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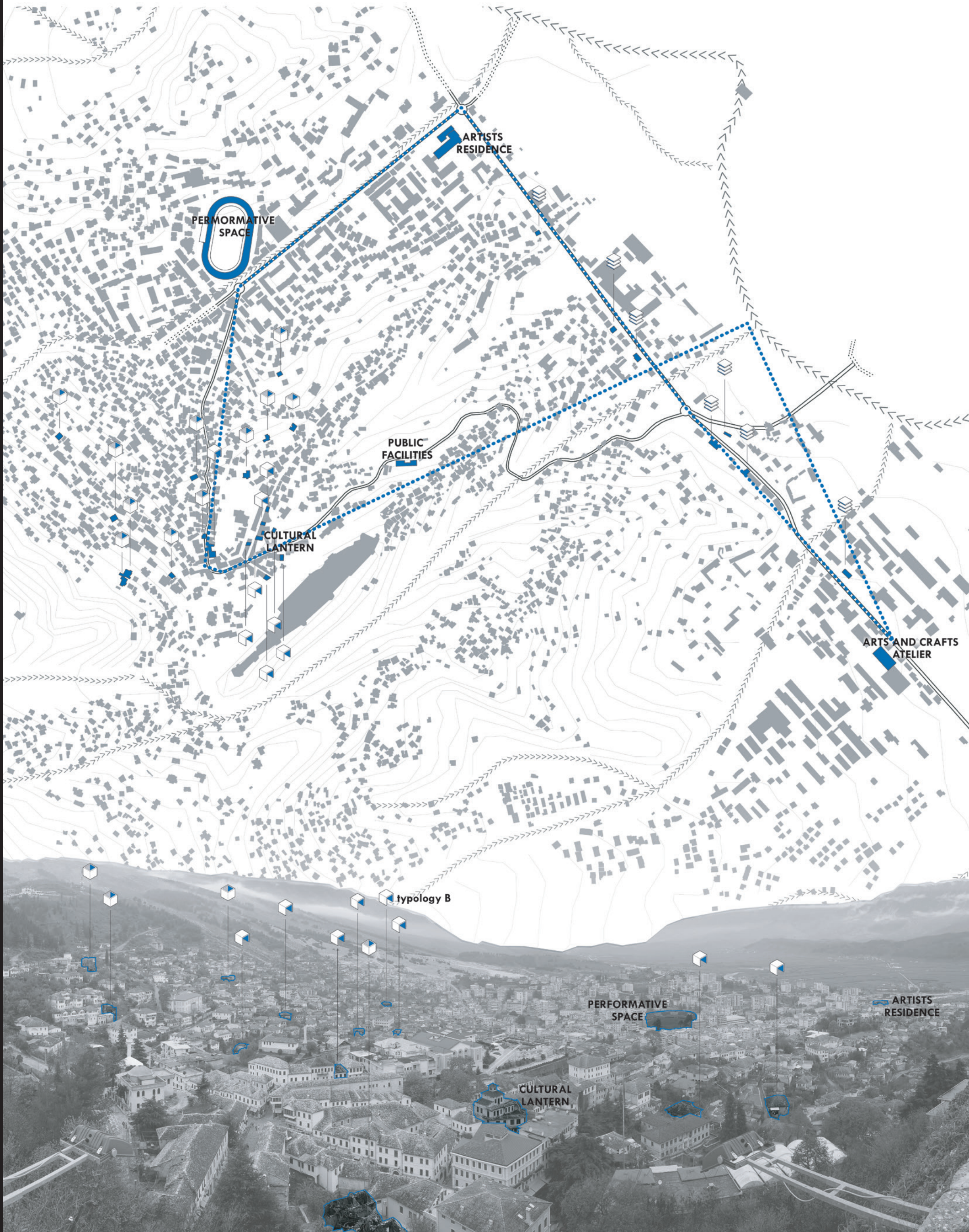
RETHINKING GJIROKASTRA

Can architecture and city planning stimulate hope and growth for shrinking cities?

A Project of the Joint International PhD Program IDAUP

POLIS University Albania / University of Ferrara Italy

RETHINKING



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Gjirokastër fortress hillside. Geotechnical hazards assessment and stabilization measures as key factors for the fortress preservation.

Keywords / accessibility, factor of safety, natural hazards, modelling, preservation, slope stability

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Abstract
The city of Gjirokastër, located in the southern part of Albania, few kilometers from the border with Greece and from the port of Saranda, is one of the main cities in the country both economically and culturally. The location, cultural heritage, and the economic potential are some of the main factors that make of Gjirokastër an important region. Due to the characteristic Ottoman architecture, since 2005, the old part of the city has also been part of the UNESCO World Heritage list. Many studies conducted by the Albanian and non-Albanian planners, architects, archeologists, and engineers emphasize the importance and values the city has. The fall of communism and the events in post 90-s had a negative impact in the city: many demographical changes, and lack of funds and projects are putting the city and its cultural values in danger.
The Old Bazaar and the Fortress are two of the most distinguished sites in town and can be seen as the main poles from which the revitalization of the city can begin. The Fortress, extending on a rocky hill, is the biggest and one of the oldest constructions in Gjirokastër. Due to its superior position relative to the other parts with an elevation of about 370 meters serves as an important landmark that divides the city into two parts.

The hill where the fortress is located may be prone to several geotechnical hazards like erosion, instability and rock falling due to natural factors including winds, water and earthquake. Studies show that the seismic activity of the area varies from 5.5- 6.5 in Richter scale. This is further compounded by factors related to the unplanned development and interventions in the nearby area which affect the initial stability of the slope. Since the fortress is one of the most representative sites of the city and can be considered a main pole of accessibility, it is vital to preserve and protect it from potential hazards that affect the structural stability. By using relevant literature related to geotechnical hazards, hazards assessment and mitigation, empirical geotechnical data together with computational modelling, this paper makes estimates the potential hazards of the rocky slope where the fortress is located and the consequent effects in the fortress itself. Based on the results provided by the analysis regarding the potential and mechanism of failure, different stabilization methods can be proposed to prevent further problems that can greatly affect the fortress and the nearby area.

Introduction

The city of Gjirokastër lies in a mountainous region with a characteristic configuration of five different mountain sides in the center of which a fortress in a rocky hill is located. In the words of the famous English writer and painter Edward Lear during his journey in Albania in 1848, Gjirokastër is a town "... crowned by what forms the most striking feature of the place, a black ruined castle that extends along its whole summit, and proudly towers, even in decay, over the scattered vassal-houses below." This shows how the fortress is tightly related with the city and its origins. The fortress, dating back to the 13th century, has housed different functions, including that of a prison. Nowadays, due to its historical values, it represents one of the strongest and most important points of the city from the touristic and cultural point of view, and it can be considered, together with the Old Bazaar, as one of the main poles from which the revitalization of a shrinking city as Gjirokastër can begin.

Due to many human and non-human factors, the fortress is facing difficulties related to its structural stability. On the other hand, the rocky hill is also prone to weathering processes that can lead to dangerous geotechnical problems that can impact the stability of the fortress itself and endanger the citizens living in the area nearby. The non-human or natural threats are related to the seismic threat, erosion, wildland fires, landslides, and rock falls, while the human factors are mainly related with the lack of financial support and a management plan, uncontrolled urban development and the abandonment of the site by the inhabitants etc. (Jigyasu et al., 2014).

In Gjirokastër, as a Museum-city enlisted in the World heritage list with many notable sites, including the fortress, there is an urgent need for a proper hazard assessment together with a risk assessment that provides the probability of occurrence of a specific hazard and the impact this hazard may have on the surrounding areas. This need is much more obvious in the case of the fortress and the hill where the fortress stands. This is considered one of the most critical zones due to the fractured layered of conglomerates on the top of the narrow ridge and the presence of a very large rock below the fort, which makes it susceptible to rock fall and toppling, and in some location even to landslides (Jigyasu et al., 2014: 24). The risk assessment must then be followed by proper mitigation measures in order to prevent or reduce the risks and the consequences they can have in the structural stability of the fortress itself and the surrounding area, since many buildings are located just below the hill.

Assessment methodology

The risk assessment requires both qualitative and quantitative data that can be obtained through previous similar studies, site visits, monitoring, thematic maps and in-situ investigations together with laboratory testing. The collected data can then be used through the help of well-defined geotechnical analytical models and software, in order to quantify the problem and give an overview or detailed information regarding the geotechnical hazard, which in the case of the fortress, will be related to the landslide and rock falling. Hazard[1] and risk[2] recognition, together with the successful treatment, require thorough understanding of a number of factors including types and forms of slope failures, geological conditions and their relationship with the potential failure form, elements of a slope stability, significance of slope activity or amount and rate of movement (Hunt, 2007: 4). The methodology used for this work consists of archival and desk research. The aim is

[1] / Hazard refers to the slope failure itself in terms of its potential magnitude and probability of occurrence (Hunt, 2007)
[2] / Risk refers to the consequences of failure on human activities (Hunt, 2007)

Fig. 1 / Gjirokastër fortress and aqueduct depicted by Edward Lear. Source / invest-in-albania.org.

Hazard	Berat	Gjirokastër	Butrint
Fire (structure)	✓	✓	✓
Wildland Fire	✓	✓	✓
Geohazard (earthquake)	✓	✓	✓
Geohazard (landslide)	✓	✓	
Geohazard (rockfall)	✓	✓	
Flooding	✓		✓

Tab. 1 / Natural hazards in three World Heritage Sites in Albania. Source: Jigyasu et al., 2014)

to obtain good knowledge of the concepts behind slope stability analysis and stabilization methods by studying relevant literature together with the collection of the necessary data to be used for generating the model using commercially available software. The generated model can then give a rough estimation of the hill stability, and according to the results, preliminary stabilization methods can be proposed. The main limitation of this work has to do with the proper determination of the geotechnical parameters needed for the analysis. Generally, these parameters are obtained through several laboratory and site tests whose number depends on the importance of the problem in hand. To overcome this issue, the necessary data needed for this work are obtained by taking in consideration the opinion of several experienced engineers and by carefully studying relevant recommendations based on empirical formulas proposed by several authors.

Topographical and Geotechnical Information

The analysis requires the usage of both qualitative and quantitative data which can be divided into three types:

- Topography configuration of the site
- Geological configuration of the site
- Geotechnical parameters of soils and rocks.

Topography

A topographical map gives detailed information regarding the configuration of the city in altitude. In order to properly analyze the slope stability a cross-section needs to be generated from the topographical map.

Geological Configuration

An approximate geological profile for the section a-a shown in Fig2. was elaborated using rough experiences from past studies which show that the fortress itself stands on a strong and well cemented conglomerate with some joints present and a height of around 20-30 meters. Below the conglomerate there are flysch deposits of mainly sandstone and claystone, and on both sides of the hill, just above the flysch, there are deposits of loose to medium dense brown to beige silty clay with a height varying from 3 to 4 meters. The geological configuration

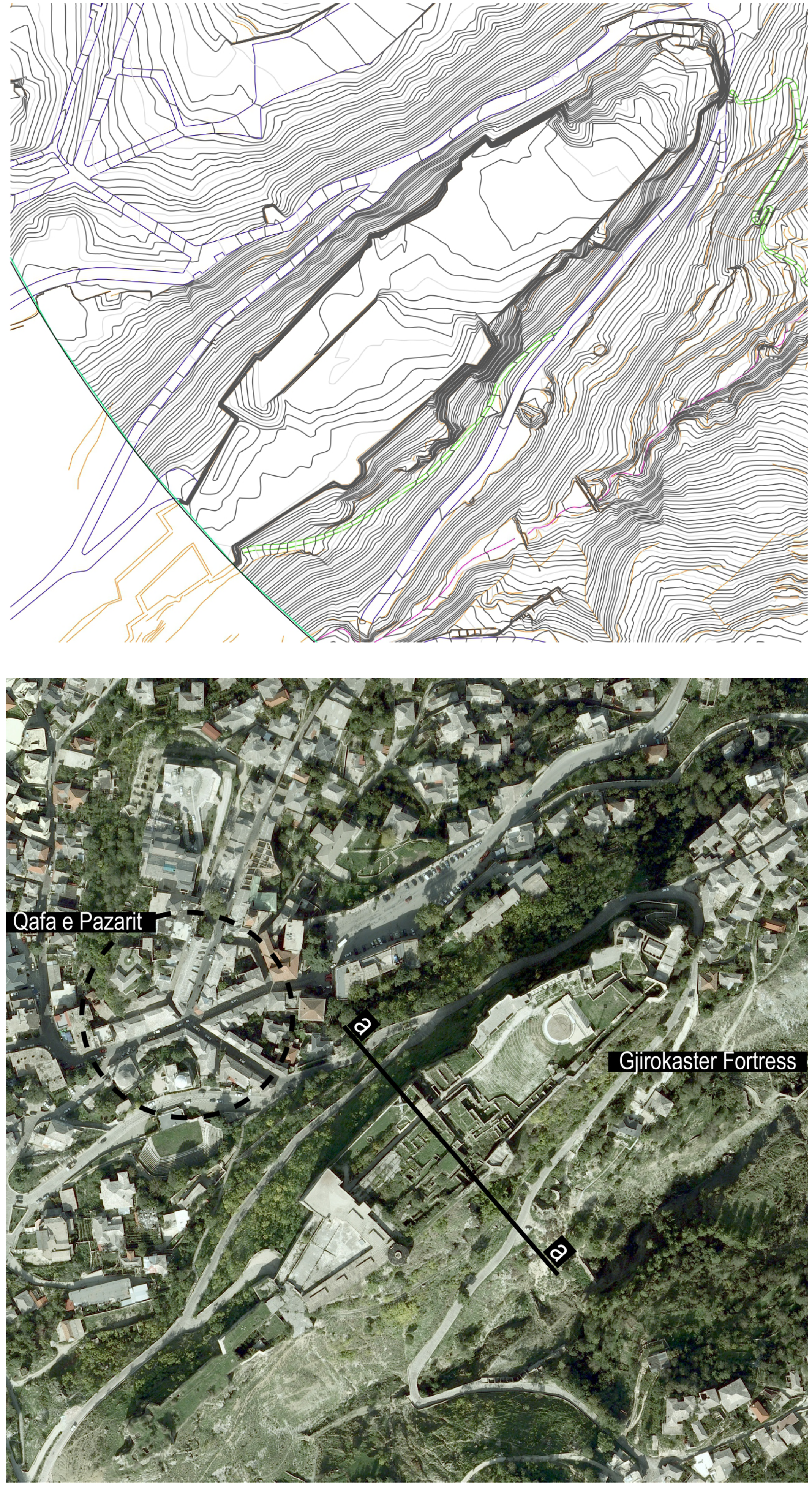

Fig. 2 / Topographical configuration of the fortress area (up) and aerial view of the zone together with the cross- section to be studied (down) (adaptation from the work of Eng. Adriatik Kodra.

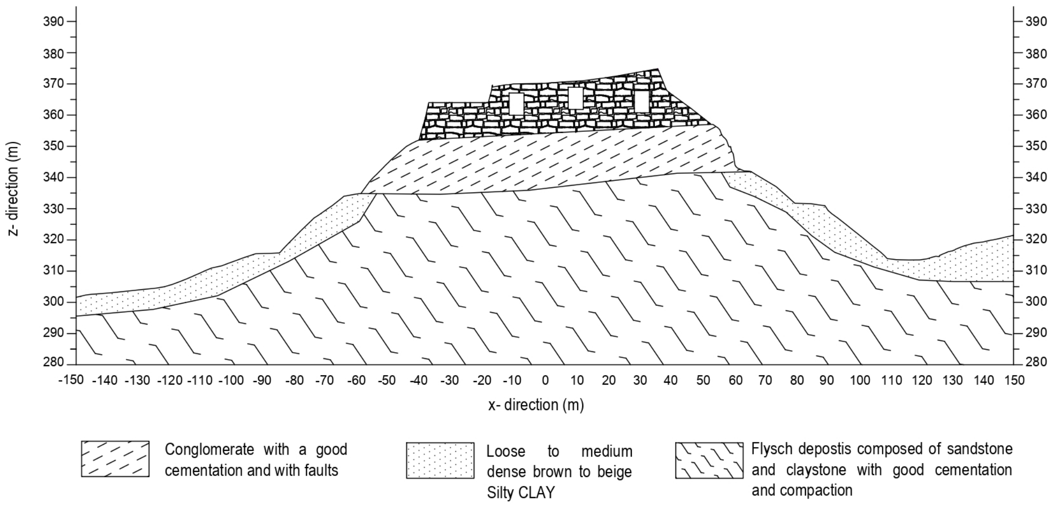

Fig. 3 / Geological profile of the hill. Source / the author, with the help of Eng. Skender Allkja)

for the section a-a is given in the picture above:

Geotechnical parameters and models

The physical and mechanical parameters of soils and rocks characterize the natural state and behavior of these materials under external static or dynamic loads. There are numerous parameters that serve as input variables for the analytical model depending on the problem at hand. Their determination is a complex process since their correct values are determined using different in-situ (terrain) and ex-situ (laboratory) tests. For the purpose of the study, it is reasonable to proceed with the determination of these parameters using a simpler approach based on quick surveys and literature recommendations. This approach is widely used and preferred where there is lack of information for a specific site, and it is applicable not only for research purposes but even in applied design situations (Sartar, et al., 2015). For example, in order to analyze the stability of two excavated slopes in the region of Sikkim Himalayas, the parameters using several recommended empirical formulas were determined, and only some quick surveys without any detailed in-situ or ex-situ tests were taken into account.

The slope stability problem requires an analysis of the shear strength of soils and rocks in the potential failure surface

$$\tau = \sigma' \tan\varphi + c \quad \text{(Mohr-Coulomb)}$$

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m\frac{\sigma_3'}{\sigma_{ci}} + s\right)^{0.5} \quad \text{(Hoek- Brown)}$$

along the slope in order to determine whether the resisting forces are higher than the destabilizing ones. Two of the most known and used theories regarding the shear strength are those of Mohr-Coulomb failure criterion (Das, 2010: 365) and Hoek- Brown failure criterion (Hoek et al., 2002). The first criterion is going to be used to characterize the silty clay deposit and the second one the flysch deposit together with the conglomerates, since this criterion is used for rocks:

The rough values of the parameters to be used as input variables for the analysis of the hill's stability are determined after a detailed study of the recommendations proposed by (Marinos & Hoek, 2001) and (Shen & Karakus, 2014) and also a detailed study regarding the flysch deposits characterization in Albania (Malaj et al., 2017). Additional information was gathered taking into consideration the opinions of several experts of the field with a broad experience in geotechnical matters. From these two different sources, the parameters were selected such as to ensure the most unfavorable situation. The information is summarized in the following table:

Soil/ Rock		Mohr- Coulomb failure criterion		Hoek- Brown failure criterion		
	γ (kN/m3)	φ (degree)	c (kPa)	σci (MPa)	mi	GSI
(1)Silty Clay	19	22	18	-	-	-
(2) Conglomerate	24	54.04	278	100	21	50
(3) Flysch deposits	23.4	17.77	53	25	4	32

Tab 2. / Shear parameters to be used in the modelling

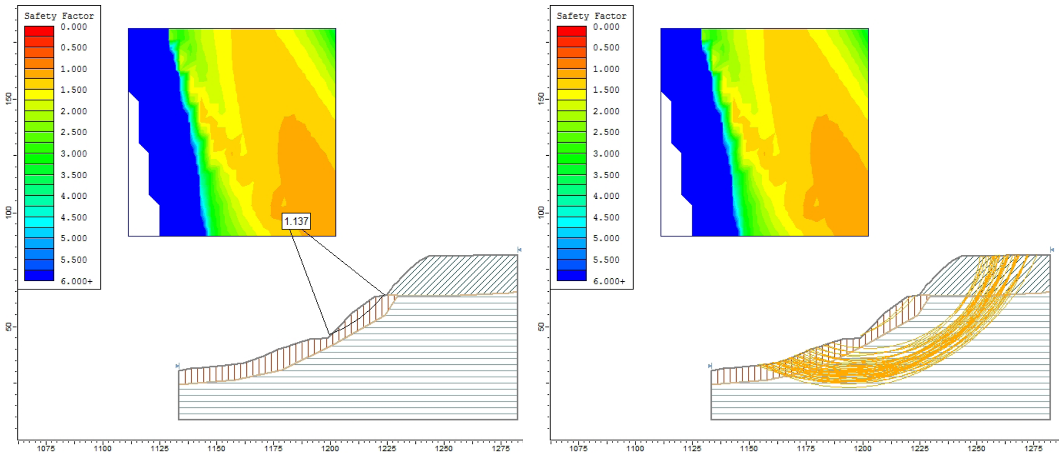

Fig. 4 / Global minimum slip surface(left) and the surfaces with a factor of safety lower than 1.2 (right) Source / the author

γ- unit weight of the soil or rock
φ- internal angle of friction
c- cohesion
σci- uniaxial compression strength of the intact rock material
mi- rock material constant
GSI- Geological Strength Index

The equivalent Mohr- Coulomb failure criterion parameters for the rocks are a result of the process of linearization of the Hoek- Brown criterion (Hoek et al., 2002:3), and it is necessary to be determined in order to perform the stability analysis.

Fortress Hill Analysis

The analysis was performed in three stages: in the first one, the geometry of the slope was generated using the topography, in the second stage all the soil and rock parameters determined in Table 2 were inputted and assigned to the proper layers. In the final stage, according to Fig 2, the analysis was performed using the auto grid option in which a grid of 20 by 20 points was created with the aim of generating a large number of points that serve as centers of potential slip surfaces, each one of them having a different radius.

The analysis's results showed that the lowest factor of safety is 1.137, which corresponds to a slip surface passing through the silty clay deposit. By applying a filter for the slip surfaces with a factor of safety lower than 1.2, it can be clearly observed that there are many dangerous surfaces along the conglomerate and flysch deposits too.

The factor of safety expresses the ratio between the resistance along a surface and the sliding forces acting on the same surface. The compiled factor of safety by the analysis of 1.2 means that the resistance exeeds the sliding forces by 20%, but geotechnical analyses are always characterized by uncertaintes related mainly to the parameters used in the model, external loads and the slope geometry itself. This is the reason why in many practical situations probabilistic methods apply to answer for these uncertaintes, or higher values of the factor of safety of around 1.5 are required to consider a slope stable (Das, 2010: 515).

Conclusions

In the case of the fortress hill, by accepting a factor of safety of 1.5 as proposed by (Das, 2010: 515), it can be concluded that there is a risk of instability, taking into account even the fact that external factors like erosion, seismic action or traffic loads (along the slope there are two roads) were not considered in the model, and their effects can further reduce the factor of safety.

Since some of the most dangerous slip surfaces pass just below the fortress, as by Fig 4, the instability of the slope can bring serious problems of rocks and soils falling and sliding, which can affect the stability of the fortress itself. In order to avoid these problems slope stabilization methods must be used to raise this factor of safety and stabilize the slope to prevent future serious problems.

While there are many stabilization methods that can be used based on many factors like the materials composing the slope, intensity and orientation of the discontinuities, slope activity, form and magnitude of potential failure etc (Hunt, 2007: 94), in the case of the fortress's hill the usage of vertical and horizontal drainange systems can be used in order to avoid water-related issues, combined with rock anchors and bolts in order to increase stabilizing forces. More detailed analyzes can be further used to better specify the stabilization methods taking into consideration technical, economical, and aesthetic aspects.

This study provides data and strategies on improving the fortress's hill stability.

While this information may be general, it is a viable starting point for more advanced analyses for both research-oriented or more specifically applied project. One way of enhancing this research would be that of taking in consideration other external factors like earthquake, water and dynamic loads due to traffic, their impact on the calculated value of the factor of safety together with detailed analysis of the stabilization interventions itself through analytical and computational modelling.

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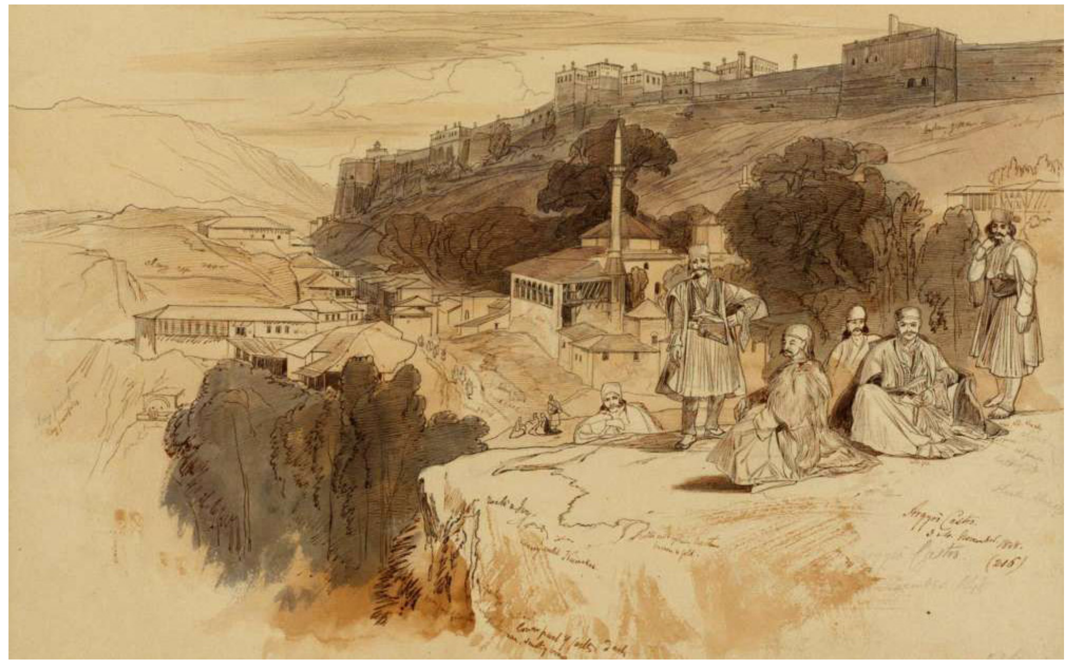

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