SLOPE STABILITY ANALYSIS AND PROPOSED MEASURES FOR THE PROTECTION OF THE ARCHAEOLOGICAL SITE OF OLYMPIA, IN S. GREECE

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ABSTRACT
The archaeological site of Olympia is located in South Greece, at the southern foot of Kronos Hill. In the present paper the stability of the unstable marly slope of Kronos Hill was investigated especially at its lower parts which are at the limit of the archaeological site. According to our investigation, the ground material is classified to silty clay or silty clayey sand of low plasticity. It is hard in dry conditions but it sutures rapidly in humid conditions, and looses its cohesion. The slope provides a very low safety factor (S.F.=0.17), which ensures the collapse of the slope. For this reason, the area was investigated and some reasonable safety measures were proposed.

KEY WORDS
Landslides, Monuments, Olympia

INTRODUCTION
The archaeological site of Olympia is located in South Greece, in the Western part of Peloponnese (Figure 1). It was one of the most important sanctuaries of the ancient period, built in a valley, between Kronos Hill and the confluence of the rivers Alpheios and Kladeos. At this Sanctuary, pan-Hellenic games called Olympic, were performed from a very early period. With the Olympic Games, the ideal of noble rivalry found its complete expression and for many centuries forged the unity and peace of the Greek world. It has not yet been established when people first began worshipping at Olympia. However, archaeological finds show that the area was at least settled from the 3rd millennium B.C. it is also known that the first Sanctuary was the Gainon, which was found at the foot of Kronos hill and was dedicated to Geia (Earth), the wife of Ouranos (Heaven). That was also it is said, the most ancient oracle of Olympia (Pausanias V, 14, 10).

Figure 1. Olympia archaeological site

The purpose was to investigate the stability conditions and possibilities of the unstable slope of the hill, at the northern limit of the archaeological site, and to propose reasonable protection measures.

GEOTECHNICAL CONDITIONS
The archaeological site is limited to the north by a steep hill slope, which is crossed by a national road of heavy traffic. The slope consists of Pliocenenic marls where many landslides occur (IGME, 1983, Figure 2).
At the lower part of the hill, 10 m higher than the level of the archaeological site, a coring borehole, of 25 m deep, was constructed on the marly slope, in order to give us core samples for laboratory tests (Figure 3). According to those tests, the material was classified as silty clay to silty clayey sand of low plasticity.
According to the grain size analysis of representative specimens, the material is composed of 22-17% clay, 43-80% silt and 35-3% sand. The liquid limit (LL) of the above specimens is 30-32%, the plastic limit (PL) is 22 and the plasticity index (PI) is 8-10%. The material presents low permeability and drainage ability. In dry conditions the material is compact, having uniaxial strength of 5-15 MPa. According to the performed triaxial tests, the cohesion is 17-23.7 kpa and the angle of internal friction is 5,2-11^0. In rain conditions the material saturates rapidly, providing unstable conditions and important earth pressures on the ancient rocky retaining wall which lean downslope, under the pressure (Figure 4). The material of the slope is similar to that of


Figure 2. Part of the archaeological site

Eptachori slope area, geologically located in the molassic formation of the Messoellenic Basin of N. Greece. (Christaras, 1997).
It is well known that erosion caused by running water or ground water and gravity is the more significant factor for the creation of landslides on unprotected slopes. The ground water decreases the shear strength of the material in an important depth, causing earth mass movements. The uncontrolled seepage of ground water, infiltrated through the joints of an impermeable silty or clay formation, also strengthens the ability of the slope for sliding (Vuillermet et al., 1994). In cases where these formations are overlain by hard rock layers, the erosion of silts and clays causes caving at the toe of these overlaying hard rocks creating toppling or sliding phenomena. Drainage is therefore critical to the stabilization of a slope. Removal of trees, with big routs, which involve to the destruction of the ancient retaining wall, strengthens the above process.
Test results were used for performing stability analysis of the slope. According to this elaboration, a safety factor of S.F.<0 was determined, providing the instability of the slope, especially at its lower part (under the road) where the archaeological site is located (Figure 6).
The instability of the slope is mainly related to the quality of the material, as it was previously described. Nevertheless, the root system of the big trees and the drainage incapacity strengthens the instability of the slope, especially at the lower parts, near to the archaeological site and create important earth pressure on the existed ancient retaining wall.

Figure 3. Bore Hole samples from Olympia (sound marl: deeper than 13.80 m)

Figure 4. The ancient retaining wall leans due to the occurred earth pressure

For this reason a retaining system, of that lower part of the slop, could not be totally safe without a sufficient drainage system to be applied and measures for removing the roots of the trees to be taken.
The support of the slope, using modern slope retaining or ground improvement methods, cannot be applied without taking into account that they have to be adapted to the ancient environment.

CONCLUSION

According to our study, the marly slope which limits the north side of Olympia archaeological site, looses its cohesion after raining, becoming unstable with S.F.=0.17. The instability of the lower part of the slope influences on the conservation of the archaeological site. The instability is due to the quality of the geo-material, the water activity and the presence of an important root system of trees, which act negatively on the existed ancient retaining wall. In order to stabilize the slope and to minimize the earth pressure on the ancient retaining wall, a drainage system should be applied at different parts of the slope, together with the removal of the roots of the trees at the lower part of the slope. A shallow vegetation retaining system could also improve the stability of the upper parts of the hill-slope. The reinforcing of the ancient retaining wall is not possible to be applied in the archaeological site without discussion, given that the methods used should be adapted to the identity of an archaeological site.

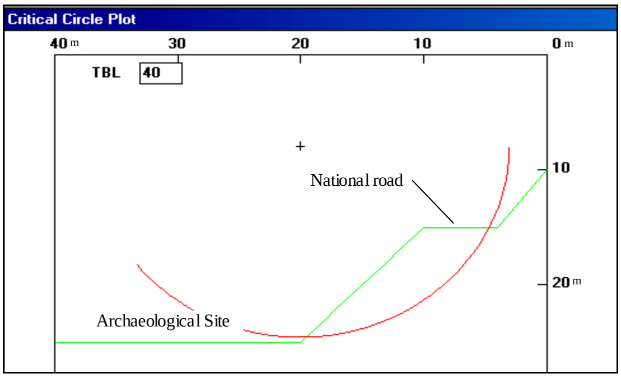

Figure 5. Critical slip circle (SF<1) obtained in rain conditions (saturated soil). It corresponds to the lower part of the slope (under the road), located at the north end of the archaeological site of Olympia. The slope is unstable providing important earth pressure on the leaning ancient retaining wall (Fig. 4)

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