In site geotechnical investigations in the city of Larissa and influence on the construction environment

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Abstract
Field testing is often a very reliable way to determine the mechanical properties of soil materials and in some cases the most appropriate and unique way to obtain accurate measurements. Geotechnical engineers and engineering geologists perform geotechnical investigations to obtain information on the physical and mechanical properties of soil and rock underlying (and sometimes adjacent to) a site to design earthworks and foundations for proposed structures. The object of the present work is the recording of the geotechnical data of the center and districts of the city of Larissa, the knowledge of which is necessary for the construction and erection of construction works, as well as the characteristics and points that need special attention in each area. Finally important conclusions refer to the construction culture, that project authorities and contractors should draw on, accordingly.

1. Introduction
A geotechnical investigation includes subsurface exploration of a site. Sometimes, geophysical methods are used to obtain data about sites. Subsurface exploration usually involves in-situ testing (two common examples of in-situ tests are the standard penetration test and cone penetration test). In addition, site investigation often includes subsurface sampling and laboratory testing of the soil samples retrieved. Of particular interest is the finding of permissible soil tensions, the knowledge of which helps the structural civil engineer to safely dimension the foundation of the buildings to be erected.

2. Methodology
In this work, SPT tests were performed on sites where buildings are to be erected, both in the center and in the districts of the city of Larissa. The purpose of the geotechnical research is, in principle, the investigation of the foundation subsoil in the area of the projects under construction with SPT field works and appropriate laboratory tests of soil engineering. Then the results of the geotechnical research are synthesized, analyzed, and evaluated regarding the foundation of the buildings under
construction. Also, the values of soil properties that emerged from the soil technical investigation were compared with the corresponding values available from the Larissa Micro-Zone study and, thus, interesting conclusions were drawn.

According to the micro-zonal study, the city of Larissa is divided into zones according to the risk of soil liquefaction, as shown in Fig.6. The name of each zone uses the capital Greek letters Α, Β, Γ, which indicate the degree of liquefaction risk.

Finally important conclusions refer to the construction culture, that project authorities and contractors should draw on, accordingly.

3. Recording of results

Soil research is presented in three different parts of the city of Larissa where new buildings will be erected as described in the dissertation of F. Kokotini (2021) [1] which presents elements of geotechnical research, foundations and building structures by the technical offices of G. Danas [2] and A. Bebis-N. Christodoulos. In each geotechnical research, research drillings are performed with SPT in situ tests while at the same time the research program, the study assumptions as well as the resulting results are presented.

3.1. Soil research in the center of Larissa

This research was carried out at 7 Patroklou st. B.BL.815A located in the center of Larissa for the construction of a three-story building with a ground floor store with a loft, first floor offices and basement and included a sampling borehole which was marked C1 (15m). (The Urban Planning Regulation for the issuance of building permits requires for each plot where buildings are to be erected, the preparation of a soil technical study. Depending on the area of the plots, a certain number of drillings is carried out. Each drilling is numbered C1, C2, etc. In the cases presented in this paper, only C1 drillings from each plot are presented, since the rest present similar results with only minor deviations.)

3.1.1. Research Program.

In more detail, the research program included 15m of research drilling and 5 SPT tests. Inside the drilling, standard penetration tests were performed at a test dilution per 2m of hole depth, continuous carrot sampling, with water flow barrier and hydrogeological observations to determine the depth of the hydrostatic level. The measurement of the hydrostatic level was done with an electric level meter 3 days after the completion of the drilling and was determined at a depth of 6.40 m. In terms of laboratory tests of the samples taken, soil engineering tests adapted to the type of properly selected samples and the needs of the research were performed, i.e., tests of classification of physical properties and mechanical properties were performed. Appropriately selected samples of the drilling provided for the execution of laboratory tests of soil engineering in accordance with the specifications of the Ministry of Environment, Physical Planning and Public Works.

3.1.2. Assumptions.

Seismic hazard zone of the Municipality of Larissa according to the Greek Seismic Code: II

Expected seismic acceleration according to the Greek Seismic Code $\alpha = 0.24g$

Classification of urban areas according to liquefaction risk: Zone Γ, i.e., high to very high liquefaction risk.

Geotechnical zone: 6

Seismic behavior: Zone F

3.1.3. Results.

Type of Foundation: Grillage strip foundation

Foundation depth (Df): 4.00m, Water level (Dw): 6.40m

Type of soil foundation: SM (Silky Sand, poorly graded sand-silt mixture, according to the Casagrande soil classification), Cohesion (c): 1.13 t/m², Friction angle (φ): 15°

Unit weight $\gamma$: 1.92 t/m³, Unit dry weight $\gamma_d$: 1.601 t/m³, Void ratio: 0.687
Water content $w$: 25.11%, N-value, SPT: $N=35$. $N' = 27$
Undrained shear strength $S_{u \neq 0}$: $S = c + \sigma' \tan \phi = 3.19$ t/m$^2$
Admissible stress ($q_{adm}$): 120 KN/m$^2$=12 t/m$^2$=1.2 kg/cm$^2$
Total uniform tolerance: 55.67mm
Differential admissible settlement for grillage strip: lower than 100 mm.

3.2. Soil research in the district of Hippocrates
The next search was carried out at 12 Vlachava st, B.BL. 898A, Hippocrates district, where a single-
story building is under study and included data from a sampling borehole which was marked C1.

3.2.1. Research Program. In more detail, the research program included 10m of research drilling and 2 SPT tests. Inside the drilling, standard penetration tests were performed at a test dilution per 3m of hole depth, continuous carrot sampling, with water flow barrier and hydrogeological observations to determine the depth of the hydrostatic level. The measurement of the hydrostatic level was done with an electric level meter 3 days after the completion of the drilling and was determined at a depth of 10m. In terms of laboratory tests of the samples taken, soil engineering tests adapted to the type of properly selected samples and the needs of the research were performed, i.e., tests of classification of physical properties and mechanical properties were performed. Appropriately selected samples of the drilling provided for the execution of laboratory tests of soil engineering in accordance with the specifications of the Ministry of Environment, Physical Planning and Public Works.

3.2.2. Assumptions. Seismic hazard zone of the Municipality of Larissa according to the Greek Seismic Code: II
Expected seismic acceleration according to the Greek Seismic Code $\alpha = 0.24g$
Classification of urban areas according to liquefaction risk: Zone $\Gamma$, i.e., high to very high liquefaction risk.
Geotechnical zone: 8, Seismic behavior: Zone D

3.2.3. Results Type of Foundation: Grillage strip foundation
Foundation depth ($D_f$): 2.00m, Water level ($D_w$): 7.00m
Type of soil foundation: SM (Silky Sand, poorly graded sand-silt mixture, according to the Casagrande soil classification)
Cohesion ($c$): 4 t/m$^2$, Friction angle ($\phi$): 15°, Unit weight $\gamma$: 1.937 t/m$^3$
Unit dry weight $\gamma_d$: 1.686 t/m$^3$, Water content: 14.88%
Void ratio: 0.601, N-Value, SPT: $N=24$
Undrained shear strength $S_{u \neq 0}$: $S = c + \sigma' \tan \phi = 22.2$ t/m$^2$
Admissible stress ($q_{adm}$): 120 KN/m$^2$=12 t/m$^2$=1.2 kg/cm$^2$
Total uniform admissible settlement: 32.23 mm
Differential admissible settlement for grillage strip foundation: lower than 100 mm.

3.3. Soil research in the district of Anthoupolis
The last survey presented in the present work was carried out at 12B Kefallinias st, in the Anthoupoli district in Larissa, where a single-story building on a flat roof is to be erected and included a sampling borehole marked C1.

3.3.1. Research Program. In more detail, the research program included 10m of research drilling and 2 SPT tests. Inside the drilling, standard penetration tests were performed at a test dilution per 3m of hole depth, continuous carrot sampling, with water flow barrier and hydrogeological observations to determine the depth of the hydrostatic level. The measurement of the hydrostatic level was done with an electric level meter 3 days after the completion of the drilling and was determined at a depth of 10m. In terms of laboratory tests of the samples taken, soil engineering tests adapted to the type of
properly selected samples and the needs of the research were performed, i.e., tests of classification of physical properties and mechanical properties were performed. Appropriately selected samples of the drilling provided for the execution of laboratory tests of soil engineering in accordance with the specifications of the Ministry of Environment, Physical Planning and Public Works.

3.3.2. Assumptions.

Seismic hazard zone of the Municipality of Larissa according to the Greek Seismic Code: II
Expected seismic acceleration according to the Greek Seismic Code: $\alpha = 0.24g$
Classification of urban areas according to liquefaction risk: does not have a high liquefaction risk (i.e., does not belong to any of the zones A, B, Γ)
Geotechnical zone: 3, Seismic behavior: Zone C

3.3.3. Results.

Type of Foundation: Grillage strip foundation
Foundation depth ($D_f$): 1.50m, Water level $\eta$ Table Water ($D_w$): > 15m
Type of soil foundation: CL-ML (Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays - Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity, according to the Casagrande soil classification)
Friction angle ($\phi$): 20°, Unit weight $\gamma$: 1.937 t/m$^3$, Unit dry weight $\gamma_d$: 1.63 t/m$^3$
Water content $w$: 22.4%, Void ratio: 0.601, N-Value, SPT: N=16, N′=11
Undrained shear strength $S_u$ for $\phi=0$: $S = c + \sigma' \tan \phi = 5.70$ t/m$^2$
Admissible stress ($q_{adm}$): 120 KN/m$^2$=12 t/m$^2$=1.2 kg/cm$^2$
Total uniform admissible settlement: 32.23mm
Differential admissible settlement for grillage strip foundation: lower than 100 mm
For calculation of the above soil parameters established literature was used [3], [4], [5], [6] set forth at the end of this paper.

4. Comparison of drilling results and micro-zone study of Larissa

The Larissa micro-zone study was prepared in 1995, following the initiative and request of the Technical Chamber of Central and Western Thessaly, headed by the professors of AUTh Mr. K. Pitilakis and S. Tsotsos [7]. However, the above study was carried out by a working group [8] set up by the Hellenic Technical Chamber which not only finalized the initial work but also categorized specific results through tables and maps such as: Geotechnical data, seismic hazard and soil response, liquefied soils and which help to compare with corresponding results of geotechnical surveys.

4.1. Comparison of city center and microzone results

More specifically, from the geotechnical survey of the Larissa city center area, it is easily understood that the values show that the values of unit weight, unit dry weight, water content and void ratio show a significant convergence with those of zone 6 of the microzonal study in which belongs to the city center, while in the calculation of cohesion, friction angle and therefore admissible stress (bearing
capacity), there is a strong value difference (Table 1). According to the researchers, this deviation is due to the large dispersion of values of soil properties that vary from place to place and especially with depth. The drained shear strength shows a small change from that of the microzonal while the number of beats N of the Standard Penetration Test (N = 35) is within the beats (N = 38-47) given by the utilization of the microzone study.

Table 1. Comparison of drilling results 3.1 and microzonal study.

| Drilling of downtown | Microzone       |
|----------------------|-----------------|
| Cohesion: \(c = 1.13 \text{ t/m}^2\) | \(c = 24.34\text{t/m}^2\) |
| Friction angle: \(\varphi = 15^\circ\) | \(\varphi = 5.8^\circ\) |
| Unit weight: \(\gamma = 1.92 \text{ t/m}^3\) | \(\gamma = 2.0 \text{ t/m}^3\) |
| Unit dry weight: \(\gamma_d = 1.601 \text{ t/m}^3\) | \(\gamma_d = 1.601 \text{ t/m}^3\) |
| Void ratio: \(e = 0.687\) | \(e = 0.65\) |
| Water content \(w\): 25.11\% | \(w = 28\%\) |
| Undrained shear strength: \(C_u = 3.19 \text{ t/m}^2\) | \(C_u = 1.35 \text{ t/m}^2\) |
| Admissible stress: \(q_{adm} = 1.2 \text{ kg/cm}^2\) | \(q_{adm} = 2.7 \text{ kg/cm}^2\) |

4.2 Comparison of Hippocrates district and micro-zone results

Subsequently, the geotechnical survey of the Hippocrates district of Larissa shows that the values of unit weight, unit dry weight, water content and void ratio show a significant convergence with those of zone 8 of the micro-zonal study to which the Hippocrates district belongs, while in the calculation of cohesion, friction angle and therefore admissible stress (bearing capacity) there is as in the previous case- a significant difference in values (Table 2). According to the researchers, this deviation is due to the large dispersion of values of soil properties that vary from place to place and especially with depth. In fact, it is characteristic that the friction angle, which is almost double, shows great heterogeneity. The undrained shear strength in contrast to case 3.1 shows a strong deviation from the corresponding micro-zonal fact which according to the authors is due to the intense clay formations of the examined zone. It should also be mentioned that the N-value of the Standard Penetration Test (N = 24) is lower enough than the N-value (N = 33-45) given by the utilization of the microzone study.

Table 2. Comparison of drilling results 3.2 and microzonal study.

| Drilling of Hippocrates | Microzoniki district |
|-------------------------|----------------------|
| Cohesion: \(c = 1.13 \text{ t/m}^2\) | \(c = 0.19 \text{ t/m}^2\) |
| Friction angle: \(\varphi = 15^\circ\) | \(\varphi = 33^\circ\) |
| Unit weight: \(\gamma = 1.937 \text{ t/m}^3\) | \(\gamma = 2.02 \text{ t/m}^3\) |
| Unit dry weight: \(\gamma_d = 1.686 \text{ t/m}^3\) | \(\gamma_d = 1.8 \text{ t/m}^3\) |
| Void ratio: \(e = 0.601\) | \(e = 0.62\) |
| Water content \(w\): 14.88\% | \(w = 21\%\) |
| Undrained shear strength: \(C_u = 22.2 \text{ t/m}^2\) | \(C_u = 0.9 \text{ t/m}^2\) |
| Admissible stress: \(q_{adm} = 1.2 \text{ kg/cm}^2\) | \(q_{adm} = 1.5 \text{ kg/cm}^2\) |

4.3 Comparison of results of Anthoupolis district and micro-zone

Subsequently, the geotechnical survey of the Hippocrates district of Larissa shows that the values of unit weight, unit dry weight, water content and void ratio show a significant convergence with those of zone 8 of the micro-zonal study to which the Hippocrates district belongs, while in the calculation of cohesion, friction angle and therefore admissible stress (bearing capacity) there is as in the previous case- a significant difference in values (Table 3). In the opinion of the authors, this small deviation is due to the fact that the soil in this district appears more homogeneous than with spatial variability [9] as in the previous cases of the center of Larissa and the district of Hippocrates. The undrained shear strength presents an intermediate state regarding cases 3.1 and 3.2 with a rather small deviation of value from the corresponding one of the microzonal. It should also be mentioned that the number the N-value of the Standard Penetration Test (N = 16) is quite far from the limits of the N-value (N = 37-
40) given by the utilization of the microzonal study, perhaps because the drilling took place in the hardest soil in zone 3 to which the district of Anthoupolis belongs.

Table 3. Comparison of drilling results 3.3 and microzonal study.

| Drilling of Anthoupoli | Microzonal district |
|------------------------|---------------------|
| Cohesion: $c = 3$ t/m$^2$ | $c = 1.9$ t/m$^2$ |
| Friction angle: $\phi = 20^\circ$ | $\phi = 12^\circ$ |
| Unit weight: $\gamma = 1.80$ t/m$^3$ | $\gamma = 2.0$ t/m$^3$ |
| Unit dry weight: $\gamma_d = 1.63$ t/m$^3$ | $\gamma_d = 1.6$ t/m$^3$ |
| Void ratio: $e = 0.601$ | $e = 0.75$ |
| Water content: $w = 22.4\%$ | $w = 23\%$ |
| Undrained shear strength: $C_u = 5.70$ t/m$^2$ | $C_u = 2.1$ t/m$^2$ |
| Admissible stress: $q_{adm} = 1.2$ kg/cm$^2$ | $q_{adm} = 1.0$ kg/cm$^2$ |

5. Seismic behavior of the examined areas
The seismic hazard study for the city of Larissa resulted in the proposal to adopt as a design earthquake, an earthquake of magnitude $M_s = 6.30$ on the Richter scale from a distance of $R = 6$ km with a probability of not exceeding 10% for a period of 80 years. In fact, this assessment completely covered the seismic shielding of the city in the recent earthquake given by the area of Damasi, which is located between the cities of Tyrnavos and Elassona.

The Municipality of Larissa according to the Greek Seismic Code belongs to the seismic hazard zone II with expected seismic acceleration according to the Greek Seismic Code $\alpha = 0.24g$. However, it should be emphasized that the general conclusion of the researchers of the utilization of the Larissa microzone study is that the seismic design actions resulting from the New Greek Seismic Code do not completely cover the city based on the data obtained from the microzone study. More specifically, the maximum seismic horizontal acceleration of the ground was found to be 38% higher than the corresponding one proposed by the New Greek Seismic Code. Therefore, the value $\alpha = 0.33g$ could be used for reasons of greater safety as the average value of active ground acceleration for the whole city of Larissa.

6. Liquefaction of soils
As is well known, in saturated loose sandy soils, under the influence of recycled dynamic loading, an increase in the water pressure of the pores develops. In some cases of a strong event, it is possible for the pore pressure to exceed the pressure that develops between the grains of the soil material so that the grains lose contact with each other, resulting in zero density, shear strength and therefore bearing capacity. Then the phenomenon of liquefaction takes place. The city center and the district of Hippocrates located near the river Pinios, belong to Zone $\Gamma$ which presents a high to very high risk of liquefaction.

Figure 4. Geotechnical map of Larissa.
Figure 5. Seismic zones of Larissa.
Figure 6. Classification of urban areas according to the risk of liquefaction.

On the contrary, the district of Anthoupolis in terms of seismic risk does not have a high risk of liquefaction (i.e., it does not belong to any of the zones A, B, $\Gamma$). Figure 6 assumes that the closer we
get to the riparian areas, the greater the risk of liquefaction while the farther we go (see Anthoupolis) the above risk is reduced.

7. The contribution of soil investigation to the environment
First of all, soil technical research determines the depth of the underground aquifer that is located in the city center at 6.40m. in the district of Hippocrates at 7.0m while in the district of Anthoupolis no aquifer was found up to 15m. Therefore, the areas that are closer to the river show -as is logical- a higher water level rise. But in addition to finding groundwater, soil research can therefore audit the ground and protect it from pollution and toxic raw materials. Geotechnical surveys are responsible for finding the parameters of the mechanical behavior of the soil, and therefore its suitability as a receiver of static or seismic loads, which lead to the choice of the type of construction to be built. The same applies in the case where sewer pipes pass within the soil mass or pipelines for the transport of gas or energy in general. A failure or leak due to poor assessment of soil conditions can lead to environmental pollution or disaster. Similar phenomena are observed from landslides or landslides due to lack of geotechnical surveys or proper planting on land slopes [10]. Also, it should be emphasized that the building - plot factor given by the Office of Urban Planning of each Municipality and multiplied by the area of the plot in which we want to build a building, gives the total square footage of the building. According to the instructions of the Town Planning, the building - plot factor is reduced from the center to the districts, with the result being that the buildings are constructed to lower height. As a result, these areas are more sparsely populated, the air circulation is better and of course more free space is created, which usually serves as a green space. Despite the great heat loads that develop during the summer months, the low buildings together with the green recreation areas contribute to the drop in temperature and the improvement of the environment and the quality of life in the above areas.

Finally, the construction of large rock-filled dams or earth-filled dams where the soil is used as a building material gave impetus to the cooperation of soil engineering research with the environment as well as the development of the field of Environmental Geotechnics.

Environmental Geotechnics is an important branch of Geomechanics and earth sciences. It even considers the results of geotechnical surveys to protect groundwater and soil from potential pollution mainly related to waste management (e.g., landfills) and the transport, storage and use of toxic raw materials (e.g., petroleum products, solvents). It also deals with the protection of the geoenvironment so that large geotechnical projects constructed e.g., dams, landfills, tunnels, etc. always observe environmental protection regulations. Further research on the environmental field could lie on roadways in view of supplement research of relevant studies for pavement evaluation [11, 12, 13], optimization of pavement evaluation methods in terms of environmental footprint [14], even for teaching implementations purposes in geotechnical courses [15].

8. Conclusions
After thorough research, comparisons and audits of results, the authors came to the following conclusions:

1. The comparison of the results of the three soil technical surveys with corresponding results of the microzonal study showed the identification of values in terms of physical properties of the soil, but with differences in mechanical properties due to spatial variability and heterogeneity of the soil.

2. A consequence of the above findings are the different values that result in the permissible ground stress. According to the researchers, the drilling results that are considered more accurate should be used. It should be noted, however, that it consists of the older statics - designers as the ground tension is taken equal to 1kg/cm².

3. Geotechnical research has shown that the hazard and liquefaction of the soil are reduced by moving away from the center and riparian areas.
4. The building - plot ratio decreases from the city center to the neighborhoods, resulting in significant green spaces and air circulation that help reduce the temperature during the summer months.

5. Finally, through this paper it became evident (section 7) that the cooperation of soil engineering and environmental geotechnics is necessary for the correct decision-making that contributes to the harmonious development of the environment.

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