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INVESTIGATION OF INFLUENCE OF BERM HEIGHTS, GRADIENT OF SLOPE EXCAVATION AND GROUNDWATER DEPTHS ON SAFETY OF WEAK ROCK SLOPE

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Keywords
Excavation Slope, Slope Stability, Berm Height, Rock, Ground Water.

Abstract
In this study, effects of berm heights, excavation slope gradients and groundwater depths on the stability of designed excavations as well as variations on the safety factors of the excavation slopes are investigated. In the study, 3 different berm heights (5m, 10m and 15m) and 2 berms usually preferred and faced at the slope excavation applications were taken into consideration. So, for instance, for a 10 m berm height, total slope height to be analyzed will be a 30m high due to for 2 berms. In addition, depending on these 3 different berm heights (5m, 10m and 15m), 3 different slope excavation gradients (45^0, 55^0 and 65^0) were also defined in the modeling. Then, for these 9 different slope excavation designs, 3 different groundwater depths were also additionally attained in the analyses. Numerical seepage analyses were performed on totally 27 different modal types. Location of phreatic water seepage lines and pore water pressure values as well as safety factors of the excavation slope failure surfaces were analyzed depending on berm heights, excavation gradients and groundwater locations for 27 different excavation and slope scenarios. This study showed that when berm heights are increased, then safety of the slope excavations is decreased.

KAZI PALYE YÜKSEKLİĞİ, KAZI ŞEV EĞİMİ VE YERALTI SUYU DERİNLİĞİNİN DÜŞÜK MUKAVEMETLİ KAYA KAZILARININ STABİLİTESİ ÜZERİNE ETKİLERİNİN ARAŞTIRILMASI

Anahtar Kelimeler
Kazı Şevi, Şev Güvenliği, Palye Yüksekliği, Kaya, Yeraltı Suyu.

Öz
Bu çalışmada, Palye tasarım yüksekliklerinin, kazı şevi eğimlerinin ve yeraltı suyu konumunun projelendirilmiş kazı şevlerinin stabilitesine olan etkisi ve kazı şevi kayma güvenliklerindeki değişim dereceleri araştırılmıştır. Uygulamada çoğunlukla alınan 5m, 10m ve 15m gibi üç farklı palye yüksekliği dikkate alınmış ve toplam yamaç kazısının yine uygulamada çoklukla karşımıza çıkan iki palye oluşturulduğunda biteceği kabul edilmiştir. Örneğin 10m palye yüksekliğinde iki palye yapıldığında modellenecek ve analiz edilecek toplam yamaç kazısı yüksekliği 30m olmaktadır. Bunun yanı sıra 3 farklı palye yüksekliğine (5m, 10m ve 15m) bağlı üç ayrı kazı şevi eğimi (45^0, 55^0 ve 65^0) modellenmiş ve 9 farklı kazı tasarımı için ayrıca 3 farklı yeraltı suyu derinliği etkisi dikkate alınmış tır. Toplamda 27 farklı model üzerinde yeraltı suyu nümerik sızma analizi yapılarak freatik hatların konumu ve kayaç boşluk suyu basınçları ayrı ayrı hesaplanmıştır. Hesaplanmış boşluk suyu basınçları stabilite analizlerinde kullanılarak kazı şevlerinin güvenlikleri palye yüksekliklerine, kazı şev eğimlerine ve yeraltı suyu derinliklerine bağlı olarak hesaplanmıştır. Analiz sonuçları, palye yüksekliği arttıkça kazı şevlerinin güvenliği azaldığını göstermiştir. Ayrıca yeraltı suyu derinliği ne kadar yüksek ise kayma yüzeylerine etki eden boşluk suyu basınçları o derece yüksek oluşmakta, kazı şevlerinin güvenliği azalmaktadır.

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1. Introduction

Excavations for the construction of structures such as dam structures, highways and buildings located on located on steep valleys and rocky rims are usually required. In such cases, slope stability has to be provided for an excavation. There are many studies on rock slope stability and excavations excavations [(Anbalagan, 1992), (Anbalagan et al, 1992), Alejano et al, 2011), (Bye and Bell, 2001),(Chen, 1995),(Coggan, 1998), (He et al, 2008), (Hoek and Bray, 1981), (Hustrulid et al, 2000), (Kanda, 2015), (Nunes et al,2004), (Stacey, 2006), (Wylie and Mah, 2004)]. Stability of the excavations and slopes are affected by various parameters and conditions such as material strength of the soil or rock, geological setting, topographical slope gradient, excavation gradient, groundwater location and excavation slope height depending on the berm levels. When the required total excavation height is sufficiently high, then the berms with some intervals and heights on the slope excavations (depending on the project type and characteristics of the slope and its material) are also usually constructed for providing safety and easiness of construction.

In many civil engineering construction projects, berm heights and widths for slope excavations are usually determined by experience depending on the project and slope characteristics such as material strength and site conditions such as existence of groundwater, gradient of the topographical slope and required total excavation height etc. However, when berm heights are chosen sufficiently high, then the safety of the excavation slopes against slides is decreased although excavation costs are minimized in this case. In addition, local site conditions such as existence of groundwater and its levels as well as soil or rock properties and gradient of the designed excavation slopes affected safety of the excavations against slide failures.

In this study, 3 different berm heights with 5m, 10m and 15m and 2 berms for each required total excavation height were taken into consideration for the analyses in the modeling to determine variations on the sliding safety of the weak rock slope excavations with homogeneous rock strength and permeability properties (Figure 1). Then, for each berm height, 3 different ground water levels and 3 different slope excavation gradients (β) such as 45^0, 55^0 and 65^0 as well were considered in the analyses to determine their effects on the stability of the slope excavations. Pore water pressures depending on the groundwater levels as well as the location of the free surface flow of the ground water are calculated numerically using finite element method by the software SLIDE. Then, those pore water pressures were applied on the calculation of factor of safety of sliding surfaces for each slope excavation scenarios in the software SLIDE.

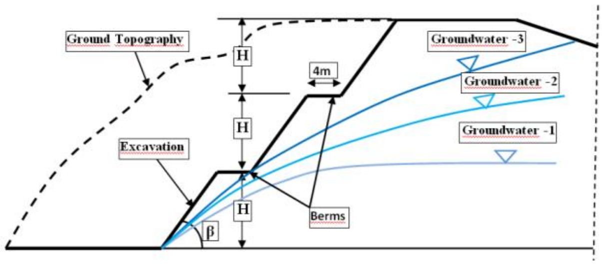

Figure. 1. Schematic view of the modelled excavation

2. Material and Method

Depending on geological condition (groundwater levels), excavation slopes and berm heights, different calculation combinations were determined. Totally, 27 scenarios and modeling, finite element seepage solutions were first performed to obtaining phreatic groundwater levels and pore water pressure values acting on the sliding surfaces of the excavation slopes (Table 1) using software SLIDE (Rocscience, 2011). Table 2 explains the meanings of the abbreviations given in Table 1.

Finally, slope stability analyses of the excavations for the 27 different scenarios were also performed to find the safety factors of the failure surfaces for each excavation type and condition by SLIDE. In stability analyses, widely used Bishop limit equilibrium method was used considering failure surfaces would be almost circular as seen in most homogeneous soil and weak rock conditions such as schist. Weak rock engineering properties used in the seepage and stability calculations are given in Table 3.

In Bishop method, horizontal internal forces (E) between slices were taken into account in the stability calculations (Bishop, 1955, Bishop Morgenstern, 1960). Whereas, vertical inter slice forces (X) were omitted. Safety factors of the sliding surfaces were calculated using Equation 1. In Equation 1, Factor of safety values (FS) are seen both side of the equation (Figure2). Therefore, in the solutions, for each FS values, iteration have to be performed to reach the solution. Software SLIDE performs this iteration for both specified In seepage analyses, permeability values of the weak rock was determined according to

Van Genuchten parameters and 2-D Darcy seepage flow equation is used and Laplace solutions of the seepage domain was obtained by finite element solution method (Equation 2).

Table 1. Analyses scenarious of excavation slopes depending on berm heights, geological and excavation conditions.

Analyses of excavation slopes depending on berm heights, ground water depth and slope			
Factor of Safety Sliding Surfaces (FS)			
Analyses Combinations	Berm Heights (H)		
	5	10	15
β45Wd1	1,56	1,291	1,22
β45Wd2	1,54	1,21	1,12
β45Wd3	1,01	0,78	0,63
β55Wd1	1,33	1,13	0,95
β55Wd2	1,26	1,01	0,86
β55Wd3	1,01	0,69	0,51
β65Wd1	1,26	0,93	0,75
β65Wd2	1,21	0,83	0,75
β65Wd3	1,06	0,8	0,75

Table 2. Meanings of abbrevations given in Table 1.

Abbreviations	Meaning
H	Berm Height (5m, 10m ve 15m)
β	Slope of Excavation (45^0, 55^0 ve 65^0)
Wd	Groundwater Depth (3 different depths:Shallow, moderate and deep)

Table 3. Weak rock engineering properties

Properties	Values
Unit weight, ϒ	19 kN/m^3
Cohesion, c	0
Internal friction angle, Ø	37^0
Permeability, k (cm/s)	$1x10^{-5}$

$$FS = \frac{\sum\left[(c.B + W.\tan\emptyset)\left\{\cos\alpha + \frac{\sin\alpha.\tan\emptyset}{FS}\right\}\right]}{\sum W.\sin\alpha} \quad (1)$$

where, FS; factor of safety, c; cohesion, Ø; internal friction angel, X and E; side forces of slices, W; slide weight, α; angel of slices with horizontal line.

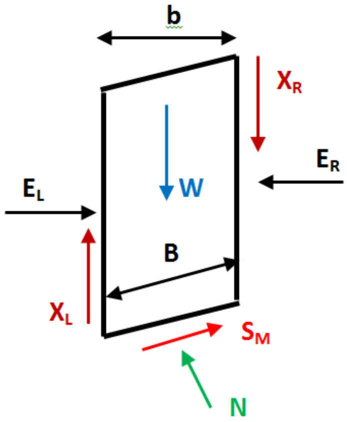

Figure 2. Bishop forces on the failure surfaces.

where, b; horizontal width of slices, S_M; shear strength at the base of slice, n; normal force at the base of slice.

$$k_{wx}\frac{\partial^2 h_w}{\partial x^2} + k_{wy}\frac{\partial^2 h_w}{\partial y^2} = 0 \quad (2)$$

Where, kw is the coefficient of water permeaility of soil, which is a function of pore water pressure (Dogan and Motz, 2005). Flow was modeled for steady state condition. For the analyses, finite element method was applied using SLIDE/Grounwater module. Number of elements were approximately 1500, and 8 noded guadrilateral elements were used in the modeling. Covegare parameter was chosen as 0.05. In order to build up the phreatic line, full of water at the level of the total berm height was assumed at the right side of the rim in the modeling, and boundary condition was chosen according to this condition.

2.1. Seepage and Slope Stability Solutions

For 27 different scenarios due to excavation slope angle, groundwater depth and berm heights, totally, 27 finite element numerical seepage modeling and solutions were first performed to locate the groundwater flow line and also obtain the pore water pressures which would be acted on the failure surfaces of the excavation to calculate safety factors of the sliding surfaces and stability of the excavated slopes as well. Shallow failure surfaces with minimum factor of safety values and also the sliding surfaces which cover only the one of two berms or one of 3 excavation slopes with same height (H) were not taken into account for the evaluations.

Instead, as more meaningful, deep failure surfaces with a minimum safety factors and also the surfaces passing through at least one berm with 2 excavated slopes were considered in the safety evaluation of the excavated slopes. Only 5 modelings out of 27 different solutions showing together with results of numerical seepage and limit equilibrium slope stability analyses are presented in Figures 3, 4, 5, 6, 7 and 8 in order not to make mass in this paper. Those figures are actually sufficient to explain the modelings and solutions performed. Factor of safety grid with all color interval values as well as deep critical failure surfaces with minimum safety factors are seen in Figures 3, 4, 5, 6, 7 and 8.

In addition, phreatic groundwater flow line and calculated pore water pressure values are also presented in these figures with color interval bandts of the pressures obtained as a result of finite element seepage analyses. Evaluation of the results will be explained in the next section.

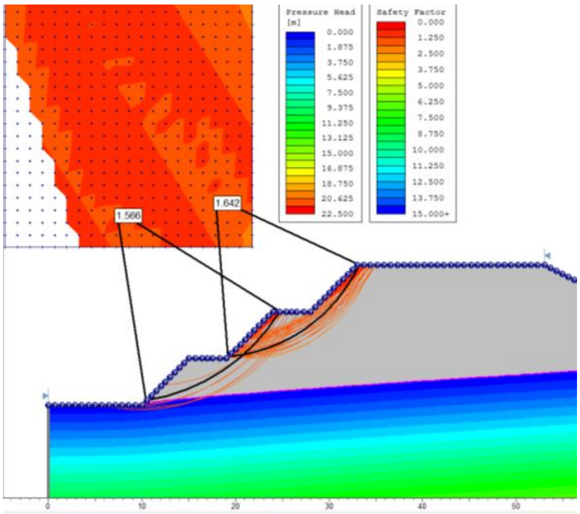

Figure 3. Numerical seepage and slope stability calculations for 5m berm heights, 45^0 excavation slopes and deepest groundwater level from the surface of the rim.

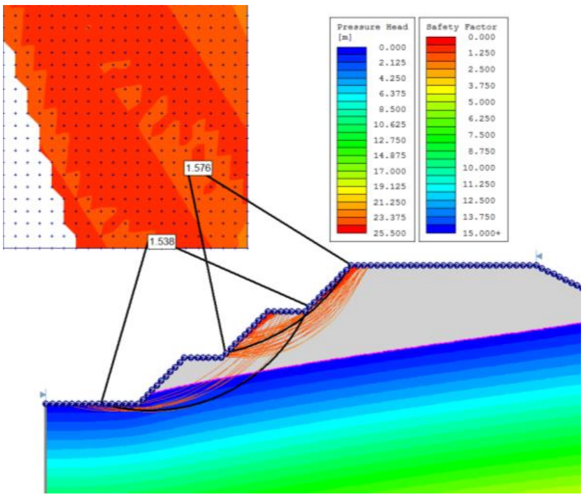

Figure 4. Numerical seepage and slope stability calculations for 5m berm heights, 45^0 excavation slopes and medium groundwater level from the surface of the rim.

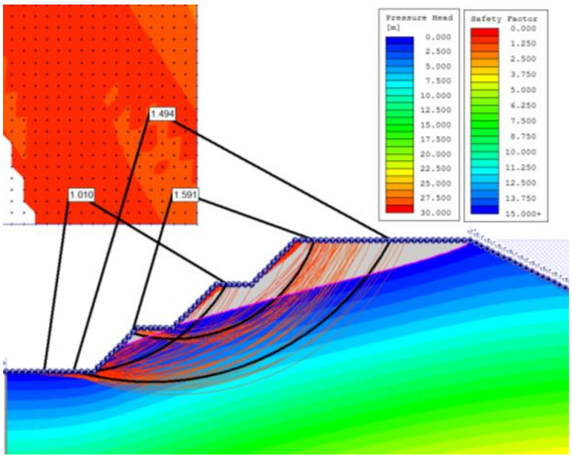

Figure 5. Numerical seepage and slope stability calculations for 5m berm heights, 45^0 excavation slopes and shallow groundwater level from the surface of the rim.

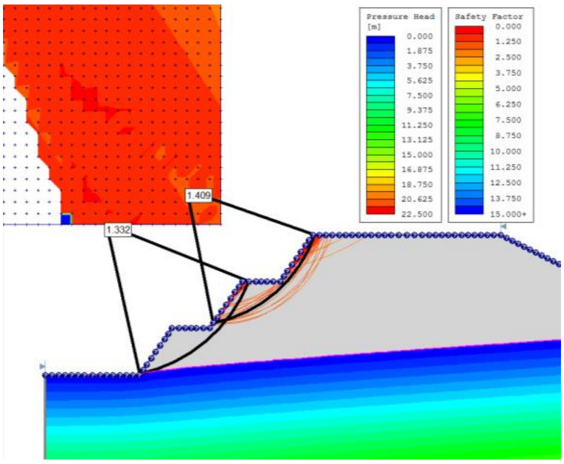

Figure 6. Numerical seepage and slope stability calculations for 10m berm heights, 45^0 excavation slopes and deepest groundwater level from the surface of the rim.

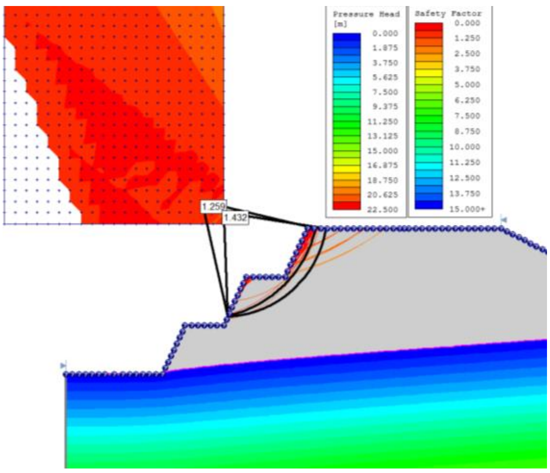

Figure 7. Numerical seepage and slope stability calculations for 15m berm heights, 45^0 slopes and deepest groundwater level from the surface of the rim.

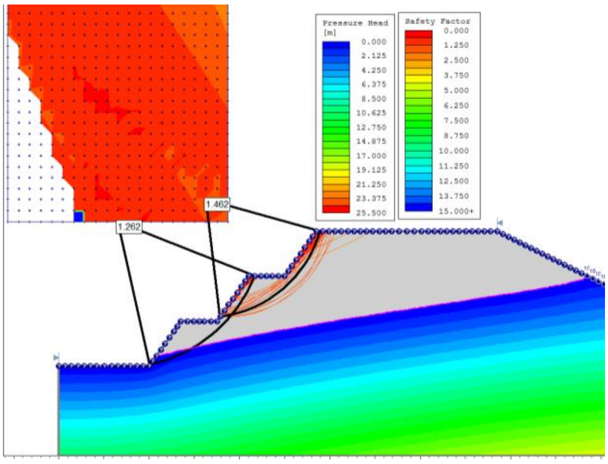

Figure 8. Numerical seepage and slope stability calculations for 5m berm heights, 55^0 excavation slopes and medium groundwater level from the surface of the rim.

3. Evaluation of Analyses Results

For excavated weak rock slope angle (β) of 45^0, depending on different groundwater levels such as d1 (deep), d2 (medium) and d3 (shallow), variation of slope minimum safety factors for deep failure surfaces with respect to berm heights is given in Figure 9. This plot gives us that excavated slope safety factors are decreased around 36% for each ground water depth when berm heights increased from 5m to 15m. In addition, when groundwater levels become shallower to the ground surface for same berm heights, then, excavated slope safety factors are also decreased approximately 57% in average. Plots given in Figures 10 and 11 are for excavation slope angle of 55^0 and 65^0 respectively, and indicate that slope safety factors are also decreased for each ground water depth when berm heights increased from 5m to 15m. In addition, when groundwater levels become shallower to the ground surface for same berm heights, slope safety factors of the excavtions are also decreased.

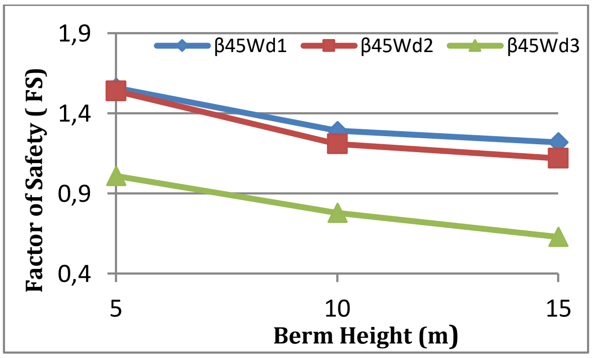

Figure 9. Variation of slope minimum safety factors for deep failure surfaces with respect to berm heights For excavated weak rock slope angle (β) of 45^0, depending on different groundwater levels such as d1 (deep), d2 (medium) and d3 (shallow).

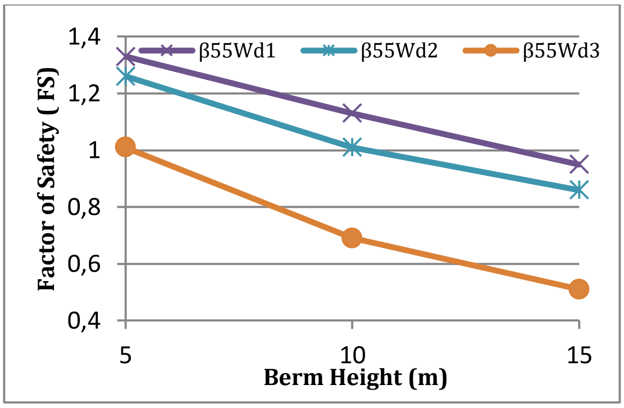

Figure 10. Variation of slope minimum safety factors for deep failure surfaces with respect to berm heights for excavated weak rock slope angle (β) of 55^0, depending on different groundwater levels.

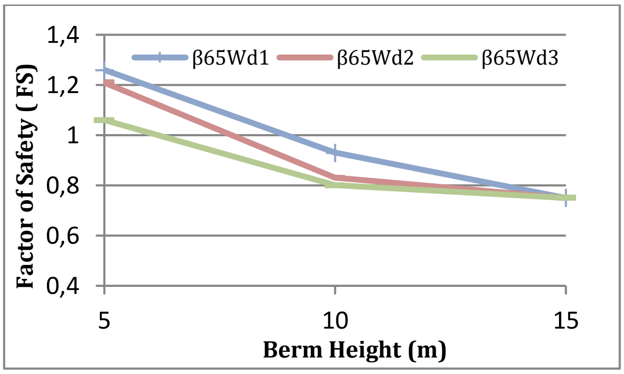

Figure 11. Variation of slope minimum safety factors for deep failure surfaces with respect to berm heights for excavated weak rock slope angle (β) of 65^0, depending on different groundwater levels.

When we evaluated Figures, 9, 10 and 11 together, it is also observed that for each groundwater depth and berm height, when excavation slope angle is more gentle, then, stability safety factors of the excavation is increased more and slopes gets much more safe. When we compare all results best safety factor is obtained for a berm height of 5m when ground water is deep and excavation slope is gentle as 45 degree.

4. Conclusion

In this study, effects of berm heights, excavation slope gradients and groundwater depths on the stability of designed slope excavations as well as variations on the safety factors of the excavation slopes are investigated. This study proved that when berm heights are increased, then stability safety factor of the slope excavations is decreased. In addition, when groundwater depth is approached close to the ground surface, then slope excavation safety also decreases. Moreover, steeper slope gradients of the excavations results in decrease of factor of safety of the failure surfaces. In other words, lower berm heights with deep groundwater levels and flatter excavation slope gradients result in increase for the factor of safety of the failure surfaces.

Conflict of Interest

No conflict of interest was declared by the authors.

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