Restoration projects and remedial works in the historical island of Ventotene

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ABSTRACT: Ventotene is a very small island in the Mediterranean sea and yet a very remarkable natural and historic site. In fact the peculiar volcanic nature of the island and the ruins of the Roman Empire are joined together as a single and unique jewel, which attracts enthusiastic visitors from all over the world. However, the island is subjected to the continuous dismantling action of the natural agents, which cause an accelerated sequence of erosive phenomena and landslides. This peculiar process, which is progressively reducing the dimension of the island, is undermining the stability of monuments and ruins and has recently determined several collapses including some casualties. The paper examines the case of Ventotene by considering several interconnected topics: the geological nature of the island, the characteristics of its monuments and ruins, the geotechnical properties of the volcanic deposits, the erosive process, the typical landslides mechanisms. Particular attention is given to the search for equilibrated criteria and methods for the reduction of natural hazard, as well as for the protection of the monuments and landscape. The restoration project of the ancient Roman harbour is finally presented in some detail.

1 INTRODUCTION

Ventotene is a small island rising in the Mediterranean sea, at the distance of approximately 50 km from the Italian peninsula, with a resident population of only about 600 inhabitants. The island is of volcanic origin and the present landscape is the result of the changes occurred over time, resulting from the action of the exogenous natural factors (sea waves, wind, rain) combined with the human activity which dates back to the first century b.C.

Nowadays the surface of the island is 1.24 km^2 and its maximum dimensions are: length 2.7 km, width 0.85 km, height = 135 m above sea level. The land of the island is relatively flat but its borders are made of very steep cliffs with the exception of the north-eastern corner, which has provided the access to the island throughout its history (Fig. 1).

During the Roman Empire, Ventotene was elected to be the residence of the exiled members of the Emperor's family, such as Augustus' daughter Julia who gave the name to the beautiful Roman Palace , whose ruins stand on the north-eastern cape of the island. The Romans constructed a wide system of cisterns and aqueducts all over the island, in order to collect rainwater and bring it to the royal palace. They also built a remarkable harbour by excavating approximately 60,000 m^3 of tuff, down to the depth of 3 m below the sea level. The harbour was equipped with a towing basin and a number of warehouses, dug into the tuff, which are still regularly used today for various commercial activities (little shops, storage facilities, etc.). This ancient Roman harbour is still regularly used nowadays for hosting yachting and fishing boats, even if a larger port was recently constructed to provide access for the large ferries connecting Ventotene to the mainland.

The Romans also excavated a large fishpond close to the port, in order to provide fresh fish to the Emperor's family. The fishpond, located south of the entrance to the harbour was also dug into the tuff. It is composed of several pools, hydraulically interconnected and communicating with the open sea to allow a continuous supply of water to the living fauna.

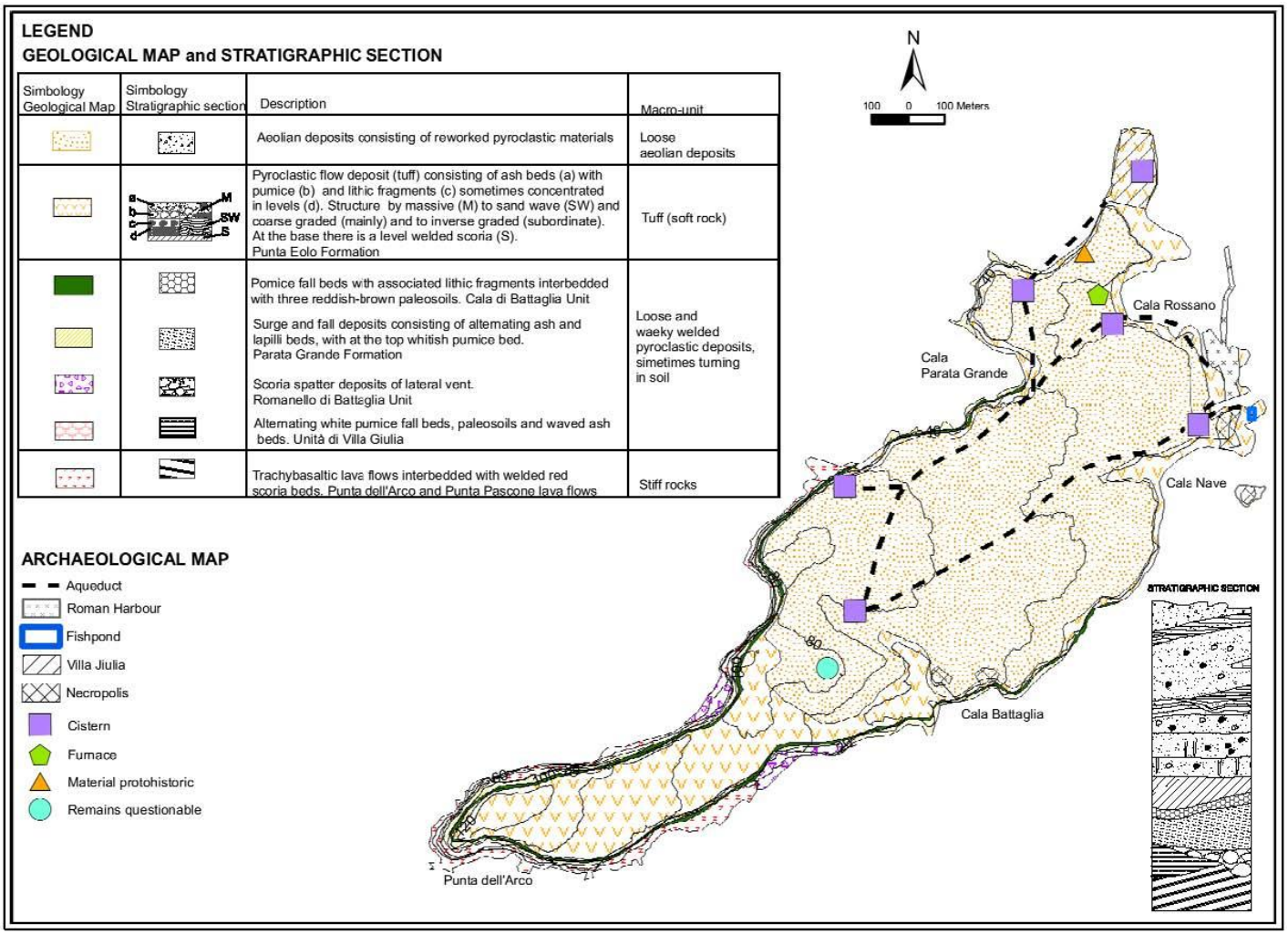

Figure 1. Geological and Archeological map of Ventotene (Bellucci et alii, 1999 mod).

After the end of the Roman Empire, Ventotene was abandoned and used only occasionally, mainly by monks, till the 18th century when the Bourbons, kings of Naples, decided to repopulate the island. The Bourbons constructed a series of buildings and roads incorporating the ancient Roman harbour, thus giving rise to the historical centre of Ventotene as it is today.

Nowadays Ventotene is a well-known touristic resort thanks to the natural beauty of the island and the transparency of the surrounding sea, combined with its unique historical and architectural features. However, the island is subjected to the continuous dismantling action of the natural agents, which cause an accelerated sequence of erosive phenomena and landslides along the coast. This peculiar process, which is progressively reducing the extension of the island, is undermining the stability of its monuments and ruins and has recently determined several collapses including some casualties.

In recent years, the writers have been engaged in the search for equilibrated criteria and methods for the reduction of the natural hazard induced by landslides as well as for the protection of the monuments and landscape. They have also contributed to the design and execution of some restoration projects. The most important project carried out so far regards the restoration of the Roman harbour.

The paper examines the case of Ventotene by considering several interconnected topics: the geological nature of the island, the location and characteristics of its monuments and ruins, the geotechnical properties of the volcanic deposits, the erosive process, the typical landslides mechanisms. Particular attention is then given to the search for equilibrated criteria and methods for the reduction of natural hazard as well as for the protection of the monuments and landscape. The restoration project of the ancient Roman harbour is finally presented in some detail.

2 EROSIVE PHENOMENA AND LANSLIDES

The island of Ventotene is the visible part of an ancient stratovolcano (or composit volcano) resulting from effusive and explosive eruptions that occurred during the Quaternary, from 0.8 to 0.33 My. (Perrotta et al., 1996).

From the morphological point of view the island is characterized by the presence of a plateau slightly

dipping towards NE, bordered by cliffs with height ranging between 130 m (southern sector) and 10 m (northern sector). The plateau surface is grooved by flat-bottomed valleys, originated along some of the main discontinuities of the underlying tuff.

The geological formations of the island can be grouped in four main lithological units (Fig. 1):

i. Loose Aeolian Deposits made by reworked pyroclastic materials.
ii. Tuff (soft rocks) composed by layers of various lithological characteristics (*Punta Eolo* Formation).
iii. Loose and weakly welded pyroclastic deposits, consisting in a complex sequence of pumice, scoria, ash, lithic and paleosoils (*Parata Grande* Formation, *Villa Giulia* Unit, *Romanello di Battaglia* Unit and *Cala Battaglia* Unit).
iv. Lava (stiff and very stiff rocks) made of trachybasaltic lava flows interbedded with welded red scoria layers (*Punta dell'Arco* and *Punta Pascone* lava flows);

Historical studies and direct observations have pointed out the widespread occurrence of landslides along the cliffs that border the entire island of Ventotene. Such landslides, which take place with remarkable frequency, are progressively reducing the extension of the island. In fact, observations and measurements carried out in the last century have pointed out that such landslides result mainly from the natural evolution of the cliffs bordering the island. This natural process is triggered by the following main exogenous factors:

- the sea waves action, resulting in the progressive excavation of the cliffs foot, leading to the collapse of the overhanging rocks and/or soils along weak sub-vertical planes;
- the wind abrasion which determines the selective erosion of the softer rocks and soils layers, resulting in the gradual formation of protruding sub-horizontal slabs of stiffer rocks, which may then collapse by flexural or block toppling;
- the infiltration of rain water, causing the progressive alteration and weakening of rocks and enlargement of genetic fractures;
- thermoclastism and haloclastism phenomena that accelerate the state of fracturing of the rocks.

The result of the previously mentioned phenomena, however, is more or less pronounced according to the local geological structure. In particular, the overall sequence of erosion and landslide is slower in the southern sector, where the tuff rests on top of the lava, and faster in the northern one, where the entire cliff is made of pyroclastic rocks and soils.

The aeolian deposits, resting on top of the tuff, are subjected to small earth slides (Varnes 1978; Cruden and Varnes 1996) occurring mainly along the coastal perimeter between Cala Battaglia and Punta Pascone through Cala Rossano (see Fig. 1). These earth landslides are favoured by the rain water which operates both by infiltration and scouring, producing grooves and funnels which may act as triggering points. The sliding surfaces are often located along the weaker contact surfaces between the primary pyroclastic deposits and the natural soil (Palma et alii, 2009).

The rock slides are diffused along the entire perimeter of the island, taking place mostly in the tuff formation with mechanisms of toppling and sliding (Varnes 1978, Cruden and Varnes 1996). These mechanisms are dictated by the sub-vertical weak planes related to cooling joints formed in the ignimbrite deposits after their emplacement. Such weak planes give rise to three principal families (k1, k2, k3) of discontinuities with dip direction of 35° (k1), 250° (k2) e 200° (k3) (Fig. 2). The single block volumes are in order of few cubic meters but the whole landslide volumes can become to hundreds of cubic meters (Fig.3).

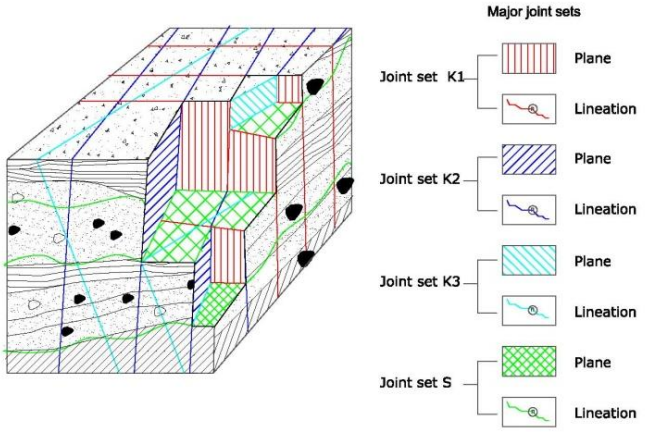

Figure 2. Schematic view of the discontinuities in the pyroclastic rocks.

3 REDUCTION OF NATURAL HAZARD AND PROTECTION OF MONUMENTS

The diffused erosion process and the frequent landslides which were previously described have recently been recognized as a dramatic threat for the entire island of Ventotene, including its monuments and archaeological remains.

Figure 3. Typical landslide of a tufaceous cliff (Parata Grande).

However, by comparing the wide extension of the natural hazards with the reasonable economical resources, it was first recognized that is not possible to stop the natural erosion process and to provide effective slope stabilization all over the island. It was then decided to identify the most valuable areas which can be effectively protected within economical availability. It was thus determined to concentrate the efforts in the north-eastern sector of the island, which is the most important from any point of view. In fact, as it was previously mentioned, this area provides the only access to the entire island, by means of two harbours, one close to the other: the ancient roman harbour and the new commercial port for the ferryboats. Moreover, the most valuable historical buildings and archaeological ruins are concentrated in this zone, as well as the most popular beaches. Four main projects were thus planned in this area as indicated in Fig. 4.
Several peculiar requirements were considered for each project, as briefly listed in the following:

i. People safety;
ii. Monuments integrity;
iii. Landscape conservation;
iv. Fauna and flora preservation;
v. Touristic industry protection,

In practice, it is necessary to satisfy the safety conditions according to the typical engineering rules and regulations but it is also required to avoid any destructive technique or possible changes to the pre-existing monuments and landscape.

Another peculiar constraint is given by the diffused occurrence of archaeological remains (pottery, fragments, etc.) which may be found in the top soil layers and that should not be removed or damaged by construction works.

Finally an important requirement to be considered is the need to work in narrow spaces which cannot be closed to the public, unless for very limited time.

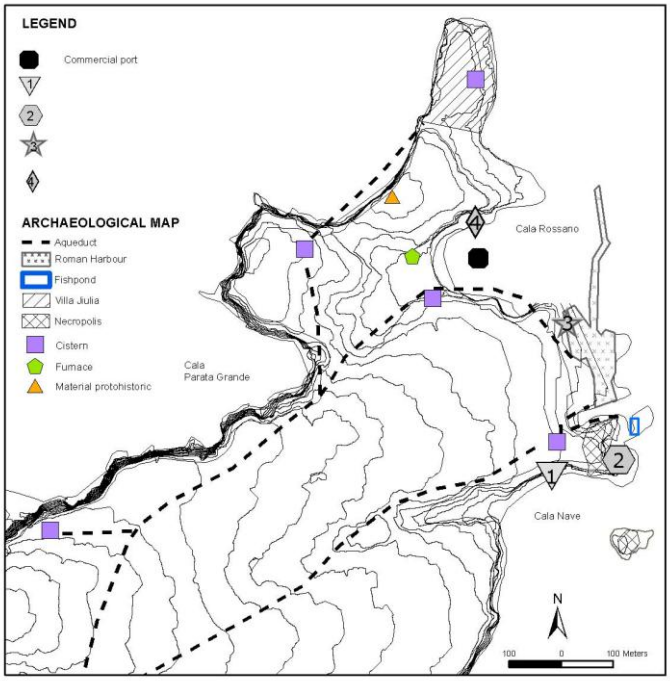

Figure 4. Slope stabilization and protection projects: 1) stabilization of the rock cliff above Cala Nave beach; 2) stabilization of the rock cliff under a Roman necropolis; 3) restoration of the ancient Roman Harbour; 4) stabilization and rock fall protection at Cala Rossano commercial harbour .

This restriction is imposed by the need to guarantee the fruition of the island not only by the inhabitants but also by the tourists which constitute the only economical resource of Ventotene.

4 RESTORATION PROJECT OF THE ANCIENT ROMAN HARBOUR

The most important project carried out so far is the restoration of the ancient Roman harbour, which is briefly described in the following. As it was previously mentioned, the ancient Roman harbour is one of the most characteristic historical evidence in the island of Ventotene, completely excavated in the tuff formation and equipped with a towing basin and a number of warehouses also dug into the tuff by the Romans (Fig. 5). These warehouses, which are still regularly used today for various commercial activities (little shops, storage facilities, etc.), consist in picturesque little caves whose entrances are aligned along the inner dock of the port which also allows the only vehicular and pedestrian access to the island.

From the morphological and geotechnical stand point, this area is characterized by the presence of a nearly vertical cliff, whose peculiar features are the result of a long and complex sequence of interacting natural and anthropic actions. In particular, the first 9 m, starting from the dock, are constituted by homogeneous tuff rock partly excavated by the Romans.

Figure 5. Global view of the Roman Harbour.

Figure 6. Tuff cliff, natural slabs and 18th century buildings before restoration works.

Figure 7. Masonry wall at the top of the cliff before restoration works.

The tuff surface has then been grooved by the wind erosive action over the centuries, giving rise to some characteristic natural rock slabs overhanging the dock with a span of about 2÷3 m (Fig. 6). The upper portion of the cliff is characterized by the presence of some old retaining walls, dating back to the Bourbons period (18th century), made of weakly cemented tuff masonry. The latter, which are up 6 m high, provide static support to some layers of pyroclastic soils and made land resting on top of the tuff (Fig. 7).

Finally, on top of the cliff there exist several masonry buildings constructed by the Bourbons, belonging to the old "*Granili*" barracks. These barracks were partly demolished during the works done in the last century, shortly before the second world war, leaving only the parade ground which is used today as a public terrace (Fig. 8).

The physical-mechanical properties of rocks and soils were estimated by in situ and laboratory investigations carried out on the port cliff and in the neighbouring areas.

The data were integrated by back analysis of previous instability phenomena which have occurred in the north-eastern area of the island, some hundred metres far from the Roman harbour. The overall results are collected in Table 1.

Table 1. Geotechnical properties of the Roman Harbour cliff.

	γ kN/m^3	σ_c MPa	c kPa	ϕ °
Pyroclastic soil	15	-----	2.5	30
Tuff	18	1.9	890	30

The restoration works were commissioned by the municipality of Ventotene, in order to ensure public safety with respect to possible falling materials resulting from two main potential causes:

i. flexural or block toppling of the natural tuff;
ii. failure of the old masonry walls.

Figure 8. Side view of the Roman and the commercial harbours from the "*Granili*" terrace, during the restoration works.

As it was previously explained, the overall design was developed not only to achieve appropriate safety factors, for both the natural tuff cliff and the pre-existing retaining walls, but also with the purpose of preserving the complex historical landscape. Therefore a detailed survey of the harbour area was preliminarily provided by means of three-dimensional laser scanning (Fig. 9) in order to document in an objective way the conditions of the premises prior to restoration, thus securing the faithful recovery of the historical complex.

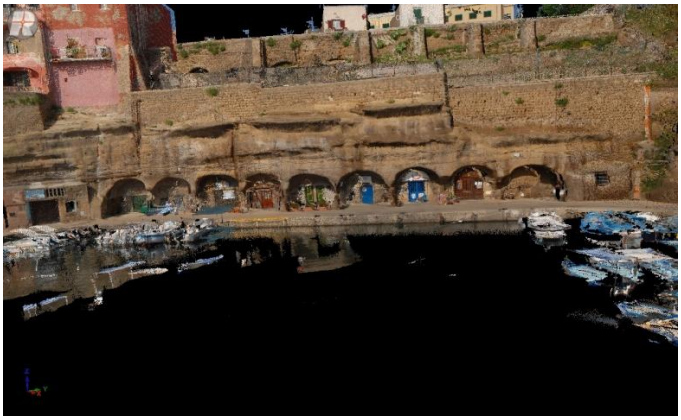

Figure 9. 3D laser scanner survey of dock, caves, cliff and masonry of the Roman harbour before the restoration works (courtesy of Idrogeo s.r.l.).

The project was carried out considering three principal requirements:

- preservation of the tuff surface, especially the rock shelves jutting up to 3 m that characterize the top section,
- representing a unique historical-landscape;
- restoration of the retaining walls of the embankment at the top of tuff formation;
- integration of the remedial works with the historical buildings built by the Bourbons above the Roman Harbour.

A special attention was paid to the yard organization, because the Roman harbour area can be considered as the *island door*, since the existing dock is the only way to access the island coming from the new commercial harbour, with a lot of tourists passing by in the spring and summer season

For this purpose a provisional steel structure was placed all over the dock to ensure full protection during the works (Fig. 10).

Moreover the project had to take account for two additional requirements:

- plan a simple and fast execution, and therefore likely to be completed before the peak touristic period of the summer season;
- provide minimally invasive works, or, alternatively, reversible ones, to avoid that remedial works could modify the historic and landscape value of the area.

Due to the morphology of the area it was necessary to operate with unusual techniques. In particular specialized climber workers, operating for the most part in rope were employed (Fig. 11), and small size manageable equipment was used (Fig. 12).

Inspections carried out on the cliff showed the good conditions of the tuff shelves and verified that there were no evidence of cracks or discontinuities. Therefore it was decided to avoid invasive remedial works and to perform a shallow cleaning of the shelves removing soil, vegetation and altered elements corresponding to the thinner breakable parts on the edges. Furthermore, in order to prevent the erosive action by the atmospheric agents, the tuff surface was treated by spray application of acrylic polymer in aqueous dispersion, able to increase the abrasion resistance without altering the wall natural aspect.

One of the most critical problem was due to the inadequate strength of the old masonry retaining walls at the top of the cliff. In fact it was recognized that it was not possible to provide effective structural strengthening to the existing walls.

Figure 10. View of the yard area and provisional steel structure over the dock.

Figure 11. Climber workers on the cliff.

Figure 12. Drilling rig for deep mixing at the top of the cliff.

However it was also considered that a new structure would have altered the architectural characteristics of the harbour. It was thus decided to improve the mechanical characteristics of the by soil at the back-side of the wall, in a zone with thickness ranging from 1.2 to 1.5 m. Such soil improvement was provided by deep mixing, which was carried on by using customized light equipment, achieving columns having 200 mm diameter (Papa and Ramondini, 2011 & 2012) . After the grout curing, the treated soil acquired compressive strengths comparable to those of a weak concrete

Following soil improvement, the old retaining tuff walls now act as a sort of coating, subjected only to its self weight and possible seismic actions. However, the walls were studded with 1.5 m long steel bars, designed to anchor the masonry in the grouted soil behind the wall. On the front face of the wall a special structural plastering, armed with FRP (Fyber Reinforced Polymer) grid was installed to ensure high protection and durability against the corrosive action of the aggressive sea environment. The work section is sketched in Fig. 13.

The final arrangement has revived the original plaster coating of the Burbon walls (Fig. 14).

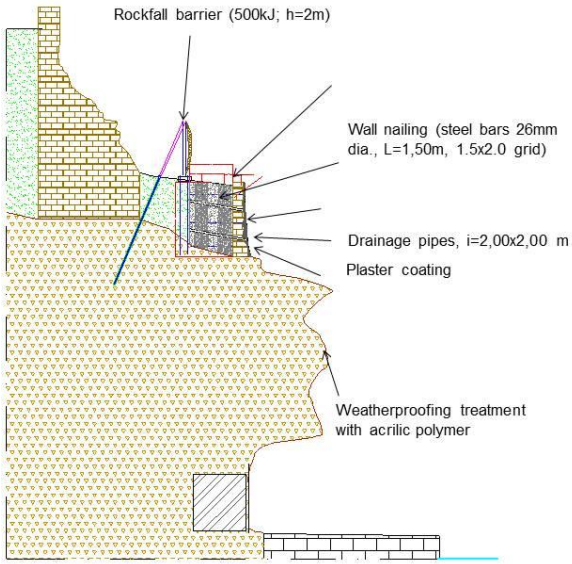

Figure 13. Schematic section of the restoration works (courtesy of Idrogeo s.r.l.).

5 CONCLUSIONS

The case of Ventotene has been described by considering several interconnected topics: the geological nature of the island, the main historical events, the characteristics of its monuments and ruins, the geotechnical properties of the volcanic deposits, the erosive process, the typical landslides mechanisms.

Figure 14. Roman harbour area after the restoration works.

Particular attention has been given to the search for equilibrated criteria and methods for the reduction of natural hazard as well as for the protection of the monuments and landscape.
By comparing the wide extension of the natural hazards with the reasonable economical resources, it was recognized that is not possible to stop the natural erosion process and to provide effective slope stabilization all over the island. It was then decided to identify the most valuable areas which could be effectively protected within economical availability. Four main projects were thus planned and designed.

It is underlined that several peculiar requirements should be met by each restoration project, in the island of Ventotene: people safety, monuments integrity, landscape conservation, fauna and flora preservation, touristic industry protection.

The restoration project of the ancient Roman harbour was then presented in some detail, providing a practical example of careful restoration works carried out by means of appropriate techniques chosen to meet the previously mentioned requirements.

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