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Analysis and Prediction of the Behavior of the Landslide at Ain El Hammam, Algeria Based on the Second Order Work Criterion

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Abstract**—**The landslide of Ain El Hammam (AEH) is characterized by a complex geology and a high hydrogeology hazard. AEH's perpetual reactivation compels us to look closely at its triggers and to better understand the mechanisms of its evolution in mass and in depth. This study builds a numerical model to simulate the influencing factors such as precipitation, non-saturation, and pore pressure fluctuations, using Plaxis software. For a finer analysis of instabilities, we use Hill's criterion, based on the sign of the second order work, which is the most appropriate material stability criterion for non-associated elastoplastic materials. The results of this type of calculation allow us, in theory, to predict the shape and position of the slip surface(s) which are liable to ground movements of the slope, before reaching the rupture given by the plastic limit of Mohr Coulomb. To validate the numerical model, an analysis of inclinometer measures is performed to confirm the direction of movement and kinematic of the sliding mechanism of AEH's slope.

Keywords**—**Landslide, second order work, precipitation, inclinometers.

I. Introduction

THE city of AEH is located at 50 km east from the capital of the city of TiziOuzou (Fig. 1). It is the site of the reactivation of an old landslide. The area affected by this movement has increasingly grown, affecting the infrastructure such as roadways and water network in the city: dislocation of buildings, opening cracks in pavements, and broken pipes, etc.

To predict the behavior of this slope, under some climatic event, and in addition to numerical modeling using finite element method, the second order work approach is proposed to predict instabilities appearing on the slope before reaching the breaking point using Mohr-Coulomb theory. Consequently, this movement is an interesting case study to model. As the slide's reactivation appears to have been triggered by local water conditions after a strong rainfall treated by [1], we modeled the problem with a hydro-mechanical finite element formulation. The criterion used to detect instability is the second order work of Hill's approach [7]. Indeed in the framework of the theory of elastoplasticity, it has been shown theoretically [2]-[4] and experimentally [5]; [6] that ruptures may occur strictly within the plastic limits of a material, when the material exhibits a non-associated flow rule. The soil behavior is mainly elastic-plastic with non-associated flow rules [3]. Therefore, the classic test of tensile strength given by the plastic limit (usually described by the Mohr-Coulomb limit in soils) is not enough. The criterion of the second order works is given by the equation:

$$w_2 = d\sigma : d\varepsilon > 0 \quad (1)$$

where σ is the Cauchy stress tensor and ε is the linear strain tensor. In this expression, the two tensors are related by their constitutive relationship. When w_2 is positive (w2 >0), the material is stable. Otherwise, a general rupture rule, and a general boundary condition can be defined on the considered solicitation path. Consequently, the material is in an unstable when state w_2 is negative. Moreover, it has also been shown that this test can detect all failure modes observed in soils: localized modes (shear bands, or compaction) and diffuse modes (liquefaction) that do not show the locations of deformations [8].

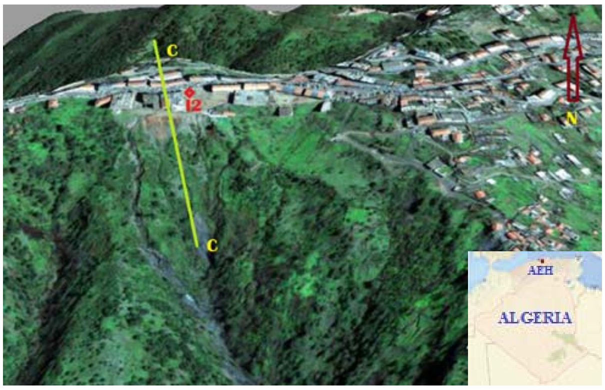

Fig. 1 Satellite view of the location of AEH landslide

In this study, to identify the mechanism of deformation and to predict the spread of the AEH landslide, we used two approaches, the first is the equivalent deviatory strain and the second is the Hill's criterion. These results are visualized by MATLAB software. Finally, to validate these results, a combination of technical instrumentation such as inclinometric measurement was followed in order to identify the deep of slip surface and to understand the sliding velocity and its direction.

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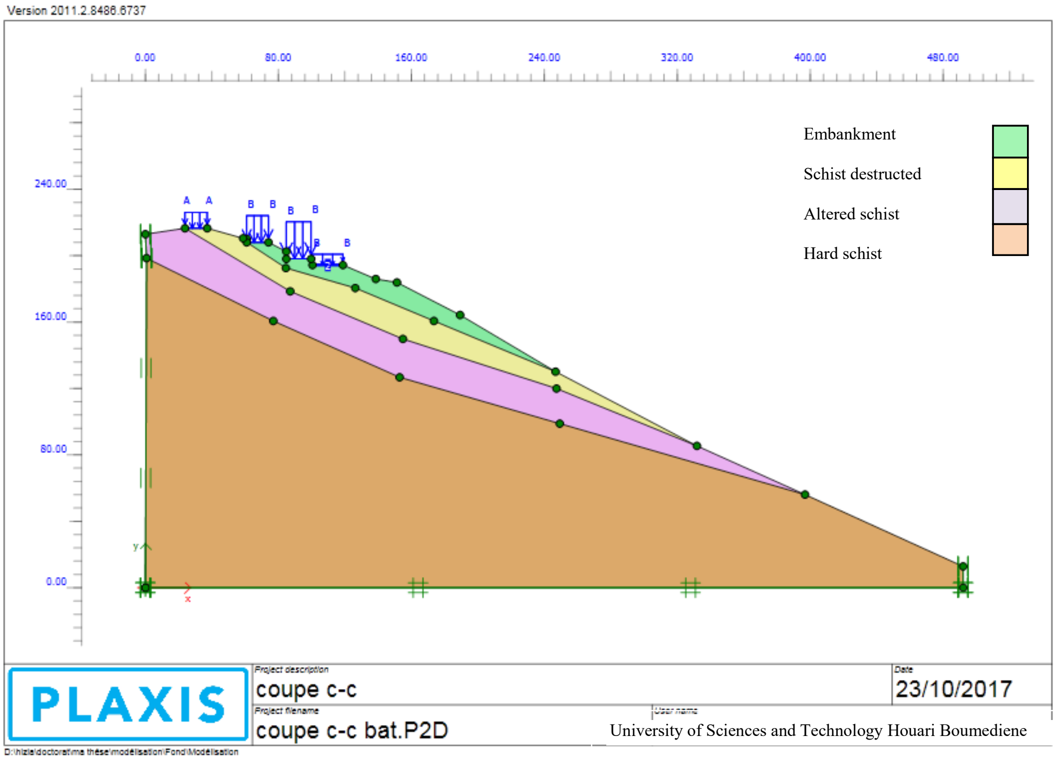

Fig. 2 C-C in middle of landslide of AEH (view Plaxis model)

II. Study Area

AEH is a mountainous town culminating at 1500-m height. Its area is about 3855 km^2; it is characterized by a Mediterranean continental climate, relatively cold and rainy in the winter and hot and dry in the summer. Temperatures vary from year to year, from −5 to 35 °C with occasional peaks at 40 °C in July and August.

The rains may spread over a period of 5 to 6 months with heavy rain and snow between November and March, with 1058.8 mm as an average annual rainfall [9].

The geology of the study area is characterized essentially by dark gray satin schists belonging to the metamorphic crystallophyllian base of the massif of the Great Kabylia. Satiny schists have a mean direction of schistosity-oriented ENE-WSW with a slope that varies from 40 to 60° to the southeast [10] (see Fig. 2).

The city of AEH is characterized by the existence of numerous water sources in the catchment leaking. This means that there is a substantial aquifer here, because the schist formations are permeable in one direction of the cleavage and in the inclination of the slope which is the main flow direction. The presence of an abundance of water has been known for a long time and is the reason behind the development of the city. The piezometric level can reach 5 m of depth in the winter season.

From geotechnical point of view, the presence of water in abundance in this region promotes a physical and chemical alteration of the rock (schist satin which is an indication of old compression clay). Schist's of metamorphic origin present multiple structures which have been exposed to the air. The rock has poor resistance to physical and chemical stresses and easily deteriorates under the action of frost or rain water [11]. The presence of water in the soil acts directly on its geotechnical characteristics [12].

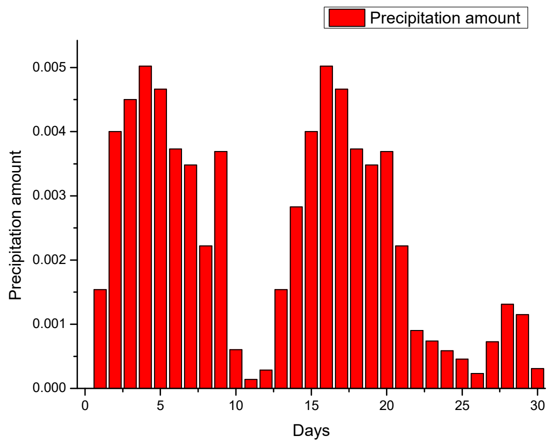

Fig. 3 Daily variation of precipitation

III. Methods

A. Numerical Models

In this paper, we present the numerical modeling of the section C-C, which was fact in the middle of the slope. The Hardening Soil Model (HSM) [13] was adopted to represent the behavior of the two first layers, Embankment and Schist destructed. By jointed rock model (JRM), we modeled the layer of altered schist, finally the layer of the hard schist was modeled with elastic linear model.

Objective of modeling

The purpose of the modeling is to determine the stress and strain fields through hydro-mechanical finite element coupled formulation.

The hydro-mechanical finite element coupled formulation takes into account with high precision the factors affecting this area: such as mechanical actions, climate and water.

Through the numerical modeling of the slip site, the hydraulic factors were identified as the most important factors for the reactivation of this landslide; we modeled the precipitation of the rainiest month which causes the sliding triggers through transient groundwater flow (Fig. 3), the level of groundwater is 8 m according to the piezometric measuring. The inclusion of non-saturation to the layers above the water table is performed using the Van Genuchten model to represent the water retention curve. These parameters are determined by Plaxis through correlations with the particle size and permeability of the given soils.

IV. Results and Discussions

A. Numerical Modeling

1. Equivalent Plastic Deviatory Strain ε^{p}_{eq}

The equivalent plastic deformation ε^{p}_{eq} is a scalar variable, representing the amount of plastic deformation ε^{p}_{ij} contained in the deformation tensor. It represents an isotropic hardening parameter.

The calculation of the equivalent plastic deformation is performed by a MATLAB program on the basis of the calculation results of Plaxis, we will help to know the state of rupture inside the unstable slope of AEH.The ε^{p}_{eq} found for the section C-C, has a circular shape, touches the two layers of unstructured schist, which gathers at a sliding surface of 40 m depth in the middle of the surface (see Fig. 4).

B. Second Order Work

The results of the second order work w2 found and showed schematically of the model by MATLAB program, a large zone of instability appearing in the embankment and destructed shale layer were negative (w2<0). In the altered shale layer, instability is identified in the direction of discontinuity joints. This also serves to validate the preferred flow direction in these schist joints according to the observations of the second order of work that shows us. In fact, these joints are filled by the alteration product which is a clay silt of low geotechnical characteristics. We can see that the evolution of unstable areas for this simulation, is fully correlated with deviatory strain, and the inclinometer measurement, which shows significant displacements on this cut.

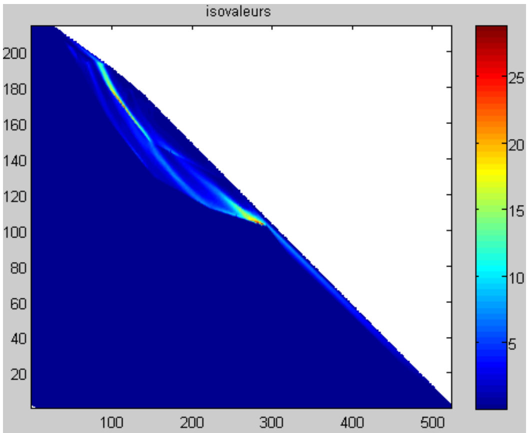

Fig. 4 Equivalent plastic deviatoric strain

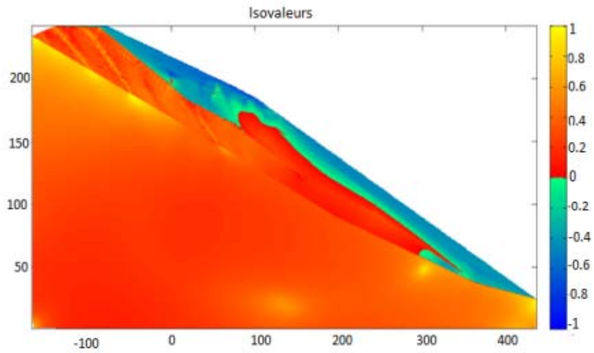

Fig. 5 Second order work of section C-C

V. Inclinometer Measurement

The inclinometer implanted near to the section C-C of the area of AEH slide (Fig. 6) is used to determine subsurface movement of landslides. We have enabled save ground deformations on a slice of 28 m, which coinciding with the depth of surface observed by equivalent Deviatory strain given by modeling and with results of second order work (see Figs. 4 and 5). This failure plane is performed along the interface between altered schist and destructed schist.

VI. Conclusion

The AEH landslide is still active and characterized by a complex structure. That is why we embarked on a numerical modeling to refine the analysis of the behavior of the slope and its long-term response mode.

We also undertook a slope stability study using in one hand the equivalent deviatory strain and Hill's criterion, and compared them with area measurements in the other hand.

Based from the results of the second order work, we concluded that the slope is unstable and there is a great risk of slipping if the slope undergoes all modeled hazards, inclinometer measurements validate the depth of the sliding surface founded by numerical modeling after strong precipitation.

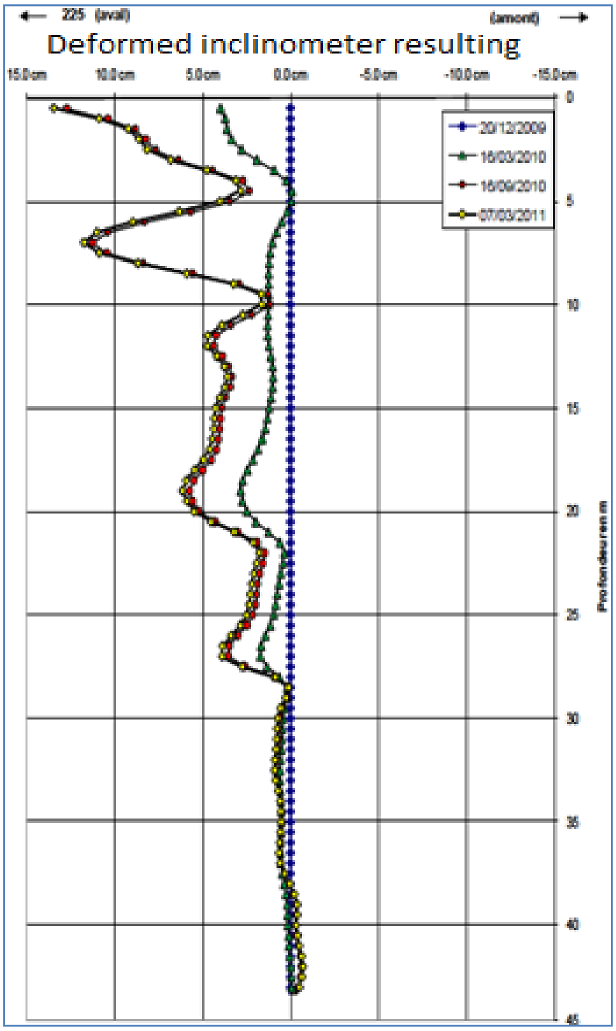

Fig. 6 Deformed inclinometer resulting

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