



Bulletin of the Geological Society of Greece

Vol. 43, 2010



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Loupasakis C. Institute of Geology and
 Mineral Exploration,
 Engineering Geology
 Department

Galanakis D. Institute of Geology and
 Mineral Exploration, General
 Geology and Geological
 Mapping Department

Rozos D. National Technical University
 of Athens, School of Mining
 & Metallurgical Engineering,
 Laboratory of Engineering
 Geology and Hydrogeology

<https://doi.org/10.12681/bgsg.11321>

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Rozos



To cite this article:

Loupasakis, C., Galanakis, D., & Rozos, D. (2010). ROCK SLOPE STABILITY PROBLEMS IN NATURAL SIGHTSEEING AREAS - AN EXAMPLE FROM ARVANITIA, NAFPLIO, GREECE. *Bulletin of the Geological Society of Greece*, 43(3), 1465-1473. doi:<https://doi.org/10.12681/bgsg.11321>

ROCK SLOPE STABILITY PROBLEMS IN NATURAL SIGHTSEEING AREAS - AN EXAMPLE FROM ARVANITIA, NAFPLIO, GREECE

Loupasakis C.¹, Galanakis D.² and Rozos D.³

¹ Institute of Geology and Mineral Exploration, Engineering Geology Department, Olympic Village, 13677, Acharnae, Greece, cloupas@igme.gr

² Institute of Geology and Mineral Exploration, General Geology and Geological Mapping Department, Olympic Village, 13677, Acharnae, Greece, galanakis@igme.gr

³ National Technical University of Athens, School of Mining & Metallurgical Engineering, Laboratory of Engineering Geology and Hydrogeology, 9 Heroon Polytechniou str., 157 80, Athens, rozos@metal.ntua.gr

Abstract

The morphological and geological setting of Greece, the active tectonics and the irrational human activities results to the fact that several natural sightseeing areas or even more, archaeological sites and monuments are located in areas with unfavourable geotechnical conditions. The selection of the proper support and protection measures in most of the cases appear to be very difficult because the applied measures must reassure the minimum aesthetic destruction of the sites.

The natural sightseeing area of the Arvanitia walkway, in Nafplio city, is a typical example of site, with extensive human activities, manifesting serious rockfall stability problems. The applied stability analysis pointed out the geotechnical problems and allowed the suggestion of measures for the improvement of the geotechnical behaviour of the rock mass. The measures were planned with respect to the natural beauty and the historical character of the site. Further more, the stability problems located at the slopes of the Kastoria lake walkway are briefly presented. The differences between the two sites revealed the geotechnical problems arising when the landplaning engineers do not take under consideration the engineering geological conditions during the construction of infrastructures.

Key words: rockfall, natural sightseeing areas, Arvanitia walkway, Nafplio city.

1. Introduction

Within the limits of Greece Territory several natural sightseeing areas or even more archaeological sites and monuments are located in areas with unfavourable geological conditions. Areas subjected to sliding, creeping or settlement phenomena have been used as foundation formations. Also several sites are founded on the base of unstable slopes arising issues for their safety and stability.

The natural sightseeing areas of Porto Katsiki beach in Lefkada and Navagio beach in Zakynthos Island are located along the base of extremely high and unstable slopes. Several sections of the walkway along the Kastoria Lake are constructed at the base of steep slopes. The slopes of the Acropolis' hill in Athens contain numerous rock wedges threatening the safety of the surrounding monuments (Andronopoulos & Koukis, 1976). Delphi archaeological site is located on the base of an extremely high limestone slope appearing numerous rockfalls. These examples clearly present the variety of the sites affected by geological – geotechnical causal factors causing slope instability.

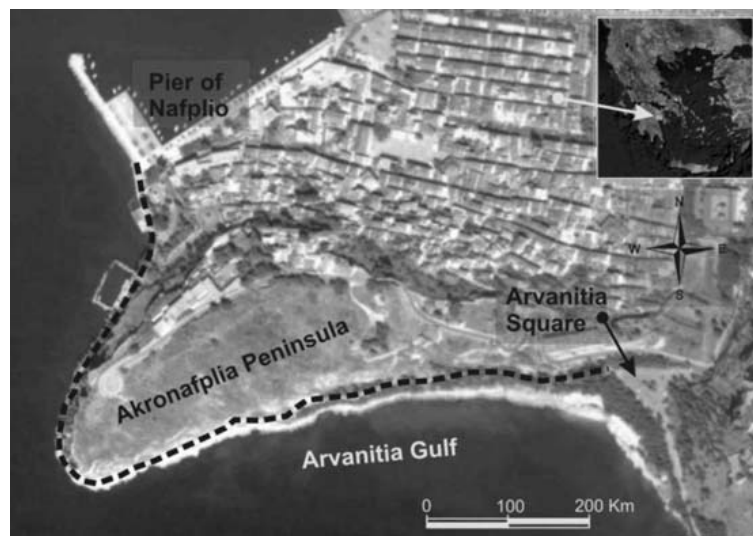


Fig. 1: Satellite pictures - taken from Google Earth - pointing the location of Arvanitia walkway in relation to Nafplio city.

The selection of the proper support and protection measures in those cases appear to be very difficult. No matter how intensive the problems are the applied measures must avoid or even restore, in a certain extent, the aesthetic alteration of the sites.

The natural sightseeing area of the Arvanitia walkway is a typical example of a site appearing rock fall stability problems. Arvanitia walkway connects the pier of the city with Arvanitia square, extending to a total length of 1100m (fig.1). The southern part of the street, along the Akronafplia gulf (650m), was constructed by means of extensive excavations along the base of the peninsula. These artificial slopes appear serious stability problems because the excavation was done using mass of explosives and without taking any measures for the removal of the overhanging rocks. Furthermore, in several sections the road was constructed attached to the base of the slopes or even worse under overhanging parts (negative inclinations). The occurred stability problems beside the numerous walkers threat the life of the climbers exercising on these slopes.

The objective of this study was to reveal and analyse the stability problems of the slopes and to propose the proper remedial measures by taking under consideration the sightseeing character of the site and the request for its minimum aesthetic destruction. Apart from Arvanitia walkway, the stability problems encountered at the slopes of the Kastoria lake walkway are briefly presented. The differences between the two sites presented the geotechnical problems arising when the landplaning engineers do not take under consideration the engineering geological setting during the construction of infrastructures.

2. Morphological - Geological setting

The old city of Nafplio was build at the north foot of Acronafplia peninsula. Arvanitia walkway encircle the peninsula connecting the pier, from the west, with the Arvanitia square, to the east (Fig. 1).

The inclination of the slopes surrounding the peninsula vary, affected mainly by the tectonics. The slopes along the north side of Acronafplia present relatively smooth inclination and therefore the city

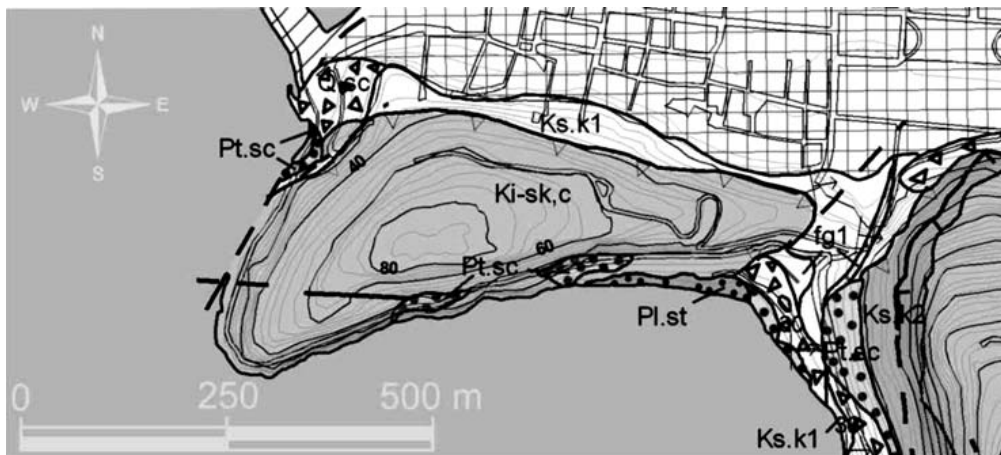


Fig. 2: Geological map of the Akronaflia peninsula. Geological formations: Ki-sk,c: Cretaceous Neritic Limestone and Base Conglomerate, Pt.sc: Pleistocene cohesive Debris, Pl.st: Pliocene Limestone Breccias with, Qs.c: Quaternary alluvial fans (Fotiadis, 2008).

extends towards the hill. On the contrary, the north-western and the southern slopes are effected by normal faults and fractures presenting steep to very steep inclination, respectively.

This status affects proportionally the safety of Arvanitia walkway. Along the southern side of Acronaflia peninsula, with the very steep slopes, the walkway is constructed attached to the base of the slopes. Also because of the limited space, in several sections extensive excavations with negative inclination, or even more a small tunnel were conducted in order to open up the walkway. On the contrary, along the north-western part of the pedestrianized street with the smoother slopes, the excavations were reduced to the minimum and the walkway was constructed on a safe distance from any steep slope.

The Arvanitia walkway was constructed intersecting mainly the Cretaceous neritic limestones and the base conglomerates (Ki-sk,c) consisting of the peninsula. Some parts of the walkways also cross Pleistocene cohesive debris (Pt.sc) and Quaternary alluvial fans (Qs.c), as shown in the geological map of figure 2 (Fotiadis, 2008; IGME, 1982).

The limestone appears to be massive with limited karstic erosion mainly along the faults. The rock mass of limestones is fractured by multiple joint sets forming numerous wedges along the natural and artificial slopes. The Pleistocene debris and the alluvial fans appear to be cohesive with favourable mechanical characteristics, classifying them as soft rocks.

During the field work numerous normal faults were recorded. The projection of the tectonic data on the Schmidt net reveals that their orientations are NE-SW, NNW-SSE and NW-SE determinately affecting the geomorphologic structure of the peninsula.

3. Geotechnical setting- safety assessment

The slopes along the Arvanitia walkway can be distinguished in two categories, taking into account both the location of the road in relation to the base of the slope and the available space for the installation of the support and protection measures. As presented in figures 3, 4 and 5 sections A, B

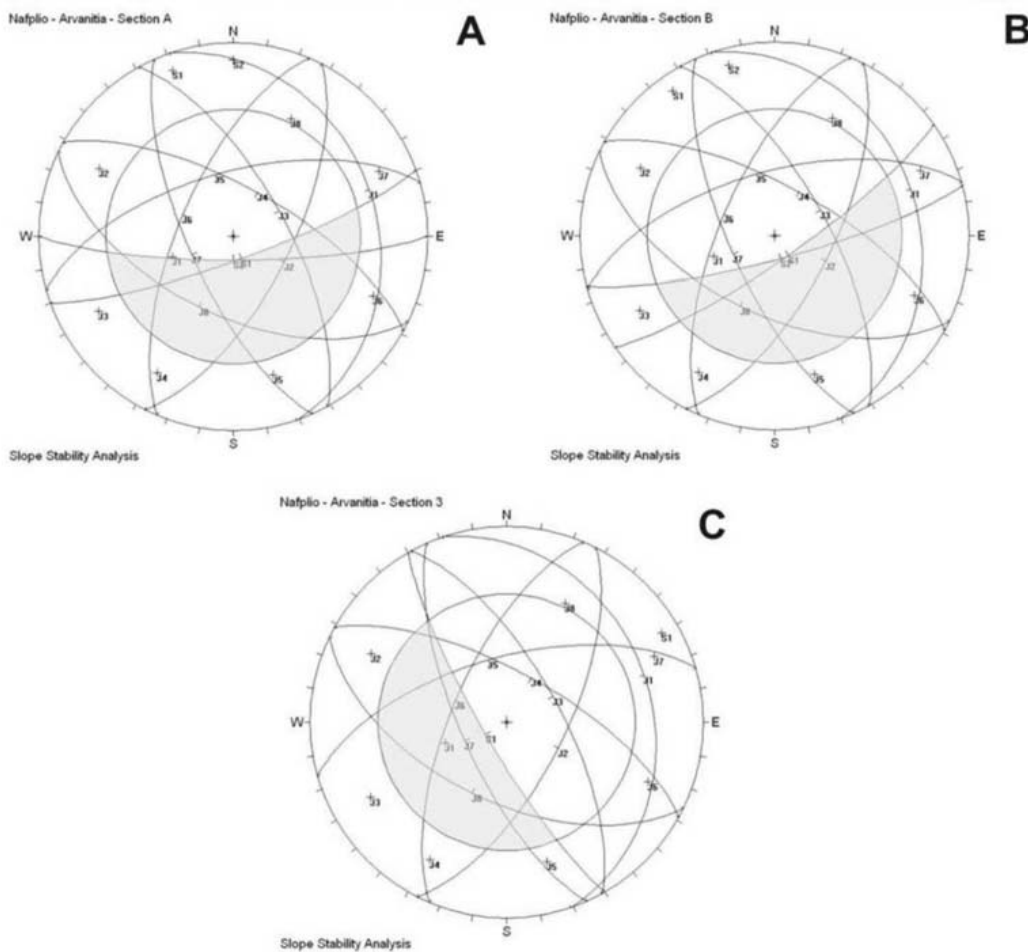
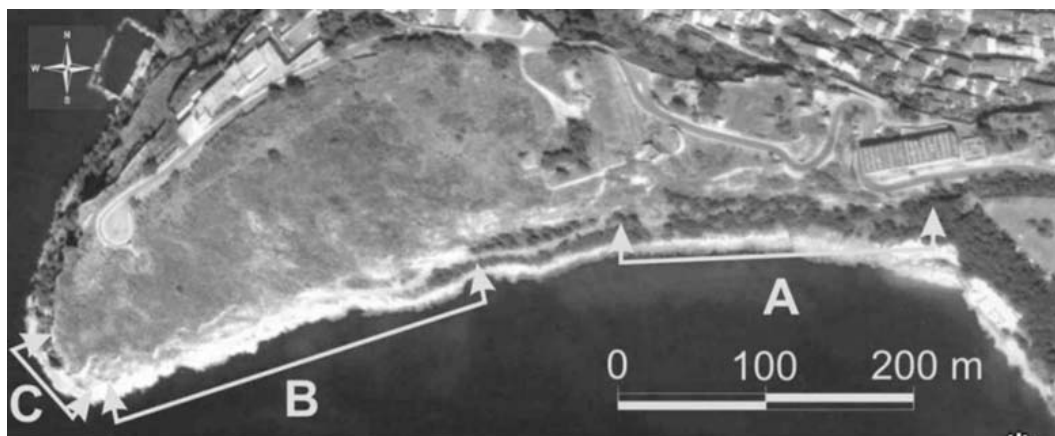


Fig 3. Satellite picture (Google Earth) pointing the parts of Arvanitia walkway (A, B and C) constructed along the base of the slopes. The Schmidt stereo diagrams presenting the numerous joint sets intersecting the A, B and C parts of the slopes. The numerous unstable wedges are clearly presented by checking the intersected major planes in the "zone of potential instability" (grey area) (Hocking, 1976; Hoek & Bray, 1981).

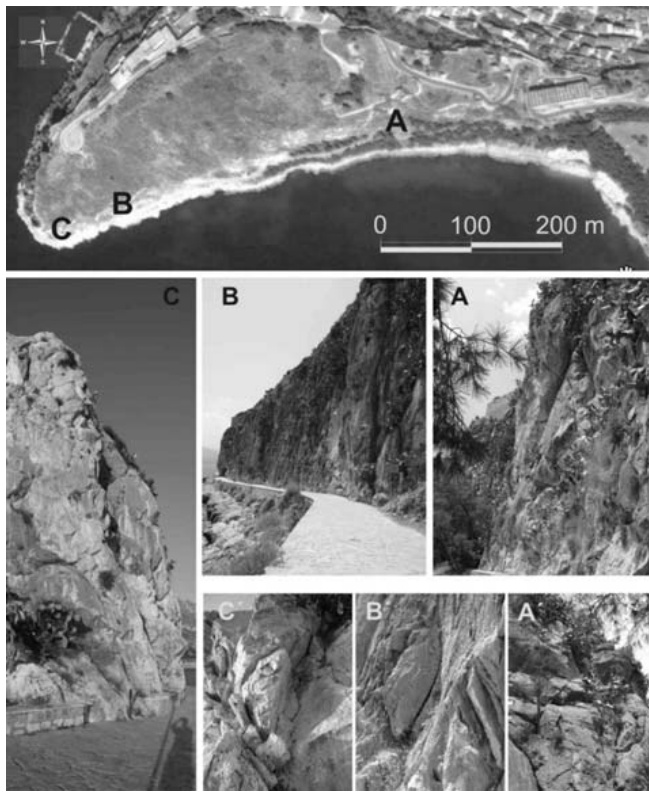


Fig 4. Photos presenting the condition of the rock mass in the before mentioned parts A, B and C of the walkway. Pictures A', B' and C' present focus on main wedges in the corresponding slopes.

and C are constructed attached to the base of the slopes without leaving any space for the installation of any protection measure. Those sections appear serious stability problems, due to the rock mass fracturing, and the disturbance caused by the excavation procedure.

The Schmidt stereo-diagrams presented in figure 3 prove that the A, B and C parts of the slopes are intersected by multiple joint sets. Most of the joints appear very high persistence (>20 m), wide spacing (1-2 m), no separation (< 0.1 mm) and lack of weathering. Those parameters explain the high RQD values (reaching up to 80-90%) and justify the also high RMR ratings (75-80) that classify the limestones in the “good” rock mass category (Kolligri, 2008). Based on the before mentioned characteristics of the joints, the wedges formed along the slopes are common and almost always oversized.

Beside the tectonics, the rock mass condition was affected by unadvised excavation procedure. The lack of any pre-splitting technique during the cutting of the artificial slopes (figure 5c), led to the intensive cracking of their rock mass. The abundance of the overhanging blocks, the height of the slopes (reaching up to 40 m) and the installation of the road on the base of the slopes without keeping any safety distance, cause serious safety issues.

All these problems are even more intensive along section C. Several meters of the walkway are constructed not only attached at the base of the slope, but along overhanging parts. Even a small tunnel was constructed in order to cross a ledge of the rocky slope (fig. 5).

The slopes along the rest of the walkway (except parts A, B and C) manifest the same tectonic fragmentation but they are not disturbed by any excavation procedure. Further more the available space along the base of these slopes, as well as the tree cover, allow the installation of all necessary protection measures without causing any aesthetic destruction to the site (fig. 6).

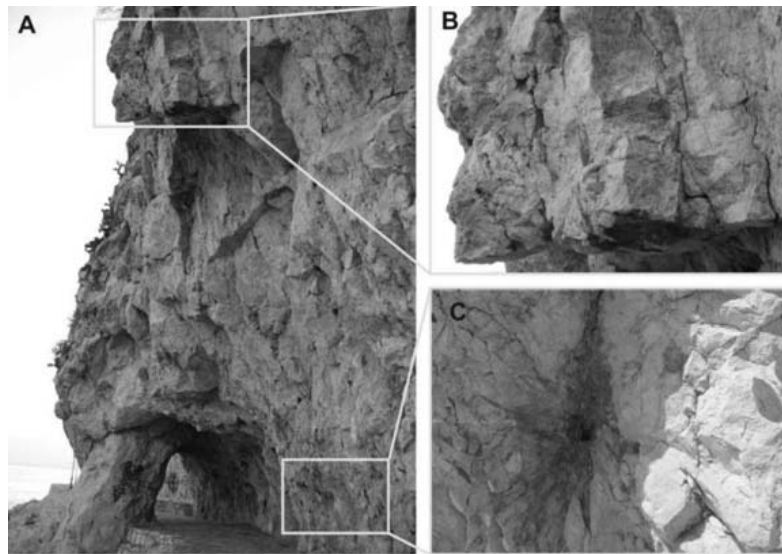


Fig 5.: A) A small tunnel constructed along section C. B) Wedges hanged over the entrance of the tunnel. C) the intense artificial fracturing around a drill used for the installation of explosives.



Fig 6.: Photos taken from the slopes extending between section A and B. The available space allows the installation of camouflaged protection measures.

4. Proposed support and protection measures

For the selection of the proper support measures of sections A, B and C, besides the stability analyses, rockfall propagation analyses were conducted (Fig. 7A), using the *RocFall* statistical analysis program. These analyses revealed that the spreading of the falling rocks covers the entire road width.

Unfortunately, the above mentioned stability problems require the application of remedial measures causing disturbance to the natural sightseeing character of the site. Indeed, the actions needed to be applied are: a) removal of all overhanging detached rock blocks, using controlled quarrying b) ap-

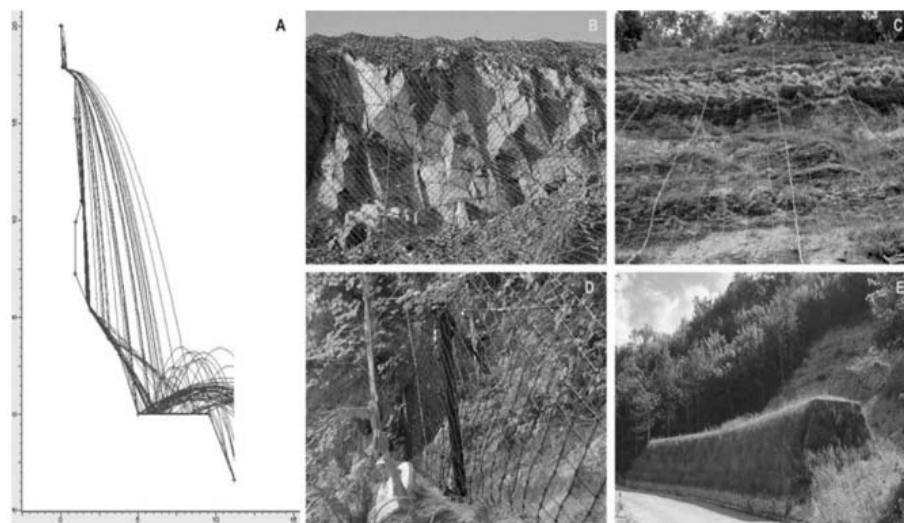


Fig 7.: A) Analysis for the estimation of the rock fall propagation in a typical cross section of the slope, B, C, D and E) typical support and protection measures. Wire nets (B and C), fences (D) and gabion boxes embankments (E).

plication of spot bolting in order to stabilize all the big rock wedges and c) installation of a high strength rockfall protection uniaxial netting along the entire slope (Fig. 7B, C).

Alternatively, as the net, causes a visible aesthetic demission, it could be substituted by the installation of a metallic frames shelter, covered on top with wavy sheet iron. Metallic frame constructions could be designed to take over the impact of a rock fall and at the same time their architectural design could make them fit the natural sightseeing setting.

The selection of the proper protection measures for the slope parts being at a distance longer than ten meters from the walkway can be easily confronted. The available modern protection fences systems (Fig. 7D) could be very effective without causing any aesthetic distraction to the sightseeing site. These fences could be installed along the base of the slopes within the limits of the declivity extending between the slope base and the walkway, and can be camouflaged by planting trees or bushes. Along the western part of the walkway, with the larger available base declivity space, gabion boxes embankments (Fig. 7E) can be installed instead of fences. The installation of these embankments is cheap and they require no maintenance expenses, unless they are damaged.

5. Rock slope stability problems in Kastoria lake sightseeing walkway

Unfortunately, the ignorance of the engineering geological characteristics and the underestimation of the stability problems led to the inappropriate land planning design of many other natural sightseeing areas all over Greece (Rozos & Nikolaou, 1996; Koukis et al. 1997; Koukis & Rozos, 1997; Koukis et al., 2005; Loupasakis & Karfakis, 2007). Figure 8 presents as an example, the sightseeing site of Kastoria lake walkway exhibiting similar geotechnical problems. The Kastoria lake walkway is a, 8,5 km long, narrow road surrounding the peninsula. The stability problems vary from section to section, but generally they are not so intensive as these reported in Arvanitia walkway. The slopes are sorter and gentler and the distance between the base of the slope and the road is sufficient

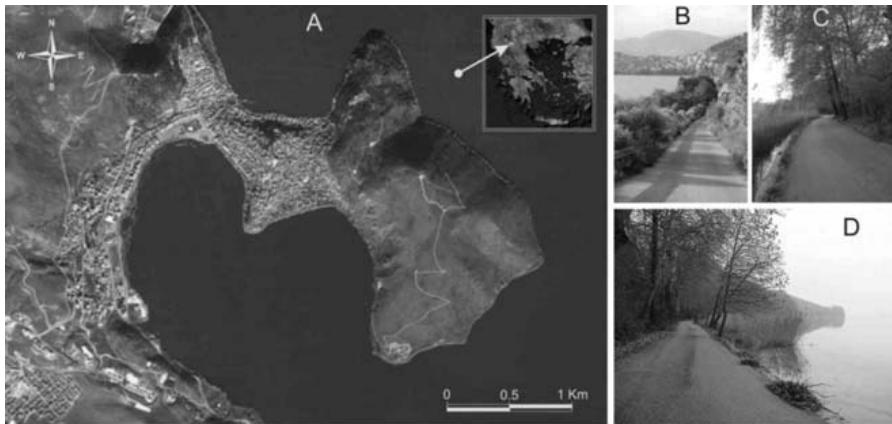


Fig 8.: A) Satellite pictures - taken from Google Earth - pointing the Kastoria peninsula surrounded by the, 8,5 km long, lake walkway, B, C and D) variant views of the walkway sections.

for the installation of proper protection measures, such as metallic fences, sort concrete walls or excavated trapping ditches (Fig. 8C & D). Limited sections with steep slopes (Fig. 8B) can be protected with wire nets, without causing serious aesthetic alteration to the site because of their reduced contribution to the total length of the road. Most of the before mentioned geotechnical problems could have been avoided if during the construction of the road the condition of the rockmass was taken under consideration. For example the road could have been constructed 1m higher in order to give space for a trapping ditch. Also, due to the shallow depth of the lake, limited section could have been constructed over the lake, avoiding the excavations.

6. Conclusions – discussion

The stability analysis of the slopes at Arvanitia practically prove that with the present conditions, the examined walkway can be considered as an extremely dangerous sight seeing location. The numerous rock blocks hanging all over the slopes can very easily harm the citizens using the road. A strong earthquake motion or even an intensive rainfall could become the triggering effect of a rockfall (WP/WLI, 1994). Moreover, the climber athletes using the slopes as a practise field could trigger a rockfall by unlocking a wedge with their own bodyweight. As it can be easily understood an incident like that could be fatal for their lives.

The proposed measures are unavoidable going to cause an aesthetic destruction to the site. The installation of netting along the entire slope faces of sections A, B and C is going to cover the natural wildness of the rockmass but also to abolish the numerous birds nesting along the slopes.

Although the morphology of the peninsula, especially along the south side, is steep, the stability problems could have been reduced or even avoided if the walkway was constructed closer to the sea over embankments without disturbing or approaching the slopes, leaving space for the installation of proper protection measures. Obviously, the walkway was designed without taking under consideration the stability problems of the slopes.

As a result, the engineering geological characteristics of the slopes should be taken into consideration when natural sightseeing areas are upgraded for public use. The proper engineering geological study helps land planning of sightseeing sites, to the direction of their correct development. Further

more, proper land planning of the facilities can reduce the hazards and, consequently, can reduce the cost of any slope support measures. It is imperative that the study of engineering geological conditions must precede the land planning and development of these sites .

7. Acknowledgments

This study was conducted in the frame of the Third Community Support Framework of IGME and was financed from the E.E.C. and from the Hellenic State.

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