Firat Univ Jour. of Exp. and Comp. Eng., 1(3), 129-138, 2022

Firat University Journal of Experimental and Computational Engineering

Fırat Üniversitesi Deneysel ve Hesaplamalı Mühendislik Dergisi

Failure mechanism of a soil slope and stabilization method: a case study

Bir zemin şevinin yenilme mekanizması ve stabilizasyon yöntemi: vaka çalışması

Mustafa KANIK[1]*

[1]Department of Geological Engineering, Faculty of Engineering, Firat University, Elazig, Turkiye.
[1]mkanik@firat.edu.tr

Received: 10.10.2022
Accepted: 25.10.2022
Revision: 22.10.2022
doi: 10.5505/fujece.2022.35744
Case Report

Abstract

In this study, the slope stability problem, which occurred when the projected excavation works of a treatment plant has been started, has been examined. The aim of this study is to determine the conditions causing the slope failure and to make the slope stable again. Then, to ensure the stability of the whole slope after all the excavations work in the project area have been completed. For this purpose, firstly, the topographic features of the slope where the failure took place were determined and a model of the failure condition was created. Field and laboratory studies were used to obtain the data to be used in slope modeling. Models reflecting the current situation were analyzed considering static and dynamic conditions and a safe slope design was created. The analyzes are carried out by Slide V.6.0. software which is based on limit equilibrium methods and Bishop Method was preferred. As a result, it was determined that the reason of the failure occurred was the change of the soil's physical and mechanical parameters due to precipitation. In the slope stability problem considered, the benching method has been proposed as an improvement method, and additionally, suggestions have been made for the disposal of surface waters by drainage methods.

Keywords: Limit equilibrium, Slide, Slope stability.

Özet

Bu çalışmada bir arıtma tesisinin projelendirilmiş kazı çalışmalarına başlandığında oluşan şev stabilitesi problemi incelenmiştir. Bu çalışmanın amacı, şev duraysızlığına neden olan koşulları belirlemek ve şevi tekrar duraylı hale getirmektir. Daha sonra proje alanındaki tüm kazı çalışmaları tamamlandıktan sonra tüm şevin stabilitesini sağlamaktır. Bu amaçla öncelikle duraysızlığın meydana geldiği şevin topografik özellikleri belirlenmiş ve duraysızlık durumunun bir modeli oluşturulmuştur. Şev modellemede kullanılacak verilerin elde edilmesi için arazi ve laboratuvar çalışmalarından yararlanılmıştır. Mevcut durumu yansıtan modeller statik ve dinamik koşullar dikkate alınarak analiz edilerek güvenli bir şev tasarımı oluşturulmuştur. Analizler limit denge yöntemlerine dayalı Slide V.6.0 paket programı ile gerçekleştirilmiştir ve Bishop Metodu tercih edilmiştir. Sonuç olarak, meydana gelen duraysızlığın nedeninin yağış nedeniyle zeminin fiziksel ve mekanik parametrelerinin değişmesi olduğu tespit edilmiştir. Ele alınan şev stabilitesi probleminde iyileştirme yöntemi olarak basamaklama yöntemi önerilmiş ve ayrıca yüzey sularının drenaj yöntemleriyle bertarafı için önerilerde bulunulmuştur.

Anahtar kelimeler: Limit denge, Slide, Şev stabilitesi.

1. Introduction

After floods, storms, and earthquakes landslides take the fourth place in the fatal natural disasters. Beside its comprehensive coverage, high frequency, and incredible destructive power [1] landslides cause significant casualties and property damage every year around the world [2 - 4]. It is possible to define two types of slopes as natural and constructed. The fact that slopes are natural or constructed does not lead slopes to stable conditions. As a result of exceeding the shear strength of the soil, a failure occurs on the slope. The shear stresses that occur along the force action surface causing this failure are determined and compared in terms of the shear strength parameters of the soil. Calculations performed using these parameters are called slope stability analyses [5].

*Corresponding author

The failure of slopes gives information about the soil and conditions at the time of failure. By performing back analyzes, the strength parameters of the soils in the study areas, the state of the groundwater and the failure model are tried to be understood [6]. As a result of these analyzes, the process of determining the failure status of a slope, the soil conditions at the time of failure and the appropriate sliding model for the situation is called back-analysis [7].

For the analysis performed at the moment of failure, the soil strength parameters and pore water pressure parameters at this moment should be taken as a basis [8]. For back analysis, many researchers used both deterministic methods [9], [10 - 13] as well as probabilistic methods [14 - 16]. Discontinuities, underground and environmental waters, soil parameters, earthquake etc. dynamic effects and slope geometry are the most important parameters controlling the stability of both natural and constructed slopes.

Shallow and deep-seated landslides innately differ in their size, extent and the risk posed [17]. Such landslide types reflect a variety of environmental and geological factors [18]. Separating these two landslide types is helpful for the protection from causalities [19 - 21].

In this study, slope stability analyzes were performed using the limit equilibrium software, Slide v.06 [22]. In this study, the cause of a failure occurred after excavation works started in a water treatment construction project area was tried to be determined for the existing ground conditions. For the slope in the same region where no failure has occurred yet, different analyzes were carried out and the stability of the slope was examined under the dynamic and static conditions. Then, precautions to be taken for possible situations have been determined.

2. Material and Method

In this study, to determine the Factor of Safety value, one of several Methods of Slices is used, The Bishop Method [23]. The assumptions made regarding the interslice forces differs the approach from the Ordinary Method of slices. The Bishop method neglects the shear interslice forces acting at the lateral sides of each slice. Bishop used three main equilibrium equations; moment equilibrium, horizontal force equilibrium and vertical force equilibriums. The factor of safety value for a typical circular failure surface is derived and it is assumed that the failure surface lies within a single type of soil which behaves in accordance with the Mohr-Coulomb failure criterion [24].

In this study, Slide v.6.0 software, using Simplified Bishop Method as an option, was preferred to evaluate the failure mechanism of the slope. The Bishop Method was preferred because it can be applied to soil and rock masses that have gained soil characteristics by weathering. As it was stated by many researchers, in the circular surface assumptions the given factor of safety values by Bishop Method are in good agreement with the factor of safety values of other rigorous methods. This method is basically the same as the Swedish Method, but it takes account the force between the existing slices so the method gives more accurate factor of safety values.

3. Slope Stability Analysis

It is desired to build a water treatment plant in the region where failure occurs. Excavations were started in this area, but after the excavations have started, a failure occurred (Figure 1). Before seeking for the reasons of the failure the data about the soil should be collected. In the study area is formed of Miocene-Pliocene aged Şelmo Formation, first defined by Bolgi [25]. The Şelmo Formation starts with fine grained conglomerate at the bottom. It consists of cross-bedded, dough-supported, magmatic grains, limestone, sandstone, and the matrix consists of sand and clay [26]. The Şelmo Formation bears traces of flovial deposits in its upper parts. Therefore, if the Şelmo Formation is considered as a whole, it can be named as fan deposits [27, 28].

Figure 1. The area where the failure in the study area occurs

Before starting the analysis, the region where the failure started was evaluated within itself, then the regions where any problem did not occur were examined in terms of possible problems and analyzes were carried out for static and dynamic situations on the specified lines. The lines have been chosen considering the regions where the excavations will take place (Figure 2). Topographic sections were determined by the studies carried out by survey engineers. Samples were collected after the failure happened. As a result of the experiments performed on the samples obtained, it was determined that the soil is CH and the unit weight of the soil is 19 kN/m^3. The mean internal friction angle is 14^o and the mean cohesion value is 71.48 kN/m^2. Ground acceleration values used in dynamic analyzes were selected according to the area of the parcel where the project took place, and the PGA (peak ground acceleration) value was specified as 0.177 g (Figure 3).

3.1. Failure Mechanism

The first model (Line I) was created by considering the excavations to be carried out in accordance with the project within the slope surface with an average inclination of 8.5°. In the prepared cross-sections, the lower elevation of the slope was measured as 672.5 and the upper elevation as 728 m. For the slope to be created during excavation, the sliding mass due to the failure (Figure 2) must be removed. As a result of this, the slope to be formed was considered as a single step and the lower elevation of this slope was given as 679 and the upper elevation as 704.50 by the survey engineers.

As a result of the analysis, the static state safety factor for the natural slope was obtained as 1.299 (Figure 4). This indicates that the factor of safety of the slope is sufficient for the given condition.

Considering the seismicity of the region, the same slope was remodeled under dynamic conditions and analyzes were carried out. The PGA value of the region in which the study area is located was specified as 0.177 g (Figure 3). When the results of the analysis are examined, the lowest safety factor for the slope is 0.998 and the structures to be built are within the effect limits of the possible failure shown in Figure 6.

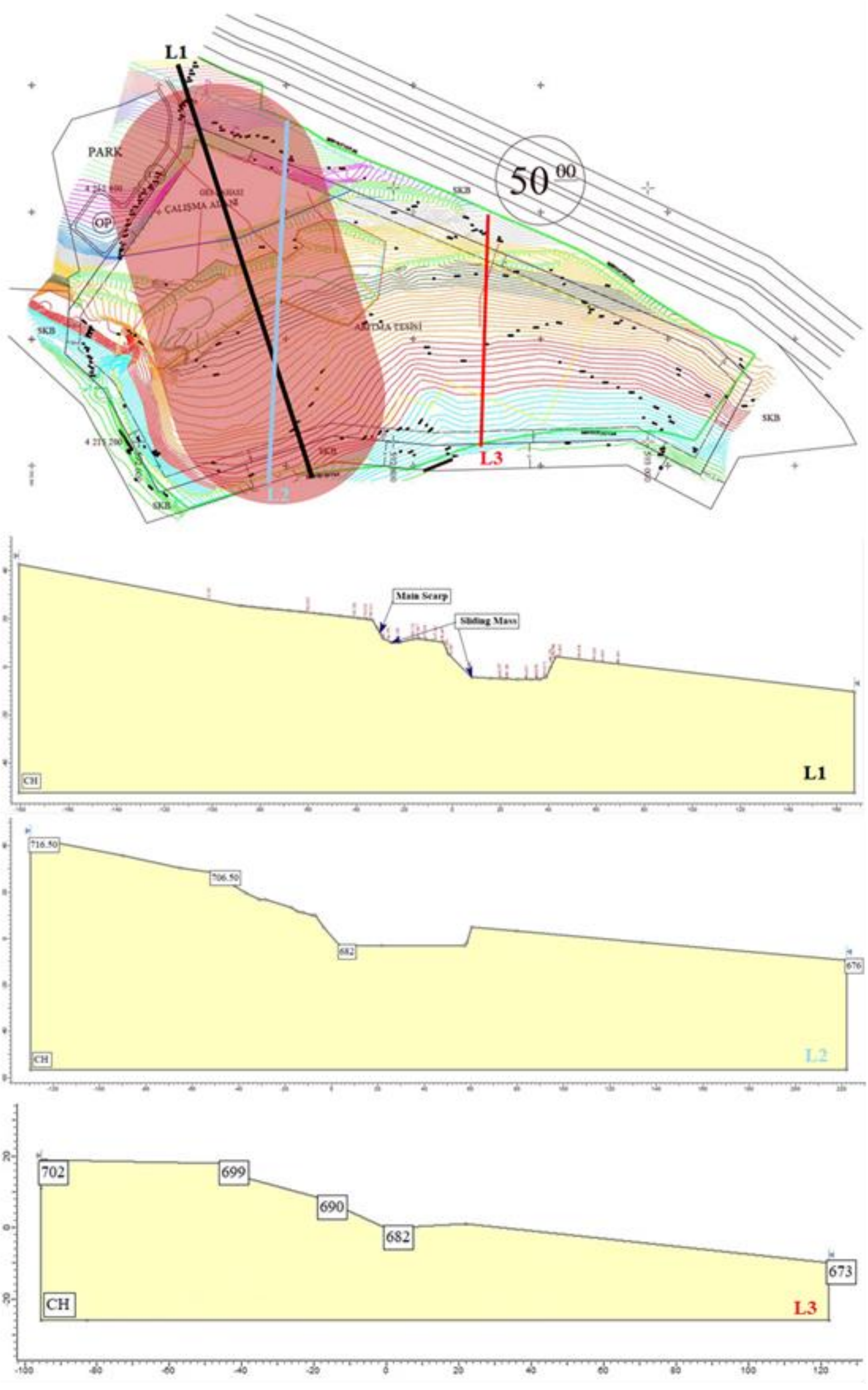

Figure 2. Instable area red circled and studied lines (L1, L2 and L3)

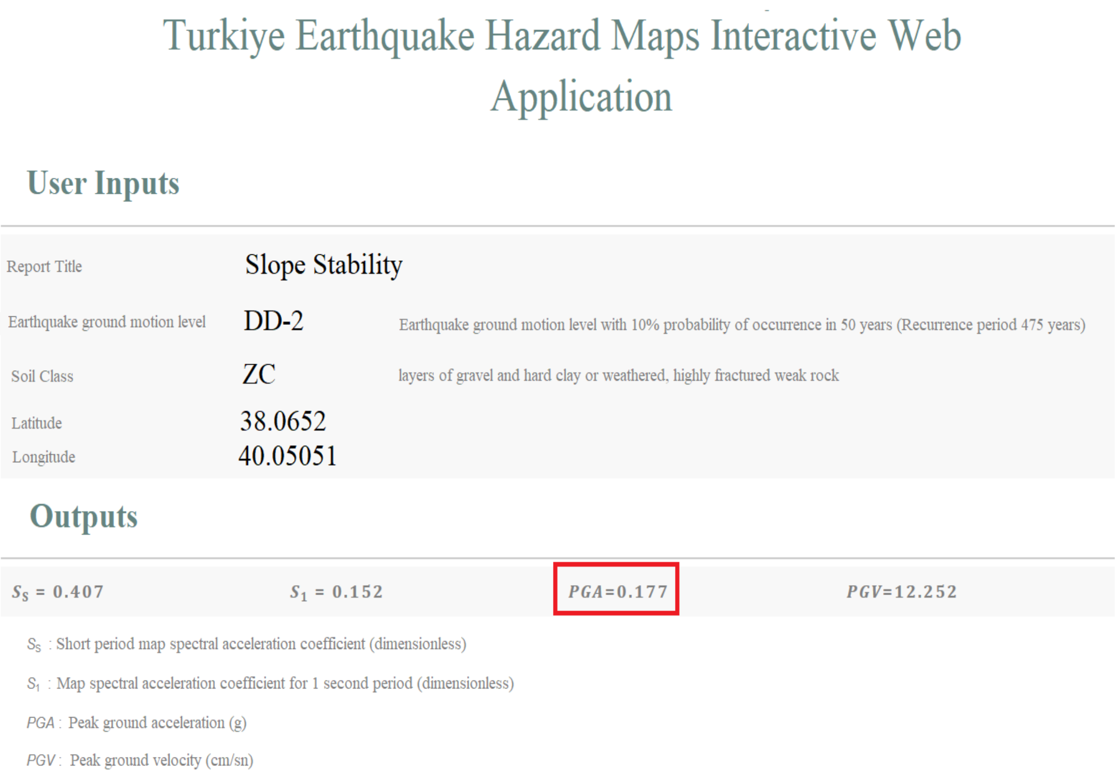

Figure 3. Peak Ground Acceleration (PGA) value

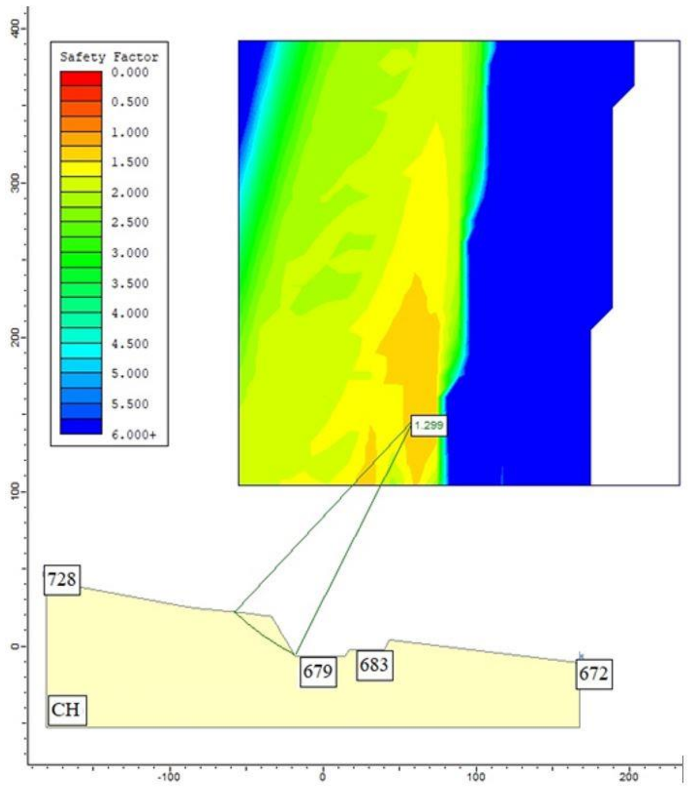

Figure 4. The minimum factor of safety (1.29) obtained for the static condition for Line-I

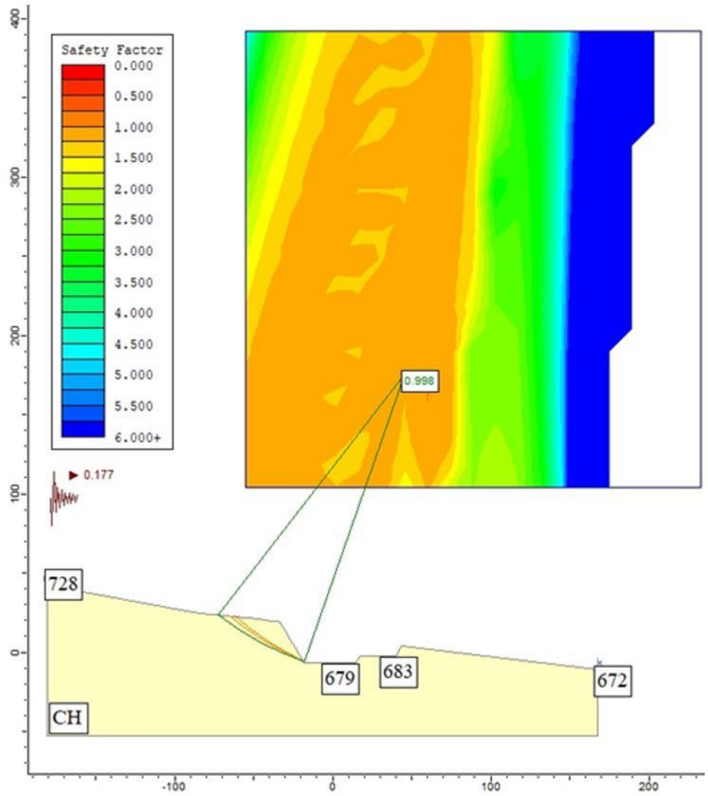

Figure 5. The minimum factor of safety (0.998) obtained for the dynamic condition for Line-I

Although the failure seems to have occurred after the excavation works started, considering the factor of safety values obtained as a result of the analyzes performed by considering the laboratory test data, it does not seem likely that any failure problem will arise under these conditions. However, there was a failure occurred in this line. In order for the stability to occur, changes in soil parameters (physical and mechanical) must have happened. This parameter change could only be possible by the precipitation that occurred before the failure in that region. Many researchers [29 - 35] revealed this with their studies in different regions. Since precipitation cannot be prevented in the region or anywhere, it is necessary to carry out studies to increase the factor of safety value.

The variation of the factor of safety value for the same conditions was examined by reconstructing a model for the benching process, which is one of the economical solutions that can be envisaged in order to increase the factor of safety value. For this purpose, 6V/6H (Bench Height/Bench Width) and 4 meters of step width were modeled and analyzed (Figure 6-7). The reason for choosing these values is to prevent possible sliding movements on slopes where mass movement does not occur, since, in the end, the entire working area where excavation works will be performed will actually be one slope. The analysis determined that the minimum safety factor of the slope in this state is 1.710 for the static situation and 1.063 for the dynamic situation. It turns out that the factor of safety of the slope in the dynamic case is close to the critical limit value. Since the dynamic conditions represent the most unfavorable conditions, the value of 1.000 to be obtained from here is sufficient for slope safety. According to TDBY [36], for the dynamic conditions safety coefficient should be greater than 1.10, but the S_{DS} (spectral acceleration coefficient) value is lower than the PGA (peak ground acceleration) value used in the analyzes; thus, 1.000 for the factor of safety value is applicable.

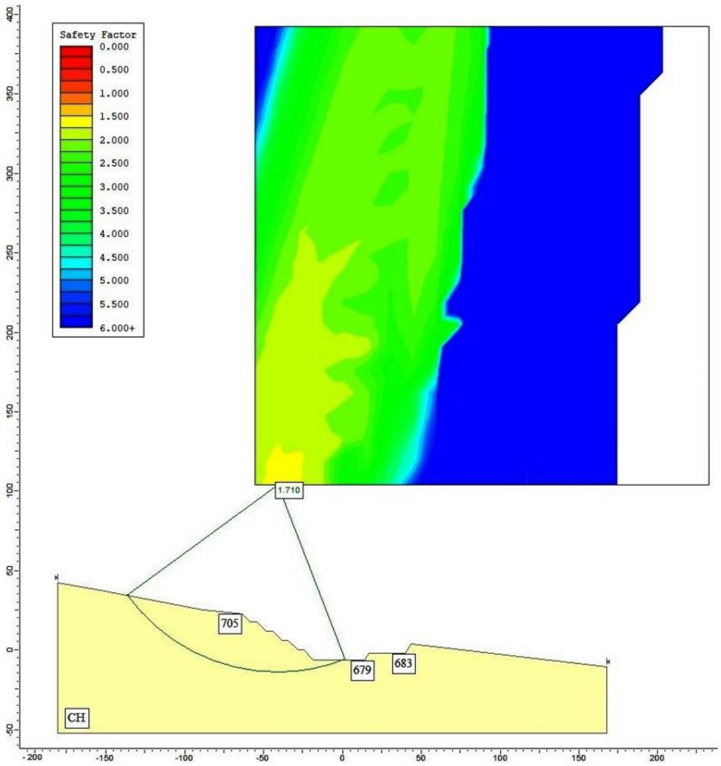

Figure 6. The minimum factor of safety (1.710) obtained for the static condition after the benching process of Line-I

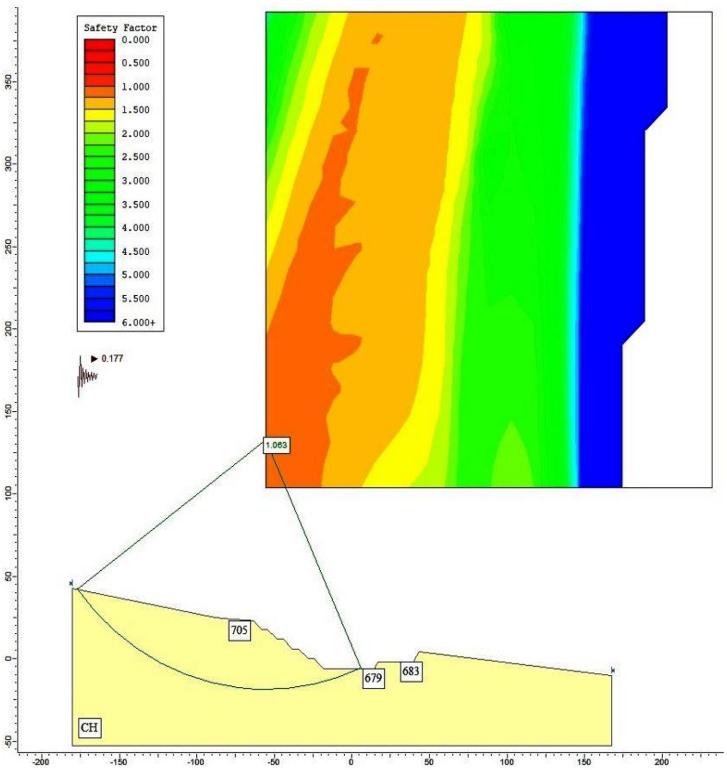

Figure 7. The minimum factor of safety (1.063) obtained for the dynamic condition after the benching process of Line-I.

3.2. Suggested Stabilization Method

Line 2 was created by considering the excavations to be carried out in accordance with the project within the slope surface with an average inclination of 8.5°. In the prepared cross-sections, the lower elevation of the slope was measured as 676 and the upper elevation as 716.5 m. The slope to be formed was considered as a single step and the lower elevation of this slope was given as 680 and the upper elevation as 706.50 by the survey engineers.

Line 3 was created by considering the excavations to be carried out in accordance with the project within the slope surface with an average inclination of 6.5°. In the prepared cross-sections, the lower elevation of the slope was measured as 673 and the upper elevation as 702 m.

For the two lines mentioned, analyzes were made considering the situations where the excavation works were finished. When all the excavation works are completed, since all three lines are part of a single slope, the slope arrangements were formed considering the 6V/6H (Bench Height/Bench Width) and 4 meters of step width. The factor of safety values obtained from the analysis are given in Table 1.

Table 1. Results of the analysis performed considering static/dynamic conditions for both benching process and no benching process

	Static Conditions		Dynamic Conditions	
Lines	No B.P.	B.P.	No B.P.	B.P.
Line 2	1.630	1.602	1.075	1.072
Line 3	1.623	2.078	1.176	1.426

** B.P.: Benching process*

4. Conclusions

Considering the static conditions analyzes performed with the data obtained from the laboratory experiments, failure occurred on the slope, although there should not have been any failure. When the analyzes carried out under the dynamic conditions checked, the factor of safety value decreases below 1,000. However, there was no earthquake activity at the time of the slope stability problem occurred. Based on the soil type (CH) forming the slopes, it is understood that there is a change in soil parameters (physical and mechanical) and a failure happened with the effect of precipitation in the region. During the study, other areas where the slope excavations were not completed in the project area were examined by two different lines (Line 2-3) and included in this study in order to avoid any failure problems might have occurred in the future. With the help of the analyzes performed within the scope of this study, models were formed for the slopes to be created in the future. Since all lines (Line 1,2 and 3) will belong to a single slope at the end of the project, all slope arrangements were modelled according to 6V/6H (Bench Height/Bench Width) and 4 meters of step width. For this reason, there has been a small decrease in the safety factor value for the dynamic and static conditions in Line II, but it is a negligible value. Apart from these precautions, covering the slope surface with shotcrete on such soils that are sensitive to water will contribute both in terms of water removal and stability. For situations or regions where water removal is thought to be ineffective, support structures such as retaining walls should be applied to the toe of the slopes formed.

5. Acknowledgement

The author would like to thank to Dr. Mesut Gor from Firat University, Faculty of Engineering, Department of Civil Engineering for his contribution to the article and the anonymous reviewers' comments to improve the paper.

6. Author Contribution Statement

In the study, Author 1 contributed (I) making the design and literature review, (ii) to checking the spelling and checking the article in terms of content.

7. Ethics Committee Approval and Conflict of Interest

There is no need for an ethics committee approval in the prepared article. There is no conflict of interest with any person/institution in the prepared article

8. References

[1] Zhang J, Kuang M, Zhang Y, Feng T. "Evaluation and analysis of the causes of a landslide and treatment measures during the excavation of a tunnel through a soil-rock interface". *Eng. Fail. Anal*., 130, 105784, 2021.
[2] Guzzetti F, Carrara A, Cardinali M, Reichenbach P. "Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, Central Italy". *Geomorphology*, 31, 181-216, 1999.
[3] García-Rodríguez MJ, Malpica JA, Benito B, Díaz M. "Susceptibility assessment of earthquake-triggered landslides in El Salvador using logistic regression". *Geomorphology*, 95, 172-191, 2008.
[4] Rai, R. Factors affecting slope failure. Lecture Notes of Chapter 2, 2017.
[5] Das BM. *Principles of Geotechnical Engineering*. Boston: Cengage Learning. 9nd ed. USA, 1994.
[6] Akbulut İ, İlker ÇAM, Aksoy T, Çağlan D, Ölmez, T. "Açık ocaklarda şev duraysızlığı ve geriye dönük analizlere bir örnek: Afşin-Elbistan Kışlaköy açık kömür ocağı". *Maden Tetkik ve Arama Dergisi*, 147(147), 115-126, 2013.
[7] Duncan JM, Wright SG. "*Soil strength and slope stability"*. New York: John Wiley and Sons, Inc., 2005.
[8] Zhang J, Tang WH, Zhang LM. "Efficient probabilistic back-analysis of slope stability model parameters". *Journal of Geotechnical and Geoenvironmental Engineering,* 136(1), 99-109, 2010.
[9] Alemdag S, Kaya A, Karadag,M, Gurocak Z, Bulut F. "Utilization of the limit equilibrium and finite element methods for the stability analysis of the slope debris: an example of the Kalebasi District (NE Turkey)". *Journal of African Earth Sciences*, 106, 134-146, 2015.
[10] Kaya A, Alemdağ S, Dağ S, Gürocak Z. "Stability assessment of high-steep cut slope debris on a landslide (Gumushane, NE Turkey)". *Bulletin of Engineering Geology and the Environment*, 75(1), 89-99, 2016.
[11] Alemdağ S. "Toprak dolgulu barajlarda gövde duraylılığının limit denge ve sayısal analiz yöntemleri ile değerlendirilmesi: Türkiye'den bir atık barajı örneği". *Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi,* 6(2), 157-173, 2016.
[12] Gör M. "Limit denge analizi (Bishop Yöntemi) ile kütle hareketinin mekanizması ve önlem yapısının analizi: Van ili örneği". *Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 11(2), 597-608, 2021.
[13] Taher NR, Gör M, Aksoy HS, Awlla HA. "Numerical investigation of the effect of slope angle and height on the stability of a slope composed of sandy soil". *Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 12(2), 664-675, 2022.
[14] Chowdhury R, Zhang S, Flentje P. "Reliability updating and geotechnical back-analysis". *In Advances in geotechnical engineering: The Skempton conference: Proceedings of a three day conference on advances in geotechnical engineering, organised by the Institution of Civil Engineers and held at the Royal Geographical Society*, 815-821, London: Thomas Telford Publishing, 2004.
[15] Zhang LL, Zhang J, Zhang LM. Tang WH. "Back analysis of slope failure with markov chain monte carlo simulation". *Computers and Geotechnics*, 37(7-8), 905-912, 2010.
[16] Akbaş B. "Probabilistic slope stability analysis using limit equilibrium, finite element and random finite element methods". Master Thesis, The Graduate School of Natural and Applied Sciences of Middle East Technical University, Ankara, 2015.
[17] Zêzere JL, Trigo RM, Trigo IF. "Shallow and deep landslides induced by rainfall in the Lisbon region (Portugal): Assessment of relationships with the North Atlantic Oscillation". *Nat. Hazards Earth Syst. Sci.*, 5, 331-344, 2005.
[18] Schmidt KM, Roering JJ, Stock JD, Dietrich WE. Montgomery DR, Schaub T. "The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range". *Can. Geotech. J.*, 38, 995–1024, 2001.
[19] Korup O. "Large landslides and their effect on sediment flux in South Westland, New Zealand". *Earth Surf. Process. Landf.*, 30, 305-323, 2005.
[20] Larsen IJ, Montgomery DR, Korup O. "Landslide erosion controlled by hillslope material". *Nat. Geosci.*, 3, 247- 51, 2010.

[21] Lin CW, Tseng CM, Tseng YH, Fei LY, Hsieh YC, Tarolli P. "Recognition of large scale deep-seated landslides in forest areas of Taiwan using high resolution topography". *J. Asian Earth Sci.*, 62, 389-400, 2013.
[22] Rocscience Inc. Slide v. 06 Software. 439 University Ave. Ste. 780, Toronto, Canada, 2014.
[23] Bishop AW. "The use of the slip circle in the stability analysis of slopes". *Geotechnique*, 5(1), 7-17, 1955.
[24] Samtani NC, Nowatzki EA. Soils and Foundations Reference Manual Volume 1. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. 20590, 2006.
[25] Bolgi TV. "Petrol Bölgesi seksiyon ölçmeleri AR/TPO/261 nolu saha ile Reşan- Dodan arası batısındaki sahanın strüktürel etüdleri". TPAO Arama Grubu, Rapor,162, 52, 1961.
[26] Kıratlıoğlu E, Bolgi,T. "AR/TPO/609 nolu Kastel sahası ve civarının jeolojik etüdü. TPAO Arama Grubu". Rapor no: 220, 36, 1961.
[27] Duran O, Şemşir D, Sezgin İ, Perinçek D. "Güneydoğu Anadolu'da Midyat ve Silvan gruplarının stratigrafisi, sedimentolojisi ve petrol potansiyeli". TPJD Bülteni, Ankara c.1/2, 99-126, 1988.
[28] Duran O, Şemşir D, Sezgin L, Perinçek D. "Güneydoğu Anadolu'da Midyat Silvan Gruplarının stratigrafisi, sedimantolojisi ve paleocografyası, paleontolojisi, jeoloji tarihi, rezervuar ve diyajenez özellikleri ve olası petrol potansiyeli". TPAO Araştırma Merkezi, Rapor No.2563, 1989.
[29] Lim TT, Rahardjo H, Chang MF, Fredlund DG. "Effect of rainfall on matric suctions in a residual soil slope". *Can. Geotech. J.*, 33, 618–628, 1996.
[30] Vanapalli SK, Fredlund DG, Pufahl DE, Clifton AW. "Model for the prediction of shear strength with respect to soil suction". *Can. Geotech. J*. 33, 379–392, 1996.
[31] Godt JW, Baum RL, Savage WZ, Salciarini D, Schulz WH, Harp EL. "Transient deterministic shallow landslide modelling: requirements for susceptibility and hazard assessment in a GIS framework". *Eng. Geol.* 102, 214–226, 2008a.
[32] Godt JW, Schulz WH, Baum RL. "Savage,W.Z. Modelling rainfall conditions for shallow landsliding in Seattle, Washington". In: Baum, R.L., Godt, J.W., High land, L.M.(Eds.), Landslides and Engineering Geology of the Seattle,Washington, area. Geol Soc Am *Rev Eng Geol* 20, 137–152, 2008b.
[33] Godt JW, Baum RL, Lu N. "Landsliding in partially saturated materials". *Geophys. Res. Lett.* 36, 2009.
[34] Baum RL, Godt JW, Savage WZ. "Estimating the timing and location of shallow rainfall-induced landslides using a model for transient, unsaturated infiltration". *J. Geophys. Res.,* 2010.
[35] Lu N, Godt JW. "Hillslope hydrology and stability". *Cambridge University Press*, Cambridge, U.K, 2013.
[36] TBDY, Türkiye Bina Deprem Yönetmeliği. T.C. Resmi Gazete; 30364, 2018.