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ENGINEERING GEOLOGICAL MAPPING IN THE URBAN AND SUBURBAN REGION OF NAFPLION CITY (ARGOLIS, GREECE)

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Abstract

In our days the strategy of an integrated planning approach in dealing with urban development matters, is a reality and engineering geology plays a primary role. In the present study an approach of the engineering geological conditions of Nafplion city and the wider area are given.

In the region of interest, four (4) sampling boreholes were drilled by IGME, up to the depth of 40m. During the boring procedure in situ SPT and permeability tests were carried out, as well as the lithology of obtained material has been described. Samples, undisturbed and disturbed, have also collected for further laboratory tests. After the completion of each borehole, piezometric tubes were installed, for the monitoring of the underground water table. Laboratory tests for the determination of physical and mechanical characteristics of all drilled formations were executed.

The geotechnical distinction and unification of the geological formations was made on a 1:5,000 topographical map, in accordance with the up to date international practice. The engineering geological map in the urban and suburban region of Nafplion city is presented and the geotechnical characteristics of the formations structuring the area are evaluated. The combination of the results of the drilling programme as well as on the engineering geological approach and the geological structure of the studied area, resulted the compilation of the engineering geological map (scale 1:5,000) of Nafplion city wide area, where 18 engineering geological types are distinguished. The boreholes data of other public bodies have been also taken into account for this compilation. As the task of this project was the contribution to the urban development of Nafplion city, this engineering geological map will be a useful tool for engineers, planners, civil authorities, etc.

Key words: *engineering geological mapping, urban development, Nafplion, Argolis, Greece.*

1. Introduction

The region of study is extended north the city of Nafplion up to Tiryntha, southern up to the Stefaniotiko hill and eastern up to Exoni region. The morphology of studied area is characterized by the mountainous landscape that prevails in southern and the soft flat landscape that dominates to the north, with the exception of certain small hills. The drainage pattern in the mountainous part has a short length, as well as in the flat part small streams and torrents are seasonal developed. In the coastal region, according bibliographic references, the aquifer is found about the sea level, while in the plain is found in depth 1-4 meters. This happens because of the in-

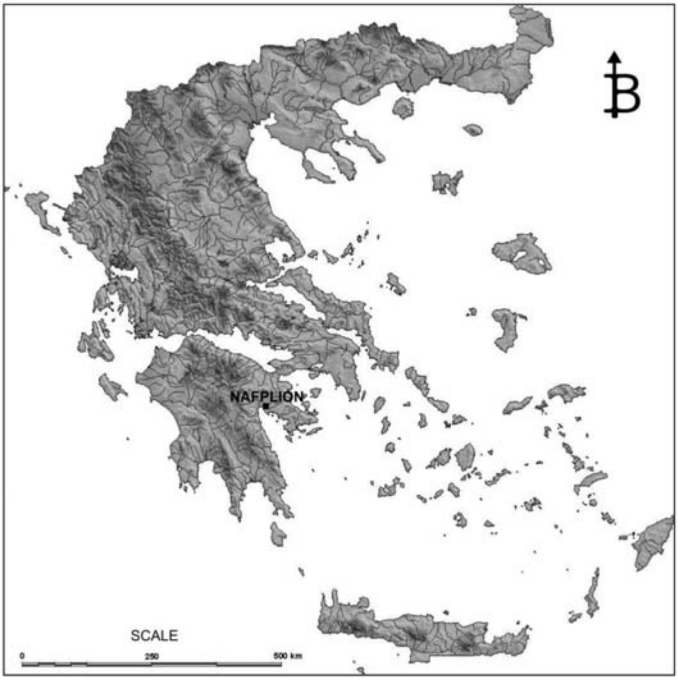

Fig. 1: Location of the wider Nafplion area, Argolis, Greece.

tensive exploitation of the wells and boreholes of the area, resulting to the subsidence of the aquifer and the salinity of waters.

2. Seismicity and seismic hazard

The wider area of Nafplion is characterized by low seismic hazard, as far as it has not been affected by very big earthquakes, but is influenced by neighbouring centres of seismic activity. Relating to the seismic action planning, according to the last modification of Greek Antiseismic Regulation (EPPO, 2001), the wider area is classified in the category I of seismic hazard, with seismic acceleration of territory A=a.g, where a=0,16 and g the acceleration of gravity (=981 cm/sec^2).

3. Geological structure

According to the IGME Geological map of Greece in scale 1:50.000 (sheet NAFPLION, by Tataris et al.) the dominated geological formations in the wide studied area from the older to younger are:

- Limestones of Middle Triassic age: They occur southern of Palamidi and eastern of Nafplion city. It concerns a carbonate rock group in which the lower members consist usually of reddish, hard limestones with cherts and thin intercalations of marls, they are followed by white-yellow slabby limestones with thin intercalations and cherts and thick-bedded ones with coarse clastic material.
- Limestones of Lower Cretaceous age: They are well bedded to massive, usually gray, and

in places with intercalations of marls. They occur at Palamidi, Akronafplia, Exostis and Profitis Elias regions.

- Limestones of Upper Cretaceous age: They occur in small outcrops at Akronafplia region and consist of thin bedded to thin slabbed limestones of white-pink colour, in places with intercalations and nodules of cherts.
- Idivided flysch of Maestrichtian age: It dominates in eastern and southeastern of Nafplion city and consists of calcite shales, sandy marls, sandstones and conglomerates with intercalations of clastic limestones. In the lower layers and towards the transition sediments to the underlying limestones serpentines are presents.
- Quaternary deposits: They occur mainly in the plain area, which is extended north of Nafplion city. They consist of thin-grains to gross-grains loose materials of coastal and terrestrial origin. On the mountainsides and hillsides of the area, old and recent screes and talus cones are developped

The tectonic activity in the studied area is quite complicated with faults, folds and upthrusts jn large scale.The folds and the large scale upthrusts appear to the preneogene formations, while the faults usually normals are responsible for the morphology of the recent landscape and the creation of seashores, such as the trench of Argive plain. The main faulting directions are E-W, NW-SE, and NE-SW.

4. Engineering geological mapping and structure of the wider Nafplion area

Engineering geology developed in response to the increasing demands of various technical works, which required a better understanding of the interaction between the ground, foundations and constructions, in order to build more economically and on a safer base.

In the Hellenic territory, engineering geological maps have been progressively developed and as far as practical have incorporated information from various technical works. Even a few years ago, there was lack of regional maps giving basic engineering geological information, such as for planning land use and technical works, the selection of the most appropriate types and methods of construction and the better protection of the environment. To this end, the engineering geological map of Greece, at a scale of 1:500,000 (IGME, 1993), constituted one of the first important efforts. In addition, the 1:10,000 engineering geological map of the wider Thessaloniki area is considered to be a basic infrastructure tool for more detailed investigations, as well as a useful aid for responsible civil authorities and technical personnel, during the preliminary stage of various technical works (Hadzinakos et. al, 1990; Rozos et. al, 1990; Rozos et. al, 2004).

The engineering geological distinction and unification of the geological formations was made on a 1:5,000 topographical map, in accordance with the up to date international practice. Necessary adjustments for the peculiarities of the Greek territory (Koukis, 1980; Koukis, 1988) and especially of the area under study were also taken into account. According to the international views and recommendations (Anon, 1972; Anon, 1979; Anon, 1981; Bell, 1981; Carter, 1983; Dearman and Matoula, 1976; Matoula et. al, 1986; UNESCO/IAEG, 1976), the above map is characterised as a multi purpose, synoptic and large scale engineering geological map, and is shown with a simplified legend in Figure 3. In the above map (Figure 2) the surface development of all lithological types is given, while their geotechnical description is presented below.

The data used in the description of the lithological types were obtained from many boreholes executed by a number of investigators from both the public and private sectors. Also, in the region of interest, four (4) sampling boreholes were drilled by IGME, up to the depth of 40m. During the boring procedure in situ SPT and permeability tests were carried out, as well as the lithology of obtained material has been described. Samples, undisturbed and disturbed, have also collected for further laboratory tests. After the completion of each borehole, piezometric tubes were installed, for the monitoring of the underground water table. Laboratory tests for the determination of physical and mechanical characteristics of all drilled formations were executed (Apostolidis and Koutsouveli, 2007).

The engineering geological map of the wider Nafplion area, at a scale of 1:5,000, contributes significantly to the optimization of land use and better planning of technical works. However, such maps cannot be considered a substitute for in situ geotechnical investigations at the microscale for every individual construction. This map distinguishes eighteen (18) engineering geological types, ET (Figures 2 and 3). Many geotechnical boreholes as well as in situ observations and sampling were used in the preparation of this map. Special emphasis was given to those units, which are present in inhabited/industrial areas. The brief descriptions of the engineering rocks and soils follow those prepared for Engineering Geological Mapping. The engineering geological type (ET) has the highest degree of physical homogenerty. It should be uniform in lithological character and physical state. These units can be characterized by statistically determined values derived from individual determinations of physical and mechanical properties and are generally shown only on large-scale maps (UNESCO/IAEG, 1976).

A little lower are given in details the descriptions of eighteen (18) engineering geological types (ET) that were divided in the region of interest, from the younger to the older one (Apostolidis and Koutsouveli, 2008):

- Type Ia: Loose materials of embankments of historical and younger age, small thickness (less than 1 m). These materials consist of structural stones, tiles, coats and other constructive materials mixed with soil deposits, which mainly have a silty-sandy composition, with some grits and gravels.

- Type Ib: Loose materials of embankments and recent deposits of sandy clays, sands and gravels in places. The thickness of this formation usually varies between 1- 4 m.

The formations of type Ia and Ib appear in a great section to the down town of Nafplion. Their geomechanical behaviour is unsatisfactory imposing the improvement of the soil to the safety of the various constructions.

- Type IIa and IIb: Deposits in river-beds. They are incohesive materials of small thickness, from cobbles of various size and origin, sands and locally silty-clays. They have divided in two types, type IIa (mainly coarse-grained materials) and type IIb (mainly fine-grained materials and sand). In general, their geomechanical behaviour is controlled by the characteristics and percentage of the fine material.

- Type III: Clays, silts and locally sandy-silts, soft, mainly grey or grizzled colour. At places, it contains organics, shells and plant remains. They are characterized, usually, by high plasticity, while locally, under certain conditions, are expected phenomena of subsidences and liquefactions.

Physical and mechanical properties (usual range of values):

w_L = 22.0 - 67.0 %   c = 6 - 122 KPa

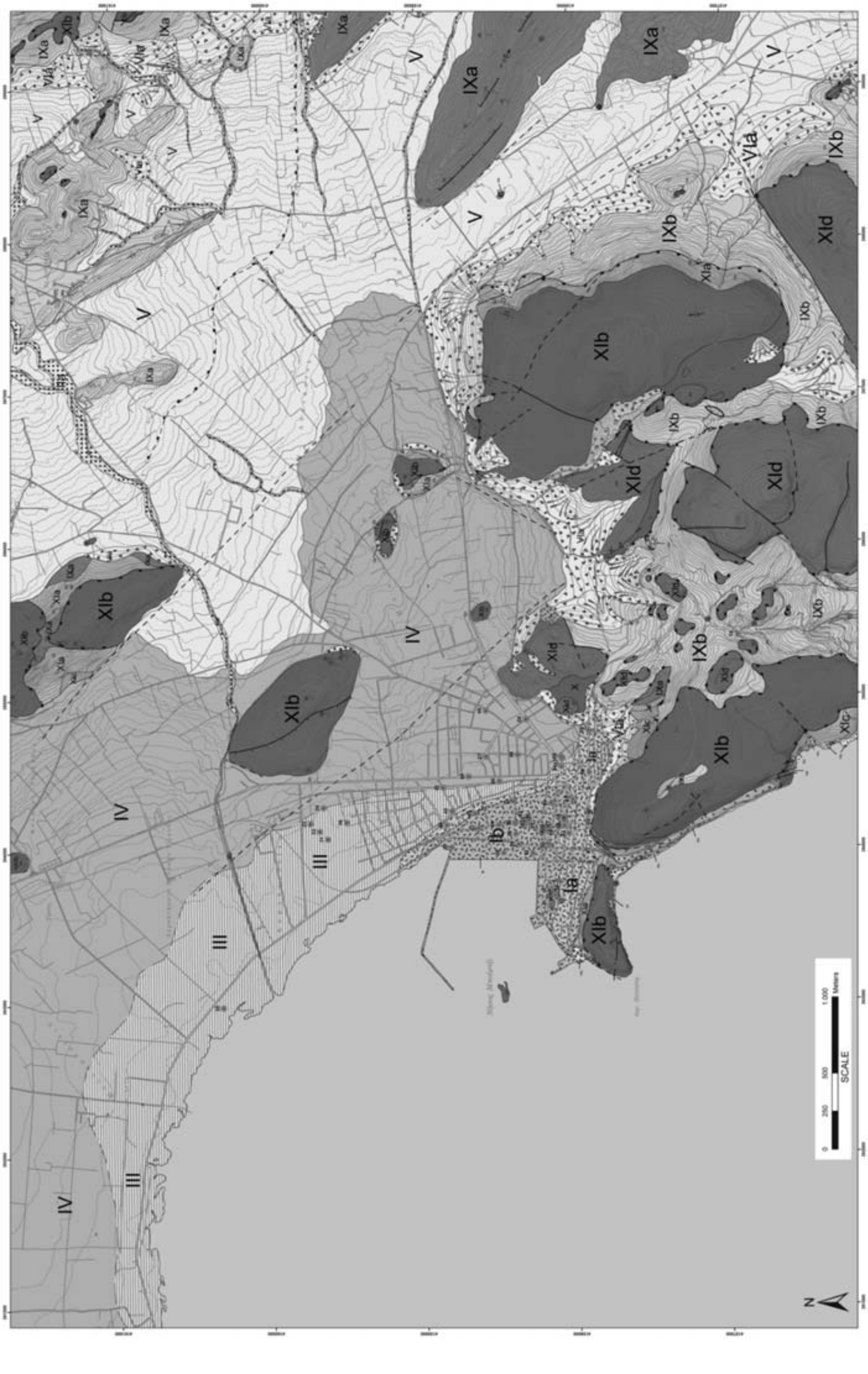

Fig. 2: Engineering geological map of the wider urban and suburban region of Nafplion city, Argolis, Greece.

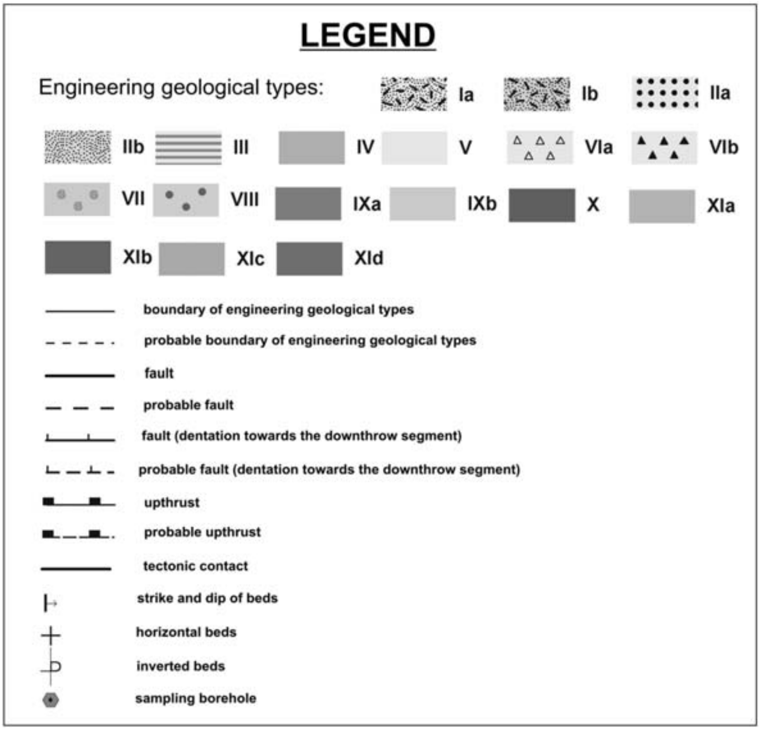

Fig. 3: Legend of engineering geological map (Figure 2).

I_P = 11.0 - 43.0 % q_u = 10 - 201 KPa

w = 17.8 - 65.3 % c_c = 0.041 - 0.46

γ_b = 16.7 - 20.3 kN/m^3 e_o = 0.728 - 1.348

e = 0.62 - 0.74

- Type IV: Clays and silts, brown or red-brown or yellow-brown colour, with small variations in the percentage of sand and small gravels at places. They are characterized by middle to high plasticity and middle to big coherence.

Physical and mechanical properties (usual range of values):

w_L = 20.0 - 65.0 % c = 8 - 155 KPa

I_P = 10.5 - 50.0 % q_u = 26 - 598 KPa

w = 13.0 - 41.4 % c_c = 0.08 - 0.33

γ_b = 18.1 - 21.6 kN/m^3 e_o = 0.499 - 1.045

e = 0.50 - 0.94

- Type V: Loose deposits of mixed phases, brown or red-brown colour. They are composed of silty-clays, sandy-clays, sands, grids, gravels and cobbles of various size and

Photo 1: The formation of engineering-geological type VII, with the characteristic fossils Strombus bubonius.

origin. They are characterized by frequent and rapid changes in their lithological composition and grain size distribution towards their horizontal and vertical development. Their behaviour is controlled by their thickness, their lithological anisotropy and the inclination of the ground (especially in the case of dynamic loading). The strong heterogenelty of these formations results in high anisotropy of their mechanical behaviour, but they usually show satisfactory shear strength parameters, especially in areas with gentle morphology. In general, their geomechanical behaviour is usually controlled by the characteristics and percentage of the fine material.

- Type VIa: Screes and talus cones. Pebbles, cobbles and small fragments of limestones, with sandy-clay materials, constitute them. Usually, they present poor coherence, with decreased geomechanical characteristics.
- Type VIb: Cohessive (usually) to semi-cohessive screes and breccias. They are composed of coarse-grained elements of different origin (mainly from limestones) and various sizes with reddish colour cement (usually red calc-clays). At places, olistholiths of various dimensions are presented. In its entirety, this formation behaves as weak-rock, with decreased geomechanical characteristics.
- Type VII: Coherssive conglomerates in banks, with red clayey cement. At places, the formation has the look of pebbly and encloses the characteristic fossils Strombus bubonius (Photograph 1). In its entirety, this formation behaves as powerful weak-rock, with satisfactory geomechanical behaviour.
- Type VIII: Cohessive conglomerates-microconglomerates, from cobbles of various origin and size and red calc-clay cement, in layers 10-15cm. In its entirety, this formation behaves as weak-rock, with satisfactory geomechanical behaviour.
- Type IXa: Flysch consisted of sandstones, quartzitic sandstones, sandy-marls, siltstones

and conglomerates with intercalations of limestones. They are usually thin-bedded, but often with sandstone layers, 0,50-1,00m thick. The layers present strong traces of horizontal tectonic deformation (folds, wrinkles, inversions, fractures and fragmentations). In macroscale, flysch is considered as an impermeable formation, allowing the occurence of small springs (usually between the fragmentation zone and/or weathering mantle and bedrock). Surface beds usually show a medium to strong weathering and a dense net of discontinuities (bedding planes and joints) causing intense secondary looseness. Flysch, usually, gives a weathering mantle of varying thickness. This formation characterized by an obvious instability, which is usually connected with the numerous heterogeneous layer contacts and the steep bed inclinations, in conjuction with the strong relief and the action of water. Therefore, problems connected with foundation of technical works are very often, usually shown as shear strength problems of the formation. In general, geotechnical behaviour presents a clear anisotropy and rapid changes, controlled by the degree of looseness (weathering-fragmentation), the orientation of discontinuties, the dip of slopes and the action of water. The landslide phenomena usually affecting weathering mantle and upper fragmentation zone.

- Type IXb: Flysch consisted of calcareous schists, sandstones, quartzitic sandstones, conglomerates, reddish marls, sandy-marls, siltstones, with intercalations of limestones in thin layers. At places, usually near upthrusts, flysch is semi-metamorphic with olistholiths of various dimensions (limestones, dolomites, ophiolites, etc). This formation is intensely fractured and multifolded and gives a weathering mantle of varying thickness. They present downgrading geomechanical characteristics and strength parameters, but unfavourable factors such as the intense-multiple fracturing and weathering of the cement, in conjunction with steep slopes and possible base erosion often cause loosening of the rockmass.

- Type X: Formation intensely fractured and multifolded, which is constituted from serpentines, ophiolites, serpentinized peridotites, siltstones, sandstones, conglomerates, limestones, cherts, etc. It is presented as one completely fractionally rockmass with decreased geomechanical characteristics, which at places, due to erosion, is changed in remaining soil.

Physical and mechanical properties (usual range) of values for soil materials of alterated mantle of serpentines:

$w_L = 30,3$ %	$c = 67$ KPa
$I_P = 14,6$ %	$q_u = 35$ KPa
$w = 20,5$ %	$c_c = 0,145$
$\gamma_b = 20,0$ kN/m^3	$e_o = 0,612$

Physical and mechanical properties (usual range) of values for soil materials of decomposed serpentine:

$w_L = 29,3 - 46,2$ %	$c = 219$ KPa
$I_P = 9,4 - 31,1$ %	$q_u = 321 - 477$ KPa
$w = 12,2 - 15,2$ %	$c_c = 0,040$
$\gamma_b = 21,4 - 24,5$ kN/m^3	$e_o = 0,266$

- Type XIa: Limestones, white or pinkish or reddish in colour, thin-bedded to thin-slabbed, hard, with nodules or lenticular silica layers at places. The intact rock is characterized by high values of strength parameters, while the rockmass shows medium to high permeability and good geomechanical behaviour for the foundation of technical works.
- Type XIb: Limestones, white-gray or grayish in colour, medium - thick-bedded or unbedded, usually fractured and strongly karstified in the upper beds. In certain cases and in a local scale, limestone rockmass breaks in fragments. Failures are usually observed as rockfalls on steep slopes, where an increased secondary loosening of the rockmass occurs or in cases where disturbances of the natural stability state and dynamic loading have taken place. In its entirety, this formation is characterized by good geomechanical behaviour.
- Type Xic: Cherts, in intercalations with thin-bedded limestones, conglomerates or breccias and few ophiolites in places. Reddish formation, with satisfactory geomechanical behaviour.
- Type Xid: Limestones and dolomites, white-gray or grayish in colour, medium to thick-bedded, compact, fractured and faulted. Underground water is restricted in the fractured zone of limestones, while dolomites are considered practically impermeable or semi-permeable. At places, usually on steep slopes, failures are observed as rockfalls. In its entirety, this formation is characterized by good geomechanical behaviour.

5. Conclusions

From the above analysis, regarding the compilation of the engineering geological map of Nafplion wider area at a scale of 1:5,000, the following remarks can be made:

- For the preparation of the above-mentioned map, which is thought to be a very useful tool for the better land use and planning, both an extended fieldwork and the evaluation of many geotechnical boreholes were used.
- Thus, eighteen (18) engineering geological types (ET) have been distinguished. Special attention was given to those units which structure inhabited zones as well as industrial areas, to avoid problems to the future development of the wider area.
- For every type, the ranges of the values of some main physical and mechanical properties examined, as well as a general description of their geomechanical behaviour, are given.
- As the task of this project was the contribution to the urban development of Nafplion city, this engineering geological map will be a useful tool for engineers, planners, civil authorities, etc.

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Notation

The following symbols were used in this paper:

w_L: liquid limit

c: cohesion (from direct shear test or triaxial shear test – Unconsolidated Undrained)

I_P : plastic index

q_u: uniaxial compressive strength

W : moisture content

c_c: compression index (from consolidation test)

γ_b: bulk density

e_o: initial void ratio (from consolidation test)

e: void ratio