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Site Investigations at Near East University-Cyprus

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Abstract

Geotechnical investigations were carried out at the proposed twenty-three storey tower structure to be constructed within the Near East University campus located in North of Nicosia, North Cyprus. The site is 7 km from the city center at the southern slopes of the Girne Mountains between 150-160m elevation which is completely covered by the Mia Milia (Dağyolu) formation of Kythrea (Değirmenlik) group consisting alternation of sandstone-siltstone-marl-claystone. The clayey formations of the group contain overconsolidated swelling soils and exhibit intermediate to high swelling potential. Therefore, detailed investigations of the swelling potential of the units are essential considering that there will be excavations for the construction of the foundations, as well as their potential influence for the overall stability of the sloping site. Investigation comprised of four exploratory boreholes and a trench. Soil samples were collected for determining physical, mechanical and chemical characteristics of subsoil. The semi quantitative X-ray diffraction analyses indicated that the predominant clay mineral is smectite, illite and chlorite or kaolinite are the other abundant clay minerals. Calcite is the major mineral of the marls, quartz and feldspar are also present at high amounts. Analysis of various field and laboratory test results were presented together with their geotechnical implications in foundation design.

***Keywords:** Nicosia, claystone, smectite, calcite.*

1 Introduction

Cyprus with an area of 9,251 km² is the third biggest island in the Mediterranean sea, and the biggest island in Eastern Mediterranean region. North Cyprus covers an area of 3,299 km². The ancient settlements and the early building sites of Cyprus were mainly located on top or at the slopes plateau of the rocky hills. The first Cypriot capital Enkomi (Alasya) (1700 BC) was established at a rocky plateau on the north bank of the Pedieos river (Figure 1). Soli (1193 BC) one of the ten city-kingdoms of Cyprus was build on pillow lavas at the slopes of

Troodos mountains, Vuni Palace (498 BC) was build on top of a limestone cap of pillow lavas and the Limniti (Yeşilırmak) islet (7,000 BC) is on top of limestone hills (Figure 2).

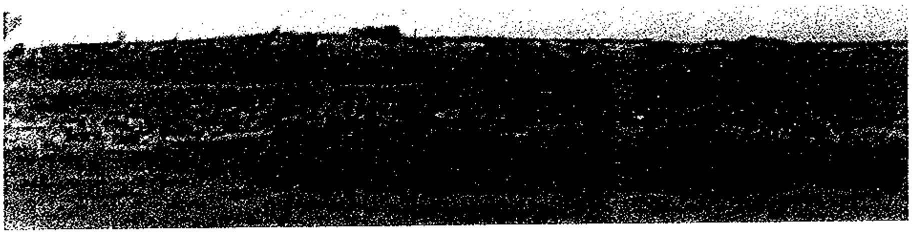

Figure 1. Ancient settlement of the first Cypriot Capital Enkomi (Alasya)

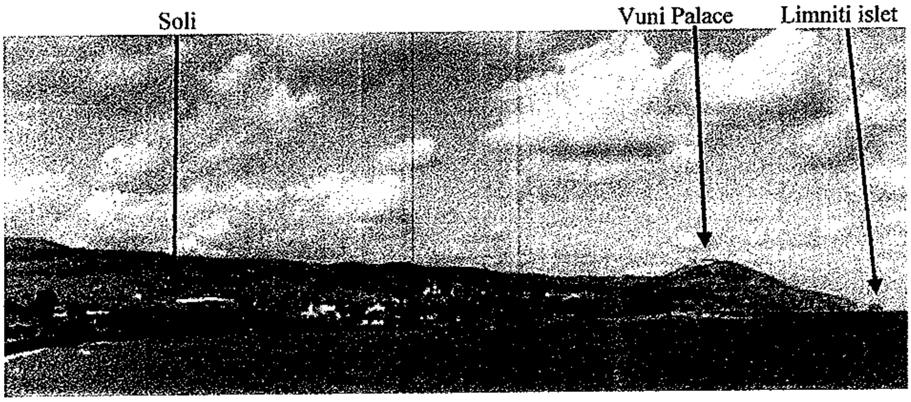

Figure 2. Ancient settlements of Soli., Vuni and the Islet of Limniti (Yeşilırmak)

Nicosia, the present capital is one of the few island capitals that do not lie on the coast. It has risen to its present importance as the administrative capital only since Lusignan times (1192-1489). Nicosia was built on a thick alluvium avoiding the nearby clay hills to avoid damages from the swelling clays. However, soft alluviums also sometimes may cause major geotechnical problems. Bedestan (build between 600 – 1200) is the oldest building suffered damages due to soft alluviums (Atalar and Das, 2005). Nicosia is covered by extensive surficial deposits. The walled city and its closed surroundings are covered by fill. Alluviums of low bearing capacity are present around the Pedios river in the southeast, southwest, and at the old bed of Pedios river in the northeast. Marl is extensively exposed in the eastern and western parts of the city. Extensive outcrops of uncemented gravel covers part of the southeast and southwest. Calcarenite, sandstone and limestone of high bearing capacity are exposed in the south and southeast (GSD, 1982).

2 Geography, Topography and Climate

Cyprus is located in the center of the triple junction of three continents Europe, Asia and Africa. The island is divided into three main features stretching in an almost east-west direction, namely from north to south: the Kyrenia range, the Mesaoria plane and the Troodos range. The Troodos range, which is the largest of the two mountain ranges, is located, in the central south of the island and rises to a height of 1951 metres (Olympos hill). The Kyrenia range is in the north of the island and rises only to 1023 metres. Mesaoria plane is located between the Kyrenia and Troodos ranges. Nicosia is almost flat lying in the Mesaoria plane at about 100 - 130m above the mean sea level.

Cyprus is a good example of a country with a typical Mediterranean climate; arid and semi-arid in character. The summer periods are long and relatively hot and dry from mid-May to mid-October, and the winters are mild and short from December to February, which are separated by short spring and autumn seasons. The Troodos range receives the highest annual precipitation of up to 1100mm, while the Mesaoria plain receives only about 300-350mm. The maximum annual precipitation in the Kyrenia range is 550mm which is slightly higher than the islands latest annual average of 489mm.

3 Geological Background

Cyprus is situated at the triple junction of Eurasia, Arabian, and African plates, and has played a very important role for the geological understanding of the Eastern Mediterranean region. The geology of Cyprus governs the topography. Despite the intensive investigations carried out there is no consensus on the geological division of the island and the tectonics of the Eastern Mediterranean region. Cyprus is mainly divided into between three to five geological zones by different researchers. Cyprus may be divided into three main geological zones from north to south according to its topography; the Kyrenia Zone, Mesaoria Zone, and the Troodos Zone.

Cyprus may be divided into six geological zones according to geological evolution and emplacement of its geological units (Atalar, 2005): (1) Troodos Zone or the Troodos Ophiolite, (2) North Cyprus (Kyrenia) Zone, (3) Mamonia Zone or Mamonia Complex, (4) South Cyprus Zone, (5) Mesaoria Zone, and (6) Alluviums (Figure 3).

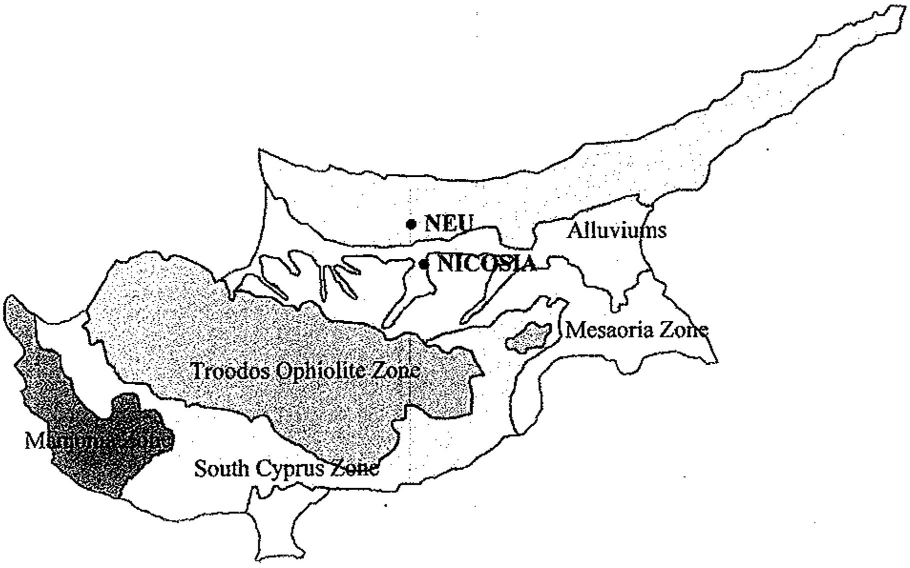

Figure 3. Geological Map of Cyprus (Revised from GSD, 2002)

The geological evolution of Cyprus started with the formation of the Troodos Ophiolite in Upper Cretaceous due to the subduction of the African plate beneath the Eurasian plate. Troodos Ophiolite comprises of plutonic, intrusive and volcanic rocks (Figure 4).

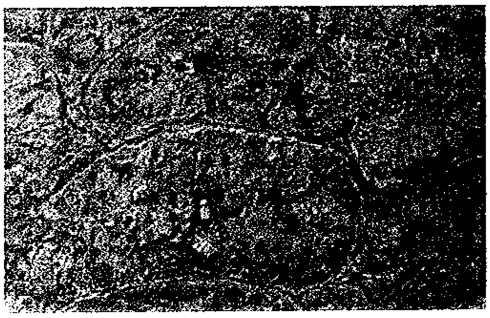
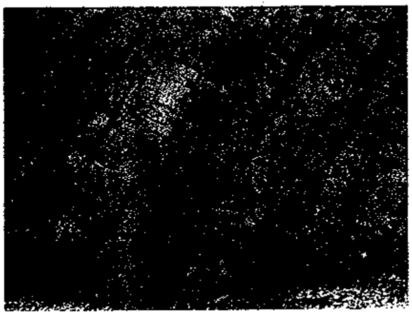

Figure 4. Pillow lavas (left) and dykes (right) of Troodos ophiolite

North Cyprus (Kyrenia) Zone, is composed of autochthonous sedimentary rocks of Upper Createaceous to Middle Miocene (including Kythrea group) and allochthonous massive and recrystallised limestones, dolomites and marbles of Permian-Carboniferous to Lower Cretaceous age. Mamonia complex comprises of igneous-volcanic, sedimentary and metamorphic rocks of Middle Triassic to Upper Cretaceous age. South Cyprus Zone is composed of mostly chalks, clays, marls and gypsium. Bentonitic Clays, Lefkara, Pakhna and Kalavasos formations are within this zone (Figure 5).


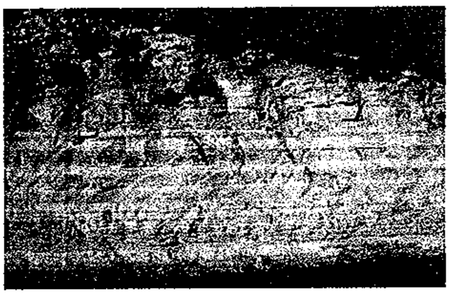

Figure 5 Chalks of South Cyprus Zone

The Mesaoria Zone consists rocks of deep and shallow marine environment of marl, sandy marl, calcarenites and terraces belonging to Pliocene and Pleistocene ages. Nicosia and Athalassa formations are within this zone. The alluviums Holocene to recent in age containing gravel, sand, silt, and clay are widespread in the Mesaoria plain, especially at Nicosia and Famagusta and at the east and west coasts as well as the stream beds all over the island.

4 Cyprus Clays

Cyprus clays occurred as a result of the alteration of the Troodos ophiolite and the pelagic sedimentary cycles that followed in the post Createceous period. The calcium corbonate content of the marls originated from the limestones and dolomites of the Kyrenia zone, the chalks of the South Cyprus zone and considerable part of it is biogenic in origin. A large part of Cyprus is covered by alluvium of low to intermediate swelling potential and clays with intermediate to extremely high swelling potential (Table 1).

North Cyprus is almost covered by clays, alluviums and claystones. Most of the problems encountered in North Cyprus, in construction involves silty – clayey soft soils due to their low strength, durability and high compressibility, and the swell shrink nature of the overconsolidated swelling soils. Landslides occur at the steep slopes of the clayey formations. There is widespread damage to the buildings constructed on swelling clays, and in major roads and highways all over the country which were founded on swelling clays (Atalar, 2002). Swelling clays of Cyprus can be divided into five groups (Figure 6):

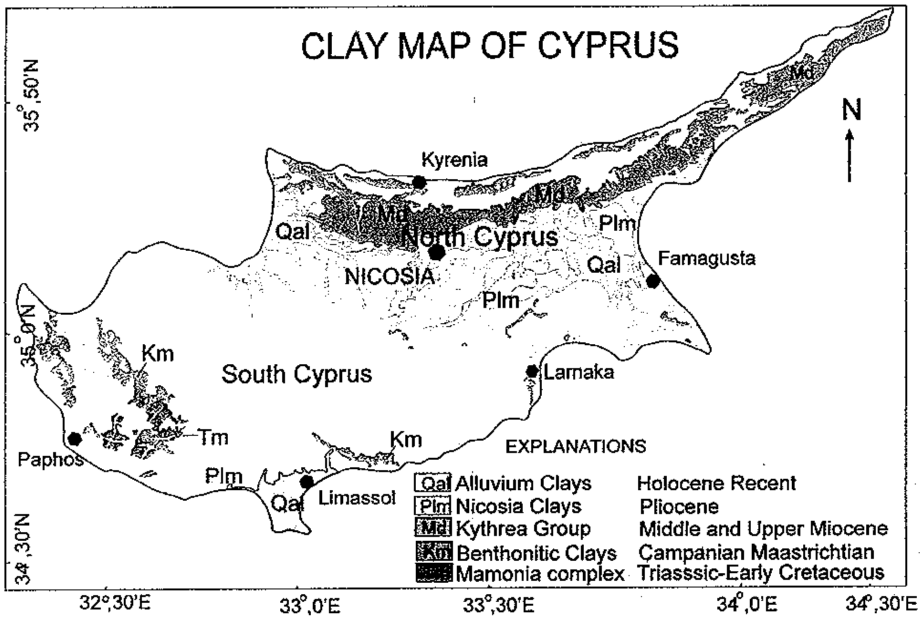

Figure 6. Cyprus Clays (Revised from GSD, 1995).

5.1. Bentonitic Clays

The bentonitic clays occurred as the first clays of Cyprus due to alteration of the pillow lavas of the Troodos ophiolite. Bentonitic clays occurrence are mainly found in Kathikas-Moni and Kannaviou formations in the south part of the Troodos ophiolite at the boundary of the pillow lavas with the postvolcanic sediments and are widespread at Paphos in the west, less widespread at Moni near Limassol, in the south and at Paralimni at the south of Famagusta in the east. In south Cyprus reaches a thickness of more than 300 metres. It is only found near Yiğitler village in North Cyprus. Bentonitic clays contain more than 35 % low swelling potential calcium montmorillonite and no high swelling potential of sodium montmorillonite. Despite that Bentonitic clays exhibit the highest swelling potential of Cyprus clays (Constantinou et al., 2002).

5.2. Clays of Mamonia Complex

In the south western part of the island near Paphos, igneous-volcanic, sedimentary and metamorphic rocks of the Mamonia Complex of Middle Triassic to Cretaceous ages also contain clays of swelling potential; however, swelling potential is much less than in the bentonitic clays because their swelling potential is acquired from the Kannaviou formation.

5.3. Clays of Kythrea Group

The Kythrea group mostly contains turbiditic rocks. The Group, consists from bottom to top, gravel, conglomerates, greywacke, marl, and mostly abyssal turbidites with a shallow environmental chalk, marl, limestone, and gypsum finishing. alternation of sandstone-siltstone-marl-claystone are widespread within the group. The group is only observed in North Cyprus and has a complete coverage of the northern and southern slopes of Kyrenia range from east to west. The Kythrea group consists Mia Milia, Skylloura, Lapatza (Pre-evaporitic) and Lapatza (evaporitic) formations. The clayey units of several metres thickness to tens of metres thickness in the different formations of the group exhibit different swelling potential. Lapatza (Pre-evaporitic) and Skylloura formations exhibit high to very high, Mia Milia intermediate to high swelling potential (Atalar, 2004).

Table 1. Swelling potential of Cyprus clays

Clays	Liquid Limit (LL)	Swelling Potential
Alluvium	Up to 48	Low - Intermediate
Nicosia Formation	53 - 91	High – Extremely High
Kythrea Group	47 - 73	Intermediate – High
Mamonia Complex	33 - 167	Intermediate – Extremely High
Bentonitic Clays	55 - 210	High – Extremely High

5.4. Clays of Nicosia Formation

In the middle of the island from east to west a belt like and in the southwest and west, overconsolidated clays with high to very high swelling potential occur in geologic units of Nicosia Formation of Pliocene age and are extensively exposed in big settlements like Nicosia, Famagusta, Larnaka and Polis. The southern parts of Nicosia and Famagusta is completely covered by this formation. The Nicosia formation mainly contains calcarenites and marls. Gravels, limestones and conglomerates are also present in this formation, Figure 6. The clay minerals contained are large amounts of montmorillonite, lesser amounts of illite and kaolinite. Some researchers describe the Myrtou formation seperate while others describe it together with the Nicosia Formation. Some units of Apolos and Athalassa formations of Pleistocene age also contain clays.

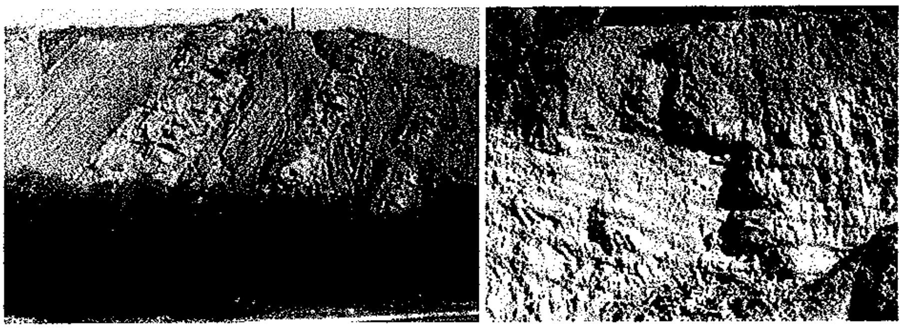

Figure 6. Mia Milia (Dağyolu) Formation (left), Nicosia Formation (right)

5.5. Alluvium Clays

The alluviums, Holocene to recent in age containing gravel, sand, silt, and clay are widespread in the Mesaoria plain, especially at Nicosia and Famagusta and at the east and west coasts, (Figure 7). They comprise loose - medium dense gravel and sand, and soft - firm silt and clays. The alluviums mostly contain low amounts of clay size material. The alluviums also contain high amount of montmorillonite (smectite). These alluviums show relatively high apparent strength in their dry state. However, with saturation their strength decreases. Most damages occur to the buildings constructed close to the stream beds. These clayey soils have low to medium swelling potential.

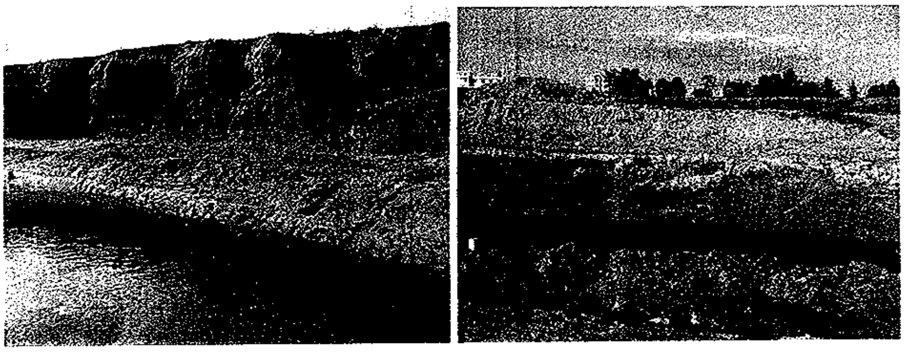

Figure 7. Recent Alluviums

5 Site Location

The site is located at the southern slopes of the Girne Mountains between 150-160m elevation which is completely covered by the Kythrea groups Mia Milia (Dağyolu) Formation consisting of sandstone-siltstone-marl-claystone alternations (Figure 8). Alteration of the subsoil is observed to be from several centimeters to several meters. The clayey soils of the formation contain overconsolidated swelling soils and exhibit intermediate to high swelling potential. Therefore, detailed investigations of the swelling potential of the units are essential considering that there will be excavations for the construction of the foundations, as well as their potential influence for the overall the stability of the sloping site.

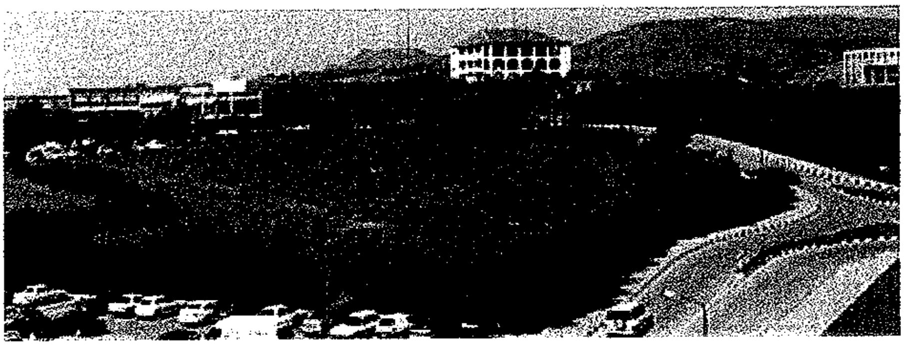

Figure 8. Tower Structure Site

6 Field Investigations

6.1. Foundation Boreholes

At the investigation area, four (4) boreholes having 25m depth each were drilled between 22th of February and 6th of March 2005. Yersusan (Kıbrıs) Ltd. executed the drills with Akar D300-H90 model rotary drilling equipment mounted on a truck, which advances by hyraulic pressure. Flight auger was used up to 1.00m depth at borehole no. 4, 1.50m depth at both borehole no. 1 and 2, and 3.00m depth at borehole no. 3. Below these depths core drilling method was utilized and core were recovered by water. The diameter of the recovered cores are about 50mm. Only two SPT's were conducted due to the hard(SPT/N=50+) subsoil conditions. Core samples of Borehole 3 and Borehole 4 are seen in Figure 9.

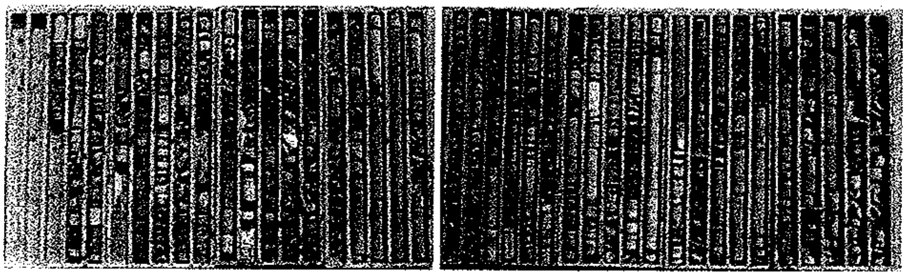

Figure 9. Core samples of Borehole 3 (left), and Borehole 4 (right)

6.2. Trial Pit

On 9th of April 2005, between 5.10m and 7.50m to the east of Borehole 2, an investigation pit having up to 2.40m depth was opened. Due to the hard subsoil conditions, undisturbed samples were only collected as big blocks. Core samples of Borehole 2 and the excavated trench are seen in Figure 10.

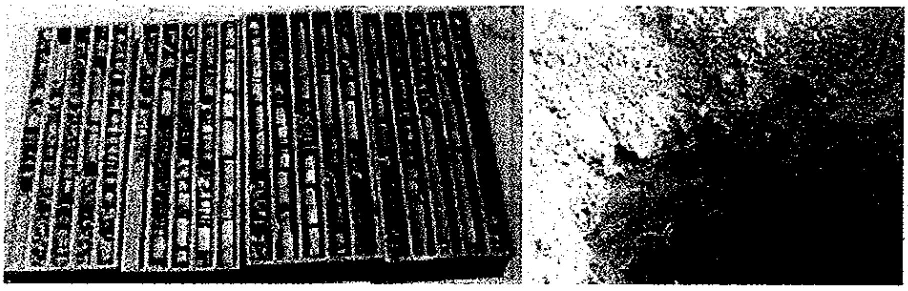

Figure 10. Core samples of Borehole 2 (left), the trench,(right)

7 Laboratory Analyses

Cores taken from boreholes and trial pit samples were investigated at Near East University Soil Mechanics Laboratory. XRD analyses were executed on ten (10) samples at General Directorate of Mineral Research and Exploration at Ankara, Turkey. In addition, thin sections are observed and carbonate ingredients were determined. Atterberg limits analyses were executed on twenty (20) samples. Liquid limit and plastic limit amounts were determined and plasticity indexes were calculated. Soil particle size analyses were executed on twelve (12) samples and on ten (10) samples grain size distributions were observed.

According to the Borehole core sample analyses it is determined that coarse grain samples contain low clay and low liquid limit amounts as low as 37%. The liquid limit amount increases up to 65% in relation with the decrease of grain size (Atalar, et al., 2006a) (Table 2).

According to the trial pit sample observations it is determined that moisture content of coarse grain samples containing low clay are about 11% and increases up to 18.2% in relation with the decrease of grain size and increased clay content (Table 3).

In XRD analyses highly encountered minerals in order of quantity are calcite, quartz, plagioclase, mica, dolomite and the highly encountered clay minerals in order of quantity were smectite, chlorite or kaolinite and illite. Fine-medium grained sandstone, siltstone, low liquid limit amounts as low as 37%. The liquid limit amount increases up to 65% in relation with the decrease of grain size (Atalar, et al., 2006a) (Table 3).

According to the trial pit sample observations it is determined that moisture content of coarse grain samples containing low clay are about 11% and increases up to 18.2% in relation with the decrease of grain size and increased clay content (Table 4).

Table 3. Borehole core analyses.

Borehole No	Depth (m)	LL (%)	PL (%)	PI (%)	Percent passing 0.075mm	Dominant grain size (mm)
NEU 1	6.75-6.80	-	-	-	50.7	-
NEU 1	9.80-9.85	48	33	15	-	-
NEU 1	14.70-14.75	48	30	16	-	-
NEU 1	20.00-20.05	49	32	17	-	0.3-0.5
NEU 1	23.15-23.20	-	-	-	49.3	
NEU 1	24.00-24-10	56	33	23	-	0.02-0.04
NEU 2	3.80-3.90	-	-	-	55.9	0.2-0.6
NEU 2	7.00-7.05	50	35	15	-	-
NEU 2	10.00-10.05	49	31	18	-	-
NEU 2	14.80-15.00	51	33	18	100.0	-
NEU 2	20.10-20.15	57	38	19	-	0.2-0.4
NEU 2	24.70-24.75	41	26	15	100.0	0.01>
NEU 3	3.00-3.45	37	26	11	100.0	0.02-0.04
NEU 3	6.70-6.75	51	36	15	99.9	-
NEU 3	8.05-8.10	48	32	16	-	-
NEU 3	14.50-14.55	53	32	21	-	-
NEU 3	19.15-19.20	51	32	19	99.9	-
NEU 3	24.60-24.65	-	-	-	67.1	0.4-0.8
NEU 3	24.70-24.75	64	34	30	-	0.02>
NEU 4	10.50-10.55	47	33	14	99.9	-
NEU 4	12.10-12.15	53	35	18	-	-
NEU 4	17.45-17.50	56	37	19	100.0	0.02>
NEU 4	18.10-18.15	-	-	-	73.4	-
NEU 4	20.00-20.05	48	34	14	-	0.3-0.5
NEU 4	25.00	65	31	34	-	0.02>

Table 4. Moisture content of soils from trial pit.

Soil description	Depth (m)	Moisture content (%)
Greenish-brownish silt-sandstone	2.40	8.0
Brownish silt-sandstone	2.40	9.1
Massive clay-sandstone	1.20 – 1.50	11.4
Bright brownish layered clay	1.20 – 1.50	16.3
Bright brownish rounded clay (outside)	1.20 – 1.50	13.0
Bright brownish rounded clay (outside)	1.20 – 1.50	11.5
Greenish rounded clay (inside)	1.20 – 1.50	18.1
Greenish rounded clay (inside)	1.20 – 1.50	18.1
silt-sandstone	1.20 – 1.50	11.7
Clay-sandstone	1.00	13.8

present at high amounts. However, when grain of the samples is coarse the clay minerals disappear (Figure 11).

Table 4. $CaCO_3$ content.

Soil description	Depth (m)	$CaCO_3$ content (%)
Greyish silt-sandstone	6.75-6.80	26
Light brown silt-sandstone	7.80-7.85	14.1
Greyish silt-sandstone	8.22-8.25	25.8
Greenish clay-siltstone	9.80-9.85	9.8
Light grey-whitish silt-sandstone	10.55-10.60	53.2
Light grey-whitish clay-siltstone	16.55-16.60	36.5
Greenish silt-sandstone	23.15-23.20	24.9

Figure 11. Fine grain sample (NEU 3, 24.70-24.75) (left), coarse grain sample (NEU 3, 24.60-24.65) (right)

8 Foundation Engineering Evaluations

8.1 Proposed Structures

The proposed structures are a 2 basement + 1 ground floor + 20 storey tower having pentagon cross-section, and 2 basement + 1 ground floor + 2 storey surrounding buildings having triangular cross-sections. Considering the excavation depths the lowest elevation is +99.70m.

8.2 Bearing Capacity and Allowable Soil Pressure

In the bearing capacity calculations, considering the discontinuities and cracked structure of the subsoil the empirical formula given below is utilized.

$$Q_{ult} = 0.5\gamma.5\ _{\gamma} + \gamma D N_q \quad (1)$$

N_γ, N_q : bearing capacity factors related to internal friction angle (is taken as Φ=26°)
γ : effective unit weight (γ_{sat}=2.2 t/m^3, γ=1.2 t/m^3)
B : width of foundation (m)
L : length of foundation (m)

According to the above mentioned equation, the calculated bearing capacity for alternating mudstone-siltstone-sandstone layers is q_{ult}=3000 kN/m^2. When a factor of safety F.S=3.0 is taken into account allowable bearing capacity will be q_{all}=1000 kN/m^2. Therefore bearing capacity of subsoil is not expected to be critical.

Considering the fractured structure and the potential disturbances that may occur during foundation excavation, in order to limit the vertical displacements, net allowable soil pressure is given as $qall_{net}$=500 kN/m^2 for foundation design. Allowable soil pressure can be increased by considering surcharge effect related to the minimum buried mat foundation depth. In this case,

$$qall = q_{all}net + \gamma D = 500kN/m^2 + 22kN/m^3 x 7.4m$$

$$q_{all} \cong 650kN/m^2 (kPa)$$

Vertical subgrade reaction value can be taken as k_s=50,000 kN/m^3. The given net allowable soil pressure can be increased by 50% in case of earthquake (Atalar et al., 2006b).

8.3 Settlement Evaluations

The settlement under the foundation basement pressure, in the order of 1000 kN/m^2 (kPa), is calculated by the empirical equation given below (Engineer Manual, 1994).

$$Sa = (1.12)qB(1-\mu^2)(L/B)^{1/2} / E_d \qquad (2)$$

q : net foundation basement pressure (taken as 1000 kN/m^2)
μ : poisson's ratio (taken as μ=0.20)
E_d : deformation modulus (taken as E_d=14,700 MPa) (Zhang, 2004)
B : width of foundation (m)
L : length of foundation (m)

Considering the above mentioned equation, for alternating mudstone-siltstone-sandstone layers, under net foundation basement pressure 1000 kN/m^2, the calculated maximum settlement is S_a=4.5mm. The settlement under the given allowable soil pressure (650 kN/m^2) is estimated to be 3.0mm.

8.4 Earth Works and Drainage

In case of structural fills are required at the subject site, the rock layer excavated from foundations, can be used as structural fills if their gradation, plasticity values are suitable.

Considering encountered rock layers beneath the foundation to the weathering effects of the atmosphere, a granular capping layer has to be utilized immediately after the foundation excavation. It is also recommended that, a 25.0 cm thick "capping" layer should be employed beneath foundations and any slabs resting on the ground. This will reduce capillary water effects on the foundations and slabs. The capping layer should be formed of GW-SW type material as described by the USCS.

It is also recommended that French type drainage trenches, surrounding the building to be constructed to prevent the surface water to intrude the foundations. These trenches should have perforated PVC or concrete pipes (Φ200 mm) laid down at their bottom. These pipes should be covered with coarse granular material and both should be enveloped in a geotextile used for filtering.

Conclusion

Subsoil investigations were conducted in order to design foundations of the proposed twenty-three storey tower structure. Investigation programme consist of four boreholes and a trench.

Soil samples were collected for determining physical, mechanical and chemical characteristics of subsoil. Analyses of various field and laboratory test results were presented together with their geotechnical implications in foundation design.

The site is located at the southern slopes of the Girne Mountains which is completely covered by Mia Milia (Dağyolu) Formation consisting of sandstone-siltstone-marl-claystone alternations. The grain size of soils are usually less than 0.5mm. The clayey soils of the formation contain overconsolidated swelling soils and exhibit intermediate to high swelling potential. In XRD analyses the highly encountered clay mineral is smectite. High carbonate content was determined in light colored samples.

The bearing capacity calculations, considering the discontinuities and cracked structure of the subsoil is utilized. Bearing capacity of subsoil is not expected to be critical.

Considering the fractured structure and the potential disturbances that may occur during foundation excavation, in order to limit the vertical displacements, net allowable soil pressure is given as $qall_{net}$=500 kN/m^2 for foundation design. Allowable soil pressure can be increased by considering surcharge effect related to the minimum buried mat foundation depth. The given net allowable soil pressure can be increased by 50% in case of earthquake.

The settlement under the foundation basement pressure, in the order of 1000 kN/m^2 (kPa), is calculated. The settlement under the given allowable soil pressure (650 kN/m^2) is estimated to be 3.0mm.

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