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Effects of Precipitation on Slope Stability in Open Mines: A Case Study

Açık Madenlerde Yağışların Şev Stabilitesine Etkisi: Örnek Çalışma

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Abstract
Today, open pit depths are increasing. As parallel, stability problems are also increasing. There are many parameters that affect the slope stability in open pits. Parameters such as rock mass quality, rock strength and groundwater level are directly effective parameters on slope stability. Groundwater and/or surface waters (such as precipitation, river etc.) also affect the stability of slopes depending on the permeability of the rock mass structure. Designers often do not consider the effect of surface waters on slope stability in open pit planning. In this study, it is explained that in an open pit design in which the effects of precipitation are also included in the design, there is no failure even though the amount of deformation on the slopes increases. In addition, how effective these precipitations are on the stability was explained.
Keywords: Open Pit, Precipitation, Deformation, Slope Stability, Rock Mechanics, Groundwater

Özet
Günümüzde açık ocak derinlikleri artmaktadır. Buna paralel olarak stabilite sorunları da artmaktadır. Açık ocaklarda şev stabilitesini etkileyen birçok parametre vardır. Kaya kütlesi kalitesi, kaya dayanımı ve yeraltı suyu seviyesi gibi parametreler şev stabilitesi üzerinde doğrudan etkili parametrelerdir. Yeraltı ve/veya yüzey suları (yağış, nehir vb.) kaya yapısının geçirgenliğine bağlı olarak şev stabilitesini de etkiler. Tasarımcılar, açık ocak planlamasında genellikle yüzey sularının şev stabilitesi üzerindeki etkisini dikkate almazlar. Bu çalışmada, yağış etkilerinin dahil edildiği bir açık ocak tasarımında, şevlerdeki deformasyon miktarı artsa bile yenilme olmadığı ve bu yağışların stabilite üzerinde ne kadar etkili olduğu açıklanmıştır.
Anahtar Kelimeler: *Açık İşletme, Yağış, Deformasyon, Şev Stabilitesi, Kaya Mekaniği, Yeraltı suyu*

1. Introduction

As it is known, one of the important problems in open pit mining is the stability of the slope system. This problem increases as the depth increases. The importance of the work in terms of engineering measurements by considering the geometry and geology of the slopes and the establishment of a monitoring system based on them is very huge. As a result of this monitoring, by finding the amount and speed of the movements on the slopes, the necessary movements on the slopes can be determined by the engineers or measurement system. This is to ensure that the engineers take precautions against these movements. The important thing here is the design. Designers determine the geometry by considering many factors in the open pit. One of the important points in this planning is to make a design that will prevent problems in stability as the open pit deepens. There are several methods used in open pit mine design. Since the slope, height, crack geometry, roughness, filling material and water condition of discontinuities can change at any time, no formula or chart has been found for the stability of rock slopes that can be applied by anyone to date. However, many researchers have suggested various analysis methods. The most commonly used stability analysis methods are (Kesgin, 2008):

- Empirical methods,
- Stress analysis methods;
- Photoelasticity methods,
- Finite element method,
- Limit balance method;
- Vector analytical method,
- Stereographic projection method,
- Physical model methods;
- Stationary scaled model method,
- Moving (kinematic) model method

Among these methods, slope stability analyzes can be made by means of charts that take groundwater into account. However, the most sensitive analysis among the analysis methods can be done with the numerical modeling method. With the development of technology, the open pit phases are also examined with this method and it is possible to apply different geometries at different times (Aksoy et. al., 2016; Uyar and Aksoy, 2019).

Bu analizler sonrası gerçekleştirilecek olam madencilik faaliyetlerinin devamlı suretle gözlemlenmesi gerekmektedir. Bu gözlem olası riskleri ortadan kaldırmak amacıyla yapılır. Mühendislik faaliyetleri (kazı, patlatma vb) sonrasında ilk hali bozulan ve denge şartları değişen doğanın deforme olması beklenmektedir. Bu deformasyonun belli sınırlar içinde olması arzulanır. Bu sınırlar, arazi şartlarına bağlı olarak değişmektedir. Bu deformasyonlar jeodezik yöntemlerle izlenirler. Jeodezik yöntemlerin kullanılabilmesi için noktalar arası yada noktalar ile uydu arasında bağlantı olması gerekir. Bu bağlantının olmadığı durumlarda jeodezik olmayan yöntemler de kullanılabilir (Kuang, 1996).

In geodetic monitoring, the point obtained from the repeated measurements of the control network at appropriate time intervals, which consists of selected points in the characteristic places of the landslide area where movement is expected, where movement is not likely, and which is suspected to move. The method, which is based on the proof of the change in coordinates with mathematical and statistical test methods, can be used for retaining walls, drainage, etc. in the landslide area. It can also be applied to control the effectiveness of these measures taken by applying them after the measures (Altan et al., 1991).

In recent years, many researchers interested in this subject have put forward different studies for modeling the data obtained from the field. They used many different methods such as inclinometer, radar tracking, geodetic tracking to collect deformation data in the field, and then combined these data with laboratory test results and tried to model the database they obtained with various methods and analyze the instability mechanism (Ozsen, 2017).

Frastia et al. (2014) using the geodetic method, Kaizong et al. (2016) akintg measurements with GPS, Zhao et al. (2015) followed the deformations using the GB-InSAR method and Osasan and Stacey (2014) using the radar tracking method. The main purpose of these monitoring is to predict instability problems.

In this study, the effects of precipitation on slope stability were investigated by long-term deformation and precipitation monitoring in a metallic ore mine. Although there is no slope failure in the mine, the increase in deformations with precipitation is clearly seen. On the other hand, the absence of any failure with the increase in deformation also shows that the open pit design was done safely.

2. Geology of Research Mine

The pre-Tertiary formations of the Biga Peninsula are the Çamlıca and Palamut metamorphics, the Denizgören Ophiolite and the Çetmi Melange.

Tertiary units in the region unconformably overlie the older basement rocks and begin with andesitic and dacitic lavas and pyroclastics covering large areas in the region. Middle Eocene aged granitoids were emplaced in these rocks, which are known as the Beyçayır formation.

Fıçıtepe Formation, which covers the older formations unconformably, shows delta and river deposition together with conglomerate, sandstone and shale containing thin coal layers. Şahinli formation and Fıçıtepe formation are followed by Soğucak formation and this formation contains reefal limestone, the contact cannot be clearly observed.

One of the products of the volcanism, in which there are rich ore deposits, is the Hallaçlar Volcanite, and it consists of altered andesite, basaltic andesite lava and pyroclastics from place to place. Shallow intrusions of generally granodioritic composition, which originate the volcanism, are called Oligomiocene Granitoids since they emplaced in the region in the Oligocene-Early Miocene interval. A generalized stratigraphic section of the region is given in Figure 1.

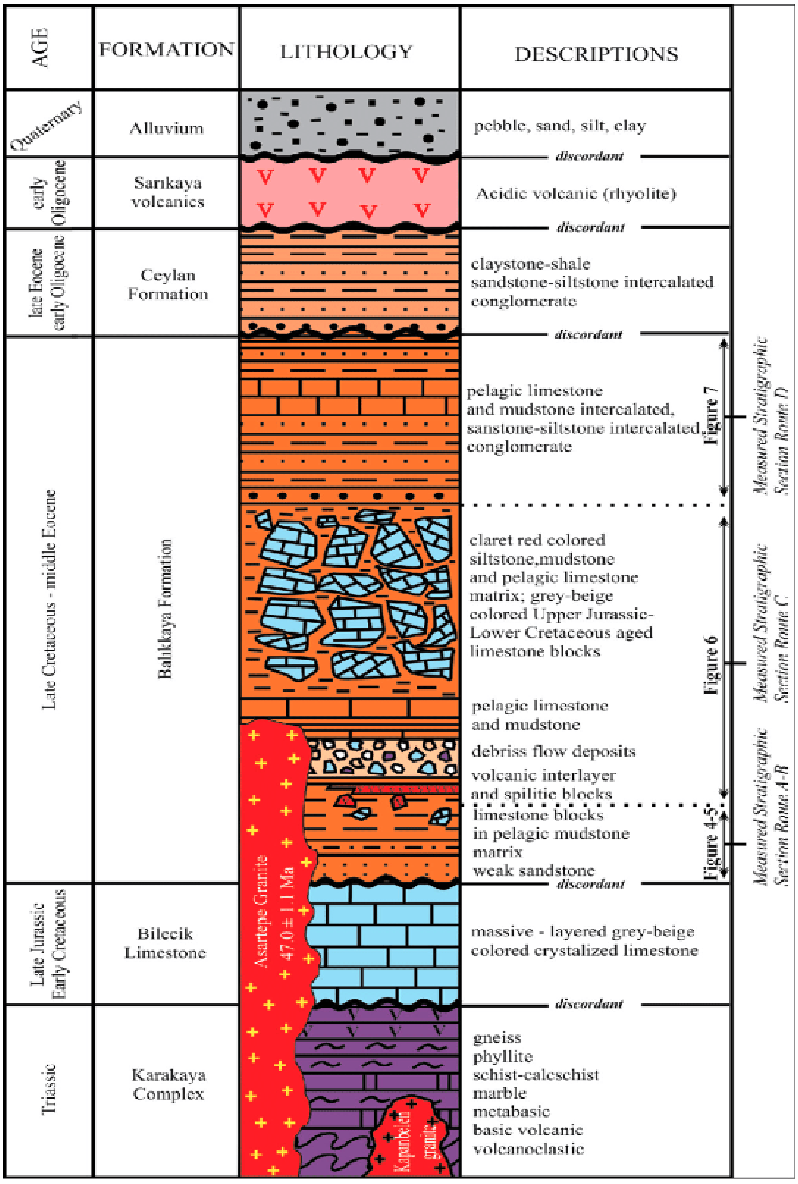

Figure 1. Biga peninsula extended stratigraphic section

3. Monitoring

In the field deformation measurements, a method that can manage and analyze the data coming from different types of sensors together was used. Thanks to the method used in tracking, deformation measurements can be taken on reflectors placed at many deformation points, thanks to its sensitivity and long-range target recognition feature. Tilt sensors detect displacements in the x and y axes, detect displacements at reference GNSS points and TPS monitoring points. The general scheme of the principle used in monitoring is given in Figure 2.

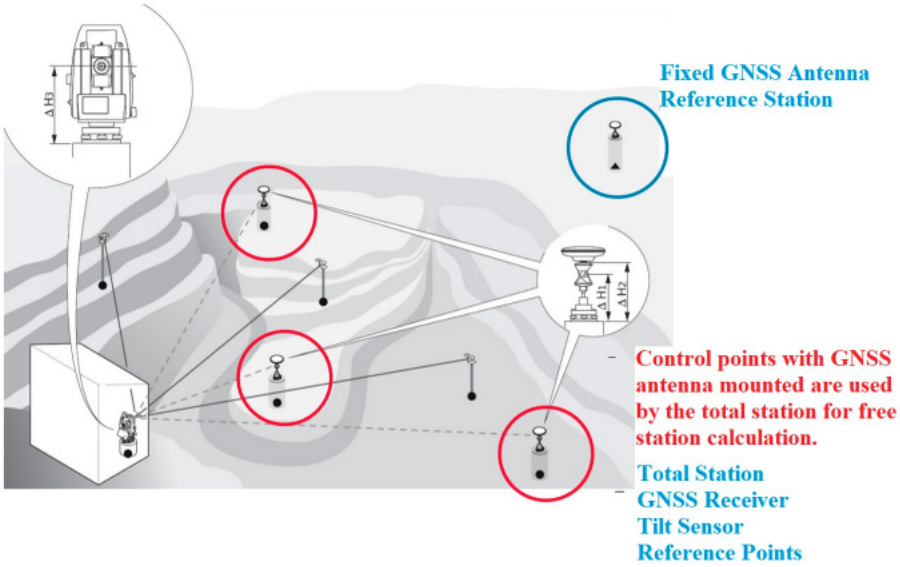

Figure 2. Principle of Monitoring System

4. Field Information and Field Research

The open pit in which the study was conducted is a metallic mine field within the borders of Çanakkale Province. As a result of the mining activities carried out in the field, the open pit is getting deeper. The dominant geological units in the open pit mine include Quartz-Felpat-Porphyry units and Micaschist units. Permeability is very low in both units. No slope failure has been observed to date. Only minor spills occur on the slopes after precipitation, depending on the rock structure. It is thought that the main cause of these spills is also precipitation. Although there is an increase in deformations after very heavy snowy and rainy days, the rock structure has been planned to tolerate these deformations. In Figure 3, an image of the pit where the research was carried out is given.

Figure 3. A view from the open mining operation where the study was carried out

Brief information about the monitoring method is given above. Within the scope of this study, long-term precipitation amounts and deformation amounts were monitored. The main purpose is to reveal the effect of precipitation on deformations. Figure 4 below shows the graphs showing precipitation amounts and deformations in three directions together.

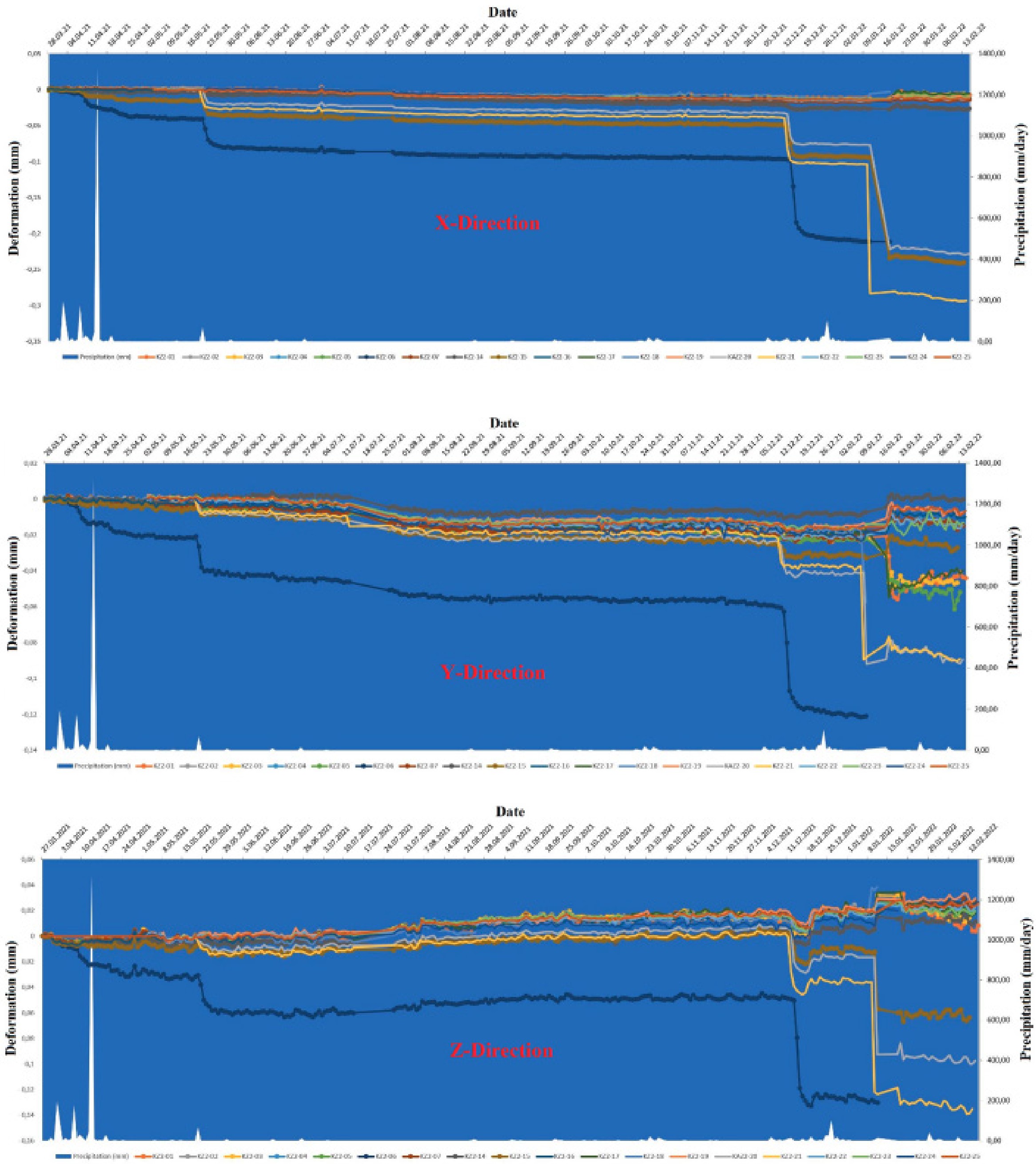

Figure 4. Time dependent precipitation and deformation values

5. Results and Discussions

The main purpose of this research is to investigate the effects of seasonally increasing precipitation on the deformations of open pit slopes. For this purpose, long-term deformation and precipitation monitoring were carried out in a metallic open pit mine located in Çanakkale province. These monitoring lasted approximately 1 year. During this time, there was no slope failure in the open mining operation. However, increases in deformations were observed in some periods. When the periods with increases in deformations are examined (Figure 4), it is seen that increases in deformations begin after a certain period of time after the onset of precipitation. For example, it is seen that the deformations started to increase with the precipitation that started with the date of 31.03.2021. However, it was observed that there was no increase in the deformation increase acceleration in the period of sudden and high precipitation (14.04.2021). It is observed that deformations increase in this period when precipitation continues. It is seen that a sudden increase in deformations started on 22.05.2021, approximately 1 month after this date. The striking factor here is that there was a precipitation of 67.80 mm/day on 21.05.2021. However, it was observed that there was little precipitation in the days before this date. From this point of view, it is seen that sudden precipitation has no effect on deformation increases. The same situation is similar with the deformation values increasing with autumn precipitation. In terms of deformation, it is seen that there is an increase in all observation points as of 12.12.2021. There is a precipitation data of 101.4 mm/day on 14.12.2021. However, the upward trend in deformation started earlier. The sudden and high amount of precipitation on 14.12.2021 did not affect this trend much.

Considering that the dominant geological units in the open pit mine are low permeable, a small amount of rain in a certain time period (from a few days to one to two weeks) causes an increase in deformations after a while. It is seen that the time between the precipitation time of the rain and the time when the deformations increase depends on the permeability of the geological units. As the permeability increases, the time for the rock to be saturated with water will be shorter, and therefore the increase in the amount of deformation will manifest itself in a shorter time.

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