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Protection of the Castle of Zakinthos, W. Greece, from landslide destruction phenomena

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ABSTRACT: The Castle of Zakinthos, which is located to the west of the same name town (Ionian islands, Western Greece), faced problems ought to landslide processes, which occurred as a result of a combination of geomorphological, geological, geotechnical and seismological parameters. In the framework of a recent effort for an overall protection-promotion of the monuments there were carried out extensive research projects, which aimed to investigate-analyse the factors which generated such destruction. Alongside the ancient walls of the Castle there were distinguished 11 different sites where the conditions significantly differentiate in each of them, and form a network with particular problems in each part. The proposed solutions for each part were based on the elimination of the parameters, where that was feasible, which were responsible for the observed damages.

RÉSUMÉ: Le château de Zakinthos, qui se trouve à l' ouest de la cité qui porte le même nom (Iles Ioniennes, Grèce), a subi des catastrophes à cause des glissements de terre, qui etaient le résultat d' une combinaison de paramètres géomorphologiques, géologiques et géotechniques. Dans le cadre d' un éffort récent pour la protection et la promotion des monuments, on a réalisé une récherche detaillée pour l' invistigation et l' analyse des raisons qui provoquent ces catastrophes. Au long de la muraille ancienne du châtau 11 sites différentes ont été considerées, où les conditions sont differentes à chaqu' une entre eux et forment un réseau des problemes particuleurs. Les solutions individuelles proposées sont basées sur la, l' élimination des paramètres, qui sont résponsables pour les catastrophes observées, où c' était possible.

1 INTRODUCTION

The Castle of Zakinthos (Fig. 1) is situated on the top of the morphological elevation which is to the west of the same name town (Zakinthos, Ionian islands, Western Greece). It consists one of the most remarkable historical monuments in the area. The ancient walls of the Castle have suffered in the course of history, apart from wartime damages, also natural destruction. Particularly due to its location at the edge of the hill it faced a series of problems that resulted from geotechnical reasons related to the founding formations, which were especially serious during seismic events. In the framework of a general investigation that aimed at the overall protection-promotion of the Castle it will be shown in brief a complete range of parameters which created the observed problems, as well as the recommended protection measures.

2 GEOMORPHOLOGICAL, GEOLOGICAL, GEOTECHNICAL AND HYDROGEOLOGICAL CONDITIONS

The studied area consists of a morphological elevation (196m), west of the town of Zakinthos. A plain develops at the apical part of the elevation, having a surface area of 0.1 km^2, and dips $5\text{-}15^0$ to the north. On this plain there were founded the ancient walls of the Castle as well as the inner archaeological buildings. On the contrary, steep slopes surrounds the horizontal plain down to the sea level, with dips often above to 100%.

In the hill of the Castle (Fig. 2) the following geological formations outcrop (Kowalczyk et al. 1977, Mariolakos et al. 1989, Lekkas 1993, Lekkas 1996):

- Kastro formation. Consists of clay-marl beds of grey and blue colour with sandstone intercalations. The thickness of this formation is above 200m. The

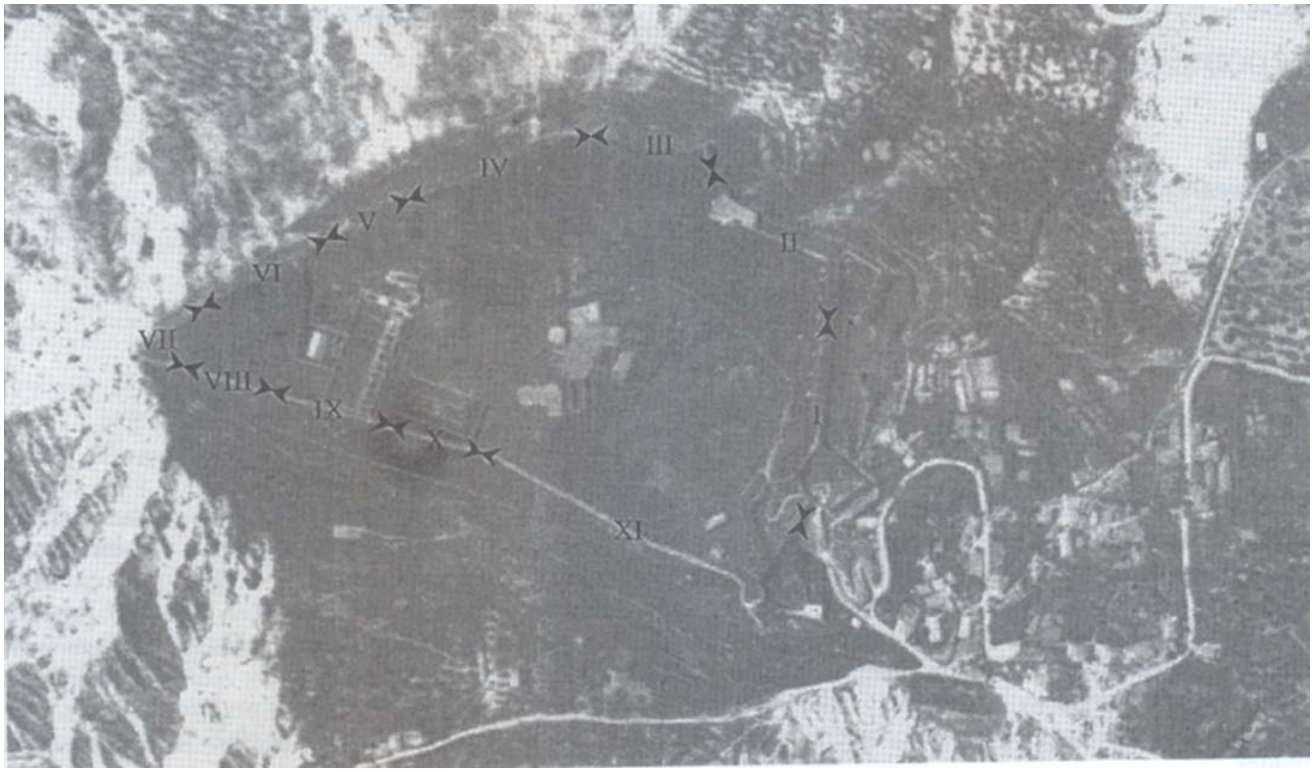

Figure 1. Aerial view of Zakinthos Castle with the distinguished parts.

age is Middle - Upper Pliocene. It occurs at the steep slopes of the Castle. The average percentage in clay material is 21%, silt is 73%, and sand is 6%. It shows the following physical and mechanical properties: bulk density γ_b: 1.70-2.22 gr/cm^3, LL: 26-45%, PL: 14-27%, n: 18-50%, Specific gravity Gs: 2.7-2.8, Unconfined compressive strength q_u: 1.70-24.50 kg/cm^3, c: 0.20-2.00 kg/cm^2, φ: 18-46^o, Permeability k: 10^{-5}-10^{-6} m/sec. It shows low to very low resistance in weathering, with a weathering rate in the range of Id_2: 10-35%. Consequent loosening of cohesion of the rock accelerated immediately after rock exposure under the climatic changes.

- Gerakas formation. Consists of rocky calcitic sandstones, sandstones with small dips 10-15^0 to the north and some marl intercalation at the base of the formation. Its thickness is up to 20m. It's age is Pleistocene and overlays the previous formation (Kastro formation). It has the following physical and mechanical properties: Bulk density γ_b: 2.2-3.2, gr/cm^3, q_u: 40-200 kg/cm^3, c: 5-30 kg/cm^2, φ: 50-70^o, Permeability k: 10^{-3} m/sec.
- Artificial fill - Regolith**.** They occur in some places, mainly inside the ancient walls and have a maximum thickness of 4m.

In the Kastro formation, which outcrop at the steep slopes, there were observed intensive weathering phenomena. These are observed mainly at the southern foot of the hill. The top formation on which the archaeological site is based is the Gerakas formation. Basically it consists of calcitic sandstones. It is a rocky formation, resistant in weathering, which overlays the marl deposits. Due to weathering of the lower formation it was generated gradual loss of founding of the upper formation and collapse of the peripheral parts of the hill, especially the edge of the top plane towards the sheer slopes.

At the same time the water penetrates downwards in the area where the calcitic sandstones occur, while further move towards the underlying marl deposits in not possible due to their low permeability. Therefore, the contact between the two formations acts as a base for the aquifer.

The way of circulation of the ground water is one more factor of deterioration of the geotechnical characteristics of Kastro formation and also accelerates the process of weathering.

Finally, the ancient walls of the Castle of Zakynthos in many cases have suffered severe damages ought to the impact of climate, the earth-quakes, intervention on the slopes, etc. As far as the earthquakes are concerned, it is found out that their influence is the determinant factor.More specifically it was found out (Lekkas et al., in press) that during the earthquakes of 1513, 1592 and 1840 there were recorded damages in the ancient walls which were caused also from the landslide of the steep slopes of the elevation, due to the seismic movements.

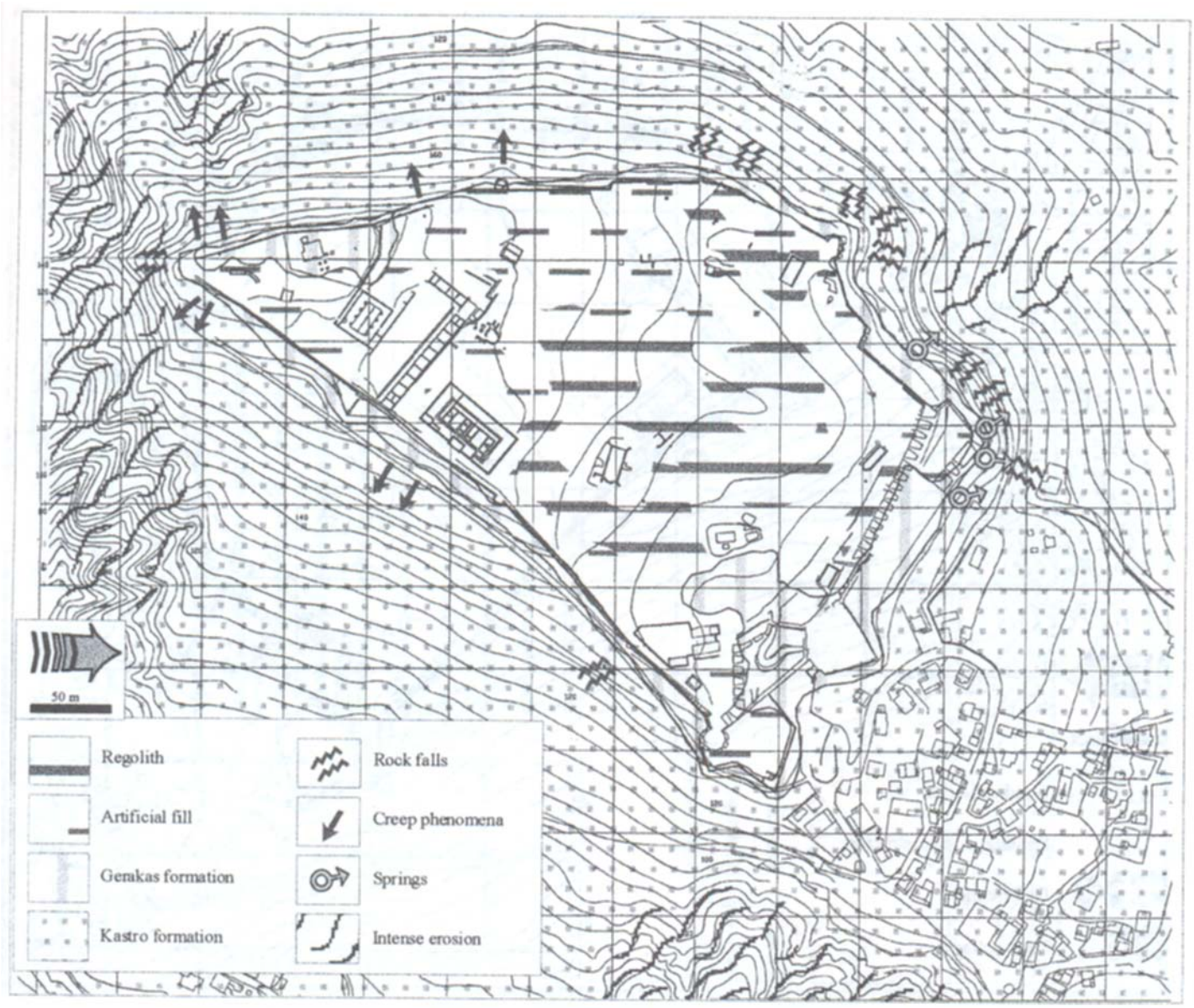

Figure 2. Geological – Geotechnical map of the area of the Castle of Zakinthos.

3 PROBLEM ANALYSIS- SOLUTIONS

Alongside the ancient walls of the Castle there were distinguished 11 different sites (Fig. 1) where each one has particular characteristics, like for instance the extent and type of damage, the geotechnical, geological, hydrogeological and geomorphological conditions. In detail:

Part I: This part is preserved in a very good state without any special problem generated by geotechnical factors (Figs. 1, 2). This is partly because of the good quality of construction but especially of the fact that the monument is founded on calcitic sandstones. The overlying marls form a relatively smooth slope which results in conditions of stability. For maintaining the good condition of the ancient walls there are suggested some works for arranging the rain waters (Fig. 3, 4).

Part II: This part is built on calcitic sandstones which overlay light colour marls (Fig. 1, 2). Within the calcitic sandstones the aquifer is developed, which is discharged to the north. The mean dips of the slopes outside the ancient walls are high, with values exceeding 100%. There are also noticed morphological discontinuities of 3-5 m high, in a short distance from the ancient walls (5-20m) mainly along the contact of calcitic sandstones with the marls. Thick to intermediate vegetation cover the slopes outside the ancient walls.

The downslope side shows remarkable geotechnical problems, which were generated from (i) the easily weathered underlying marls, mainly along the plane of the artificial section, (ii) the slake durability of the

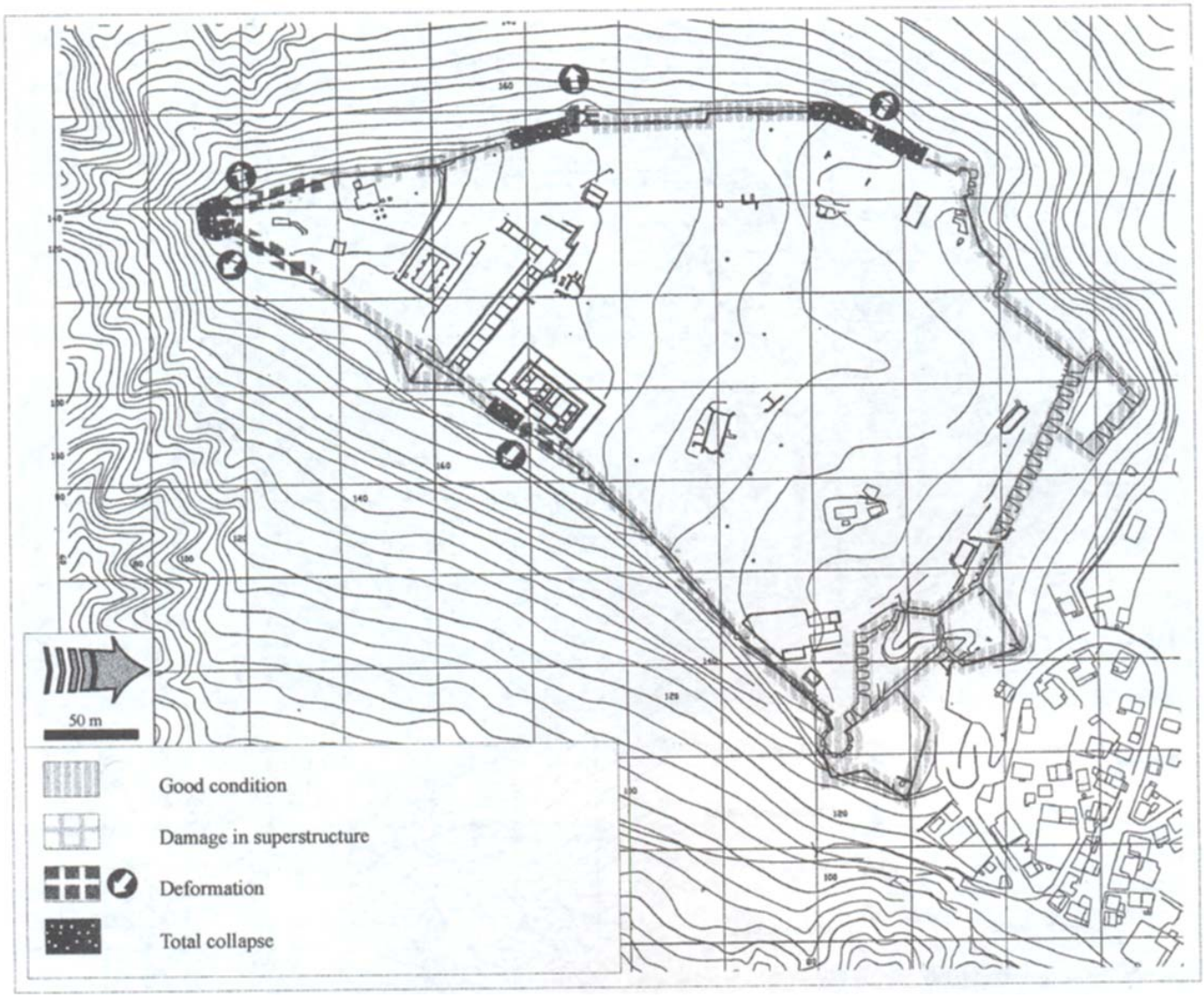

Figure 3. Condition of ancient walls – Problems at the Castle of Zakinthos.

rock mass of the overlying formation which hosts the aquifer and is cut by a dense network of discontinuities. The combination of the above factors creates the instability conditions of the sandstone rock mass which gradually extends towards the inner part of the rock or upwards the slope (Fig. 3).

To eliminate the degradation processes which act on the slope, the following measures are suggested: (I) forbid any intervention on the slopes of the road, (ii) works to arrange the superficial waters, (iii) renewal of the forest at the downslope side of the ancient walls, and (iv) earth retaining structures for the rock mass (Fig. 4).

Part III: The state of the ancient walls is characterised by discontinuous repetition of parts with big and small damages (Fig. 3). This is partly due to the quality of construction of the monument, and also to the geological-geotechnical problems. Especially the downslope side of the slope, which has morphological dips over 70%, consists of marls at the bottom and calcitic marls at the top. The gradual weathering of the lower formation of marls causes elimination of support at the marginal parts of the sandstones of the upper formation. As a result, sporadic rock falls occur, with rock size up to $2m^3$. Furthermore intermediate to thick vegetation covers the whole surface of the slope.

To work out a solution for the observed problems in this location, it is considered necessary to do some works aiming to suspend weathering of the marls. Suspension of weathering can be attained with the renewal of the forest (Fig. 4).

Part IV: The state of the ancient walls is very good without special problems (Fig. 3). For long term protection of this part they are suggested: (i) blockage of the ancient wall openings used for water discharge, (ii) works for forest rejuvenation and (iii) avoid any intervention in the downslope side of the slope (Fig. 4).

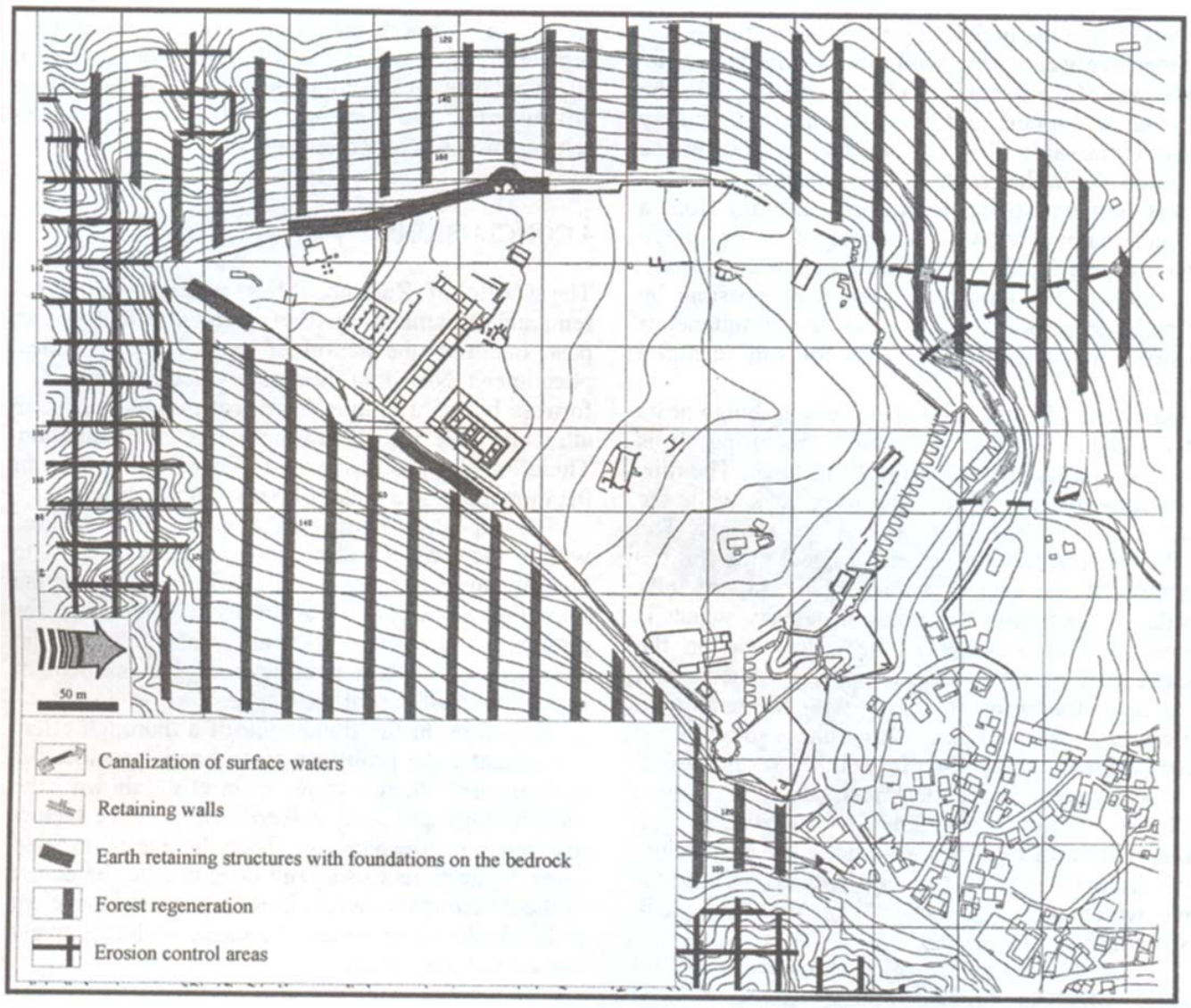

Figure 4. Schematical representation of protection solutions of ancient walls in the Castle of Zakinthos.

Part V: It is built on calcitic sandstones and marls. The morphological dips of the slope of the outer part exceed 80%. The downslope side is covered by thick vegetation of plants which often show bending due to creeping phenomena. This part of the ancient walls has suffered relatively big damages which were created partly due to the nature of the founding constructions, as well as to the high morphological dips (Fig. 2, 3).

To encounter these problems and especially to protect the parts of the ancient walls that have been preserved, the following are suggested: (i) avoidance of extra loading in the inner part of the ancient walls, (ii) works for renewal of the forest (Fig. 4). Further measures for intervention would be of low effectiveness and high cost. These works could be carried out in the framework of a possible rebuilt of parts of the ancient walls, mainly on the direction of: (i) deep founding on the fresh basement rocks, (ii) suspending weathering processes by doing small scale forestry works.

Part VI: This part has suffered small damages which are located basically at the top structural levels. To maintain its good state the following suggestions are proposed: (i) avoidance of loading in the inner part of the ancient walls, (ii) gentle interventions in the forest which is situated in the downslope area, by deforesting the old age or destroyed plants and gradually planting new ones with deep-rooting system (Fig. 4).

Part VII: This part is located at the southernmost edge of the Castle and has an overall length of about 70m (Fig. 1). Essentially it is the southernmost corner of the ancient walls which ended in a round rampart. This part was destroyed from landslide due to the earthquakes. About half of the length of the ancient walls has been destroyed, while the remained part is at a marginal stability due to landslide phenomena (Fig. 3).It is noteworthy that in

this particular area the underlying marls are characterised by intensive weathering while the overlying calcitic sandstones show instability phenomena ought to the removal of support. Additionally, the morphology shows remarkable dips, and weathering phenomena are extensive in the southern slope. Any intervention in this part would be particularly difficult from a technical point of view and certainly it requires large outlay, especially due to these particular conditions. Protection in the long term, would be possible by planting deep-rooting trees and by simultaneous construction of specific systems for soil retention (Fig. 4).

Part VIII: This part shows a growing bulge at its outer side, as well as successive fracturing. It is founded on a regolith which is 1.5m thick. The dips in the area are high with values over 50%, while the slopes are covered with sparse vegetation. The combination of the high morphological dips and the founding of the ancient walls on the superficially weathered formation generates instability which is expressed with a bulge at the outer side on the ancient wall as result of creeping movements and subsequent fracturing in places with the maximum deformation (Fig. 3). To work out a solution for these problems, the following actions are proposed: (I) works to rejuvenate the forest, (ii) avoid to load with extra material the inner part of the ancient walls, (iii) earth retaining structures for the ancient walls from the downslope side with a low ancient wall, which will be founded on the fresh rock basement (Fig. 4).

Part IX: The area as a whole, is characterized by stability which is shown by the good condition of this part of the ancient walls (Fig. 3). For maximum protection of the monument in the short as well as the long term, the following are suggested: (I) embellishment of the entrance rampart area, (ii) works for renewal of the forest (Fig. 4).

Part X: It is based on weathered calcitic sandstones, of 1-2m thick which are subject to creeping movements. The morphological dips shown in this area are high, with values over 70% (Fig. 2). The downslope side is covered with intermediate density vegetation. The trees show typical bending, due to creeping of the soil (Fig. 3). To cope with the problems, at least for the preserved part of the ancient wall, the following are proposed: (i) earth retaining structures for the ancient wall from the downslope side with a low ancient wall which will be founded on the unweathered basement rock, (ii) reforming the forest in this area by cutting and removing the destroyed plants and plant new ones with deep rooting system (Fig. 4).

Part XI: The good geotechnical behaviour of the geological formations contributes, at a large extent, in the preservation of this particular part of the Castle in a good condition. For the long term protection of this part the following are suggested: (i) avoidance of opening new roads on the slope downwards the ancient walls, (ii) careful rejuvenation of the forest (Fig. 4).

4 CONCLUSIONS

The Castle of Zakinthos has repeatedly suffered remarkable damages in the recent and and further past, ought to the action of natural geodynamical phenomena. Now that the Castle does not serve as a fortress but as a unique historical monument, is an attraction pole for cultural activities and recreation. Therefore the protection and general promotion of the monument is a mater of particular significance.

The repeated damages the Castle has suffered within the last decades were ought not only to natural causes but also to human intervention on the founding slope or to unsuccessful measures for protection without previous analysis of the significance of each parameter of the problem at each individual part of the Castle.

Therefore, in the framework of a thorough effort to encounter the problems-protect and -promote the monuments, there were briefly shown the methodology and analysis-verification of the factors that generated the damages. Then there are presented some suggestions to suspend or eliminate the action of the determinant factors in each part of the ancient wall, which can be achieved because of the relatively low cost of the project.

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