Safety assessment and land planning development of abandoned quarries in urban areas – A case study from the city of Athens, Greece

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Abstract: Numerous abandoned quarries are located in urban areas all over the Greece. The quarries are the remains of extensive construction activity in the last century. The gradual change of their usage to active public areas, environmentally compatible with the urban surrounding, generates issues regarding the safety of the constructed infrastructures. The objective of this paper is to present, by means of a case study, the problems encountered with the main infrastructures constructed in an abandoned quarry and to analyse the influence of the land-planning design on the reduction of the rock fall hazard and of the support measures cost.

The paper is based on a case study of the stability problems of the slopes surrounding the infrastructure of the Attiko Alsos Park. This park is located in Athens (Greece) and it is built in the abandoned quarries of the Turkovounia hill. The local geological conditions combined with the haphazard quarrying procedure have produced various stability problems. Also, the construction of the infrastructure at the base of the unstable slopes, without keeping any safety distance, causes serious safety issues related with the land planning design of the site.

Résumé: Plusieurs carrières abandonnées sont dispersées autour de régions urbaines au domaine hellénique. Ces carrières sont les restes de l'activité constructive étendue durant le siècle précèdent. La modification progressive de leur usage aux espaces actives destinés au public, et compatibles avec l'environnement urbain, cause des problèmes de sécurité aux infrastructures construites. Le but de ce rapport est de présenter les problèmes dus aux infrastructures principales construites à une carrière abandonnée et d'analyser l'influence du plan territorial à la réduction du risque de rochers tombés par hasard et du coût des mesures de support.

Le rapport se refére à un cas d'étude des problèmes concernant la stabilité de pentes autour des infrastructures du parc «Attiko Alsos». Ce parc est situé à Athènes et il est construit dans une carrière abandonnée à la colline de Turkovounia. L' exploitation impitoyable de ce carrière, combinée avec les conditions géologiques spécifique de la région, cause de problèmes de stabilité variés. En plus la construction des infrastructures du parc tout près de pentes instables, sans garder la distance nécessaire, provoque des troubles sérieux de sécurité reliés aux plans territorials de ce site.

Keywords: urban geosciences, slope stability, risk assessment, excavations, limestone, case studies.

INTRODUCTION

The extensive construction activity of the last century and the excessive need for construction materials led to the excavation of numerous quarries all over Greece. Most of the quarries were excavated near the expanding cities or major transportation axes. The continuous expansion of the cities led to the embodiment of the abandoned quarries into the urban environment.

In most of the cases, the abandoned quarries were turned into solid waste and rubble disposal sites. The gradual incorporation of the quarries into the cities generated the need for the change of their usage to an environmentally compatible use. Most of them were turned into public gardens, sports fields, open air theatres or were used by the local authorities for covering their needs for worksites, in general.

This paper is based on the study of the stability problems encountered at the slopes surrounding the infrastructure of Attiko Alsos Park. This park is constructed into the abandoned quarries of the Turkovounia hill. Besides the public garden the park comprises an open air theatre, a volley ball and a basket ball field, a coffee-bar and an extensive parking area. As presented in Figure 1, the theatre is constructed in the south-western part of the quarry, the sports fields in the north and the remaining infrastructure in the central and in the eastern part, away from the quarry slopes.

The objective of this paper is to present the problems occurred at the main infrastructure and to analyse the influence of the land-planning design on the reduction of the rock fall hazard and of the support measures cost.

GEOLOGICAL SETTINGS

The quarries comprising Attiko Alsos Park are excavated into the Turkovounia limestones. The limestones are light to dark grey, heavy bedded to massive and occasionally medium bedded, recrystallized, karstic and intensively fractured. The limestone overlies or lies enclosed in a marly horizon consisting mainly of hard arenaceous marls, with thin marly limestone intercalations. The limestones were most probably deposited on the marly horizons upper member in form of big olistoliths (IGME, 2002). These formations occupy all the hilltops of the city of Athens (Niedermayer J., 1971, Andronopoulos B. and Koukis G., 1976).

Before the construction of the park, the abandoned quarries of the Turkovounia hill were turned into rubble disposal sites. The deposition of materials inside the open pit of the quarry led to the reduction of the slopes height and to the formation of flat areas. Consequently the majority of the infrastructure is founded on looser material which led to settlement of the heavy constructions (e.g. theatre).

Figure 1. Aerial photographs of the Turkovounia hill (left) and of the "Attiko Alsos" park (right). The boundaries of the quarry are marked by the yellow dotted line. The quarry occupies an area of 200.000 sq.m. (about 50 acres).

During the engineering geological mapping of the quarry, thirty one (31) normal faults were located. The projection of the tectonic data on the Schmidt net reveals that the orientation of their main attitude is E-W (Figure 2). This means that the main tensile stress field orientation is N-S.

Most of the faults exhibit intensive karstic weathering, turning them in wide karstic fissures. Those voids are 0.5m to 2m wide and are filled with clay or stalagmitic materials (Figure 3). When the karstic fissures intersect, the voids can become extremely wide (Figures 4 and 5)

Evaluation of the tectonic data collected from the joints, revealed that numerous joint sets are not related to the major tectonic structure's stress field. As presented in Figure 6, the statistical evaluation of the tectonic data shows ten (10) joint sets. Most of them appear locally distributed. It seems some of the local discontinuities were affected, besides the stress field, by the excavation procedure. The blasting of the rock mass, without using any pre-splitting techniques, reveal discontinuities are affected mostly by the anisotropy and the lack of homogeneity of the rock mass and secondarily by the stress field. This conclusion is supported by the fact that all the locally distributed discontinuities appear very small length (10-20 cm), exhibit random spacing, no separation and show no evidence of karstic weathering.

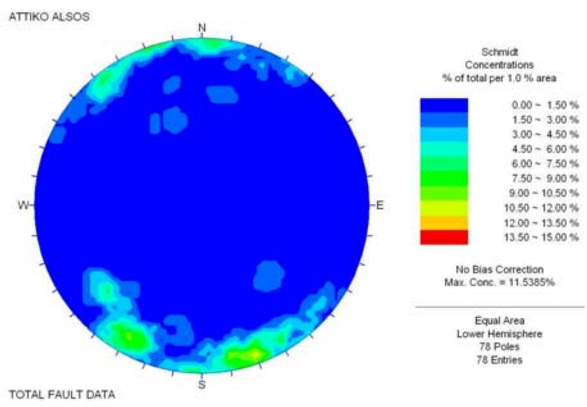

Figure 2. Stereographic projection of the faults' data.

SAFETY ASSESSMENT

The engineering geological mapping and data evaluation revealed stability problems of the quarry rock slopes fall into three categories (Karfakis J. & Loupasakis C., 2005). This categorisation is based mainly on the rock fall mechanism:

- Rock falls of over hanging blocks – remains of the excavation procedure.
- Rock falls of blocks trapped – enclosed into the karstic fissures' clay or stalagmitic filling materials.

- Slide of wedges formed by the joints' sets.

The quarrying procedure was extremely haphazard. The extensive use of explosives without applying any pre-splitting technique, combined with the repeated fractured and karstificated zones, led to the intensive break up of the rock mass along the slopes surface. Although in most of the cases the size of the blocks is not that big, the superabundance of the blocks, the height of the slopes (reaching up to 50 m) and the construction of the infrastructure on the base of the slopes (Figure 7) has created serious stability problems (Figure 8).

Figure 3. The brown and the dark grey zones intersecting the slopes are the wide karstic fissures which are filled with clay or stalagmitic - calcitic materials.

Figure 4. Extremely wide karstic fissure (up to 15 m) filled with clay materials. The material has enclosed blocks of the Turkovounia limestone. During the excavation the surrounding limestone was untouched in order to avoid moving the enclosed materials.

Figure 5. Extremely wide karstic void (up to 10 m) forming a small cave. This cave is formed on the extension of the zone presented in figure 4. The blocks located next to the cave are coming from the zone mentioned above witch is filled with clay materials.

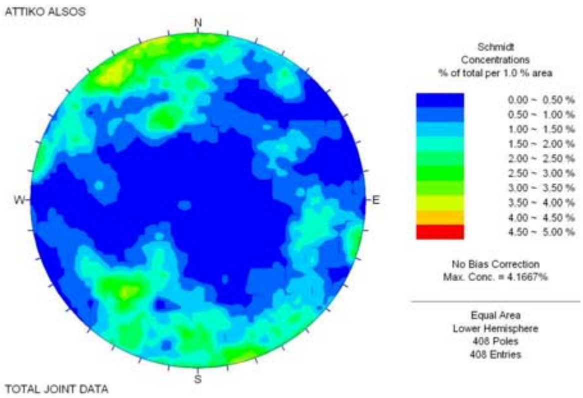

Figure 6. Stereographic projection of the joints data.

As previously mentioned the wide karstic fissures are filled with clay or stalagmitic material, which encases blocks of the limestone (Figure 4) or the blocks are trapped in a stalagmitic net. The gradual erosion of the surrounding material leads to the releasing of the blocks which fall down slope and accumulate at the base (Figure 5).

Despite ten joint sets located in several sections of the slopes, the stability problems caused by wedges appear local in their manifestation. Most of the joints appear very small in length (10-20 cm), big random spacing (1-2 m), no separation (< 0.1 mm) and are not weathered. The characteristics explain the high RQD values (reaching up to 70-80%) and justify the also high RMR ratings (75-80), that classify the limestones in the "good" rock mass category. The wedges formed along the slopes are infrequent and almost always very small. Therefore, no extra measures are necessary for the avoidance of these slides. As an exception to the rule, in a relatively small section of the slope surrounding theatre, extremely large wedges are formed. The intersection of the slope with a wide fractured zone has led to the formation of large wedges determined by long joints (Figures 9 and 10).

Combining the stability problems mentioned above with the land-planning design of the infrastructure it is easy to locate the sections of the slopes which exhibit slope stability problems and subsequently safety issues. Consequently, sections with intensive stability problems are; the area of large wedges over the theatre; the slopes surrounding the cave (Figure 7); and the slopes surrounding the sports fields, which exhibit severe stability problems along their entire length (Figure 11).

The infill material deposited post quarrying, at the base of the section with the large wedges, has formed an inclined surface reaching the top of the theatre (Figures 7 and 8). This morphology, in case of rock fall or sliding, enables the immediate rolling of the blocks into the theatre facilities. It is obvious that if an incident like this occurs during a performance it can cause serious human casualties.

The flat area surrounding the cave was defined by the land-planning engineers as a sightseeing location. The slopes surrounding the cave are 50m high and, as presented in Figure 5, comprise large limestone blocks. These blocks are the remains of the excavation procedure, which over hang the slopes, and blocks stack into the clay filling materials of the nearby karstic fissure. The extreme height of the slopes and the continuous erosion of the clay filling materials make support measures difficult and expensive. Also, the poor decoration of this small cave makes the application of expensive support measures unreasonable.

The slopes surrounding the sports infrastructure exhibit all the stability problems outlined above. The 30m high slopes are filled with over hanging blocks, the karstic fissures enclose numerous blocks and the intersected joint sets form several small wedges. Considering all the stability problems were obvious and expected, the main safety issues associated with the infrastructure were caused by the incorrect land-planning design of site and not by the rock mass condition. As presented in Figures 9, 10 and 11 all the facilities were constructed directly under the slopes without maintaining any safety distance. Even rows of seats were constructed under the over hanging blocks.

Figure 7. Panoramic picture of the slopes surrounding theatre. The notes point out the section of the slope with the large wedges and the location of the cave presented in Figure 5.

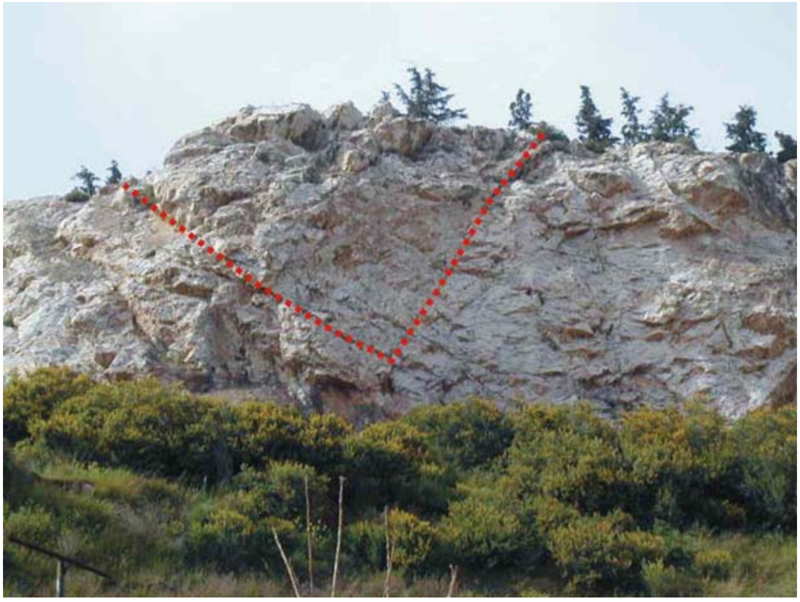

Figure 8. Large wedge formed in a small section of the slope surrounding theatre. The height of the slope is 20m. As presented in Figure 9, the rubble materials deposited on the base of the slope, form an inclined surface ending up on the top of the theatre.

Figure 9. The basket ball field including the rows of seats are installed on the base of a slope (30m high), without keeping any safety distance. The section of the slope presented in this figure is intersected by a fractured and karstificated zone filled with stalagmitic materials.

PROPOSED MEASURES

The Turkovounia quarries are visible from a great distance and the rocks are used as nests from a large number of birds. Therefore the proposed measures for the remediation of the slopes were based on the requirement for gentle environmental distraction and to be aesthetically sympathetic to the site. The stability measures proposed for the slopes surrounding theatre are:

- Application of spot rock bolts for the stabilization of the large wedges of the small slope section presented in Figures 7 and 8.
- Restriction of access to the area surrounding the cave. The construction of an observation post on a higher level is recommended, in order to satisfy the plans of the land-planning engineers.
- Installation of a safety fence or a wide hedgerow around the theatre in order to prevent the access to the base of the slopes. The post quarrying material deposited on the base of the slopes extending over theatre (besides the section with the large wedges) forms a wide plain area, sufficient for stopping the rock blocks from rolling into the facilities (Figures 1 & 3). However, it is obvious that the access to the area would be dangerous, because of the continuous rockfalls.

Figure 10. A big rock mass block coming from the fractured and karstificated zone mentioned in Figure 7. It caused damage on the tiers and on the fence of the basket ball field.

Figure 11. Panoramic picture of the slopes surrounding the sports fields. All the sports' infrastructures are located at the base of the slopes without keeping any safety distance.

For the protection of the sports fields, the construction of a containment wall is proposed. It is recommended the containment wall be 2.5m high, with a 1m to 1.5m high metal net along its top. The wall should be constructed 2m away from the base of the slope and be combined with a metal net installed along the entire forehead of the slope. This metal net can prevent the falling rock blocks from jumping away from the slope and the containment wall can stop them before they end up into the infrastructure. The application of those protective measures presupposes the redesign of the tiers.

Although that the installation of the measures proposed for the protection of the sports fields cause a relative aesthetic distortion of the site, the mistaken land-planning design of the infrastructures does not allow the application of more inconspicuous protective measures. On the contrary, there were other, more effective measures (e.g. gunite), rejected because they cause severe distraction of the site.

As presented in Figure 1, the quarry was big enough to allow multiple land planning design. Most of the described proposed measures could be reduced, if during the land planning design of the site the engineering geological data had been taken into consideration. If the theatre and the athletic facilities were constructed a few meters away from the base of the slopes most of the protective measures would become reduntant.

As an example, Figure 12 presents an alternative land planning design of the site. According to the land planning design, if the theatre was constructed in the location marked with the yellow outline, then the distance between slope with the large wedges and the theatre could became efficient for eliminating the risk. The configuration of a flat area between the theatre and the slope, create an area capable of trapping the wedges in case of sliding. Consequently no spot rock bolts are necessary for the support of the wedges.

If the basket ball and the volley ball fields were constructed 10 to 15 m away from the slope, the installation of a safety fence or a wide hedgerow between the fields and the base of the slope, could replace the containment wall system. Figure 12 presents an example of a more rational land planning design of the sports field.

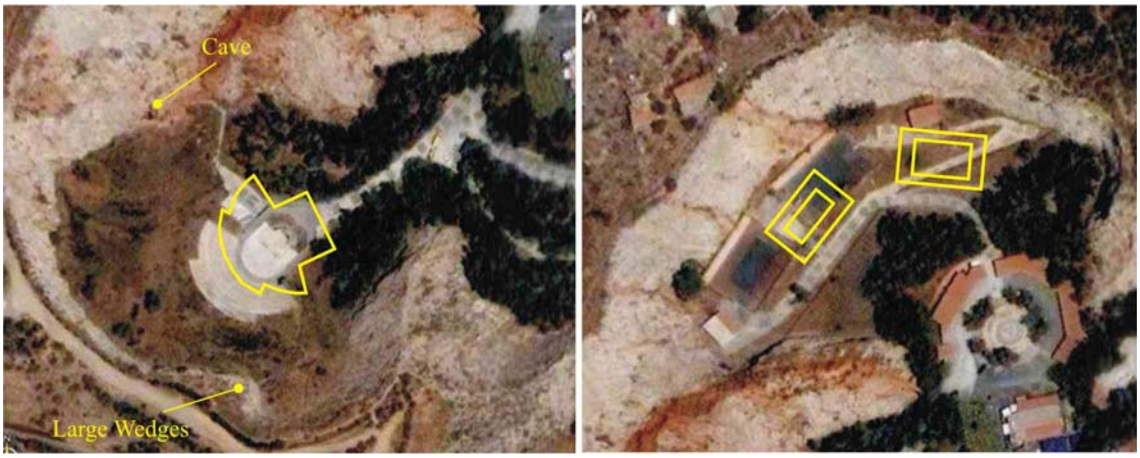

Figure 12. Aerial photographs of the theatre (left) and the sports field (right) presenting an alternative land planning design of the site. The yellow outlines present alternative locations of the infrastructures. The operation of the main facilities in those locations demands less protective measures.

CONCLUSIONS

The stability problems associated with the rock slopes of abandoned quarries can be extensive. The local geological conditions combined with the quarrying procedure generate various rock falls and wedge slides. As a result, the engineering geological characteristics of the slopes surrounding the quarries should be taken into consideration when a quarry is turned into public area. The engineering geological compatible land planning design of infrastructure into the abandoned quarries could reduce the risk and the cost of the construction. It is imperative the study of the engineering geological conditions of these sites must precede the land planning and the architectural study.

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