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ENGINEERING GEOLOGICAL MAPPING OF THE PALLINI URBAN AREA

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Abstract

Engineering geological thematic maps can provide substantial information for the development of cities, the land planning of future infrastructures and even more for the planning of the natural hazards prevention and/or mitigation.
To this direction the engineering geological map of the Municipality of Pallini, at the Eastern Attica prefecture, at a scale of 1:20.000, was compiled. For that purpose, the following workflow was adopted: Firstly, a desk study helped in selecting the relevant topographic and geologic maps, which were digitized and introduced in a GIS environment. Secondly, the data coming from detailed geological mapping were elaborated to the same GIS environment. Thirdly, geotechnical data collected from borehole logs, such as lithostromatographic sequence, in situ tests and laboratory tests were introduced in geotechnical database. The statistical evaluation of this data provided estimates for numerous geotechnical parameters. Finally, the engineering geological map was compiled by merging the geological formations into lithologic units according to their origin, age, natural condition, and geotechnical characteristics.
Key words: *lithologic units, physical characteristics, mechanical properties.*

Περίληψη

Οι τεχνικογεωλογικοί θεματικοί χάρτες δύναται να παρέχουν σημαντικές πληροφορίες για την ανάπτυξη των πόλεων, τον χωροταξικό σχεδιασμό των μελλοντικών υποδομών και ακόμη περισσότερο για τον σχεδιασμό της πρόληψης ή/ και της ανάσχεσης των φυσικών καταστροφών.
Προς την κατεύθυνση αυτή συντάχθηκε τεχνικογεωλογικός χάρτης του Δήμου της Παλλήνης, της Νομαρχίας Ανατολικής Αττικής, σε κλίμακα 1:20.000. Για τον σκοπό αυτό η ακόλουθη ροή εργασίας υιοθετήθηκε: Πρώτον, στα πλαίσια των εργασιών γραφείου συλλέχθηκαν οι σχετικοί τοπογραφικοί και γεωλογικοί χάρτες οι οποίοι ψηφιοποιήθηκαν και εισήχθησαν σε περιβάλλον ΓΣΠ. Δεύτερον, δεδομένα που συλλέχτηκαν στα πλαίσια των εργασιών πεδίου από λεπτομερή γεωλογική χαρτογράφηση εισήχθησαν στο ίδιο περιβάλλον ΓΣΠ. Τρίτον, στοιχεία που συγκεντρώθηκαν από γεωτεχνικές γεωτρήσεις, όπως, λιθοστρωματογραφικές ακολουθίες, αποτελέσματα επί τόπου και εργαστηριακών δοκιμών, εισήχθησαν σε αντίστοιχη γεωτεχνική βάση. Η στατιστική επεξεργασία των δεδομένων αυτών παρέχει εκτιμήσεις για πολλές γεωτεχνικές παραμέτρους. Τέλος, ο τεχνικογεωλογικός χάρτης συντάχθηκε ενοποιώντας τους σχηματισμούς σε λιθολογικές ενότητες με βάση

τη φυσική κατάσταση, την προέλευση, τη σχετική ηλικία, τα λιθολογικά χαρακτηριστικά, και τη γεωτεχνική συμπεριφορά.

Λέξεις κλειδιά: *λιθολογικές ενότητες, φυσικά χαρακτηριστικά, μηχανικές ιδιότητες.*

1. Introduction

The study area occupies 18,93 km^2 in Eastern Attica prefecture and is located 18km E-NE of Athens (Figure 1). The terrain is gentle in the major part, where the Mesogia Basin is developed, and becomes hilly at the piedmont of Penteli Mountain, with a maximum elevation of about 400m.

Pallini is currently undergoing a rapid urban development with many new constructions developed and the population is expected to grow in the forthcoming years. Under these circumstances engineering geological mapping can support land use planning by providing substantial information. Therefore, the examination of the engineering geological conditions and finally the compilation of the engineering geological map of this area, which is the main purpose of this study, give a valuable tool to local authorities and engineers for its correct planning and development.

Figure 1 - Location map of the Municipality of Pallini.

2. Geological Aspects

The alpine bedrock of the study area belongs to the Attico–Cucladic Massif (Katsikatsos, 1992). The formations of the autochthonous system occur at the northern part, consisting of marbles (Figue 2d). The crystalline limestones and schists with bodies of ophiolitic rocks, outcropping at the hilly area of Kantza, belong to the Neo – Hellenic Nappe.

Post alpine formations mainly Upper Miocene in age and of lacustrine and fluviolacustrine origin occupy the major part of the study area. According to Mettos, 1992, they cover a part of the Mesogia Basin and consist of marls (Figure 2b) with sandstones, breccioconglomerates and travertine intercalations (Figure 2c). Loose fluviolacustrine formations including fans, talus cones, occur at the piedmont of Penteli Mountain (Figure 2a).

Generally, the Neogene formations and in some places the schists of the Neo – Hellenic Nappe are covered by younger unconsolidated materials such as Pleistocene deposits.

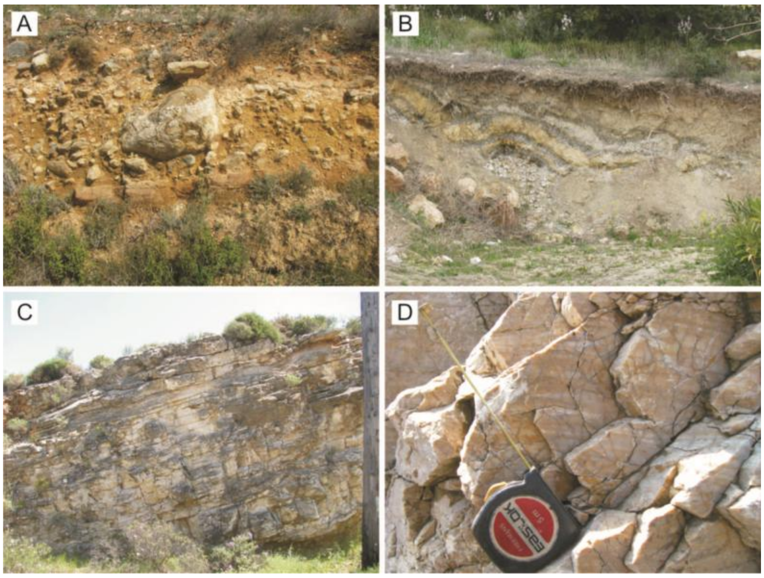

Figure 2 – (a) Mixed phase formations of fluviolacustrine origin, (b) Marls` slubbings, (c) intensively fractured travertine, (d) intensively fractured marbles.

3. Engineering Geological Behaviour of the Formations in the Study Area – Compilation of the Engineering Geological Map

The need of compilation of engineering geological maps was completely understandable the last 40 years. At the beginning of that period the international community were started to recognize the value of those maps regarding every kind of civil works (dams, tunnes, etc), infrastructures as well as urban and land planning.

In Greek territory the compilation of engineering geological maps of wider areas such as urban or industrial sites started to be published the last 3 decades. Characteristic examples are the map of Xanthi, *1:25.000* in scale (Marinos and Xidakis, 1991), map of Achaia county, *1:100.000* in scale (Rozos, 1989), map of Athens, *1:25.000* in scale (Sabatakakis, 1991), geotechnical map of Greece, *1:500.000* in scale, (IGME, 1993), map of Trikala town, *1:10.000* in scale (Koukis, et al., 1997), map of Athens prefecture, *1:10.000* in scale (IGME – University of Patras, 2009), map of wider Thessaloniki area, *1:10.000* in scale (Rozos et al., 2004), map of Patras town, *1: 5.000* in scale (Rozos, et al., 2006), land suitability maps of Trikala Prefecture (Bathrellos, et al., 2012).

The engineering geological map of the study area, proper for urban planning and development, was compiled at a scale of 1:20.000. For its compilation a large number of data obtained by field work, laboratory tests as well as by bibliographic sources were systematically collected and evaluated. This distinction was made according to guide of UNESCO (UNESCO/I.A.E.G, 1976).

Based on this guide, the geological formations in the examined area were grouped into 7 lithological units according to the scale of the map. However, the analysis of the behavior of every unit includes much more information and data than those which the guide indicates. This is because of the abundance of available data and the uniformity of the lithological types included in every lithological unit. Therefore, the min, max, mean, and standard deviation for every geomechanical parameter examined are given. These geomechanical parameters (physical and mechanical properties) that were used to characterize the lithological units, according to available data and new lab tests, are: Liquid limit (w_L), Plasticity index (PI), Bulk unit weight (γ_b), moisture content (w) initial void ratio (e_o), unconfined compressive strength (q_u), total cohesion (c) total angle of friction (φ), effective cohesion (c΄), effective angle of friction (φ΄), compression index

(C_c), standard penetration test (N_{SPT}) for soils, and porosity (n) dry density (ρ_d), unconfined compressive strength (σ_c), Young modulus (E), diametrical point load index (I_{s50d}), axial point load index (I_{s50a}), indirect tensile strength from Brazilian test(σ_t) and slake durability index (I_{d1}) for rocks.

Unit 1: Streambed deposits

The lithological unit of those deposits consist of brownish red, grayish and brownish yellow clayey to silty gravels (GC - GM), with intercalations of brownish red clayey sands (SC) of low to medium plasticity. Sandy clays of medium to high plasticity (CL) and silty sands are also occurred as intercalations. This unit occupies the bed and banks of torrents in the study area with maximum thickness ranging from 0.5-8m. It is high permeable but does not develops a significant aquifer. Table 1 presents the descriptive statistics of the physical and mechanical properties of this unit.

Table 1 – Descriptive statistics for the physical and mechanical properties of Unit 1.

Clayey to silty gravels (GC – GM)						
	w_L (%)	**PI (%)**	**γ_b (kN/m^3)**	**w (%)**	**c (kPa)**	**φ (°)**
min	23	9	20,5	5,8	7,8	30
max	39	20	23,2	21,8	35,3	40
mean	29	12	21,9	14,1	21,5	35
std	4	3	1,3	5,6	13,7	5
Clayey sands (SC)						
min	18	5	19,9	11,3	19,6	5
max	42	22	21,5	19,6	23,5	33
mean	29	13	20,6	16,7	20,0	21
std	8	4	0,6	3,8	9,2	11
Lean clays (CL)						
min	30	13	17,8	4,8	0,7	21
max	44	19	20,5	21,0	19,0	31
mean	35	16	18,8	11,7	9,8	26
std	5	2	1,2	6,3	9,1	5

Unit 2: Mixed phase Pleistocene deposits

Brownish red, medium to very dense, clayey sands (SC) and medium dense to dense clayey gravels (GC) are the main lithological types of this unit. Very stiff clays of moderate to high plasticity and medium degree of compressibility also occur. These formations cover a large part of the study area and its thickness varies reaching up to 20m. The coarse-grained layers are high permeable and can develop local aquifers. Table 2 presents the descriptive statistics of each physical and mechanical property of this unit.

Unit 3: Coarse grained Neogene deposits

This unit consists of fluviolacustrine loose brecciated materials with intercalations of marly soils and thin layers of sandstones (Figure 2a). These formations occupy a large part the area adjacent to Penteli Mountain. The mainly coarse nature of this unit does not allow the sampling of proper specimens for lab tests.

Unit 4: Travertinoid limestones

These limestones are yellow – brown, weak to moderate weak, thin to thick bedded, very porous and frequently fractured (Figure 2c).

Table 2 – Descriptive statistics for the physical and mechanical properties of Unit 2.

Clayey sands (SC)												
	w_L (%)	**PI (%)**	**γ_b (kN/m^3)**	**W (%)**	**c (kPa)**	**φ (°)**	**c΄ (kPa)**	**φ΄ (°)**	**C_c**	**e_o**	**q_u (kPa)**	**N_{SPT}**
min	20	4	18,7	4,9	9,8	29	17,2	10	0,070	0,370	46,0	12
max	33	19	22,4	20,6	106,0	43	62,7	32	0,145	0,531	59,0	>50
mean	27	11	20,6	10.0	37,2	35	46,9	21	0,108	0,451	52,5	
std	3	4	1,2	5,7	39,7	5	21,0	8	0,040	0,080	6,5	
Clayey gravels (GC)												
min	20	5	21	7,7	0,0	38	8,0	38	----	----	----	12
max	30	19	21	15,4	24,0	46	8,0	46	----	----	----	>50
mean	26	11	21	11,7	12,0	42	8,0	42				
std	4	4	0	3,1	12,0	4	0,0	4				
Lean clays (CL)												
min	26	7	19,0	7,7	0,0	9	0,0	26	0,080	0,412	189,0	25
max	43	29	21,6	24,7	194,0	30	18,4	34	0,260	0,860	635,0	>50
mean	33	16	2,3	15,6	82,8	23	6,4	30	0,147	0,647	481,6	
std	5	5	5,1	5,1	58,2	8	7,0	2	0,070	0,180	173,6	

The rock mass quality according to RQD measurements can be characterized as very poor to fair. They are permeable due to their secondary porosity and the dense joint sets, but the developed aquifers are poorer than those of the unit 2 (Lekkas, 1992). The main mechanical properties of the intact rock are listed in Table 3.

Table 3 – Descriptive statistics for the main mechanical properties of Unit 4.

	σ_c (MPa)	**E (MPa)**	**I_{s50d} (MPa)**	**I_{s50a} (MPa)**
min	10,71	6781,54	0,39	0,64
max	25,15	11306,25	1,98	2,05
mean	18,64	9043,90	1,03	1,52
std	5,50	2262,35	0,69	0,51

Unit 5: Neogene deposits mainly fine-grained

This unit consists of Upper Miocene deposits, mainly marls, with intercalations of sandstones and breccioconglomerates. The thickness of this unit may exceed 150m and occupies the largest part of the study area. Local aquifers developed in the weathering zone of the marls and when the sandstones and brecciocongolomerates occur. The marls (Figure 2b) are stiff to hard and white, yellow and green in color. According to USCS, they can be classified as clays of low to high plasticity (CL, CH) and silts of low to high compressibility (ML, MH) (Figure 3). A distinctive property of these soils, according to oedometer tests results, is the high swelling pressure (up to 294kPa). Moreover, grey organic marls locally occur with compression index (C_c) up to 0,547.

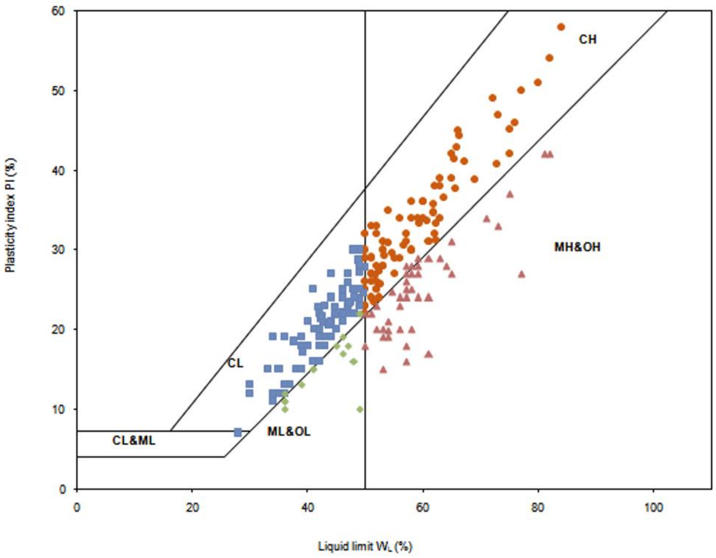

Figure 3 – Projection of the samples studied in the Casagrande plasticity chart.

Table 4 presents the descriptive statistics of each physical and mechanical property of the marly formations.

Table 4 – Descriptive statistics for the physical and mechanical properties of inorganic marls of Unit 5.

Fat clays (CH)												
	w_L (%)	**PI (%)**	**γ_b (kN/m^3)**	**W (%)**	**c (kPa)**	**φ (°)**	**c´ (kPa)**	**φ´ (°)**	**C_c**	**e_o**	**q_u (kPa)**	**N_{SPT}**
min	50	18	16.9	12,2	0,0	9	0,0	24	0,060	0,540	100,0	20
max	86	61	25,0	42,7	196,6	28	98,0	36	0,289	1,110	687,8	>50
mean	59	33	19,4	27,2	88,4	19	35,1	30	0,140	0,779	366,9	
std	8	8	1,2	5,6	64,4	5	41,3	3	0,040	0,131	160,6	
Lean clays (CL)												
min	28	7	17	12	0,0	4	8,2	13	0,060	0,362	109,0	28
max	48	30	23	44	421,6	49	421,6	47	0,280	1,040	824,2	>50
mean	42	20	19	22	95,0	23	114,1	26	0,124	0,714	354,0	
std	5	4	1	5	93,3	12	125,5	9	0,050	0,160	206,9	

Silts of high compressibility (MH)												
min	50	15	17,4	14,7	7,0	15	2,1	4	0,030	0,469	69,0	11
max	82	42	24,2	42,1	80,0	30	45,0	33	0,222	1,296	2595,0	>50
mean	60	25	19,9	26,0	30,0	21	19,7	16	0,107	0,741	424,3	
std	7	6	1,5	8,3	20,5	5	13,5	9	0,050	0,220	483,5	
Silts of low compressibility (ML)												
min	25	10	17,1	10,1	0,0	11	19,0	18	0,037	0,413	57,0	11
max	49	22	21,6	30,3	225,0	50	59,6	25	0,126	1,827	2186,0	>50
mean	41	15	19,8	21,9	35,6	27	33,7	22	0,078	0,652	395,1	
std	6	3	1,0	5,3	67,2	11	15,4	3	0,020	0,14	514,9	

Due to the various degrees of diagenesis, the marls locally behaves like rock material and can be characterized as weak to moderate weak, of very low durability, moderate weathered and fractured. The rock mass quality according to RQD measurements is very poor to fair. The main physical and mechanical properties of the intact rock are listed in Table 5.

Table 5 – Descriptive statistics for the main physical and mechanical properties of rocky marls.

	n (%)	**ρ_d (kN/m^3)**	**Id_1 (%)**	**σ_c (MPa)**	**E (MPa)**	**I_{s50d} (MPa)**	**I_{s50a} (MPa)**
min	10,39	18,52	4,20	0,57	357,60	0,21	0,16
max	24,72	23,82	15,50	38,10	1019,58	1,78	1,31
mean	16,71	19,79	9,80	6,71	659,65	0,69	0,52
std	5,90	1,63	5,65	8,46	242,30	0,45	0,30

The sandstones intercalations are red, yellow or grey, weak to moderate weak, thin to medium bedded, fine to coarse grained, slightly to moderate altered and frequently fractured. The rock mass quality according to RQD measurements is very poor to fair. The main physical and mechanical properties of the intact rock are listed in Table 6.

Table 6 – Descriptive statistics for the main physical and mechanical properties of the sandstones of Unit 5.

	n (%)	**ρ_d (kN/m^3)**	**σ_c (MPa)**	**E (MPa)**	**I_{s50d} (MPa)**	**I_{s50a} (MPa)**
min	5,69	20,88	2,35	193,05	0,32	0,27
max	16,23	24,80	23,61	6325,63	4,33	1,94
mean	9,585	22,94	9,30	1715,71	1,21	0,68
std	4,06	1,52	6,34	2061,40	1,24	0,53

The breccioconglomerates are loose to well cemented with yellowish brown clayey-sandy matrix, weak to moderate weak, slightly to moderate weathered and moderate to high fractured. The rock mass quality according to RQD measurements can be characterized as very poor to poor. The main physical and mechanical properties of the intact rock are listed in Table 7.

Table 7 – Descriptive statistics for the main physical and mechanical properties of breccio-conglomerates of Unit 5.

	n (%)	**ρ_d (kN/m^3)**	**σ_c (MPa)**	**E (MPa)**	**I_{s50d} (MPa)**	**I_{s50a} (MPa)**
min	0,28	22,84	3,81	471,16	0,31	0,30
max	17,22	26,07	19,09	4367,72	5,69	3,91
mean	8,05	24,81	7,58	1870,70	1,29	0,99
std	6,28	1,20	5,35	1303,16	1,52	1,08

Unit 6: Marbles and crystalline limestones

Marbles and crystalline limestones of the autochthonous system and the Neo – Hellenic Nappe, respectively, of the Attico - Cycladic massif, constitute this unit. These formations outcrop in a small part at the northern and at the hilly region of Kantza. They are mainly white in colour, thick bedded to massive, moderate to high strong and highly fractured (Figure 2d). The main mechanical properties of the intact rock are listed in Table 8.

Table 8 – Descriptive statistics for the main mechanical properties of carbonated rocks of Unit 6.

	σ_c (MPa)	**I_{s50d} (MPa)**	**σ_t (MPa)**
min	31,97	1,22	5,25
max	71,69	3,13	7,23
mean	55,222	2,08	6,24
std	13,22	0,65	0,99

Unit 7: Schists

This unit includes mica schists, with tectonized ophiolitic bodies, highly fractured, moderate to high weathered, and weak to moderate strong. They create a weathering zone which can reach up a thickness of about 7m. The main mechanical properties of the intact rock are listed in Table 9.

Table 9 – Descriptive statistics for the main mechanical properties of schists of Unit 7.

	σ_c (MPa)	**E (MPa)**	**I_{s50d} (MPa)**	**I_{s50a} (MPa)**
min	10,60	779,50	0,40	0,90
max	34,10	3219,20	3,75	5,01
mean	22,35	1999,35	2,07	2,95
std	11,75	1219,85	1,67	2,05

Based on the above lithological units, the engineering geological map of the study area was compiled at a scale 1:20.000 and is presented in Figure 4.

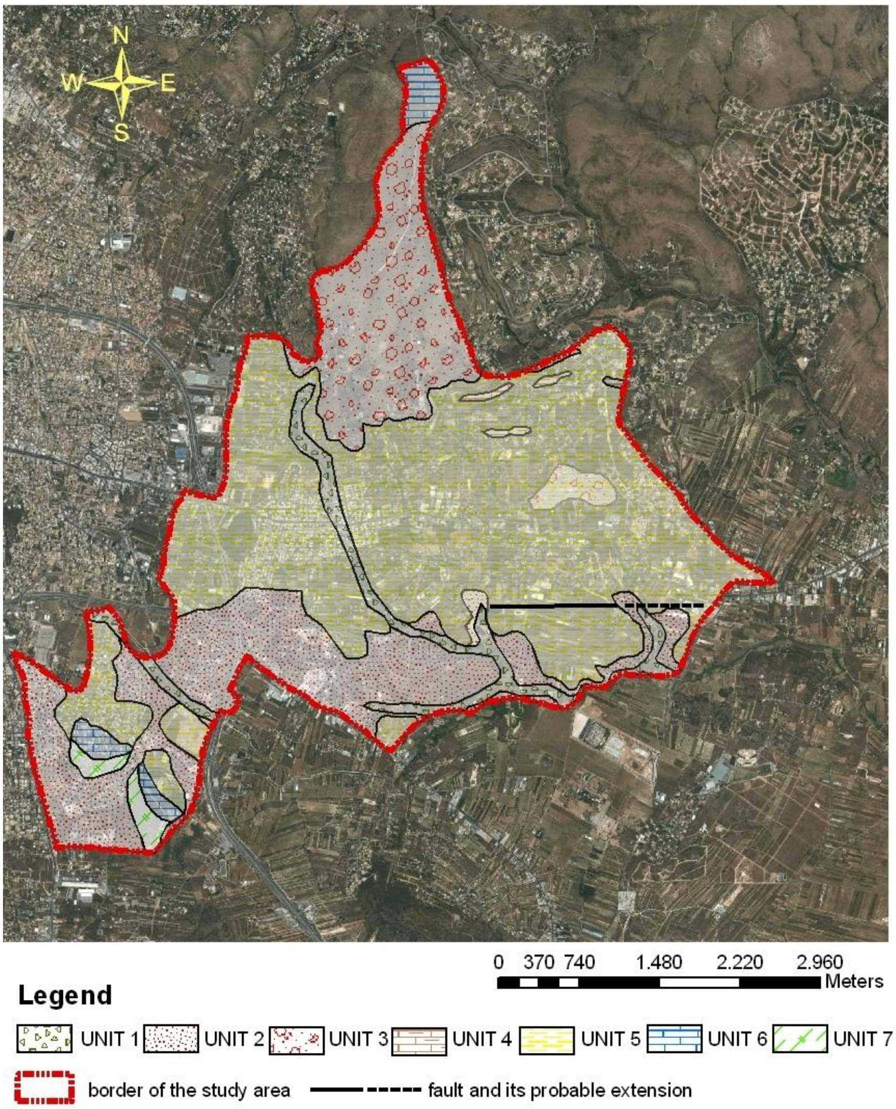

Figure 4 – Engineering geological map of Pallini prefecture.

4. Correlation of Compression Index (C_c) with Physical Parameters

In the last six decades, various single and multiple variables empirical equations have been developed by researchers (Carter and Bentley, 1991; Holtz and Kovacs, 1981; Murthy, 1993) for the estimation of the compression index (C_c) by correlating it with other physical parameters.

In the current study an attempt has been made to estimate the compression index (C_c) of fat clays (CH) from other physical and index properties. For this reason a multiple regression analysis was performed using the liquid limit (w_L) and the initial void ratio (e_o) as independent variables.

Subsequently, the estimated empirical equation is:

$$C_c = 0{,}317e_o + 0{,}00168w_L - 0{,}123 \quad (1)$$

It has a fairly good R^2 (0,703) and both independent variables are involved to the above equation. The equation (1) is plotted three dimensionally together with the data set in Figure 5.

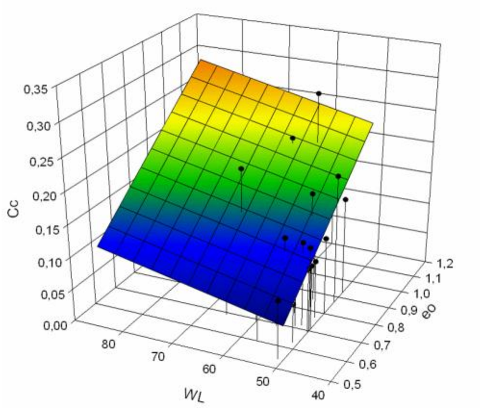

Figure 5 – 3D – plot of the best – fit multiple regression plane relating compression index (C_c) to both liquid limit (w_L) and initial void ratio (e_o), as described by equation (1) in the text.

5. Results

A large number of geotechnical data were collected and evaluated. From the combination of the geotechnical database and geological information, a multipurpose engineering geological map compiled at a scale 1:20.000. The map and the geotechnical values quoted in this paper can be used as a general guide for site investigation and design calculations. Moreover, in the frame of the examination of the various physical and mechanical properties of fat clays, a correlation between compression index (C_c), with both liquid limit (w_L) and initial void ratio (e_o), was thought to be valuable for engineers, who work in the wider study area.

6. Acknowledgments

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