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Landslide risk: study of soil instability of an area in the region of Tetouan, Occidental Rif (Morocco)

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ABSTRACT: The study area is located in the North of Morocco on the Mediterranean coastline. The purpose of this article is to know the principles of a study of soil stability using geological study and geotechnical test, in order to characterize and to undertake the stability of the areas subject of movement and particularly for landslides by a numerical method (SLIDE 5.0). It will also enable to define the nature of soil at the site using mechanical test and the pressumeter tests supplemented by laboratory tests to understand and deduce the risk of instability affecting this area. The studies and tests have allowed us to highlight a schistose soil. This schist are quite permeable, therefore the flow of water into soil, particularly clays and schist, and when it is saturated in water, its internal cohesion decreases very significantly, which causes the landslides. It is important to understand these instabilities in order to better characterize and define the kind of preventions for this area, where the subject of this study.

KEYWORDS: geology, geotechnical, Slide5.0, test, landslide…

1 INTRODUCTION

The stability of the entire slope is threatened by gravity; between imperceptible distortion on certain aspects and incessant falling blocks in the hallways of the high mountains, landslides cover a broad category of movements along the slopes [1]. They are frequent and constitute a permanent risk in almost all regions of the world. Their study and monitoring, which should allow the prediction of their release, have become a priority for natural disasters.

Geological complexity, morphology steep relief and relatively abundant rainfall make the Rif region where slope movement; commonly referred landslides are most common in Morocco. If damage in human life in relation to these phenomena are rare, they nevertheless have a significant impact on land they directly threaten the infrastructure of the region.

The slope instability is rarely attributed to a single factor, but it is the combination of several, difficult to dissociate because of mutual interactions [2]. Landslides are characterized by the appearance of shear surfaces relatively well defined within the environment.

The damage does not save more buildings because the geological risk associated with these processes does not worsen with the expansion of urban centers, sometimes too fast and without prior planning [3].

The objective of this study is to define the nature of the soil means of geological and geotechnical studies, supplemented with a stability study of the ground by a numerical method (Slide 5.0).These combined methods will allow us to characterize the type of ground movement affecting this area.

1.1 Presentation of the study area

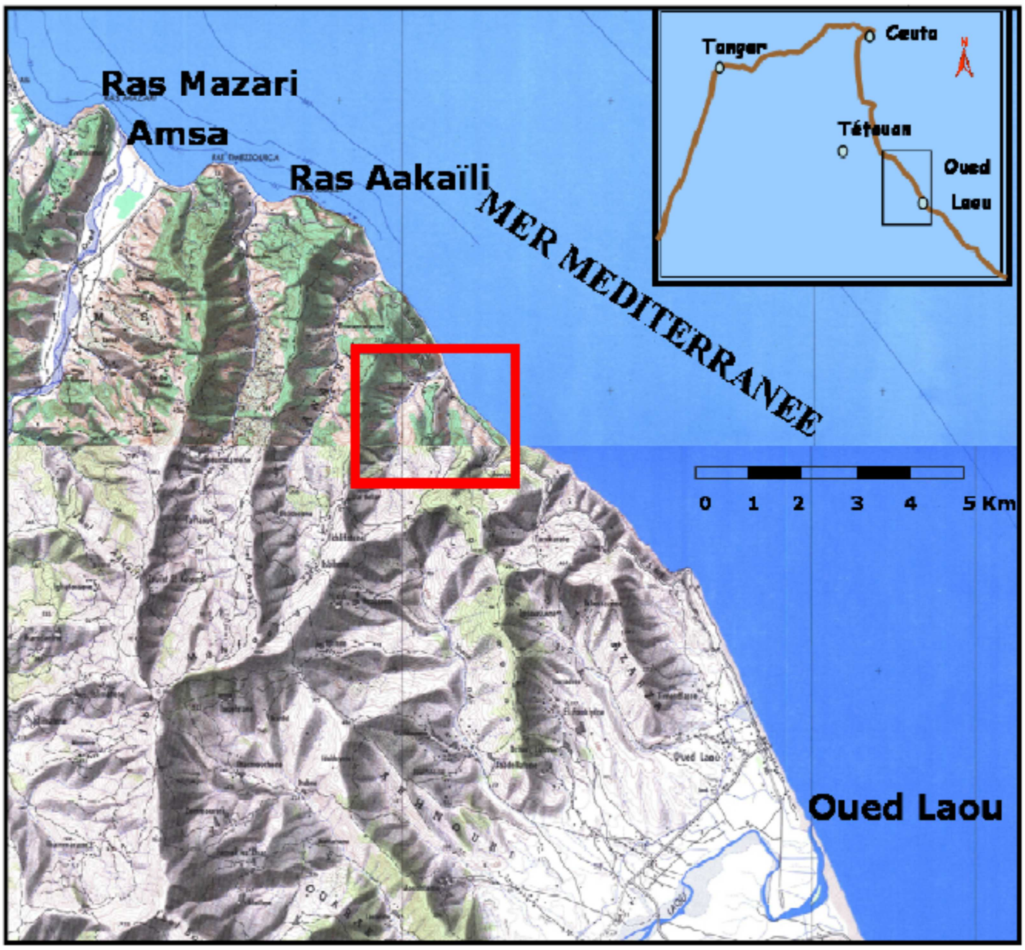

Fig. 1. Geographical location of the study area at 1:50,000 topographic maps of Ras Mazari and Talembote

The study area is located in northern Morocco on the Mediterranean coastline. It is bordered to the northwest by the Ras Mazari, and south-east region of Oued Laou.

1.2 Geomorphology

In general, it is a ridge with a maximum altitude of about 350 NGM, pyramidal with three sides: a larger eastern side directly overlooking the coast; a North East side; and a slope south-southwest.

1.3 Climate

As the majority of Moroccan territory, the study area is characterized by high climatic irregularity. This occurs mainly in the rainfall which varies greatly from one year to another, and also within one year. This climate can be classified in the sub-humid, wet periods with features and semi-arid.

1.4 Hydrology and Hydrography

Hydrological and hydrographic point of view, the watershed including the study area is bounded by two rivers, the river Laou and its tributaries in the southeast and the river Amsa at Northwest.

The analysis of the sector shows that drainage system is a small area to poor drainage system concentrated in the north-east of the site, and composed of some troughs more or less branched, including runoff s' performs generally towards the sea (east direction).

1.5 GEOLOGY

Geologically, the site belongs in its entirety to the Akaili unit (Silurian) belonging to the field of Ghomarides whose abundant geological formations are flyschoides composed of limestones, sandstones, conglomerates and schists.

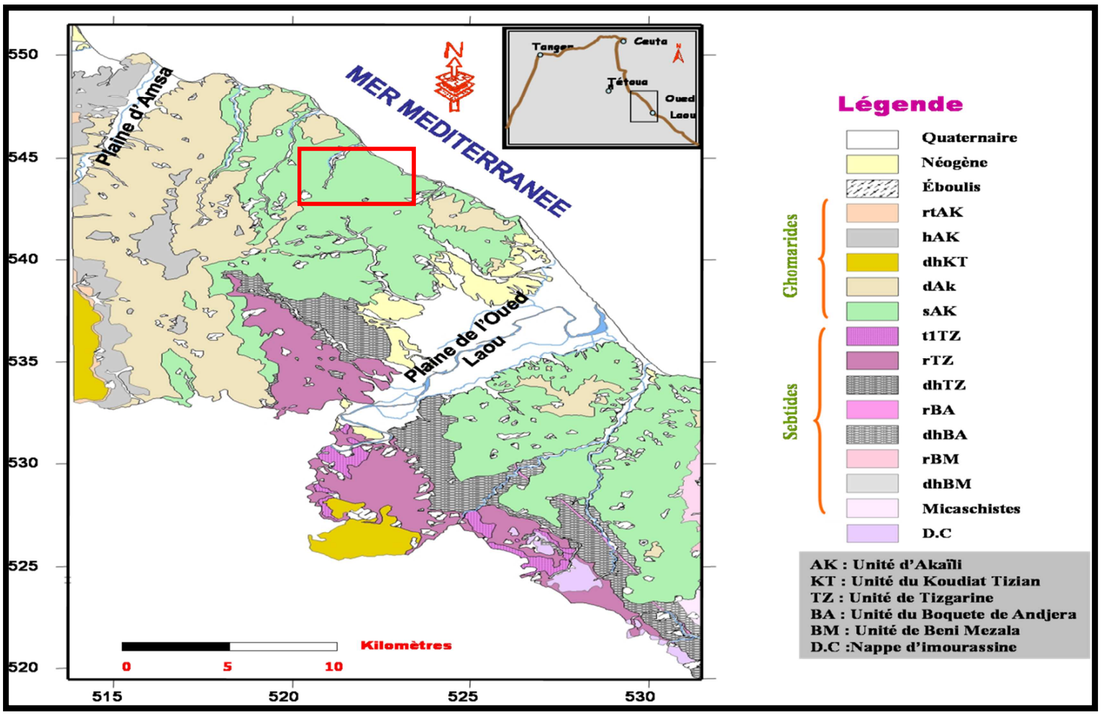

Fig. 2. Geological map of the study area (Saarig Zaakia,2007) [4]

Thus, the facies representatives are glistening sandstone schist and conglomerates with pebbles quartz stretched of the Silurian, and limestone. In addition, recent deposits covering the entire study area, with the exception of some small areas denuded by the sliding planes or along of slopes. Red clays are confined arched terraces from the sliding phenomenon while colluviums are in the southeastern part of the area.

2 MATERIALS AND METHODS

2.1 GEOLOGICAL AND GEOTECHNICAL STUDIES OF THE SITE

The recognition of soil allows us to understand the problems that can arise during the study of a construction project or during the sinister expertise.

2.1.1 GEOLOGICAL STUDY

Geological reconnaissance is the first step; it identifies the soil by visual observation of the different layers, confirmed by examining the geological maps.

Examination careers or trenches located near the area, gives immediate information on the sub-layers. Recognition was thus performed using coring [5], from what we could establish summary geological sections of our area.

2.1.2 GEOTECHNICAL STUDY

The geotechnical study allowed us to identify the site using the soil tests [6] (Atterberg limits), the pressuremeter test wich gives information on the strength and deformability. This study is also complemented by tests on the granulometry of soil, the degree of fragmentability or degradability of material (schists). These analyzes were conducted on soil materials taken from the site and transported to the laboratory for testing.

The campaign in situ of recognition consisted of the execution of ten (10) cores drilling from 10 meters in 2008, then fifteen (15) cores drilling from 15 to 20 meters deep in 2011.

2.2 NUMERICAL METHOD TO STUDY STABILITY: SLIDE (VERSION 5.0)

2.2.1 PRINCIPLE AND CHARACTERISTICS OF THE MODEL

The principle of calculating slope stability is to determine the safety factor SF by which is dividing the resistance of the sliding surface so that the potentially permanent mass is at the limit of equilibrium.

This factor can be written as follows:

$$FS = \frac{Q_{\max}}{Q}$$

Where Q: value that defines the vector or tensor applied to mass (horizontal force H, V vertical force, moment M). Qmax: maximal value of Q.

The SLIDE software is a tool of stability analysis in geotechnical with or without reinforcements. It allows to study projects, and not just sections, that is to say that the management of phasing of implementation is integrated in the software: from an initial cut (which must include all the elements will be used in phasing: geometric lines, characteristic of the slope overload reinforcements, the water parameters etc…).

Some features of the model:

- Homogenization of the slope of a single material;
- No pressure water (dry);
- Circular research of slip surface (Grid Search)).

It is this last feature that gives us all probable sliding surfaces with a coefficient of security value.

This automatic search of rupture surfaces can be made by three (3) methods for circular sliding surfaces; Grid Search ; Slope Search; Auto Refine Search. It is much more recommended to use the method « Grid Search», because it is the default method, but also it is that which requires a rack in the middle of sliding.

The definition of the grid can be made by the user (Adding the Grid option) or automatically created by Slide (Automatic Grid option).

Thereafter, it is necessary to define the type of material order to choose the appropriate method for the simulation.

First methods that are applicable to the sliding is examined; by default the methods chosen in Slide are those Bishop simplified and Janbu simplified. It is also possible to perform the calculation according to any method of user request.

After analysis and simulation, it is noted that the sliding surfaces are color-coded depending on the safety factor; and the safety factors that varies depending on the analysis method chosen. The overall minimum sliding surface thus defined, is the surface with the lowest coefficient of all security sliding surfaces analyzed. The global minimum safety factor is displayed next to the center sliding surface.

3 RESULTS AND DISCUSSION

3.1 GEOLOGICAL ANALYSIS

The exploitation of geological data and sections realized, shows that, generally, the soil is predominately schistose, and with the exception of some core drilling that are predominately clayey.

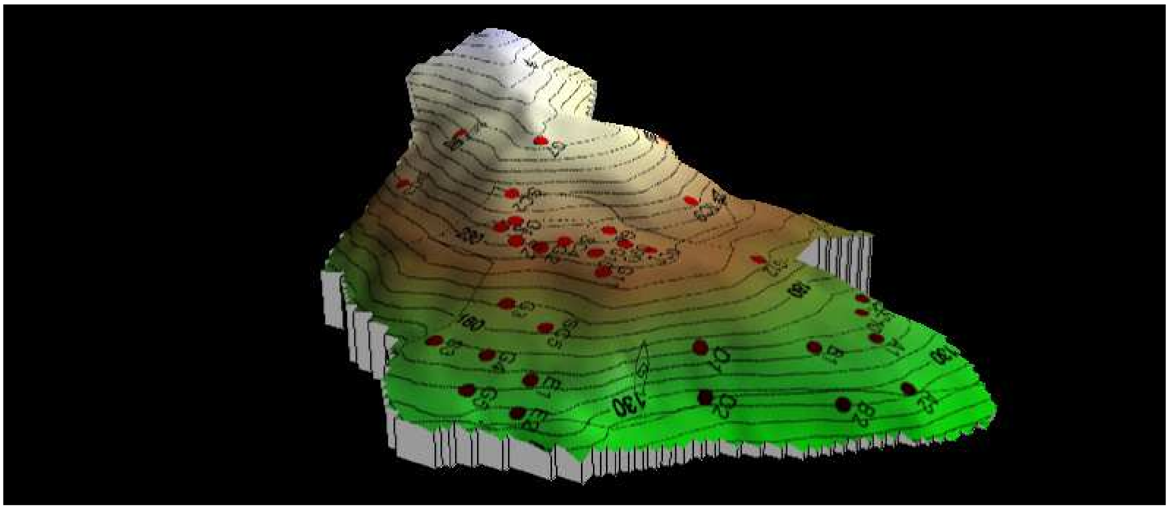

Fig. 3. Map of distribution of core drilling

Locally, fronts set up along the road show schist facies (smoke color) overlain by schists interbedded calcareous. The front of the schists to the south of the site shows slope deposits (scree and colluvium, etc.) of different types and sizes. The upstream part of the site shows generally greenish schist.

3.2 GEOTECHNICAL ANALYSIS

According to the cuts realized and the statements of natural fronts, we can define three lithological groups distinct:

- Group 1 (wholesome schist): located by our polls in the upper part of the site. This is an area generally stable, which skinning of his vices can only be done after weeding of the site.
- Group 2 (clay-schist): according core drilling realized (SC2, SC8, SC9, S2, S3, G1, G4, G5, G8), a vertical alternating of the gravelly clay with schists is observed. This testifies that there had been a reorganization of the material probably an old sliding. This alternation was observed even in the horizontal direction.
- Group 3 (gravelly clay and screes) : these facies encountered in the core drilling SC4, SC5, G3, located in the downstream part of the site are clearly visible on the fronts to the south of the site. It is loose soil without cohesion, from a filling (terrace deposits, witnesses of an ancient sliding). The areas in which these facies have been encountered are susceptible to movement when changing their characteristics geometric and intrinsic.

The pressuremeter tests were carried out in several drill holes such as S2-S3-G3-G4-G5-G6-G8-G9-G10-G11-G12-SC4 and SC5. The results obtained on the first meters of some polls have been exploited. We note that the clay soils are characterized by low pressure limits as the case of polls G4- G5- G8.

The identification tests on soil samples have given the following results:

- Gravelly red clay

This material has the following characteristics:

- o A percentage of fines (elements of diameter <0.08 mm)60% to 70%;
- o Between 8 and 18% elements higher than 2 mm;
- o A liquid limit WL between 41 to 51% ;
- o An index of plasticity Ip between 19 to 30.2%;
- o This is a fine soil (according to the classification LCPC), this is "Clays little plastic to plastics" named Ap.

- Schist crumbled

The tests performed on the fine portion of this material have the following characteristics:

- o A percentage of fines (elements of diameter <0.08 mm) is 15 to 20% ;
- o A liquid limit WL between 31% to 48% ;
- o An index of plasticity Ip between 11% to 27%;

- This is a fine soil (according to the classification LCPC), this is "Clays little plastic to plastics" named Ap ;
- The rock portion of this material has a coefficient of fragmentability Fr =10.53%. This is a fragmentable material because FR > 7.

- Compact schist

This material has a coefficient of Los Angeles test LA= 26%. It is in this case a soil which is class according to standard NF P 18-650-2/A1, that is to say « 20 < LA>50 : high quality of material ».

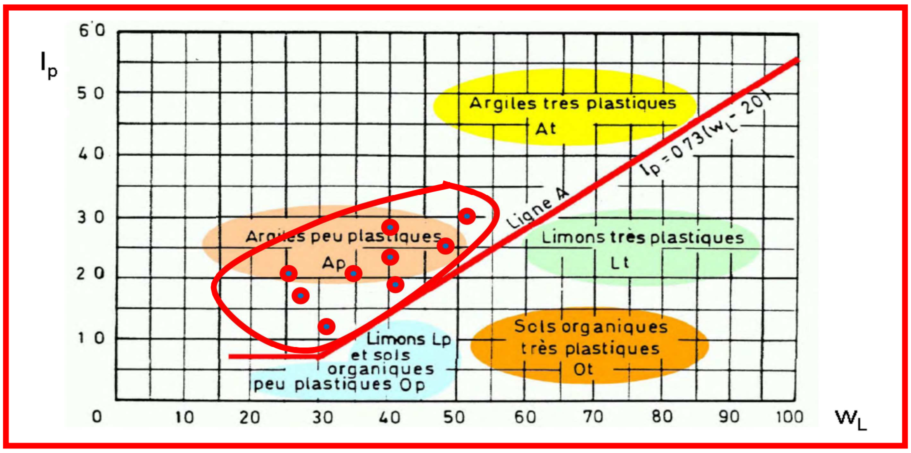

Fig. 4. Soil classification in the laboratory. Diagram of plasticity[7]

The projection of points on the diagram for soil classification allows us to classify these soils in clay soils little plastic.

3.3 Definition of the type of instability via Slide 5.0

The terrain consists of a mixture of gravelly clay, colluvium, schists and limestone pleated; these shale facies in sound condition will be considered coherent rocks do not generate instability, but this is not really the case in the study area.

To understand the stability of the site, the software analyzes in Slide5.0 to find the factors of safety FS as was described earlier in this article, has allowed us to make a comparison between the slope in the natural state (before the start of construction in 2008) and the state of the slope after earthworks (2011).

To do this we performed three (3) passing through the various polls profiles:

- A first profile through the polls G1-G2-G3-G4-G5-G6 ;
- A second profile through the polls G8-G9-G10-G11 ;
- A third profile through the polls S1-S2-S3.

It should be noted that this software takes into account mainly the topography, but also the mechanical parameters of the soil were determined in the laboratory. These parameters are taken as a result: a value of soil cohesion C= 1KN/m^2, a density of the material d= 18KN/m^3 and an internal angle of rubbing ϕ= 30°.

3.3.1 Safety factor before earthmoving (natural slope)

The first step of the simulation is done on the different profiles in the natural state of the site before work begins.

The result of the safety factors FS obtained by Bishop simplified method for different profiles are shown as following:

- Profile 1

The analysis has given a coefficient of minimum security FS=0,865.

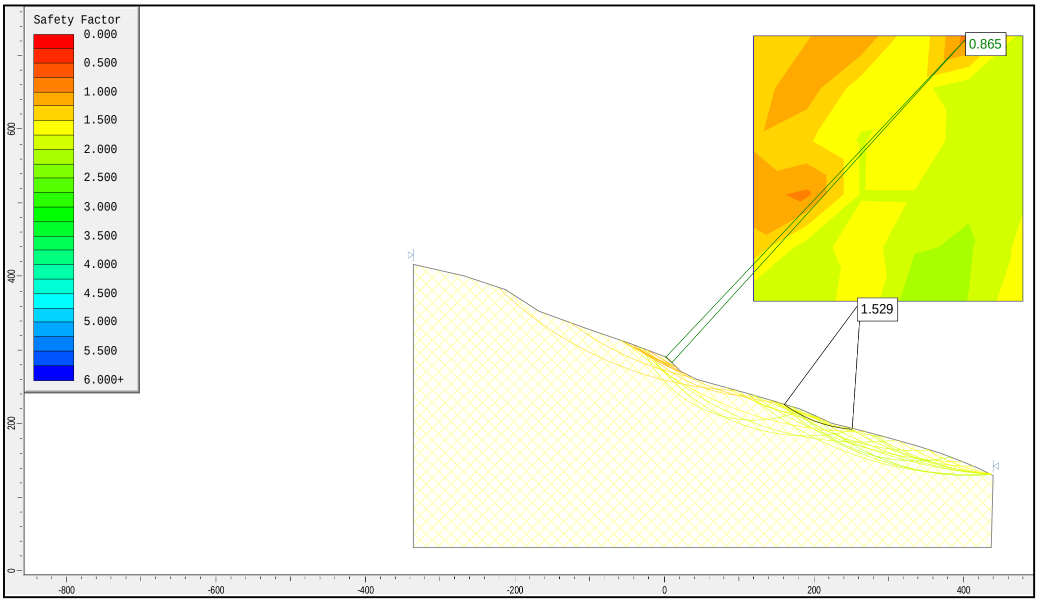

Fig. 5. Results of the analysis for the first profile before earthmoving

- Profile 2

The analysis has given a coefficient of minimum security FS=1,301.

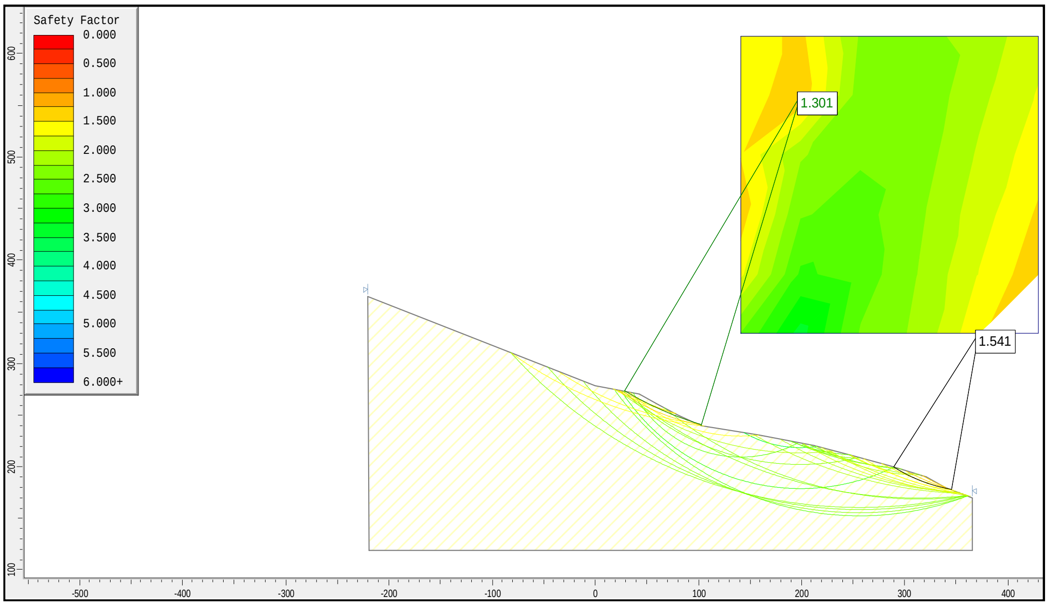

Fig. 6. Results of the analysis for the second profile before earthmoving

- Profile 3

The analysis has given a very low safety factor FS of the order of 0.751.

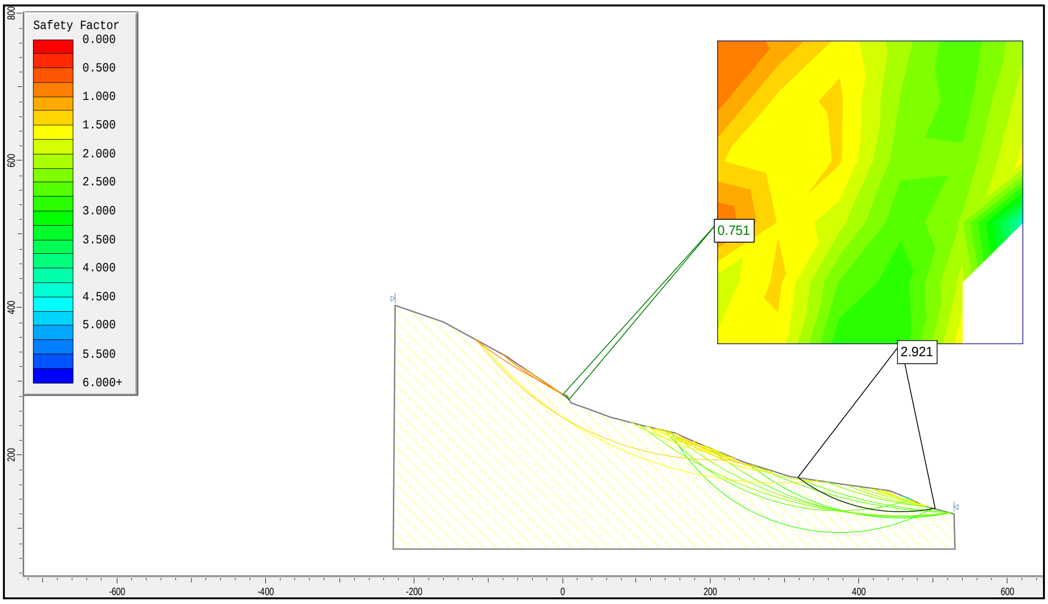

Fig. 7. Results of the analysis for the third profile before earthmoving

3.3.2 SAFETY FACTOR AFTER EARTHMOVING

Respectively for the same profiles passing through the various polls we obtained the following results:

- Profile 1: a minimum safety factor FS= 0,938.

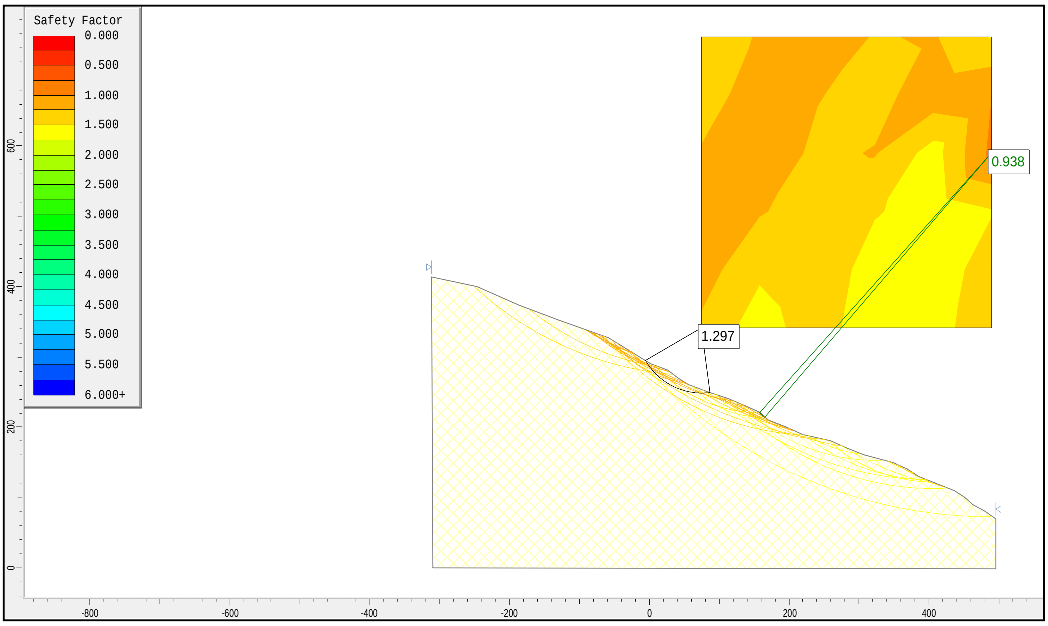

Fig. 8. Results of the analysis for the first profile after earthmoving

- Profile 2: a minimum safety factor FS= 0,919.

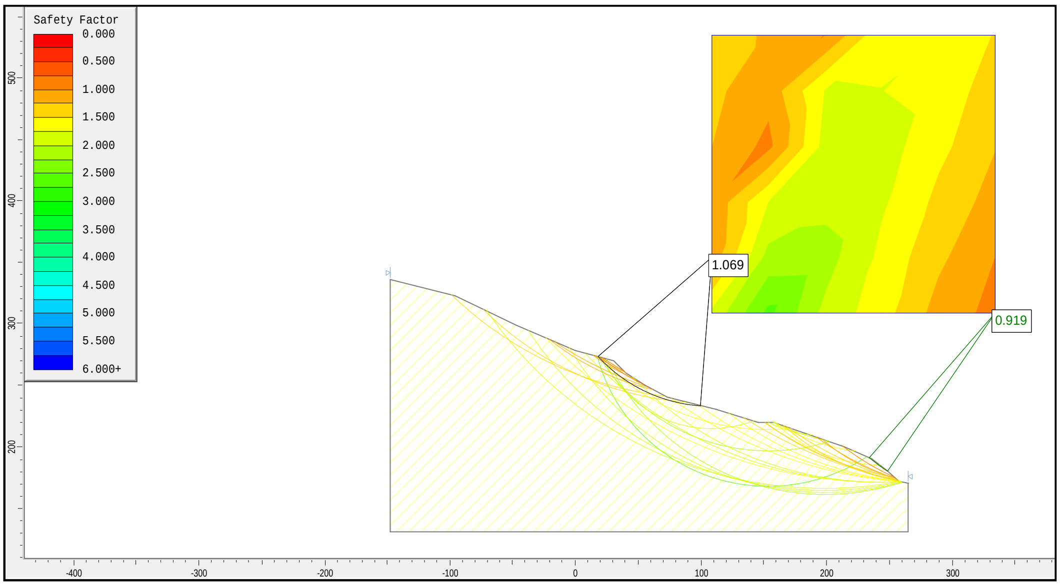

Fig. 9. Results of the analysis for the second profile after earthmoving

- Profile 3: a minimum safety factor FS= 0,997.

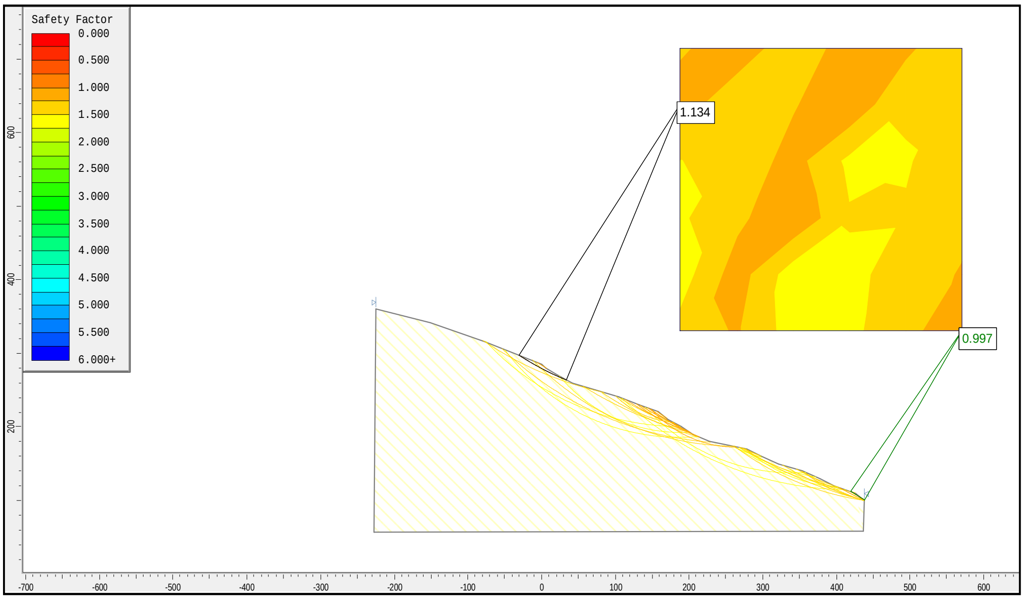

Fig. 10. Result of analysis for the third profile after earthmoving

Thus, we can see that the values of FS before earthmoving are relatively low in the case of the first and the third profile, unlike the second profile (FS = 1.3), but these values show that there has already had the rupture. Compared to the results of the analysis after the start of earthworks, there is a marked improvement in FS at profiles 1 and 3, in contrast to a decrease of FS at the profile 2. In all cases, these values do not reach the minimum permissible value for the security of some important structures which is the order of 1.25 to 1.4. Thus the study site risks possible instability phenomena taking into account the parameters of topography in this study.

Table 1: Value of the safety factor according to the structure [8]

FS	Structure
<1	Danger
1.0-1.25	contestable safety
1.25-1.4	Satisfactory security for minor structures contestable safety for dams, or when the rupture would be catastrophic
>1.4	Satisfactory for dams

However, we can define the unstable zone that develops on the bedrock composed of dark and reddish clays, schists containing quartzite. This lithology corresponds to the Silurian of Akaili (Ghomarides).

Two types of instability can arise in this area:

- Sliding bench on bench of the schists: schist is rocks foliated, their stability depends mainly on their inclination. In the presence of water, interbeds movements may arise and cause generally superficial movements and / or prismatic dislocations.
- Rockslide of clayey gravel: phenomenon mainly due to steep slopes and the change in the water status of these facies.

3.3.3 INTERVENING FACTORS IN THE INSTABILITY

These instabilities are determined by intrinsic and extrinsic factors on the ground.

- Intrinsic factors

  This is the set of characters and specific parameters to the ground; it is the topographic slope, lithology and structure.

  - Topographic slope
    The terrain is characterized by relatively important slopes to facilitate movements. Generally, the large number of instability affects slopes moderately pitched and moderately high. These instabilities become scarce in areas with low and high slopes.
    In the case of low slopes, the action of gravity is too weak to drag the rock masses. While in the second case (steep slopes) that are often cliffs, these are phenomena of rockslide or collapse blocks of various sizes that manifest themselves. Thus, our study can be classified according to the degree of slope, among the areas at risk of sliding as shown in the analysis from the slide 5.0 software.
  - Lithology
    Lithological point view, the ground consists of shale and limestone with folds. These facies show in the metric and centimetric scale, several planes orthogonal from each relation to others and spaced a few centimeters. This is a very jointed structure and the rock is more consistent as a whole by acquiring an eroded appearance. The core drilling implanted in the stable area of the site (upstream) showed a schist being flush between 1 to 2 m in depth. These schists are generally altered and debited to all depths recognized.
  - Structure
    Besides the diaclases, the ground shows a larger scale; the presence of a set of faults that affect it. Indeed, the study of terrain and geomorphological analysis on the map and aerial photos clearly show the existence of a large number of these faults.
    It is mainly vertical normal faults or steeply dipping to the sea and some setbacks. The faults are grouped into several families: NNW- SSE à N-S, NW-SE, E-W, NE-SW.
    The family NNW-SSE to N-S materialized by three major faults along the sector from its southern boundary to become farther north (Tamernoute), the coast line in cliff.
    The family NW-SE is represented by faults segmented; whose junctions are often hidden by the vegetable mold or deposits recent slopes.

- Extrinsic factors

  Mention of these factors, the slope exposure east wind, high rainfall area and significant seismic activity frequency. In our case, it is predisposed to generate movements, joints and faults that have weakened the rock also play plans for infiltration of rainwater. This water allocates far in altering the rock, reducing its internal cohesion and overcharging of the first meters of the soil. This phenomenon is getting worse because of the slope exposure humid winds from the east (Cherki) which increases the water content of soil and decreases the evaporation.

Such a sol, including all factors favoring landslides, simple vibrations (seismic) can at any time trigger instability. This one, according to this study often takes plans faults NNW-SSE à NW-SE as a primer.

Detachment of blocks and their fall on the slopes are often caused by neotectonic deformations which are exerted in the steep escarpments, these blocks rush down the slopes up softening their slopes where they stop.

4 Conclusion

The Study area is characterized by a particular geomorphology, which is that of the entire Rif chain, with very complex character.

The geotechnical study of the project showed that the soils are predominantly schistose. The crumbled schists are permeable, thus facilitate the passage or flow of water in the soil (which consists mainly of clay), and when the soil is saturated with water, its internal cohesion decreases rapidly, which causes the sliding.

The core drilling and geological study of the site have detected landslide areas located downstream of the site.

Studies also demonstrate that it is better to take an angle for earthworks α=27°to 30° instead of 45°, because the ground becomes unstable when the earthmoving is made at an angle relative to 45°.

We can say that: this sliding is a set of small sliding "parasites" from a very old and large rotational landslide or curve, and in recent years when quantities of materials has become quite large and abundant accompanied by a significant rainy season, new fracture surfaces have arisen.

When we want to stabilize a sliding, not matter whether the rupture surface is circular, planar, etc ...; it would be of great importance to know its dimensions and have an idea about its origin, that is to say if it is an overload, a water flow, soil alteration or simply runoff exceptional, because the choice of the stabilization method into depends.

Faced with a problem of stability, a first solution is to franking movements of unstable slopes without preventing. Thus, we need to know whether to:

- Implement or move the buildings, the art or the road outside the work area moving in a sector recognized as a stable?
- Design the work so that it is not damaged by the landslide: adapting the method of construction so that the foundations are separated from the moving soil?

Acknowledgment

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