THE STABILITY OF MONUMENTS OVER COASTAL CLIFFS IN THE BAY OF NAPOLI

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SUMMARY: the instability of coastal cliffs along the shoreline of the bay of Napoli and its islands often threatens the integrity of monuments existing at the top of the cliff. In most cases the cliff is made by Neapolitan yellow tuff, a soft volcanic rock, and the instability is triggered by the erosive action of sea waves.
The cases of Castel dell'Ovo and of three churches belonging to the ancient village of Terra Murata on the island of Procida are reported. Instrumental monitoring of some fissures shows in all cases cyclic displacements, essentially connected to thermal variations, without long term increase. The failure of the cliffs and of the overlying buildings occurs thus suddenly, without forewarnings.
The possible preventive and remedial measures are briefly discussed.

1. INTRODUCTION

Along the shoreline of the bay of Napoli and its islands there are a number of steep cliffs in volcanic materials (yellow or grey volcanic tuff, indurated pozzolana), subjected to the erosive action of the sea waves and other agents. As a consequence, different forms of slope instability occur, the most frequent being the fall of large blocks by sliding or toppling.
In many locations the top of the cliff is characterised by the presence of villages, or monuments such as castles, churches, villas, archaeological remains. Some of them are badly threatened by the evolution of the cliffs, and accordingly remedial measures have been adopted or are being designed. We can list, for instance: Castel dell'Ovo, on the ancient island of Megaris [1], [2]; the remains of the imperial villa of Pausylipon [3], [4]; the island of Nisida; the castle of Baia; the Terra Murata village on the island of Procida; the castle of Ischia.
The problem dates back to ancient times. In A.D. 202 Settimius Severus and Caracalla formally testify the construction of structures to protect the city from the sea: " ..*molem novam ad defensionem viae adluvione mares corrupta fecerunt."*

The present paper reports the examples of Castel dell'Ovo and of some churches on the southern shore of the island of Procida; in both cases the results of monitoring over some years are available.

2. CASTEL DELL'OVO

Castel dell’Ovo (fig. 1) is a massive fortress standing on the islet of Borgo Marinaro, the ancient Megaris. It dates back to the 1st century b.C., when the islet was occupied by Lucullo’s villa. In the 5th century A.D. some Basilian monks founded the monastery of San Salvatore and excavated a number of passages and cavities in the tuff cliff.

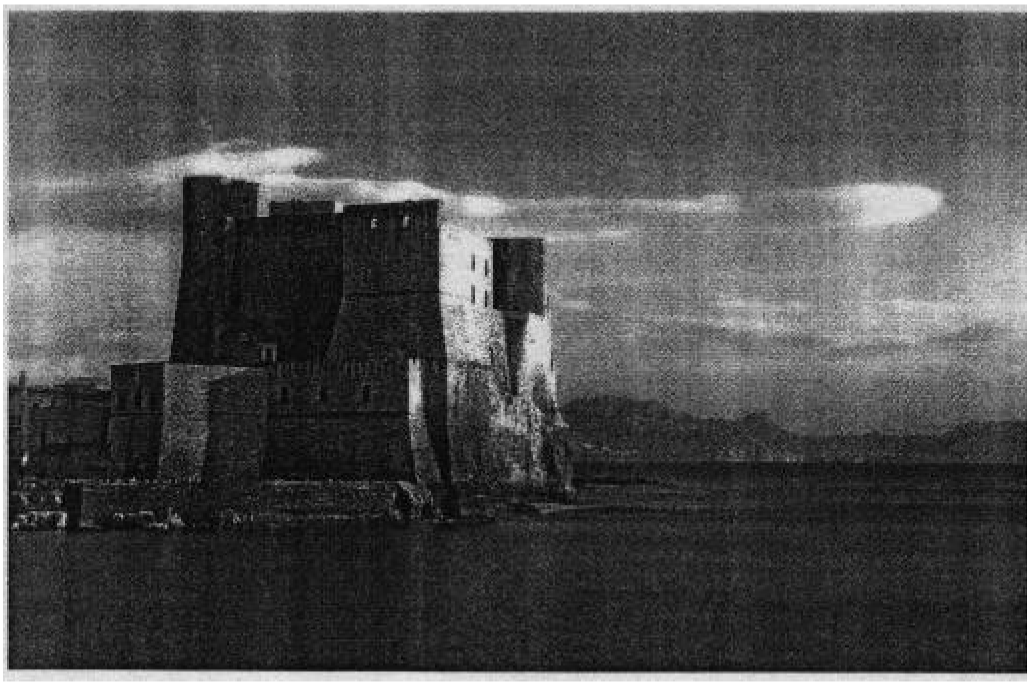

Figure 1: A picture of Castel dell’Ovo taken from the seashore

The construction of the fortress begun in 1128. In the following centuries Norman, Swabian and Spanish repeatedly modified and enlarged it. The name of the castle probably owes to its egg-shape in plan. However an evocative medieval legend connects this name to Virgilius - poet and wizard - who is believed to have bound the fate of the castle to a fragile egg hidden in the dungeons. The castle would collapse in the case the egg was broken.

The castle was indeed bombed and destroyed by Charles VIII. Restored in the late 17th century, it has reached the present time with minor further restorations and modifications.

Recently a system of thin fissures has been detected in the buildings at the top of the castle, and in the underlying cavities in the tuff cliff. A finite element analysis of the stress state in the masonry of the buildings and in the underlying soft rock [5] suggests the possibility that the load acting in the buildings (essentially archives), in conjunction with some weakening induced by the sea environment, could cause some overstressing of the vaults and the walls of the cavities. A monitoring program was thus established to detect any progress of the cracks.
In fig. 2 a plan view of the network of cavities (the so called "complesso Basiliano") is reported, together with the location of the instruments. Six displacement sensors (LVDT) and three temperature sensors (TEMP) were installed on some of the cracks.

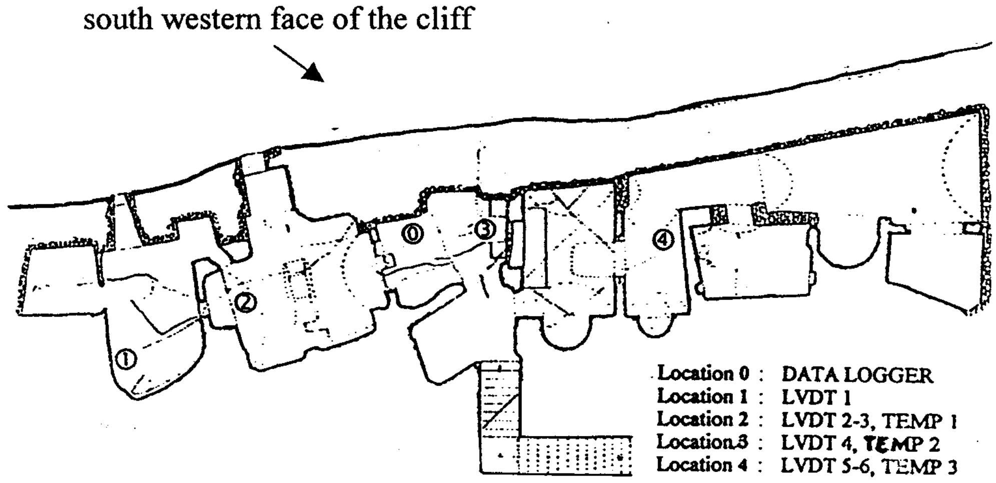

Figure 2: Plan view of *Complesso Basiliano* with the location of the instruments

The LVDTs (resolution: 0.005 m; range: ± 10 mm) were installed across the cracks. Close to some of the LVDTs temperature sensors with an operating range of 0-50 °C were also installed. An automatic data acquisition system was set up allowing 6 sets of readings to be taken and stored each day. The installation was completed in March 1996.
The results collected between March 1996 and March 1998, when the system was dismantled, will be presented and discussed.
The relative displacements between the two sides of the crack, normal to the crack itself, are plotted in Fig. 3. The negative sign indicates closing of the cracks.
As a general trend, the observed displacements are rather small, with a maximum value of approximately 0.4 mm (LVDT6).
All the sensors reveal small daily displacement cycles, following very closely the daily changes of the temperature. To provide a more detailed view on this aspect, the daily measurements over a typical week are plotted in Fig. 3. Also the seasonal cycles of displacement appear to be strictly connected to temperature fluctuations.

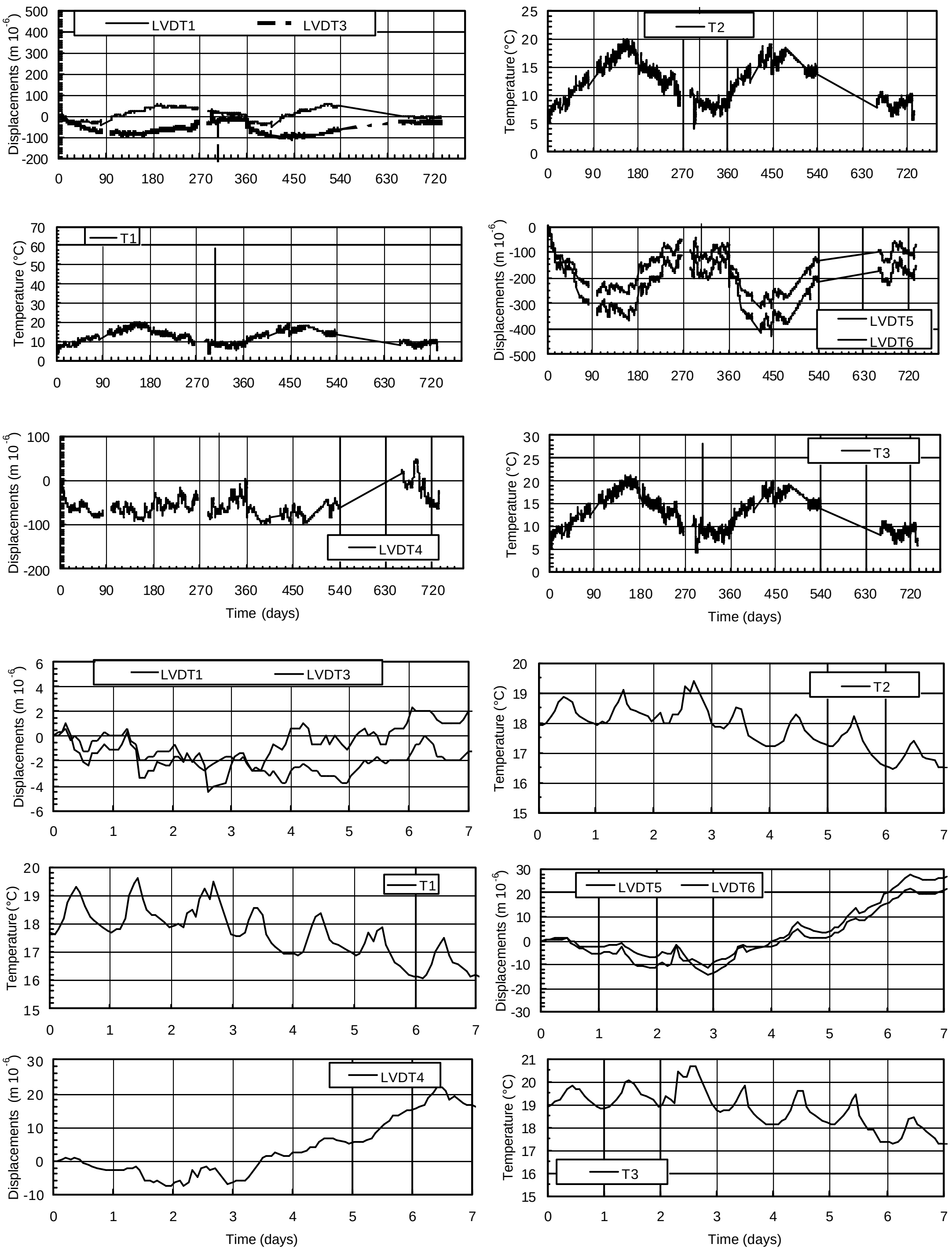

Figure 3: Displacements and temperature changes over 2 years and a typical week

As stated by Burland and Standing [6], two to five years are needed to get a comprehensive understanding of the evolution of building cracks and soil structure interaction problems. In the present case, there is no evidence of long term increase of the opening of the monitored cracks.

3. THREE CHURCHES ON THE SOUTHERN SHORE OF THE ISLAND OF PROCIDA

The village of Terra Murata (fig. 4) is located on the highest hill of the island of Procida, at an elevation of around 100 m above sea level. It developed in the middle ages around the Abbey of St. Michael Archangel, the main reference and aggregation centre of the island all over the Middle Ages.

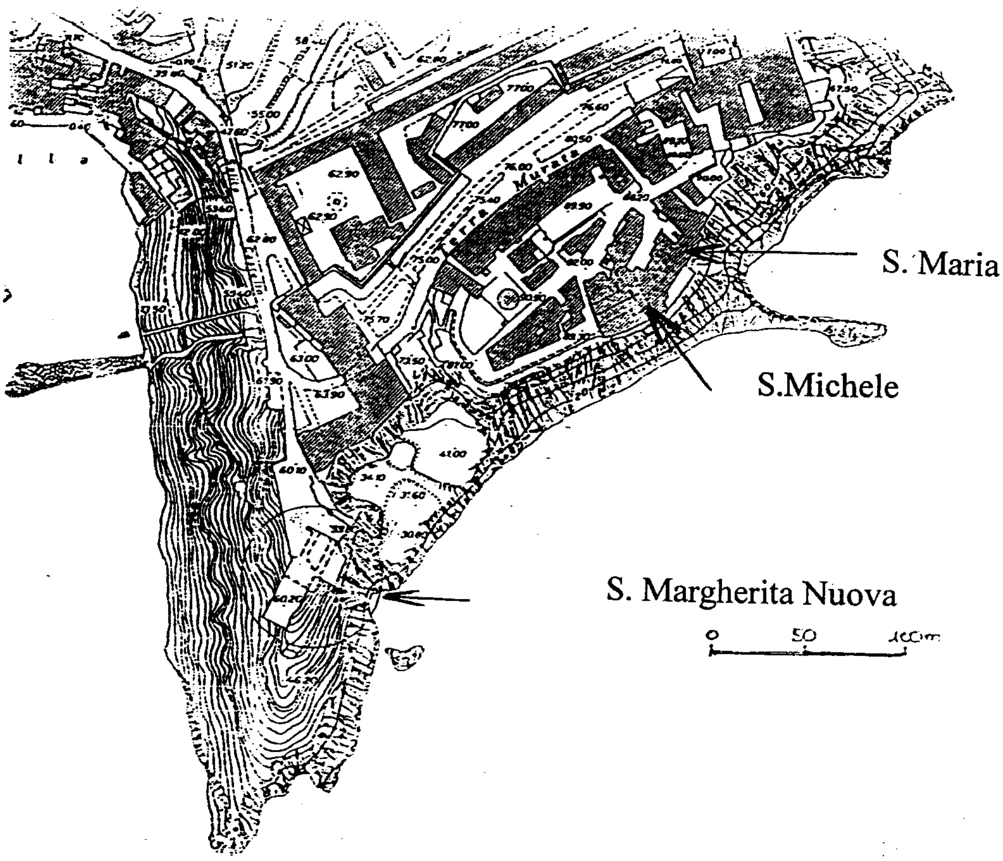

Figure 4: A map of the village of Terra Murata (Procida)

In the XVI Century the whole island was given by the emperor Charles V to the D'Avalos family as a feud; in 1563 the cardinal Innico D'Avalos constructed the castle and surrounded the village with walls (hence the name Terra Murata, i.e. Walled Land). The monumental complex of the Abbey is located at the top of the south eastern cliff of the hill, dropping straight on the sea (fig. 5). Ancient documents testify that formerly there were terraces with vineyards below the Abbey. The eroding action of the sea and the exploitation of tuff quarries produced a withdrawal of the cliff, that now threatens the overlying buildings. The foot of the cliff is underexcavated by the sea (fig. 5)

The lower part of the cliff, till an elevation of around 50 m above sea level, consists of volcanic tuff, while the upper part underlying the abbey consists of indurated pozzolana. As it may be seen in fig. 5, the Abbey rests on a huge complex of retaining structures, forming an intricate network of underground floors.

The Abbey includes the monumental church of St. Michael and the smaller chapel of the Holy Mary of the Purity of the Nuns. A system of thin fissures, roughly parallel to the cliff, occurs in both churches and in the underlying basements and vaults; their opening has been monitored by displacement transducers over a period of one year.

The main features of the installed monitoring system are similar to those described in § 2, with the addition of some dummy instruments installed on the intact masonry. As a general trend (fig. 6) the observed displacements are rather small; a maximum value of approximately 0.4 mm (LVDT1 and LVDT3) has been recorded. The reference sensors (LVDT6, LVDT9, LVDT12 and LVDT16) show that the combined effects of temperature changes on sensors and intact masonry are as high as 0.15 mm. All the sensors reveal small daily displacement cycles, following very closely the daily changes of temperature. Also the seasonal cycles of displacement are strictly related to temperature fluctuations.

In 1585 the Dominican friars built the church and the cloister of St. Margherita Nuova at the south western point of the hill of Terra Murata. The cloister was essentially hanging on a complex of retaining structures and directly exposed to sea waves. During the domination of Napoleon at the beginning of the XIX Century, when all the monasteries were abandoned, the cloisters was substantially demolished by the action of the sea (fig. 7). It may be seen that the sea is still underexcavating the cliff below the remains.

The church of St. Margherita has been recently restored, and the cloister will be reconstructed.

4. CONCLUDING REMARKS

The problems of the conservation of monuments at the top of tuff cliffs on the shoreline are difficult and treacherous. Due to the brittle behaviour of the tuff, the collapse of the cliff and of the overlying structures may occur suddenly, without forewarnings. These features nullify the use of displacement measurements for alarm and prevention purposes.

The usual consolidation and stabilisation measures for rock cliffs are nailing and anchors across fissures, sealing of fissures by bonding compounds, surface protection by anchored meshes and/or shotcrete, etc. These are often unsafe in the aggressive marine environment, and often cannot be adopted for very tight landscape constraints.

The experience collected over some centuries shows that prevention and remedial measures are to be searched in a continuous and careful maintenance of the structures on one side, and on a mitigation of the eroding action of the sea on the other side.

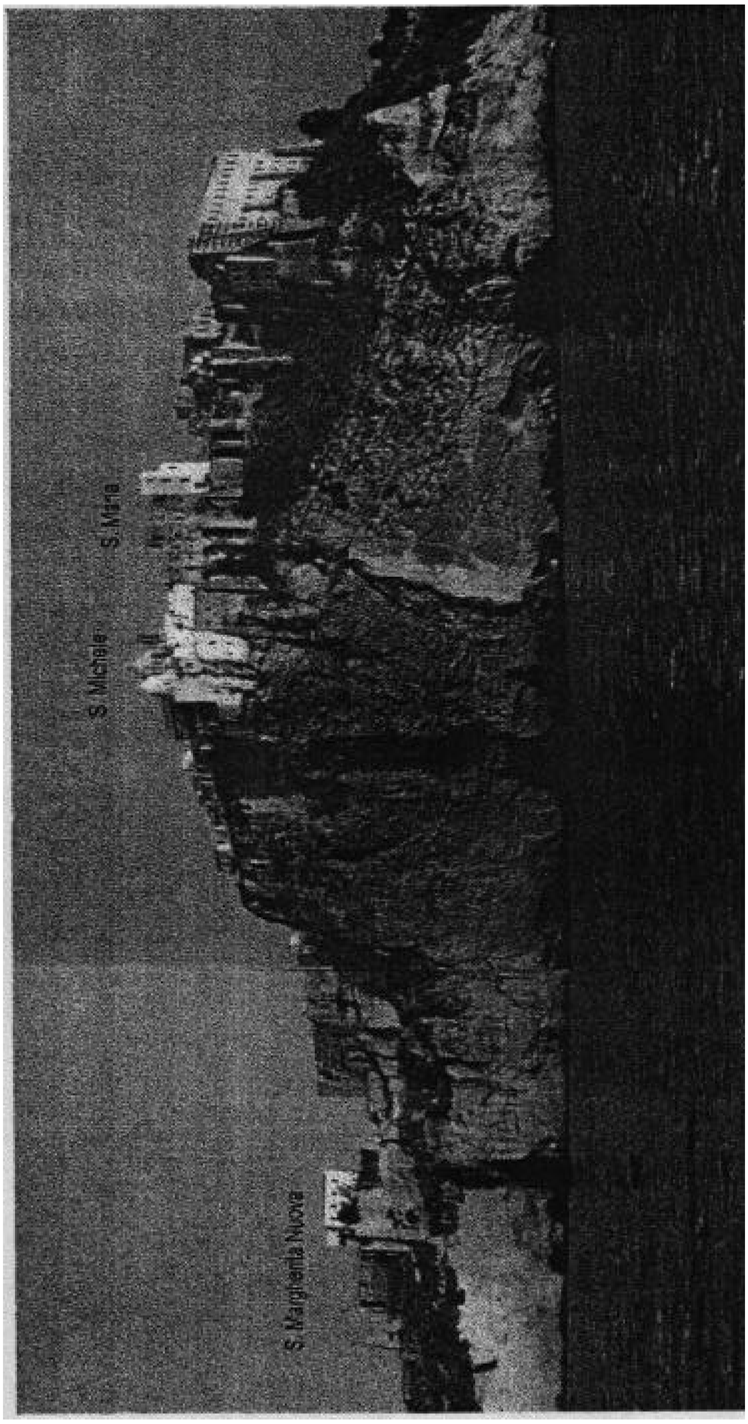

Figure 5: A picture of the village of Terra Murata taken from the sea

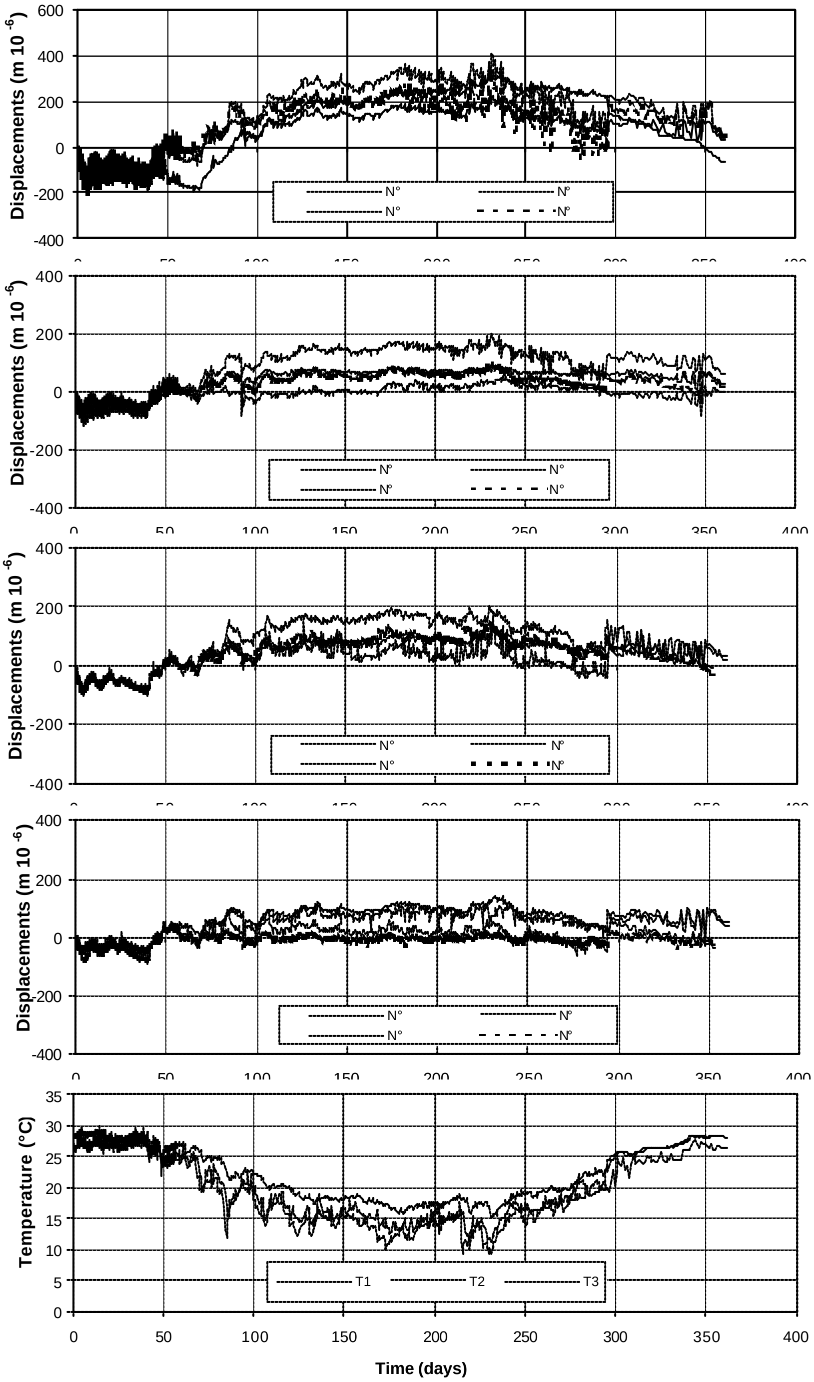

Figure 6: Displacements and temperature changes over 1 year

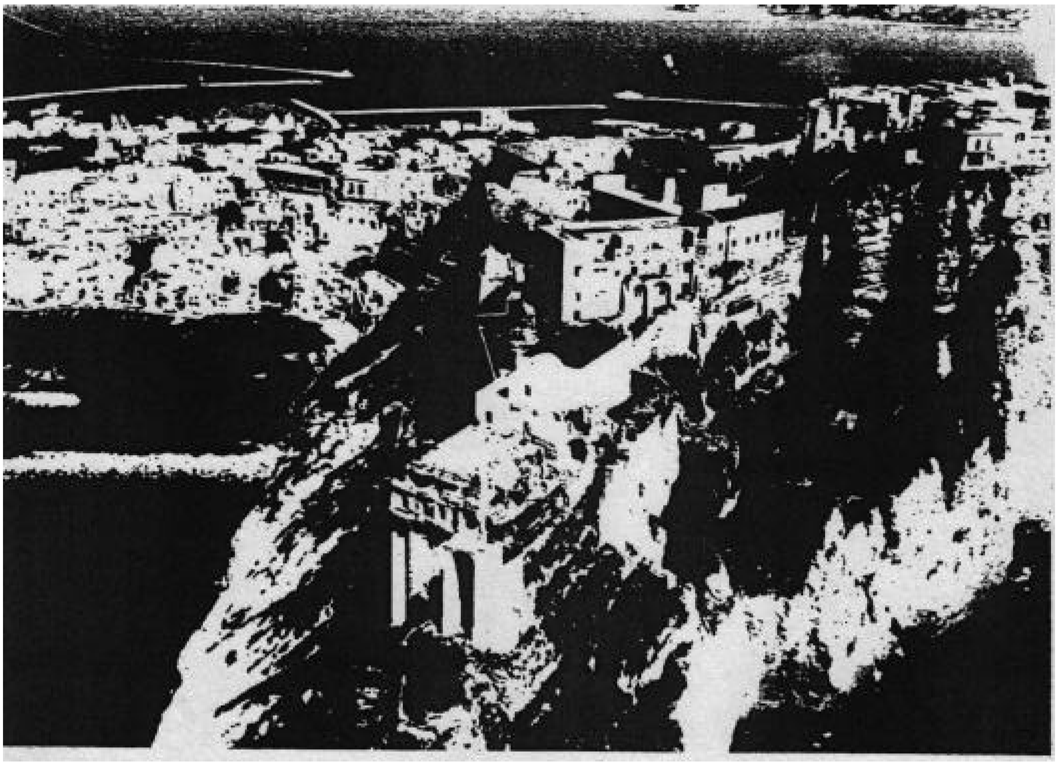

Figure 7: An aerial picture of S. Margherita Nuova with the demolished cloister

The latter may be obtained by protective jetties at the toe of the cliff, possibly underwater. Underwater and/or discontinuous protections from the sea waves have been adopted frequently in the Roman times to protect the villae of the coast of Posillipo [4].

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