ESTIMATION OF THE STABILITY OF A MARLY SLOPE, AFTER RAINING. THE CASE OF KAPSALI AREA, IN KITHIRA ISLAND

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Abstract

In April 2004, the southern part of Kithira Island, in the uphill area of the touristic Kapsali Golf, consisting of marl and overlain by limestone, was affected by a large scale landslide, divided in two parts. This landslide destroyed the road Kapsali – Kalamos.

Our investigation was performed using a combination of lab tests data of cohesion (c) and angle of friction (ϕ) of the material and back analysis technique of the slope, taken the conditions at failure time.

The slope presents a limited stability which decreases during heavy raining. As it was derived from the analysis, the activation of sliding is related to the silty clayey (CL-ML) character of the material, in relation to the rain conditions and the low porosity of the material which does not permit the easy drainage of the slope.

The occurrence of new slides, in the area, could be real in the future if no protective schedule would be established.

The concept of the investigation

The concept of this investigation is related to the use of the back analysis technique for providing a realistic slope stability analysis. In this framework, the derived data, of possible c and ϕ values, were used for investigating other, neighbor, site of the marly, fine grained, formation.

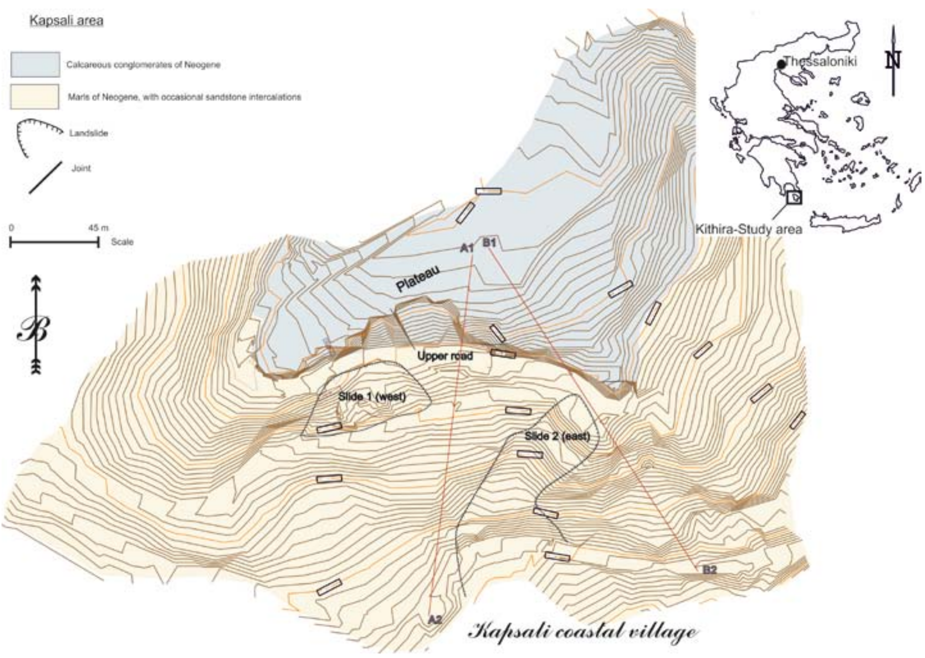

Fig. 1. Geological sketch with the location of the landslides and the studied cross sections (A_1-A_2 & B_1-B_2)

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Location

The investigation area is located at the southern part of Kithira Island, at the uphill area of Kapsali Golf, along the road which connects Kapsali village with Kalamos Village, capital of the island. The landslides were occurred in marls overlain by limestones.

The geological formations at landslide area

The area, which is located at the uphill area of the village, mainly consists of marls with occasional thin sandstone intercalations. The marl is partly weathered, consisting of silty clay (with occasional low percentages of sand), of low plasticity. The stratification of the formation presents a dip-direction of 280/35 (Fig. 2). The upper part of the area consists of calcareous conglomerates (called: plateau"), which are tectonically divided in big blocs, limited by vertical big joints, of E-W and NW-SE directions (Fig. 3). Two faults, of NW direction, limit the northern part of the area. The above measured tectonic data coincide to the general tectonic activity system of the island (DANAMOS, 1992). Kithira Island is a high seismicity area, as result of the western Greek arc's seismotectonic activity which gave, from 1750 to 1937, earthquakes of M=6.0-7.2 (PAPAZACHOS & PAPAZACHOU, 2002).

Fig. 2. Marl of Neogene

Fig. 3. Calcareous conglomerate of Neogene

Fig. 4. The crest of the eastern sliding "Slide 2"

Fig. 5. The toe of the western sliding "Slide 1)

Slope stability analysis

As already referred, the slope consists of marls overlain by calcareous conglomerates. The landslides occurred in the marl. The marl is generally weathered given, in many cases, the impression of a soil. Under dry conditions, the material is hard and cohesive but under humid conditions, looses rapidly its cohesion. The water penetration is low, approximately 10^{-6} taken into account its grain size distribution ($k=100xd_{10}^2=100x0.001^2=0.0001$ mm/sec = 10^{-6} cm/sec). The landslide is totally located in the marl and affects the road to Kapsali Village (Figs. 4). In Fig. 5, the toe of the western sliding (slide 2) is presented.

According to our lab-tests, the material is characterized as silty clay (CL-ML) of low plasticity, having the follow parameters: a) clay: 14,31%, b) silt: 74,56%, c) sand: 11,13%, d) LL: 11, e) PL: 5, f) PI: 6, g) ϕ=23,2^0 and h) c=0,227kg/cm^2.

The slope stability analysis was performed using both BISHOP (1955) and MORGENSTERN & PRICE (1965) methods, which gave similar results. For this reason, in the present paper, only the method of MORGENSTERN & PRICE (1965) was used.

According to our lab test results, the slope, in dry, presents sliding circles of limited stability, with values FS_{min}= 1,05 – 1,3. These coefficients decrease under 1 (slide west: FS_1= 0,993 & slide east: FS_{2up}=0,958 and FS_{2low}=0.996) in intensive raining conditions, which were considered as realistic for the time of failure.

In our investigation, we considered, the marl as homogeneous, even if there are occasional thin sandstone intercalations, accepting c and ϕ values which correspond to the failure moment.

According to the calculations using lab test c &ϕ values combined with back analysis data, we estimated, for marl, c=4kN/m^2 and ϕ=18^0. Furthermore, it was estimated a moisture of 15% which gives an apparent weight of 23kN/m^3.

Using the data used, at the slides 1 and 2, a new slope stability analysis was performed along to the axes A_1-A_2 and B_1-B_2 (Fig. 1).

Slide 1 (western)

The crest of the landslide is located at a height of 71m (Fig. 1, 6) while the toe is located at a height of 62m (Figs. 1, 5, 6). The sliding is circular with W-SW direction. This rotational movement created a failure of 2,5m high and an horizontal opening of 0,5-1,5m. For estimating the cohesion (c) and the internal friction (ϕ) of the marl and performing the slope stability analysis, we used the back analysis technique, for saturated conditions, which are similar to the raining conditions of the sliding time. So, we arrived to the following data: c=4kN/m^2 and ϕ=18^0, for the given landslide geometry and safety factor SF=0,993.

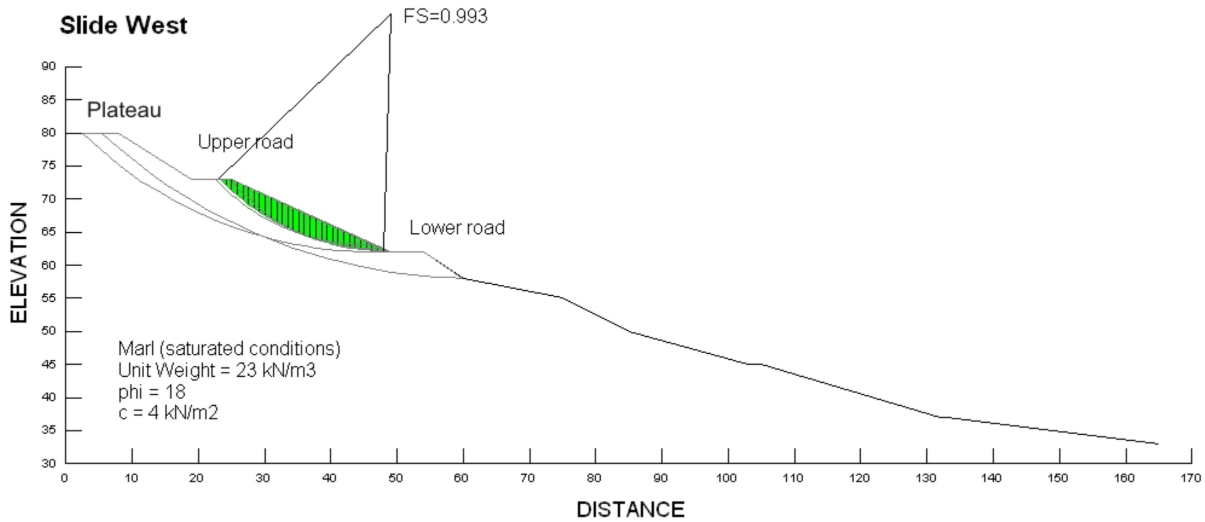

Fig. 6. Slope stability analysis of "Slide 1" using back analysis technique

The above used values were also verified in the Eastern Slide. It is interesting to mention that several possible sliding circles are given in Fig. 6 but this which is used refers to the slide occurred, living possible the occurrence of a bigger sliding if the slope is not protected.

Slide 2 (Eastern)

This slide occurs two sliding parts. The crest of the upper sub-sliding is located at a height of 70m (Fig. 1, 4, 7) while its toe daylights at a height of 64m (Figs. 1, 7). The crest of the lower sub-sliding is located at a height of 55m while the toe daylights at a height of 44m, not far from the houses (Fig. 1, 8). The sliding covers an area of about 3000m^2 with a width of 45m. The sliding was activated toward S-SW direction. The vertical slip, at the crest of the sliding was 5m.

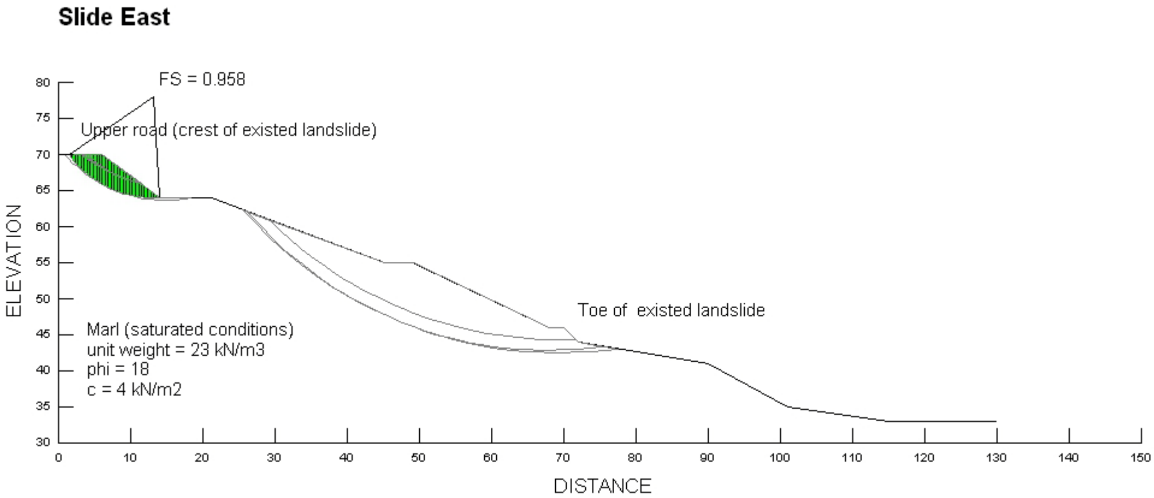

Fig. 7. Slope stability analysis at the upper part of the eastern slide (slide 2), using back analysis technique

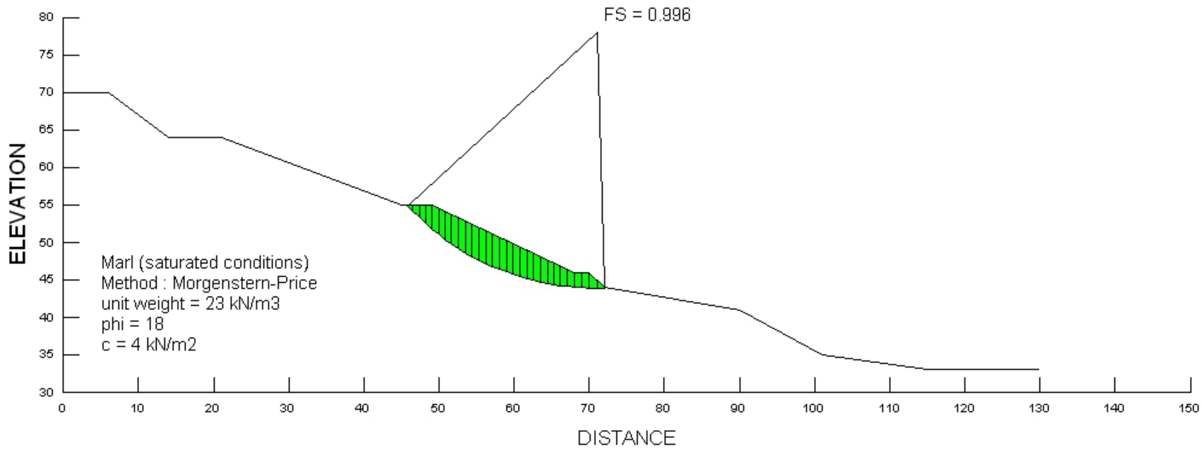

Fig. 8. Slope stability analysis at the lower part of the eastern slide (slide 2), using back analysis technique

For similar reasons as for slide 1, we arrived to the following data: c=4kN/m^2 and ϕ=18^0 and safety factor SF=0,958, for the upper sub-slide and SF=0,996 for the lower sub-slide.

Slope stability analysis along A1-A2 and B1-B2 axes

The results of above slope stability tests were used for analyzing the slope stability along the neighbor cross-sections A1-A2 (Figs. 1, 9) and B1-B2 (Figs. 1, 10).

According to our elaboration, the sliding circles give safety factors A1-A2: SF=0,926 (Fig. 9) and B1-B2: SF=0,66 (Fig. 10).

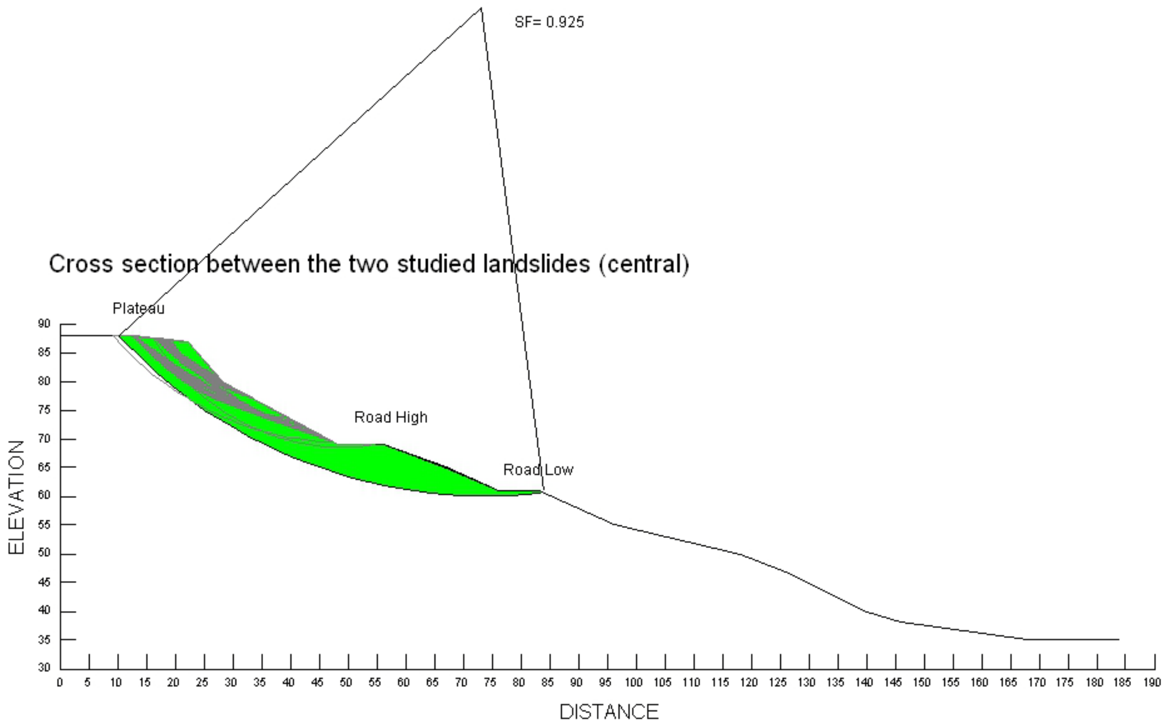

Fig. 9. Slope stability analysis along the axis: A1-A2, using back analysis data

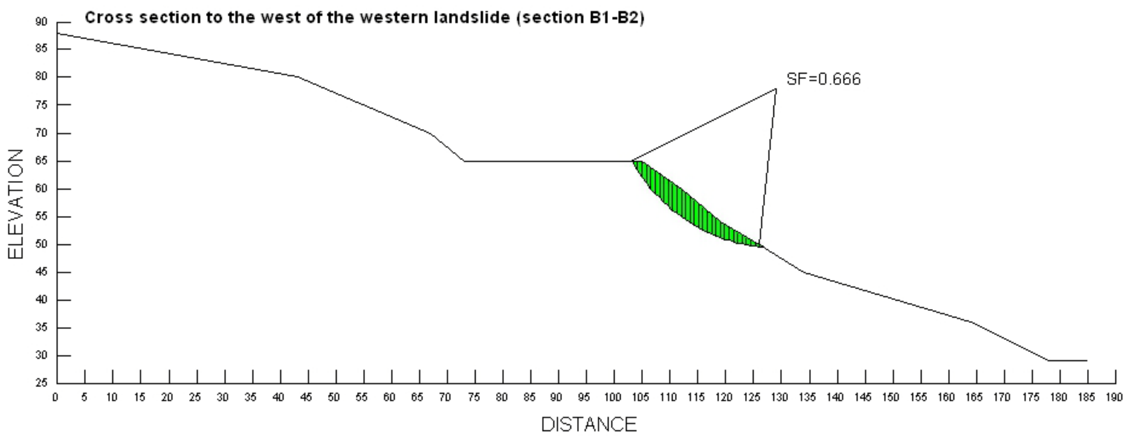

Fig. 10. Slope stability analysis along the axis: B1-B2, using back analysis data

Conclusion

According to our investigation, we conclude that:

- The combination of the calculations using lab test data with the back analysis technique takes in mind the conditions of the failure time.
- The slope presents a limited stability which decreases during heavy raining. As it was derived, the landslides were activated by the heavy rain in relation to the low porosity of the silty-clayey (CL-ML) identity of the material which did not permit the easy drainage of the slope.
- As we saw, in the casea A1-A2 and B1-B2, the occurrence of new slides, in the area, can be real if no protective studies and measures are taken.

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