresses, pore water pressure, drainage and finally shear strength of the materials. The design criteria of instability consist of avoiding building high slope, the use of good quality ground and avoiding slope in weak ground, designing structures capable of displacement, and stabilization. From engineering point of view the movement of mass happens when the shear stresses exceed the strength of the materials, thus any process which causes increase in the stress or less shear strength in the areas of potential failure can be hazardous. To design effective preventive methods and control of landslides, not only effective parameters of failures but also the complete geometry and the amount of the displaced soil, rock mass are required.

4 Sample Test Results

To access the required samples the in-situ sampling was done by a core testing machine with 4 in bit diameter and the 38 mm cores prepared in the laboratory. Based on type of bedding and geological section, the green marl is only located in the slope of the tunnel and all the tests are done in green marl as follows.
1-Humidity tests : the test results of the water content of the samples are as follows (Table 1). 2-Porosity, void ratio, dry and saturated density : the results are as follows (Table 1) 3-Uniaxail compressive strength (UCS) : the UCS in dry and saturated state with Young's modulus are as follows (Table 2) 4-Triaxail compression test : the test results with CU, CD (undrained, drained) are as follows (Table 3) 5-Swelling test : the test results are as follows (Tables 4,5):

Table 1: Physical properties of rock samples

Depth of sample (cm)	Water content (%)	Density (gr/cm^3)		Porosity (%)	Void ratio (%)
		Dry	Sat		
70	14	1.60	1.90	32	0.47
50	14	1.66	1.98	31	0.45
100	16	1.75	2.10	34	0.51
75	15	1.67	2.00	32	0.47
75	17	1.58	1.91	37	0.59

Table 2: Uniaxial compression strength test

Description of rock samples	Young 's modulus (kg/cm^2)	UCS (kg/cm^2)
Vertical to direction of sampling (sat)	93	2.78
Parallel to direction of sampling (sat)	88	2.38
Vertical to direction of sampling (sat)	98	3.70
Parallel to direction of sampling (sat)	97	3.20
Vertical to direction of sampling (sat)	57	1.70
Parallel to direction of sampling (sat)	53	1.60

Table 3: Triaxial compression test

Description of rock samples	Cohesion (kg/cm^2)	Friction angle (degrees)
Parallel to direction of sampling (CU)	0.81	18
Vertical to direction of sampling (CU)	0.95	18
Parallel to direction of sampling (CD)	0.72	25
Vertical to direction of sampling (CD)	0.83	26
Parallel to direction of sampling (CU)	1.05	18
Vertical to direction of sampling (CU)	1.20	18
Parallel to direction of sampling (CD)	0.88	26
Vertical to direction of sampling (CD)	0.98	27
Parallel to direction of sampling (CU)	0.60	15
Vertical to direction of sampling (CU)	0.53	14
Parallel to direction of sampling (CD)	0.50	21
Vertical to direction of sampling (CU)	0.45	21

Table 4: Free swelling test

Description of rock samples	Density (dry) gr/cm^3	Density (sat) gr/cm^3	Swelling value mm
Parallel to direction of sampling	1.63	1.95	0.13
Vertical to direction of sampling	1.62	1.98	0.23
Parallel to direction of sampling	1.75	2.03	0.25
Vertical to direction of sampling	1.70	2.00	0.31
Parallel to direction of sampling	1.75	1.90	0.13
Vertical to direction of sampling	1.75	1.91	0.33

Table 5: Swelling pressure test

Description of rock samples	Density (dry) gr/cm^3	Density (sat) gr/cm^3	Swelling pressure kg/cm^2
Vertical to direction of sampling	1.61	1.83	0.18
Parallel to direction of sampling	1.59	1.83	0.10
Parallel to direction of sampling	1.72	1.89	0.40
Vertical to direction of sampling	1.73	1.89	1.66
Vertical to direction of sampling	1.72	2.00	1.82
Parallel to direction of sampling	1.59	1.83	0.71
Parallel to direction of sampling	1.63	1.86	0.69

5 Slope Characteristics

The third Kuhrang portal has 20 degrees inclination which is not safe due to available research on similar marls [1]. The safety dip of slope in this type material, in saturated condition is anticipated to be 10 degrees. The test results are obtained from samples with laboratory analysis after two days of saturation. Thus, it can be expected that swelling behavior appears in test results. Different analyses which are important in limit equilibrium methods with the use of software are Janbu [2], and modified Bishop [3]. In this research, the Clara software (1988) is used, which can solve soil, rock slope stability in two dimensions, and three dimensions. Clara software [4] can analyze the problems of water table characteristics with different pore pressures, discontinuities, weak planes, different types of external loading and tension cracks. In this software, to find critical circle three methods (single sliding circle, auto search, grid search) are used for any types of Bishop and Janbu analyses.

6 Stability Analysis

6.1 First Case

According to the first case study, the level of water table behind the dam is considered 80 m above the top of tunnel. Slope topography is shown with maximum available water table in Fig 1. Both analyses are done [2,3] with three methods, single sliding circle, auto search, and grid search (Figures 2,3,4). The input data (c,γ,φ) are used in saturated condition. The test results of c, φ are considered the least values in the analyses because of the need to increase safety factor. The results show the specified slope in fully saturated condition which is relatively stable.

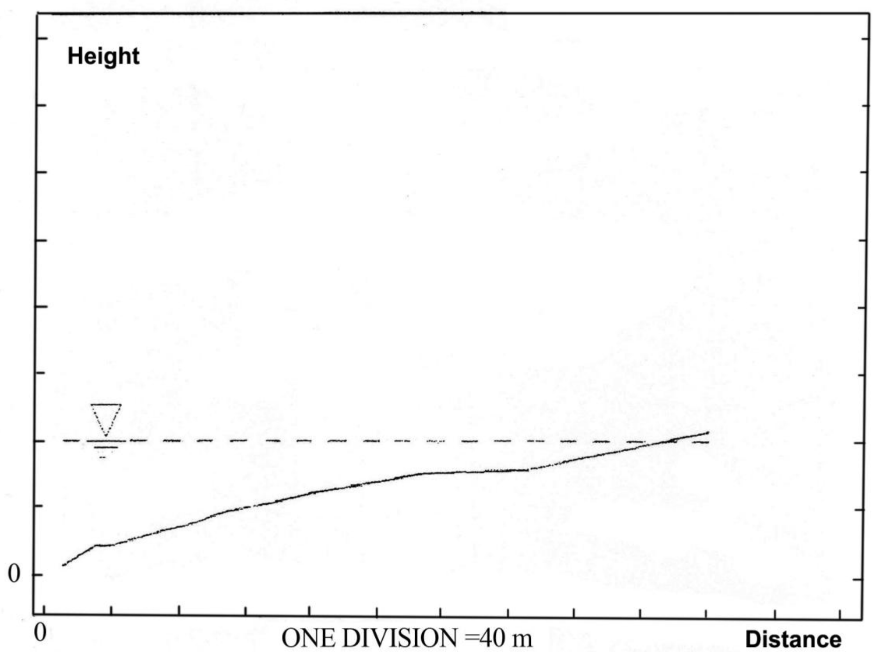

Figure 1: Topography of the area and water table

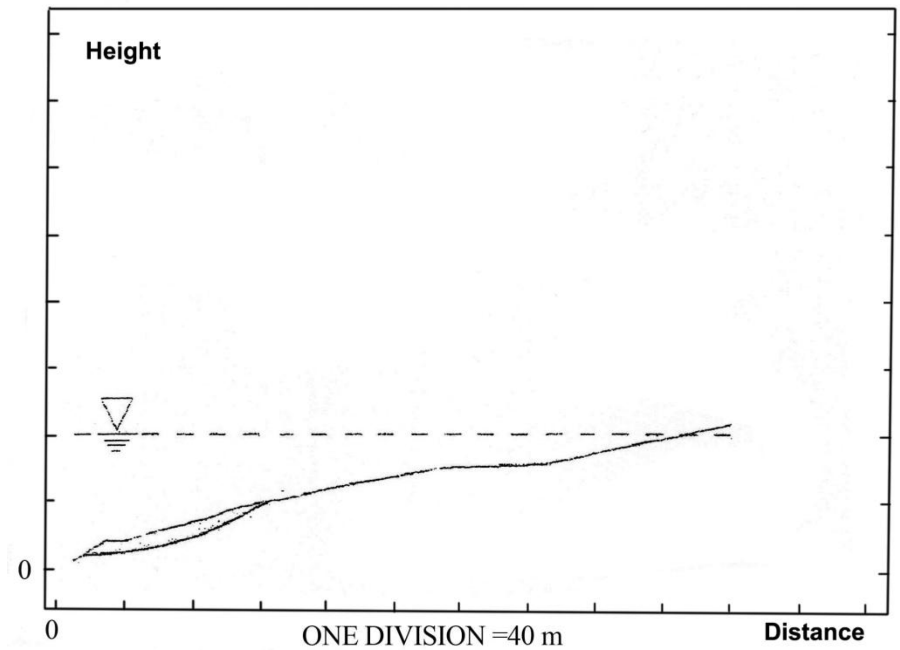

Figure 2: Failure curve with single sliding circle

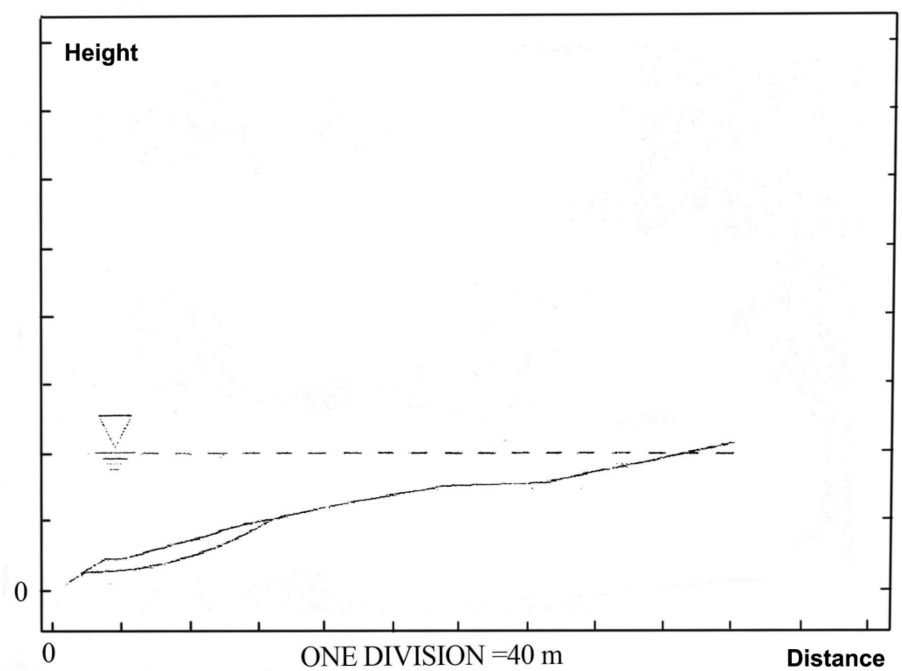

Figure 3: Failure curve with auto search method

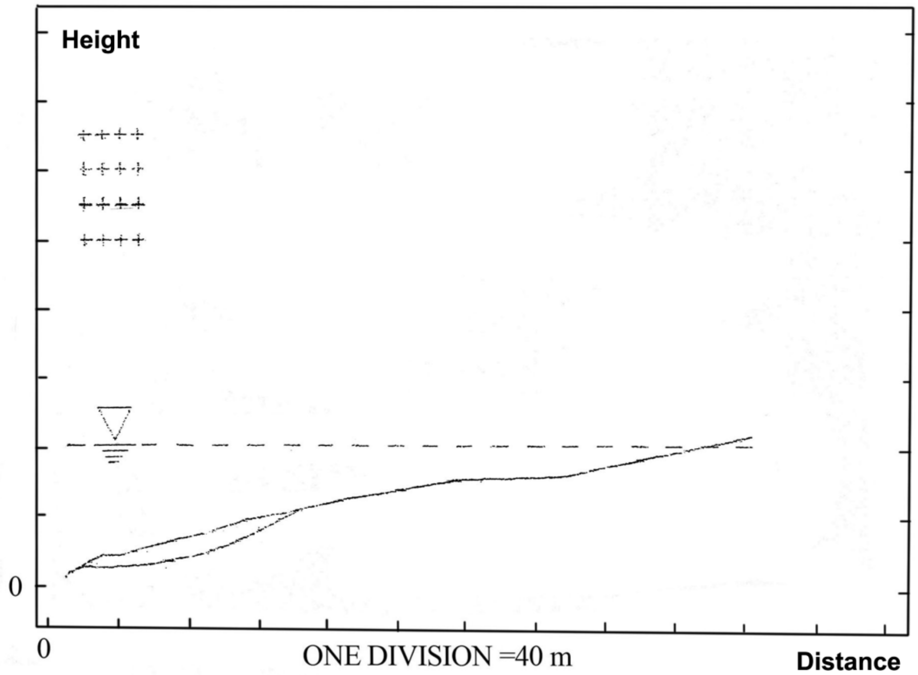

Figure 4: Failure curve with grid search method

6.2 Second Case

The other case with the height of 40 meter water level above the roof of tunnel is considered. Clara software is capable of considering 12 layers with different characteristics, which can analyze the slope stability. The layers are numbered from bottom to top. Each layer is characterized with reference number. The first layer is saturated marl and second one, the upper layer, is dry marl (Figure 5). The three methods consist of single sliding circle, automatic search and grid search (Figures 6,7,8). In this case the obtained results also indicate the slope is stable.

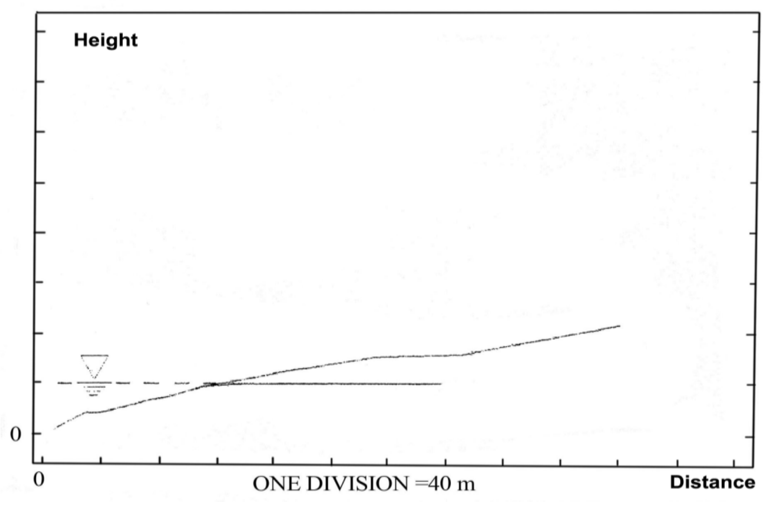

Figure 5: Sequence of layers and water table

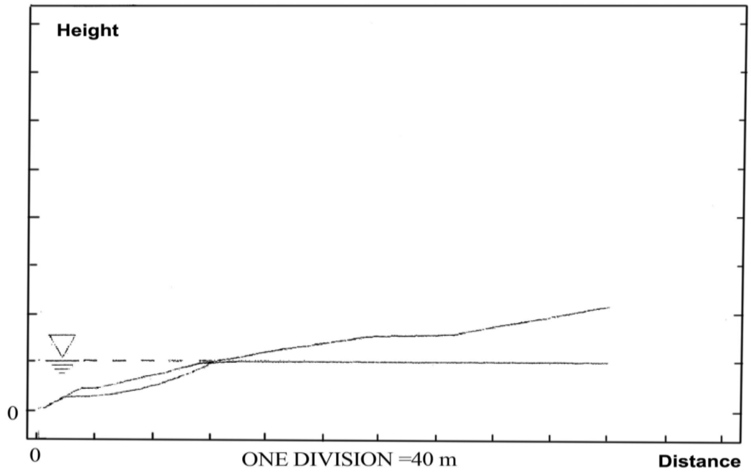

Figure 6: Failure curve with single sliding circle

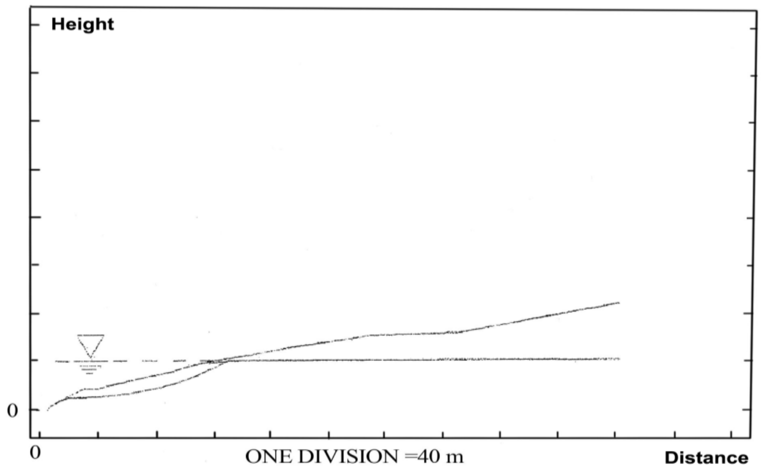

Figure 7: Failure curve with auto search method

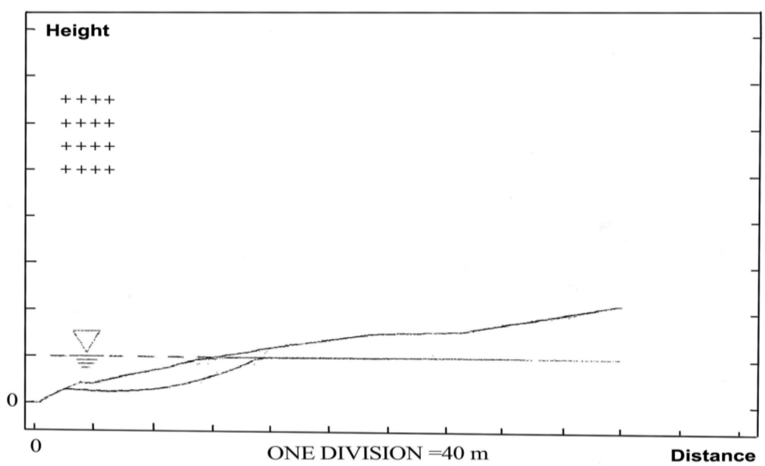

Figure 8: Failure curve with grid search method

7 Sensitivity Analysis

This assessment is important to compare real conditions of soil during test and the conditions of soil during test and the conditions which may exist. All of the tests consist of errors in measurements and interpretation. As the effective parameters of stability have not constant values and change in specified domain, the effect of these changes in safety factor is assessed with sensitivity analysis.

8 The Effect of Cohesion on Safety Factor

The changes of safety factor due to cohesion are plotted in Figures 9,10. As it is observed, the effect of cohesion on safety factor is linear. One of the specifications of swelling in marls cohesion reduces after swelling.

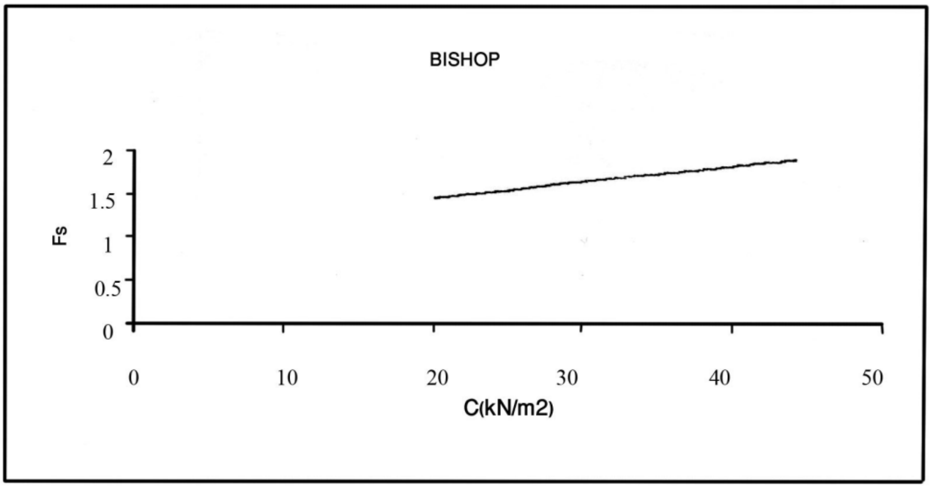

Figure 9: Effect of cohesion on FS in Bishop method

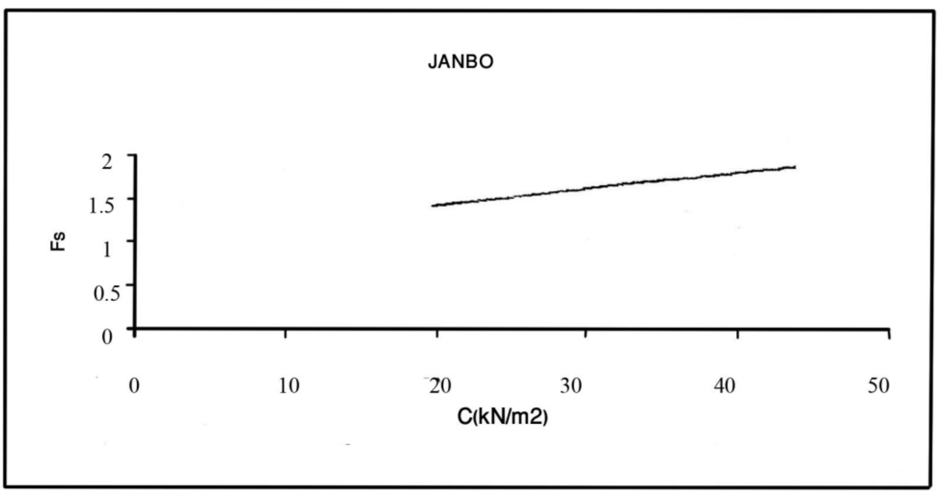

Figure 10: Effect of cohesion on FS in Janbu method

9 The Effect of Internal Friction on Safety Factor

The effect of this parameter on safety factor is shown in Figures 11,12. The internal friction has a very dominant effect on location of the sliding surface.

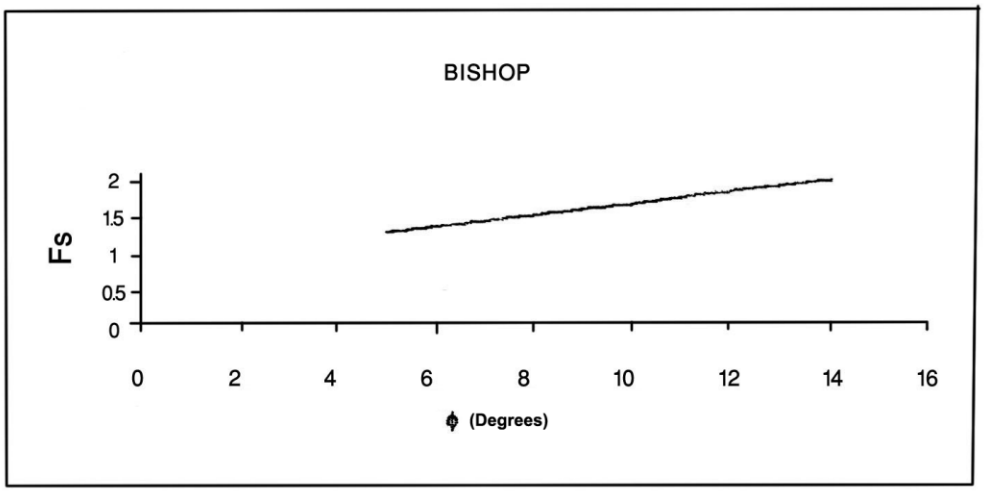

Figure 11: Effect of friction on FS in Bishop method

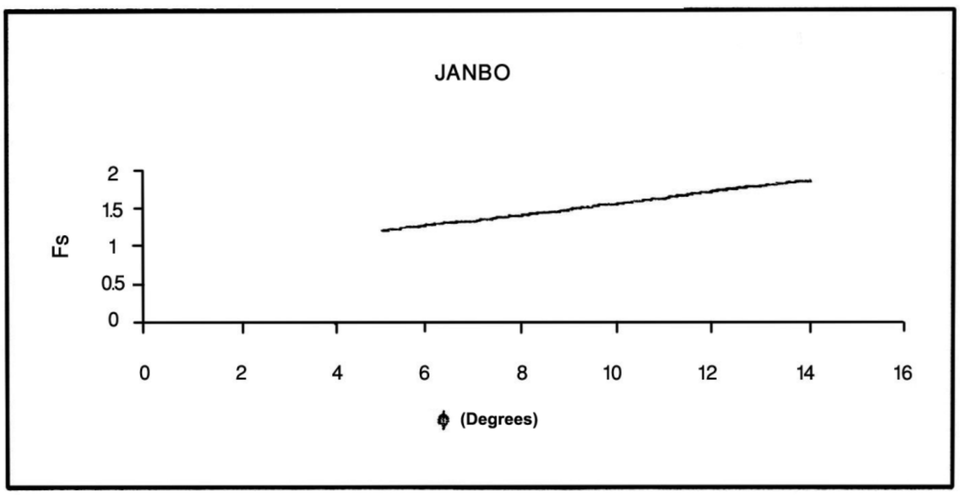

Figure 12: Effect of friction on FS in Janbu method

10 The Effect of Unit Weight on Safety Factor

The weight force in each specified segment in the analysis is defined as moving force, and reduction of γ considerably increases safety factor as it is shown in Figures 13,14. The results show that submerged slope and saturation of soil and γ increases. This state indicates that the stability of the specified slope in saturated state is lower than dry state.

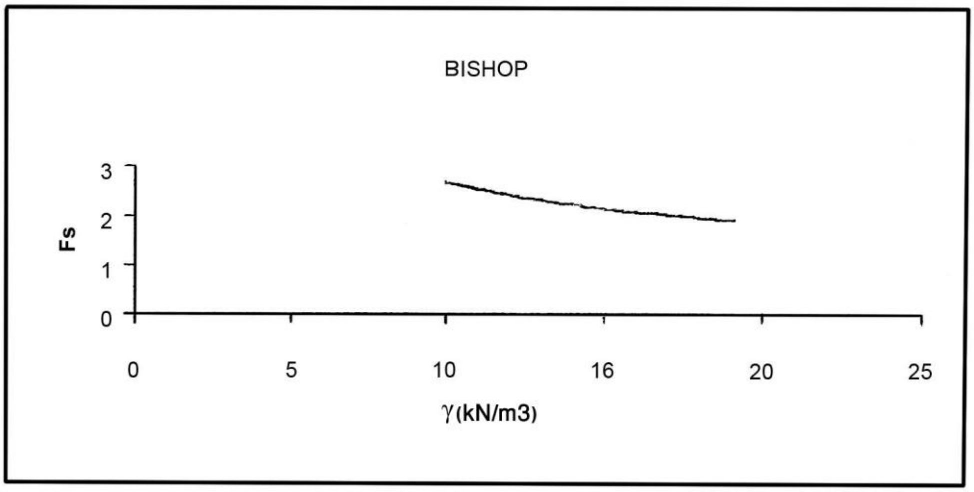

Figure 13: Effect of unit weight on FS in Bishop method

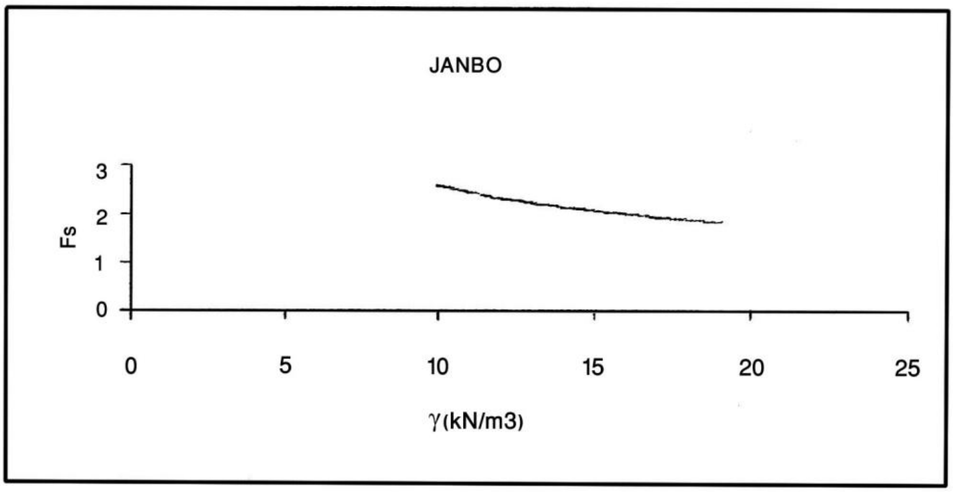

Figure 14: Effect of unit weight on FS in Janbu

11 Conclusions

In this study, considering the natural slope on young marls at the third Kuhrang tunnel portal, the laboratory tests were assessed by the use of Clara software. Both Bishop and Janbu methods which are general ones in limit equilibrium analyses were utilized with different water tables behind the dam. It is concluded that the safety factor in all c,γ,φ to specified slope stability is acceptable.

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