Reduction of landslide risk by the use of mild explosives: the case of Rhodes city (Greece)

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Abstract

The historic hill of Monte Smith commands a splendid view of Rhodes city (Dodekanese – Greece) which attracts thousands of tourists every year. The road that connects the city with the airport passes along the northern hill slopes, which host extensive landslides and rockfalls because of an erodible formation, which provides gradually decreasing support for the overlying, competent one. Such phenomena are continuous and are quite exacerbated during strong earthquakes. Because of the character of the region, the touristic importance and generally the necessity for preservation of the physio - geographical image, many solutions – methods have been suggested in order to deal with the problem. The most advantageous one was the demolition of the unstable rock blocks using explosives. This method proved to be quite effective, as no landslides have occurred since its implementation.

1 Introduction

The city of Rhodes is situated at the NE part of the island and has been an economic, commercial and administrative center of the wider area for many centuries. The past decades tourism has developed astoundingly all over the island and consequently many parts of the island have flourished.

The airport, about 10 km SW of the city, handles more than 1.000.000 passengers every year. The road that connects the city of Rhodes with the airport passes alongside the western slopes of Monte Smith hill, which are quite steep (slope gradient > 100% at places) (Fig. 1).

A problem that has emerged the recent decades after the construction of the road is the continuous landslides and the rockfalls at the foot of the slope that endanger both pedestrians and passing-by vehicles. Such problems have been aroused during earthquakes damaging the road, passing-by vehicles, infrastructure and beauty spots.

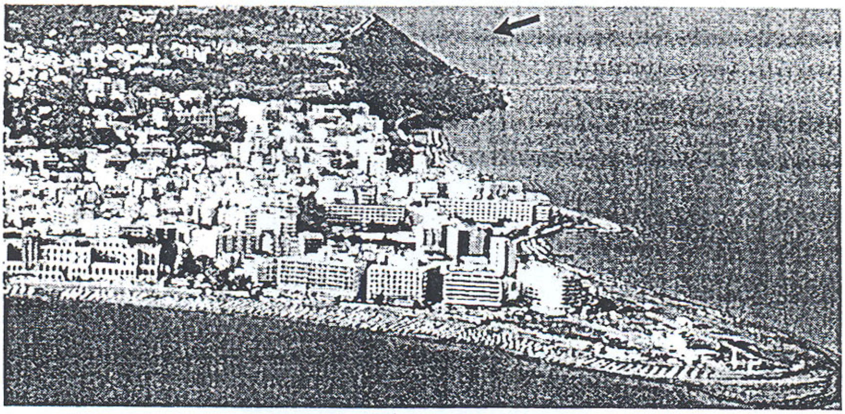

Figure 1: View of the town of Rhodes, the Monte Smith hill and the area accommodating the landslides (arrow).

Restoration interventions due to the existing morphology that had been now and again suggested, did by no means follow the preservation and safety codes, while they also detracted from the natural and historical features of the slope. So, a new method described below has been proposed, based on the demolition of rock-blocks using explosives.

2 Morphological conditions

The road that links the city of Rhodes, the town of Ealyssos and the airport passes along the western slopes of Monte Smith hill, which flanks the southward development of the city of Rhodes. The Monte Smith hill is truncated by a planation surface that has rotated eastwards along a N-S axis creating mild slopes of 20-30% dip. On the contrary, the uplifted block is characterized by steep morphological gradient and discontinuities that exceed 100% (SW slopes).

The aforementioned area lies on a fault block rotated eastwards along a N-S axis. Such observations have been recorded over the island of Rhodes [1], [2].

The rotated block is responsible for the steep slope of about 170 m length and 195 m height in Kritika area. The part of the slope prone to landslides is about 500×200. The area that needs stabilization –intervention lies at the lowermost part of the slope at an altitude of 40-50 m along the road that connects the city of Rhodes – Ealyssos – the airport for about 300 m. The rest of the road is not at stake since it passes alongside the foot of the slope (Fig. 2).

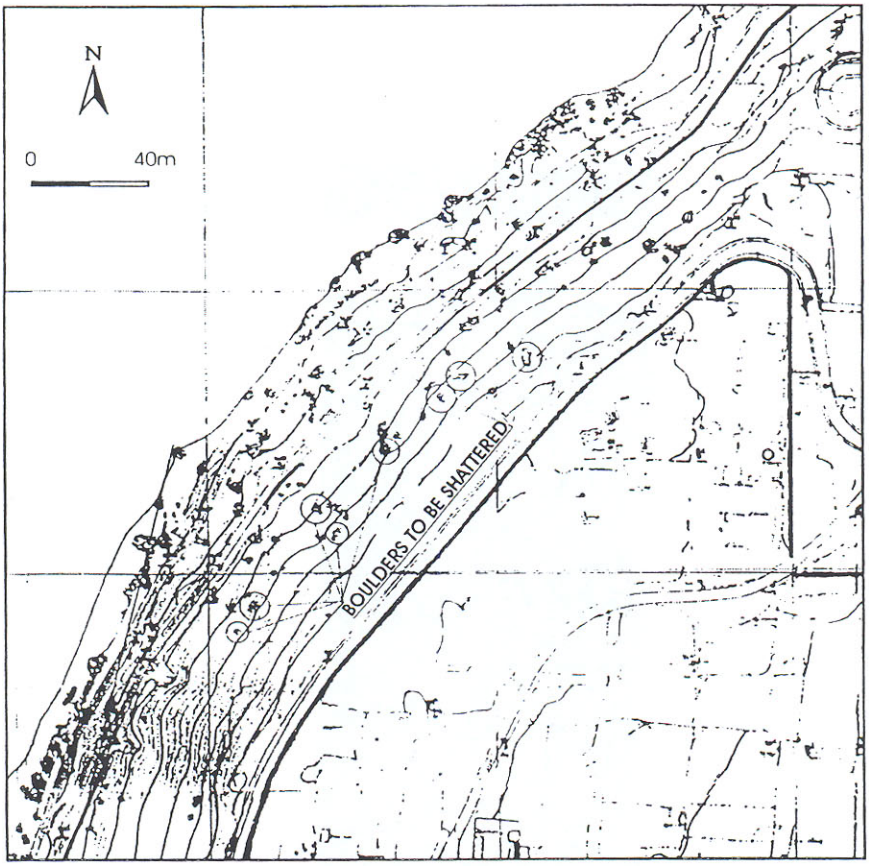

Figure 2: Map of risk removal of rock boulder slides at the slope of "Kato Petres".

3 Geological structure – geotechnical framework

Two geological formations outcrop at the slopes of Monte Smith that are prone to landslides as well as in the broader area, [1], [3]:

Asgourou Formation. It is the lowermost formation that occupies the steep western slopes of Monte Smith hill. It is a coastal or of shallow water formation with apparent thickness of more than 150 m. It consists of continuous vertical and horizontal alternations and wedges of sands, sandstones, gravels, clay and marl. Abundant ostracods are observed locally while large accumulations of shells are described. The formation is assigned to Pliocene - Lower Pleistocene [4]. It dips about 15° eastwards. It is semi-cohesive and particularly prone to incision especially where sand horizons dominate.

Rhodes Formation. It comprises Pleistocene [4] bioclastic limestones with sparse marly alternations deposited in deep waters, up to 20 m thick. It overlies

Asgourou formation uncomformably with an angle of about 10° and dips eastwards. It outcrops on the plateau of Monte Smith hill which corresponds to the planation surface that dips 20-30% eastwards. It is a very cohesive formation that is frequently offset by a fabric of vertical neotectonic faults or joints. Both tectonic and layer discontinuities are responsible for the rock fragmentation and the formation of blocks of varying dimensions (Fig. 3).

The above post-alpine geological formations lie uncomformably over the older post-alpine, molassic and alpine ones and occupy an expanded area of the island.

4 Description of landslides

There are a few references for historical landslides [2], [3], [5] that were triggered by seismic events. Recently, after the construction of the two-way road in two levels, landslides have occurred more frequently than ever (regardless of seismic vibrations) and have damaged the retaining walls, the road pavement, passing-by vehicles, while fortunately no human loss has been recorded.

The main reason for the landslides – rockfalls is the erodibility of the underlying formation of Asgourou so that the competent overlying limestone of Rhodes loses its support and stability (Fig. 4). The decreasing support of Rhodes formation is exacerbated by the construction of the roads at the foot of the slope. Furthermore, preventive measures such as the construction of retaining walls keeping rock boulders from rolling down not only did not reduce the risk but also accelerated the erosion of the slope.

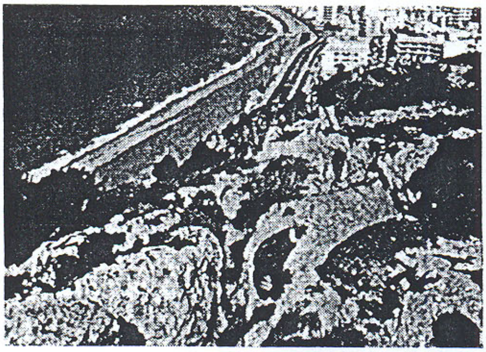

Figure 3: Rocky masses of the Rhodes formation at the top of Monte Smith hill.

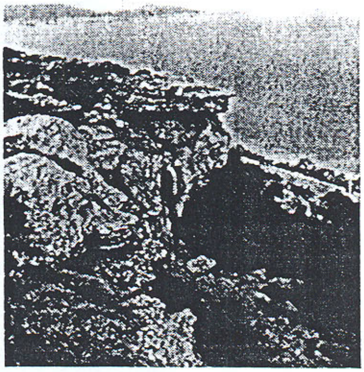

Figure 4: 'Hanging' rock boulders of Rhodes formation that overlies the erodible Asgourou one.

Virtually, there exist at least four sites where the Rhodes limestones have lost support from the underlying Asgourou formation at the upper place of the slope.

Moreover, at least 15 limestone blocks with size of few tens to hundreds of cubic meters have slided downwards on the slope and few have reached the coastline.

The past years and during the earthquake of 1987 massive blocks were cut off and moved downslope damaging the road while right after the seismic vibrations measures were taken, such as the construction of stone retaining walls at the base of boulders which were on the verge of sliding, as well as the planting of trees on an expanded area of the slope. During the 26th February 1998 earthquake with Ms=5.0 and epicentre close to the airport, extensive rock slides were observed, causing damage to the retaining walls and destroying the road pavements at three sites, while the car circulation was preventively interrupted (Fig. 5).

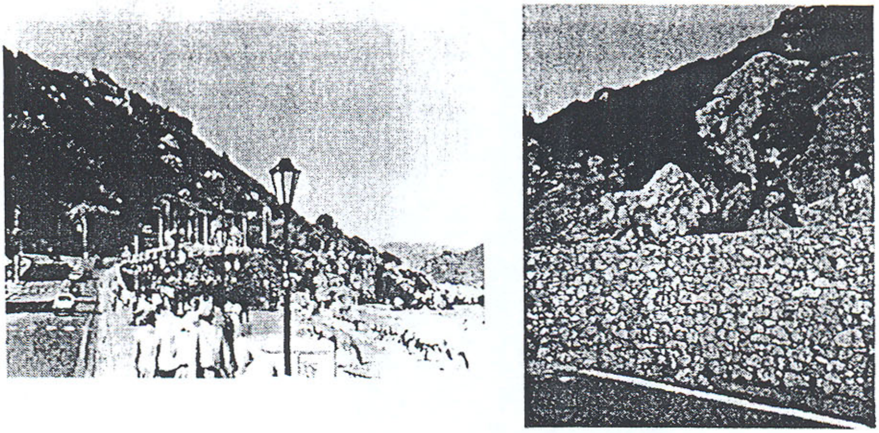

Figure 5: Rocky boulders at the top of Monte Smith that slided during the 26 February 1998 earthquake.

The slope, before the intervention, was alarmingly prone to landslides – rockfalls given the fact that at least ten boulders were hanging in unstable equilibrium, which compelled the authorities to take measures in order to remove the risk.

5 Selection – Description of method

Plenty of typical methods have been suggested during the recent past for the removal of landslide – rockfall risk. However, the extensive rockfalls and landslides during the February 1998 earthquake necessitated effective measures to be taken before the onset of the summertime touristic season.

The advantages and disadvantages of the methods proposed are described in Table 1, taking into consideration the following factors:

- The morphological conditions of the slope to be modified.
- The historical features.

- The physico-geographic features and the environment.
- The formations that outcrop the area and their geotechnical characteristics.
- The know-how and the available technical means.
- The economic demands of each method.

As it is illustrated on the table I, the method proposing the controlled shattering – demolition of the rock boulders is the most advantageous, so its implementation took place. What seemed important was the selection of blocks that were to be exploded before the drilling and emplacement of the explosives. Priority was given to the selection of risky boulders so that fewer slides would occur after the vibrations of the explosion-demolition (Fig. 6).

Figure 6: Demolition of the unstable rock boulders at the Monte Smith hill.

Measures were taken for the protection of the citizens from the demolition such as interruption of the car circulation. No shattered fragments fell onto the road pavement. On the contrary, they covered a part of the slope (downslope of the boulders) a fact that decreased the erosion of the lower formation which has already been mentioned to have been the main reason for the lack of support of the rocky mass (Fig. 7).

6 Conclusions

The method of controlled demolition-shattering of big rocky blocks that was implemented at the hill of Monte Smith is surprisingly more effective than other ones which are characterized by poor effectiveness, extravagant economic demands, alteration of environmental and historical features and so on. Due to the existing morphological conditions and their size, the boulders endangered the safety of the inhabited area and the road. So, it was an immediate need to remove

Table 1: Advantages-disadvantages of proposed methods for the risk removal.

IMPLEMENTATION OF METHOD	**ADVANTAGES**	**DISADVANTAGES**
Concrete retaining walls	• Classic approach • Satisfactory know-how	• Difficulty in accessibility and construction • Haphazard foundation • Possible foundation erosion • Environmental alteration • High cost
Stonework	• Classic approach • Satisfactory know-how	• Difficulty in accessibility and construction • Haphazard foundation • Possible foundation erosion • Environmental alteration • High cost
Anchorage - Nailing	• Classic approach • Satisfactory know-how	• Difficulty in accessibility, implementation and construction • Friable boulders • Absence of anchored layer • Risk of future fracturing • High cost • Dubious results
Mechanical induced fracturing	• Definite removal of risk • Conservation of environmental features	• Difficulty in accessibility • High cost • Risk of accidents
Tree plantation	• Reduction of erosion • Secondary supplement • Conservation of environmental features	• Partial measure
Meshes and retaining walls	• Classic approach • Satisfactory know-how	• Difficulty in accessibility and construction • Dubious results • High cost
Covers	• Feasibility of construction • Classic approach	• Environmental alteration • Aesthetic detraction • Extravagant cost • Slope aggravation
Shattering with explosives	• Definite removal of risk • Low cost • Conservation of environmental features • The deposition of fragments results in the degrading of erosion of the underlying formation.	• Risk of accidents

the risk. Priority was given to the selection of boulders to be shattered first based on the feasibility of triggered landslides – rockfalls by the explosion.

Figure 7: Coarse fragments as a result of the demolition-shattering of rocky boulders at the slope of Monte Smith hill. The coarse material contributes to the reduction of slope erosion, which is responsible for the manifestation of such phenomena.

After the drilling and emplacement of the explosives, the shattering of the hanging' boulders was accomplished successfully and the smaller fragments covered the area downslope. This fact contributed to the reduction and control of the erosion of the underlying formation, which was responsible for the gradual loss of support of the rocky mass.

It is worth mentioning that the manifestation of such phenomena has been drastically reduced within the last two years since the engineering intervention, and almost no rockfalls of even small fragments have been recorded.

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Risk Analysis III

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