UNIVERSITY OF CYPRUS

UNIVERSITY CAMPUS

GEOTECHNICAL INVESTIGATIONS
GENERAL REPORT

Client: UNIVERSITY OF CYPRUS

Nicosia, November 2004
SH Soil Engineering Ltd

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FAX NO. :22892550 **DATE: 21/12/04**

ΓΕΩΤΕΧΝΙΚΗ ΕΡΕΥΝΑ ΣΤΟ ΧΩΡΟ ΤΗΣ ΠΑΝΕΠΙΣΤΗΜΙΟΥΠΟΛΗΣ

Αναφερόμαστε στη σύσκεψη που είχαμε στις 17 Δεκεμβρίου 2004, και παραθέτουμε πιο κάτω τις πρόσθετες πληροφορίες/εισηγήσεις που μας ζητήσατε.

1. References for bearing capacity formula used.
For cohesive soils, the "Skempton" Bearing Capacity factors and formula are used. These factors and formula are given in nearly all Soil Mechanics textbooks such as:
- (a) Elements of Soil Mechanics by G N Smith
- (b) Foundation Design and Construction by M J Tomlinson
- (c) Soil Mechanics by R F Graig
- (d) The Mechanics of Engineering Soils, by P L Capper & W F Cassie.
- (e) A Short Course in Foundation Engineering by N E Simons & B K Menzies

A copy of these bearing capacity factors is attached in a graphical form.

2. Coefficient of Subgrade Reaction k_s
Values of this coefficient may be estimated after establishing first the value of the Modulus of Elasticity E_s and then using the equation:

$$k_s = \frac{E_s}{B(1-\mu^2)}$$

Where: B = foundation width
μ = Poisson's ratio of the soil

3. Angle of shearing Resistance φ for cohesionless soils
Various empirical relationships can be used to estimate φ from the SPT results. One such method is the one given in Fig.8.9 attached.

4. Comments and suggestions regarding swelling pressures form the Marl are attached.

Best Regards

N. Stylianou

ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΥΠΡΟΥ
ΓΡΑΦΕΙΟ ΑΝΑΠΤΥΞΗΣ ΠΑΝ/ΠΟΛΗΣ
Ελήφθη 22.12.04 | Θεώρηση | Ενη.ιέρ.
Κοιν. LP SA
Ενέρ.

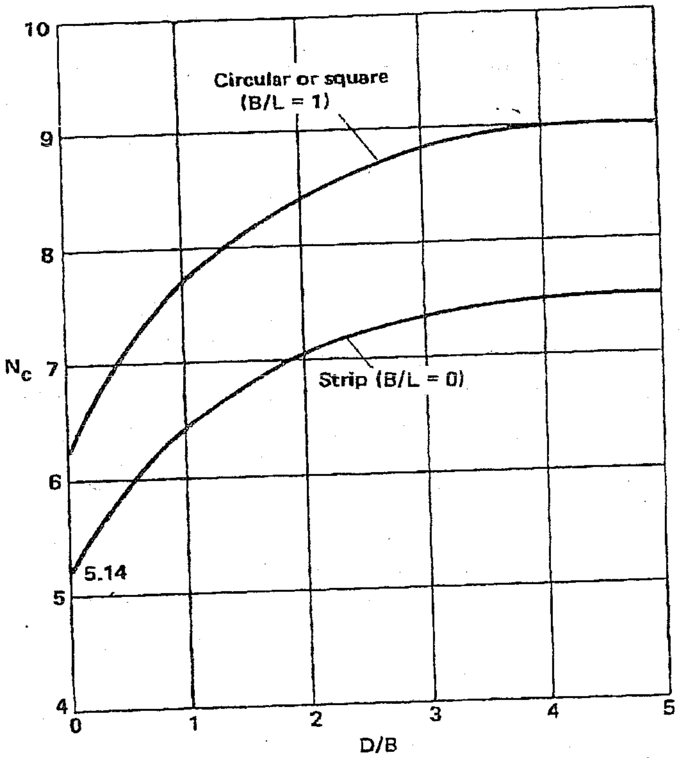

Fig. 8.5 Skempton's values of N_c for $\phi_u = 0$. (Reproduced from A. W. Skempton (1951) *Proceedings of the Building Research Congress*, Division 1, p. 181, by permission, Building Research Establishment: Crown Copyright).

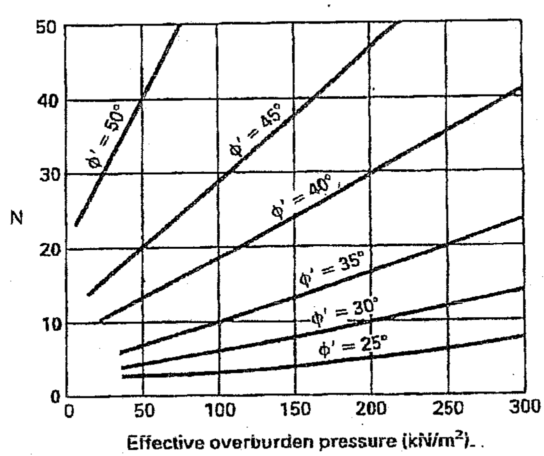

Fig. 8.9 Correlation between shear strength parameter ϕ', standard penetration resistance and effective overburden pressure. (Reproduced from J. H. Schmertmann (1975), *Proceedings of Conference on In-Situ Measurement of Soil Properties*, by permission of the American Society of Civil Engineers).

Due to rapid deterioration of the Marl when exposed, it is important to keep such exposure to minimum if the construction of a basement down to Marl level is envisaged. As soon as the excavation for the foundation is completed and the bottom of the excavation cleaned carefully, it should be covered with a blinding concrete of about 80mm thick. The construction of the foundations should proceed and completed as soon as possible. Drying and wetting of the bottom of excavations in the Marl should be avoided.

The Marl is a potentially expansive soil with generally a "medium" potential expansiveness. Although the measured swelling pressures were generally either zero or low (25 to 50 kN/m^2) and only in one case a high swelling pressure of 450 kN/m^2 was measured, the possibility of swelling pressures on the foundations and retaining walls is real and must be considered and allowed for in the design calculations. Swelling may be caused either from an increase in the moisture content of the Marl or by "unloading" due to excavations. As it can be seen from Table 3.3, the initial moisture content of the sample (BH N5, d=7.50m) which showed high swelling pressure, was 24.4% and its final (after consolidation) 27.4%, an increase of 3%. Therefore, measures should be taken in the designs to protect the Marl from either surface or ground water and keep its moisture content constant to avoid swelling or shrinkage.

Sulphates in soils or groundwater may attack concrete depending on their concentration. For sulphate concentration in soils less than 0.2% of SO_3, ordinary Portland cement may be used with maximum water/cement ratio of 0.55. For SO_3 of 0.2% - 0.5%, the minimum cement content should be 330 kg/m^3 and the water cement ratio less than 0.50. The SO_3 obtained from the chemical analysis on the khaki Marl samples was less than 0.2%, no special measures are required for foundations on this layer. In the case of the deeper grey silty Marl a value of SO_3 of 0.323% was found. For foundations in this layer, the appropriate concrete quality specified above should be used.

CONTENTS

1. INTRODUCTION

This is the general report on the geotechnical investigations carried out in the area of the Campus of the University of Cyprus. The report describes the field and laboratory work carried out and includes the results of the in-situ and laboratory tests performed both graphically and in a Summary form. It gives an account of the engineering properties of the strata encountered and typical values of allowable bearing capacity and settlement of foundations.

The work was undertaken on behalf of the Office for the Development of the University Campus of the University of Cyprus, after the award of the relevant Contract to SH Soil Engineering Ltd by the University of Cyprus, letter reference Π.Κ. 115.1.6.28/CDO 028/3.

The University Campus is located 5.5 km South-East of Nicosia center in the broader area of Athalassa, Figure 1. The location of the area investigated is shown in Figure 2. The Campus area was divided into seven sites and each one was dealt with separately. Hence, seven individual geotechnical investigation reports were issued separately. The reader should refer to the individual reports of each site for detailed information on the laboratory results and fieldwork performed.

The Geological Survey Department and others previously carried out geological investigations in the broader area of the University Campus and in specific areas where various structures and works have been constructed. The work carried out previously is described in the following reports:

1. University of Cyprus, Geological – Geotechnical Report, July 1994. (Geological Survey Department)
2. Supplementary exploratory boreholes drilled at the proposed site of the University of Cyprus, April 1995 (Geological Survey Department).
3. University of Cyprus- Detailed Geological Investigation, June 1998 (Geological Survey Department)

4. Site Investigations for the proposed buildings of the University of Cyprus- Volumes I and II, September 1998 (Geoinvest Ltd)

The purpose of the geotechnical investigations carried out was to establish the geological profile at the Campus of the University, obtain the geotechnical characteristics and engineering properties of the strata encountered, and record the water table profile at the site.

The Campus area investigated has several designated potential sites for future development of the University of Cyprus.

2. FIELD WORK

The Field Work carried out consisted of the drilling of a total of 35 boreholes having a total depth of 336.3m, the recovery of disturbed and undisturbed soil samples, in-situ testing, measurement of the water table and taking water samples for chemical analysis.

Drilling was carried out using the rotary 'crawler' type rig, Casagrande C6 type, and a high capacity air compressor for removing the drilled material.

2.1 Boreholes

The 35 boreholes drilled in the area were numbered N1 to N35 and their depths ranged between 7.00 and 15.2m. Their approximate position is shown on the Borehole Location Plan, Fig 2. The depth of each borehole is given in Table 2.1. The boreholes had a diameter of 135 mm and the method of drilling used was a combination of rotary and percussive drilling using the 'down-the-hole hammer'. The cuttings of the soil were removed using air and sometimes air and water flushing. With this method all boreholes are cased during the drilling process.

The soil layers encountered in the boreholes are described in the Borehole Records, presented in each of the individual reports for the seven Sites. Photographs of samples of the soil layers encountered are also presented in the same reports.

2.2. Sampling

Four types of soil samples were recovered from the boreholes during drilling:

(a) **Disturbed** representative bulk samples were recovered from the soil cuttings brought to the surface by air flushing. These samples are suitable for identifying and describing the soil layers encountered and carrying out classification tests, such as particle size distribution, Atterberg Limits etc.

(b) **Disturbed** samples recovered from the split spoon sampler of the Standard Penetration Tests. These are suitable for identifying and describing more accurately the soil layers encountered and performing classification tests as above.

(c) **Undisturbed** cohesive samples recovered from the split spoon sampler of the Standard Penetration Test. Apart from the above classification tests, these samples are suitable for performing Unconfined Compression Tests and in some cases Quick Undrained Triaxial Tests. In addition they can be used for carrying out natural moisture content tests and natural density tests.

(d) Ten **Undisturbed (U100)** samples were recovered from the Marly layers from the Boreholes shown in Table 2.1. The samples were taken using 100mm diameter by 460mm long U100 sampling tubes. Penetration of the tubes was effected by pushing them into the soil layers using the drilling rig equipment.

Also five **water sample** were taken from different boreholes for chemical analysis.

2.3 In-situ Testing

In-situ testing performed in the boreholes consisted of the Standard Penetration Test (SPT). The tests were generally performed at intervals of 1.50m. The total number of tests performed was 207 and the results were recorded in the Borehole Records. The number of tests performed in each borehole is given in Table 2.1. The SPT results are also presented graphically in Figures 4 and 5 for the Alluvium deposits and Marly layers respectively. The tests were performed in

TABLE 2.1

FIELD WORK CARRIED OUT

BH.NO.	DEPTH m		SPT	U100	Water
	Tender	Drilled	No.	No.	No.
N1	14,0	15,2	8		
N2	12,0	15,0	8	1	1
N3	10,0	10,5	7		
N4	12,0	15,0	8		
N5	12,0	8,0	6	1	
N6	12,0	10,5	9		
N7	9,0	11,5	7	1	
N8	9,0	10,5	8		1
N9	9,0	7,5	5		
N10	12,0	7,5	5		
N11	7,0	10,5	7		
N12	9,0	10,5	6	1	
N13	7,0	11,2	6	1	
N14	12,0	7,5	4	1	
N15	12,0	7,5	5		
N16	9,0	7,5	5		
N17	9,0	10,5	6	1	
N18	9,0	9,5	6		1
N19	7,0	10,5	7		
N20	7,0	10,5	7		
N21	7,0	9,0	6		
N22	7,0	9,0	6		1
N23	7,0	9,9	5	1	
N24	7,0	9,0	6		
N25	7,0	10,5	7		
N26	7,0	9,0	6		
N27	9,0	9,0	6		1
N28	7,0	9,0	6		
N29	9,0	7,5	5		
N30	7,0	7,5	4	1	
N31	7,0	9,0	5	1	
N32	7,0	7,5	5		
N33	7,0	7,5	5		
N34	7,0	9,0	6		
N35	0,0	7,0	0		
TOTALS	**301,0**	**336,3**	**208**	**10**	**5**

accordance with BS 1377:90 titled 'Methods of Testing Soils for Civil Engineering Purposes'. A standard split spoon sampler is driven into the soil to a depth of 450 mm by the repeated blows of a 63.5 kg standard penetration monkey trip hammer. The number of blows for every 150mm penetration is recorded. The penetration resistance 'N' is defined as the number of blows required to drive the sampler into the soil the last 300 mm.

In the sandy coarse gravel layers the open split sampler is substituted by a closed cone sampler. In this case no sample is recovered.

3. LABORATORY TESTING

Laboratory testing was carried out on selected disturbed and undisturbed samples recovered. The tests included classification tests (natural moisture content, particle size distribution, Atterberg limits, specific gravity, natural density), shear strength tests (unconfined compression and triaxial tests) swelling and consolidation tests on samples of the Marl and chemical tests on soil samples. Full chemical analysis of 5 water samples was also carried out. The number and type of tests carried out are outlined in the following sections and most of the results are presented in a Summary Form in Tables 3.2, 3.3, 3.4 and 3.5. Table 3.1 presents the type and number of each test carried out in each of the 7 Sites.

The purpose of the laboratory tests was to establish the mechanical characteristics of the soil layers and deduce their engineering properties, which are required for the proper design of the foundations of the proposed structures.

3.1 Classification Tests

Classification tests carried out on selected samples included natural moisture content, liquid and plastic limit, particle size distribution by wet sieving and sedimentation (hydrometer) tests, specific gravity and density tests. The results of these tests, enable the classification and correlation of the soil strata and their comparison with other tests such as SPT, shear strength

TABLE 3.1

LABORATORY WORK CARRIED OUT

	TYPE OF TEST	NO. IN TENDER	SITE NO.							FINAL TOTAL NO.
			1	2	3	4	5	6	7	
1	Particle size (wet or dry seiving)	18	3	6	6	4	4	7	10	40
2	Particle size (hydrometer)	18	5	4	5	5	4	5	6	34
3	Atterberg Limits	25	5	4	5	5	4	5	6	34
4	Natural Moisture Content	25	29	29	23	25	6	28	35	175
5	Specific Gravity	8	5	4	5	5	4	5	6	34
6	Natural Density Test	0	19	18	16	16	5	12	22	108
7	Undrained Triaxial Test	8	3	4	2	2		2	2	15
8	UnconfinedCompression Test	15	10	6	8	10	5	6	16	61
9	Consolidation Test	8	1	2	2	2		1	2	10
10	Swelling Pressure Tests	5	1	2	2	2		1	2	10
11	Montmorillonite content	8	1	2	1	1		1	1	7
12	Water Chemical Tests	6	1	1		1		1	1	5
13	Soil Chemical Tests: SO3, SO_4 &CL	8	1	3	1	1		1	1	8

and consolidation tests. They are also useful for a better understanding of the behavior of the soil layers encountered.

3.1.1 Natural Moisture Content

A total of 175 natural moisture content tests were performed mainly on cohesive samples, most of them samples of Marl, recovered from the split spoon sampler and from the undisturbed U100 samples. The results for the Marl samples are presented in a graphical form, Fig.6, where the moisture content was plotted against depth. Some of them are also presented in the Summary of Test Results Table 3.2

The plot of the natural moisture content of the Marl, Fig. 6, shows a large scatter of the moisture content values. However, the variation with depth, shows, as expected, lower moisture content at shallow depths and a gradual increase at greater depths. This is because these soils are affected by the weather at the shallow depths.

3.1.2. Atterberg Limits

The Liquid Limit of 34 cohesive samples was found using the Cone Penetration Method. Their Plastic Limits were also determined and hence their Plasticity Index obtained. The results are presented in the Summary of Test Results, Table 3.2. Twenty two of the samples were from the khaki silty Marl and gave liquid limit values of 49.2% to 60.0% with plastic limit ranging from 31.1% to 36.1%, and plasticity index ranging from 17.7% to 25.5 %. Seven samples were grey silty Marl and gave liquid limits ranging from 43.1% to 50.0%, plastic limits 27.0% to 30.9% and plasricity index 13.4% to 20.6%. The other five samples were from the brown silty sandy Clay taken from the top layer and gave liquid limits of 35.0% to 54.0 %, plastic limit of 21.1% to 32.4 % and plasticity index of 14.5% to 21.6 %.

The above results have also been plotted on the Plasticity Classification Chart, Figure 7. The results plot below the A-line for all Marl samples. According to this Chart the khaki Marl may be characterized as highly elastic silt of high plasticity, and the brown silty sandy Clay as inorganic Clay of medium plasticity. The grey Marl is characterized as inorganic silt-clay of intermediate plasticity.

3.1.3. Specific Gravity

The specific gravity of 34 cohesive or fine-grained samples tested also for their particle size distribution (hydrometer), was found. Samples of the khaki Marl gave specific gravity values of 2.76 to 2.82 whereas samples of the brown Clay, gave values of 2.71 to 2.78.

3.1.4 Natural Density Tests

A total of 105 natural density tests were carried out on khaki silty Marl and grey Marl samples including 8 on the brown sandy Clay samples. The density of the khaki Marl samples was found to vary from 19.1 to 20.0 kN/m^3, of the grey Marl from 19.0 to 19.9 kN/m^3 and of the brown sandy Clay 19.4 to 22.6 kN/m^3. Some of the results are presented in the Summary of Test Results, Table 3.2 .

3.1.5 Particle Size Distribution

The particle size distribution of 74 samples was found. Thirty four of the samples were fine grained cohesive samples and the hydrometer (sedimentation) method was used for the finer particles and wet sieving for the coarser ones. The remaining 40 samples were non-cohesive, sands and sandy gravels and the wet sieving method was adopted. The results are presented in the individual report for each Site.

The samples of the khaki and grey Marl gave clay size particles (<2μm), ranging from 8% to 32% .

The particle size distribution of the coarser deposits, show a variation of Sands with Gravels and sandy Gravels.

SUMMARY OF TEST RESULTS

TABLE 3.2

BH NO.	Depth m	Natural Moisture Content %	Natural Density kN/m3	Specific Gravity	Liquid Limit %	Plastic Limit	Plasticity Index %	Cohesion cu kN/m2	Angle φu	Soil Type
N1	6,50	23,06	19,5	2,73	55,0	31,1	23,9	230		Khaki silty Marl
N2	10,00	30,80	19,8	2,75	49,2	31,2	18,0	160		Khaki silty Marl
N2	12,00	32,32*	18,8*	2,77	52,0	34,3	17,7	160	4	Khaki silty Marl
N3	10,00	31,6*	19,8*	2,79	43,1	27,0	16,1	130	0	Grey silty Marl
N4	11,50	31,90*	19,3*	2,76	51,4	31,0	19,4	150	6	Khaki silty Marl
N5	7,50	27,90*	19,4*		57,4	32,9	24,5	137	18	Khaki silty Marl
N6	6,00	28,33	20,2	2,70	58,0	32,5	25,5	360		Khaki silty Marl
N6	7,00	26,70*	20,0*					300	17	Khaki silty Marl
N7	11,00	33,63*	19,0*	2,67	43,5	30,1	13,4	65	10,5	Grey silty Marl
N8	2,00				37,5	21,8	15,8			Brown silty Clay
N8	10,00	33,09*	19,7*	2,68				95	18,5	Grey silty Marl
N9	2,50	28,78	19,3	2,78	56,0	34,5	21,5	255		Khaki silty Marl
N9	7,00	28,08	19,9	2,74	51,2	33,2	18,0	260		Khaki silty Marl
N10	7,00	29,62	19,5	2,75	54,3	32,6	21,7	300		Khaki silty Marl
N12	10,00	32,16*	19,5*	2,74	54,5	36,1	18,4	275	0	Khaki silty Marl
N13	10,70	31,61*	19,4*	2,73	49,5	29,2	20,4	150	2,5	Grey silty Marl
N14	4,00	26,53	19,7	2,77	53,5	34,1	19,4	385		Khaki silty Marl
N14	7,00	33,27*	19,3*	2,80	54,5	34,5	20,0	300	6	Khaki silty Marl
N15	5,50	30,19	19,5	2,75	52,0	33,1	18,9	202		Khaki silty Marl
N16	7,00	26,64	20,5	2,76	55,3	34,8	20,5	317		Khaki silty Marl
N17	10,00	32,59*	19,5*	2,75	49,5	29,4	20,1	170	4	Grey silty Marl
N19	8,50	36,28	19,2	2,75	56,3	34,8	21,5	100		Khaki silty Marl
N19	10,00	29,15	20,2	2,74	49,8	29,2	20,6	103		Grey silty Marl
N20	8,50	35,69	19,1	2,77	53,9	31,7	22,2	124		Khaki silty Marl
N20	10,00	30,46	19,7	2,72	49,5	29,5	20,0	134		Grey silty Marl
N21	4,00	29,61*	19,9*	2,85	54,0	32,4	21,6	180	0	Brown silty Clay
N22	5,50	17,89	21,7	2,84	55,0	33,6	21,4	240		Khaki silty Marl
N23	7,00	30,46	19,6	2,87	56,0	34,8	21,2	220		Khaki silty Marl
N23	9,50	29,8*	19,7*	2,84	50,0	30,9	19,1	230	2,5	Grey silty Marl
N24	5,50	19,53	21,8	2,84	35,8	21,1	14,7	135		Brown silty Clay
N27	7,00	33,86	20,1	2,76	56,5	34,5	22,0	44		Yellow-khaki sandy silty Marl
N30	7,00	30,32*	19,4*	2,81	60,0	35,0	25,0	145	7	Yellow-khaki silty Marl
N31	8,50	33,64*	19,4*	2,82	54,3	35,5	18,8	185	6	Yellow-khaki silty Marl
N32	2,50	28,61	19,4	2,71	37,7	21,7	16,0	123		Brown silty sandy Clay
N33	2,50	20,02		2,78	36,0	21,5	14,5			Brown silty sandy Clay
N33	5,50	21,99	20,9	2,77	55,6	34,8	20,8	392		Yellow-khaki silty Marl

*Average of three results

It must be mentioned that large size gravels could not be included in the samples recovered from the boreholes since these were broken down by the drilling operations. Therefore this should be born in mind when examining the particle size distribution curves of the sandy gravels.

3.2 Unconfined Compression Tests

Sixty one unconfined compression tests were performed on selected cohesive samples. Out of these 53 samples were samples of khaki silty Marl, 3 of grey Silty Marl and 5 of brown sandy Clay. The samples were recovered from the split spoon sampler and were considered suitable for these tests. The tests were performed using the triaxial compression machine with suitable attachments designed for such tests.

The stress-strain curves obtained are presented in the reports for each individual Site. The undrained cohesion c_u obtained from samples of the khaki silty Marl ranged from 44 to 425 kN/m^2, whereas c_u for the grey Marl varied from 100 to 134 kN/m^2. The brown sandy Clay gave c_u values of 52 to 135 kN/m^2.

3.3 Triaxial Tests

Fifteen sets of quick undrained triaxial tests were carried out on undisturbed samples of the khaki silty Marl and the grey sitly Marl. The tests were performed on samples recovered from the U100 sampler. The samples tested had a diameter of 35mm and a height of 70mm. They were tested in the triaxial machine using cell pressures of 100, 200 and 300 kN/m^2.

The stress-strain curves obtained and the corresponding Mohr circle of stresses are presented in the relevant individual reports for each Site. The undrained cohesion c_u obtained from the Mohr circle of stresses ranged from 65 kN/m^2 to 300 kN/m^2 with angles of shearing resistance φ_u of 0° to 18.5°.

3.4 Swelling Pressure Tests

Ten Swelling Pressure Tests were performed on undisturbed specimens, which were also tested for their consolidation characteristics. The tests were performed in the Oedometer front-loading machine on Marl samples. The specimens had a diameter of 50 mm and a thickness of 19.05mm.

After placing each specimen in the Oedometer machine, it was first loaded with a load approximately equal to its effective overburden pressure. Water was then added to the consolidation cell and the specimen observed for any swelling tendency. In case a tendency for swelling was observed, this was prevented by loading the specimen accordingly. The loads on the specimen and the corresponding time were recorded. The results are presented in the relevant figures in the individual reports for each site.

As it can be seen from Table 3.4 the swelling pressures observed on the samples tested, range from zero to 450 kN/m^2.

Table 3.4: Swelling Pressure Tests Results

BH NO.	Depth m	Soil type	Swelling Pressure kN/m^2
N2	12.00	Khaki silty Marl	No swelling
N5	7.50	Khaki silty Marl	450
N7	11.00	Grey silty Marl	No swelling
N12	10.00	Khaki silty Marl	No swelling
N13	10.70	Grey silty Marl	No swelling
N14	7.00	Khaki silty Marl	25
N17	10.00	Grey silty Marl	25
N23	9.50	Grey silty Marl	25
N30	7.50	Khaki silty Marl	50
N31	8.50	Khaki silty Marl	50

3.5 Consolidation Tests

Ten consolidation tests were performed, on the same samples of the Marl tested also for their swelling pressure. The results are presented in a Summary Form in Table 3.3. The purpose of the consoilidation tests is to produce the 'e-log P ' curve (voids ratio against pressure) for each sample, and calculate the modulus of volume change m_v and coefficient of consolidation c_v , which are required for the calculation of the settlement of foundations. The average m_v values for the khaki Marl varied from 1.57 to 6.14 x 10^{-5} m^2/kN with average c_v ranging from 2.15 to 6.39 m^2/year. For the grey Marl, the average m_v values varied from 4.27 to $6.14x10^{-5}m^2$/kN and average c_v values from 3.39 to 6.72 m^2/year .

3.6 Montmorillonite and Chemical Tests

Seven montmorillonite tests were carried out to determine the montmorillonite content of samples of the khaki silty Marl. Montmorillonite tests are not included in the British Standard Methods of test for Soils for Civil Engineering Purposes BS 1337:1990, but this was a requirement from the Client.

The montmorillonite content of the samples tested are given in Table 3.5 below.

The chemical tests carried out as required by the Contract, included the determination of sulphate content of SO_4 and Chloride content Cl.. Chemical tests were performed on eight samples of the Marl and the results are presented in Table 3.5 below.

SUMMARY OF CONSOLIDATION TEST RESULTS

TABLE 3.3

B.H. NO.	Depth m	Soil Type	Initial Moisture Content %	Final Moisture Content %	Initial Bulk Density kN/m^3	Initial Void Ratio	Final Void Ratio	Av. Coeffic. of Vol. Change m_v m^2/kNx10^{-5}	Av. Coeffic.of Consolidation c_v m^2/year	Initial Saturation Sr %
N2	12,00	Khaki silty Marl	31,2	30,6	19,0	0,915	0,834	4,050	5,10	94
N5	7,50	Khaki silty Marl	24,4	27,4	19,8	0,685	0,711	1,570	6,39	95
N7	11,00	Grey silty Marl	31,8	27,9	19,3	0,868	0,763	5,580	6,72	100
N12	10,00	Khaki silty Marl	32,5	30,1	19,3	0,892	0,793	6,020	3,13	100
N13	10,70	Grey silty Marl	31,9	29,4	19,1	0,890	0,784	5,830	4,01	98
N14	7,0-7,45	Khaki silty Marl	33,1	33,4	19,5	0,910	0,877	2,627	5,43	100
N17	10,0-10,45	Grey silty Marl	32,1	29,7	19,4	0,868	0,774	4,273	3,39	100
N23	9,50	Grey silty Marl	31,3	28,4	19,5	0,916	0,809	6,140	3,50	97
N30	7,0-7,45	Yellow-khaki silty Marl	32,2	31,5	19,3	0,924	0,873	3,308	2,15	98
N31	8,5-8,95	Yellow-khaki silty Marl	34,7	32,4	19,0	1,000	0,898	4,378	4,21	98

Table 3.5: Chemical Test Results

BH NO.	Depth m	Soil type	SO_4 (%)	SO_3 (%)	Cl (%)	Montmorillonite (%)
N2	12,00	Khaki silty Marl	0,120	0,100	0,041	16,25
N5	7,50	Khaki silty Marl	0,114	0,095	0,053	18,75
N7	11,0	Grey silty Marl	0,388	0,323	0,039	13,75
N12	4,00	Brown silty Clay	0,038	0,032	0,013	20,00
N12	7,00	Khaki silty Marl	0,064	0,053	0,018	17,5
N25	5,90	Brown-khaki Clay	0,055	0,044	0,018	18,75
N29	5.70	Khaki silty Marl	0.092	0.077	0.036	15.0

3.7 Chemical Tests on Water

Full water chemical analysis was carried out on five water samples taken from five different Boreholes and the results for each sample are given in the separate reports for each site.

4. SITE GEOLOGY

4.1 The Site

The University Campus area is shown on the Location Plan in Fig. 2. It has a maximum length of about 1100 metres and a maximum width of 750 metres. A stream, named Kaloyeros, flows from Southwest to Northeast, separating the Campus area in two. A valley of about 400 to 500 meters wide extends on both sides of the stream. The vegetation existing on the site was generally dry grass with some eucalyptus and other trees found in certain locations of the area.

4.2 General Geology

The main bedrock in the broader area of the University Campus is the Marl of the Nicosia-Athalassa Formation. The Marl is stiff to hard and has a yellowish-khaki colour. The khaki Marl is underlain by the grey Marl which is usually more silty and sandy.

The Marl is overlain by younger deposits, such as the Fanglomerates, composed mainly of gravels in a calcareaous silty sand matrix with a variable degree of cementation. This layer is found on the hillsides or on top of the hills on either side of the valley. Talus, or hill wash material, usually composed of brown clayey sandy silty or sandy silty clay is found on the lower part of the hill slopes and in the stream valley.

Finally, the stream valley is covered by Alluvium deposits composed of sands and sandy gravels. The overall depth of the Alluvium deposits reaches a maximum of 9.0 metres.

4.3 Information from Boreholes

The strata encountered by the boreholes drilled at each of the seven sites, is presented in the Borehole Records included in each individual report. Geotechnical Sections are presented for each site in these reports.

The Geological Section, Fig.3, included in this report, shows the strata encountered in three adjacent sites (sites 4, 6 and 7) and indicate the geological profile across the valley.

The geological profile of the Campus area may be distinguished into five layers:

Layer 1 is composed of grey and white sandy Gravels weakly cemented in a whitish (calcareous) matrix, known as Fanglomerates. This layer was found over part of Site 1 only, and its maximum thickness drilled was 5.50 meters.

Layer 2 is composed of brown clayey silty Sand with some gravel in places or brown sandy Clay. Its maximum thickness found in various places is of the order of 4.00 metres.

Layer 3 is the Alluvium deposits generally encounterd in the valley on either side of the Kaloyeros stream. These deposits are composed either of brown fine silty Sand and grey Gravel or dense grey sandy Gravel with traces of silty clay. Layers of silty Clay were also encountered within these deposits. The maximum thickness of these deposits is about 9.00 meters.

Layer 4 is the khaki silty Marl which is stiff to hard with a considerable variation in thickness. Its thickness is smaller in the valley where the Alluvium deposits overly the Marl, with minimum thickness of 0.70 metres (BH N24) and greater on the higher grounds, reaching a thickness of about 11.0 meters (BH N1). In some areas the khaki Marl becomes sandy and its colour changes to yellowish –khaki.

Layer 5 is the stiff to hard silty and sometimes sandy grey Marl found below the khaki Marl. Its thickness has not been proved.

4.4 Ground Water

Ground water was encountered in most of the boreholes drilled with the exception of a few which were drilled, entirely in the Marl and on higher ground. The depth and approximate elevation of the ground water measured during the drilling operations but also after the Winter of 2003/20004, are given in Table 4.1. The water depth during the drilling operations was generally measured after one or more days the relevant borehole was completed. As it can be seen, the water table is higher at the higher grounds which form the sides of the valley and lower in the valley area. A rise of the water table has been recorded after the winter months of 2003/04. This rise was generally of the order of 1.20 meters in the valley which is covered by the Alluvium deposits. The depth of the water in the valley just after the winter months was of the order of 2.5 meters.

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TABLE 4.1 - GROUND WATER LEVEL MEASUREMENTS

BH. NO.	BH Appr. Elevation m	Water during drilling			Water after winter of 03/04		
		Water Depth m	Appr. Water Elevation	Date	Water Depth m	Appr. Water Elevation	Date
N1	137,5	7,20	130,30	9 Oct03	5,24	132,26	29Feb04
N2	138,5	6,60	131,90	9 Oct03	BH not found - earthworks		
N3	141,3	BH blocked					
N4	137,4	9,60	127,80	9 Oct03	5,24	132,16	29Feb04
N5	134,5	7,55	126,95	30 Sep03	6,59	127,91	29Feb04
N6	133,5	8,10	125,40	30 Sep03	BH blocked		
N7	130,5	3,90	126,60	30 Sep03	2,90	127,60	29Feb04
N8	130,3	3,85	126,45	30 Sep03	2,79	127,51	29Feb04
N9	137,5	No water			Dry		
N10	138,5	No water			Dry		
N11	134,8	5,90	128,90	31Oct03	4,09	130,71	29Feb04
N12	135,6	7,00	128,60	4 Nov03	BH not found - vegetation		
N13	134,2	5,50	128,70	5 Nov03	BH not found - site works activity		
N14	135,5	No water			1,97	133,53	29Feb04
N15	135,2	No water			BH not found - site works activity		
N16	132,6	No water			BH not found - site works activity		
N17	131,2	3,95	127,25	11 Nov03	BH not found - site works activity		
N18	131,8	4,00	127,80	6 Nov03	BH not found - site works activity		
N19	134,2	5,20	129,00	30 Oct03	3,42	130,78	2 Mar 04
N20	132,4	4,00	128,40	29 Oct03	BH not found due to vegetation		
N21	131,5	3,55	127,95	9 Oct03	2,30	129,20	2 Mar 04
N22	131,0	3,50	127,50	16 Oct03	BH not found due to vegetation		
N23	130,95	3,80	127,15	16 Oct03	2,62	128,33	2 Mar 04
N24	131,2	3,35	127,85	16 Oct03	BH not found due to vegetation		
N25	130,6	4,05	126,55	16 Oct03	BH not found due to vegetation		
N26	130,7	4,40	126,30	16 Oct03	BH not found due to vegetation		
N27	131,8	4,55	127,25	20 Oct03	BH not found due to vegetation		
N28	133,8	No water			BH not found due to vegetation		
N29	130,6	3,75	126,85	21 Oct03	BH not found due to vegetation		
N30	131,8	No water			BH not found due to vegetation		
N31	129,7	3,00	126,70	24 Oct03	BH not found due to vegetation		
N32	129,3	3,35	125,95	22 Oct03	BH not found due to vegetation		
N33	129,5	3,55	125,95	23 Oct03	BH not found due to vegetation		
N34	128,6	3,25	125,35	23 Oct03	BH not found due to vegetation		
N35	132,0	BH blocked					

Note: Elevations are only approximate and are based on the contour map

5. ENGINEEERING PROPERTIES OF STRATA

Summaries of the laboratory test results have been presented in Section 3. A general description of layers encountered presented in this section, is based on the in-situ testing and the laboratory test results.

5.1 Layer 1 - Cemented sandy Gravels

As mentioned above, this layer consists of weakly cemented sandy gravels. Due to the cemented and compact nature of the layer, the Standard Penetration Resistance N-values obtained were very high and in most cases there was refusal to penetration of the SPT sampler.

5.2 Layer 2 - Clayey silty Sand or Sandy Clay

This layer has shown a large variation both in texture and engineering characteristics. This is reflected in the test results of the particle size distribution and the in-situ Standard Penetration Test. The layer varies from clayey silty Sand to silty sandy Clay with the presence of gravel. A large variation of the Standards Penetration Resistance 'N' has been recorded with 'N' values varying from 5 to 44. It is obvious that the low values indicate quite weak layers with low shear strength and high compressibility.

5.3 Layer 3 - Sands and Gravels (Alluvium deposits)

The Alluvium deposits also exhibit a large variation both in texture and engineering properties . As mentioned, they vary from silty Sand with gravel to sandy Gravel with traces of clay. The Standard Penetration Resistance 'N' values of this layer have been plotted against depth and are presented in Figure 4. The very large scatter of the results, show the very large variation of the shear strength and compressibility of the layer. It should be mentioned here that N values obtained in Layer 2 are also included in Figure 4.

5.4 Layer 4 - Khaki silty Marl

This layer of the khaki silty Marl is considered as the 'bedrock' in this area. The variation of its natural moisture content and other classification test results has been discussed in Section 3. Other engineering properties are discussed below.

5.4.1 Standard Penetration Resistance

The Standard Penetration Resistance values measured in this layer, but also in Layer 5 (the grey Marl), have been plotted in Figure 5. The plot shows a considerable scatter in the N-values with generally a lower boundary of about 18 and a higher boundary of about 48 (neglecting 3 very low values of N=14 and two high values of 49 and 52). No definite conclusion can be drawn with respect to the variation of 'N' with depth.

5.4.2. Shear Strength

To assess the shear strength of the khaki Marl layer, a considerable number of Unconfined Compression Tests was carried out. Also 8 number of quick undrained traixial tests were performed. In order to try and obtain a correlation of undrained cohesion c_u and SPT 'N' values, the values of the cohesion c_u have been plotted against the 'N' values in Figure 8. Although no definite conclusion or relationship can be drawn from this plot, an attempt was made, using the appropriate function in the Excel spread sheet, and the following relationship of c_u and 'N' values was obtained:

$$\mathbf{c_u = 103{,}35 \log N - 119{,}4} \quad (\mathrm{kN/m^2})$$

The shear strength parameters c_u and φ_u obtained from the 8 triaxial tests performed ranged from 137 to 300 kN/m^2 and 4° to 18° respectively.

5.4.3. Modulus of Elasticity

The modulus of elasticity E_s was estimated from the stress-strain curves of the triaxial and unconfined compression tesst. These estimated values showed also a large variation, with E_s ranging from 40,000 kN/m^2 to 80,000 kN/m^2. An average value of 70,000 kN/m^2 could be adopted for most cases of geotechnical calculations.

5.4.4 Swelling and Compressibility of the Marl

The swelling pressure measured on Marl samples is given in Table 3.4. Most of the results show zero or very low swelling pressure, with exception of one sample which has shown a swelling pressure of 450 kN/m^2 which is quite high.

In Figure 9, the potential expansiveness of the khaki Marl is shown to be generally 'meduium', with 4 results indicating 'high' and 2 'low' potential expansiveness.

The values of the coefficient of volume change m_v obtained from the consolidation tests and which are used to calculate the consolidation settlement of foundations, are given in Table 3.3. The average m_v values for the khaki Marl varied between 1.57 to 6.14 x 10^{-5} m^2/kN.

5.5 Layer 5 - Grey silty Marl

The engineering properties of the Grey Marl are quite similar to those of the khaki Marl except for the shear strength, where lower average values were generally obtained.

5.5.1. Standard Penetration Resistance

Eight Standard Penetration Tests only were performed in the grey Marl and the penetration resistance 'N' obtained ranged from 21 to 28 with an average of 23.5.

5.5.2 Shear Strength

Six triaxial tests performed on samples of the grey Marl gave c_u values of 65 to 230 kN/m^2 and φ_u of 0^0 to 18.5^0. Three unconfined compression tests gave c_u values of 103, 134, and 140 kN/m^2.

5.5.3 Modulus of Elasticity

The Modulus of Elasticity of the grey Marl is quite similar to the values proposed for the khaki Marl. The value of 70000 kN/m^2 may be used as an average figure for elastic settlement calculations.

5.5.4 Swelling and Compressibility

Four swelling and four consolidation tests were performed on samples of the grey silty Marl. The results of the swelling tests are presented in Table 3.4. Two of the samples have shown no swelling pressure whereas for the other two, a swelling pressure of 25 kN/m^2 was recorded.

Figure 9 shows a 'medium' potential expansiveness of the grey Marl.

The average m_v values which are used to calculate the compressibility of the Marl varied between 4.27 and 6.14 x 10^{-5} m^2/kN .

6. BEARING CAPACITY AND SETTLEMENT OF FOUNDATIONS

The Bearing Capacity of the strata encountered and the settlement of the foundations depend on the engineering properties of the strata and the type, shape and depth of the foundations to be adopted. Hence, the allowable bearing capacity values and estimated expected settlement given below for the different layers **are only indicative**. The bearing capacity and settlement of foundations can be found when the foundation loads, their depth and type are known.

6.1 Layer 1- Cemented sandy Gravels

The bearing capacity of this layer is quite high due to the cemented and compact nature of the layer and hence the high SPT values recorded. An allowable bearing capacity of 500 kN/m^2 may be considered conservative. The expected settlement of isolated footings on this layer is expected to be very low and within tolerable limits.

6.2 Layer 2 – Clayey silty Sand or sandy Clay

This layer is quite variable over the Campus area investigated and bering capacity values of 100 to 300 kN/m^2 have been estimated for the layers found at the various sites. Each Site should therefore be considered separately very carefully.

6.3 Layer 3 – Sands and Gravels (Alluvium deposits)

The allowable bearing capacity of foundations on the Alluvium deposits depends on the nature of the deposits, i.e.sands or gravels, and the degree of compactness. Estimates of the allowable bearing capacity were made using the results of the in-situ and laboratory testing. The bearing capacity was found to vary from 250 to 500 kN/m^2. The foundation settlement would not exceed 25mm if the appropriate bearing capacity value is adopted.

6.4 Layer 4 – Khaki silty Marl

As proposed in the reports for the individual sites, the allowable bearing capacity of foundations on this layer should not exceed 400 to 500 in order to keep the expected settlement within acceptable limits. Typical settlement calculations for 1.5m square isolated footing have shown that the settlement is generally less than 20mm.

7. CONCLUSIONS AND RECOMMENDATIONS

The strata encountered by the boreholes drilled over the Campus area may be differentiated into four different layers:

Layer 1 is the grey and white sandy weakly cemented Gravel, found only over part of Site 1.

Layer 2 is the brown clayey silty Sand or brown sandy Clay.

Layer 3 is the Alluvium deposits composed of either fine silty Sand with Gravel or Sandy Gravel.

Layer 4 is the khaki silty Marl, which is considered 'the bedrock' in this area, and which varies from stiff to hard.

Layer 5 is the grey, stif to hard,silty sandy Marl.

General description of these layers and their engineering properties are given in the relevant sections of this report. Indicative allowable bearing capacities and foundation settlements have also been given above. More detail information the reader should refer to the reports prepared for each individual site.

In view of the different nature of the above layers, the foundation type, bearing capacity and foundation settlement must be reconsidered carefully and relevant calculations performed by an experienced Geotechnical Engineer using the engineering parameters given in this report.

Consultation with a Geotechnical Engineer during the design of the foundations is strongly recommended. Professional consideration of the engineering properties and extensive calculations for the bearing capacity and settlement of the foundations should be made in order to achieve both safe and economic foundations.

Due to rapid deterioration of the Marl when exposed, it is important to keep such exposure to minimum if the construction of a basement down to Marl level is envisaged. As soon as the excavation for the foundation is completed and the bottom of the excavation cleaned carefully, it should be covered with a blinding concrete of about 80mm thick. The construction of the foundations should proceed and completed as soon as possible. Drying and wetting of the bottom of excavations in the Marl should be avoided.

The Marl is a potentially expansive soil with generally a "medium" potential expansiveness. Although the measured swelling pressures were generally either zero or low (25 to 50 kN/m^2) and only in one case a high swelling pressure of 450 kN/m^2 was measured, the possibility of swelling pressures on the foundations and retaining walls is real and must be considered and allowed for in the design calculations. Swelling may be caused either from an increase in the moisture content of the Marl or by "unloading" due to excavations. As it can be seen from Table 3.3, the initial moisture content of the sample (BH N5, d=7.50m) which showed high swelling pressure, was 24.4% and its final (after consolidation) 27.4%, an increase of 3%. Therefore, measures should be taken in the designs to protect the Marl from either surface or ground water and keep its moisture content constant to avoid swelling or shrinkage.

Sulphates in soils or groundwater may attack concrete depending on their concentration. For sulphate concentration in soils less than 0.2% of SO_3, ordinary Portland cement may be used with maximum water/cement ratio of 0.55. For SO_3 of 0.2% - 0.5%, the minimum cement content should be 330 kg/m^3 and the water cement ratio less than 0.50. The SO_3 obtained from the chemical analysis on the khaki Marl samples was less than 0.2%, no special measures are required for foundations on this layer. In the case of the deeper grey silty Marl a value of SO_3 of 0.323% was found. For foundations in this layer, the appropriate concrete quality specified above should be used.

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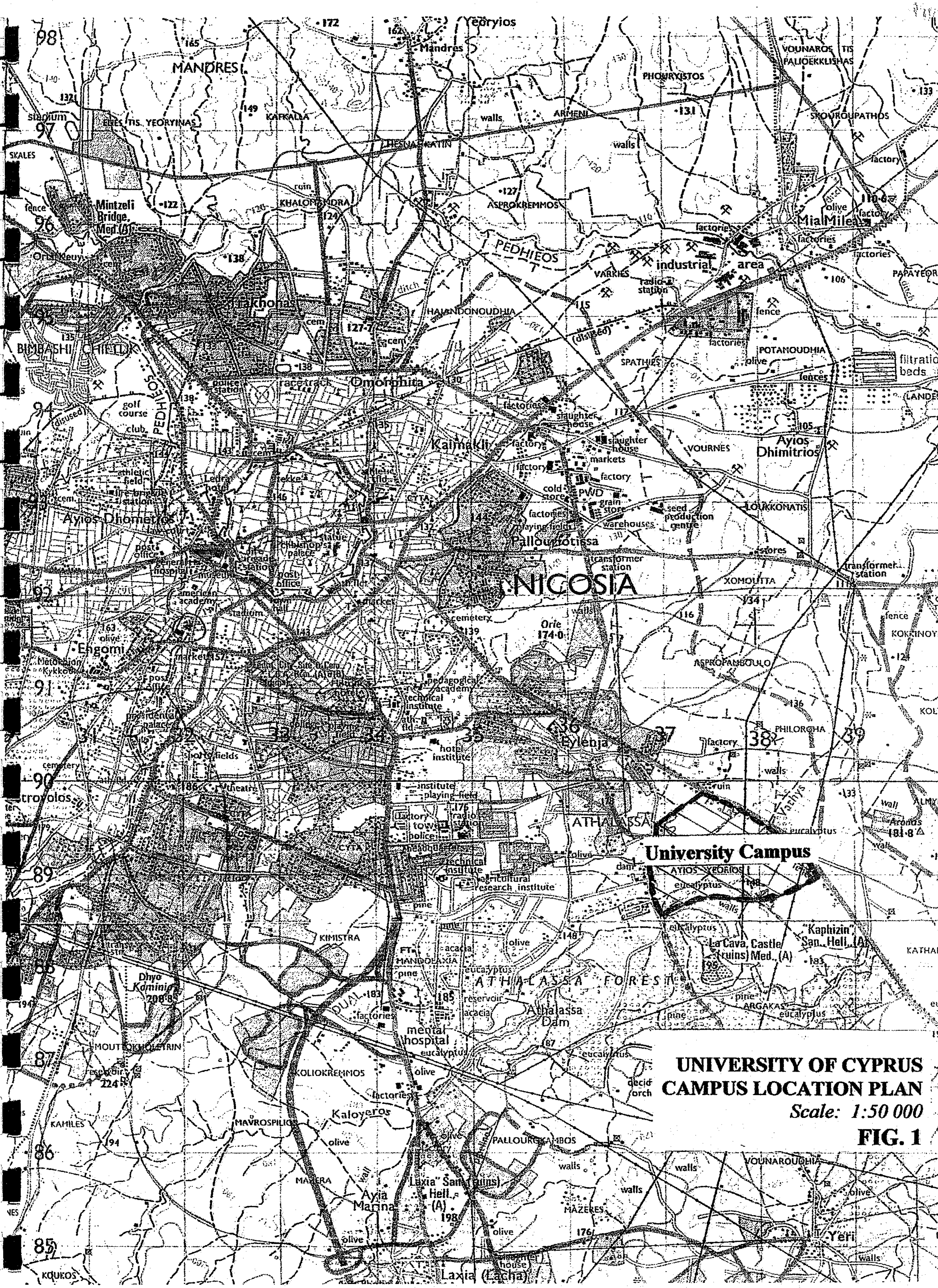
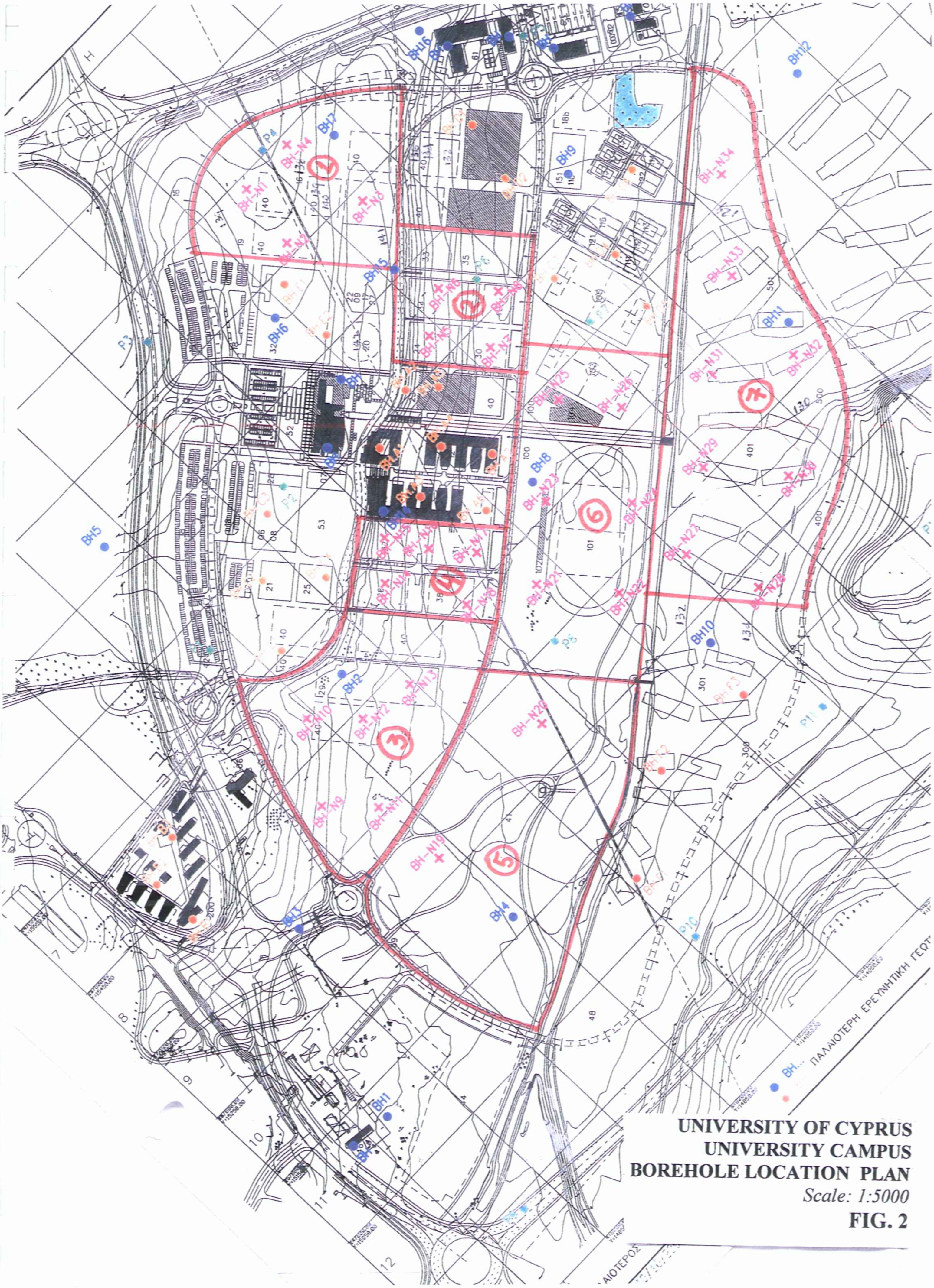
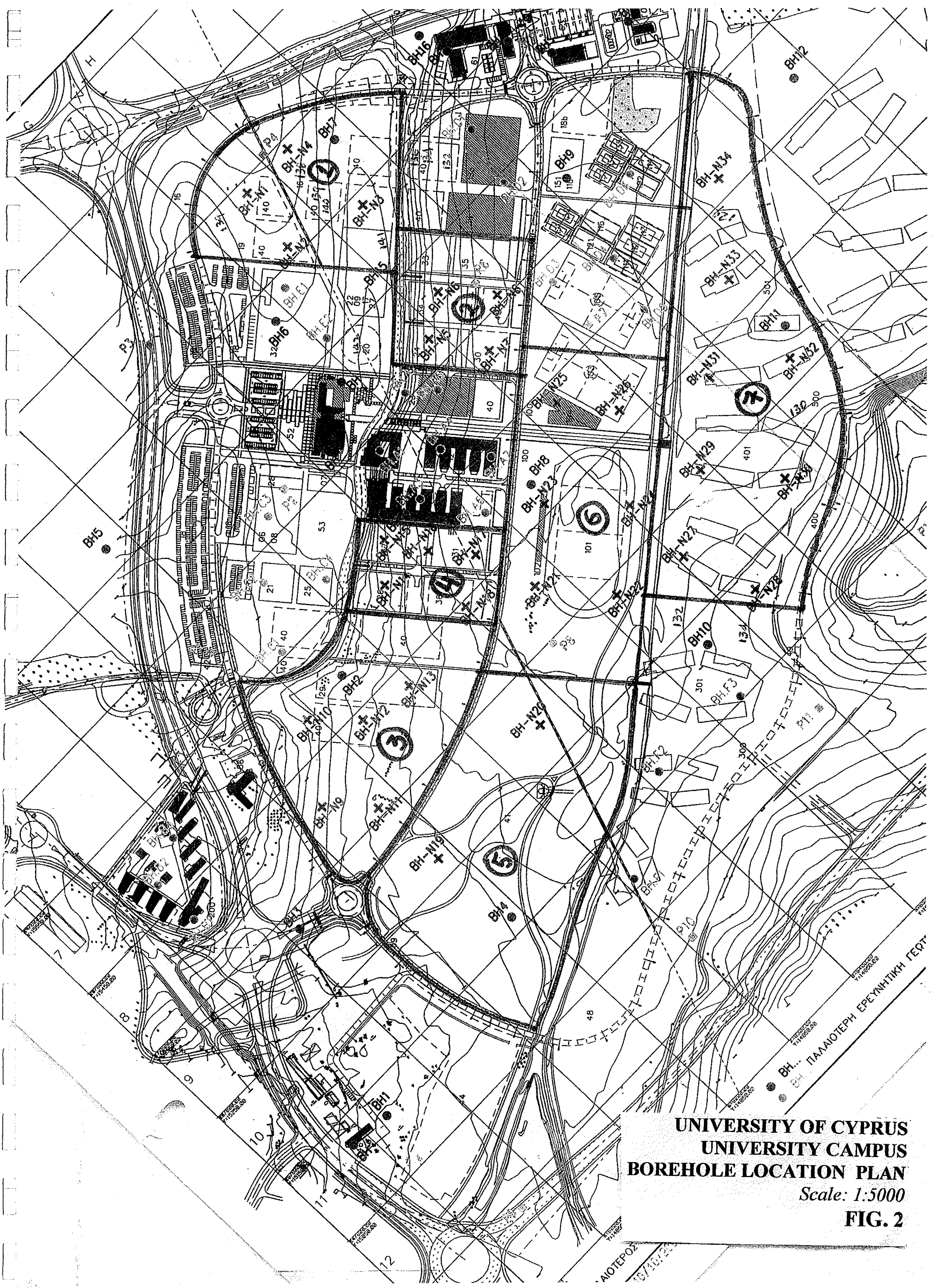
APPENDIX A



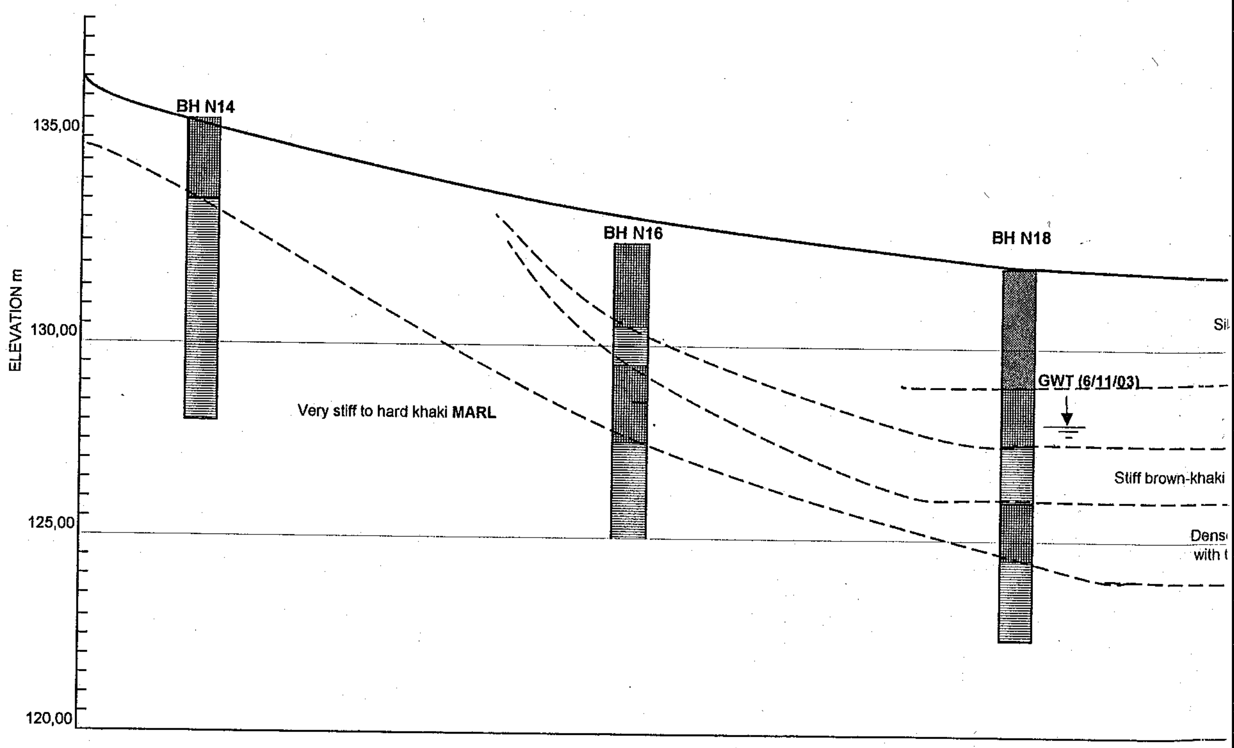
UNIVERSITY OF CYPRUS
CAMPUS LOCATION PLAN
Scale: 1:50 000
FIG. 1



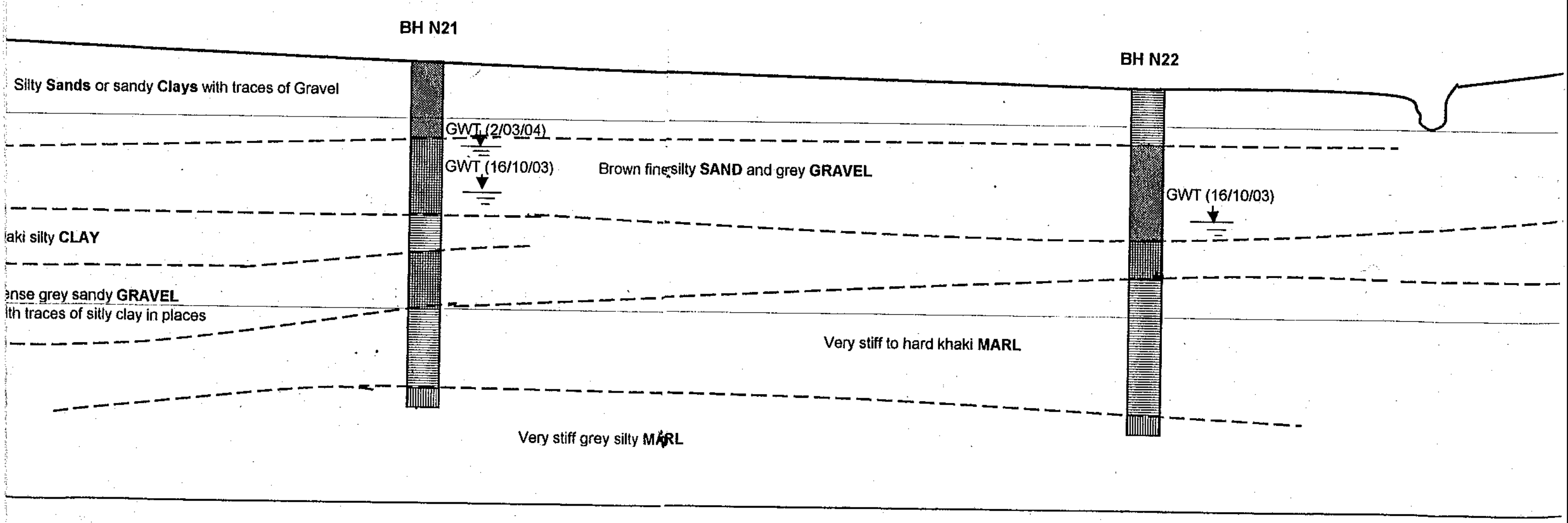
UNIVERSITY OF CYPRUS
UNIVERSITY CAMPUS
BOREHOLE LOCATION PLAN
Scale: 1:5000
FIG. 2

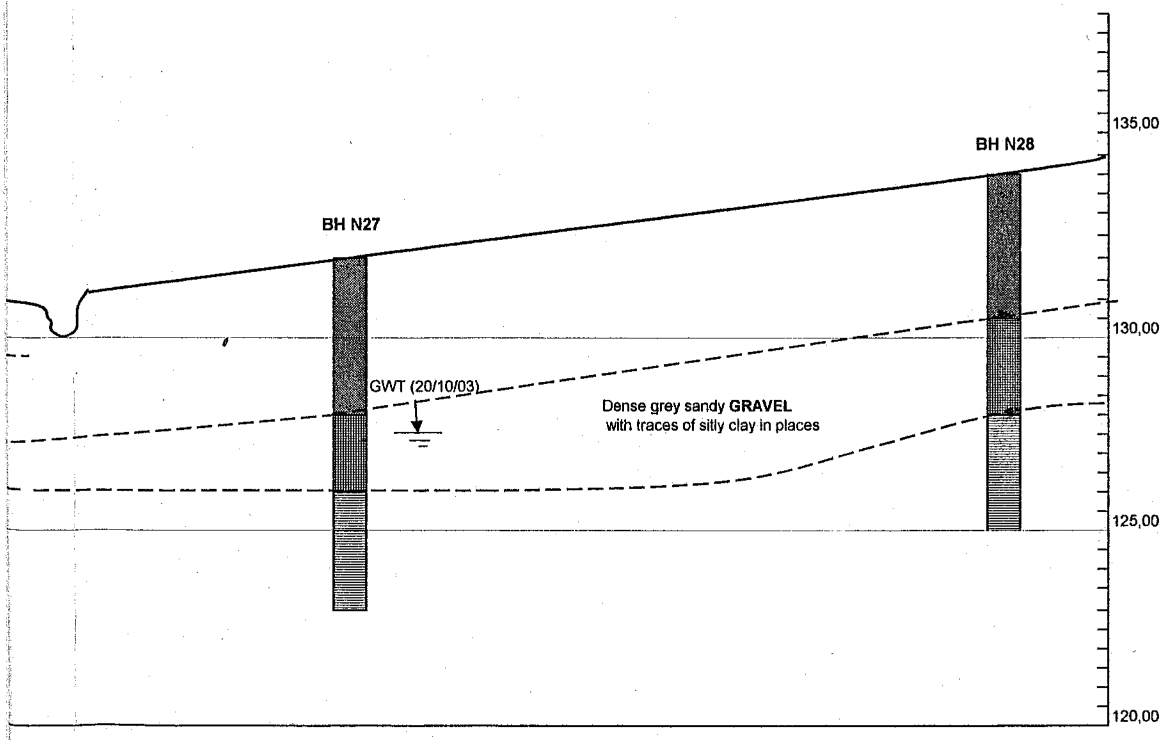


UNIVERSITY OF CYPRUS
UNIVERSITY CAMPUS
BOREHOLE LOCATION PLAN
Scale: 1:5000
FIG. 2



BH N14
BH N16
BH N18
135,00
130,00
125,00
120,00
ELEVATION m
Very stiff to hard khaki MARL
GWT (6/11/03)
Stiff brown-khaki


BH N21
BH N22
Silty Sands or sandy Clays with traces of Gravel
GWT (2/03/04)
GWT (16/10/03)
Brown fine silty SAND and grey GRAVEL
GWT (16/10/03)
aki silty CLAY
ense grey sandy GRAVEL
ith traces of silty clay in places
Very stiff to hard khaki MARL
Very stiff grey silty MARL



NOTE:
Drawn boundaries between layers are infered, based on the borehole findings and are not exact

CAMPUS OF UNIVERSITY OF CYPRUS

GEOLOGICAL SECTION

FIG. 3

STANDARD PENETRATION RESISTANCE

Project: University of Cyprus
Site Location: University Campus - Sites"1 to 7"
Client: University of Cyprus **Soil:** Alluvium deposits

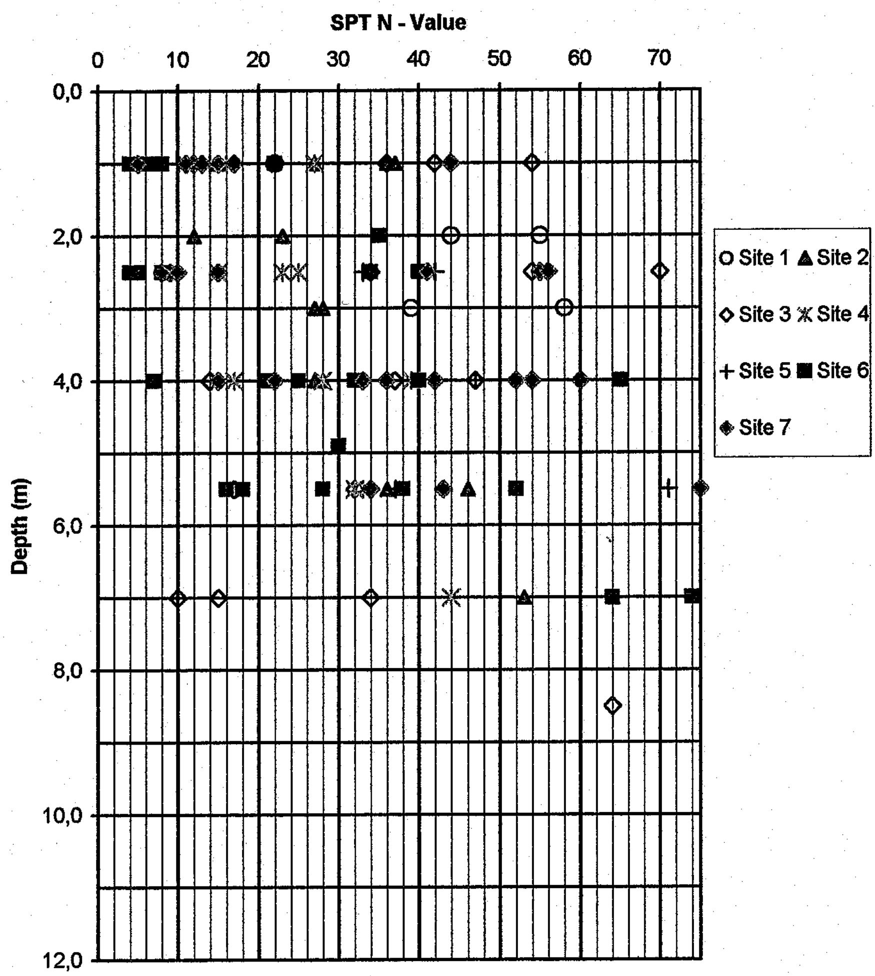


FIG. 4

UC G SPT ALLUVIUM

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STANDARD PENETRATION RESISTANCE

Project: University of Cyprus
Site Location: University Campus - Sites "1 to 7"
Client: University of Cyprus **Soil:** Silty (Nicosia) MARL

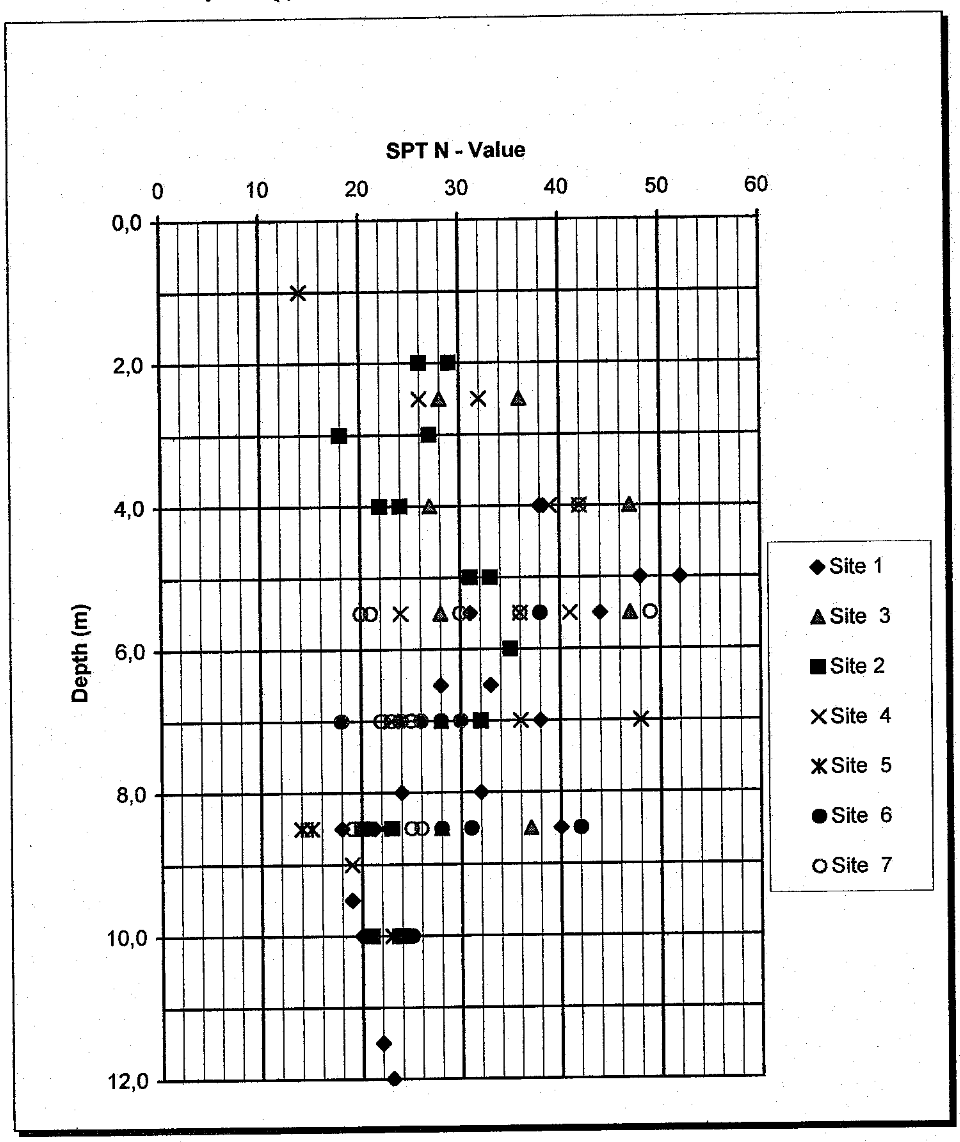

FIG. 5

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NATURAL MOISTURE CONTENT

Project: University of Cyprus
Site Location: University Campus - Sites "1 to 7"
Client: University of Cyprus **Soil:** Silty (Nicosia) MARL

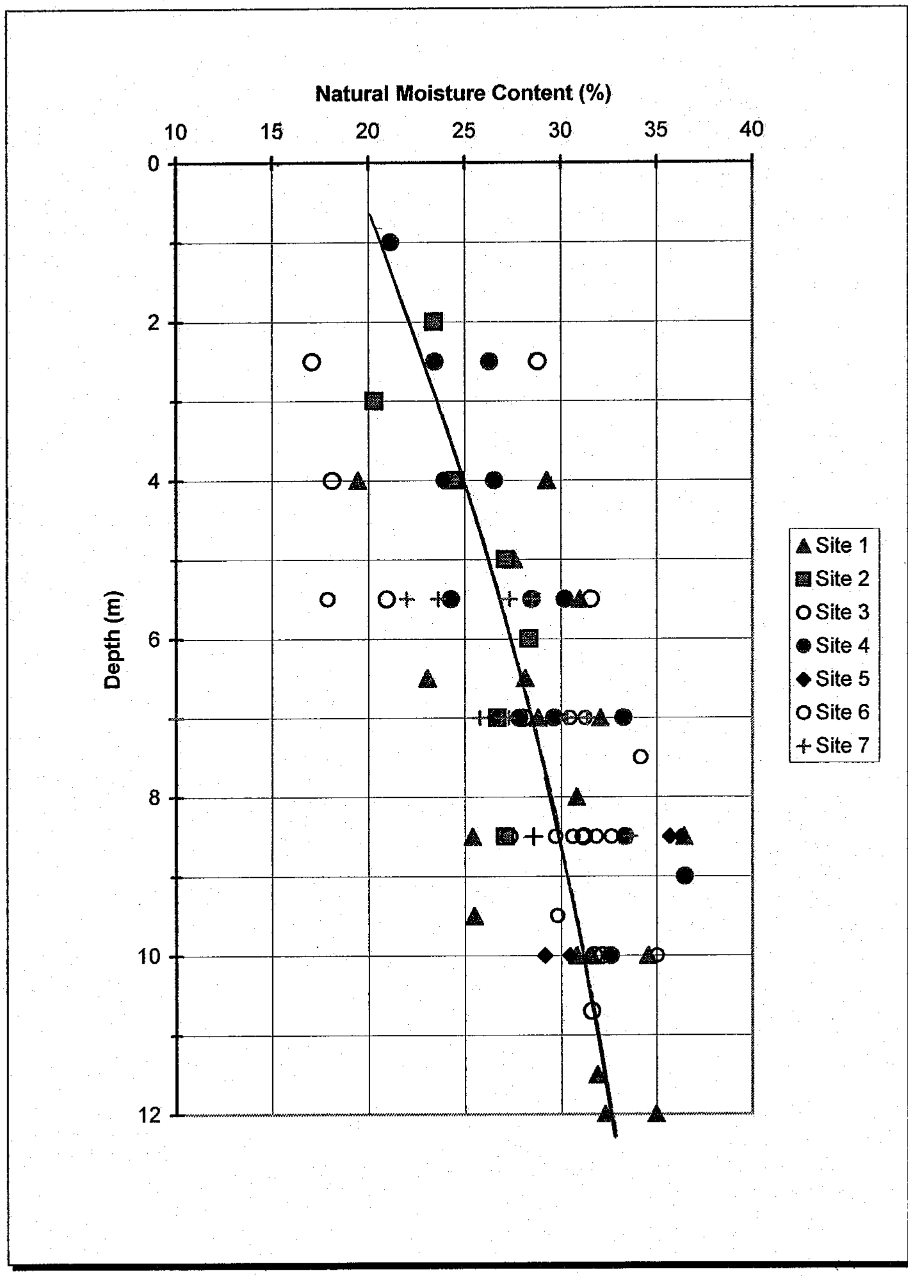

FIG. 6

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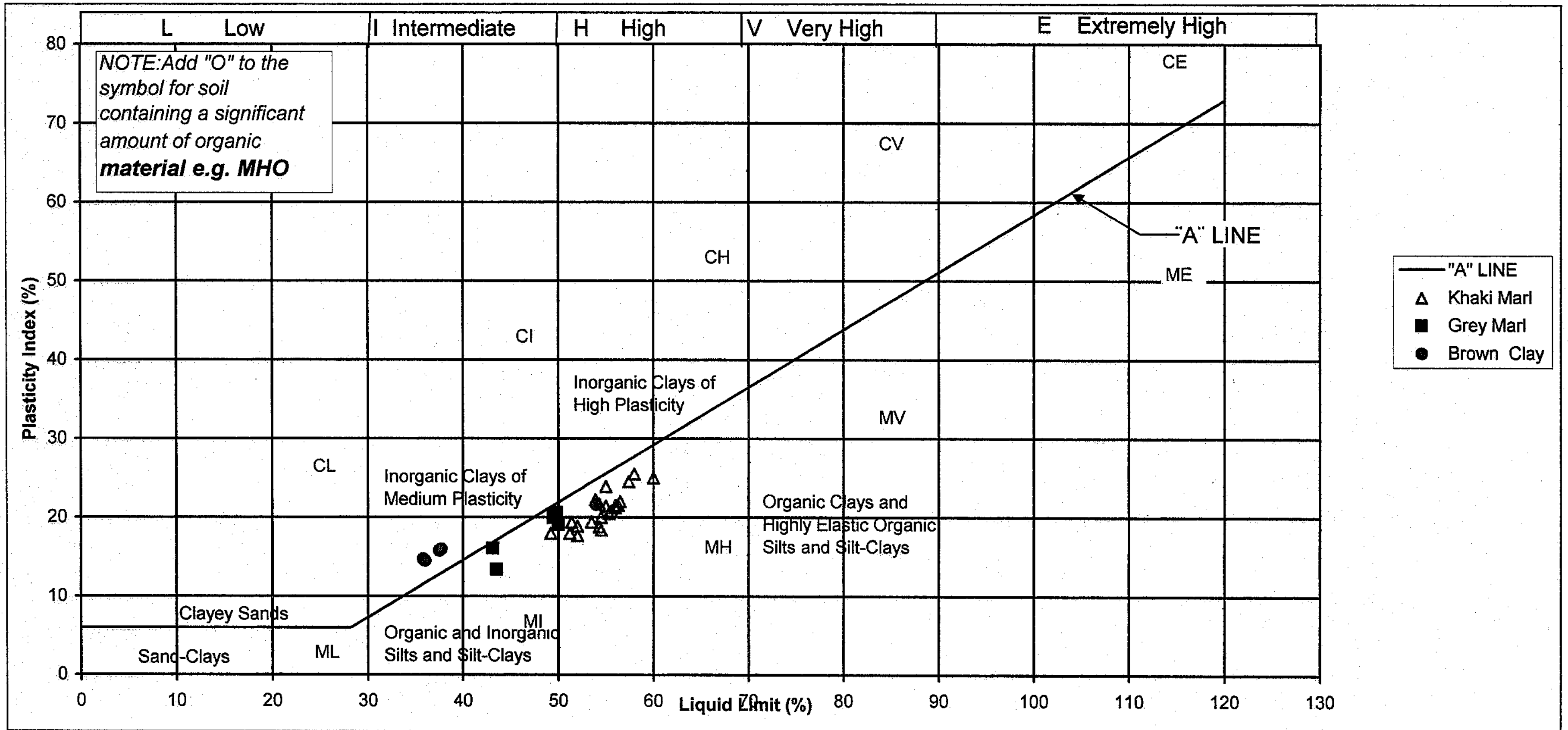
PLASTICITY CLASSIFICATION CHART

Project: University of Cyprus
Site Location: University Campus - Site "1 to 7"
Client: University of Cyprus

Date: November 2004
Operator:



SILT(M-SOIL),M,plots below "A" Line
CLAY,C,plots above "A" Line

M and C may be combined as FINE SOIL,F

FIG. 7

UC G PLASTICITY CHART

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UNDRAINED COHESION Cu versus SPT 'N' VALUE

Project: University of Cyprus
Site Location: University Campus - Sites "1 to 7"
Client: University of Cyprus

Soil: Silty (Nicosia) MARL

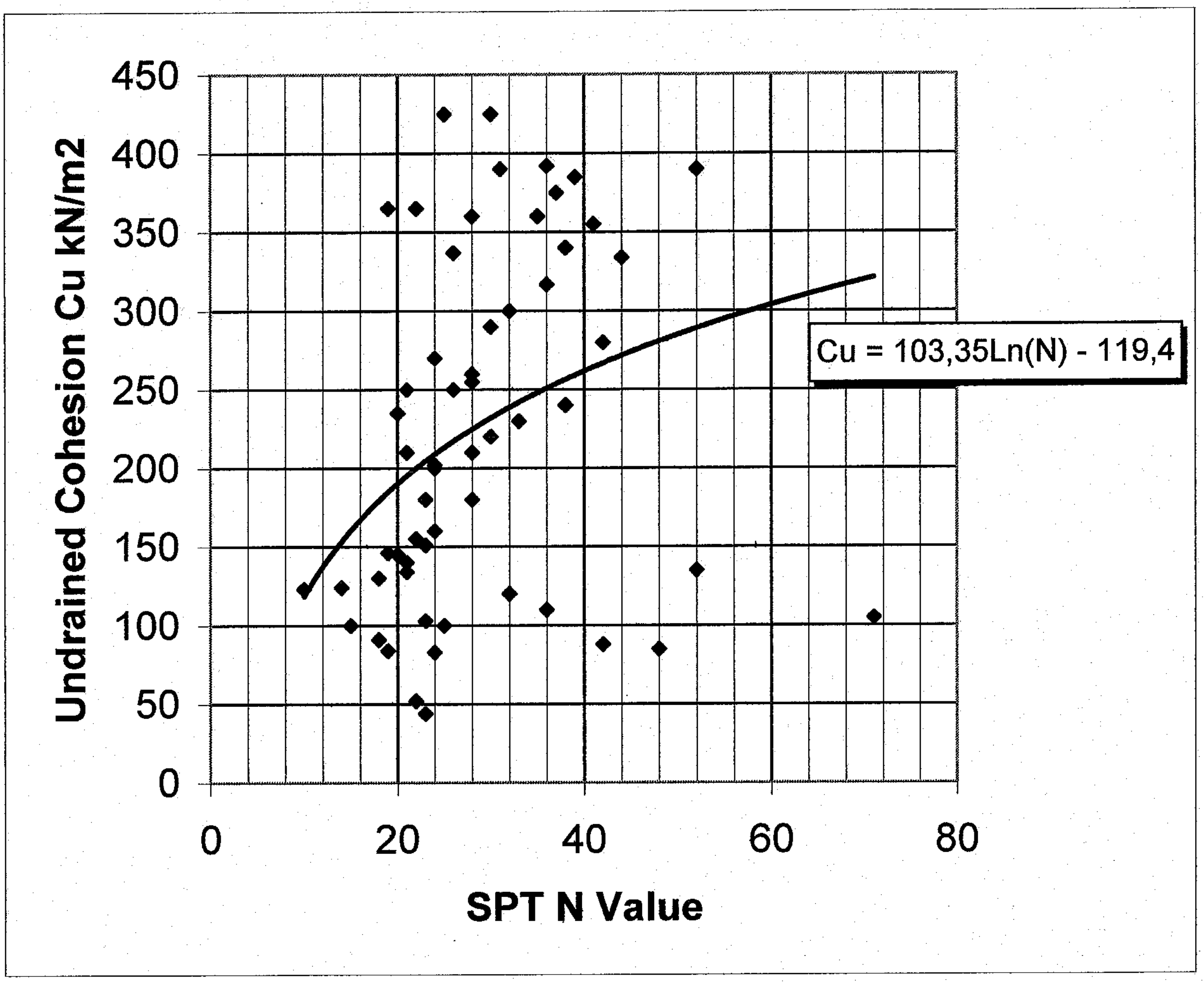
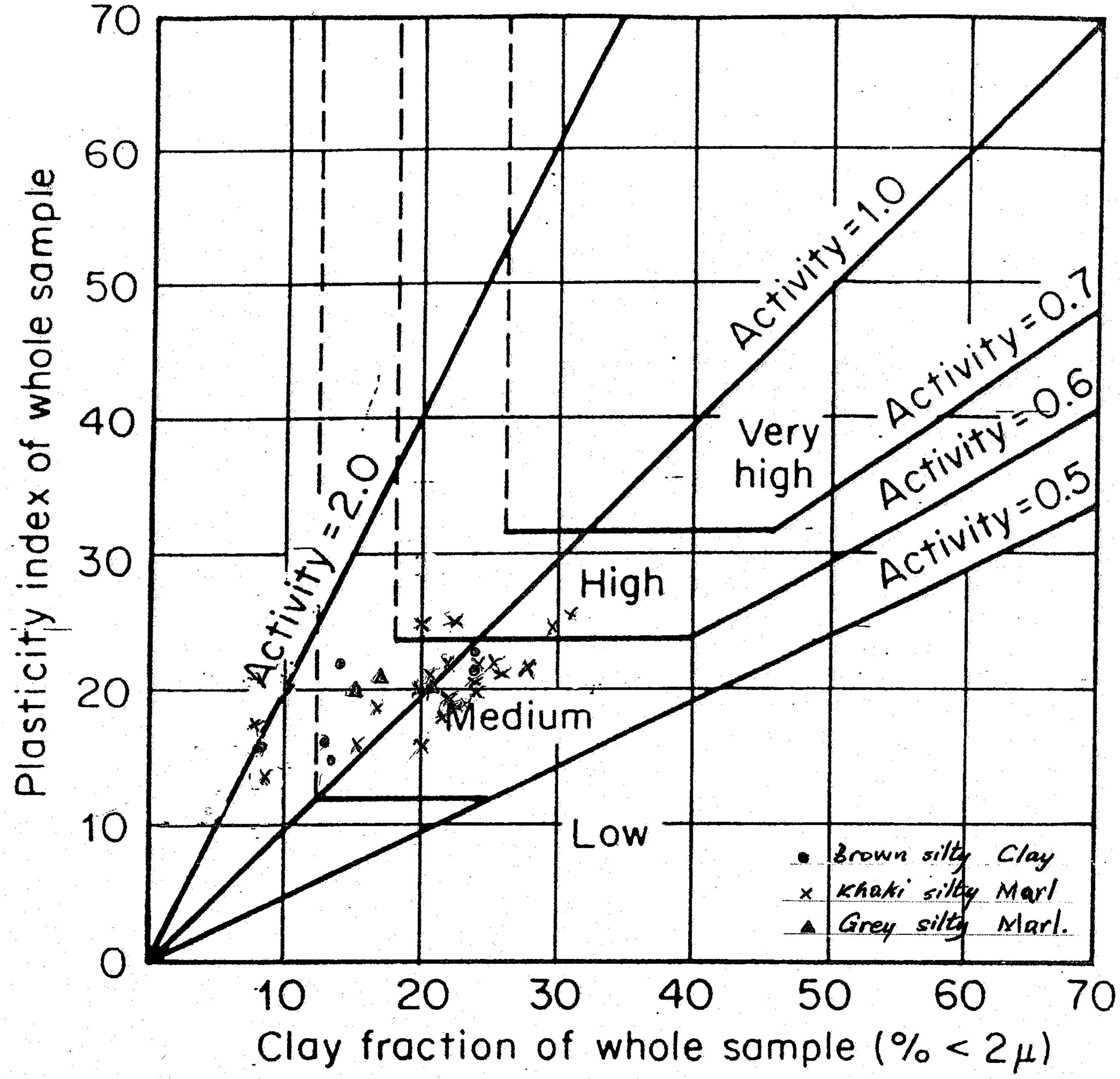


FIG. 8



Potential expansiveness	Inch per foot of soil*
Very high	**1.0**
High	**0.5**
Medium	**0.25**
Low	**0**

*After Van der Merwe (1975).[65b]

FIG. 10.40 Proposed modified chart for determining expansiveness of soils. [*From Williams and Donaldson (1980)*[65a]*; after Van der Merwe (1975)*[65b].]

FIG. 9