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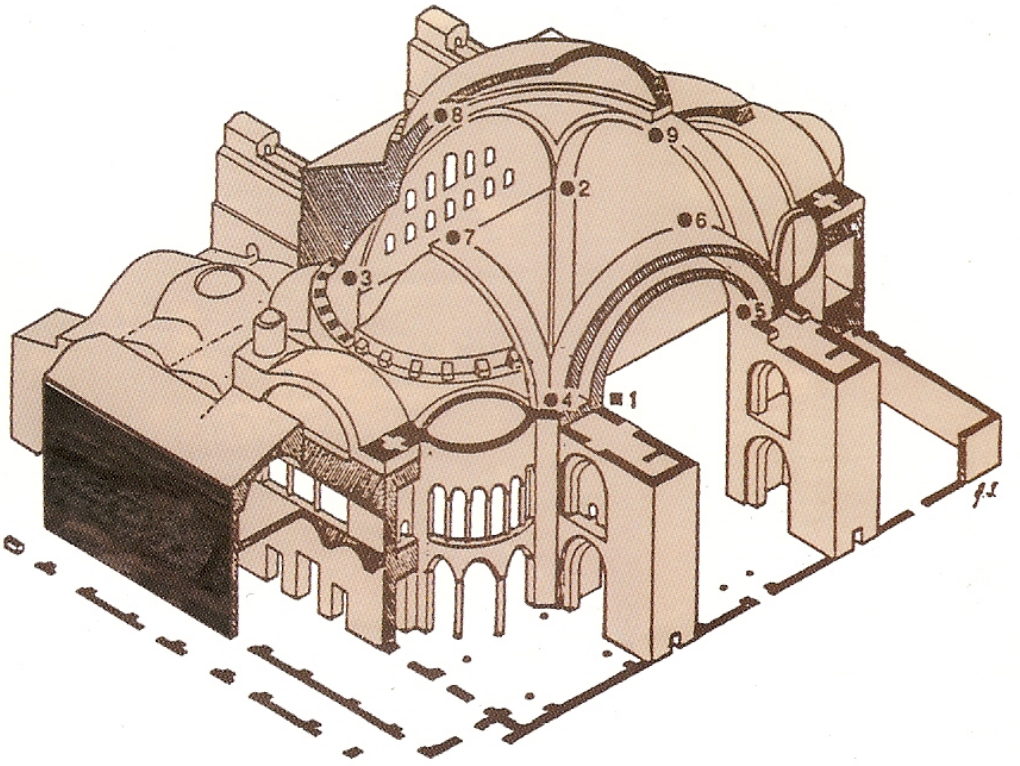
COMPATIBLE MATERIALS RECOMMENDATIONS FOR THE PRESERVATION OF EUROPEAN CULTURAL HERITAGE

PACT 59 2000

Revue du groupe européen d'études pour les techniques physiques, chimiques, biologiques et mathématiques appliquées à l'archeologie - Conseil de l'Europe



Scientific Editors: A. Moropoulou, G. Biscontin, J. Delgado Rodrigues, M. Erdik

In the memory of the late and regretted Manthos Zaphiropoulos

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PROTECTION OF BURIED MONUMENTS AGAINST GROUND WATER ACTIVITY USING GROUTING TECHNIQUES

Christaras B.[1], Mariolakos I.[2], Chatziangelou M.[1]

Abstract

The use of grouting was studied in order to protect buried monuments against ground water activity. The concept is to create an impervious shell, which isolates the floor and the walls of the building, so as the monuments to be impervious.

The type of the chemical grouts as well as the length and the number of necessary boreholes must be calculated by taking into account the penetration of the grout, expressed by the radius of grout, and the orientation of the boreholes. Although the proposed method is expensive, it establishes permanent drainage conditions regarding to pumping.

The Macedonian Tomb of Anthemion, located near Naoussa City in N. Greece, was used as a pilot example for study, given that it is buried in recent loose sediments consisting of clay, sand and gravel where the aquifer overflows the floor.

Location of tomb and geological settings

The Macedonian Tomb of Anthemion is located between Kopanos and Lefkadia villages, on the national road connecting Veroia and Edessa Cities, in Northern Greece (Fig. 1). This monument is of the 3rd c. B.C. and contains frescos of significant importance (Petsas, 1966, Alamani, 1995, Christaras et al,

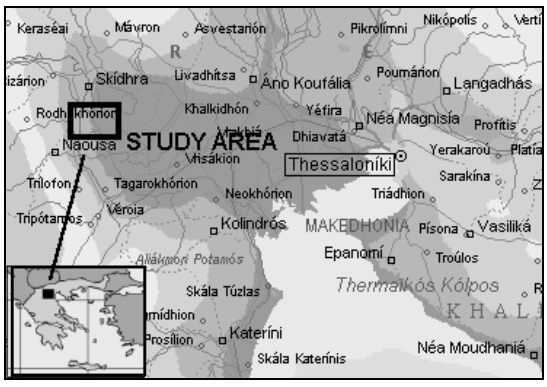

Figure **Σφάλμα! Άγνωστη παράμετρος**

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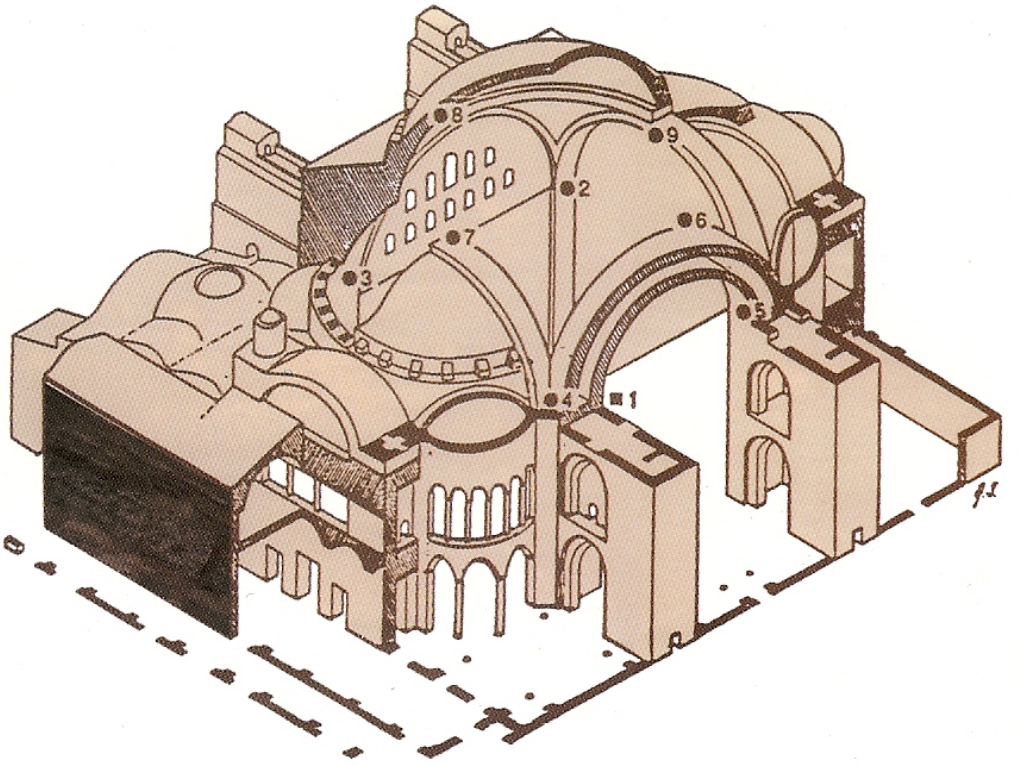

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1997). The Tomb consists of two rooms and presents Ionian style architecture. It was constructed using big block of travertine, which are very abundant in the area. Now, it is buried in the soil, due to the sedimentation.

Geologically, the area is located in the western part of Almopia zone (Kilias & Moundrakis, 1989). The surrounding area of the Tomb is consisted of resent alluvial deposits with fans and talus cones as well as Pleistocene lacustrine and continental deposits, with clay, loam, sand, conglomerates and travertine (IGME, 1982). The thickness of these deposits is estimated about 100 m and increases up to 200-300 m to the east.

The reservoir of the rivers and aquifers of the study area is the mountainous limestone masse located to the West of the Tombs (Vermio Mountain), (Athanasias & Soulios, 1995). According to the borehole data, the formations, in which the Tomb is 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 level varies from 6.97 to 8.05 and the hydraulic gradient has estimated 12-14%.

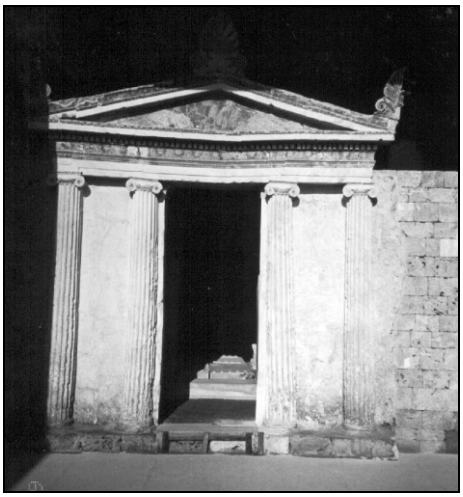

Figure **Σφάλμα! Άγνωστη παράμετρος αλλαγής.**. The tomb of Anthemion.

The groundwater overflows the floor of the monument causing damages related to a) the weathering of the walls and frescos and b) differential settlements and instability of the construction. The depth of the groundwater table is not constant during the year but increases during summer, when irrigation activities start. During this period a big quantity of surface water enrich the aquifer rising the water table.

Impermeation grouting technique

Impermeation grouting technique tries to be applied as a proposed method for establishing permanent drainage conditions regarding to pumping. The purpose of this method is to create an impervious shell, which isolates the floor and the walls of the tomb. Thus, all the walls of the tomb are achieved to be impervious.

According to the borehole data, the most suitable grout is estimated for every geological formation and the radius of grout.

The first estimation of the grout mix is based on the D_{10} of the grain size distribution. So, if D_{10} varies between 0.02mm and 0.5mm, colloidal solutions or polymersis used, such as silica or lignochrome gels, tannins, organic colloids on polyurethane. If D_{10} is less than 0.02mm, pure chemical solutions are used such as acrylamides, aminoplast or phenoplast.

Another estimation of the grout mix is based on the permeability of the soil. Thus, if the permeability is 10^{-4} cm/sec an acrylamide based grout is used. The viscosity of grout is less than 2cp. If the permeability is higher than 10^{-3}cm/sec, chrome lignin and phenoplast is used. The viscosity of grout is 5cp. If the permeability is higher than 10^{-2}cm/sec, a silicate-based grout with viscosity 10cp or a simple grout mix can be used.

When the two estimations are completed, the most suitable grout is chosen according to the tables of Shroff & Shah (1993). The main characteristics of the strength and permeability of the grouts, and the soil where grouting will be applied, are mentioned in these tables. So, the more suitable grout can be chosen, according to the kind of the soil and the two previous estimations.

The next stage of our method is to calculate the radius of the grout as to calculate the distance of each grouting and the exacted number of groutings. The radius of the grout is given by $t = (an/3khr)(R^3-r^3)$(Raffle & Greenwood, 1961), where k = soil permeability (m/sec), h = injection head (m), t = time (sec), r = radius of source (m), R = Radius of grout at time (m).

Table 1. Estimation of the type of grout for the Anthemion Tomb.

Borehole	**Depth (m)**	**D_{10} (mm)**	**Permeability of soil (cm/sec)**	**Type of grout**	**Strength & Permeability data after grouting**	**Investigator**
G3	3.20-4.10 5.0-7.00 7.00-7.5	0.015	$3.6 \cdot 10^{-3}$	AM-9	q_u=1242psi $\sigma_1-\sigma_3$=1230psi q_u=3.1kg/cm^2	Graf, 1982 Caron, 1963
>>	10.40-12.40	0.17	$2.25 \cdot 10^{-2}$	Silicate grouted sand Formamide or Formic Acid+Ethyl acetate	$\sigma_1-\sigma_3$=3200KN/m^2 q_u=250KN/m^2 (10 days curing)	Clough, 1979
>>	12.40-15.0	0.12	$1.7 \cdot 10^{-2}$	Silicate grouted sand Formamide or Formic Acid+Ethyl acetate	$\sigma_1-\sigma_3$=3200KN/m^2 q_u=250KN/m^2 (10 days curing)	Clough, 1979

According to the borehole data, it was made an attempt on estimation of the type of the grout mix and calculation of the influence radius of the grout. So, at the depth from 10.40 m to 15.0 m where D_{10} differs from 0.02 mm to 0.5 mm, the most valuable grout mixes are colloidal solutions or polymers such as silica or ligno chrome gels, tannins, organic colloids on polyurethane. At the depth from 3.2 m to 7.50 m where D_{10} is less than 0.02 mm the most valuable grout mixes are pure chemical solutions such as acrylamides, aminoplast or phenoplast. The viscosity is 10 cp.

The last estimation of the grout mix type and the grout radius are shown on Tables 1 & 2.

Table 2. Calculation of the radius of grout for the Anthemion Tomb.

Borehole	**Depth (m)**	**Injection head h (cm)**	**Porosity n (%)**	**Radius of injection pipe r (cm)**	**Time t (sec)**	**Ratio of viscosity of grout to that of water a**	**Radius of grout R (cm)**
G3	3.20-4.10 5.0-7.00 7.00-7.5	924 1520 1786	15	2.5	2100	10	41.18 48.61 51.3
>>	10.40-12.40	2348	10	2.5	2100	10	94.05
>>	12.40-15.0	2670	10	2.5	2100	10	89.41

Conclusions

The conclusions of our investigation can be summarized as follows:

1. The studied Macedonian Tomb present important weathering and settlement problems.
2. The soil is highly permeable, consisting mainly of gravel and clayey sand, alternated, in some cases, with thin layers of clay.
3. The described impermeation grouting technique is suggested in order to protect the tomb from the groundwater. The radius of grout varies from .5 to 1 m, depending on the grain size of the soil.

Acknowledgements

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