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SAFETY ASSESSMENT AND PROTECTION OF MONUMENTS LOCATED IN CAVES – A CASE STUDY FROM THE CITY OF VOLOS, GREECE

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Abstract

The holy shrine of Panagia (Saint Maria) Goritsis is located in a cave on the outer limits of the city of Volos, on the coastline. The stability problems caused by the loosening of the rockmass and the expansion of the joints generated issues about the safety of the numerous worshippers visiting the church every day.
The cave is located into the Middle Triassic – Upper Jurassic marbles of the Pelagonian zone. The fragmentation of the rockmass along the two faults intersecting the slope until the coastline, combined with the weathering action of waves led to the formation of the cave. Although the action of the waves was cut of by the construction of the narthex and the surrounding buildings, the stability problems of the cave are intensified by the dynamic loading of the roof. The ceiling of cave is located 1 to 3 metres under the national road and the railway line connecting Volos with Agia.
The selection of the proper support measures was complicated. The limited space, the small depth and most of all the religious and the historical value of the cave led to the selection of light support measures combined with the imposition of restriction for the reduction of the dynamic and the static loading.
Key words: *Religious monument, rockmass loosening, rockfalls.*

Περίληψη

Το Ιερό Προσκύνημα Γενεσίου Θεοτόκου Γορίτσης εντοπίζεται σε σπήλαιο στα όρια της πόλης του Βόλου, κατά μήκος της ακτογραμμής. Τα προβλήματα ευστάθειας που έχουν προκληθεί από τη χαλάρωση της βραχομάζας και τη διεύρυνση των ασυνεχειών δημιούργησαν ζήτημα αναφορικά με την ασφάλεια των πολυάριθμων προσκυνητών που επισκέπτονται το ναό.
Το σπήλαιο εντοπίζεται εντός των Μέσω Τριαδικών – Άνω Ιουρασικών μαρμάρων της Πελαγονικής ζώνης. Ο κατακερματισμός της βραχομάζας κατά μήκος των δύο ρηγμάτων που τέμνουν το πρανές στη θέση του σπηλαίου, σε συνδυασμό με τη διαβρωτική δράση των κυμάτων καθόρισαν τον μηχανισμό γένεσης του σπηλαίου. Παρόλο που η δράση των κυμάτων έχει πλέον ανασταλεί τα προβλήματα αστάθειας του σπηλαίου έχουν ενταθεί εξαιτίας της δυναμικής φόρτισης της οροφής του. Η οροφή του σπηλαίου βρίσκεται 1 έως 3 m κάτω από τον εθνικό δρόμο και τη σιδηροδρομική γραμμή που συνδέουν το Βόλο με την Αγιά.

Η επιλογή των κατάλληλων μέτρων υποστήριξης ήταν πολύπλοκη. Ο περιορισμένος χώρος, το μικρό βάθος αλλά κυρίως η θρησκευτική και ιστορική αξία του μνημείου οδήγησαν στην επιλογή ήπιων μέτρων προστασίας, σε συνδυασμό με την επιβολή περιορισμών για τη μείωση της δυναμικής φόρτισης της οροφής.
Λέξεις κλειδιά: *Θρησκευτικά μνημεία, χαλάρωση βραχομάζας, καταπτώσεις βράχων.*

1. Introduction

Limestones and marbles occupy almost 20 % of the Greek dominion (Koukis *et al.* 2005). The numerous caves formed in those formations, mainly due to the karstic weathering and secondarily due to the tectonic fragmentation of the rock mass, quite often are occupied by monuments.

The stability problems occurring in those caves usually cause damages to the monuments and prevent people from visiting them. Despite that, those problems are handled with difficultly due to the restrictions arising from the monumental character of the sites.

The holy shrine of Panagia (Saint Maria) Goritsis is a typical example of religious monument located into a cave appearing stability problems. The description of the geomorphological and the geological conditions of the site, the description of the stability problems and the presentation of the proposed support measures can be a useful reference for the confrontation of similar situations.

2. Geomorphological settings

The holy shrine of Panagia (Saint Maria) Goritsis is located in a cave on the south-eastern outer limits of the city of Volos. As presented in the satellite picture of figure 1, it is placed on the coastline, along the foot of Pillion Mountain.

The geomorphological settings of the surrounding area are completely altered by the human activities. Several buildings, including the narthex, and a pier have been constructed across the coastline (Fig. 2). The national road and the railway line connecting Volos with Agia are crossing a few meters over the cave's ceiling (Fig. 3). Further more; an extremely large abandoned quarry is located over the cave, across the national road. This quarry was active for more than ten years during the '70's and the '80's.

Based on the above mentioned geomorphological settings it can be easily understood that the cave, during the last century, operates in an environment of intensive dynamic loading.

3. Geological settings

The cave is located into the Middle Triassic - Upper Jurassic marbles with a locally intercalated horizon consisting of calcite schists (I.G.M.E. 1986, I.G.M.E. 1987, Mountrakis 1987). The marbles are medium - bedded and locally thick - bedded to massive, of white-grey to black grey colour, with no karstic weathering.

The marbles hosting the cave are thick – bedded. The orientation settings of the bedding surfaces are 245/25 and they appear very low spacing (15-25 cm). The geological mapping (Loupasakis and Nikolaou 2005) revealed the existence of two major joint sets, which affect intensively the mechanical behaviour of the rock mass. The orientation settings of those joints' sets are J_1: 328/81 and J_2: 68/82. Those joints appear to have low to very low persistence (<1,5 m) and low spacing (1-2 m). They have no separation and, concerning their roughness, they can be characterised as lightly rough planar. Note that all discontinuities are completely healed by calcitic materials. As presented in figure 5, the joints and the bedding cause slab jointing of the rock mass.

The cave is intersected by two faults, F_1: 334/82 and F_2: 315/70 (Fig. 4). The generation mechanism of the cave is related directly with the existence of those faults. As mentioned before

Figure 1 – Satellite images presenting the location of the holy Shrine of Panagia Goritsis

this cave is not a product of the karstic weathering of the marbles. The waves acted on the mechanically strained rock mass, along the faults, and led to the excavation of the cave.

Those faults appear very wide separation and, concerning their roughness, they can be characterised as rough planar to undulating (I.S.R.M. 1981). Further more, mylonitic material (crush breccia) was located along the faults.

4. Disruption of the cave

The holy shrine consists of two major sections, the section sited into the cave and the narthex constructed in front of the caves exits, along the coastline. Note that, the exits of the cave coincide with the intersection of the faults with the slope face. Further more, the cave can be distinguished in five smaller sections (sections A, B, C, D and the Sanctuary), as the main chamber is divided in parts by three columns, natural or human made. Those columns provide the necessary support to the roof. The sections and the location of the columns are clearly presented at the top view of figure 4.

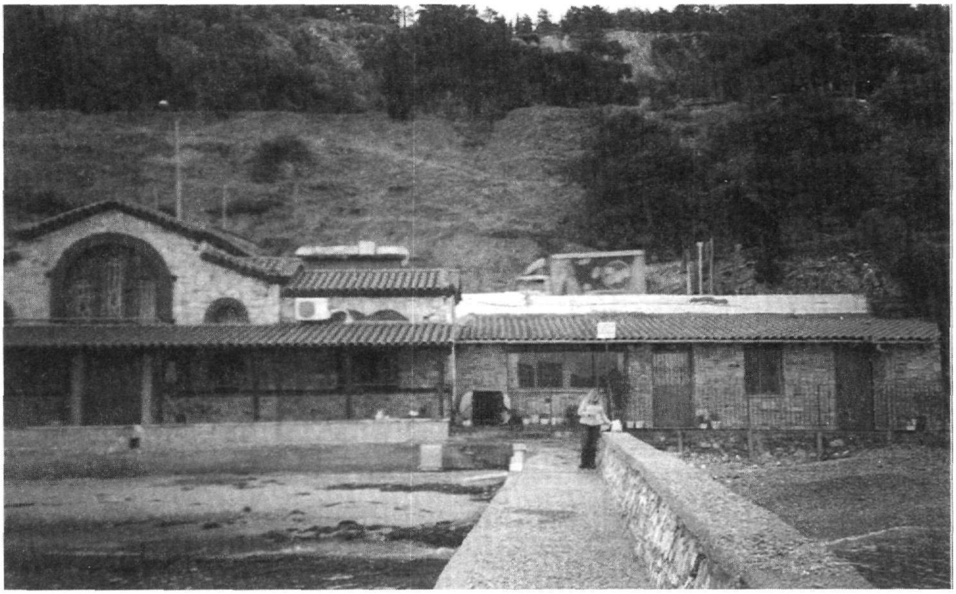

Figure 2 – Front view of the holy shrine. The coastline and the position of the national road are clearly presented

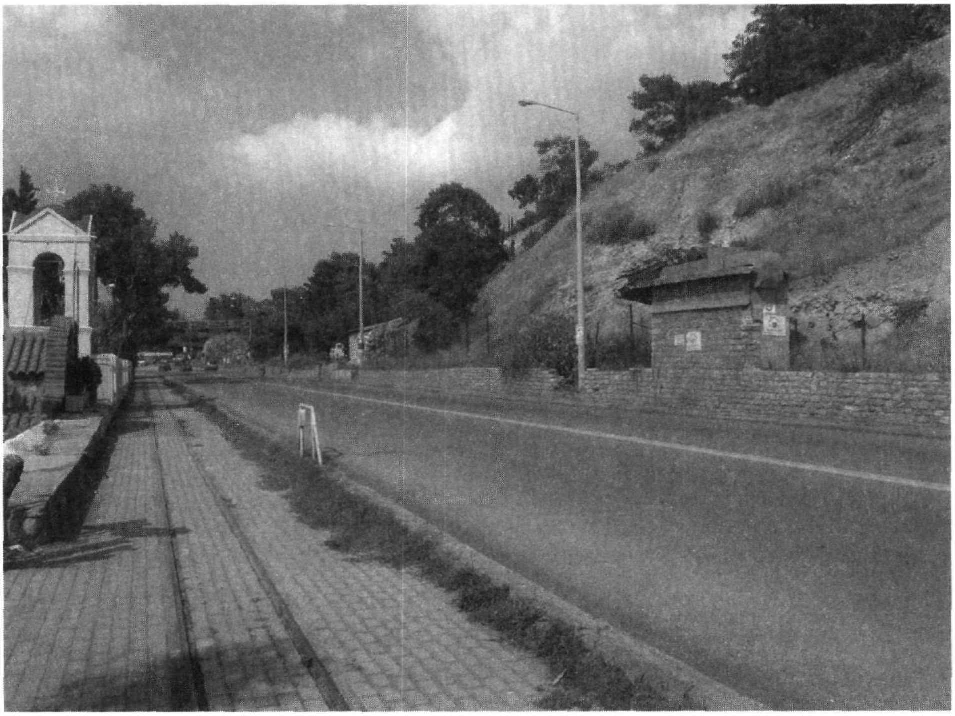

Figure 3 - The national road and the railway line passing over the ceiling of the cave

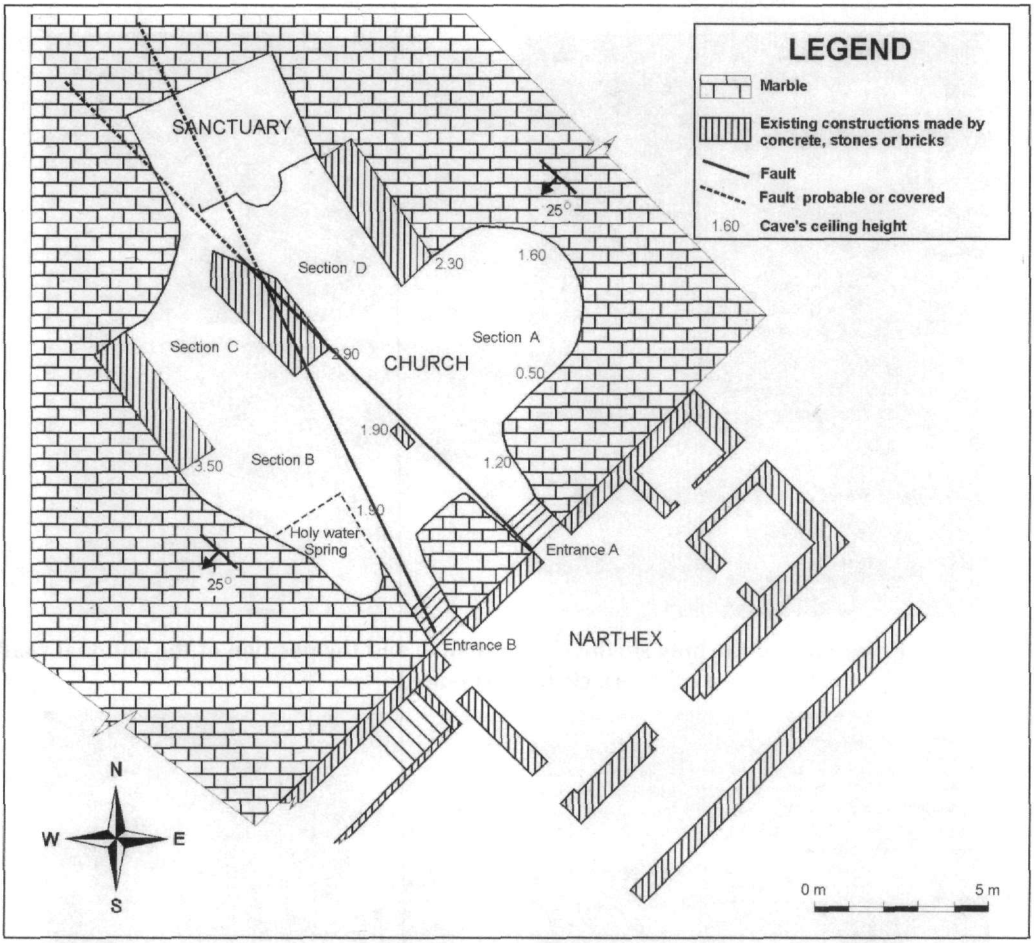

Figure 4 - Top view of the holy shrine presenting the morphological and the geological settings of the cave

Based on the stability of the roof, the cave can be distinguished in two main sections. The first one includes sections C, D and the Sanctuary and the second one the sections A and B. The main difference between the two sections is the distance between the ceiling of the cave and the level of the over crossing road. The inner section of the cave (consisting of sections C, D and the Sanctuary) is higher and as a result the marble layer on the ceiling is thin. On the contrary, the outer section of the cave (consisting of sections A and B) is sorter and the marble layer is much thicker. Generally, the height of the cave decrease respectively to the dip direction of the bedding and the thickness of the marble on the roof decrease proportionally to the height (Fig. 4).

The inner section of the cave is already supported by remedial structures and the outer is almost unsupported. The roof of the outer section is formed by the bedding surfaces.

The floor level of the cave is almost 50 cm under the floor level of the narthex. As mentioned before, the narthex was constructed over the sea level in order to protect the cave from the waves. So, the cave traps the underground waters gushing out temporarily along the faults, causing the cave to flood. For that reason the cave's floor is surrounded by a drainage channel leading the water to the sea. Before the installation of the church a temporary spring was located in the south corner of the cave at the "holy water spring" location (Fig. 4).

5. Stability Problems

The reduced thickness of the marble layer on the ceiling of several sections caused, in the past, serious stability problems. Those problems were probably located during or right after the construction of the over crossing road and they led to the construction of rigid arcs consisting of marble blocks and concrete. In figure 4 it is shown that those arcs extent only in the sections C, D and the Sanctuary. Sections C and D are separated by a column constructed in the middle of the inner section in order to decrease the span between the walls and in order to increase the bearing capacity of the arcs. The Sanctuary, because of its reduced size, is supported only by one arc. The inner section of the cave is sufficiently supported by those arcs. The oversized columns, the reduced height of the cave and the reduced span of the arcs provide a stable and safe environment. No rock falls have been reported in this section of the cave.

Those arcs are covered by stones of the surrounding marble, by wood or by hagiography and they fit completely with the interior of the holy shrine. Figure 5 presents a view of the ceiling on section D and on the Sanctuary (section D is covered by marble stones and the Sanctuary is covered by wood). Also, figure 6 presents a side view of the arc covered by hagiography.

The outer section of the cave is unsupported and the shape of the ceiling is completely formed by the bedding surfaces. Although that, the mechanical characteristics of the marble rock mass are very good, the intersection of the cave's roof by the faults, the relatively large unsupported bedding plates and the extensive spans between the walls of the section generated several stability problems.

According to the church-wardens, numerous small to medium size gravels failed from the ceiling during the last year, causing relatively small damages to the floor and to the pews of the church. Luckily no injuries were reported. Those gravels were detached from the areas surrounding the two faults and from the north western corner of section B (Fig. 7). Mylonitic materials or joints with very low spacing characterize the intensive fracturing of the rock mass in those areas.

Except from the areas with the intensive fracturing, there were located two areas where gradual bending of the bedding plates and proportional loosening of the rockmass along the bedding surfaces is observed. Those areas are located in the middle of wide unsupported arcs. The first one of the above mentioned arcs is located in the middle of section A and the second in the middle of the wedge located between sections A and B (Fig. 8). Although that, along the wedge a concrete column was constructed for the prevention of the loosening of the rock mass, the position and the orientation of the column did not efface the problem. The exact locations of all the above mentioned unstable areas are pointed on the top view of figure 9.

The stability of the wedge does not appear to be a threat because it is supported by three columns. Two of them are constructed by concrete or by marble stones and concrete and the other one constitutes a natural extension of the wedge's marble. Those columns are clearly presented in figure 9.

6. Proposed support measures

The monumental character and the ecclesiastical use of the cave generate serious issues during the selection of the proposed support and protection measures. Further more, the reduced thickness of the marble layer on the ceiling of the cave and the reduced inner space decreased much more the available options. It is obvious that, the application of support measures similar to those applied to the underground constructions (metallic arcs, shotcrete etc.) was inconceivable.

Figure 5 - Ceiling view of the Sanctuary and of section D. Sections supported by rigid arcs constructed by marble blocks and concrete. The Sanctuary is covered additionally by wood

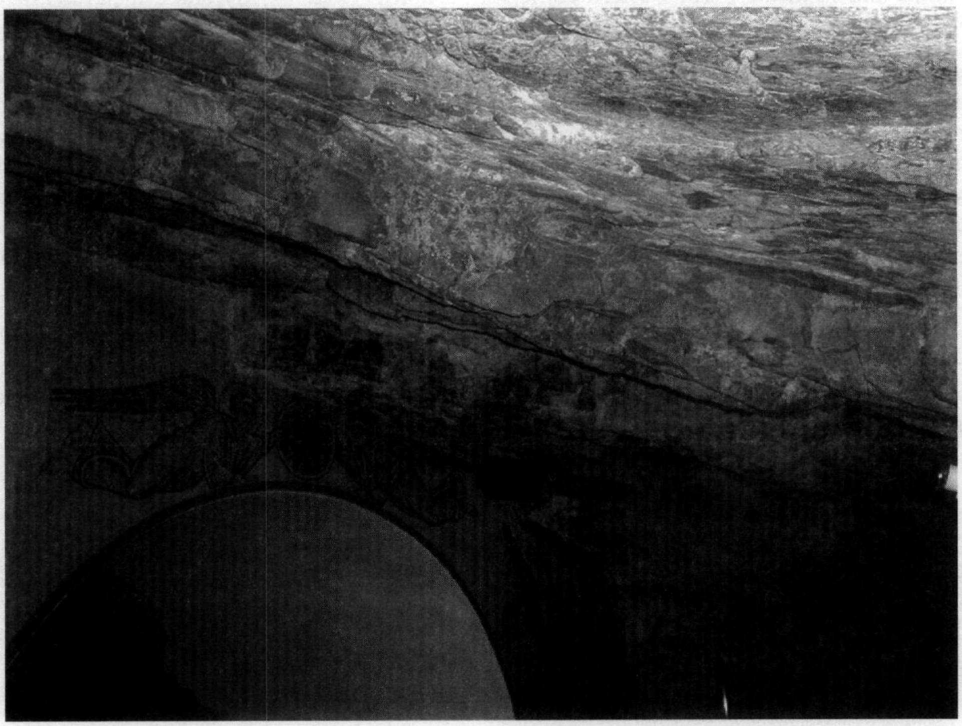

Figure 6 - Ceiling view of section A. Unsupported Section. This picture clearly presents a side view of the arc supporting section D, covered by hagiography

Figure 7 - Ceiling view of section B. Unsupported Section. The north western corner of the section, appearing the rock falls, is clearly presented

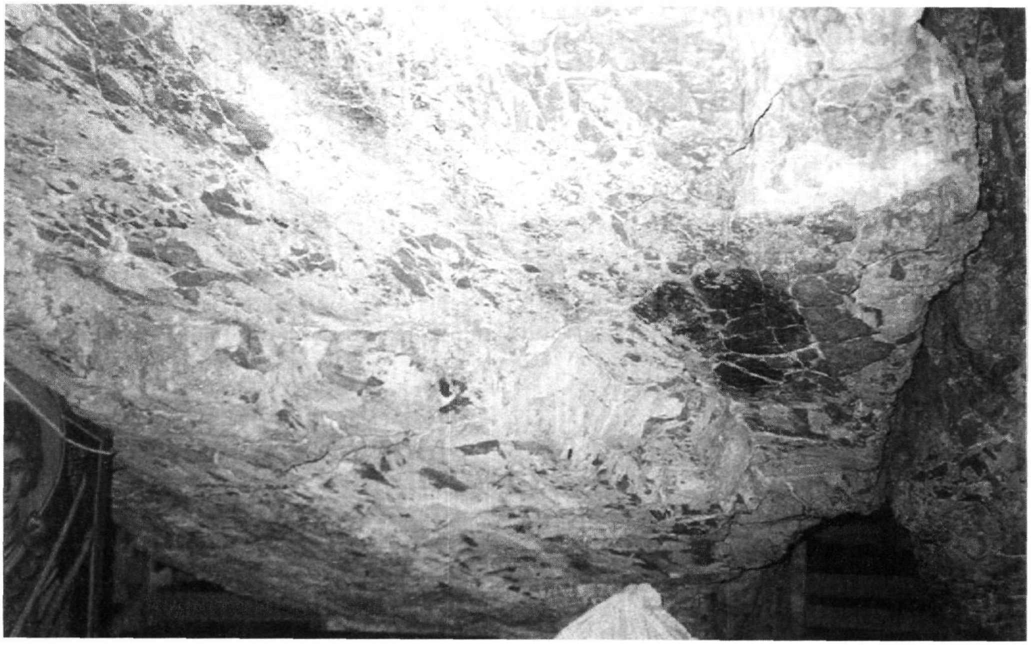

Figure 8 - View of the wedge formed by the faults intersecting the cave. The concrete column constructed for the support of the wedge is visible on the left side of the figure

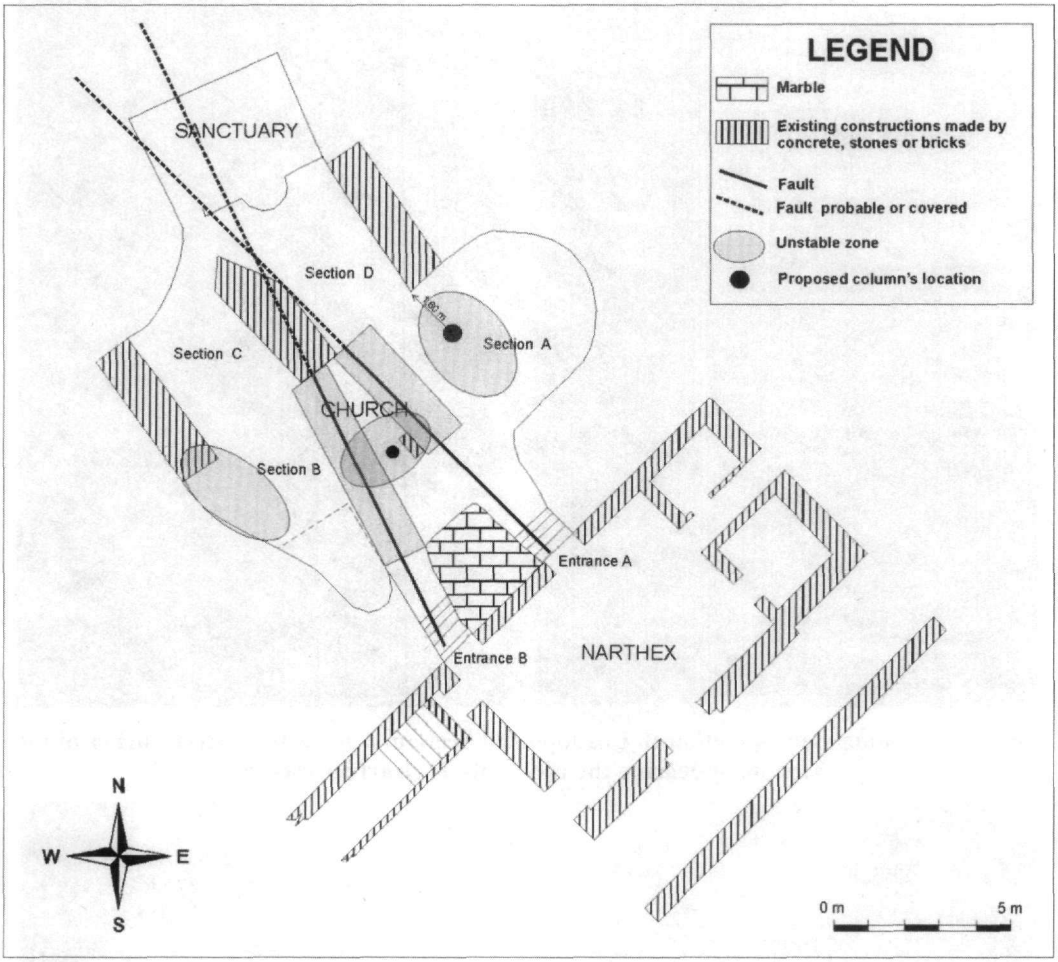

Figure 9 - Top view of the holy shrine presenting the position of the unstable zones and the proposed support measures (Loupasakis and Nikolaou 2005)

The measures that were finally proposed were aiming to the reduction of the dynamic loading of the cave's roof and to the prevention of the rock falls and of the rock mass loosening (Loupasakis and Nikolaou 2005). Those measures cause the minimum possible disturbance to the shrine's interior and they were set out as follows.

- Construction of one concrete column in the middle of each one of the two unsupported arcs, for the prevention of the rock mass loosening. The exact locations of the columns are presented in the top view of figure 9.
- Systematic inspection and removal of the over hanging rock blocks, especially along the intensively fractured zones. The rock blocks must be removed without the imposition of force which can cause further loosening of the rock mass.
- Application of soldering resins along the zones with the mylonitic materials. The intensive fracturing of the rock mass along the faults makes the hand collection of the blocks impossible.

- Installation and systematic observation of geodesic mark along the ceiling of the cave, for the prevention of large rock mass movements. Although that, the stability of the wedge does not appear to cause any problems, all extra precautional measures must be taken in order to reassure the safety of the numerous visitors.
- Imposition of measures for the reduction of the over crossing vehicles' speed (warning traffic plates, speed control radars etc.). This measure aims to the reduction of the dynamic loading and the vibrations affecting the cave. Note that, because of the nearby industries the road is frequently crossed by heavy tracks.
- Installation of antivibration layer along the section of the road and the railway line over crossing the cave. This measure, also, aims to the reduction of the dynamic loading and the vibrations affecting the cave.
- Imposition of measures for the prohibition of the vehicles' parking over the cave (forbidding traffic plates etc.). This measure aims to the reduction of the static loading of the cave's roof.
- Construction of an open channel drainage network along the road and the surrounding slopes for the reduction of the water infiltration. This measure aims to the reduction of the loosening and eroding effect of the infiltrated water. Also helps the prevention of the cave's flooding during the periods with intensive rainfalls.

It is obvious that the proposed measures are a combination of light constructions, soft interventions and prohibitions aiming to the reduction of the stability problems. Those measures must be reconsidered if the stability problems increase despite their implementation. For example, the extension of the arcs to the inner (higher) parts of sections A and B is an acceptable stability measure, compatible with the ecclesiastical character of the cave, which can be applied in that case. Grouted rebar or bulged cables drilled from the road can be applied also.

7. Conclusions

From the above described combination of support and protection measures it is obvious that the stability problems of caves occupied by monuments, in many cases, can be treated in respect to the monuments' physiognomy. Although that, in some cases the stability problems are too intensive and the imposed protection measures alter the site, even then, procedures causing the minimum destruction can be applied. Engineering geology can help to this direction as the evaluation of the geological parameters leads to the selection of measures able to activate the available rock mass potentials and decrease the severeness of the support measures.

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