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GEOLOGICAL AND GEOTECHNICAL CONDITIONS OF THE CITY OF AGRINION, GREECE

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ABSTRACT

The city of Agrinion in Western Greece is subjected to a high seismic risk due to the seismotectonic regime of the broader area, which adjoins to the convergence boundary of the African and Eurasian plates. The recent detailed geological survey revealed that the city is located on the northern border of a graben striking E-W, characterized by the presence of normal faults within the urban region. The broader area of the municipality of Agrinion consists of: (i) flysch formation including alternating layers of mainly sandstones and siltstones, (ii) moderately cemented to loose conglomerates-breccia, (iii) alluvial deposits and fans, (iv) terrace deposits and (v) swamp deposits. The geological program included the execution and the evaluation of the data of thirty boreholes, cone penetration tests (CPT), two cross-hole tests, standard penetration tests and laboratory testing. Based on the results of the above investigations, six geotechnical units were determined. According to the results of cross-hole tests, the seismic bedrock coincides with the flysch formation, exhibiting shear wave velocities greater than 700 m/sec. Finally the shear strength and deformability parameters of different geotechnical units were estimated, as well as the bearing capacity and settlement of shallow and deep foundations (piles) for these units were assessed.

INTRODUCTION

The city of Agrinion is located in Western Greece being 160 km^2 in extent and moderately populated with 50.000 inhabitants. The south-southwestern part of the city is a flat plain area, while the northern is a hilly or semi-mountainous one. Regarding the seismicity, the broader area of western Greece is characterized by high seismic activity, as it adjoins to the convergence boundary of the African and Eurasian lithospheric plates. In the context of seismic hazard mitigation of the area, a detailed study was carried out including geological, neotectonic, geotechnical and urban planning investigations.

The main results of the geological and geotechnical study, including data of the site investigations and in-situ and laboratory testing, are described below.

GEOLOGICAL SETTING

The broader area of the city of Agrinion is underlain by the following lithologic units from the older to the younger ones:

- Flysch: It consists of alternating layers of sandstones, siltstones and rarely microbreccia – conglomerates. It represents the geological bedrock of the area and its thickness exceeds 1.000 m. It outcrops only in a limited zone at the northern part of the city.
- Conglomerates – Breccia: These are semi-cemented to loose, red-reddish brown in color, with a silty and rarely clayey matrix. The gravel and cobbles have diameters varying from few cm to 25-30 cm. This unit outcrops at the eastern part of the city and its thickness is about 150 m.
- Dokimion formation: It consists of silts and clays with sand and well-rounded limestone gravel of a diameter 1-5 cm. It is located at the western-southwestern part of the city.

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- Alluvial fans: They are loose breccia – conglomerates, with red clayey matrix, developed as alluvial cone, at the eastern plain area of the city.
- Terrace deposits: These consist of cobbles, sands, silts and clays and are located at the north-western part of the city, with a great thickness variation.
- Alluvial deposits: these deposits consist mainly of clays and silts, while the coarse – grained materials include sandstone gravel and cobbles. They cover the main part of the plain area at the southern and western part of the city.
- At certain areas of the southern part of the city, swamp deposits are located, consisting of high plasticity clays and silts.

NEOTECTONICS

The main neotectonic macrostructure of the broader area is the neotectonic depression of Trichonis, where Trichonis and Lisimachia lakes are developed. It is an elongated neotectonic graben, with an E-W main direction. At the northern and southern boundaries of this graben, the presence of long normal faulting zones are observed striking E-W.

The city of Agrinion is located at the northern boundary of this depression, where the corresponding faulting zone crosses the area. The resulted morphological regime, which separates the area into two parts (the flat plain and the hilly – semimountainous one) is attributed to this neotectonic macrostructure.

The faulting zone is not visible through the urban area, because it is covered by recent deposits and buildings, but it was detected by the geotechnical investigations during the present study. This fault zone is considered to be an active tectonic structure and, due to its great length, can be characterized as a seismic fault accommodating seismic foci or being activated by near field earthquakes.

GEOTECHNICAL INVESTIGATIONS

A detailed investigation was carried out for the determination of geotechnical conditions of the city of Agrinion, consisting of:

- Five exploratory boreholes, at depths of about 20 to 50 m.
- Standard Penetration Tests (S.P.T.), which were carried out during drilling, at about 1.50-2.50 m depth intervals.
- Eight Cone Penetration Tests (C.P.T.), from the aforementioned tests, some were executed by using a mechanical cone and others by using an electrical one.
- Cross-Hole tests at two sites, in order to determine the dynamic characteristics of soil formations, such as seismic velocities V_s and V_p and shear modulus G_o. The S.P.T. mechanism, rich in shear wave energy (and poor in compressional one), was used as a mechanical impulse source, placed in line with an inhole receiver, including a 3-component pick up unit (sensor geophones).
- A series of laboratory tests, for the determination of physical and mechanical properties of soil formations.

DISCUSSION OF RESULTS

Engineering Geological and Geotechnical Conditions

The detailed logging of the borehole samples, including also logs of twenty five (25) previously executed boreholes in the study area, as well as the evaluation of in-situ and laboratory testing results, allowed grouping of the soil formations into six (6) geotechnical units, based on engineering geological criteria.

- Unit I: Brown, brownish-yellow to grayish-brown soft to stiff sandy clays with gravel (mainly CL).
- Unit II: Brown, brownish-gray, grayish-yellow, brownish-red to dark gray hard sandy clays, with sandstone gravel (CL) and thin interlayers of silty and clayey gravel.
- Unit III: Brown, brownish-red clayey sands with gravel (mainly SC); locally thin interlayers of sandy clay.
- Unit IV: Brown clayey gravel (GC) to poorly graded gravel (GP).
- Unit V: Weathered flysch, consisting of sandy clay (CL) and silty clay (CL-ML), with thin interlayers of silty sand.

- Unit VI: Flysch formation, consisting mainly of clayey sandstone layers.

Typical geotechnical parameter values, based on the in-situ and laboratory testing results, are given in table 1. By evaluating the subsurface findings gathered from boreholes logging or penetration tests (SPT, CPT), the geotechnical N-S section was established (Fig. 1). The boundaries between different soil units, although interpreted from borehole descriptions, are subjected to some approximation. From this cross-section, the following are concluded:

Table 1 : Geotechnical characteristics of units I-VI (in brackets the mean value, with asterisk test over water table).

Geotechnical Characteristics	Geotechnical units					
	I	II	III	IV	V	VI
(%) passing sieve no200	18-96 (73)	25-89 (66)	22-71 (34)	13-68 (26)	29-65 (49)	17-74 (47)
Liquid limit, W_L(%)	23-52 (31)	21-43 (30)	28-68 (41)	25-30 (28)	22-27 (24)	26-NP --
Plasticity index, I_P (%)	8-29 (15)	7-26 (14)	10-45 (22)		9-14 (11)	12-NP --
Natural water content (%)	14-29 (19)	13-21 (18)	12-18 (15)	9-15 (12)	14.7-19.4 (17.05)	8.8-19.4 (15)
Bulk density (t/m^3)	1.92-2.23 (2.08)	2.00-2.26 (2.14)	1.82-2.06 (1.97)		2.05-2.31 (2.18)	2.11-2.28 (2.10)
N_{SPT}	2-40 (21)	19->50 (45)	9->50 (24)	>50 >50	>50 >50	>50 >50
V_P (m/s)	430-680* (539)* 1056-1876 (1401)	1423-2331 (2003)			1201-1787 (1579)	2435-3821 (3209)
V_S (m/s)	226-316 (268)	361-569 (498)			337-420 (377)	597-1048 (833)
G_o (MPa)	100-210 (151)	275-683 (534)			248-388 (313)	785-2638 (1703)
CPT, q_c (MPa)	1-3		3-3.5			
Unconfined compressive Strength, q_c (MPa)	93-377 (204)	99-820 (362)	200-589 (356)		74-170 (122)	118-180 (154)
UU test, c_u (kPa)	40-230 (110)	54-113 (84)				
CUPP test, c′ (kPa), φ'^{o}	40 22°30′					
Direct shear test, c′ (kPa), φ'^{o}	27-45 19-29					
Consolidation test, C_c	0.043-0.164 (0.121)	0.06-0.15 (0.09)				

- The geological bedrock represented by flysch formation (Units V and VI), is located at the north part of the city, at the depth of about six metres, being in tectonic contact with neogene deposits.
- The Pliocene and recent deposits, cover the greater part of the city of Agrinion (Units I, II, III, IV).
- Units I and II are well developed (horizontally and vertically), with a maximum thickness at the north and northwest part of the city, more than 52 m.
- Unit III covers Units I and II at the south and west part of the city and overlays Unit IV at the northeastern part.
- Unit IV, underlays units I and II and outcrops at limited areas at north and south-southeast parts of the city.

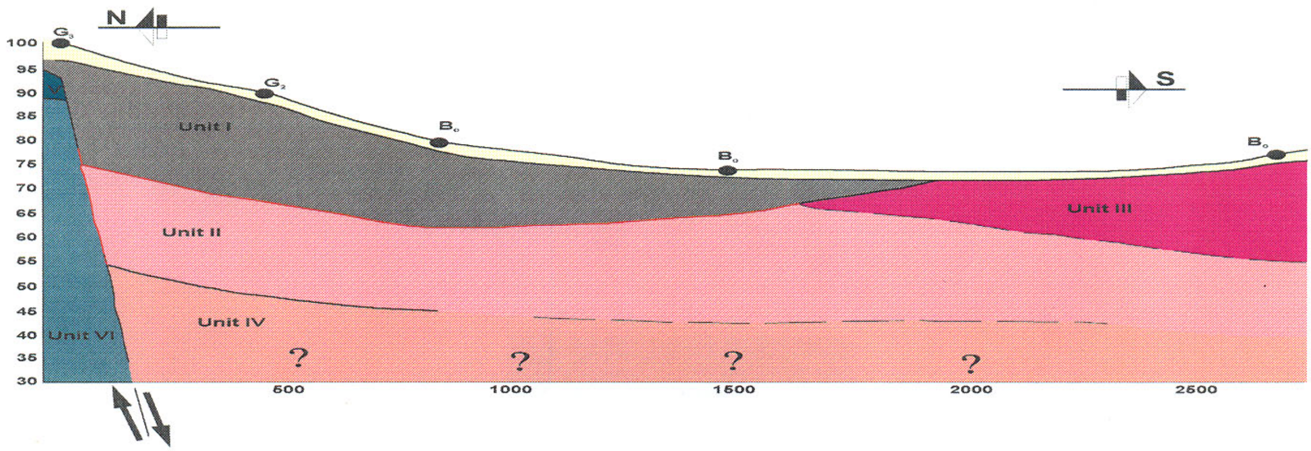

Figure 1 : Geotechnical cross-section.

- At the northern part of the city, the trend of a probable normal fault striking East-West was revealed, as shown in the cross-section of figure 1.

Variation of Dynamic Parameters of Geotechnical Units

The cross-hole tests enabled P and S-wave velocities (V_p and V_s) as well as shear modulus (G_o) to be determined as function of the depth for different geotechnical units as illustrated in figure 2. Also, in table 1 the variations of V_p, V_s and G_o values, as well as their mean value of each geotechnical unit are summarized. Interpretation of in-situ measurements for the two examined sites enabled the following remarks:

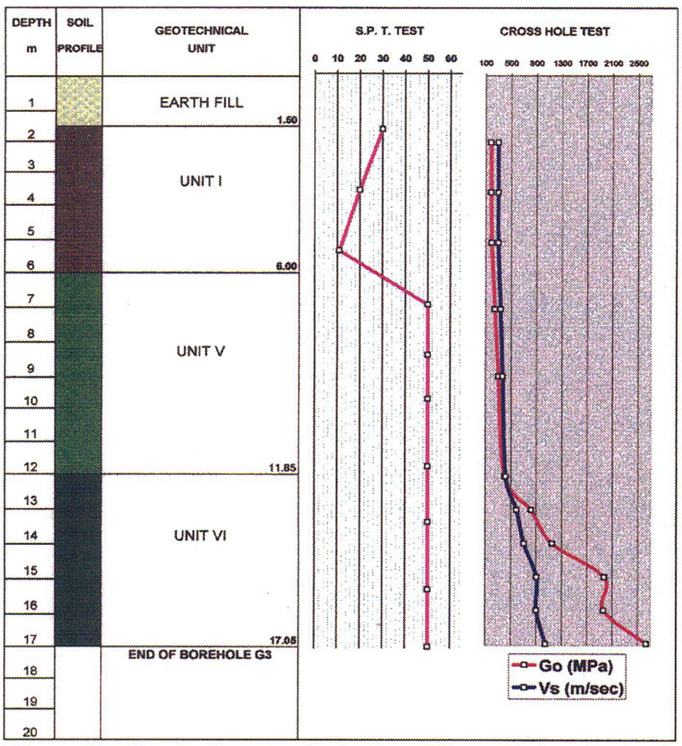

Figure 2 : Typical geotechnical profile with in-situ test results.

- V_s, G_o and V_p values show a general increase with depth, which is more obvious for units V and VI.
- For Unit I, V_s, G_o and V_p values, show a small variation due to the horizontal and vertical homogeneity of this unit. V_p values are lower (V_p<1.000 m/s) above the water table.
- For Unit II, V_s, G_o and V_p values, present a great variation probably due to its vertical homogeneity.
- For Units V and VI, V_s and G_o values, are markedly high and increase with depth.
- Flysch formation (Unit VI), which constitutes the geological bedrock of the region, exhibits high values of V_s (greater than 700 m/s) and thus can be considered also as the "seismic" bedrock.

EVALUATION OF SHEAR STRENGTH AND DEFORMATION PARAMETERS OF GEOTECHNICAL UNITS

The evaluation was carried out for the Units I, II and III, which predominate the area, and also most of the technical works are resting or founded on them.

Shear Strength parameters

For Units I, II where the cohesional character of the materials predominates, the evaluation of shear strength parameters (drained and undrained) was based on:

- The results of laboratory tests, such as: unconfined compression tests, quick (UU) and consolidated undrained (CUPP) triaxial compression tests and direct shear tests.
- Correlation of Standard Penetration Test (SPT) "N" values with unconfined compression (q_u) (Terzaghi and Peck, 1967).
- Estimation of undrained shear strength from Cone Penetration Test (C.P.T.) results, by employing an equation of the form:

  $q_c=c_u N_k+\sigma_o$ (Robertson and Campanella, 1983),

  Where q_c: cone resistance, c_u: undrained shear strength, N_k: cone factor and σ_o: in-situ overburden total pressure.

For Unit III, where granular soils predominate, the evaluation of shear strength parameters was based on:

- Correlations between SPT "N" values and angle of shearing resistance "φ", as proposed by Peck, Hanson and Thornburn (1974).
- Correlations between C.P.T. cone resistance (q_c) and friction angle (φ) (Robertson and Campanella, 1983).

Deformation Parameters

For Units I & II the evaluation of deformation parameters was based on:

- The results of one-dimensional consolidation (oedometer tests).
- Correlations between cone resistance (q_c) and stress-strain (constrained) modulus M (Mitchell and Gardner, 1975).

For Unit III the evaluation of deformation parameters was based on:

- Correlations between SPT "N" values and stress-strain modulus Es

  $$Es=a+c(N\pm 6) \text{ in bars}$$
  $$Es=3.3(N+15) \text{ in bars}$$

- Correlations between CPT cone resistance q_c and stress-strain (constrained) modulus M (Robertson and Campanella, 1983).

The so evaluated shear strength and deformation parameters appear in table 2.

Table 2 : Shear strength and deformation mean values of geotechnical parameters of Units I, II, III.

Units	Shear strength parameters		Deformation parameters	
	Undrained	Drained	Compression Index C_c	Stress-strain Modulus (Es or M)
I	c_u=100 kPa	c'=35 kPa $\varphi'=25^o$	C_c=0.121	M≈6 MPa
II	c_u=200 kPa		C_c=0.074	M≈8 MPa
III		$\varphi'=35^o$		E_s≈10 MPa

Finally, the bearing capacity and settlements of shallow foundations as well as deep foundations (piles) were assessed.

Shallow Foundations

Shallow foundations resting on units I or III were examined:

- In the case of Unit I an undrained analysis was carried out for the evaluation of the bearing capacity (q_{ult}=460kPa). The total settlements (immediate & consolidation) were assessed 3.2 cm and 6.5 cm for square and strip footings respectively.
- In the case of Unit III, a drained analysis was carried out, considering water table at the ground surface, which came up to a q_{ult}=318kPa. The settlements were assessed 1.40 cm and 2.85 cm for square and strip footings respectively.

Deep Foundations

The bearing capacity and the subsequent settlements were evaluated by the DIN 4014 (1990) procedure.

Two different cases involving "short" and "long" piles were examined. The short piles (1=10 m) penetrated either units I or III (q_{ult}=2.44 MN and 1.43 MN respectively), while the long pile (1=20 m) penetrated both units I and II (q_{ult}=4.32MN).

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