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Engineering Geological Factors of Damage at Greek Monuments and Sites included in the World Heritage List of UNESCO

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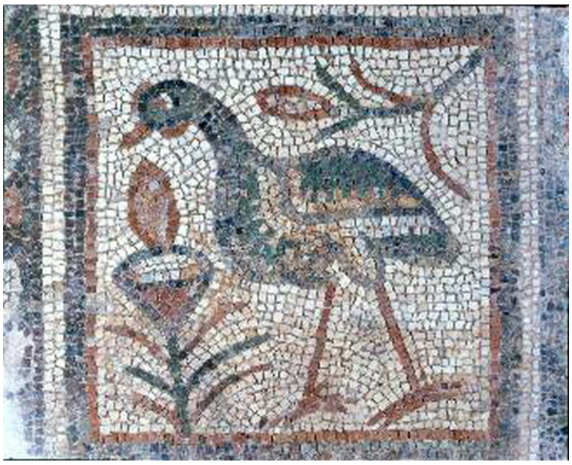

International Association of Engineering Geology and the Environment (IAEG) -Commission 16
"Engineering Geology and Protection of Ancient Monuments and Archaeological Sites"

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IAEG C16 - UNESCO World Heritage (Greece)
"Engineering Geology and Protection of Ancient Monuments and Archaeological Sites"

Cultural Heritage and engineering geological factors of damage

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The ancient monuments and achaeological sites need protection particularly in regions like the Mediterranean basin, where the seismotectonic regime is active, and the engineering geological conditions are complex.

- **These geoenvironmental conditions are common in the above area, due to the common geological and geotectonic evolution of the Mediterranean basin, during the geological time.**
- **For this reason, the geological formations (soils or rocks), which were used either as foundation base of the monuments or for the exploitation of their construction materials, are similar in expected sites of more than one country.**
- **Phenomena like, settlement and slope movements as well as earthquakes and tectonic activity contribute to the damage of the historical buildings. The ground water activity is also an important factor, especially in cases where monuments are buried in the soil where the aquifer is higher of their floors. The landslide phenomena are very often at old castles because they are mainly located on the top of the hills and the slopes of the mountains. The origin of the stones used in the construction of monuments is also important to be determined, for application the reconstruction activities.**

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ACROPOLIS OF ATHENS

Engineering geological conditions and problem:

The Acropolis (and Parthenon) is built on an isolated and uplifted rock consisted of massive to thickbedded limestone. Big unstable blocks are created on the steep slops of the hill because of the karstification and the tectonic. The joint net is locally close spaced, with planes of considerable length, fairly dipping towards the slope. Except karstification the rock is subjected to the air prolusion, the temperature variation and the mechanical action of the wind. The former situation causes important rock falls that generate damages to the monuments and the surrounding buildings.

The Acropolis hill, so called the "Sacred Rock" of Athens, is the most important site of the city. During Perikles' Golden Age, ancient Greek civilization was represented in an ideal way on the hill and some of the architectural masterpieces of the period were erected on its ground. ***D***uring the Classical period (450-330 B.C.) three important temples were erected on the ruins of earlier ones: the Parthenon, the Erechtheion, and the Temple of Nike. The Propylaea, the monumental entrance to the sacred area was also constructed in the same period.

The Acropolis of Athens

Parthenon

Protection measures already taken:

1) Limited retaining walls (discreet) with drainage
2) Systematic rock bolts
3) Intensive rock bolting on hang over boulders
4) Filling of the joints with concrete to reduce infiltration.
5) Construction of intensive drainage system of the top platform to reduce infiltration.

Rockfalls

Filled joints

Retaining wall

References on studies already done:

•B. Andronopoulos, G. Koukis, (1988). Engineering geological problems in the Acropolis of Athens, Balkema, Rotterdam, Brookfield, pp.1819-1831

•G. Koukis, (1982), slope stability problems of the Acropolis hill of Athens, 4th International congress of international association of engineering geology, New Delhi, pp. III.169-III.179.

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DAFNI MONASTERY

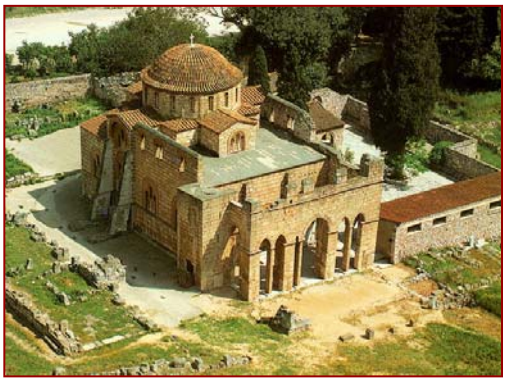
Engineering geological conditions and problem:

•The Monastery of Dafni composes a very important Byzantine monument, which is located between the mountains of Korydallos and Egaleo, in the western suburban area of Athens. The monument was included in the list of Unesco's World Heritage in 1990. The nave is stand out due to the way that its dome is grounded, which has 8m diameter.

•The stability problems are mainly related to the damages caused by the eartquake of Sept. 7, 1998.

•The site is crossed by seismic faults

•Consevarion of building stones, marble columns, and mortars is also needed



Protection measures already have been taken or have to be taken:

• Geotechnical-seismotectonic study

•Stabilization of the buildings in relation to the geotecnical and seismological features.

•In 1889 and 1897, after the damage caused by earthquakes, restoration was carried out on the church by the Greek Archaeological Society and the mosaics were cleaned and consolidated by a team of Italian artisans. The building was then bound with iron, the north side was buttressed, the west side of the narthex and the dome were entirely rebuilt. In 1955-57 the Restorations Department of the Ministry of Culture proceeded to further restorations on the church and the cloister and repaired the mosaics. In 1960 the walls filling the arches in the western wall of the exonarthex were removed and in 1968 the west entrance to the monastery was cleared

•The Monastery needs protection after the damage caused by the earthquake of Sept., 7, 1998.

Clockwise strike-slip movements

References on studies already performed:

•MARIOLAKOS I., CHRISTARAS B., MANOUTSOGLU E., MORAITI E. AND MARIOLAKOS D. (2001). Damages due to the earthquake of September 9, 1999, in Athens. The case of thearcaeological site of Dafni Monastery. Int. Meet. "Sea-level changes and Coastal Evolution & Neotectonics (INQUA) – National Taiwan University Taiwan, abstr. pp. 66 (doc. in press)

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DELOS (CYCLADES ISLANDS)

Engineering geological conditions and problem:

• Weathering of stones (marble and granite) by polluted atmosphere and marine spray.
•Decays by supply of matter such as brown crusts (on marbles sheltered from rain).
• Damages by loss of matter such as dissolution (on marbles exposed to rain).
•Other degradations by loss of matter such as granular disintegration and contour scaling (on parts exposed to rain).
•The presence of marine salts leads to dissolution and crystallization cycles of salts, especially inside the marble and the granite porous network. This mechanism occurs: a) by capillary transfer of water and salts from the ground and b) by fixation of water vapor by sea-salts deposited on the stone by the wind.

Protection measures already taken or have to be taken:

•Protection against weathering of building stones
•Consolidation of weathered surfaces using apropriate materials which donnot cause damage to the other parts.
• Diagnosis of damage and consolidation result using non destructive tecniques

Other information:

Delos was the most important Panhellenic sanctuary, and, according to mythology, the birth-place of Apollo and Artemis. The first signs of habitation on the island date from the 3rd millenium B.C., and important remains of the Mycenaean period have been uncovered in the area of the sanctuary. In the 7th century B.C. Delos was already a known Ionic centre because of its religious importance as the birth-place of Apollo. Athenian influence was initiated on the sanctuary with the first purification of Delos by Peisistratos in 540 B.C. but it gradually developed into a proper domination lasting - with short intervals - until the end of the 4th century B.C., when Delos was finally declared free and independent (314 B.C.). The independence of the island lasted until 166 B.C. when the Romans gave it over to the Athenians.

References on studies already performed:

•CHABAS, A.; JEANNETTE,D. ;LEFEVRE, R.:"Atmospheric causes of the marble and granite damage in the archaeological site of Delos (Cyclades Islands, Greece).Protection and conservation of the cultural heritage of the Mediterranean cities.5th Int. Symp. on the Conservation of Monuments in the Mediterranean Basin.April 2000.

•CHRISTARAS, B. (2000). Effectiveness of in situ P-wave measurements in monuments. Journal of Nepal Geol*ogical Society, Vol. 22, pp.45-48.*

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DELPHI ARCHAEOLOGICAL SITE

Engineering geological conditions and problem:

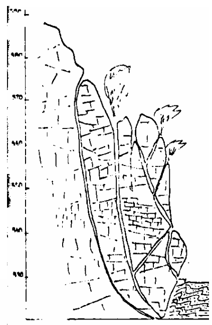
•The development of the sanctuary and the oracle of Delphi began in the 8th century B.C. with the establishment of the cult of Apollo. After the First Sacred War the sanctuary increased its pan Hellenic religious and political influence.

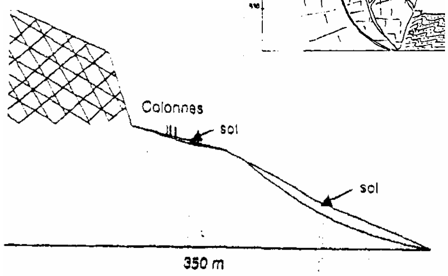
• The archaeological site is built under a vertical steep slop consisted of limestone. In the rock mass almost vertical discontinuities are developed which are intersected by joints, fractures and open cracks. This pattern of fracturing results in a progressive loosening of rock mass witch is then subjected to weathering and erosion processes. Zones of weakness have been developed on the rock cliff where favorable conditions have been created for limestone blocks to be detached causing extensive rock falls.

•The most destructive earthquakes were the following:
– 600 BC: complete destruction of the sanctuary
–373 BC: extensive damage of the archaic temple of Apollo, mainly by rockfalls (devastation of Helice town in Corinth Gulf).
–1870 AD: significant damage to the monuments (reactivation of the Arachova-Delphi fault zone)

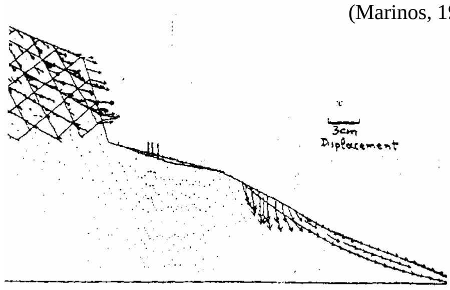
•Major causes of instability:
•Rockfalls,
• Ground creep
•Foundation subsidence and deformation

Schematic cross section of the rock slope (rockfalls)





Discrete element model of the slope above the archaeological site (Marinos, 1999)



Max. displacement profiles during the seismic excitation, (Marinos, 1999)

Protective measures already performed:

• Stability modeling (including slope stability analysis for seismic excitation) performed by the Geotechnical Dept. of the National Technical University of Athens and the Lab. de Mechanique des Terrains de l' Ecole des Mines de Nancy.

Proposed protection measures:

1)Systematic rock bolting

2)Cement injections

3)Removing of small rocks

References on studies already done:

•C.V. Constantinidis, J.Christodoulias, A.I. Sofianos, (1988).Weathering processes leading to rockfalls at Delphi archaeological site, Proceedings of the international symposium of IAEG on "The engineering geology of ancient works, monuments ant historical sites, Balkema, Rotterdam, Brookfield, pp. 201-205.
•K. S. Koroniotis, A.A. Collios, A. Basdekis, (1988).Stabilization of the rock slopes at the region of Kastlia spring at Delphi, Proceedings of the international symposium of IAEG on "The engineering geology of ancient works, monuments ant historical sites, Balkema, Rotterdam, Brookfield, pp. 207-211.
•Marinos, P., (1997). Engineering Geology and Geotechnical Engineering of the Archaeological Site of Delphi, Greece. IAEG Int. Symp. "Engineering Geology and the Environment", Athens.
•Marinos, P. (1999). The archaeological site of Delphi, Greece. A site vulnerable to earthquake and landslides. UNESCO-IGCP 425 Int. Meet. "Landslide Hazard Assessment and Mitigation for Cultural Heritage Sites and Other Locations of High Society Value", Paris, pp. 83-90.

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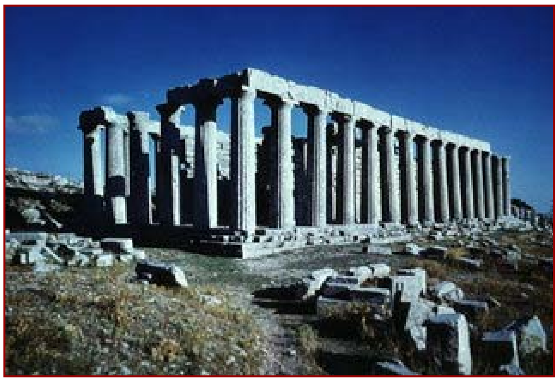
TEMPLE OF APOLLO EPICURIUS AT BASSAI

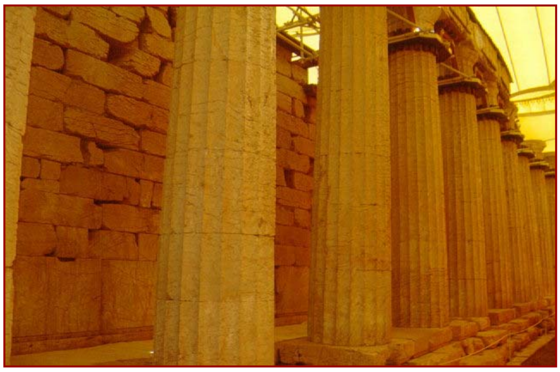
Engineering geological conditions and problem:

•It is a Doric peripteral temple made from local light grey (Upper Cretaceus) limestone, and consists of a prodome and a cella. It is orientated north to south. In the cella there was a column with a corinthian capital, which is the oldest known example of its kind.

•The monument is mainly built using a limestone.

•The main problem is related to the weathering due to the rainwater activity and to the damage of the building stones due to the frost action and the wide range changes of temperature.





Protection measures already have been taken or have to be taken:

•In 1902, the 1st Archaeological society of Athens began systematic archaeological research of the area, under the direction of K.Kourouniotis, with the assistance of K.Romaios and P.Kavvadias. It was continued in 1959, 1970 and from 1975-1979, under the direction of N.Gialouris.

•Small scale restorations have been carried out by the civil engineer N.Balanos and professor H.Bouras. More recently, research has been completed, by the Committee of the Temple of Epicurean Apollo, for the restoration of the temple.

•At the present time conservation work on the temple is being done under the supervision of the Committee of the Epicurean Apollo, which is based in Athens.

Other information:

•It is the first nearly complete temple still surving, with for the the first time, all three architectural styles: Doric, Ionian and Corinthian. The temple was erected on a raised area, 1,131m, called the 'Bassai', meaning little vale in the rocks.

References on studies already performed:

•THEOULAKIS, P. & KOUZELI, K. (1988). Provenance of the building materials of the Temple of Apollo Epicurios at Bassai, Greece. Proc. Int. Symp. of IAEG on «The Engineering Geology of Ancient Works, Monuments and Historical Sites», Balkema Edt., Athens, pp. 661-665.

•BELOGIANNIS, N. & THEOULAKIS, P. (1988). Causes and mechanism of stone alteration at the Temple of Apollo Epicurios at Bassai, Greece. Proc. Int. Symp. of IAEG on «The Engineering Geology of Ancient Works, Monuments and Historical Sites», Balkema Edt., Athens, pp. 763-770.

•7th EPHORATE: Reports on conservation activities

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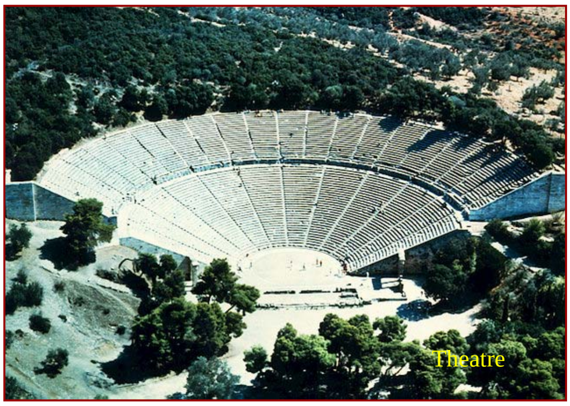
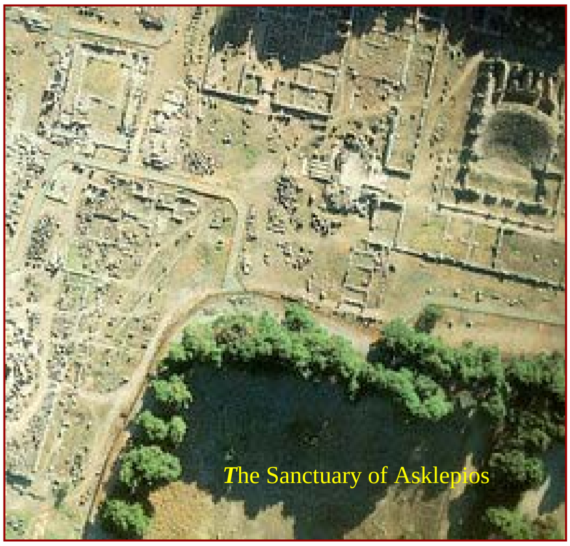
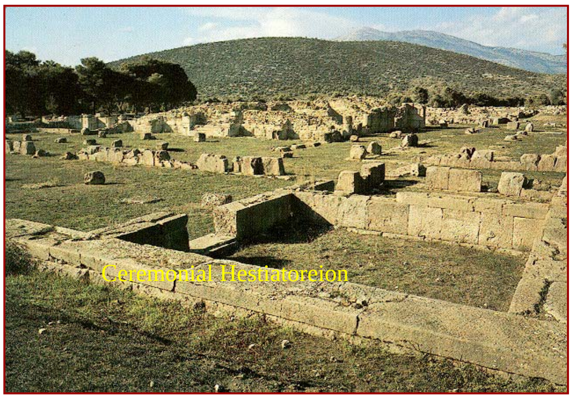
ARCHAEOLOGICAL SITE OF EPIDAURUS (THEATRE)

Engineering geological conditions and problem:

- The Sanctuary of Asklepios at Epidaurus was the most celebrated healing centre of the ancient world. The cult is attested as early as the 6th century B.C.
- Weathering of stones
- Seismic hazard


Theatre


The Sanctuary of Asklepios


Ceremonial Hestiatoreion

Protection measures already have been taken or have to be taken:

The French Scientific Mission was the first to conduct excavations on the site. However, all the monuments of the Asklepieion have been brought to light in systematic excavations carried out by the Greek Archaeological Society (1879-1926).

The first restoration works at the Asklepieion started on the Theatre in 1907, and continued in 1954-1963. In 1984, the task of rescuing the sanctuary from decay as well as improving its presentation as a whole, while organizing an instructive and controlled route for the large number of visitors, was undertaken by the Committee for the Preservation of the Epidaurus Monuments.

The restoration of the Abaton, the Tholos, the Propylon of the "Gymnasium", and the Gate of the West Parodos of the Theatre, with extensive conservation treatment of the authentic material, is in various stages of implementation. Also, for the direct rescue of the authentic material of other monuments, Greek and Roman, conservation is currently in progress. In 1988, the Asklepieion was included in the World Heritage List

References on studies already performed:

4TH EPHORATE OF PREHISTORIC AND CLASSIC ANTIQUITIES: Reports on excavations and restoration activities

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THE TUNNEL OF EUPALINOS (PYTHAGOREIO - SAMOS ISL.)

Engineering geological conditions and problem:

•The aqueduct of the ancient city of Samos (Pythagoreio), called the "two-mouthed tunnel" by Herodotus, is one of the most significant technical achievements of Greek antiquity.

•It is a tunnel 1036 m long, hewn from the rock through Mt. Kastron, starting from the north side and ending to the south. It is located 55 m. above sea level and 180 m. below the top of the mountain. The dimensions of the tunnel are 1.80 x 1.80 m. Inside it, at a depth of 2-9 m. is the channel that carried the water to the city. Two architectural phases have been distinguished: a) the Archaic, with the polygonal masonry and the pointed roof and b) the Roman, with a barrel-vaulted roof.

•The aqueduct was the work of Eupalinos, son of Naustrophos, an engineer from Megara. Its construction started in 550 B.C., during the tyranny of Polycrates and lasted for ten years. Many Lesbian prisoners were used by the Samians for the completion of the work.

Protection measures already have been taken or have to be taken:

•The inhabitants of Samos attempted to use the aqueduct in 1882 but their effort was not successful.

• Ninety years later, between 1971 and 1973, the German Archaeological Institute of Athens undertook the task to finally uncover the tunnel.

•Tunnel stabilization

References on studies already performed:

•21th EPHORATE OF PREHISTORIC AND CLASSIC ANTIQUITIES: Reports on excavation and restoration activities

KNOSSOS IN CRETE ISLAND

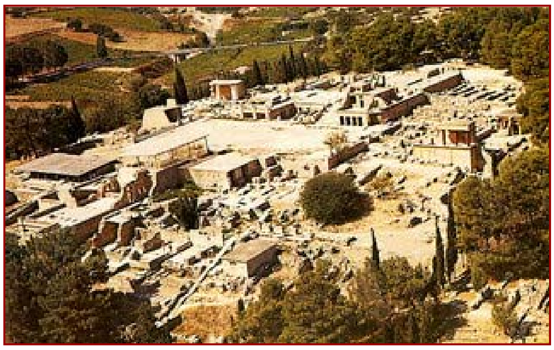
Engineering geological conditions and problem:

• Knossos is the site of the most important and better known palace of Minoan civilization. According to tradition, it was the seat of the legendary king Minos. The Palace is also connected with thrilling legends, such as the myth of the Labyrinth with the Monotaur, and the story of Daidalos and Icaros.

•The site was continuously inhabited from the Neolithic period (7000-3000 B.C.) until Roman times. The Linear B tablets (Mycenaean script) of the 14th century B.C. mention the city as ko-no-so.

•An earthquake and probable eruptions of Thyra volcano destoyed the town before 1890 BC. The new Palace built in 1700 BC and destoyed in 1570 BC, by an earthquake. It was rebuilt in 1450 BC and redestroyed in 1375 BC. A new town which was built, was destroyed definitively in 823 AD.

•Weathering of natural building materials is an important cause of damage.



Protection measures already have been taken or have to be taken:

• Restoration of buildings

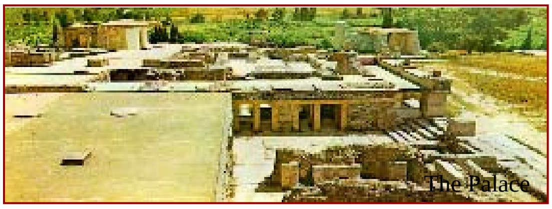
•Conservation of the building stones consisting mainly of biogenic limestone, marly limestone and gypsum.

•Conservation of frescos is also needed

The restoration of Knossos Palace to its present form was carried out by Arthur Evans. The interventions were mostly imposed by the need to preserve the monuments uncovered. The Archaeological Service of the Ministry of Culture carries out only consolidation work, whenever necessary.

Frescos, 14-12th c. BC

The Throne



The Palace

References on studies already performed:

•23th EPHORATE OF PREHISTORIC AND CLASSICAL ANTIQUITIES: Reports on excavations and restoration-conservation activities.

•MORAITI, E & CHRISTARAS, B. (1991): Weathering of marly limestones used in the antiquities of Crete, Greece. Stratigraphy and mechanical consideration. 2nd. Int. Symp. Conserv. Monum. Medit. Basin, pp. 483-492

•SAVIGNIONI, L. & DE SANCTIS, G. (1901). Esplorazione Archaeologica delle provincie occidentali di Creta. Mon. Ant., Rona, vol. 11, pp. 72-110.

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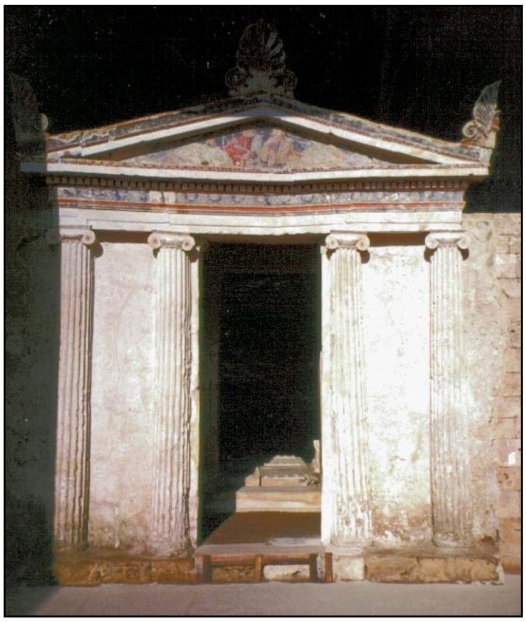
LEFKADIA MACEDONIAN TOMBS

Engineering geological conditions and problem:

The damages are mainly related to the groundwater, which, usually covers, the floor of the monuments. Furthermore, differential settlements cause damage to the stability of the monuments while the existed humidity causes damage to the frescos. The formations in which the Tombs are buried, are consisted of alluvial deposits with clay, sand, gravel and conglomerates.The soil materials are generally loose and coarse grained, presenting, active porosity and permeability that vary depending on the grain size distribution of the soil. The depth of the groundwater varies from 7.5 to 8 m. The permeability of the soil is 2-3.10$^{2\cdot}$ and the hydraulic gradient 12-14 %



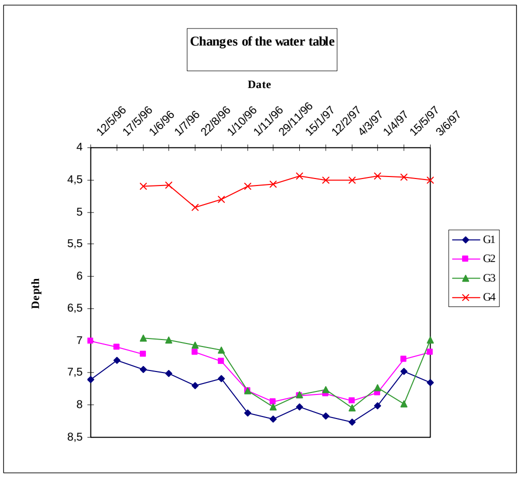
Protection measures already taken or have to be taken:

•The tombs need permanet drainage.

•A pumping borehole systeme is already established

•A drainage trench could involve to the better drainage

•An impermeation grouting shell was calculated to be constructed in order to permanently protect the tombs from the water. The number of the boreholes that is needed to impermeate the building that includes the Krisis tomb is 46 and for the Krisis tomb is 24. The total length of boreholes for the first case is 750,54m and for the other one is 297,62m



Other information:

The Macedonian Tombs of Krisis, of Anthemion and Kaliklis (3rd c. B.C., found outside the walls of the ancient city Mieza) were located along the road connecting Pella, the capital of Macedonia, to Mieza, which was one of the important commercial cities during the period of the 4th - 2nd c. B.C.

References on studies already performed:

CHRISTARAS B., MARIOLAKOS I., FOUNDOULIS J., ATHANASIAS S. & DIMITRIOU A. (1997): Geotechnical input for the protection of some Macedonian Tombs in Northern Greece. IVth Int. Symp. on the Conservation of Monuments in the Mediterranean Basin, Rhodes, pp. 125-132.

CHRISTARAS B., MARIOLAKOS I., FOUNDOULIS J., LEMONI EL., DIMITRIOU A. & CHATZIANGELOU M. (1999). Impermeation grouting techniques in the protection of monuments. Examples from Macedonian Tombs in Greece. *Journal of Nepal Geol. Soc. Katmandu, Vol.20.*

MARIOLAKOS I., CHRISTARAS B., FOUNDOULIS J., LEMONI EL., DIMITRIOU A. & CHATZIANGELOU M. (1999). Drainage procedures at the Macedonian Tombs of Lefkadia area, N. Greece. *5th Hydrogeological Congress of the Geol. Metal. Soc. Cyprus, Nicosia (in press).*

CHRISTARAS B., MARIOLAKOS I., FOUNDOULIS J., CHATZIANGELOU M., DIMITRIOU A., AND LEMONI EL. (2000). Impermeation of Macedonian Tombs in N. Greece using grouting techniques. *Vth Int. Symp. on the Conserv. of Monuments in the Medit. Basin, Seville, pp. 417-423.*

CHRISTARAS B., ZOUROS N. & MARINOS P. (2000). Heavy rain and mass movements in pyroclactic formations. Examples from Sarno (Italy) and Lesvos Island (Greece). *Geoeng2000, An International Conference on Geotechnical & Geological Engineering, Melvourne (in press).*

CHRISTARAS B., MARIOLAKOS I., CHATZIANGELOU M. (2000). Protection of buried monuments against ground water activity using grouting techniques. *INCOMARECH RAPHAEL 2000.*

17th EPHORATE OF PREHISTORIC & CLASSICAL ANTIQUITIES: Reports on Archaeological and Conservation Studies

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PETRIFIED FOREST OF LESVOS ISLAND

Engineering geological conditions and problem:

The area enclosed by the villages of Eressos, Antissa and Sigri, exposes large accumulations of fossilised tree trunks comprising the Petrified forest of Lesvos. Isolated plant-fossils have been found in many other places of the island, including the villages Molyvos, Polichnitos, Plomari and Akrasi. The formation of the petrified forest is directly related to the intense volcanic activity in Lesvos island during late Oligocene - middle Miocene. The volcanic eruptions during this time, produced lavas, pyroclastic materials and volcanic ash, which covered the vegetation of the area. The rapid covering of tree trunks, branches, and leaves led to isolation from atmospheric conditions. Along with the volcanic activity, hot solutions of silicon dioxide penetrated and impregnated the volcanic materials that covered the tree trunks. Thus the major fossilisation process started with a molecule by molecule replacement of organic plant by inorganic materials. In the case of the Petrified forest of Lesvos, the fossilisation was perfect due to favourable fossilisation conditions. Therefore morphological characteristics of the tree trunks such as the annual rings, barkers, as well as the internal structure of the wood, are all preserved in excellent condition.

•**All of the genera and species determined, belong to higher plant groups:** *Angiospermae* and *Gymnospermae.*

Taxodioxylon gypasaceum

Protection measures already have been taken or have to be taken:

•In order to protect the Petrified forest and ensure its proper management, five terrestrial and marine areas with fossil accumulations, as well as all the isolated fossils were declared as Protected Natural Monument with a special Presidential Decree (443 /1985).

•The need for further research and protection of the fossils led to the establishment of the Natural History Museum of Lesvos' Petrified Forest in 1994.

•Other information:

•The recently established Natural History Museum of Lesvos' Petrified Forest, therefore, has the potential to be a centre for palaeontological and other scientific research. Further research in the Petrified Forest will provide new data concerning the stratigraphy, palaeoecology, palaeoclimatology, and palaeogeography of the Southeast Mediterranean area, at the Cross-roads of Europe and Asia

•In addition the Museum will organize special environmental education programs in order to cultivate a widespread sense of respect to the Earth's Heritage and the Natural monuments, among young students.

References on studies already performed:

•VELITZELOS, E.(1988). The petrified forest of Lesbos. Mosion, Magasin Olympic Airways, February 88, pp. 60-73.

•VELITZELOS, E. (1993). Neue palaofloristische Daten zu kanophytischen Floren Griechenlands. Doc. nat., 78, pp. 1-17.

•ZOUROS, N., VELITZELOS, E. & SERAIDIS, P. (2001). Prified forest of Lesvos. New findings of the palaeoflora strengthen the uniqueness and worldwide charactere of the monument. 3ed Int. Symp. «Natural Monumnets and Protected Areas Management (1998)», UNESCO, Lesvos Isl. pp. 34-48.

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"Engineering Geology and Protection of Ancient Monuments and Archaeological Sites"

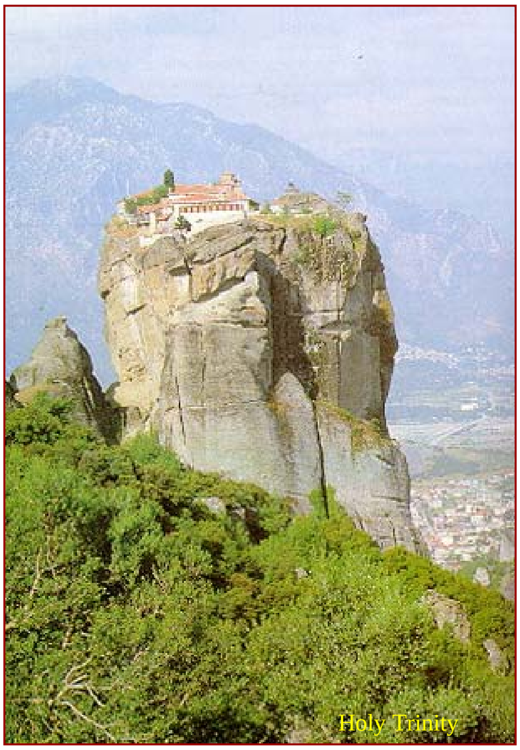
METEORA

Engineering geological conditions and problem:

• Meteora is from the biggest and most important group of monasteries in Greece after those in Mount Athos. We can locate the first traces of their history from 11th c. when the first hermits settled there. The rock monasteries have been characterized by Unesco as a unique phenomenon of cultural heritage and they form one of the most important stations of cultural map of Greece.

•The most important engineering geological problems are related to the stability of the rocky slopes and the stability of the monasteries. Weathering is also an important cause of damage of the masonry.

•The rock consists of conglometrate



Holy Trinity

Protection measures already have been taken or have to be taken:

• Stabilization of rock slopes

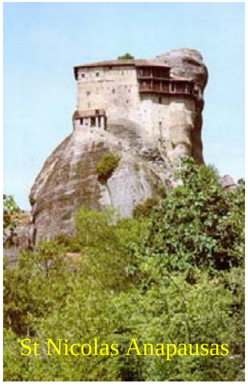
•Stabilization of the Monasteries

•Restoration of the Monasteries

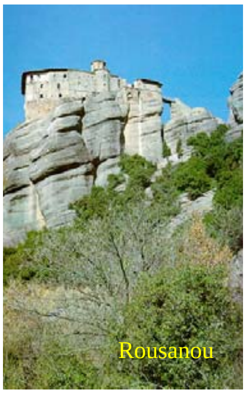
•Preservation of icons

•Consolidation of building stones and mortars

A great part of the monasteries (Katholika, cells, other buildings) have been restored and the rest of them is being restored, while in plenty of them the conservation of the wall paintings has been fulfilled.



St Nicolas Anapausas



Rousanou

Other information:

The most important Monasteries are: 1) The Holy Monastery of Great Meteoron, 14o AD, 2) The Holy Monastery of Varlaam, 16o AD, 3) The Holy Monastery of Rousanou, 16o AD, 4) The Holy Monastery of St. Nocolas Anapausas, 16 AD, 5) The Holy Monastery of St. Stefen, 16o AD, 6) The Holy Monastery of Holy Trinit, 15o AD.

References on studies already performed:

•7TH EPHORATE OF BYZANTINE ANTIQUITIES: Reports on Archaeological and Conservation Studies

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MYSTRAS

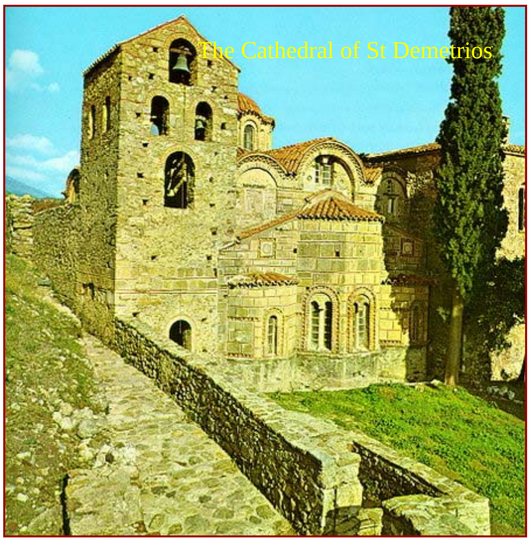
Engineering geological conditions and problem:

• Mystras occupies a steep foothill on the northern slopes of Mt. Taygetos, 6km. NW of Sparta. The castle on the top of the hill was founded in 1249 by the Frankish leader William II de Villeharduin. After 1262 it came under Byzantine control, and at the middle of the 14th century became the seat of the Despotate of Moreas. In 1448 the last emperor of Byzantium, Constantine XI Palaeologos, was crowned at Mystras. In 1460 the hill was captured by the Turks and in 1464 Sigismondo Malatesta of Rimini managed to capture the city but not the castle. For a short period Mystras came under the control of the Venetians (1687-1715) but was again taken over by the Turks. It was one of the first castles of Greece to be liberated in 1821. The foundation of modern Sparta by king Otto in 1834 marked the end of the old town's life.

•The engineering geological problem is related to the stability of the slopes, where the castle is built.


The Castle


The Palaces of the Mystras Despots


The Cathedral of St Demetrios

Protection measures already have been taken or have to be taken:

For many years, large-scale consolidation and restoration work has been carried out on the religious and secular monuments of the site, by the Committe for the Restoration of the Mystras Monuments and the 5th Ephorate of Byzantine Antiquities. The conservation of the wall paintings of the churches has already been completed and the restoration of the Palaeologan Palace will soon be finished.

Other information:

The most important monuments of the site are: 1) The castle, 2) the Cathedral of St. Demetrios, 3) the Church of St. Theodore, 4) the Monastery of Our Lady Peribleptos, 5) the Church of Our Lady Evangelistria, 6) the Monastery of Our Lady Pantanassa, 7) the Palaces of the Mystras Despots (Kantakouzenoi and Palaeologoi), 8) the Urban Buildings.

References on studies already performed:

•5TH EPHORATE OF BYSANTINE ANTIQUITIES: Reports on archaeological studies and on Restoration activities

•COMMITTE FOR THE RESTORATION OF THE MYSTRAS MONUMENTS: Reports on Restoration activities

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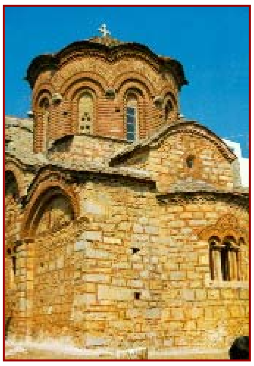
NEA MONI (AND AGIOI APOSTOLOI CHURCH) IN CHIOS ISL.

Engineering geological conditions and problem:

• Nea Moni (New Monastery) is a monument of 11th c. AD. The catholicon (main church) is decorated with marble revetments and mosaics. The refectory (Trapeza) lies to the SW of the catholicon while the west end of the precinct is occupied by the imposing defence tower. The half-subterranean Cistern, which is preserved intact, dates to the 11th century. The actual cells were constructed later and many of them are almost completely ruined today. The monastery is enclosed by an irregular in plan, stone perimeter wall.

•Slope instability aspects

•Weathering of the building stones and the mortars



Protection measures already have been taken or have to be taken:

•In modern times, many efforts have been made for the restoration of the monument and the preservation of the mosaics in the catholicon.

•In 1857, the abbot of the monastery Gregorios Photeinos carried out extensive restoration work in the catholicon, and completely altered its external appearance. The dome of the church, which had collapsed in the earthquake of 1881, was reconstructed in 1900. In the 1960's the mosaics were restored and since then, restoration has been carried out from time to time in several buildings of the monastic complex.

•Slope stabilization

•Conservation of mortars

•Restoration of the masonry

•Conservation of the icons

Other information:

Today the monument is used as a convent for nuns. A two-storeyed building of cells, located to the NW of the catholicon, has been reconstructed and now houses the Museum with the remaining treasures of the monastery.

References on studies already performed:

3RD EPHORATE OF BYZANTINE ANTIQUITIES: Reports of restoration activities

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ARCHAEOLOGICAL SITE OF OLYMPIA

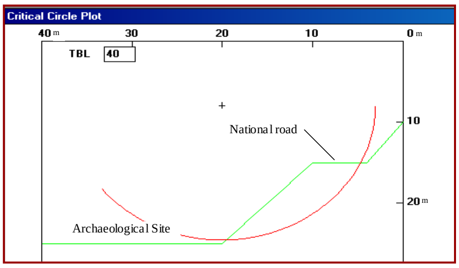
Engineering geological conditions and problem:

The archaeological site is limited to the north by a steep hill slope, which is crossed by a national road of heavy circulation. The slope (at the level of the archaeological site) consists of fine-grained soil, 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 in compact, presenting uniaxial strength of 5-15 MPa. According to the performed UU 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 is sutured rapidly, providing unstable conditions with earth pressures on the old rocky wall. According to our stability analysis, a safety factor of S.F<1 determines the instability of the lower part of the slope, under the road, toward the archaeological site

Protection measures that have to be taken:

Stabilization of the slope minimizing the earth pressure on the ancient retaining wall:

- Drainage of the slope,
- 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 methods used for reinforcing the ancient retaining wall should be adapted to the identity of the archaeological site.



Other information:

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, where Olympic games 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. The archaeological finds show that the area was at least settled from the 3rd millennium B.C.

References on studies already performed:

CHRISTARAS, B., MARIOLAKOS, I., DIMITRIOU, A., MORAITI E. & MARIOLAKOS, D. (2002), "Slope Instability at Olympia Archaeological Site, in S. Greece" - Int. Symp. UNESCO "Landslides Risk Mitigation and Protection of Cultural and Natural Heritage", Kyoto, pp. 339-342.

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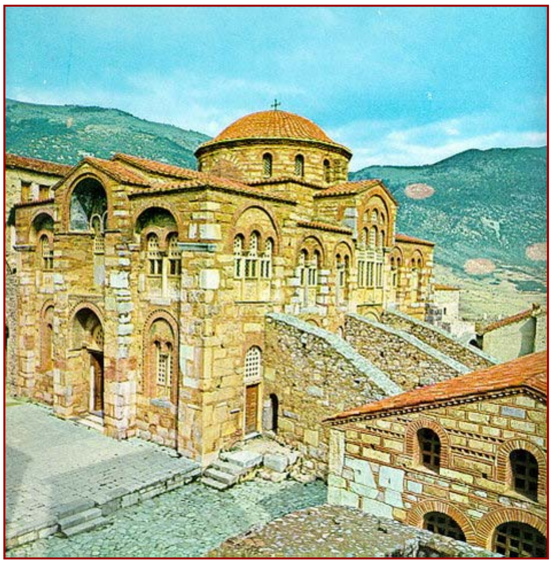
MONASTERY OF HOSSIOS LUCKAS

Engineering geological conditions and problem:

• The monastery lies on the west slope of Mt. Helikon, below the acropolis of ancient Steirion. It was built

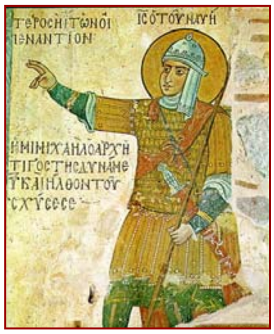
during the 10-11th c. AD.

- Weathering of building stones
- Weathering and damage of marble columns
- Stability problems of the monuments
- Landslide phenomena
- Damage of frescos and icons
- Fractures on the walls



Protection measures already have been taken or have to be taken:

- A conservation research was performed in th eframe of a EU program, during 1995 (GSRT-GR-EPET II)
- Characterisation of stones
- Estimaton of the depth of damage using ultrasonic techniques
- Determination of the treatment effectiveness by measuring the increase of the compressive strength and the ultrasonic velocity of the treated specimens
- Conservation of building stones and mortars
- Stabilization of the monument
- Conservation of frescos
- Slope stability analysis



References on studies already performed:

•1st EPHORATE OF BYZANTINE ANTIQUITIES: Reports on restoration activities.

•CHIRISTARAS, B. (1997): Estimation of damage at the surface of stones using non destructive techniques, Structural Studies, Repairs and Maintaince of Historical Buildings, *in* Advances in Architectural Series of Computetional Mechanics Publications, Southampton, pp. 121-128.

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MEDIEVAL FORTIFICATIONS IN THE CITY OF RHODES.

Engineering geological conditions and problem:

• The monumental group composed by the fortification of Rhodes covers an area of 350000m^2 around the town of the Knights.

•The sections open to visitors are to be found on different levels along the medieval moat and the peripheral park where the old fortified slope or "glacis" was situated, outside the fortification in the direction of the new town.

•The medieval fortifications in the city of Rhodes need big scale interventions as well as required restoration of departments that has collapsed, because of the action and the circulation of water and the action of plant's roots in a particularly porosity material of construction (sandstone - limestone).

Protection measures already have been taken or have to be taken:

•Examination of the engineering geological conditions at the foundation area.

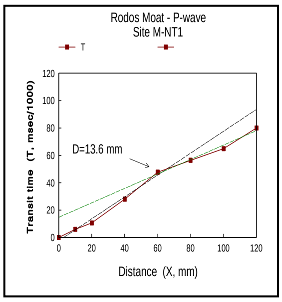
•Seismic hazard analysis

•Protection of the fortification constructions (masonry and limestone foundations) from earth pressure phenomena.

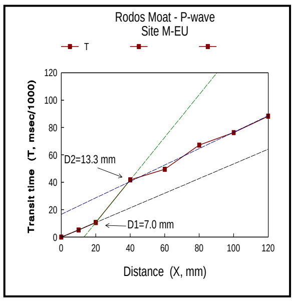
•Act as an additional supporting structure at specific points and strengthen the foundations.

•Non-destructive evaluation and consolidation of building stones and mortars.

Estimation of the consolidation depth of building stones, using indiretct ultrasonic techniques



Non-treated block



Consolidated block

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MOROPOULOU, A., TSIOURVA TH., THEOULAKIS, P., CHRISTARAS, B. & KOUI, M (1998). Non-destructive evaluation of pilot scale treatments for porous stone consolidation in the Medieval City of Rhode. *PACT 56 (Revue du Conseil de l' Europe), pp. 259-278).*

PITILAKIS, K. (1998). Medieval city of Rhodes: Geotechnical soil conditions seismic hazard analysis & seismic design loads. 4th Course of EU-DGXII on "The fortification in the Mediterranean Basin", pp. 250-264.

LEKKAS, E., SAKELLARIOU, D. & LOSIOS, S. (1997). Observations on the action of geologically induced hazards in the ancient city of Rhodes (Greece), Proc. 4th Int. Symp. Cons. Mon. Med., Rhodes, pp. 239-246.

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SIMONOS PETRA MONASTERY IN MOUNT ATHOS

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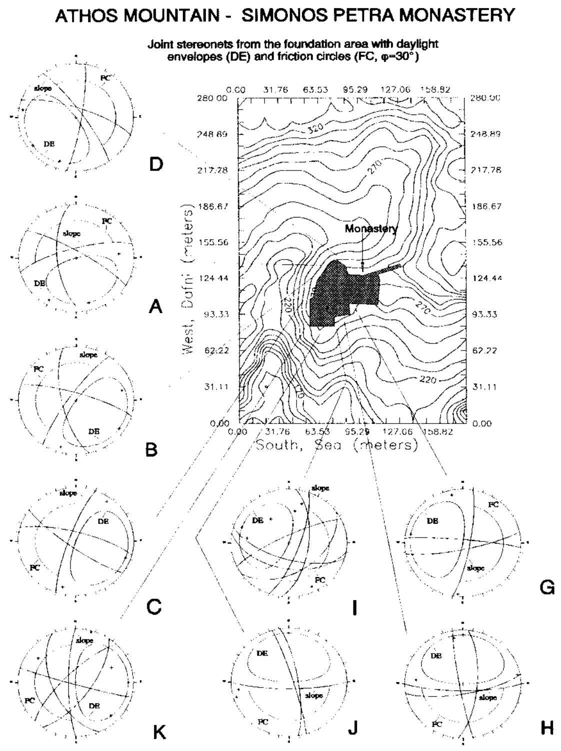
Engineering geological conditions and problem:

Mount Athos peninsula is located in Macedonia (N. Greece) and is administratively connected directly to the Patriarchate of Constantinople. It is a place of great historical and religious interest, where only Monasteries for men are built. The Monasteries are historical buildings of the 10th to 14th century. During the centuries they were destroyed and burned down several times, while they were rebuilt, enlarged and expanded including newly constructed buildings.

Simonos Petra Monastery was built around 1257 AD, on an isolated rock at the SW side of the peninsula. It was burned down several times and consequently only the lower parts of the construction, close to the rock base, are of that age. The western part of the present building was built in 1590 AD while the eastern part was built after the fire of 1891 AD.

The tectonic structures determined in the area cause unstable geotechnical conditions at the foundation rock mass. The presence of an important neotectonic fault of SW dip direction distinguishes two sections in the rock mass decreasing the stability of the Monastery. Furthermore, an important fault of E-W direction cuts through the site close to the building's western wall, creating fractures both to the building and the foundation rock.

A slope stability analysis was performed with the determination of important unstable wedge and planar failures and the calculation of their factors of safety, using both field measurements and laboratory test results. The rock mass quality was estimated at several representative sites and a geomechanical classification was performed. According to the results of the data elaboration, the rock mass quality in the southern and western slopes of the foundation area is low and of limited stability, causing damage to the monument. These instability phenomena are related to the neotectonic conditions of the broader area.



Slope stability analysis at the site of Simonos Petra Monastery

Proposed protective measures:

In order to protect the monument, a net bolts is necessary to be applied, in the sites where the approach is possible. Grouting could be used only in cases where the material is very broken and the discontinuites open. All the protection techniques have to respect the environment.

References on studies already performed:

CHRISTARAS, B., MOROPOULOU, A., DIMITRIOU, A. & DIAMANDOPOULOU, M. (1993): Geotechnical and weathering conditions at the Simonos Petras Monastery of Mount Athos, Greece. Proceed. of Int Congr. STREMA, Bath.

.**CHRISTARAS, B.** & MOROPOULOU A. (1994): Environemntal effects on the Monasteries of Mount Athos. The case of Symonos Petra Monastery. Proceed. of 3d Int. Congr. Conserv. Monum. Medit. Basin. Venezia

.*** (1995):*"Soil Dynamics and Earthquake Engineering*", Elsevier Publ., Princeton , 14 (1995), pp. 307-312

.**CHRISTARAS, B.,** PAVLIDIS, SP. & DIMITRIOU, A. (1994): Slope stability investigation in relation to the neotectonic conditions along the osuth-western coast of Mount Athos. The case of Symonos Petra Monastery. 7th Congr. I.A.E.G. Lisboa pp. 1577-1583.

.**CHRISTARAS.B,** DIMITRIOU, AN. & MAZZINI, E. (1995): Rockmass quality at the foundation area of the Simonos Petra Monastery, in Mount Athos - Greece. Intern. Congr.La Cita Fragile in Italia, pp. 191-196.

.Dimitriou, A., **Christaras, B**., Dimopoulos, G. & Pavlides, Sp (1997): Geotechnical aspects at four Monasteries in Mount Athos (N. Greece). A first approach of the stability conditions of the geological formations at their foundation sites. Intern. Symp. of IAEG, "Engineering Geology and the Environment", Athens. Balkema Publ. pp. 3113-3122.

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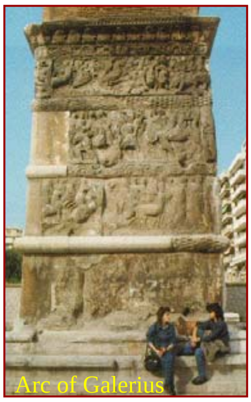
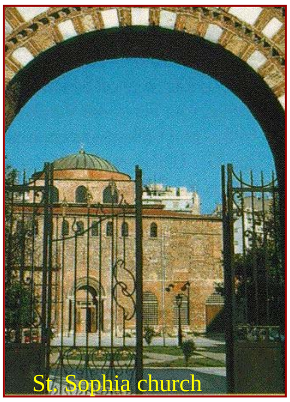
MONUMENTS OF THESSALONIKI

Engineering geological conditions and problem:

- The city was founded in 315 BC
- Quaternary and anthropogenic deposits (fine to coarse grained deposits)
- Settlement phenomena.
- Ground water presence
- Humidity and weathering of stones, mortars and frescos (icons).
- Stability of the monuments related to static, geotechnical and seismic causes.

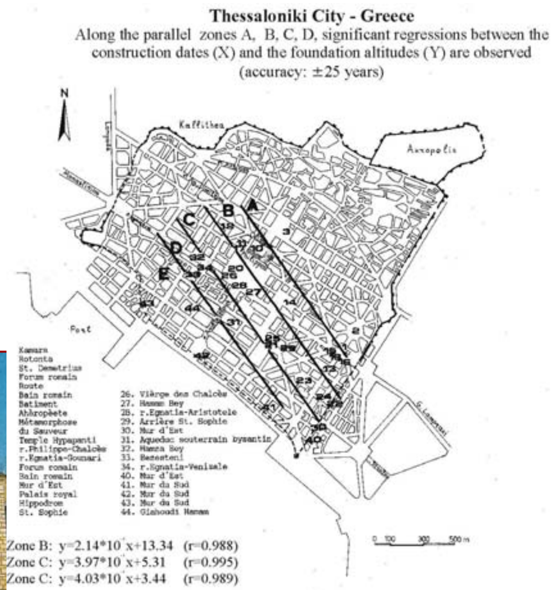

White Tower

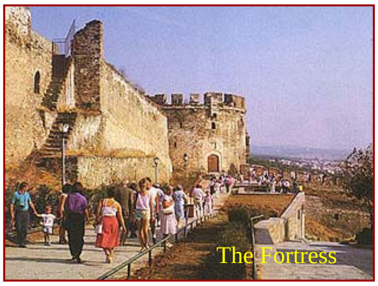

Arc of Galerius


St. Sophia church

Protection measures already have been taken or have to be taken:

- Stabilization of the foundation and masonry of the churches especially after the earthquake of 1978.
- Confrontation of the settlements and other geotechnical causes
- Consolidation of stones and mortars
- Conservation of frescos (icons) and mosaics
- Other restoration activities on the roman, paleochristian and bysantine monuments - eg. Roman Agora (3rd c. AD), Roman Palace (3rd c. AD), Arc of Galerius (3rd c. AD), Rotonda (3rd c. AD), Achaeropeitos church (5th c. AD), St. Demetrios church (5th c. AD), St. Sophia church (7th c. AD), Virgin of Halkes church (11th c. AD), Transfiguration (Metamorphosis) of our Lord church (14th c. AD), White Tower (15th c. AD) etc. The mosques and the baths of the turkish period are also under restoration.




The Fortress


St. Demetrios church

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- PAPAGIANNI, I. (1997): Proc. 4th Int. Symp. Conserv. Mon. Medit., Rhodes, Techn. Chamb. Gr. Publ., pp. 265-274.