ELECTROGAS MALTA CONSORTIUM

Delimara LNG Regasification Terminal

Geotechnical Investigation for Offshore Marine Works – Evaluation Report

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1. INTRODUCTION

1.1 Purpose and Scope

This report contains presentation and evaluation of the geotechnical investigations which were carried out for the offshore installations of the LNG Regasification Terminal at Delimara, Malta for the purpose of deriving geotechnical design parameters for offshore pile calculations for the jetty, the central platform, and the mooring and breasting dolphins.

The results of the field investigations and laboratory tests are contained in the report No. 2779-77-CI-RE-00003_Rev00 " Geotechnical Investigation for Offshore Marine Works – Factual Report ", (14 Dec. 2014). This report will be referred to hereafter as Factual Report.

1.2 Work Performed

Planning of the field investigations and the laboratory testing was made by Castor Ltd. Representative on Site who additionally supervised drilling of boreholes and laboratory tests.

Execution of the offshore boreholes and the laboratory testing was done by Messrs Terracore Ltd., Malta.

In addition to the laboratory testing in Malta, a number of triaxial and oedometer tests were carried out in UK by Messrs Geolabs and Environmental Scientifics Group (ESG).

2. BACKGROUND INFORMATION

The offshore installations consist of the jetty, the central platform and the mooring and breasting dolphins, the layout of which is shown in figure 1 together with the borehole locations.

All offshore installation will be founded on raked piles.

Detailed descriptions of the geometry of the installations, the loads and the arrangement of the piles are given in the Design Reports.

3. OFFSHORE FIELD INVESTIGATIONS AND LABORATORY TESTS

3.1 Offshore Field Investigations

Ten offshore boreholes, namely G1 to G10, were drilled at the locations shown in figure 1.

Boreholes were rotary drilled with the aid of a hydraulic drilling rig which was placed on a barge with crane named Bezz V. The barge was stabilized at the borehole locations with the aid of two vertical tubular spikes with diameter of 1m and 15m long at shallow depths, and with the aid of four concrete anchor blocks 2mx2mx2m at deeper depths. Borehole locations were placed by a surveyor. Photographs of the barge and the drilling rig are given in appendix B.

All boreholes were drilled with continuous sampling. In the soil formations standard penetration tests were executed every 2m to 3m, and undisturbed samples were obtained at about 4m intervals with the aid of a piston sampler and in Shelby tubes both 75mm in diameter. In the rock formations double tube core barrels T2 86mm were used. Borehole exploration logs are given in the Factual Report.

All samples were properly labeled and packed for transportation to the testing laboratories in Malta and UK.

3.2 Laboratory Tests

Laboratory tests were carried out in accordance with the British Standards BS1377:1990. Test results are given in the Factual Report. Tables 1 to 8 summarize the results of the classification tests, triaxial tests, oedometer tests, organic contents of soils, and rock mechanics tests. Statistical presentations of the soil and rock properties are given in figures 4 to 9.

Soil description is according to the Unified Soil Classification System (USCS).

4. PRESENTATION OF THE GEOTECHNICAL INVESTIGATION DATA

4.1 Brief Description of the Subsurface Conditions

The results of the geotechnical investigations are summarized in the subsurface sections of figures 2 and 3. It can be seen from these figures that subsoil can be broadly differentiated in the upper soil formations and the underlying soft rock and hard rock formations.

The upper soil formations consist of the following layers:

- Layer Ia: Sea bottom. Very soft silt (ML) and silty sand (SM) with thickness of about 1 m
- Layer I: Very soft to soft clay (CL), silty sand (SM) and loose clayey gravel (GC)
- Layer II: Very stiff clay (CL) and medium dense clayey gravel (GC), clayey sand (SC) and silty sand (SM)
- Layer I Ia: Hard clay (CL) and dense clayey gravel (GC)

The underlying soft rock and hard rock formations consist of the following layers:

- Layer III : Very soft to soft clay marl, light brown colour
- Layer IV: Soft marly limestone of grey colour.

Important Note: The main characteristic of the soil formations is that they have low values of specific gravity of grains (GS), which were found to vary between 2.41 and 2.68 with a single value to 2.72 (see table 1). Similar/ the soft and hard rock formations have low values of bulk unit weight of the order of 2.20Mg/m^3 (see tables 7 and 8).

In the subsequent paragraphs descriptions of each layer are given in some detail.

4.2 Layer Ia

This layer consists of very soft silt (ML) and silty sand (SM) with zero resistance to standard penetration. They are sea bottom materials with thickness of about 1m.

Classification properties are given in figure 4.1. Statistical presentation of properties is given in figure 4.2. Water contents are high varying between 22 and 64 percent and dry unit weights low: two values equal to 1.07Mg/m^3 and 1.55Mg/m^3 were determined. Original data are given in table 1.

Unconsolidated undrained triaxial tests yielded low shear strength values c_u varying between a minimum of 8kPa and a maximum for 25kPa (see figure 4.2c). Values were obtained from table 4.

Figure 4.3 shows stress paths of three consolidated undrained triaxial tests with pore pressure measurements (CUPP). From this plot it can be shown that the effective stress parameters are c'=0kPa and φ'=48.6°. [Equations applied : c'=b'/cosa', sincp'=tana']. Analytical data are given in the factual report and summarized in table 2.

Organics content was found to be equal to 7.5 percent (table 6).

4.3 Layer I

This layer consists of very soft to soft clay (CL), silty sand (SM) and loose clayey gravel.

Classification properties are presented in figure 5.1. Statistical presentation of properties is given in figure 5.2. Water contents are high of the order of 43 percent, and dry unit weights are low of the order of 1.30Mg/m^3. Original data are given in table 1.

Resistance to standard penetration is low of the order of 9 blows for 30cm penetration (figure 5.2c). Original data were obtained from the borehole exploration logs in the Factual Report.

Unconsolidated undrained shear strength values c_u are low fluctuate between a minimum of 5kPa and a maximum of 43kPa (figure 5.2d). Values were obtained from table 4.

Figure 5.3 shows stress paths of unconsolidated undrained triaxial test with pore pressure measurements (CUPP) from which the shear strength parameters deduced are c'=7.2kPa and φ'= 40.2°. Analytical data are given in the Factual Report and summarized in table 2.

Figure 5.4 shows the results of consolidated drained triaxial tests(CD) plotted in terms of (σ1'+σ3')/2 versus (σ1'-σ3')/2. Analytical data are given in the Factual Report and summarized in table 3. From these plots deduced shear strength parameters are c'=5.1kPa andcp'=41°.

Figure 5.5 shows the results of 7 oedometer tests plotted in terms of oedometer modulus $E_O$ed versus vertical pressure (E_{oe}d=1/Mv). Analytical data are given in the Factual Report and summarized in table 5. Oedometer modulus values are low: At vertical pressures equal to the overburden plus 200kPa, E_{oe}d varies between 2100kPa and 6000kPa with two higher values equal to 9500kPa and 120O0kPa (table 5).

Organics content was found to vary between 2.8 and 17.0 percent (table 6).

4.4 Layer II

This layer consists of very stiff clay (CL) and medium dense clayey gravel (GC), clayey sand (SC) and silty sand (SM).

Classification properties are presented in figure 6.1. Statistical presentation of properties is given in figure 6.2. Water contents are of the order of 30 percent and dry unit weights of the order of 1.50Mg/m^3. Original data are contained in table 1.

Resistance to standard penetration varies between 8 and 32 blows for 30cm penetration (figure 6.2c). Original data were obtained from the borehole exploration logs in the Factual Report.

Unconsolidated undrained shear strength c_u values vary between 26kPa and 81kPa (see figure 6.2d and table 4).

Figure 6.3 presents the results of 2 oedometer tests plotted in terms of oedometer modulus $E_O$ed versus vertical pressure. Analytical data are given in the Factual Report and summarized in table 5. At vertical pressures equal to the overburden plus 200kPa, E_{oed} values were found to be equal to 8000kPa and 1000kPa (table 5).

4.5 Layer IIa

This layer consists of hard clay (CL) and dense clayey gravel (GC), clayey sand (SC) and silty sand (SM).

Classification properties are presented in figure 7.1. Statistical presentation of properties is given in figure 7.2. Water contents were found to be the order 20 percent and dry unit weights are of the order 1.60 Mg/m^3. Original data are contained in table 1.

Resistance to standard penetration varies between 16 and 64 blows for 30cm penetration (figure 7.2c). Original data were obtained from the borehole exploration logs in the Factual Report.

Unconsolidated undrained shear strength c_u vary between 35kPa and 88kPa (see figure 7.2d and table 4).

Figure 7.3 presents the results of 2 oedometer tests plotted in terms of oedometer modulus Eoed against vertical pressure. Analytical data are given in the Factual Report and summarized in table 5. At vertical pressures equal to the oedometer plus 200kPa, E_{oe}d values were found to be equal to 1100kPa and 2100kPa (table 5).

4.6 Layer III

This layer consists of very soft to soft light brown clay marl. Statistical presentation of strength and bulk unit weight is given in figures 8.1 and 8.2. Original data are given in the Factual Report and summarized in tables 7 and 8.

Uniaxial compressive strengths vary between 3.2MPa and 9.5MPa. Young's modulus values vary between a minimum of 510kPa and a maximum of about 2400kPa. Reported Poisson's ratio values are in general high and not realistic.

Point load strength Is_{50} axial varies between 0.10MPa and 11MPa, and Is_{50} oblique between O.IOMPa and 7.4 MPa.

Bulk unit weigth is low of the order 2.20 Mg/m^3.

4.7 Layer IV

This layer consists of low strength marly limestone of grey colour. Statistical presentation of strength and bulk unit weight is given in figures 9.1 and 9.2. Original data are given in the Factual Report and summarized in tables 7 and 8.

Uniaxial compressive strengths vary between a minimum of 2.3MPa and a maximum of 16.7MPa. Young's modulus values vary between a minimum of 900kPa and a maximum of about 14000kPa. The majority of the reported Poisson's ratio values are high and therefore not realistic.

Point load strength Is_{50} axial varies between 0.214MPa and 3.5MPa, and Is_{50} oblique between 0.2MPa and 3.2MPa.

Bulk unit weight is low of the order of 2.15 Mg/m^3.

4.8 Seismicity

According to EN 1998-1:2004 the subsurface formations are classified to the following ground types:

Layer la :	Ground type D, expect where sandy : liquefiable S_2 (offshore).
Layer I:	Ground type D
Layer II:	Ground type D
Layer I la:	Ground type D
Pile tip foundation	
Layer III:	Ground type A
Layer IV:	Ground type A

5. EVALUATION AND SELECTION OF GEOTECHNICAL DESIGN PARAMETERS

5.1 Evaluation of the Geotechnical Investigation Data

Evaluation of the field investigations and the laboratory tests, leading to selection of geotechnical design parameters is given in Appendix A. Sheets A-1 to A-15 present the evaluation of strength and compressibility parameters of the upper soil formations, while sheets A-16 to A-27 present the evaluation of strength and compressibility parameters of the underlying soft and hard rock formations.

Cautious estimates of design parameters for each borehole are given in sheets A-29 to A-38.

5.2 Selection of Design Parameters for the Offshore Installations

On the basis of the above presentation, selected design geotechnical parameters for each offshore installation are given in figures 10 to 31.

TABLES

TABLE 1 SUMMARY OF LABORATORY TEST RESULTS

Borehole/ Sample	Depth (m)	Water content (%)	Dry unit weight (Mg/m^3)	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI	GRADATION ANALYSIS Gravel (%)	Sand (%)	Fines (%)	Specific Gravity (Gs)	Soil type	Layer
G 1/3	3.0	25	1.56	43	12	31	56	21	23		GC	I
G 1/4	4.0	30		41	12	29	43	26	31	2.59	GC	I
G 1/6	6.7	48	1.03	54	12	42	9	12	80		CH	I
G 1/7	7.9	23		35	7	28	16	28	56		CL	I
G 1/8	12.3	27		35	8	27	11	18	71		CL	II
G 1/11	16.9	18		28	11	17	26	29	46	2.55	SC	II
G 1/15	23.7	22		30	8	22	11	18	71		CL	II
G 2/2	1.3	12		NP	NP	NP	10	89	2		SP	I
G 2/4	4.0	78		NP	NP	NP	4	50	45		SM	II
G 2/6	7.5			NP	NP	NP	1	39	60	2.43	ML	II
G 2/7	10.9	22		28	7	21	23	59	18	2.68	SC	II
G 2/9	13.2	23	1.58	36	8	28	37	17	46	2.44	GC	IIa
G 2/12	18.6	24		25	8	17	34	30	36	2.52	GC	IIa
G 3/2	0.8	32		NP	NP	NP	19	78	3		SP	Ia
G 3/3	3.3	54		NP	NP	NP	3	75	21		SM	I
G 3/4	6.9	61		NP	NP	NP	4	70	25	2.64	SM	I
G 3/5	10.4	45		NP	NP	NP	4	67	28	2.63	SM	I
G 4/1	0.8	22		NP	NP	NP	39	55	6		SP-SM	Ia

TABLE 1 SUMMARY OF LABORATORY TEST RESULTS (continued)

Borehole/ Sample	Depth (m)	Water content (%)	Dry unit weight (Mg/m^3)	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI	GRADATION ANALYSIS			Specific Gravity (Gs)	Soil type	Layer
							Gravel (%)	Sand (%)	Fines (%)			
G 4/2	1.3	31	1.42	NP	NP	NP						I
G 4/3	2.5	45		NP	NP	NP	4	81	15		SM	I
G 4/5	6.0	45	1.16	NP	NP	NP	3	64	32	2.51	SM	I
G 4/6	7.0	38	1.26	NP	NP	NP	3	68	29	2.48	SM	I
G 5/2	0.8	32		NP	NP	NP	29	68	3		SP	Ia
G 5/4	7.0	28		46	11	35	5	16	79	2.45	CL	I
G 5/8	10.8	16	1.68	30	9	21	28	28	43	2.55	GC	II
G 5/11	16.7	17	1.68	29	7	22	19	58	23		SC	IIa
G 5/13	21.6	13	1.72	28	8	20	38	18	44		GC	IIa
G 6/1	1.6	48	1.07	NP	NP	NP	3	27	71		ML	Ia
G 6/2	2.7	23		NP	NP	NP	14	25	60		ML	Ia
G 6/3	4.6	27	1.55	46	12	34	16	27	57	2.52	CL	Ia
G 6/5	7.7	28		39	11	28	14	21	65	2.39	CL	II
G 6/6	8.7	18		NP	NP	NP	38	26	35		GM	IIa
G 6/8	12.1	28	1.38	35	8	27	27	16	57	2.41	CL	IIa
G 6/9	14.1	29	1.36	39	10	29	51	13	36		GC	IIa
G 6/12	17.1			39	12	27	49	16	36		GC	IIa
G 6/13	18.9			40	12	28						IIa

TABLE 1 SUMMARY OF LABORATORY TEST RESULTS (continued)

Borehole/ Sample	Depth (m)	Water content (%)	Dry unit weight (Mg/m^3)	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI	GRADATION ANALYSIS Gravel (%)	GRADATION ANALYSIS Sand (%)	GRADATION ANALYSIS Fines (%)	Specific Gravity (Gs)	Soil type	Layer
G 6/14	20.3	10	1.74	41	8	33				2.58		IIa
G 7/2	1.5	64		NP	NP	NP	7	37	56		ML	I
G 7/5	5.3	69		NP	NP	NP	7	38	55		ML	I
G 7/7	6.9	39		NP	NP	NP	1	67	32		SM	I
G 7/9	9.1	30	1.51	37	9	28	14	21	66		CL	I
G 7/10	9.9	33					3	16	81	2.48		I
G 7/11	11.3	39	1.26	36	9	27	11	47	42		SC	II
G 7/12	12.3	39		34	10	24	7	27	66	2.39	CL	II
G 7/14	15.9	26		NP	NP	NP	32	48	20		SM	II
G 7/16	19.7	26		37	10	27	35	24	41		GC	II
G 7/17	20.6	20	1.62	NP	NP	NP				2.50		II
G 8/2	2.5	65		NP	NP	NP	2	68	30		SM	I
G 8/5	6.0	67		NP	NP	NP	2	67	31		SM	I
G 8/7	8.9	53		NP	NP	NP	5	43	53	2.56	ML	I
G 8/7	10.8	39		NP	NP	NP	1	74	25	2.63	SM	I
G 9/-	0.5	64		NP	NP	NP	0	89	11		SP-SM	Ia
G 9/3	3.5	37		NP	NP	NP	2	89	9	2.68	SP-SM	I
G 9/4	4.2	56										I

TABLE 1 SUMMARY OF LABORATORY TEST RESULTS (continued)

Borehole/ Sample	Depth (m)	Water content (%)	Dry unit weight (Mg/m^3)	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI	GRADATION ANALYSIS			Specific Gravity (Gs)	Soil type	Layer
							Gravel (%)	Sand (%)	Fines (%)			
G 9/5	5.4	62		NP	NP	NP	4	69	26		SM	I
G 9/-	8.2	58		NP	NP	NP	19	36	44	2.52	SM	I
G 9/-	8.9	31										I
G10/-	0.5	22										Ia
G10/-	2.5	27		NP	NP	NP	34	37	29		SM	I
G10/-	3.6	36		NP	NP	NP	4	83	13	2.72	SM	I
G10/7	6.6	40		NP	NP	NP	6	72	21		SM	I
G10/-	6.8	52										I
G10/-	8.8	48		NP	NP	NP	3	67	30		SM	I

NP: Non Plastic

TABLE 2 SUMMARY OF TRIAXIAL TEST RESULTS CUPP

Bore hole	Sample	Depth (m)	INITIAL CONDITIONS Water Content (%)	INITIAL CONDITIONS Dry Unit Weight (t/m³)	COMPRESSION Cell pressure σ_3 (kPa)	COMPRESSION Effective stress σ'_3 (kPa)	COMPRESSION Maximum Axial Stress $(\sigma_1-\sigma_3)$(kPa)	FINAL CONDITIONS Water Content (%)	FINAL CONDITIONS Dry Unit Weight (t/m³)	Effective Strength Parameters	Soil Type	Layer	N_{SPT}
G1	3	2.45	37	1.36	340	29	88	31	1.5	Not Reported	GC	I	6
			40	1.32	380	63	225	31	1.46				
			33	1.43	160	160	255	27	1.58				
G3	4	6.45	42	1.66	490	40	183	43	1.24	c'= 0kPa φ'=36°	SM	I	7
			51	1.63	610	160	194	44	1.21				
G4	3	2	55	1.63	350	50	164	48	1.63	c'= 0kPa φ'=52°	SM	I	8
			73	1.68	400	100	182	52	1.7				
			60	1.63	500	200	320	45	1.68				
G5	3	3	43	1.26	340	39	177	35	1.37	c'= 5kPa φ'=41.5°	SM	I	7
			44	1.24	380	80	211	35	1.36				
			46	1.24	460	160	312	35	1.38				
G5	4	6.45	40	1.50	340	38	94	30	1.67	c'= 9kPa φ'=40°	CL	I	7
			43	1.49	380	79	200	30	1.72				
			41	1.38	460	160	247	31	1.54				
G6	3	4.2	80	1.62	340	40	75	61	1.69	c'= 0kPa φ'=47°	CL	Ia	0
			78	1.6	380	80	131	57	1.73				
			66	1.71	460	160	220	43	1.85				
G7	10	9.35	34	1.43	350	50	107	29	1.53	c'= 8kPa φ'=37°	CL	I	11
			38	1.31	400	100	195	35	1.37				
			40	1.28	500	200	235	35	1.37				
G8	4	5.5	39	1.81	50	50	181	34	1.39	c'= 10kPa φ'=37°	SM	I	5
			38	1.78	220	220	416	32	1.44				
G10	3	3.3	30	1.95	40	40	129	26	1.58	c'= 0kPa φ'=41°	SM	I	7
			31	1.86	160	160	442	31	1.46				

CUPP: Triaxial test consolidated, undrained with pore pressure measurements.

NOTE: N_{SPT} values were taken from closest depths.

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TABLE 3 SUMMARY OF TRIAXIAL TEST RESULTS CD

Bore hole	Sample	Depth (m)	INITIAL CONDITIONS Water Content (%)	Dry Unit Weight (t/m^3)	Effective stress σ'_3 (kPa)	Maximum Axial Stress $(\sigma_1-\sigma_3)$(kPa)	FINAL CONDITIONS Water Content (%)	Dry Unit Weight (t/m^3)	Effective Strength Parameters	Soil Type	Layer	N_{SPT}
G2	9	12.7	16	1.92	140	626	15	1.94	Not realistic Not reported	GC	IIa	24
			16	1.95	280	483	14	2.02				
G3	3	3	50	1.14	40	197	47	1.18	c'= 17kPa φ'=38°	SM	I	5
			52	1.12	80	324	43	1.59				
			54	1.06	160	576	38	1.31				
G8	2	5.45	50	1.14	50	222	44	1.20	c'= 4kPa φ'=40°	SM	I	4
			51	1.08	100	434	43	1.37				
			50	1.16	200	795	41	1.35				
G8	6	8.9	61	1.05	50	186	44	1.25	c'= 2kPa φ'=40°	ML	I	2
			72	0.94	100	373	46	1.23				
			76	0.91	200	730	40	1.28				
G9	4	7.75	51	1.00	40	131	50	1.14	c'= 0kPa φ'=41°	SM	I	43
			48.1	1.04	80	300	45	1.20				
			52.1	1.07	160	620	36	1.34				

CD: Triaxial test consolidated, drained.

NOTE: N_{SPT} values were taken from closest depths.

TABLE 4 SUMMARY OF TRIAXIAL TEST RESULTS UU

Borehole	Sample	Sample Depth (m)	INITIAL CONDITIONS Water content (%)	INITIAL CONDITIONS Dry unit weight (t/m^3)	CONDITIONS DURING TESTING Cell pressure σ_3 (kPa)	CONDITIONS DURING TESTING Maximum axial stress $(\sigma_1-\sigma_3)$(kPa)	FINAL CONDITIONS Water content (%)	FINAL CONDITIONS Dry unit weight (t/m^3)	Soil type	Undrained shear strength c_u (kPa)	Layer	N_{SPT}
G1	2	1.5	22	1.66	50	539	22	1.66	GC	270	I	6
	8	12.2	31	1.57	120	52	31	1.57	CL	26	II	43
	10	16.6	26	1.49	160	116	26	1.49	SC	58	II	43
	15	23.5	23	1.72	230	128	23	1.72	CL	64	II	32
G2	2	1.0	27	1.73	50	41	27	1.73	SM	21	I	17
	4	3.8	80	0.84	50	40	80	0.84	SM	20	I	17
	7	10.4	30	1.25	110	78	30	1.25	SC	39	II	24
G3	2	0.5	34	1.46	50	45	34	1.46	SM	23	Ia	6
	5	9.9	47	1.16	110	66	47	1.16	SM	33	I	7
G4	2	1.0	33	1.27	50	45	33	1.27	SM	23	I	8
	6	6.5	49	1.14	50	89	49	1.14	SM	45	I	9
	7	8.0	21	1.83	80	157	21	1.83	-	79	I	9
G5	2	0.5	27	1.28	50	50	27	1.28	SM	25	Ia	7
	5	10.7	24	1.53	110	162	24	1.53	GC	81	II	7
	13	21.2	26	1.63	210	85	26	1.63	GC	43	IIa	16

TABLE 4 SUMMARY OF TRIAXIAL TEST RESULTS UU (continued)

Borehole	Sample	Sample Depth (m)	INITIAL CONDITIONS Water content (%)	INITIAL CONDITIONS Dry unit weight (t/m^3)	CONDITIONS DURING TESTING Cell pressure σ_3 (kPa)	CONDITIONS DURING TESTING Maximum axial stress $(\sigma_1-\sigma_3)$(kPa)	FINAL CONDITIONS Water content (%)	FINAL CONDITIONS Dry unit weight (t/m^3)	Soil type	Undrained shear strength c_u (kPa)	Layer	N_{SPT}
G6	1	1.2	34	1.09	50	16	34	1.09	ML	8	Ia	0
	2	2.4	70	0.95	50	38	70	0.95	MH	19	Ia	0
	7	9.6	25	1.68	100	126	25	1.68	CL	63	IIa	47
	9	12.0	28	1.58	120	157	28	1.58	CL	79	IIa	34
	10	14.0	23	1.64	140	175	23	1.64	GC	88	IIa	35
	14	18.8	34	1.46	190	71	34	1.46	-	36	IIa	52
G7	7	6.8	37	1.33	70	85	37	1.33	SM	43	I	3
	9	9.4	32	1.44	90	207	32	1.44	CL	104	I	11
	12	11.8	39	1.27	120	61	39	1.27	SC	31	II	11
G8	2	2.0	55	1.04	50	10	55	1.04	SM	5	I	4
	4	5.5	59	1.05	60	16	59	1.05	SM	8	I	5
G9	-	5.3	27	1.26	50	80	27	1.26	SM	40	I	7
G10	2	2.3	21	1.65	40	61	21	1.65	SM	31	I	48
	6	8.5	43	1.13	40	35	43	1.13	SM	18	I	1

UU: Triaxial test unconsolidated, undrained.

NOTE: N_{SPT} values were taken from closest depths.

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TABLE 5 SUMMARY OF ONE-DIMENSIONAL CONSOLIDATION TEST RESULTS

BH	Sample	Depth (m)	Overburden stress (kPa)	Water content (%)	Liquid Limit (%)	Plasticity Index	Dry unit weight (t/m^3)	Specific Gravity	Void ratio e_o	Degree Saturation (%)	Oedometer Modulus E_{oed} (kPa)	Soil type	Layer	N_{SPT}
G1	4	3.45	35	24	41.4	29.3	1.55	2.59	0.708	90	12000	GC	I	6
G2	8	10.4	100	30	27.9	21.1	1.37	2.68	0.937	86	11000	SC	II	24
G3	4	6.4	65	55	37.9	37.9	1.04	2.64	1.542	95	5800	SM	I	7
	5	10.0	100	47	NP	NP	1.18	2.63	1.246	101	6000	SM	I	7
G4	6	6.7	65	22	NP	NP	1.63	2.48	0.622	92	21000	SM	IIa	9
G6	9	12.0	120	27	35.3	27.2	1.50	2.41	0.766	95	11000	CL	IIa	34
G7	11	10.8	110	53	36.3	27.4	1.00	2.65	1.657	93	3700	SC	I	11
	17	20.4	205	22	26.6	26.6	1.64	2.65	0.617	99	8000	GC	II	24
G8	6	8.9	90	65	NP	NP	0.91	2.56	1.899	96	2100	ML	I	2
G9	4	7.8	80	55	NP	NP	1.08	2.52	1.450	96	4000	SM	I	43
G10	3	3.3	35	36	NP	NP	1.30	2.72	1.042	94	9500	SM	I	5

NOTES:
Compression Index Cc is taken from the virgin compression curve.
The oedometer modulus (E_{oed}) is taken at vertical pressure equal to the overburden pressure γH + 200kPa.
Coefficient of consolidation is given as average value.
N_{SPT} values were taken from closest depths.

NP: Non Plastic (Silt)

TABLE 6 SUMMARY OF ORGANICS CONTENT DETERMINATIONS

Borehole	Sample	Depth (m)	Loss on Ignition (%)	Soil Type	Layer
G4	2	1.3	2.79	SC	I
G6	1	1.5	17.02	CL	I
G7	2	1.5	10.13	ML	I
G8	7	10.8	8.54	SM	I
G9	1	1.0	7.52	SM	Ia
G10	6	8.9	5.23	SM	I

TABLE 7 SUMMARY OF UNIAXIAL TEST RESULTS ON ROCK SPECIMENS

Borehole	Depth (m)	Specimen diameter D (cm)	Specimen height H (cm)	Ratio H/D	Specimen weight (gr)	Unit weight γ (t/m³)	Load at failure F (N)	Stress at failure σ_c (MPa)	Stress at failure σ_{c50} (MPa)	Young's modulus E_m (MPa)	Poison ratio	Layer	Lithology
G1	27.6	5.84	12.90	2.21	734	2.12	13100	4.64	4.77	1690	0.40	III	Clay Marl
G1	30.2	NR	NR	2.21	NR	NR	NR	11.23	NR	2890	0.26	IV	Marly Limestone
G1	33.2	5.88	13.00	2.21	778	2.22	41300	16.24	16.72	7610	0.37	IV	Marly Limestone
G2	30.9	5.84	12.70	2.18	710	2.09	39300	15.07	15.50	11960	1.18	IV	Marly Limestone
G2	33.5	5.82	15.80	2.72	710	2:10	39200	14.44	14.84	3110	0.50	IV	Marly Limestone
G2	33.8	5.82	12.40	2.14	689	2.08	3700	15.11	15.53	2760	0.27	IV	Marly Limestone
G3	13.8	NR	NR	2.22	NR	NR	NR	4.19	NR	1790	0.80	III	Clay Marl
G3	16.4	5.82	12.80	2.19	672	1.97	14800	5.62	5.78	1230	0.96	III	Clay Marl
G3	17.4	5.32	12.80	2.41	561	1.97	10500	4.74	4.79	2140	0.22	IV	Marly Limestone
G3	20.5	5.83	11.00	1.89	599	2.04	26900	9.45	9.71	5150	0.55	IV	Marly Limestone
G3	25.8	5.83	12.30	2.12	670	2.04	38300	14.27	14.67	4670	0.59	IV	Marly Limestone
G4	8.5	5.83	12.90	2.21	736	2.14	21500	8.00	8.22	2380	0.36	III	Clay Marl
G4	11.6	5.83	12.80	2.19	746	2.17	35800	13.56	13.94	1670	0.23	IV	Marly Limestone
G4	15.4	5.87	12.60	2.15	726	2.13	25500	9.14	9.41	1520	0.28	IV	Marly Limestone

TABLE 7 SUMMARY OF UNIAXIAL TEST RESULTS ON ROCK SPECIMENS (continued)

Borehole	Depth (m)	Specimen diameter D (cm)	Specimen height H (cm)	Ratio H/D	Specimen weight (gr)	Unit weight γ (t/m³)	Load at failure F (N)	Stress at failure σ_c (MPa)	Stress at failure σ_{c50} (MPa)	Young's modulus E_m (MPa)	Poison ratio	Layer	Lithology
G4	19.1	5.77	12.60	2.18	726	2.23	41200	15.73	16.14	6340	0.61	IV	Marly Limestone
G4	22.1	5.80	12.60	2.17	717	2.16	33400	12.89	13.24	1750	0.23	IV	Marly Limestone
G5	29.0	5.84	12.80	2.19	736	2.15	26200	9.59	9.86	4070	0.28	IV	Marly Limestone
G5	30.6	NR	NR	2.21	NR	NR	NR	11.43	NR	5800	0.41	IV	Marly Limestone
G5	35.1	5.84	12.80	2.19	711	2.07	42800	15.94	16.39	2580	0.34	IV	Marly Limestone
G5	36.2	5.83	12.80	2.19	746	2.19	44200	16.54	17.00	2160	0.50	IV	Marly Limestone
G6	21.5	5.82	12.90	2.21	737	2.15	26400	9.52	9.78	2210	0.28	III	Clay Marl
G6	23.3	5.81	13.10	2.25	743	2.18	33000	12.46	12.80	1210	0.28	IV	Marly Limestone
G6	25.3	5.81	13.00	2.24	761	2.21	33600	12.59	12.93	970	0.24	IV	Marly Limestone
G6	29.5	5.82	13.00	2.24	750	2.16	41600	15.59	16.02	1430	0.21	IV	Marly Limestone
G7	22.1	5.80	12.80	2.21	716	2.12	12500	4.77	4.90	510	0.29	III	Clay Marl
G7	25.0	5.82	13.00	2.24	779	2.29	34100	12.79	13.14	1990	0.59	IV	Marly Limestone
G7	28.6	5.81	12.80	2.21	752	2.21	48000	15.81	16.24	2230	0.30	IV	Marly Limestone
G8	16.7	5.91	12.00	2.03	702	2.10	14400	5.39	5.55	13960	1.30	IV	Marly Limestone

TABLE 7 SUMMARY OF UNIAXIAL TEST RESULTS ON ROCK SPECIMENS (continued)

Borehole	Depth (m)	Specimen diameter D (cm)	Specimen height H (cm)	Ratio H/D	Specimen weight (gr)	Unit weight γ (t/m³)	Load at failure F (N)	Stress at failure σ_c (MPa)	Stress at failure σ_{c50} (MPa)	Young's modulus E_m (MPa)	Poison ratio	Layer	Lithology
G8	18.8	5.55	12.40	2.23	631	2.20	5700	2.30	2.34	900	0.30	IV	Marly Limestone
G8	22.3	5.89	12.40	2.11	709	2.10	23000	8.57	8.83	1600	1.14	IV	Marly Limestone
G8	22.7	5.00	9.50	1.90	408	2.18	27800	14.49	14.49	3000	0.21	IV	Marly Limestone
G9	9.2	5.77	11.50	1.99	640	2.12	10100	3.90	4.00	NR	NR	III	Clay Marl
G9	14.1	6.26	16.40	2.62	1056	2.98	9700	3.20	3.33	NR	NR	III	Clay Marl
G9	16.0	5.64	10.10	1.79	535	2.12	26200	10.43	10.66	4090	0.19	IV	Marly Limestone
G9	18.0	5.88	12.90	2.19	753	2.16	35600	12.94	13.32	2230	0.20	IV	Marly Limestone
G9	18.3	6.64	16.30	2.46	1209	2.14	35100	10.10	10.63	NR	NR	IV	Marly Limestone
G9	19.7	6.45	17.30	2.67	1203	2.13	32500	9.90	10.36	NR	NR	IV	Marly Limestone
G9	24.0	5.88	12.50	2.12	719	2.12	34700	12.56	12.93	1590	0.26	IV	Marly Limestone
G9	25.0	6.39	16.50	2.59	1117	2.11	30000	9.40	9.82	NR	NR	IV	Marly Limestone
G10	13.9	6.14	13.40	2.18	842	2.13	23200	7.80	8.09	NR	NR	IV	Marly Limestone
G10	14.5	5.87	12.80	2.19	756	2.18	30400	11.24	11.57	1950	0.31	IV	Marly Limestone
G10	14.7	6.72	15.60	2.33	1189	2.15	23900	6.70	7.07	NR	NR	IV	Marly Limestone

TABLE 7 SUMMARY OF UNIAXIAL TEST RESULTS ON ROCK SPECIMENS (continued)

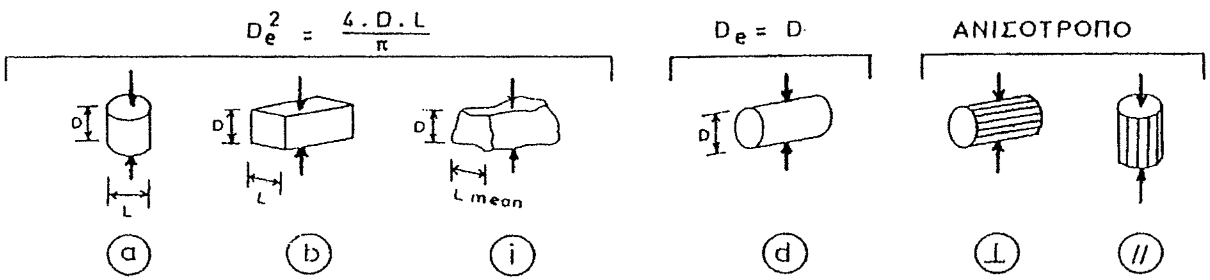
Borehole	Depth (m)	Specimen diameter D (cm)	Specimen height H (cm)	Ratio H/D	Specimen weight (gr)	Unit weight γ (t/m^3)	Load at failure F (N)	Stress at failure σ_c (MPa)	Stress at failure σ_{c50} (MPa)	Young's modulus E_m (MPa)	Poison ratio	Layer	Lithology
G10	18.6	6.74	15.50	2.30	1172	2.12	23200	6.50	6.86	NR	NR	IV	Marly Limestone
G10	19.0	5.92	12.80	2.16	801	2.27	46200	16.68	17.19	5800	0.07	IV	Marly Limestone
G10	21.5	5.87	12.70	2.17	735	2.14	35600	13.04	13.42	1980	0.43	IV	Marly Limestone
G10	24.6	6.55	16.20	2.46	1162	2.03	33300	9.90	10.39	NR	NR	IV	Marly Limestone

NR: Not Reported

TABLE 8 SUMMARY OF POINT LOAD TEST RESULTS

Borehole	Depth (m)	Test type	Pick distance D (mm)	Character. dimension L (mm)	Equivalent dimension De (mm)	Failure Load F (N)	Index $Is = F/De^2$ (MPa)	Correction coefficient	Corrected index Is(50) (MPa)	Anisotropy index Ia<=1	Layer	Lithology
G1	26.20	d	71.31	-	71.31	160	0.10	1.12	0.20	1.00	III	Marl
		a	70.60	71.3	80.06	180	0.20	1.15	0.20			
G1	27.60	d	58.06	-	58.06	290	0.20	1.01	0.20	0.40	III	Marl
		a	58.16	58.1	65.56	510	0.50	1.04	0.50			
G1	31.50	d	58.89	-	58.89	740	0.50	0.99	0.50	0.50	IV	Marly Limestone
		a	58.72	58.9	66.35	1450	1.00	0.99	1.00			
G1	33.20	d	58.69	-	58.69	610	0.40	1.00	0.40	0.26	IV	Marly Limestone
		a	58.60	58.7	66.17	1870	1.50	1.03	1.60			
G2	26.20	d	66.35	-	66.35	8150	6.80	1.09	7.40	0.68	III	Marl
		a	66.08	66.4	74.71	11590	9.80	1.09	10.60			
G2	30.90	d	58.37	-	58.37	1360	1.10	1.03	1.20	0.61	IV	Marly Limestone
		a	58.34	58.4	65.84	2040	1.80	1.04	1.90			
G2	33.50	d	58.24	-	58.24	1150	1.00	1.04	1.00	0.47	IV	Marly Limestone
		a	58.22	58.2	65.70	2470	2.10	1.03	2.20			
G2	33.80	d	58.19	-	58.19	1050	0.90	1.03	0.90	0.64	IV	Marly Limestone
		a	58.26	58.2	65.69	1740	1.40	1.03	1.50			
G3	13.75	d	58.24	-	58.24	130	0.10	1.03	0.10	1.00	III	Marl
		a	58.24	58.2	65.71	140	0.10	1.00	0.10			
G3	16.35	d	58.49	-	58.49	360	0.30	1.02	0.30	1.50	III	Marl
		a	58.45	58.5	65.97	270	0.20	1.05	0.30			

ΤΥΠΟΙ ΔΟΚΙΜΩΝ



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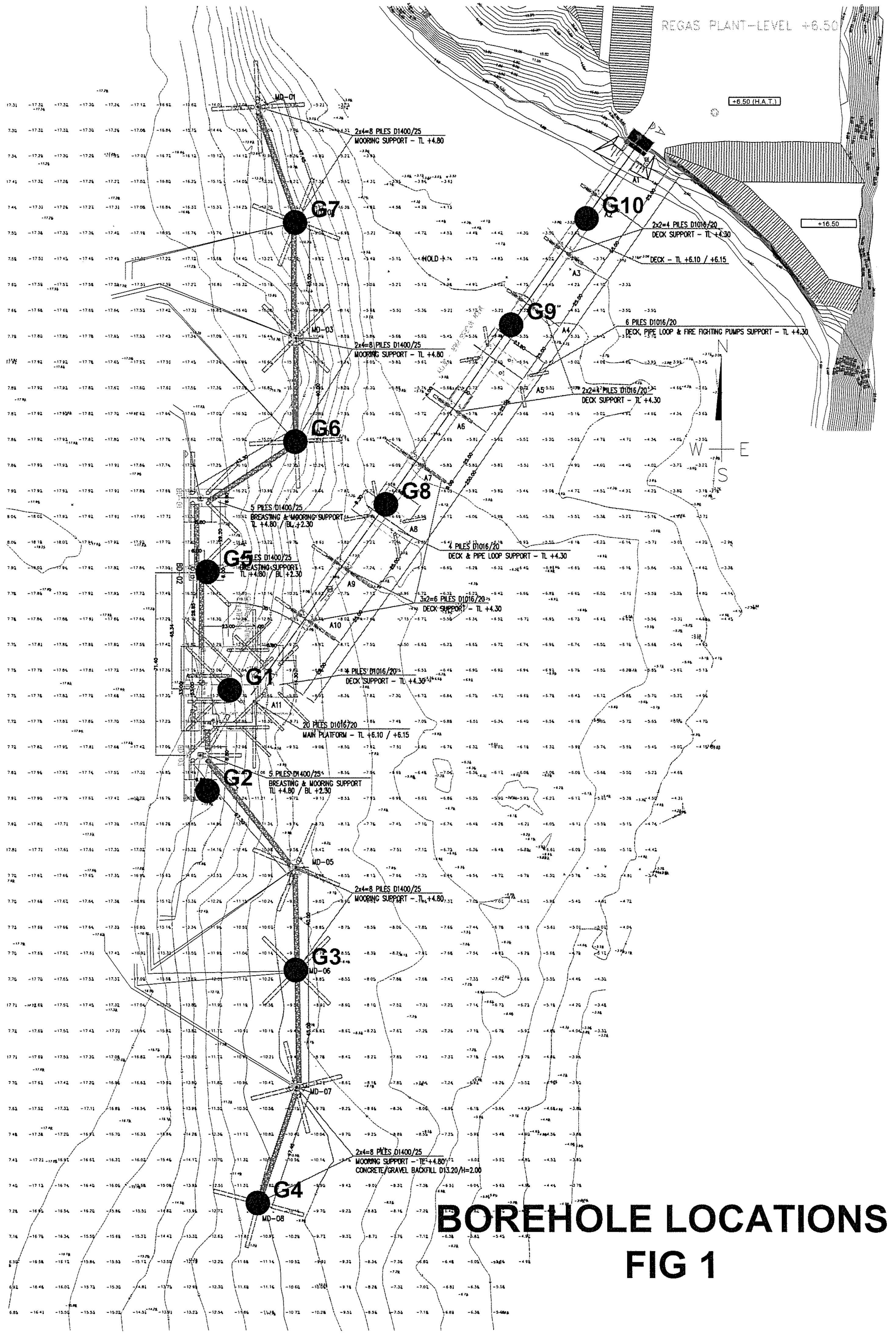
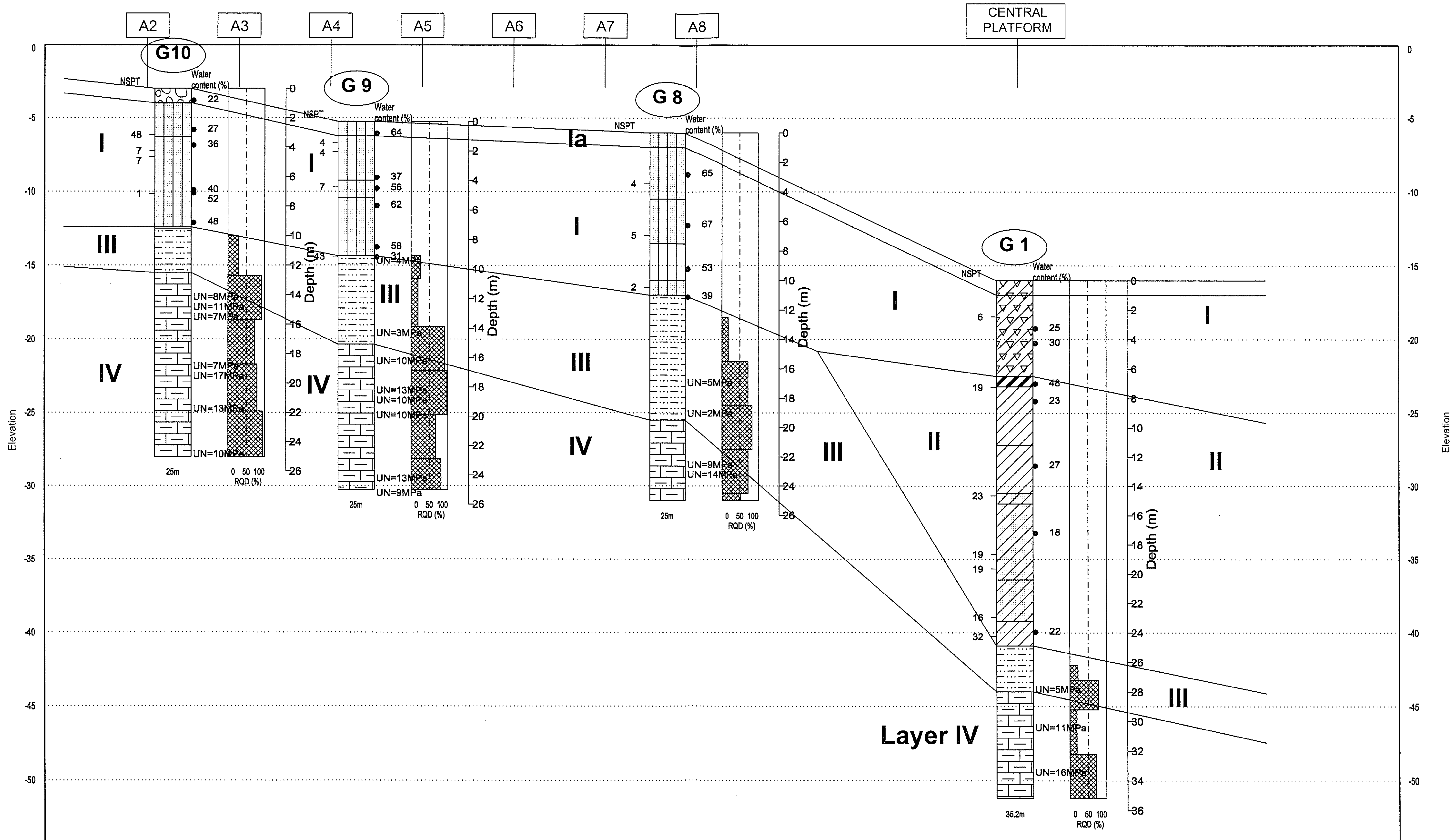
FIGURES



BOREHOLE LOCATIONS

FIG 1



LEGEND

10 ⊣ Standard Penetration Test NSPT (blows/30cm)

R ⊣ Refusal to SPT

R(50/7) ⊣ Penetration of 7 cm for 50 blows

● 25 Water Content (%)

UN= Uniaxial Compression Strength (MPa)

GRAVEL (GC)

CLAY (CH), high plasticity

CLAY (CL)

SAND (SC)

MARL

LIMESTONE MARLY

SAND (SM)

SILT (ML)

BOULDERS

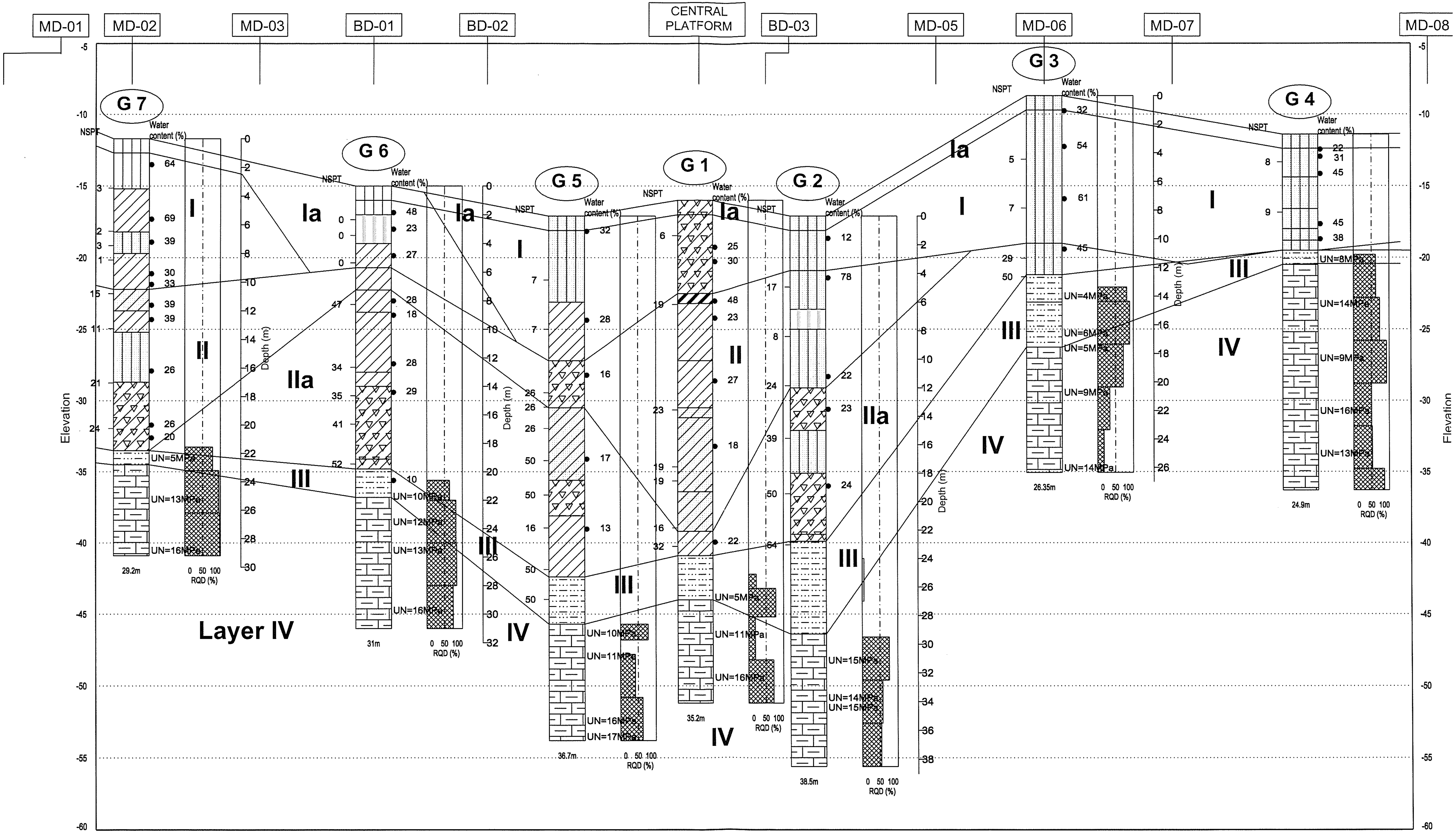
SCALE

Vertical 1:250

Horizontal 1:100

CASTOR LTD

SUBSURFACE PROFILE
JETTY & CENTRAL PLATFORM
FIG 2



LEGEND

10 ⊣	Standard Penetration Test NSPT (blows/30cm)
R ⊣	Refusal to SPT
R(50/7) ⊣	Penetration of 7 cm for 50 blows
● 25	Water Content (%)
UN=	Uniaxial Compression Strength (MPa)

- GRAVEL (GC)
- CLAY (CH), high plasticity
- CLAY (CL)
- SAND (SC)
- MARL
- LIMESTONE MARLY
- SAND (SM)
- SILT (MH), high plasticity
- CLAY AND GRAVEL
- SILT (ML)

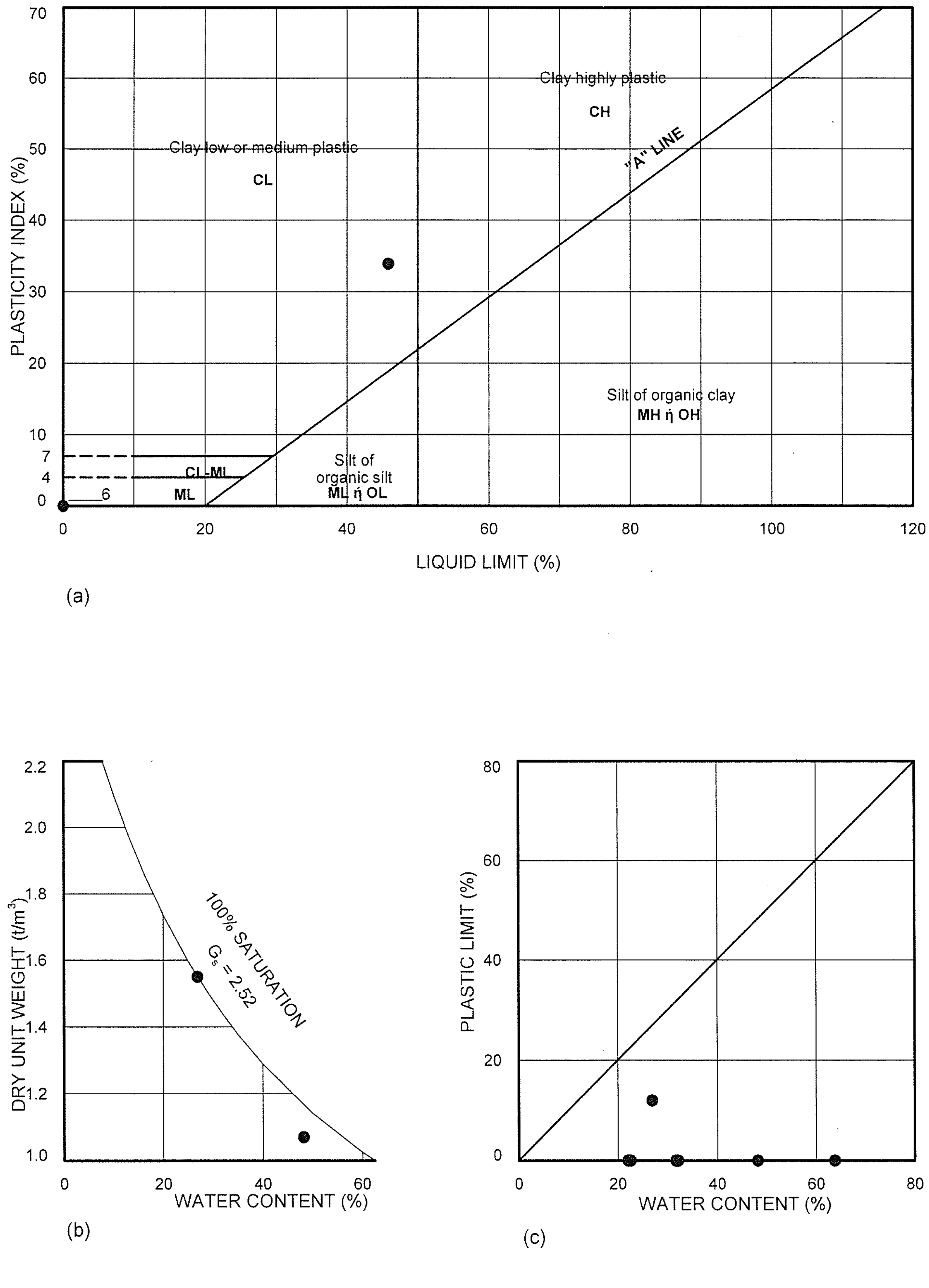
SCALE

Vertical 1:250

Horizontal 1:125

SUBSURFACE PROFILE MOORING & BREASTING DOLPHINS FIG 3

CASTOR LTD

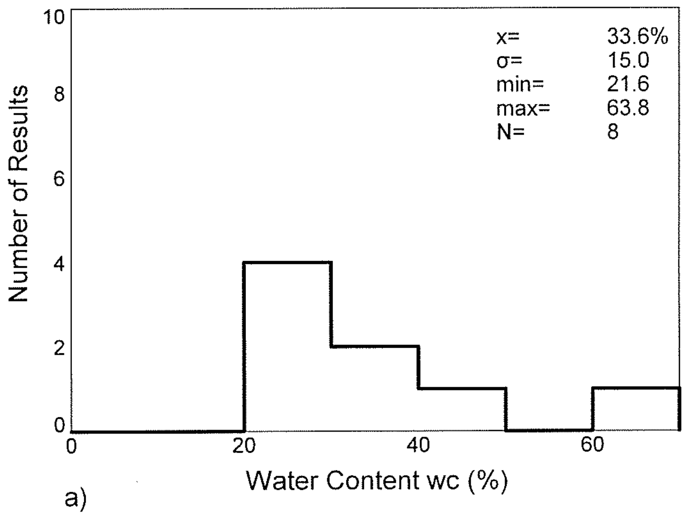


Layer Ia: Sea bottom. Very loose
silt (ML) and silty sand (SM).

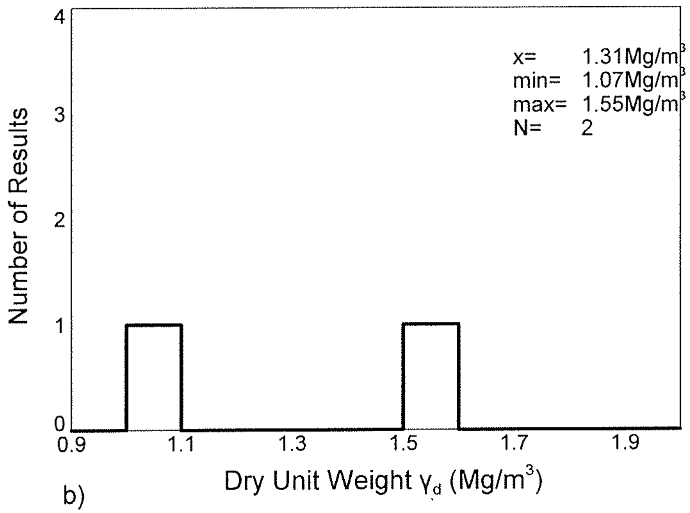
LAYER Ia
CLASSIFICATION PROPERTIES
FIG 4.1

LAYER Ia

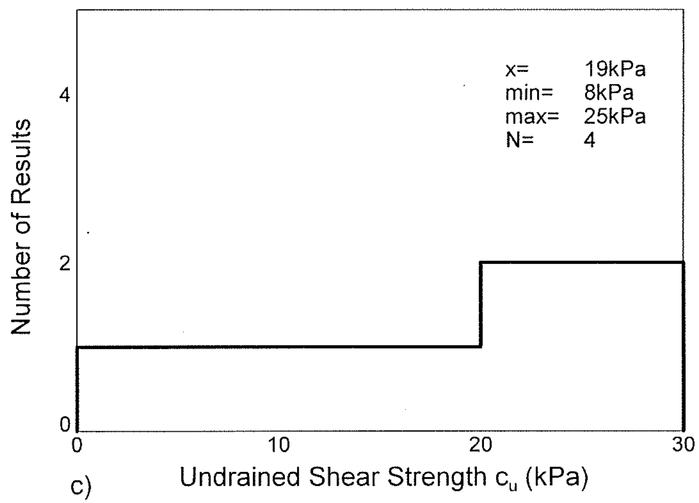
Sea bottom. Very looset silt (ML) and silty sand (SM)



a)



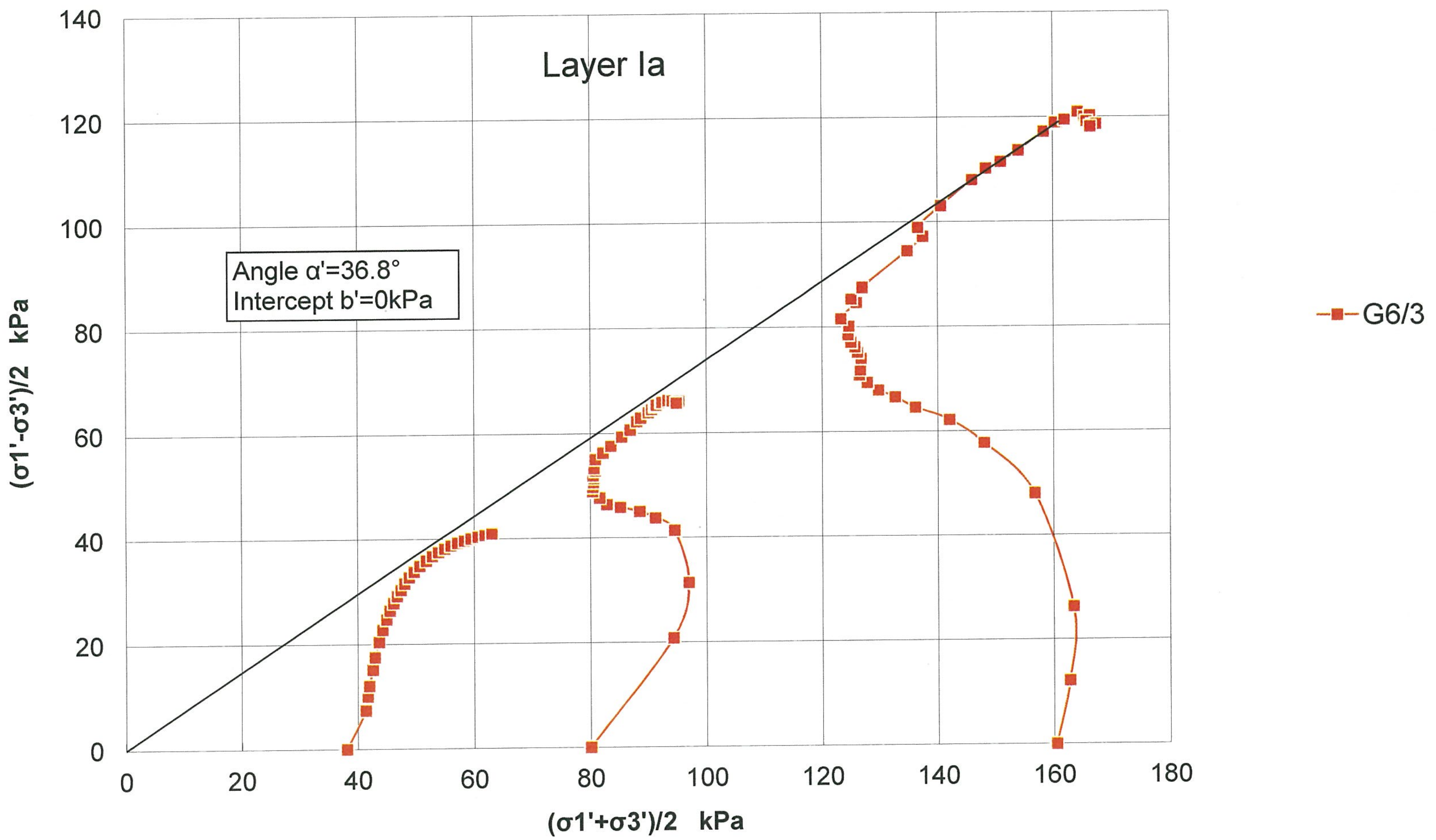
b)



c)

STATISTICAL PRESENTATION OF PROPERTIES
FIG 4.2

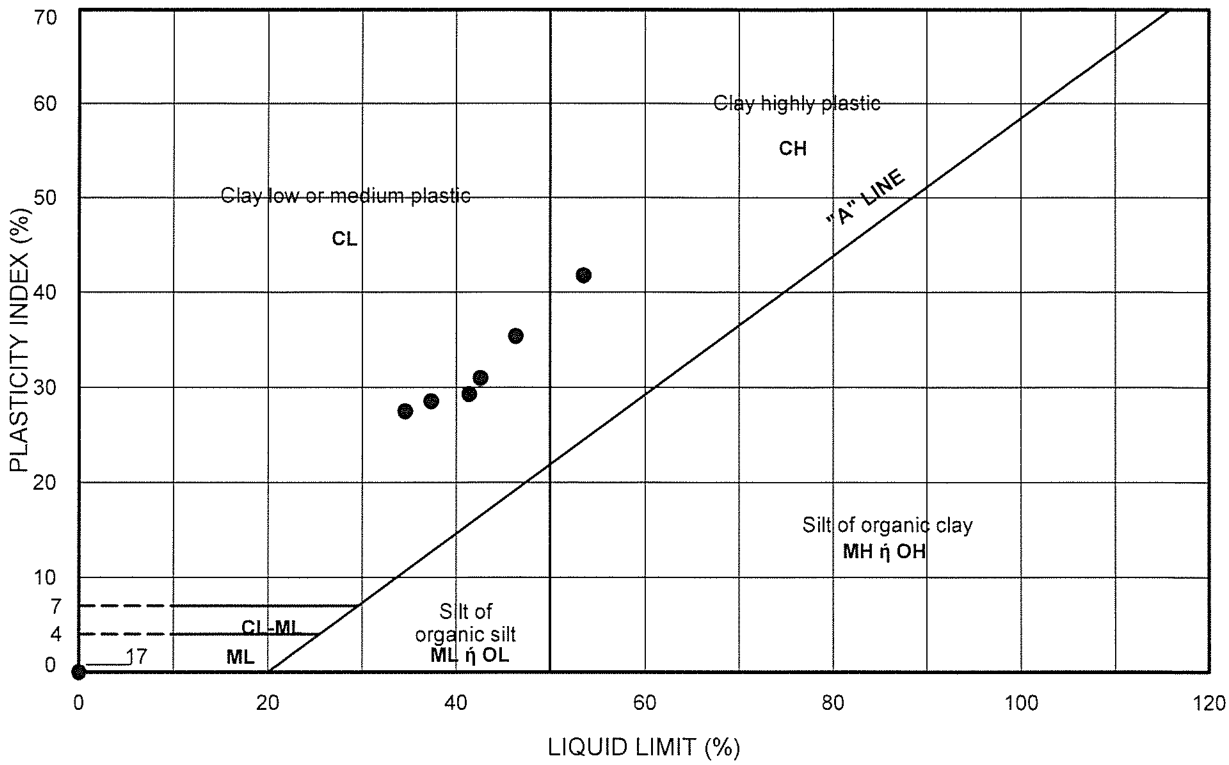
CASTOR LTD



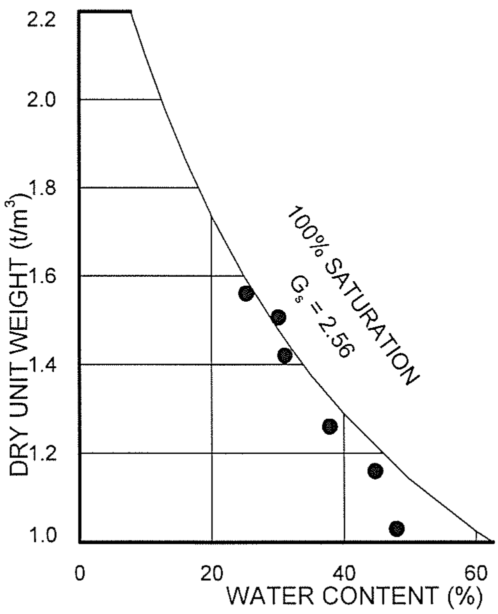
Layer Ia: Sea bottom, very loose silt (ML) and silty sand (SM).

Layer Ia
STRESS PATHS
FIG 4.3

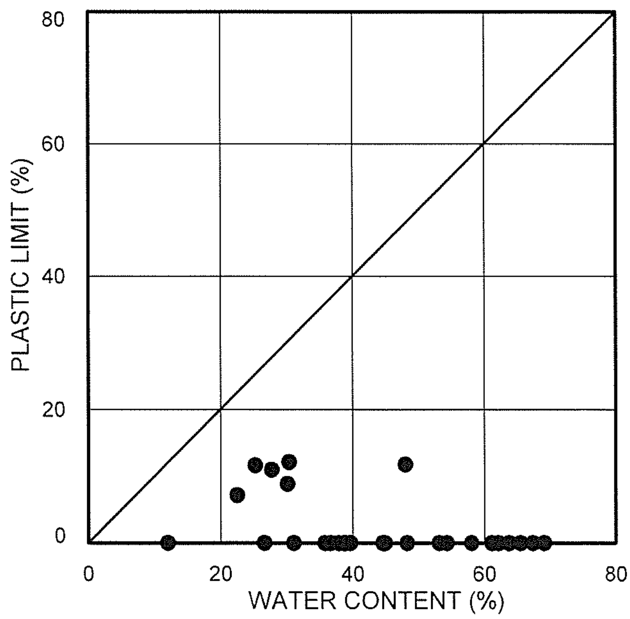
CASTOR LTD



(a)



(b)



(c)

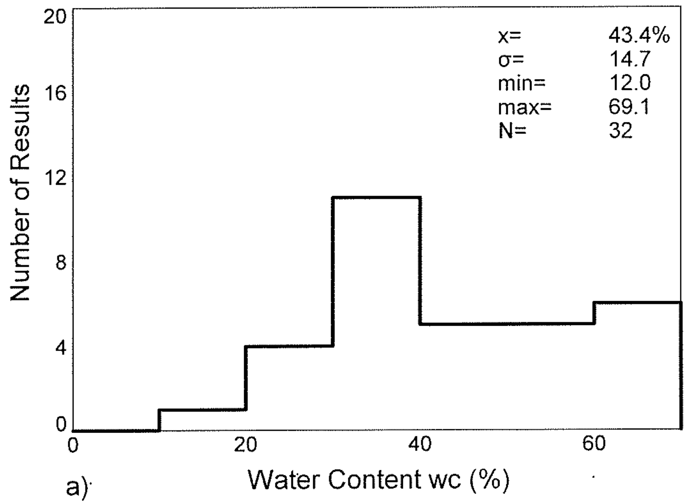
Layer I: Very loose silty sand (SM), very soft to soft clay (CL) and loose clayey gravel (GL).

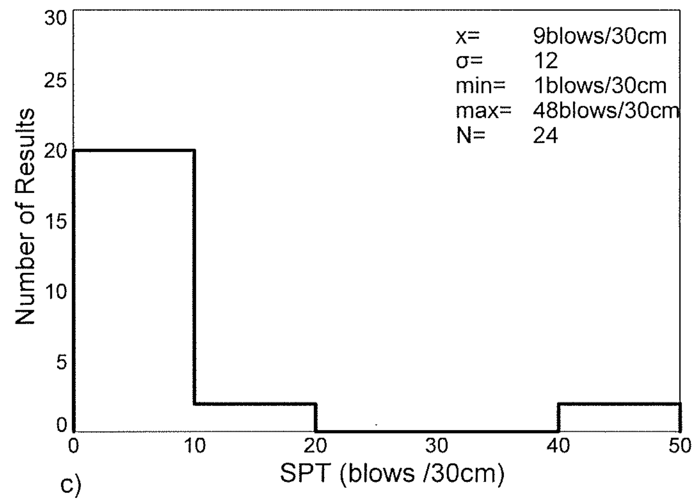
LAYER I
CLASSIFICATION PROPERTIES
FIG 5.1

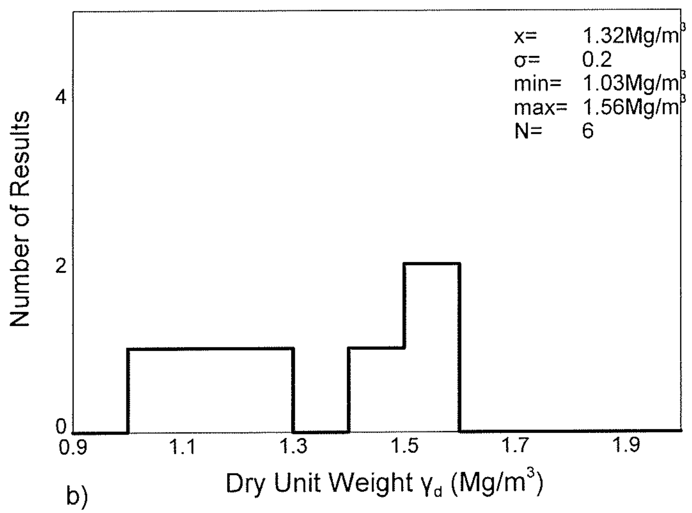
CASTOR LTD

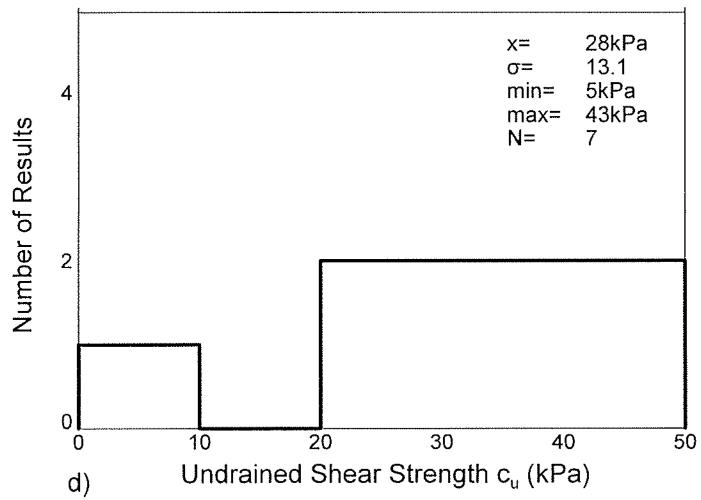
LAYER I

Very loose silty sand (SM), very soft to soft clay (CL) and loose clayey gravel (GC)





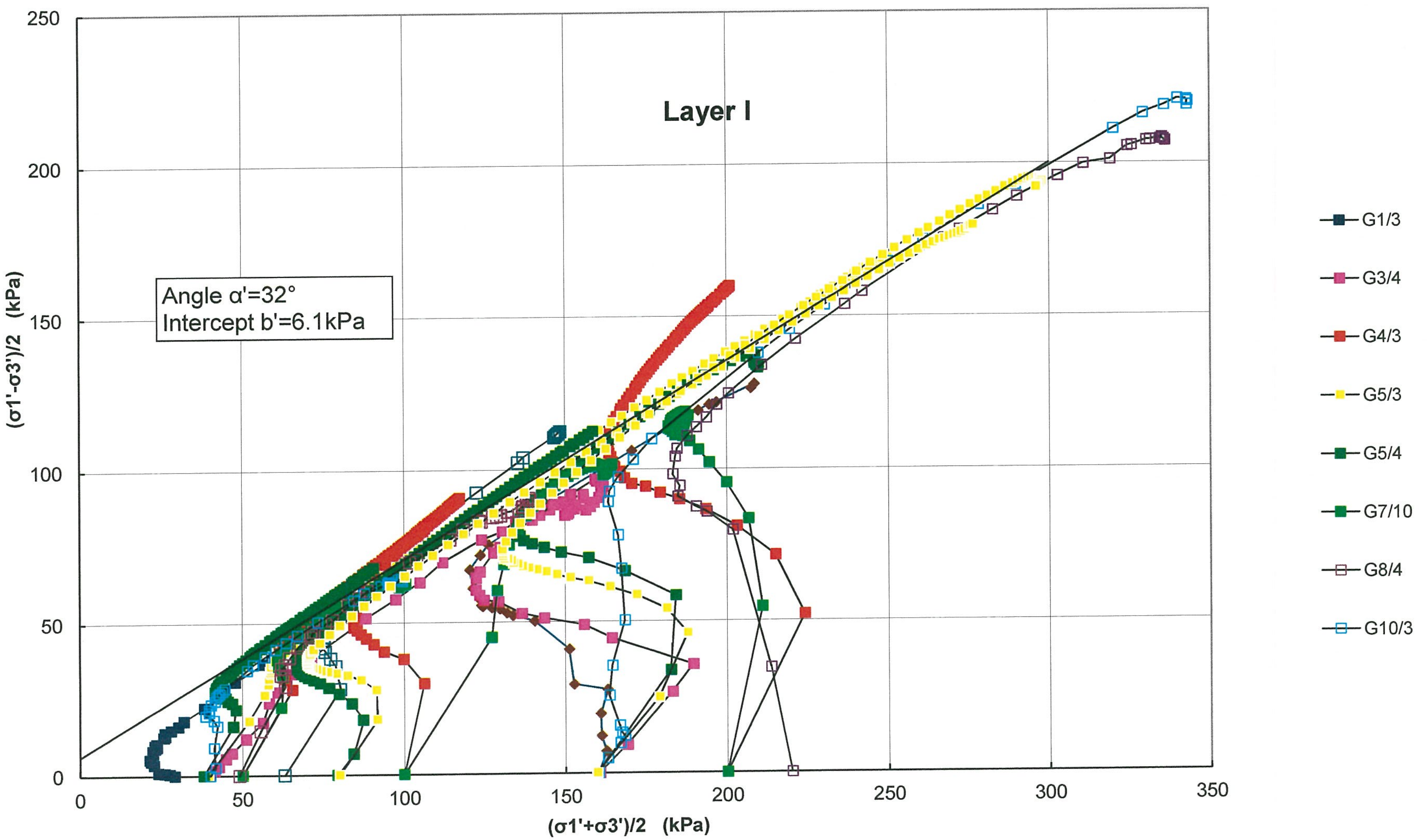




STATISTICAL PRESENTATION OF PROPERTIES

FIG 5.2

CASTOR LTD

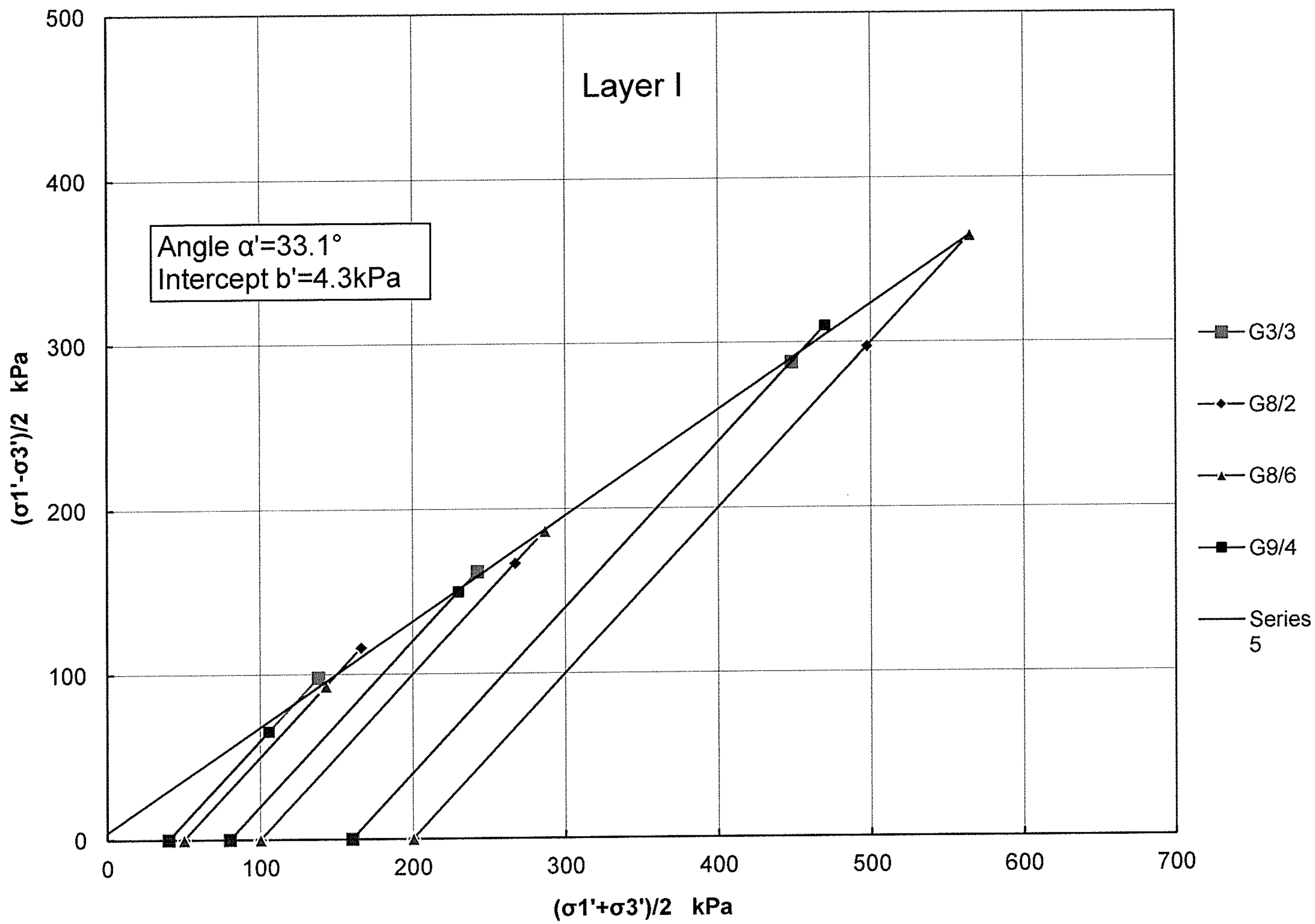


Layer I: Very loose silty sand (SM), very soft to soft clay (CL) and loose clayey gravel (GC).

Layer I
STRESS PATHS

FIG 5.3

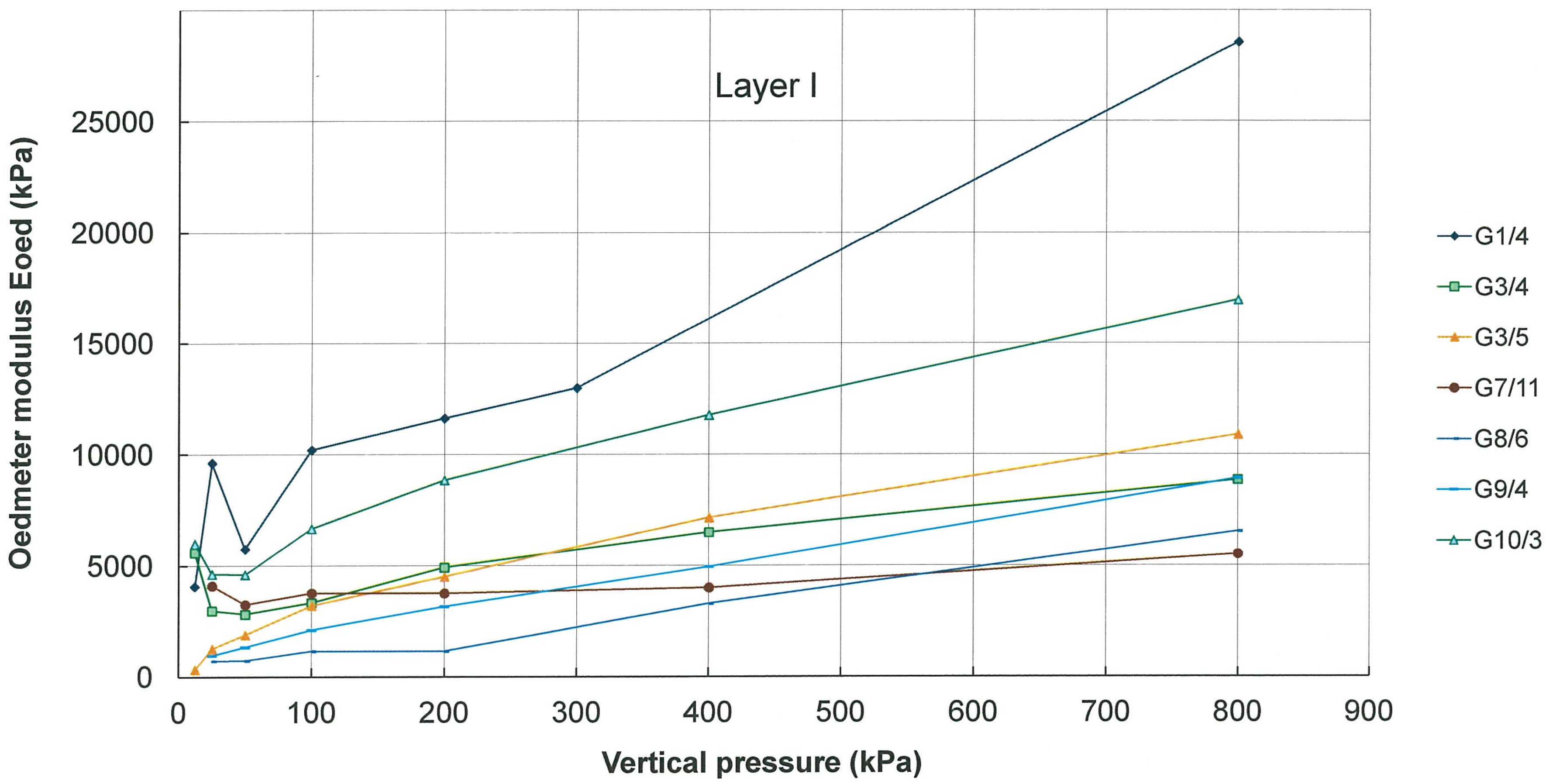
CASTOR LTD



Layer I: Very loose silty sand (SM), very soft to soft clay (CL) and loose clayey gravel (GC).

Layer I
CONSOLIDATED DRAINED TRIAXIAL TESTS
FIG 5.4

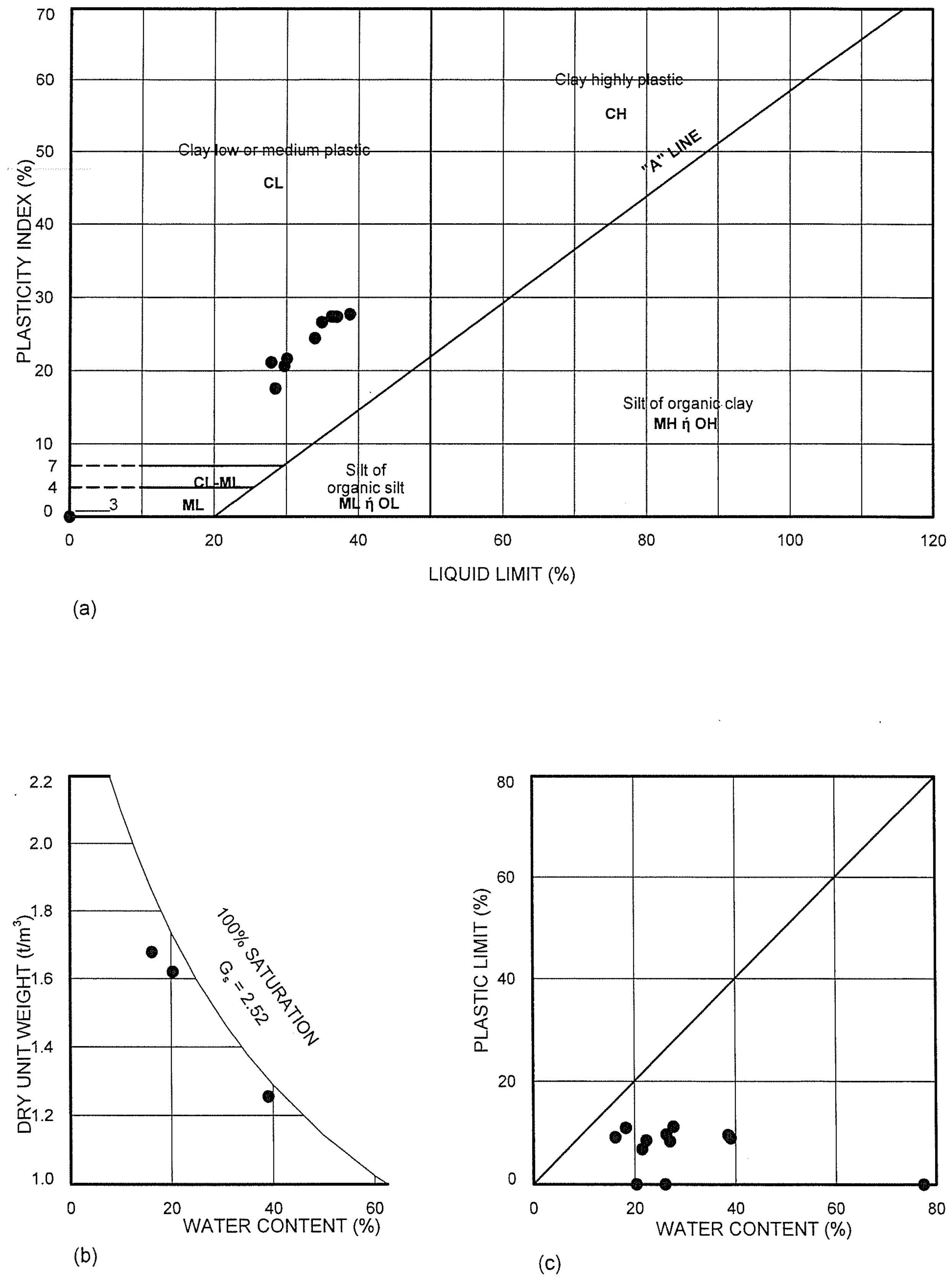
CASTOR LTD



Layer I: Very loose silty sand (SM), very soft to soft clay (CL) and loose clayey gravel (GC).

LAYER I
ONE-DIMENSIONAL CONSOLIDATION TESTS
FIG 5.5

CASTOR LTD



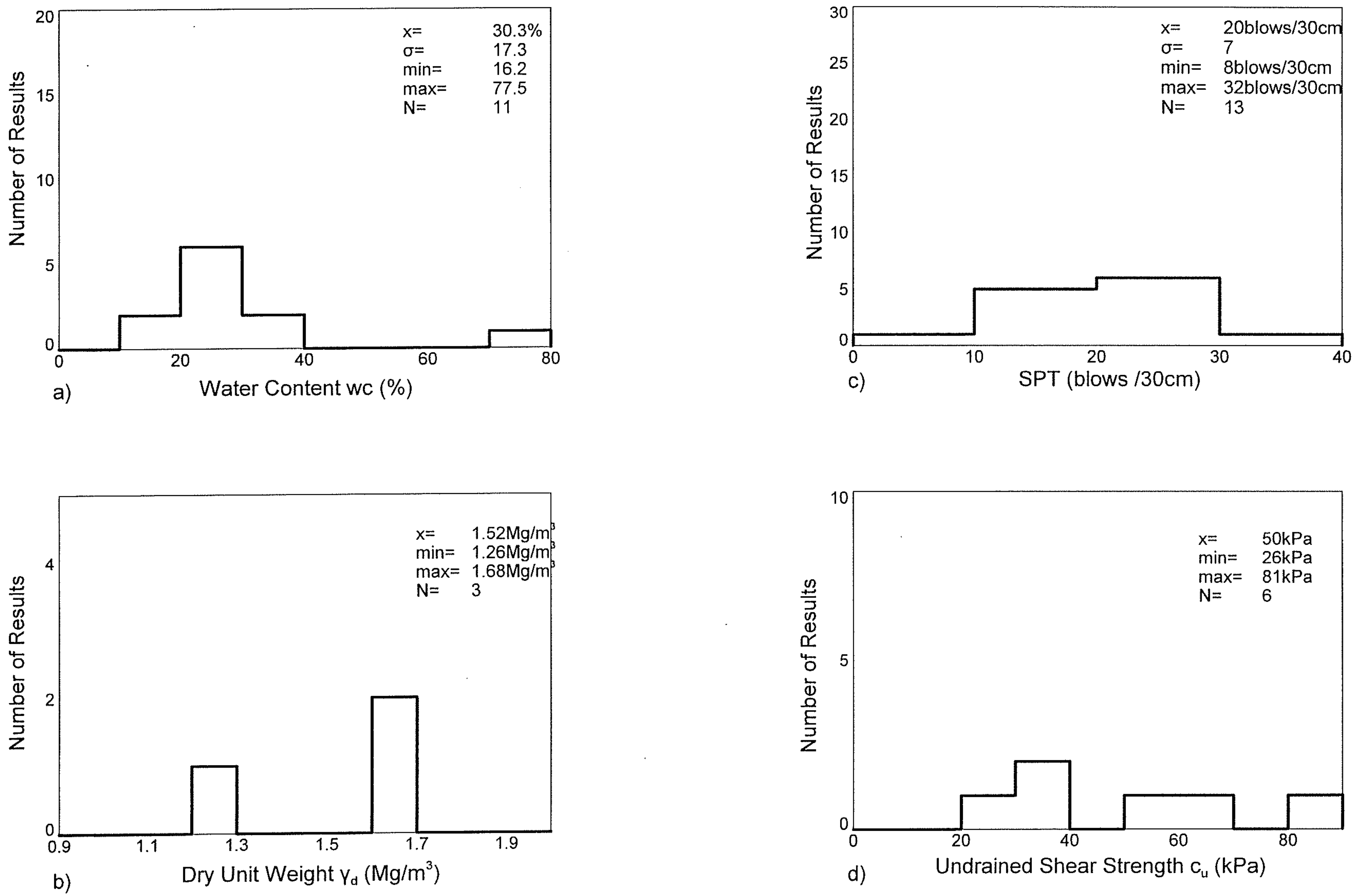
Layer II: Very soft to soft clay (CL),
and medium dense clayey gravel (GC)
clayey sand (SC) and silty sand (SM).

LAYER II
CLASSIFICATION PROPERTIES
FIG 6.1

CASTOR LTD

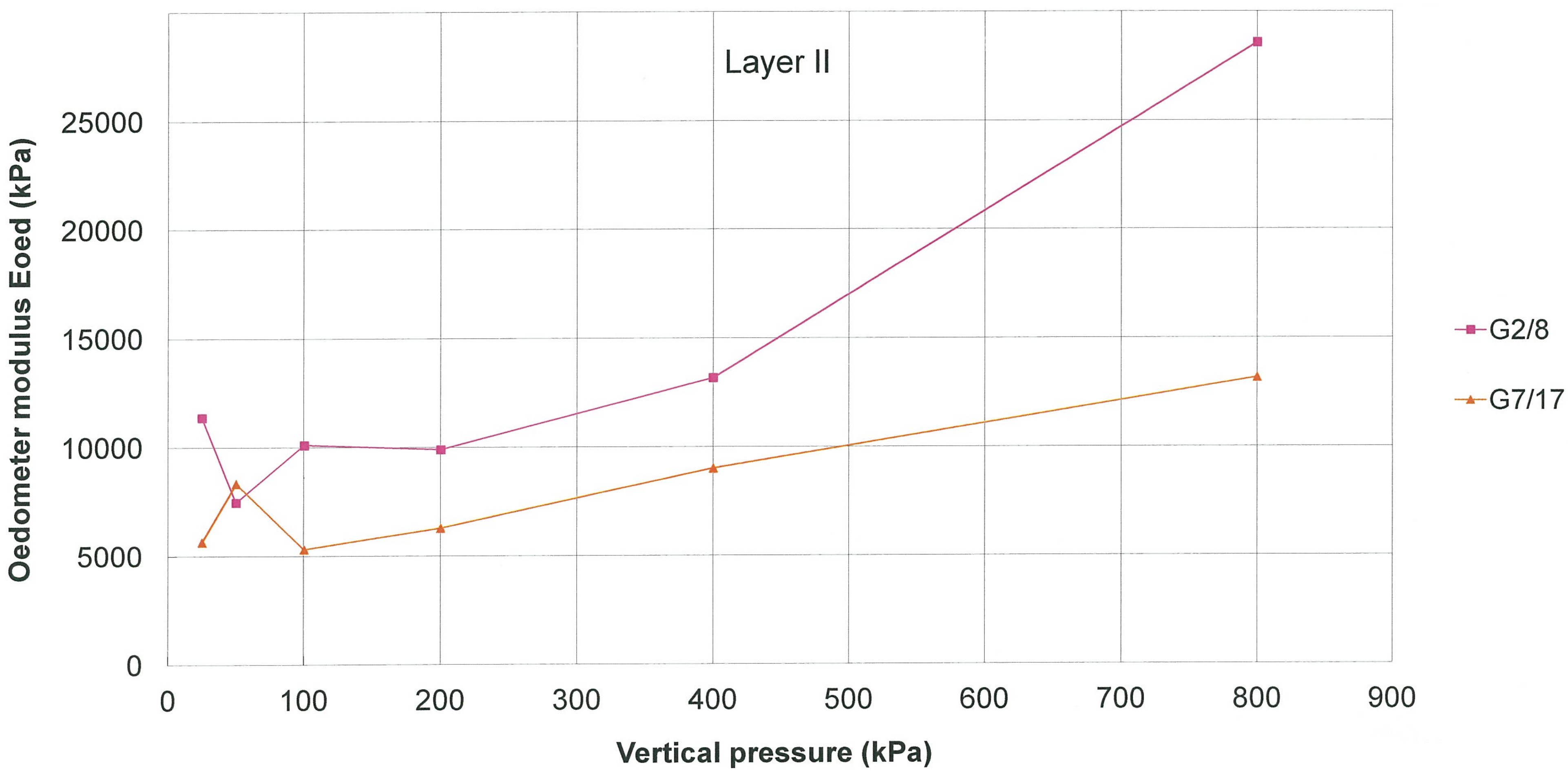
LAYER II

Very soft to soft clay (CL)
and medium dense clayey gravel (GC)
clayey sand (SC) and silty sand (SM).



STATISTICAL PRESENTATION OF PROPERTIES
FIG 6.2

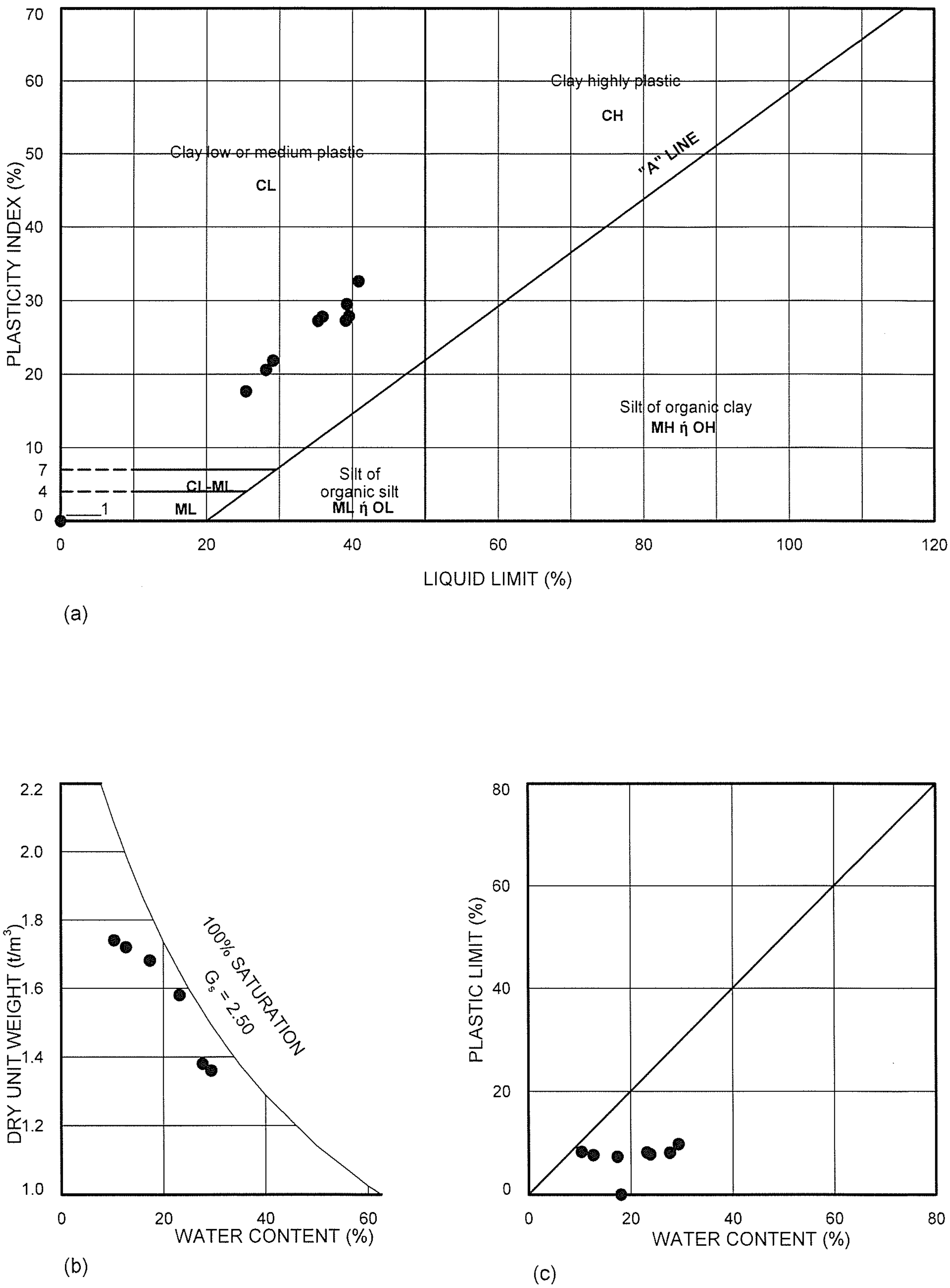
CASTOR LTD



Layer II: Very soft to soft clay (CL), and medium dense clayey gravel (GC), clayey sand (SC) and silty sand (SM).

LAYER II
ONE-DIMENSIONAL CONSOLIDATION TESTS
FIG 6.3

CASTOR LTD

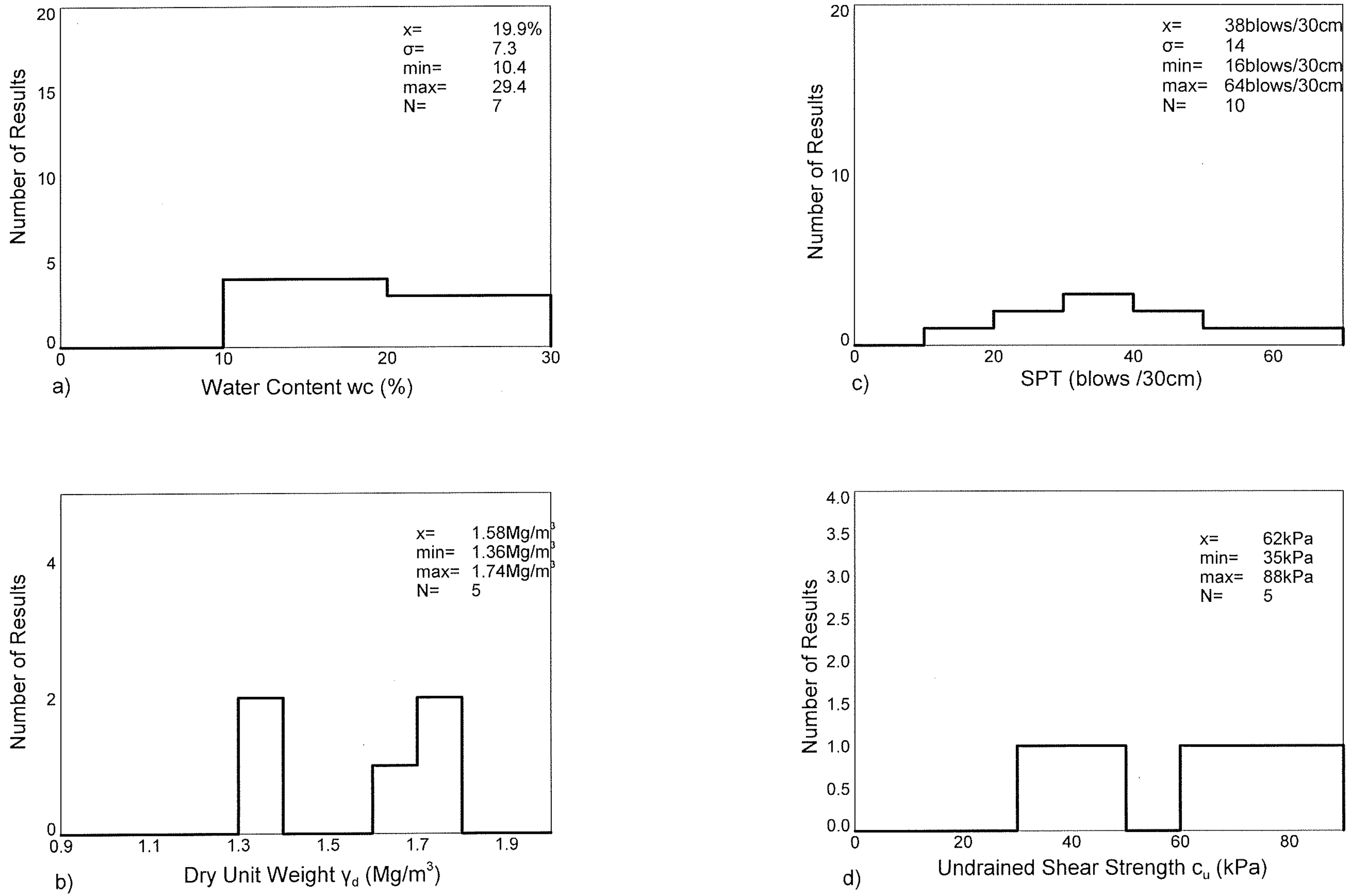


Layer IIa: Hard clay (CL), medium dense clayey gravel (GC),
clayey sand (SC) and silty sand (SC).

LAYER IIa
CLASSIFICATION PROPERTIES
FIG 7.1

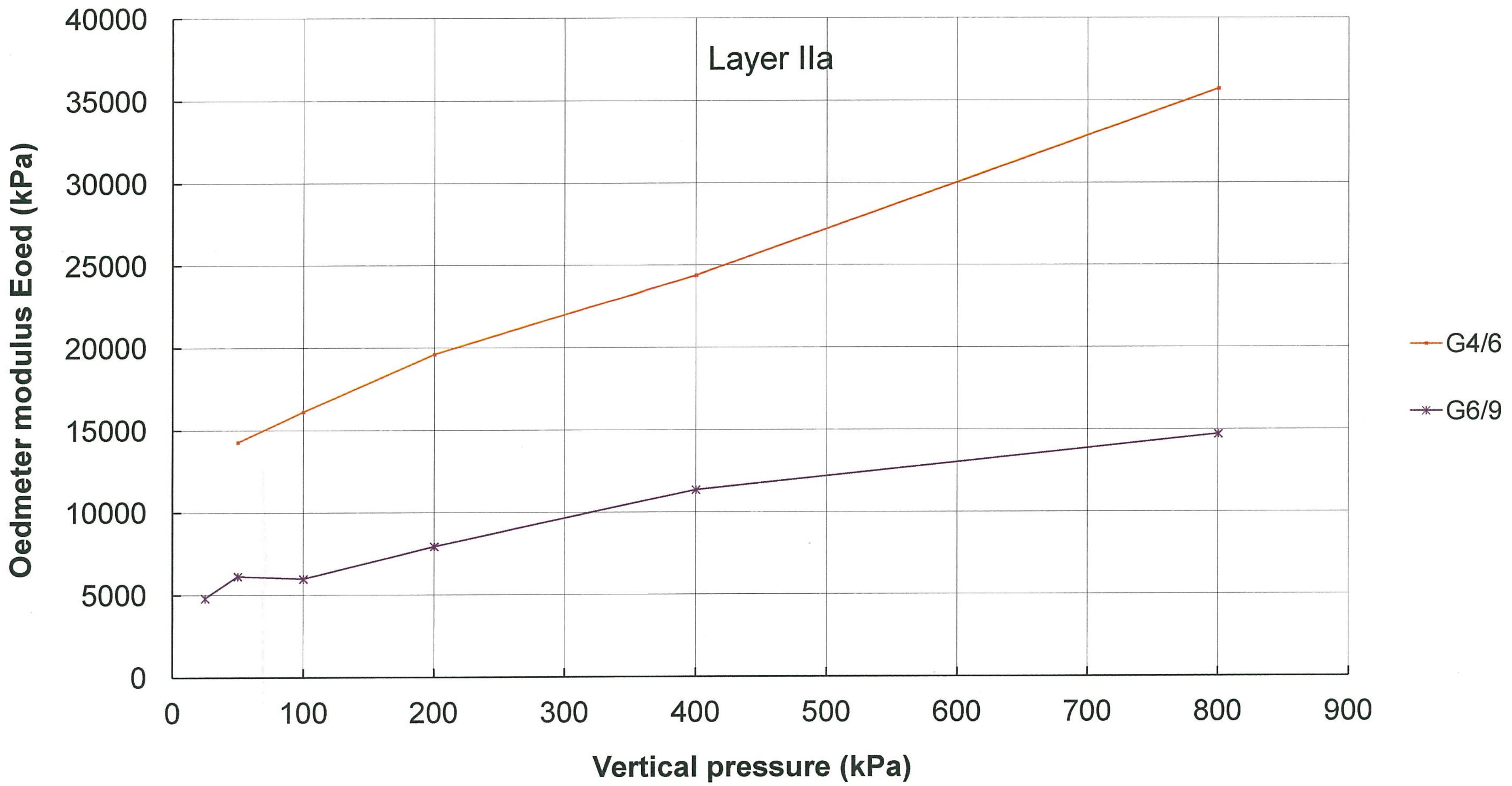
LAYER IIa

Hard clay (CL), medium dense clayey gravel (GC),clayey sand (SC) and silty sand (SC)



CASTOR LTD

STATISTICAL PRESENTATION OF PROPERTIES
FIG 7.2



Layer IIa: Hard clay (CL), medium dense clayey gravel (GC), clayey sand (SC) and silty sand (SM).

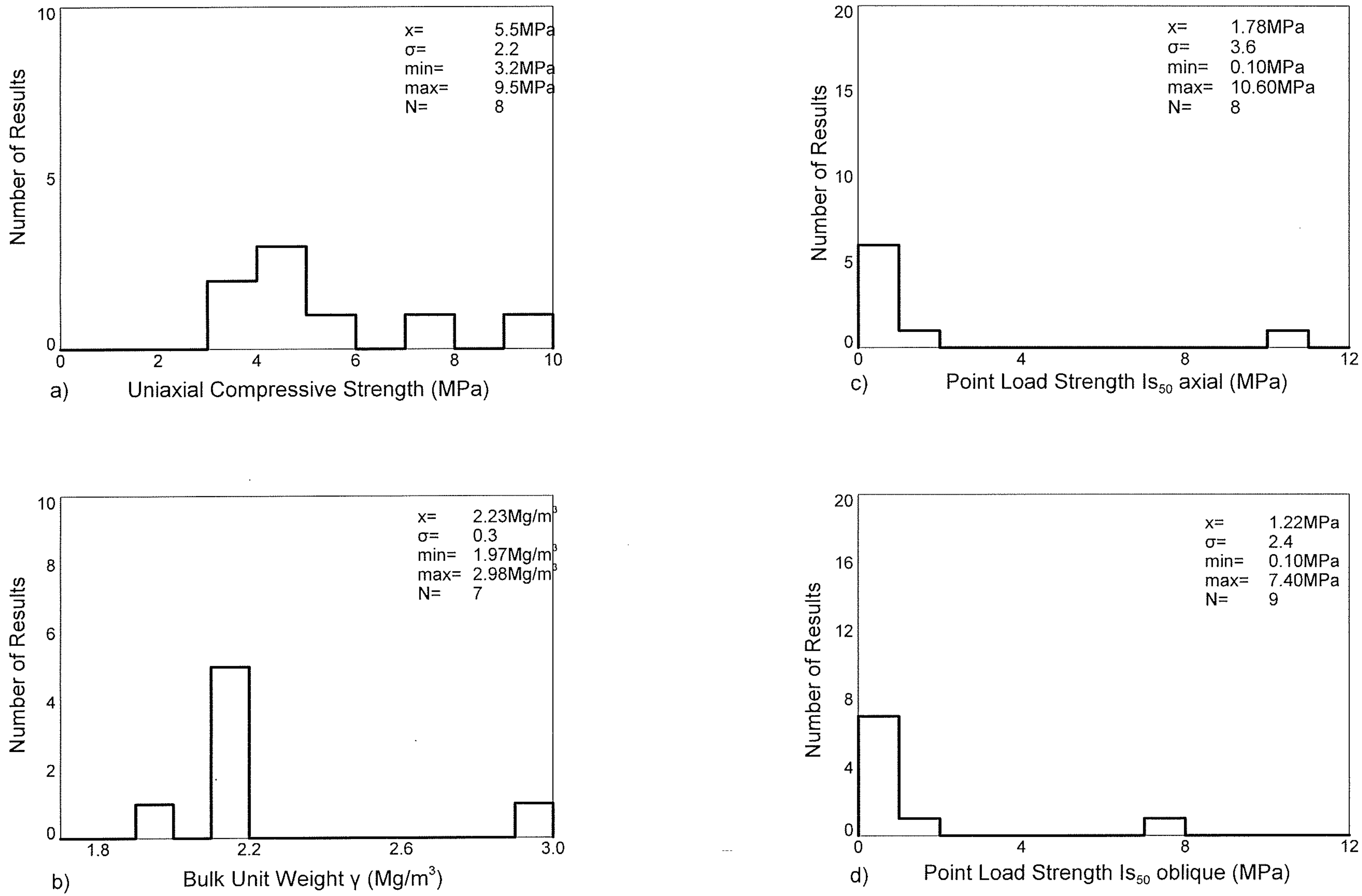
LAYER IIa

ONE-DIMENSIONAL CONSOLIDATION TESTS

FIG 7.3

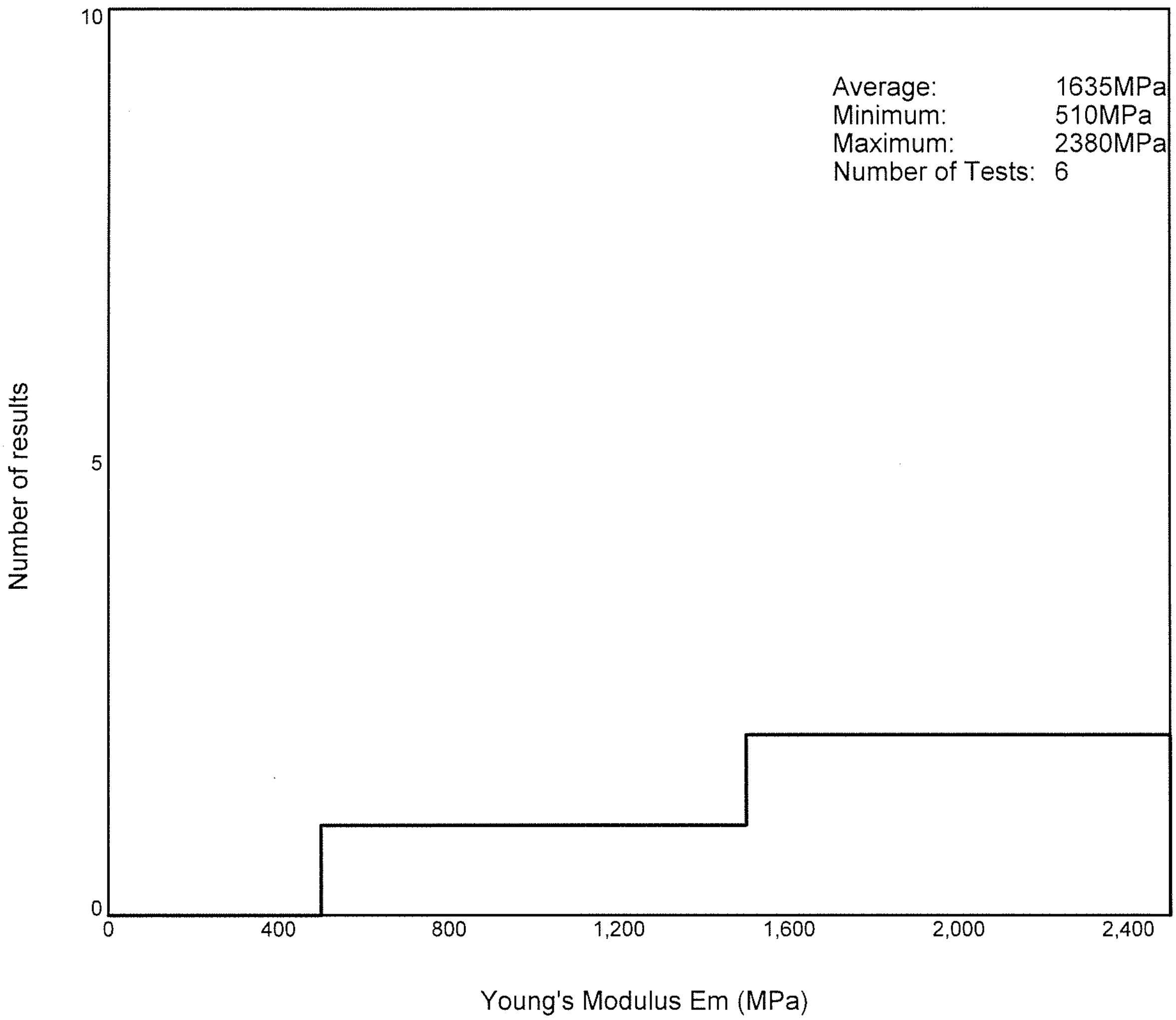
LAYER III

Very low strength clay marl, light brown colour



STRENGTH AND BULK UNIT WEIGHT
FIG 8.1

CASTOR LTD

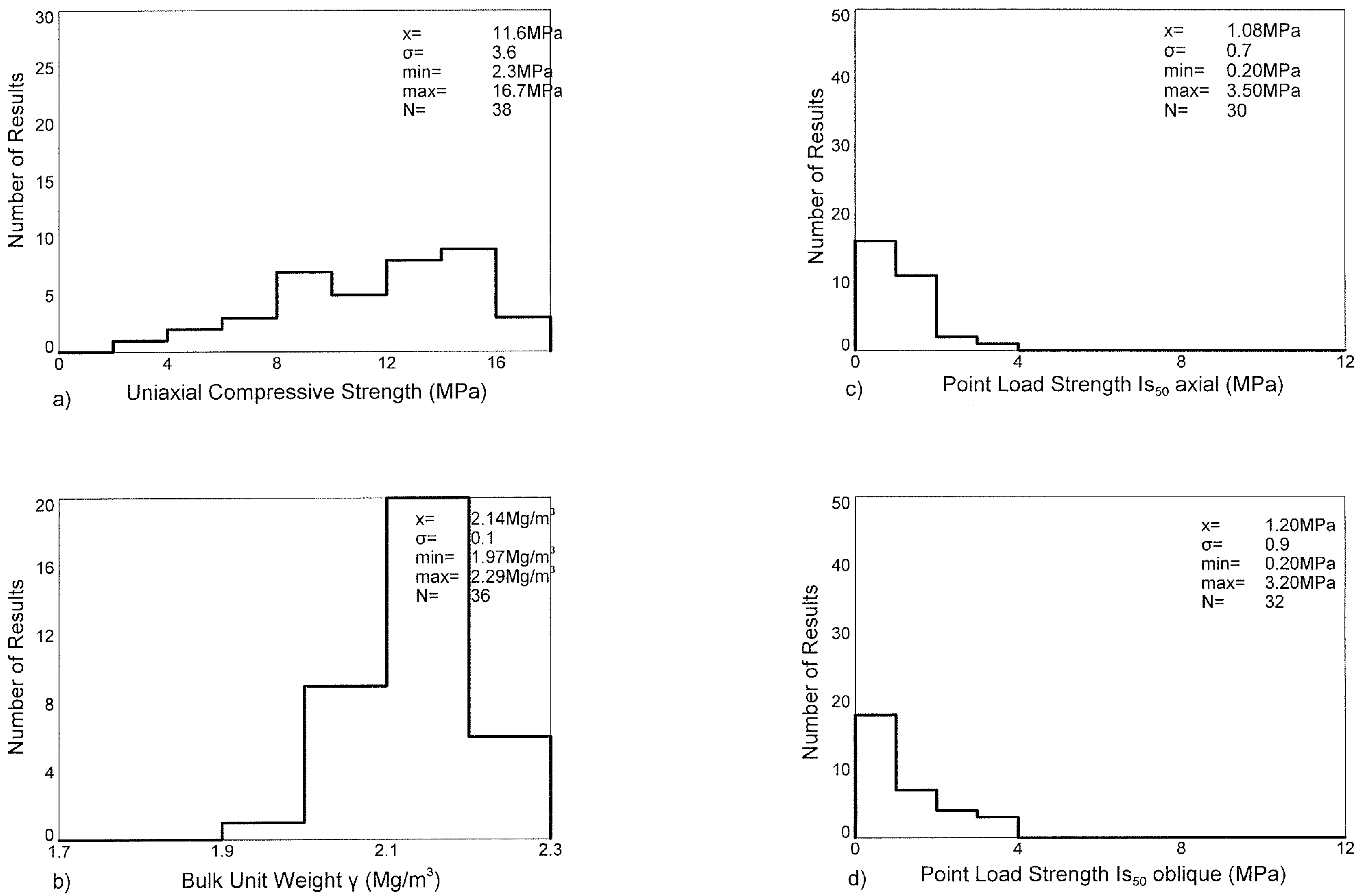


Layer III: Very low strength clay marl, light brown colour.

LAYER III
YOUNG'S MODULUS Em
STATISTICAL PRESENTATION
FIG 8.2

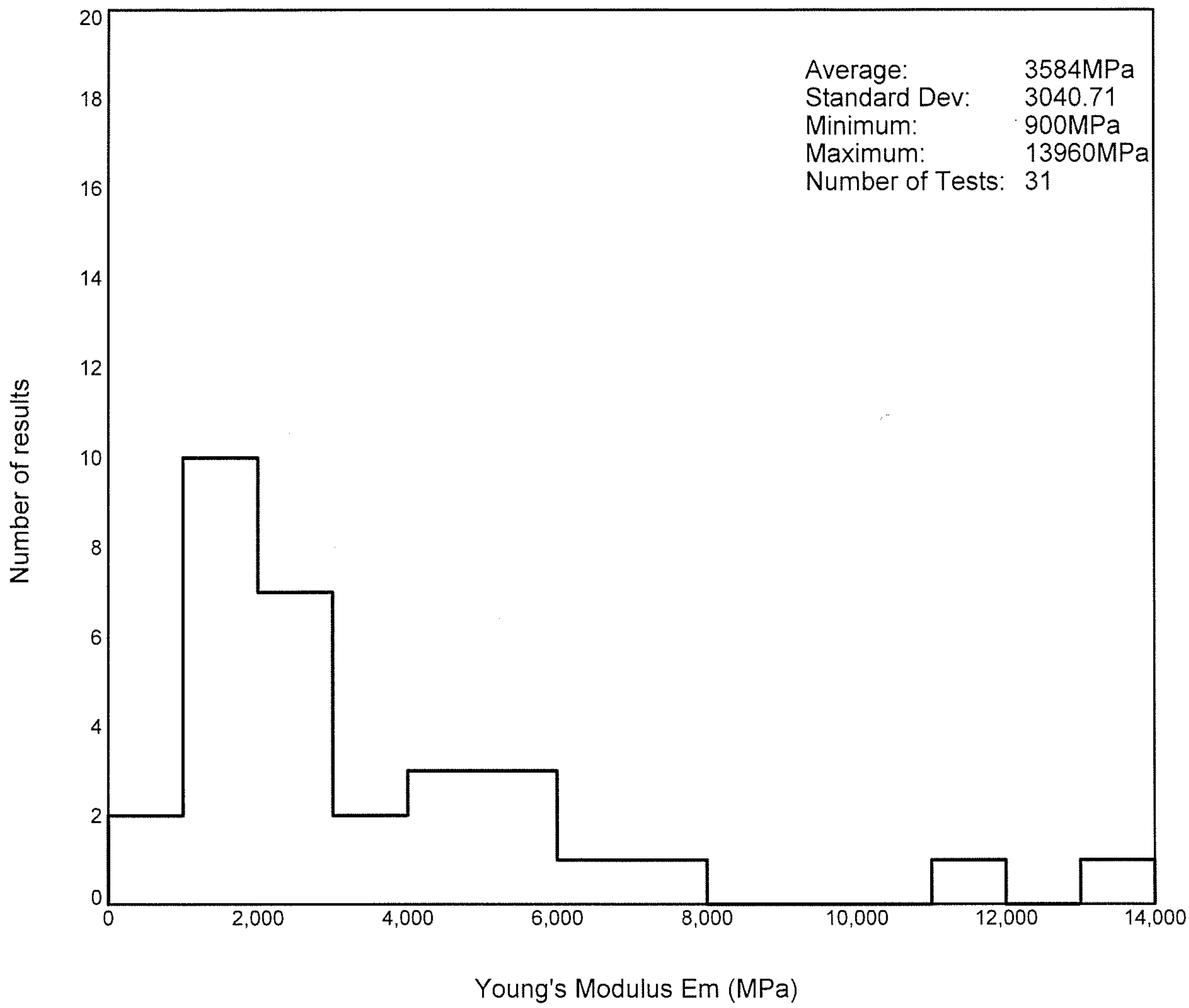
LAYER IV

Low strength marly limestone of grey colour



STRENGTH AND BULK UNIT WEIGHT
FIG 9.1

CASTOR LTD



Layer IV: Low strength marly limestone of grey colour.

LAYER IV

YOUNG'S MODULUS Em
STATISTICAL PRESENTATION
FIG 9.2

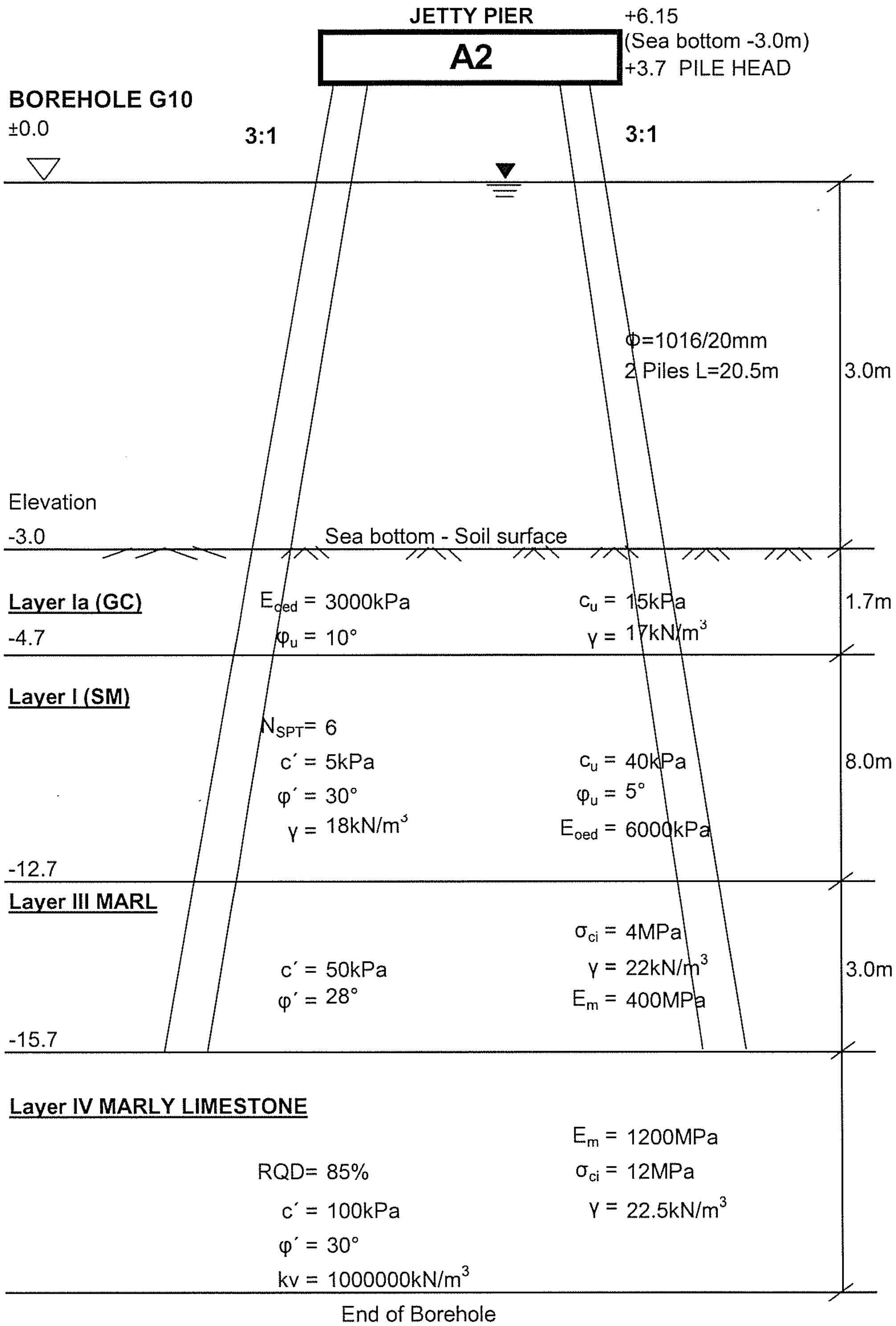


Fig. B4 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c' = Effective cohesion

φ' = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm (for soil)

JETTY PIER A2
DESIGN PARAMETERS
FIG 10

CASTOR LTD

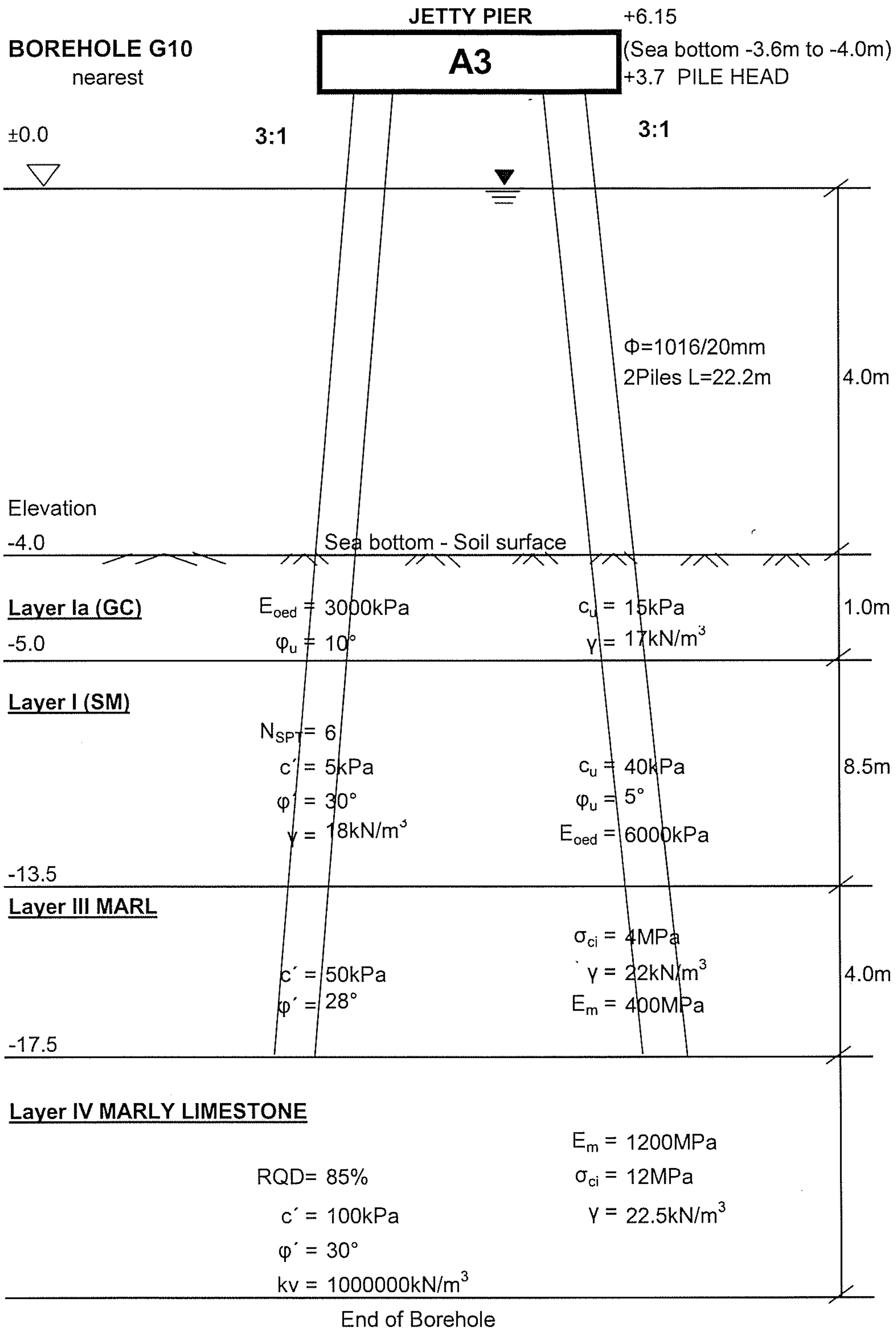


Fig. B4 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c' = Effective cohesion

φ' = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD = Rock quality index

E_m = Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A3
DESIGN PARAMETERS
FIG 11

CASTOR LTD

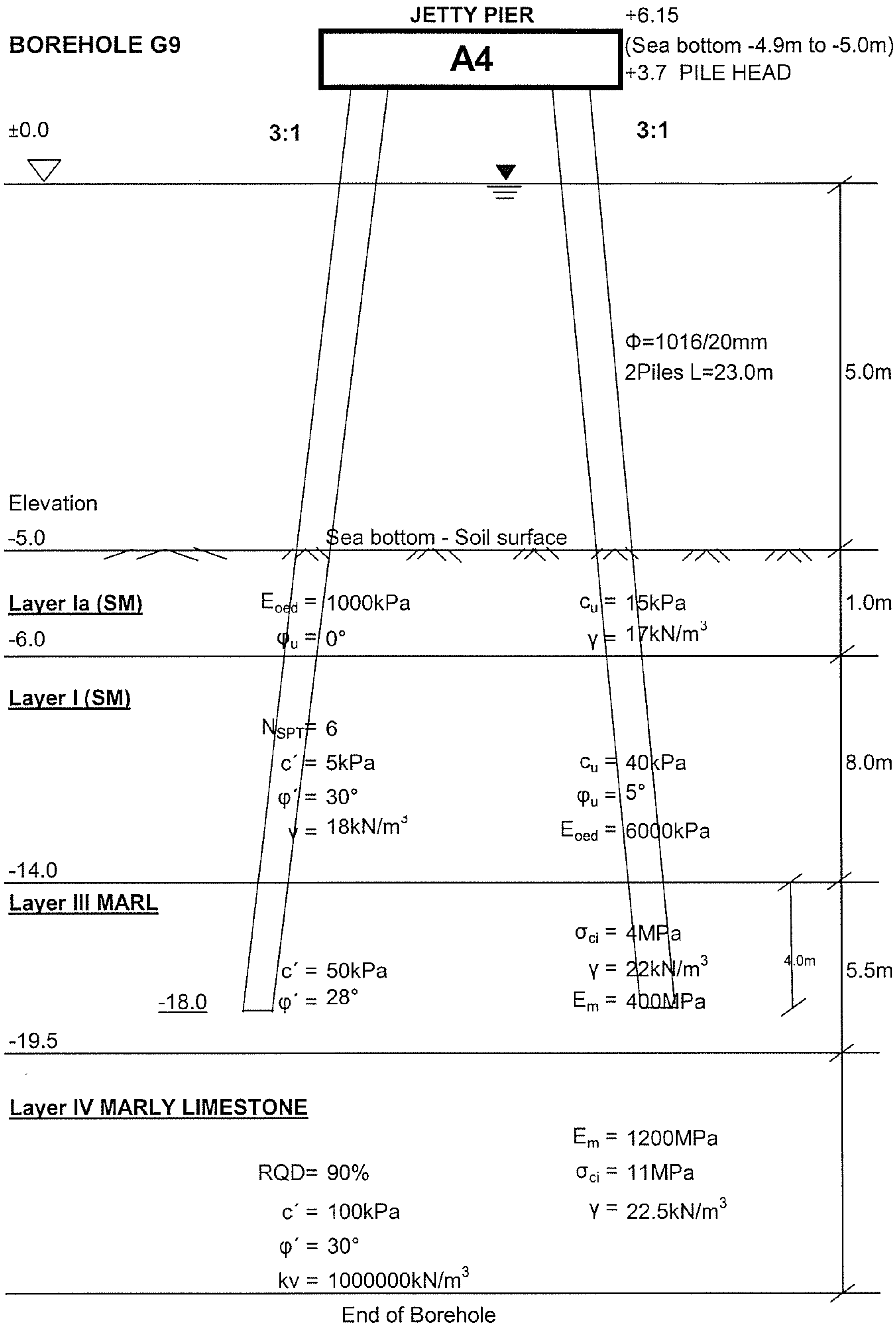


Fig. B3 (no scale)

Legend

c_u= Undrained shear strength
$φ_u$= Undrained friction angle
c´ = Effective cohesion
φ´ = Effective internal friction angle
$σ_{ci}$ = Uniaxial Compressive Strength
γ = Wet unit weight
E_{oed} = Oedometer modulus
RQD= Rock quality index
E_m= Rock mass deformation modulus
N_{SPT} = SPT , blow counts/30cm

JETTY PIER A4
DESIGN PARAMETERS
FIG 12

CASTOR LTD

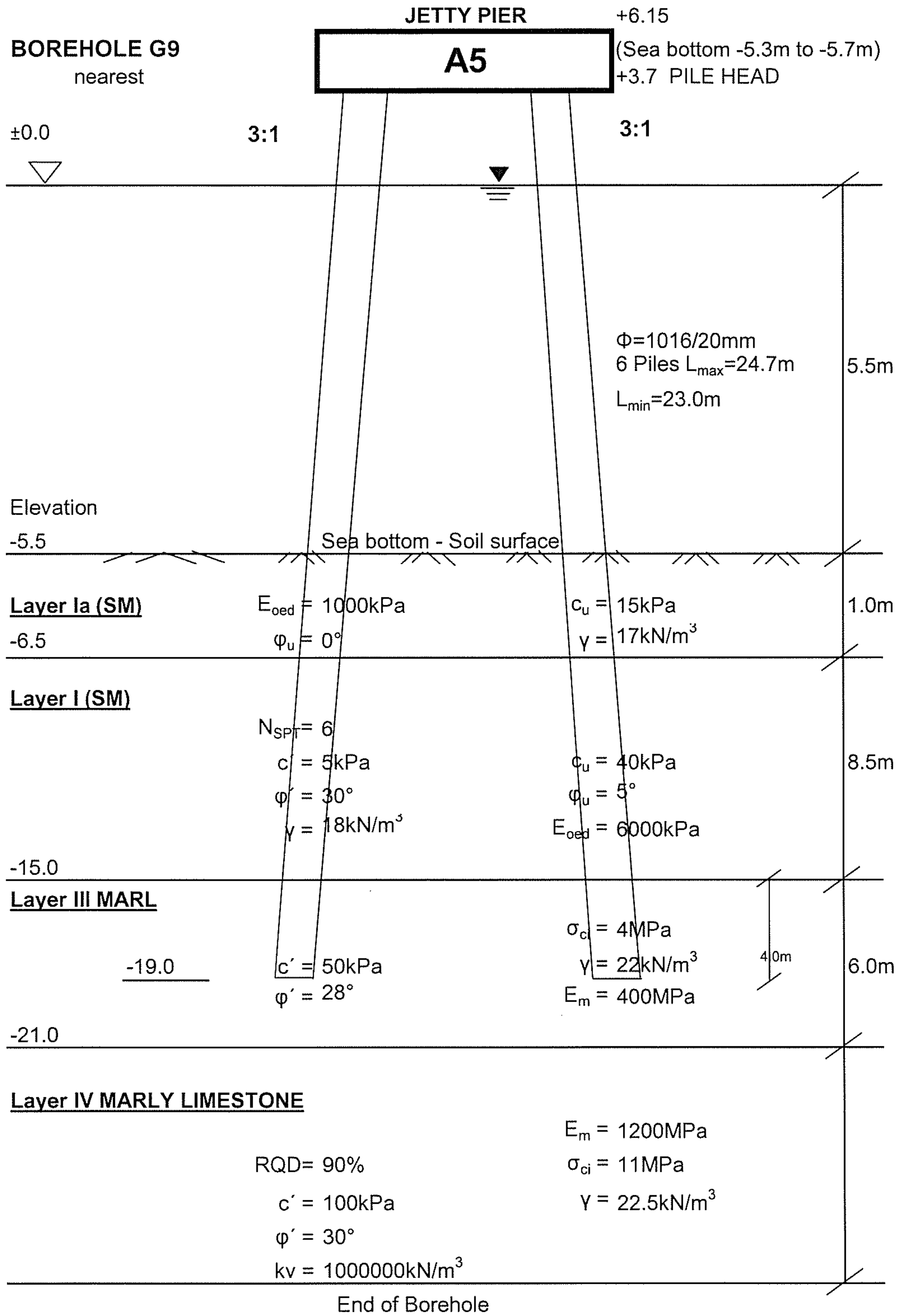


Fig. B3 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ' = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A5
DESIGN PARAMETERS
FIG 13

CASTOR LTD

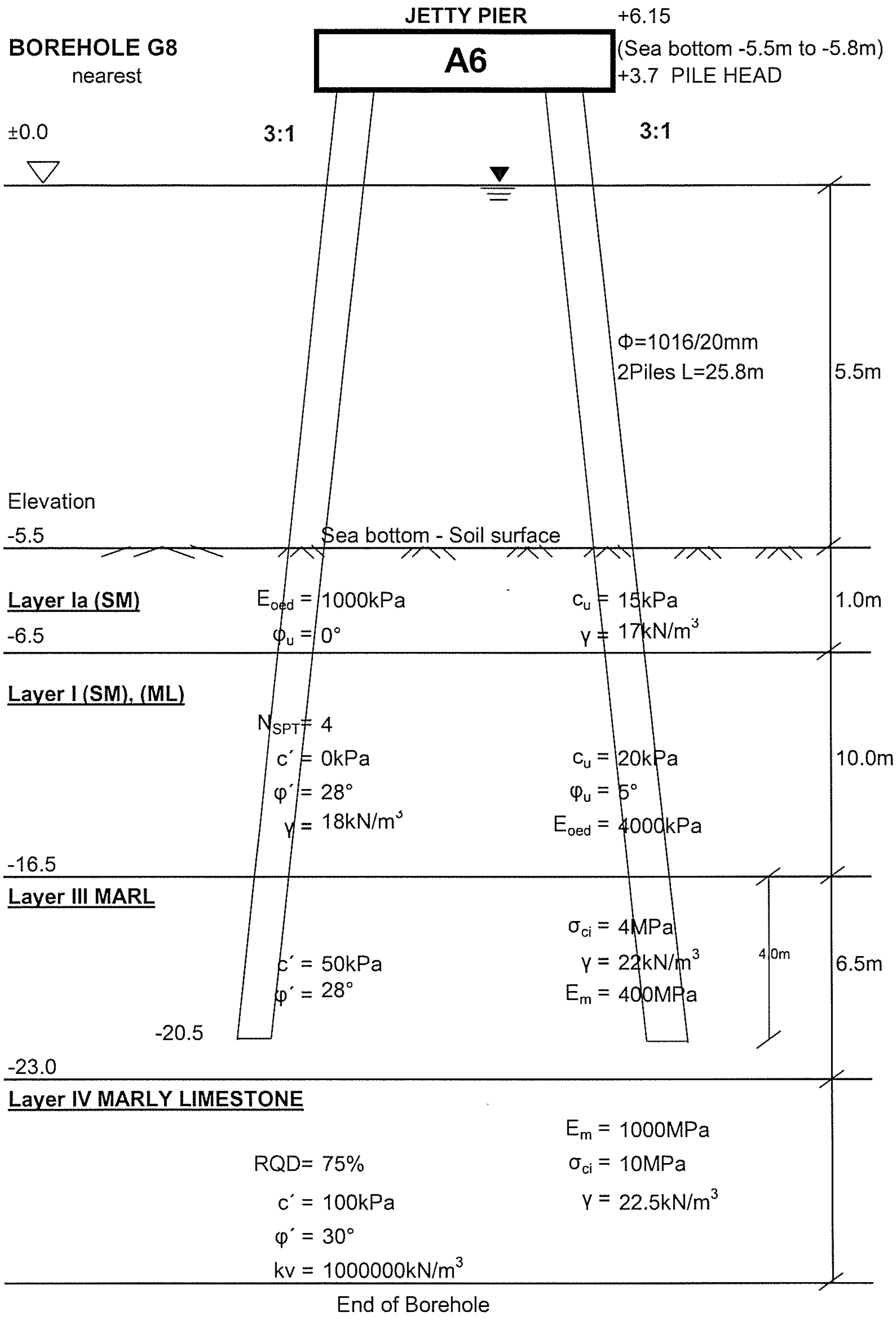


Fig. B2 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c' = Effective cohesion

φ' = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A6
DESIGN PARAMETERS
FIG 14

CASTOR LTD

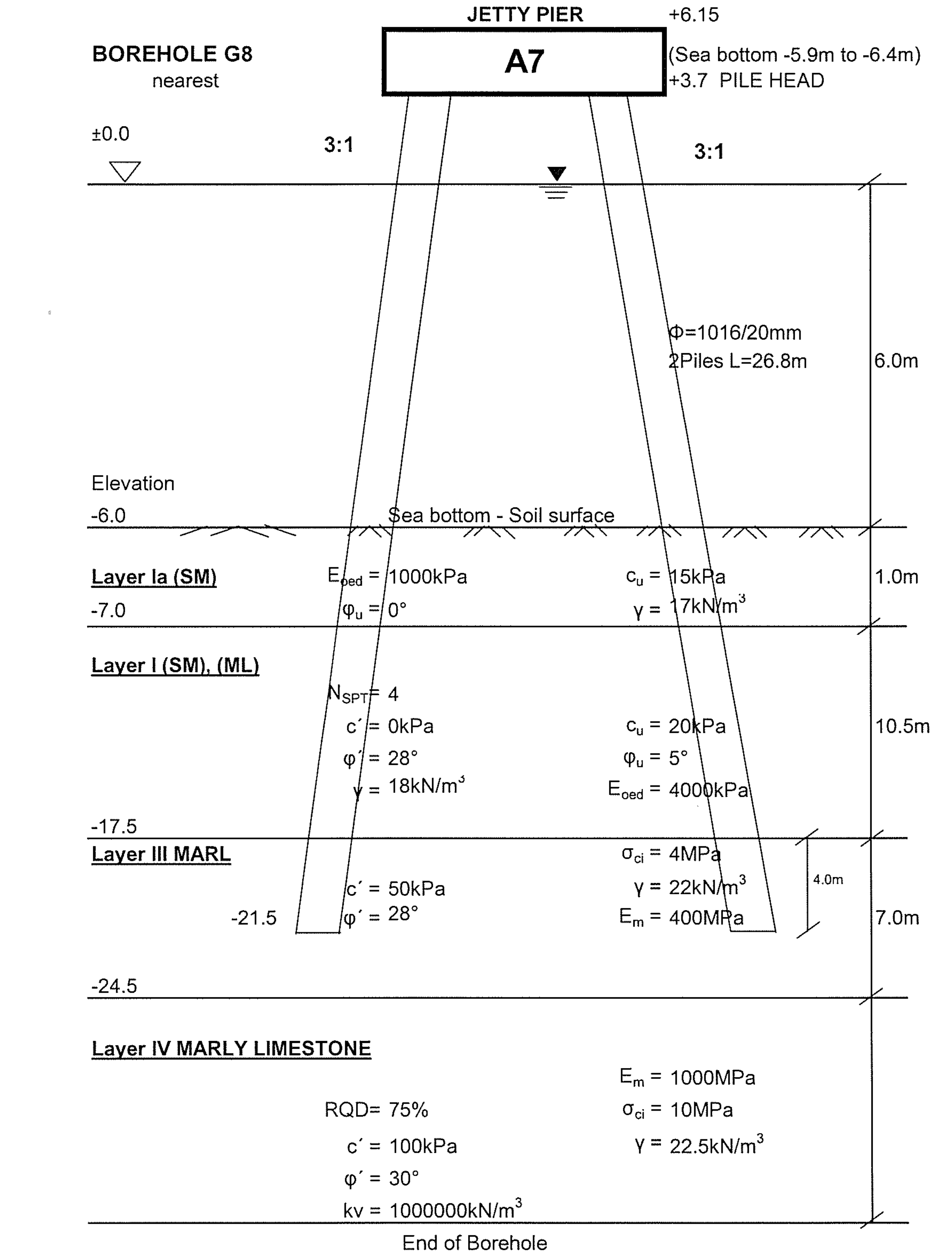


Fig. B2 (no scale)

Legend

c_u = Undrained shear strength	σ_{ci} = Uniaxial Compressive Strength
φ_u = Undrained friction angle	γ = Wet unit weight
c' = Effective cohesion	E_{oed} = Oedometer modulus
φ' = Effective internal friction angle	RQD= Rock quality index
	E_m = Rock mass deformation modulus
	N_{SPT} = SPT , blow counts/30cm

JETTY PIER A7
DESIGN PARAMETERS
FIG 15

CASTOR LTD

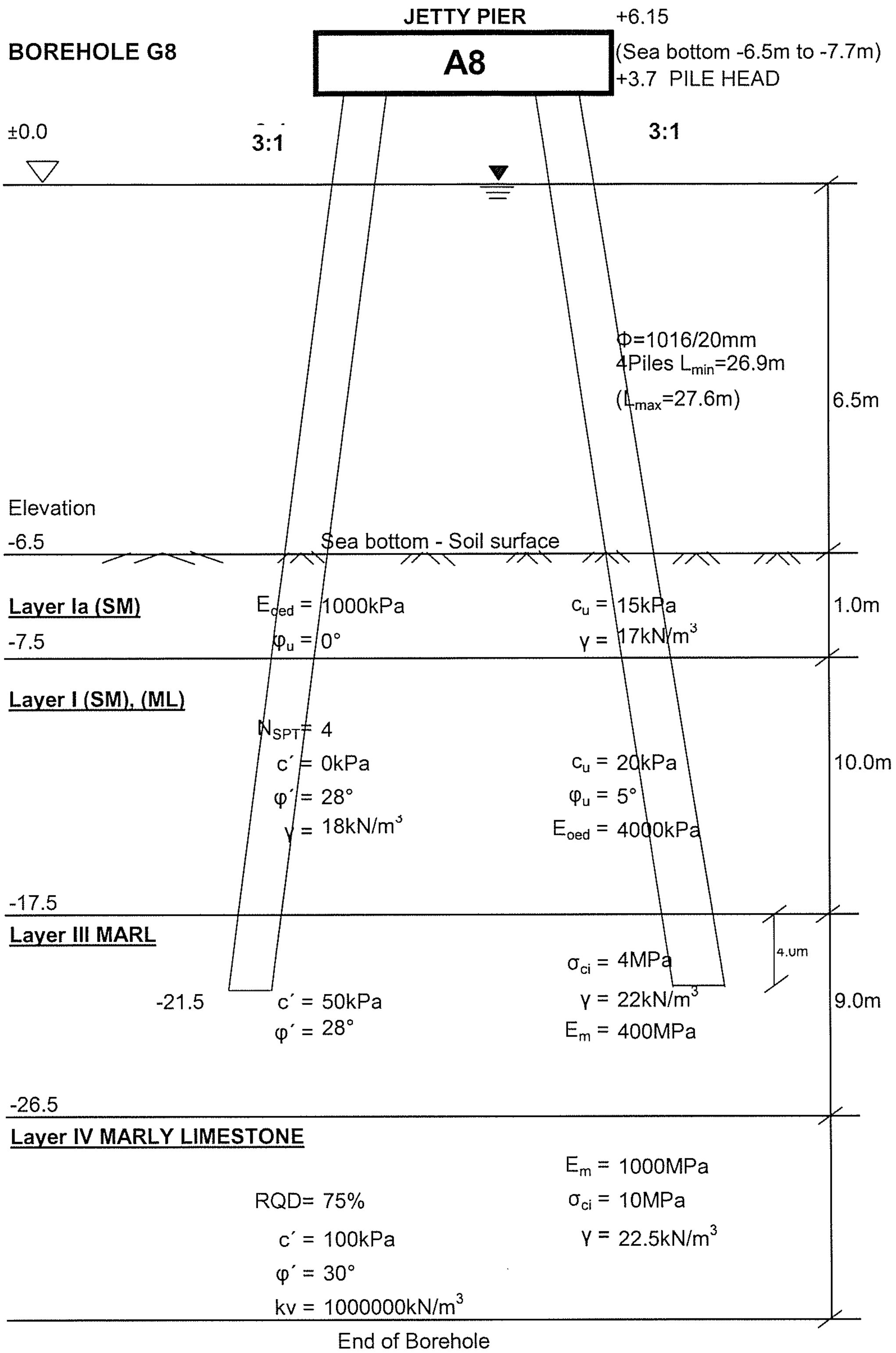


Fig. B2 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c' = Effective cohesion

φ' = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m = Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A8
DESIGN PARAMETERS
FIG 16

CASTOR LTD

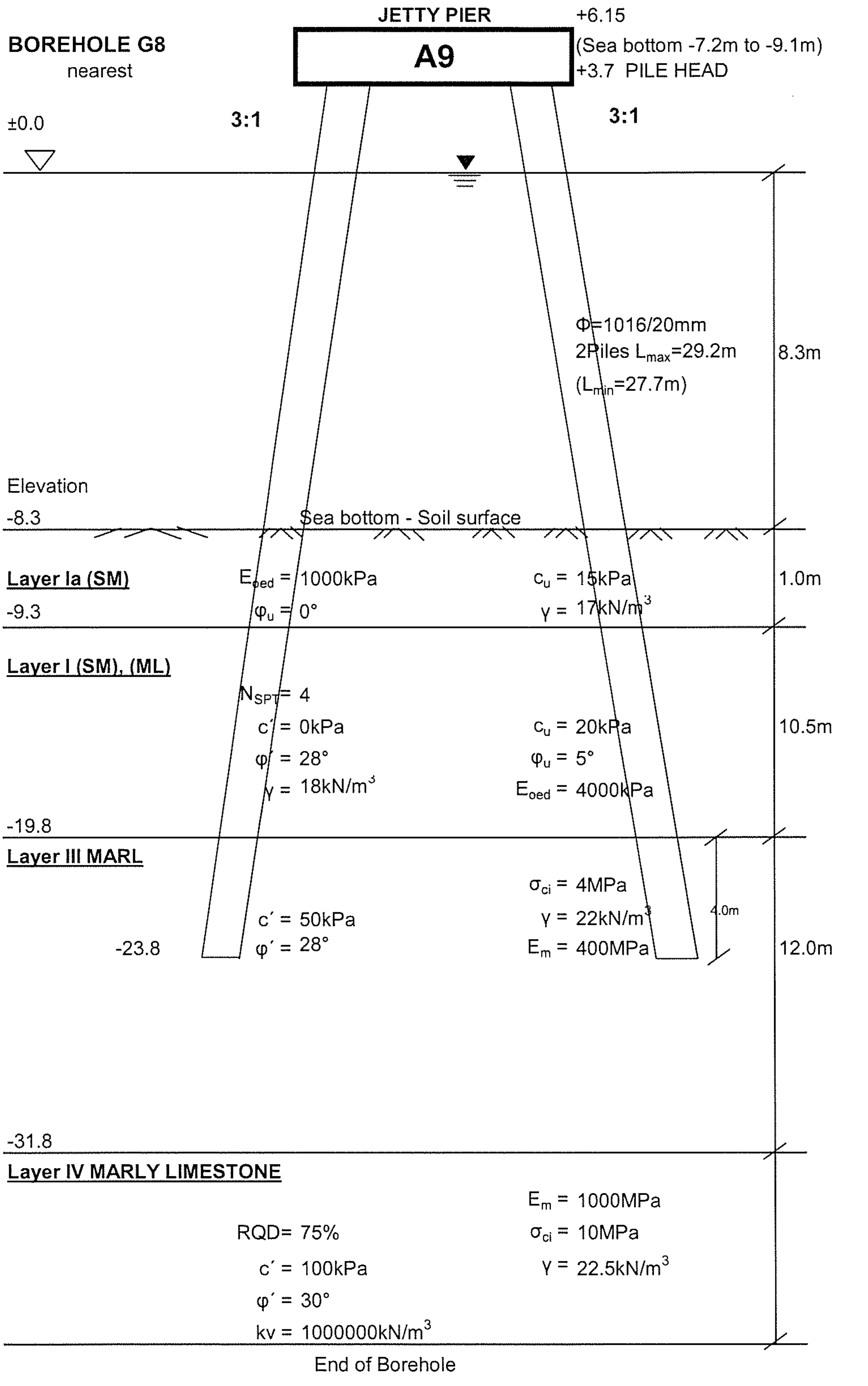


Fig. B2 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c′ = Effective cohesion

φ′ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A9
DESIGN PARAMETERS
FIG 17

CASTOR LTD

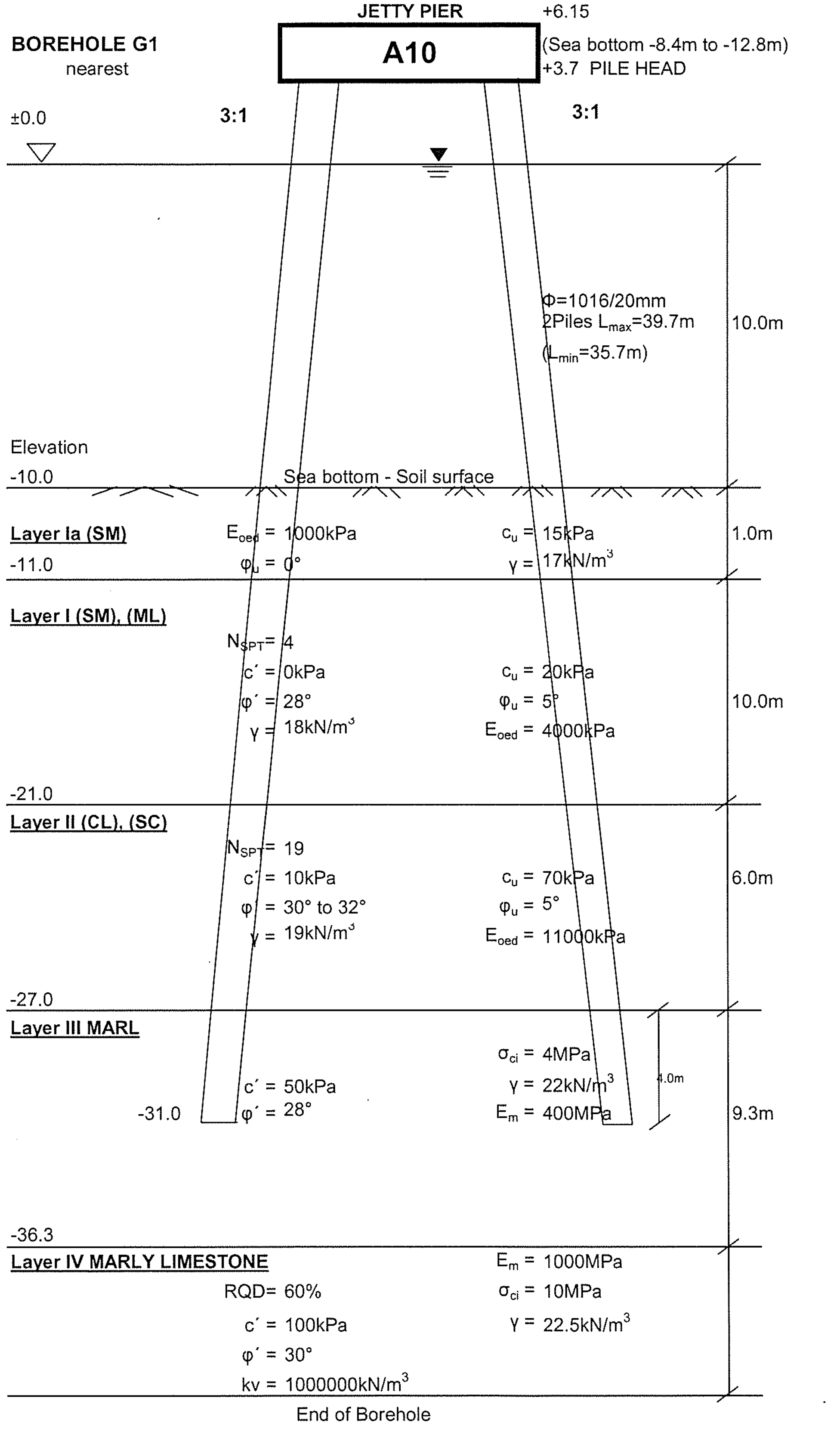


Fig. B2 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c' = Effective cohesion

φ' = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A10 DESIGN PARAMETERS FIG 18

CASTOR LTD

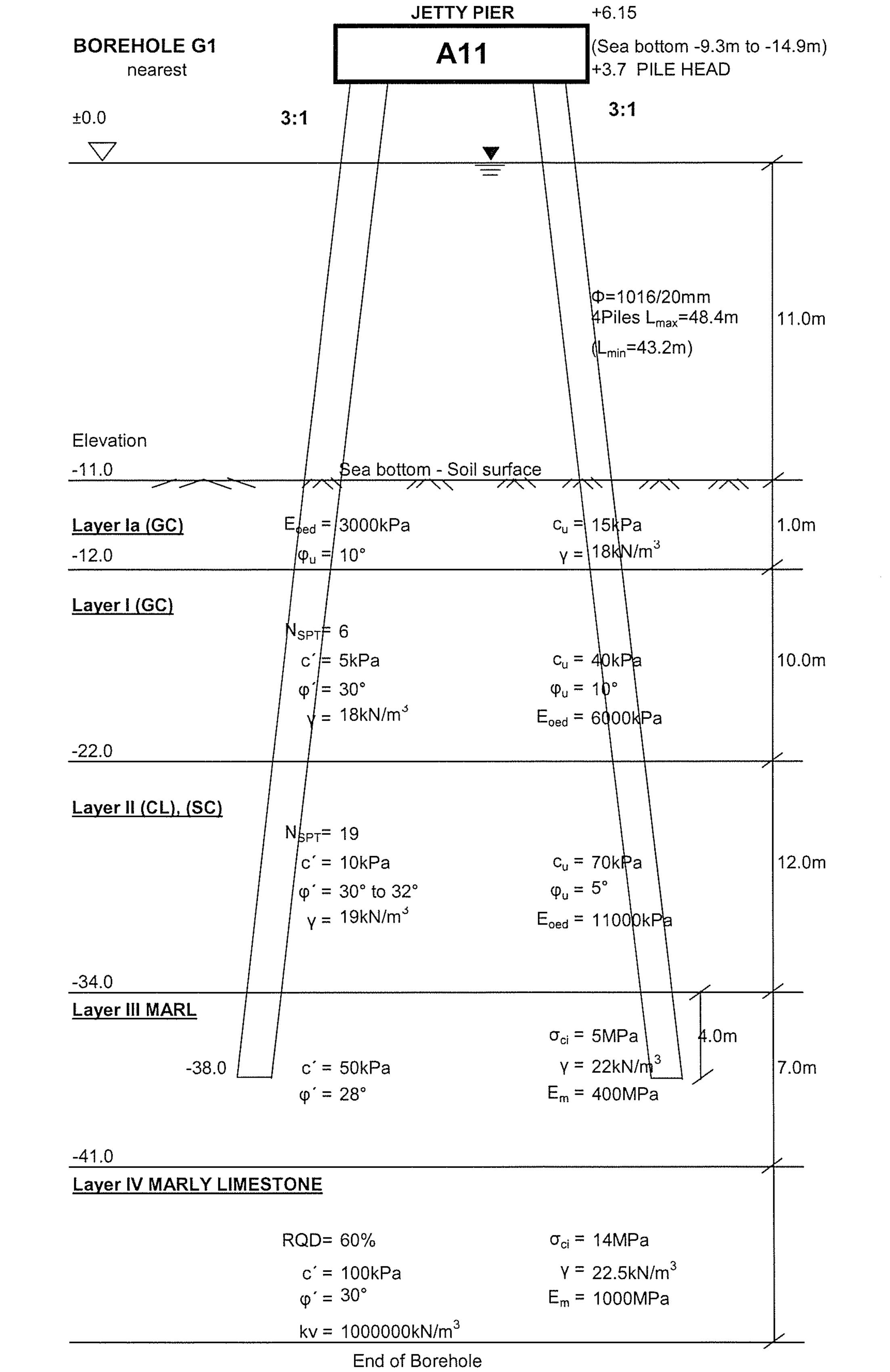


Fig. B1 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m = Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

JETTY PIER A11
DESIGN PARAMETERS
FIG 19

CASTOR LTD

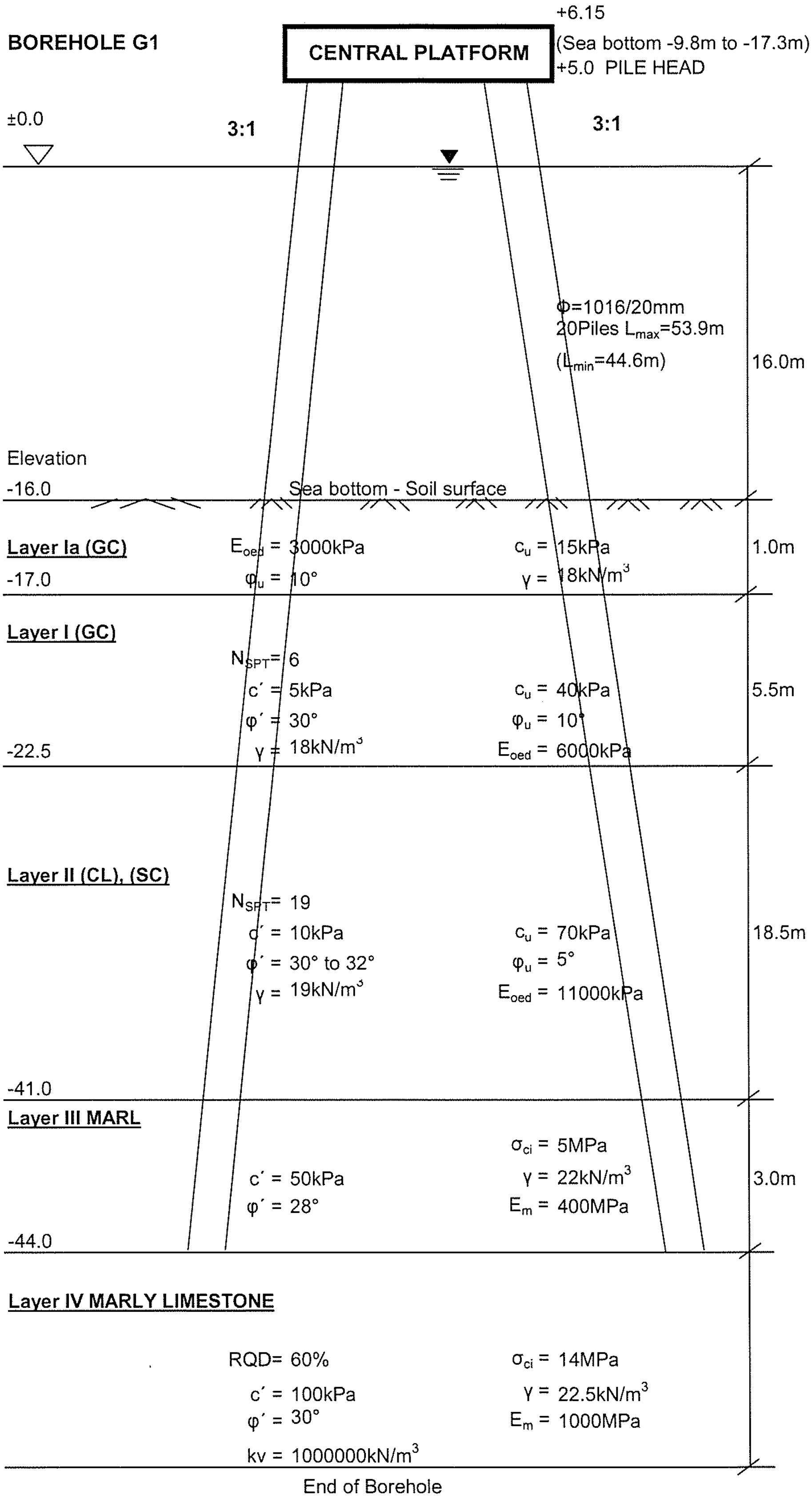


Fig. B1 (no scale)

Legend

c_u= Undrained shear strength
$φ_u$= Undrained friction angle
c´ = Effective cohesion
φ´ = Effective internal friction angle
$σ_{ci}$ = Uniaxial Compressive Strength
γ = Wet unit weight
E_{oed} = Oedometer modulus
RQD= Rock quality index
E_m= Rock mass deformation modulus
N_{SPT} = SPT , blow counts/30cm

CENTRAL PLATFORM DESIGN PARAMETERS
FIG 20

CASTOR LTD

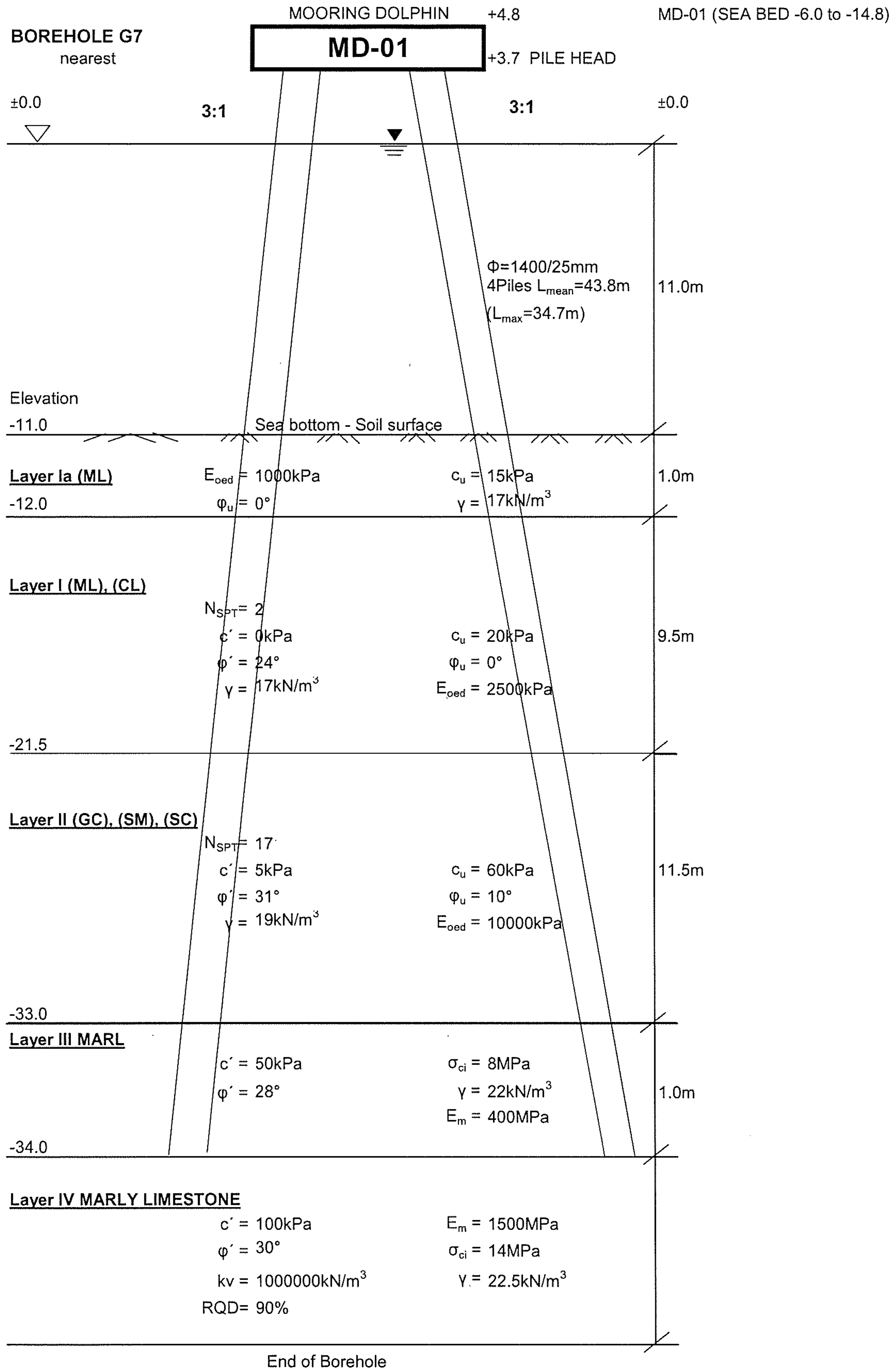


Fig. A1 (no scale)

Legend

c_u= Undrained shear strength

$φ_u$= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

$σ_{ci}$ = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

MOORING DOLPHIN MD-01
DESIGN PARAMETERS
FIG 21

CASTOR LTD

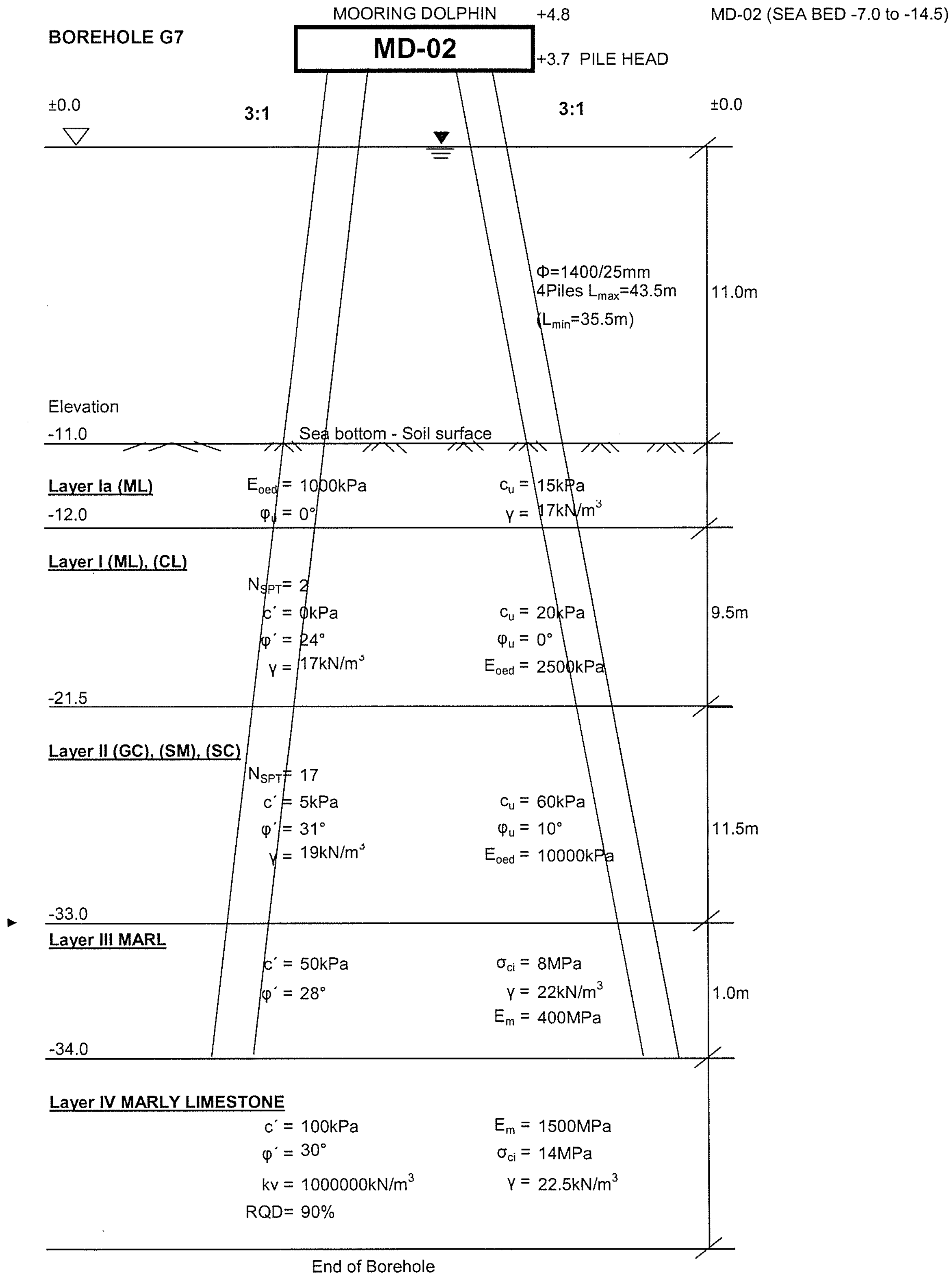


Fig. A1 (no scale)

Legend

c_u = Undrained shear strength

$φ_u$ = Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

$σ_{ci}$ = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m = Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

MOORING DOLPHIN MD-02
DESIGN PARAMETERS
FIG 22

CASTOR LTD

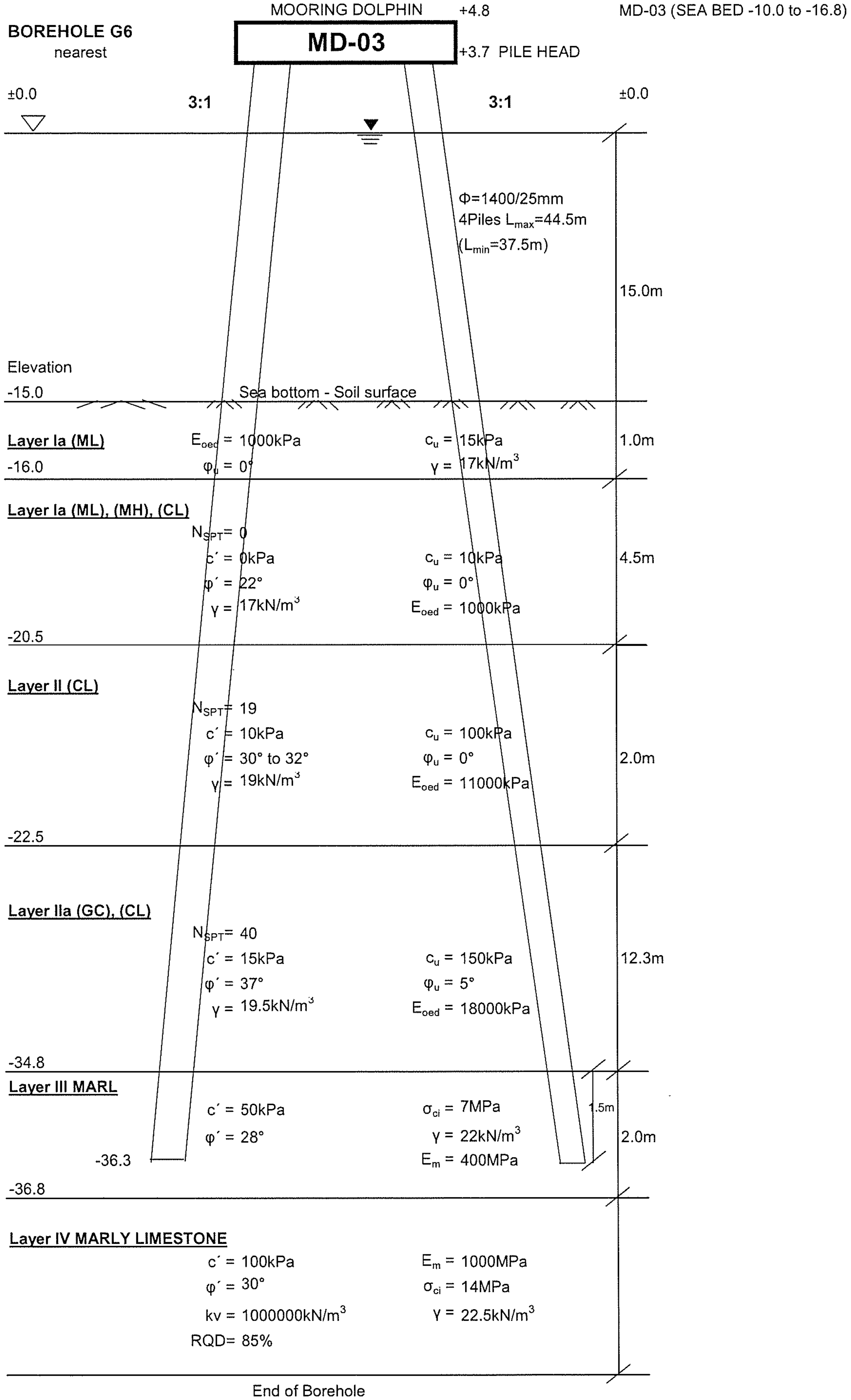


Fig. A2 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

FIG 23

CASTOR LTD

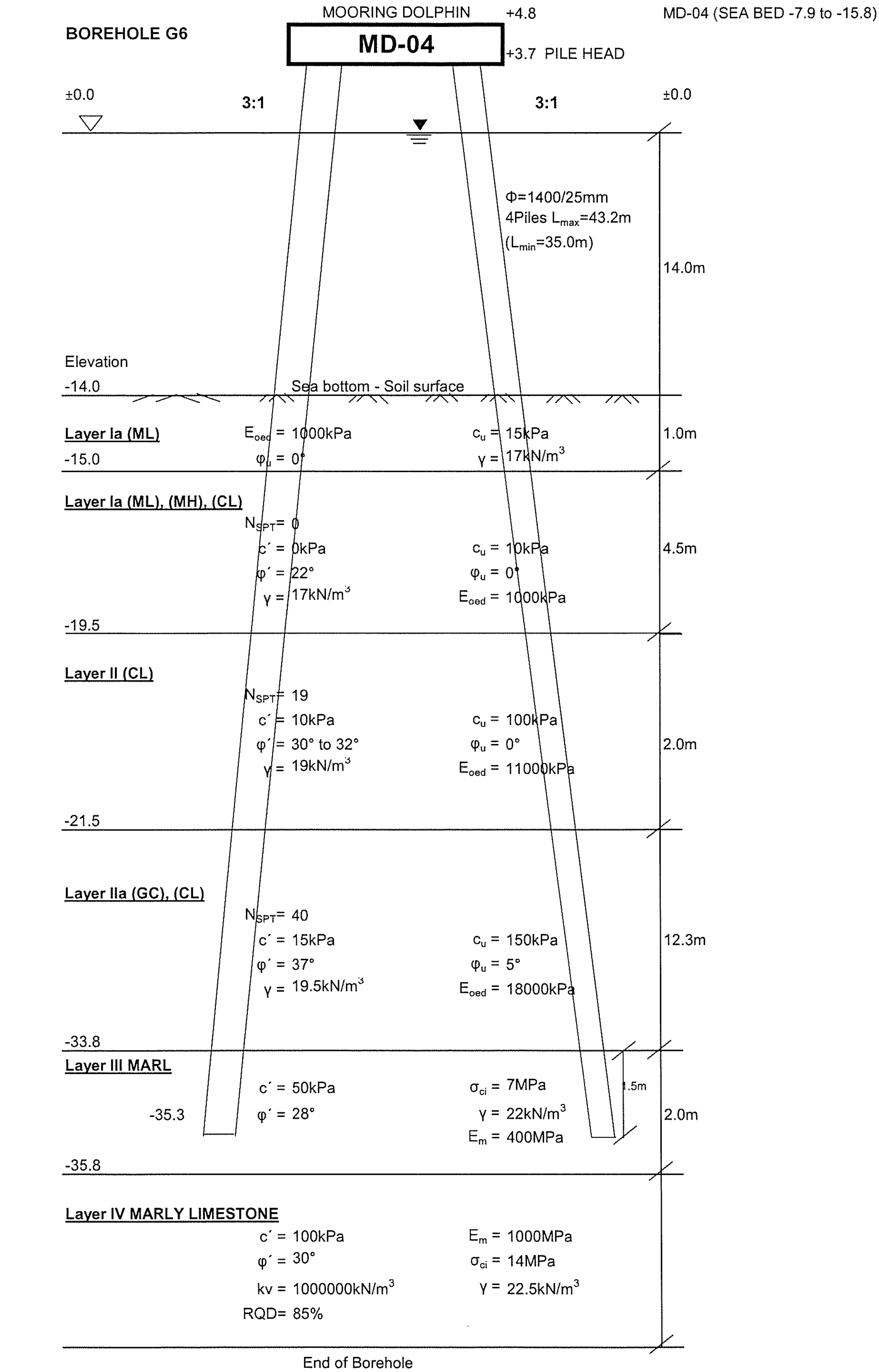


Fig. A2 (no scale)

Legend

c_u= Undrained shear strength
φ_u= Undrained friction angle
c´ = Effective cohesion
φ´ = Effective internal friction angle
σ_{ci} = Uniaxial Compressive Strength
γ = Wet unit weight
E_{oed} = Oedometer modulus
RQD= Rock quality index
E_m= Rock mass deformation modulus
N_{SPT} = SPT , blow counts/30cm

FIG 24

CASTOR LTD

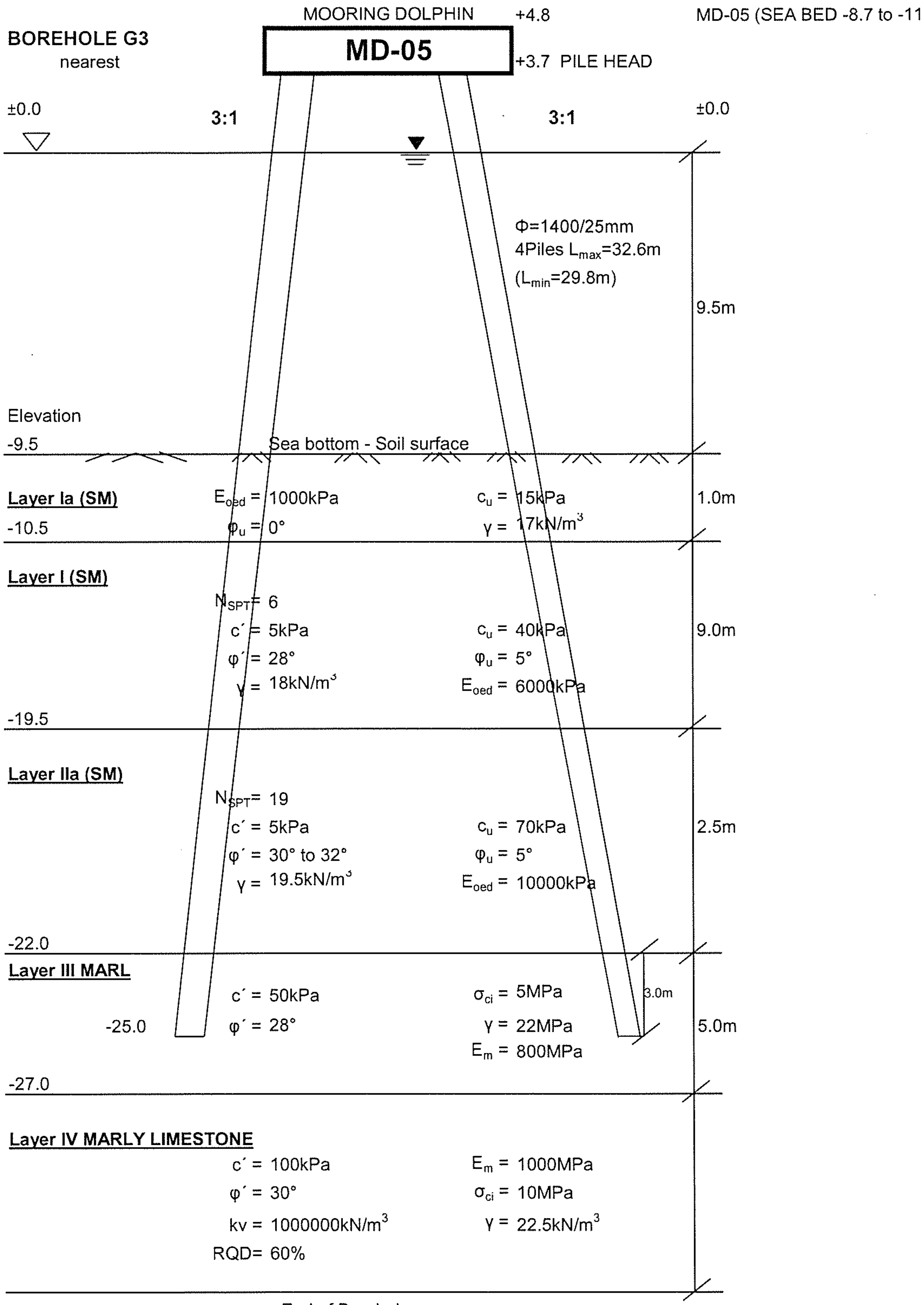


Fig. A5 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

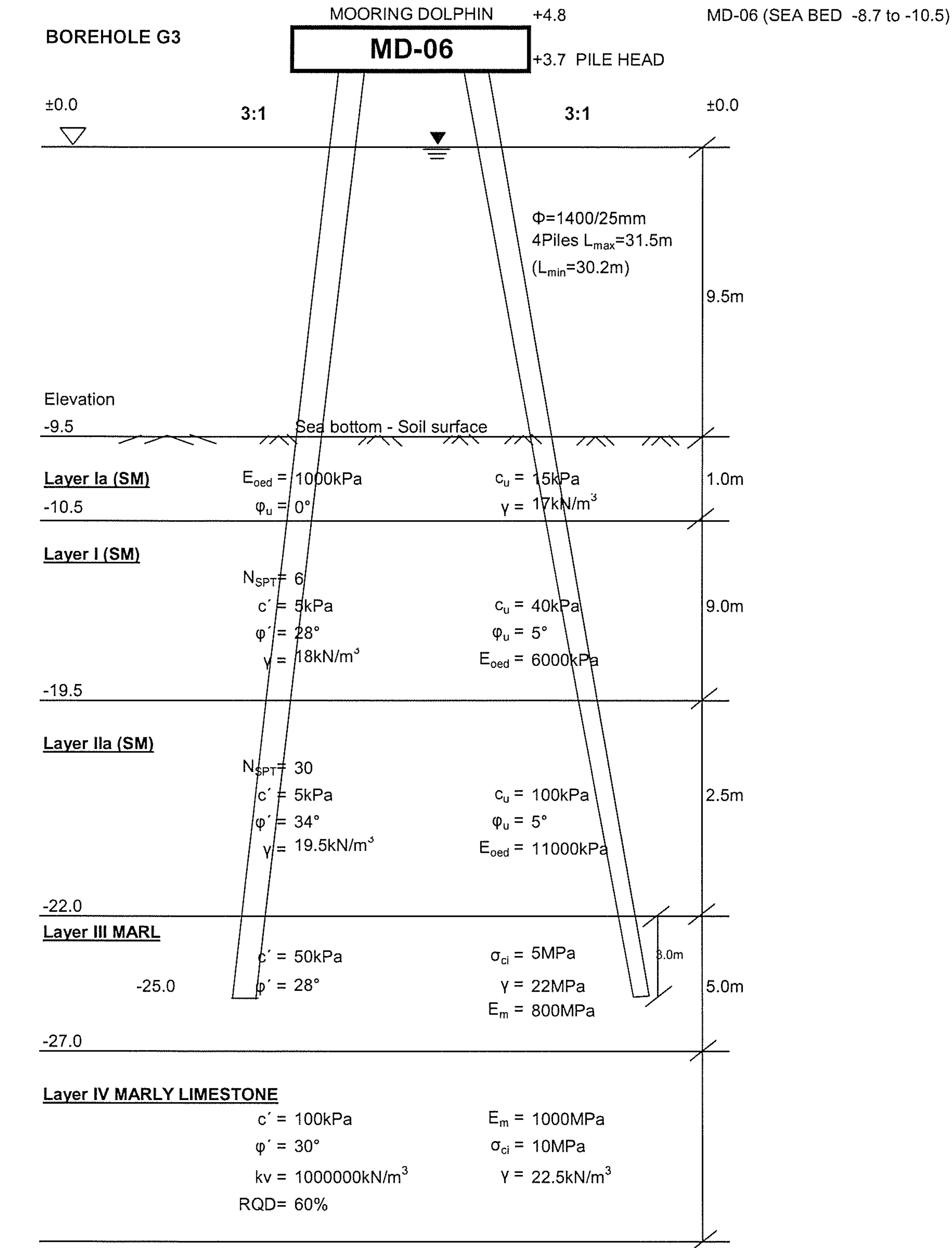
E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m = Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

MOORING DOLPHIN MD-05
DESIGN PARAMETERS
FIG 25



End of Borehole

Fig. A5 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

MOORING DOLPHIN MD-06
DESIGN PARAMETERS
FIG 26

CASTOR LTD

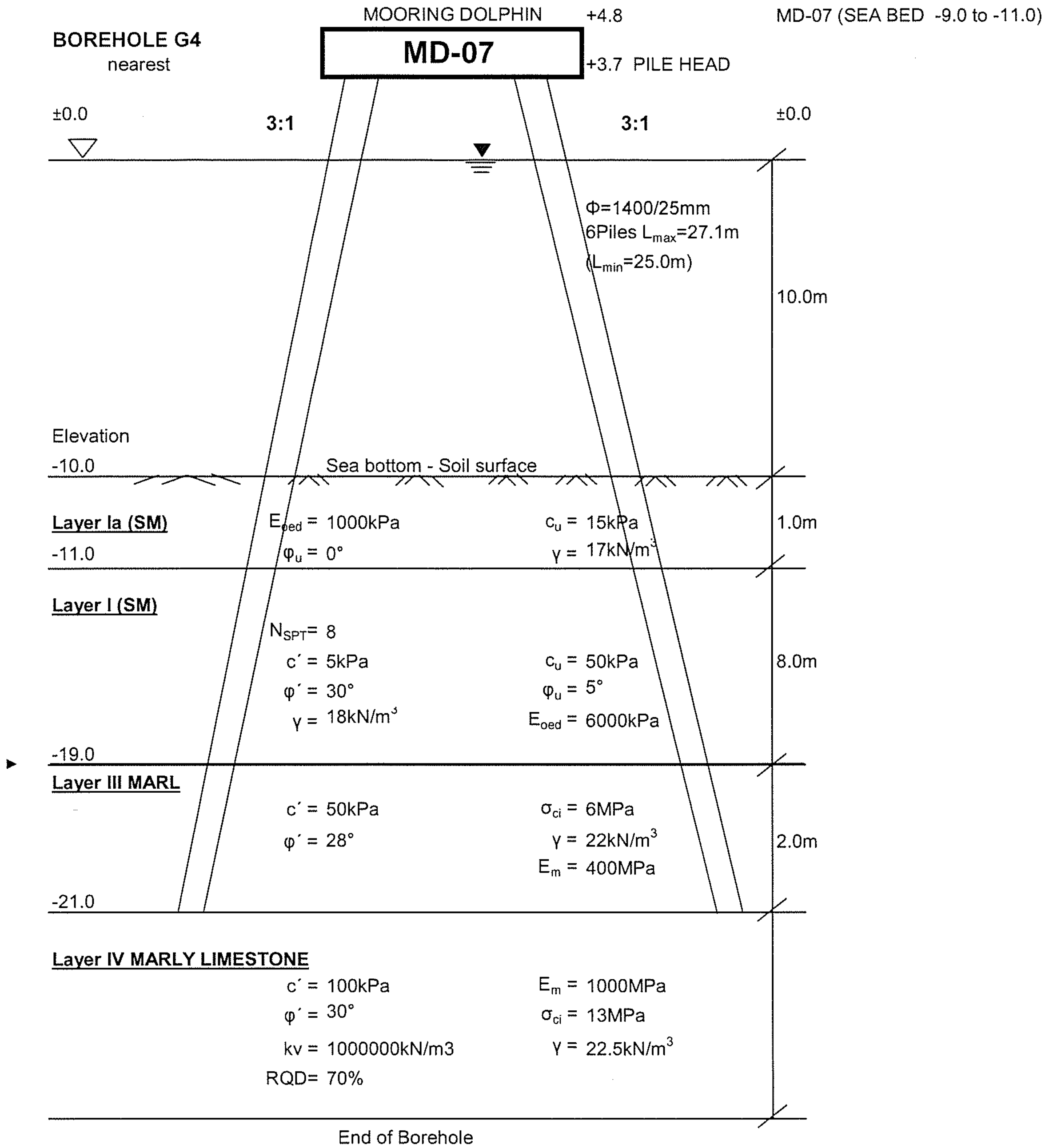


Fig. A6 (no scale)

Legend

c_u= Undrained shear strength

$φ_u$= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

$σ_{ci}$ = Uniaxial Compressive Strength

γ = Wet unit weight

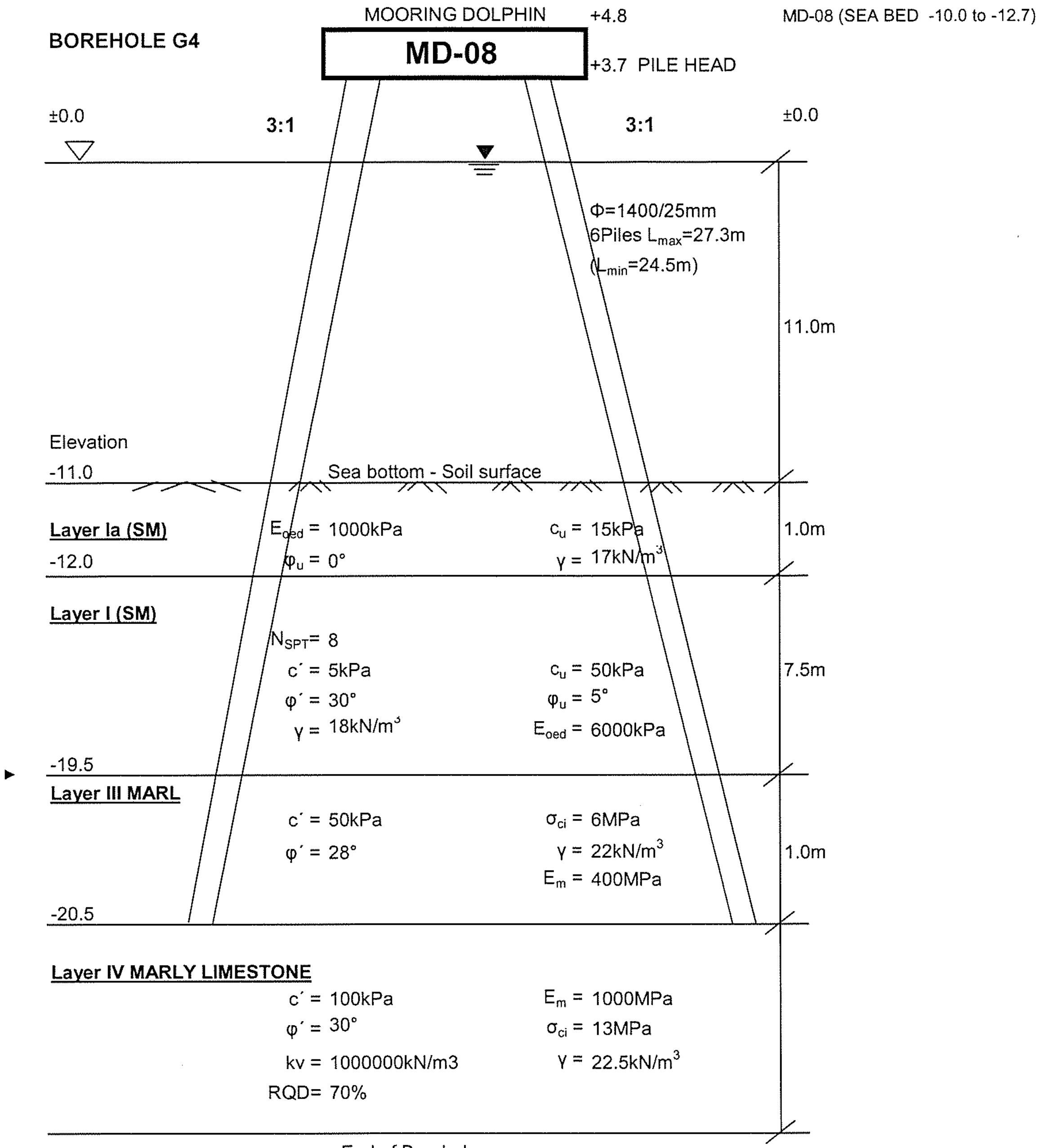
E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

MOORING DOLPHIN MD-07
DESIGN PARAMETERS
FIG 27



End of Borehole

Fig. A6 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

MOORING DOLPHIN MD-08
DESIGN PARAMETERS
FIG 28

CASTOR LTD

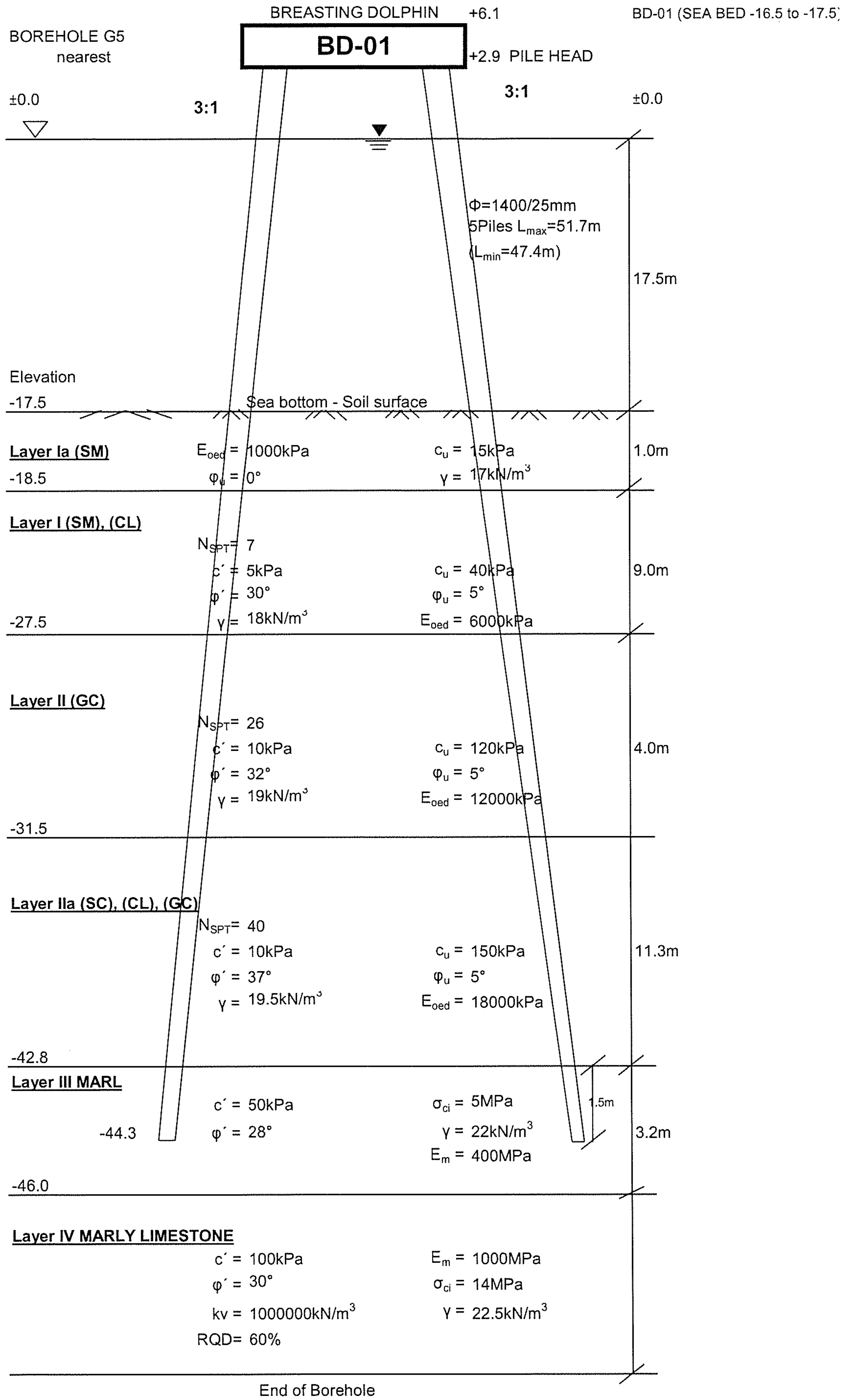


Fig. A3 (no scale)

Legend

c_u= Undrained shear strength

$φ_u$= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

$σ_{ci}$ = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

FIG 29

CASTOR LTD

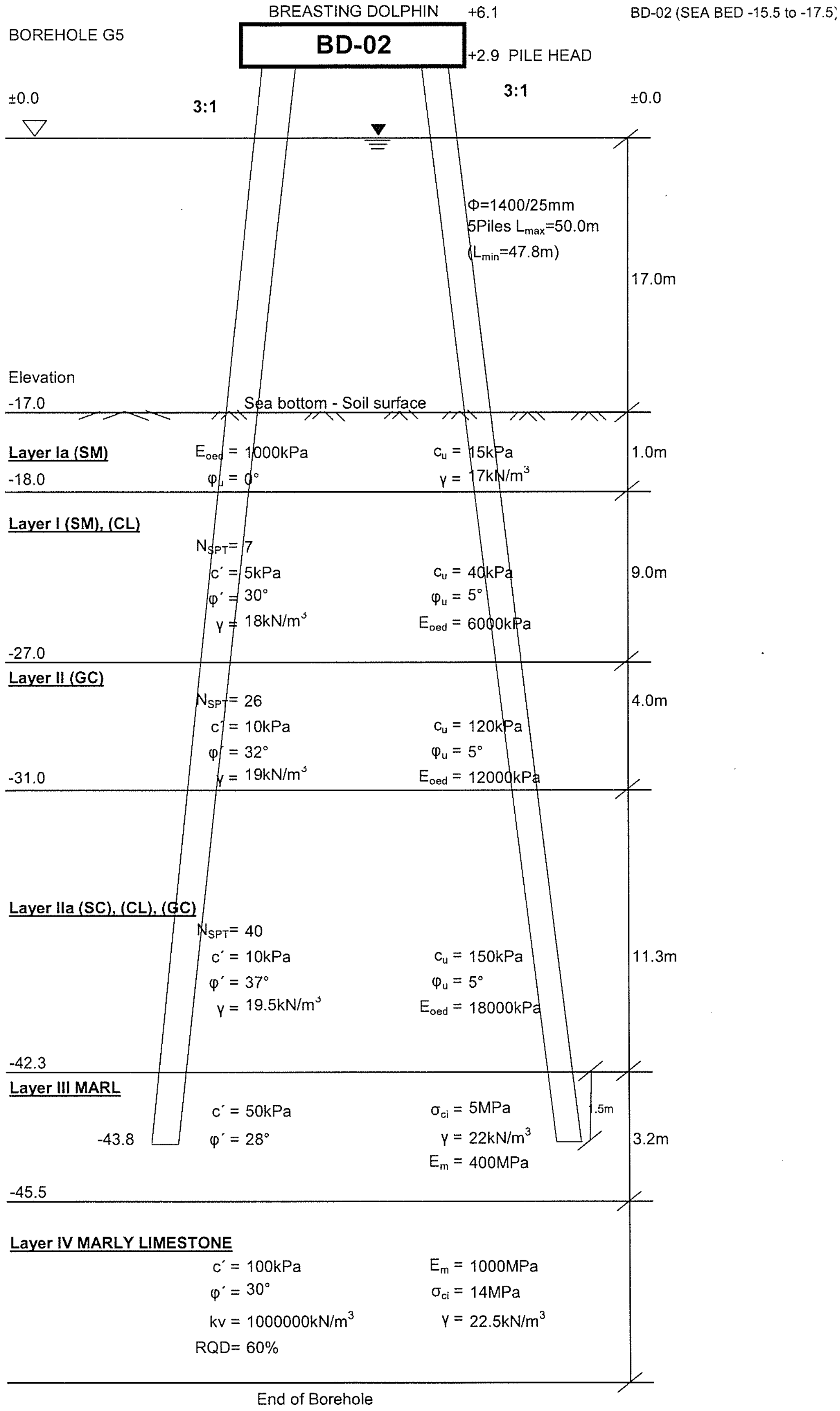


Fig. A3 (no scale)

Legend

- c_u= Undrained shear strength
- $φ_u$= Undrained friction angle
- c´ = Effective cohesion
- φ´ = Effective internal friction angle
- $σ_{ci}$ = Uniaxial Compressive Strength
- γ = Wet unit weight
- E_{oed} = Oedometer modulus
- RQD= Rock quality index
- E_m= Rock mass deformation modulus
- N_{SPT} = SPT , blow counts/30cm

FIG 30

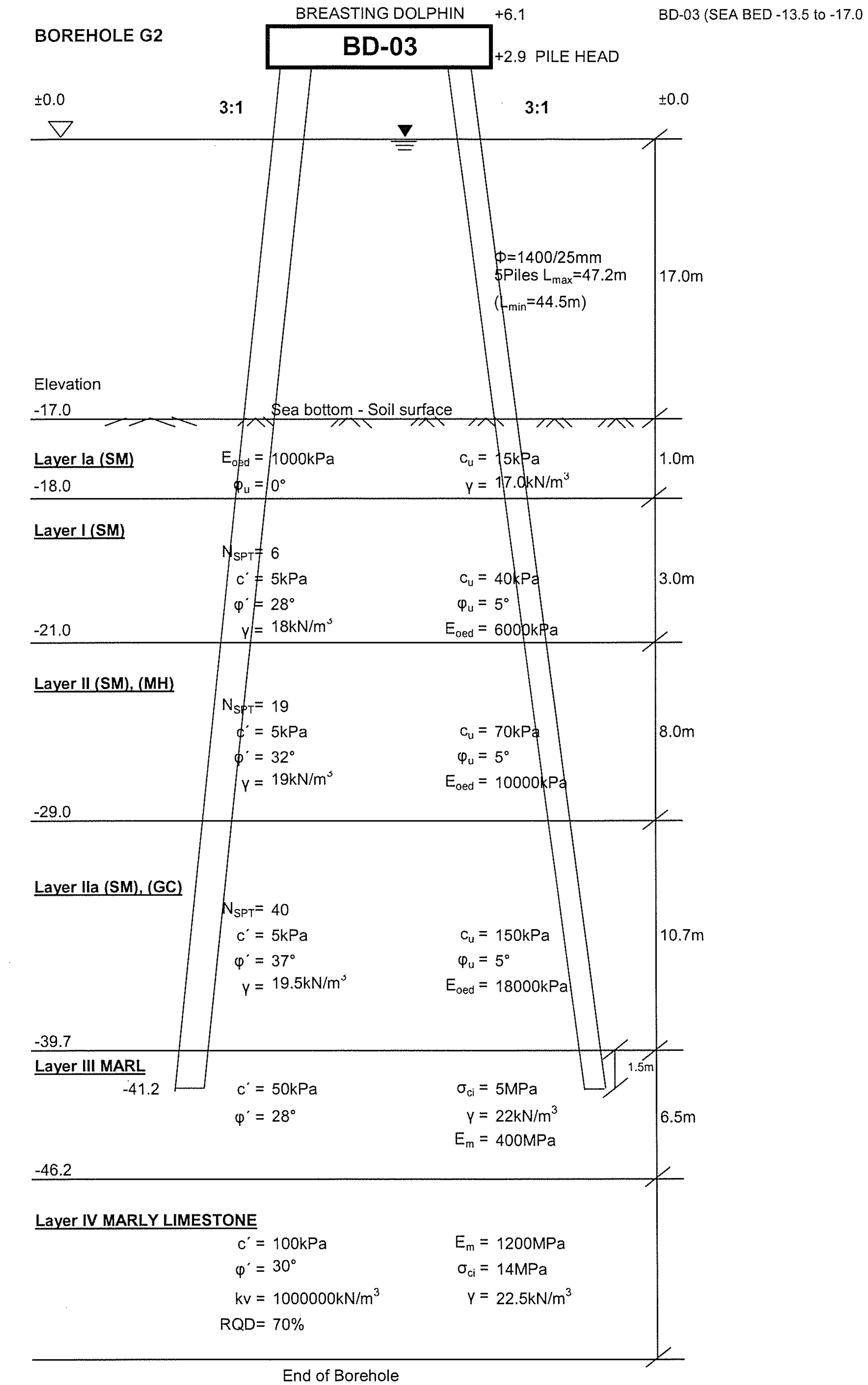


Fig. A4 (no scale)

Legend

c_u = Undrained shear strength

φ_u = Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m = Rock mass deformation modulus

N_{SPT} = SPT , blow counts/30cm

FIG 31

APPENDIX A

EVALUATION AND SELECTION OF GEOTECHNICAL DESIGN PARAMETERS

A1. DESIGN PARAMETERS FOR SOIL FORMATIONS

A1.1 Effective Strength Parameters c' & φ'

a) General Relationships

Table 22. Correlations of internal friction angle and SPT N-values (data from Hatanaka and Uchida (1996) and Broms and Flodin (1988))

Soil Type	φ (degrees)	Reference
Angular and well-grained soil particles	$\phi = (12N)^{0.5} + 25$ (See Note)	Dunham (1954) (#1)
Round and well-grained or angular and uniform-grained soil particles	$\phi = (12N)^{0.5} + 20$ (See Note)	Dunham (1954) (#2)
Round and uniform-grained soil particles	$\phi = (12N)^{0.5} + 15$ (See Note)	Dunham (1954) (#3)
Sandy	$\phi = (20N)^{0.5} + 15$ (See Note)	Ohsaki et al. (1959)
Granular	$\phi = 20 + 3.5(N)^{0.5}$ (See Note)	Muromachi et al. (1974)
Sandy	$\phi = (15N)^{0.5} + 15 \leq 45$ (N > 5) (See Note)	Japan Road Association (1990)
Sandy	$\phi = (20N_1)^{0.5} + 20$ N_1 = N-value normalized to 1 tsf of overburden pressure using the Liao and Whitman (1986) equation. It is the recommendation of this report to use $N_{1,60}$ with this correlation.	Hatanaka and Uchida (1996)

Equation 1

Note: As originally proposed, these correlations used the uncorrected SPT blowcount, N. However, hammers delivering 60% of the theoretical energy have been the most commonly used hammers for SPT tests, and it seems likely that the data on which these correlations were based was obtained primarily from tests with such hammers. It therefore seems logical to use N_{60} with these correlations, and it is the recommendation of this report that this be done.

(McGregor and Duncan, 1998)

Table A1

Representative values for angle of internal friction ϕ

Soil	Type of test*: Unconsolidated-undrained, U	Consolidated-undrained, CU	Consolidated-drained, CD
Gravel			
Medium size	40–55°		40–55°
Sandy	35–50°		35–50°
Sand			
Loose dry	28–34°		
Loose saturated	28–34°		
Dense dry	35–46°		43–50°
Dense saturated	1–2° less than dense dry		43–50°
Silt or silty sand			
Loose	20–22°		27–30°
Dense	25–30°		30–35°
Clay	0° if saturated	3–20°	20–42°

*See a laboratory manual on soil testing for a complete description of these tests, e.g., Bowles (1992).

Notes:

1. Use larger values as γ increases.
2. Use larger values for more angular particles.
3. Use larger values for well-graded sand and gravel mixtures (GW, SW).
4. Average values for gravels, 35–38°; sands, 32–34°.

Figure 2-35 Correlation between ϕ' and plasticity index I_p for normally consolidated (including marine) clays. Approximately 80 percent of data falls within one standard deviation. Only a few extreme scatter values are shown [*Data from several sources: Ladd et al. (1977), Bjerrum and Simons (1960), Kanja and Wolle (1977), Olsen et al. (1986).*]

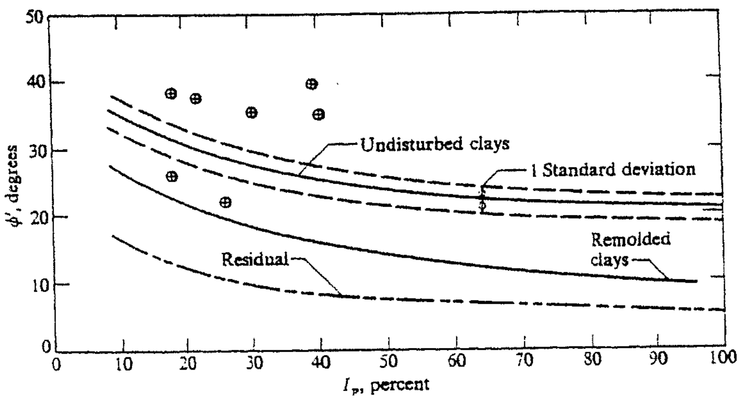


Fig. 2

(Bowles, 1996)

Table A2

TABLE 3.5
COMMON PROPERTIES OF COHESIONLESS SOILS**

Material	Compactness	D_R, %	N*	γ dry,† g/cm³	Void ratio e	Strength‡ ϕ
GW: well-graded gravels, gravel-sand mixtures	Dense	75	90	2.21	0.22	40
	Medium dense	50	55	2.08	0.28	36
	Loose	25	<28	1.97	0.36	32
GP: poorly graded gravels, gravel-sand mixtures	Dense	75	70	2.04	0.33	38
	Medium dense	50	50	1.92	0.39	35
	Loose	25	<20	1.83	0.47	32
SW: well-graded sands, gravelly sands	Dense	75	65	1.89	0.43	37
	Medium dense	50	35	1.79	0.49	34
	Loose	25	<15	1.70	0.57	30
SP: poorly graded sands, gravelly sands	Dense	75	50	1.76	0.52	36
	Medium dense	50	30	1.67	0.60	33
	Loose	25	<10	1.59	0.65	29
SM: silty sands	Dense	75	45	1.65	0.62	35
	Medium dense	50	25	1.55	0.74	32
	Loose	25	<8	1.49	0.80	29
ML: inorganic silts, very fine sands	Dense	75	35	1.49	0.80	33
	Medium dense	50	20	1.41	0.90	31
	Loose	25	<4	1.35	1.0	27

*N is blows per foot of penetration in the SPT. Adjustments for gradation are after Burmister (1962).[24] See Table 6.4 for general relationships of D_R vs. N.

†Density given is for G_s = 2.68 (quartz grains).

‡Friction angle ϕ depends on mineral type, normal stress, and grain angularity as well as D_R and gradation (see Fig. 3.29).

**From Hunt (1984).[1] Reprinted with permission of McGraw-Hill Book Company.

(Hunt, 1983)

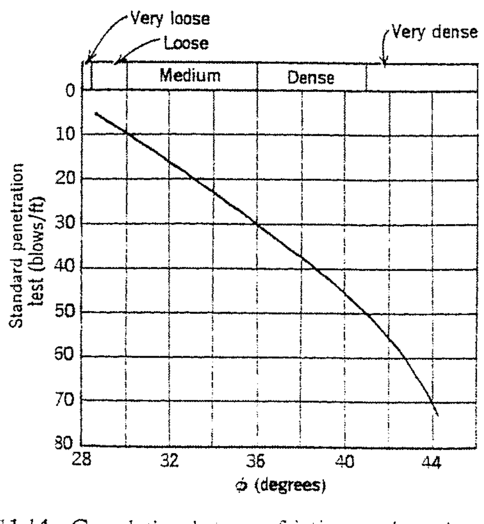


Fig. 11.14 Correlation between friction angle and penetration resistance (From Peck, Hanson, and Thornburn, 1953).

Fig. A1

Table A3

1 Soil Exploratory Work, Soil Investigations and Theoretical Soil Properties

1.1 Mean Soil Properties for Preliminary Designs (R 9)

1.1.1 General

The values in Table R 9-1, designated with the secondary sign cal, are theoretical values. They can be employed in the statical calculations for preliminary designs without further reductions. Mean values of a larger area are concerned here, whereby the values determined later on after the assessment of the various soil investigations for the relevant structure, for example according to R 96, section 1.12, can lie both above, as well as below.

1.1.2 Theoretical Values (Table R 9-1)

Type of Soil	Density: Above Water cal γ	Density: Sub-merged cal γ'	Final Strength: Angle of Internal Friction cal φ'	Final Strength: Co-hesion cal c'	Initial Strength[1]) Shear Strength cal c_u	Coefficient of Compres-sibility cal E_s
	kN/m³	kN/m³	degree	kN/m²	kN/m²	MN/m²
Non-cohesive Soils						
Sand, loose, round	18	10	30	–	–	20 – 50
Sand, loose, angular	18	10	32.5	–	–	40 – 80
Sand, medium dense, round	19	11	32.5	–	–	50 – 100
Sand, medium dense, angular	19	11	35	–	–	80 – 150
Gravel without sand	16	10	37.5	–	–	100 – 200
Coarse gravel, sharp edged	18	11	40	–	–	150 – 300
Sand, dense, angular	19	11	37.5	–	–	150 – 250
Cohesive Soils	(Empirical Values for Undisturbed Samples from the North German Area)					
Clay, semi-firm	19	9	25	25	50 – 100	5 – 10
Clay, difficult to knead, stiff	18	8	20	20	25 – 50	2.5 – 5
Clay, easy to knead, soft	17	7	17.5	10	10 – 25	1 – 2.5
Boulder clay, solid	22	12	30	25	200 – 700	30 – 100
Loam, semi-firm	21	11	27.5	10	50 – 100	5 – 20
Loam, soft	19	9	27.5	–	10 – 25	4 – 8

(Table R 9-1 cont)

Type of Soil	Density: Above Water cal γ	Density: Sub-merged cal γ'	Final Strength: Angle of Internal Friction cal φ'	Final Strength: Co-hesion cal c'	Initial Strength[1]) Shear Strength cal c_u	Coefficient of Compres-sibility cal E_s
	kN/m³	kN/m³	degree	kN/m²	kN/m²	MN/m²
Silt	18	8	27.5	–	10 – 50	3 – 10
Soft, org. slightly clayey sea silt	17	7	20	10	10 – 25	2 – 5
Soft, very org. strongly clayey sea silt	14	4	15	15	10 – 20	0.5 – 3
Peat	11	1	15	5	–	0.4 – 1
Peat under moderate initial loading	13	3	15	10	–	0.8 – 2

cal φ' = Theoretical value of the angle of internal friction in cohesive and non-cohesive soils
cal c' = Theoretical value of the cohesion, corresponding to cal φ'
cal c_u = Theoretical value of the shear strength from undrained tests in saturated cohesive soils

[1]) The appertaining angle of internal friction is to be assumed at cal $\varphi'_u = 0$

1.1.3 In the absence of other information, loose deposit is to be assumed for undisturbed sandy soil. Except in older geological stratifications, medium dense compaction is to be expected only after compaction by vibration or tamping. The values for gravelly sand are the same as for sand. The density given for coarse gravel is a rough average value. The actual density depends on the type of rock.

1.1.4 The angles of internal friction cal φ' and the cohesion cal c' for cohesive soils are rough average values for calculating the final stability (consolidated state = final strength). If soft to stiff clay and silty clay layers of considerable depth will receive a surcharge such as backfill, structures, etc., the influence of pore pressure is to be considered in the determination of the active earth pressure (initial strength). In some cases, the initial strength may also be considered in the determination of the passive earth pressure.

1.1.5 As static penetrometer tests in loosely deposited soils can frequently be executed economically and quickly in many cases, it is frequently justifiable to already carry out such tests for preliminary designs. As a result, the correct classification in the table, section 1.1.2 is enabled through the thereby determined approximate degree of density of sand. Reference is made to DIN 4094 and to [1], as well as [2] regarding the evaluation for cal c_u and the expected modulus of volume change.

(EAU, 1985)

b) Selection of Soil Design Parameters c' & φ'

Borehole G1

Layer I:

(GC)	From empirical equations	$\varphi=(12N)^{0.5}+20=28^{\circ}$ c'=5kPa, φ' = 28°
$N_{SPT}=6$	From laboratory test results	c'=-, φ' = -°
	Selected values	c'=5kPa, φ' = 30°

Layer II:

(CL), (SC)	From empirical equations	$\varphi=(15N)^{0.5}+15=32^{\circ}$ c'=10kPa, φ' = 32°
$N_{SPT}=19$	From laboratory test results	c'=-, φ' = -
	Selected values	c'=10kPa, φ' = 32°

Borehole G2

Layer I:

(SM)	From empirical equations	$\varphi=(20N)^{0.5}+15=26^{\circ}$ c'=5kPa, φ' = 26°
$N_{SPT}=6$	From laboratory test results	c'=-kPa, φ' = -°
	Selected values	c'=5kPa, φ' = 28°

Layer II:

(SM), (MH)	From empirical equations	$\varphi=(15N)^{0.5}+15=32^{\circ}$ c'=5kPa, φ' = 32°
$N_{SPT}=19$	From laboratory test results	c'=-, φ' = -°
	Selected values	c'=5kPa, φ' = 32°

Layer IIa:

(GC), (SM)	From empirical equations	$\varphi=(12N)^{0.5}+15=37^{\circ}$ c'=5kPa, φ' = 37°
$N_{SPT}=40$	From laboratory test results	c'=-kPa, φ' = -°
	Selected values	c'=5kPa, φ' = 37°

Borehole G3

Layer I:

(SM)	From empirical equations	$\varphi=(20N)^{0.5}+15=26^{\circ}$ c'=5kPa, φ' = 28°
$N_{SPT}=6$	From laboratory test results	c'=0kPa, φ' = 36° c'=17kPa, φ' = 38°
	Selected values	c'=5kPa, φ' = 28°

Layer IIa:

(SM)	From empirical equations	$\varphi=(12N)^{0.5}+15=34^{\circ}$ c'=5kPa, φ' = 34°
$N_{SPT}=30$	From laboratory test results	c'=-kPa, φ' = -°
	Selected values	c'=5kPa, φ' = 34°

Borehole G4

Layer I:

(SM)	From empirical equations	$\varphi=(20N)^{0.5}+15=27^\circ$
		$c'=5kPa$, $\varphi' = 27^\circ$
$N_{SPT}=8$	From laboratory test results	$c'=0kPa$, $\varphi' = 52^\circ$
	Selected values	$c'=5kPa$, $\varphi' = 30^\circ$

Borehole G5

Layer I:

(SM), (CL)	From empirical equations	$\varphi=(20N)^{0.5}+15=26^\circ$
		$c'=5kPa$, $\varphi' = 26^\circ$
$N_{SPT}=7$	From laboratory test results	$c'=9kPa$, $\varphi' = 40^\circ$
		$c'=5kPa$, $\varphi' = 41^\circ$
	Selected values	$c'=5kPa$, $\varphi' = 30^\circ$

Layer II:

(GC)	From empirical equations	$\varphi=(12N)^{0.5}+15=32^\circ$
		$c'=10kPa$, $\varphi' = 28^\circ$ -32°
$N_{SPT}=26$	From laboratory test results	c'=-, φ' = -$^\circ$
	Selected values	$c'=10kPa$, $\varphi' = 32^\circ$

Layer IIa:

(GC), (CL), (SC)	From empirical equations	$\varphi=(12N)^{0.5}+15=37^\circ$
		$c'=10kPa$, $\varphi' = 30^\circ$ -37°
$N_{SPT}=40$	From laboratory test results	c'=-, φ' = -$^\circ$
	Selected values	$c'=10kPa$, $\varphi' = 37^\circ$

Borehole G6

Layer Ia:

(ML), (MH), (CL)	From empirical equations	$\varphi=(12N)^{0.5}+15=19^\circ$
		$c'=0kPa$, $\varphi' = 19^\circ$
$N_{SPT}=0-1$	From laboratory test results	$c'=0kPa$, $\varphi' = 47^\circ$
	Selected values	$c'=0kPa$, $\varphi' = 22^\circ$

Layer II:

(CL)	From empirical equations	$\varphi=(15N)^{0.5}+15=32^\circ$
		$c'=10kPa$, $\varphi' = 32^\circ$
$N_{SPT}=19$	From laboratory test results	c'=-, φ' = -$^\circ$
	Selected values	$c'=10kPa$, $\varphi' = 32^\circ$

Layer IIa:

(GC), (CL)	From empirical equations	$\varphi=(12N)^{0.5}+15=37^\circ$
		$c'=15kPa$, $\varphi' = 37^\circ$
$N_{SPT}=40$	From laboratory test results	c'=-, φ' = -$^\circ$
	Selected values	$c'=15kPa$, $\varphi' = 37^\circ$

Borehole G7
Layer I:

(CL), (ML)	From empirical equations	$\varphi=(12N)^{0.5}+15=20^o$
		$c'=0kPa$, $\varphi' = 20^o$
$N_{SPT}=2$	From laboratory test results	$c'=8kPa$, $\varphi' =37^o$
	Selected values	$c'=0kPa$, $\varphi' = 24^o$

Layer II:

(GC), (SM), (SC)	From empirical equations	$\varphi=(15N)^{0.5}+15=31^o$
		$c'=5kPa$, $\varphi' = 31^o$
$N_{SPT}=17$	From laboratory test results	c'=-, φ' = -
	Selected values	$c'=5kPa$, $\varphi' = 31^o$

Borehole G8
Layer I:

(SM), (ML)	From empirical equations	$\varphi=(20N)^{0.5}+15=24^o$
		$c'=0kPa$, $\varphi' = 24^o$
$N_{SPT}=4$	From laboratory test results	$c'=10kPa$, $\varphi' = 37^o$
		$c'=2kPa$, $\varphi' = 40^o$
	Selected values	$c'=0kPa$, $\varphi' = 28^o$

Borehole G9
Layer I:

(SM)	From empirical equations	$\varphi=(20N)^{0.5}+15=26^o$
		$c'=0kPa$, $\varphi' = 26^o$
$N_{SPT}=6$	From laboratory test results	$c'=0kPa$, $\varphi' = 41^o$
	Selected values	$c'=5kPa$, $\varphi' = 30^o$

Borehole G10
Layer I:

(SM)	From empirical equations	$\varphi=(20N)^{0.5}+15=26^o$
		$c'=5kPa$, $\varphi' = 26^o$
$N_{SPT}=6$	From laboratory test results	$c'=0kPa$, $\varphi' = 41^o$
	Selected values	$c'=5kPa$, $\varphi' = 30^o$

A1.2 Undrained Shear Strength c_u

a) General Relationships

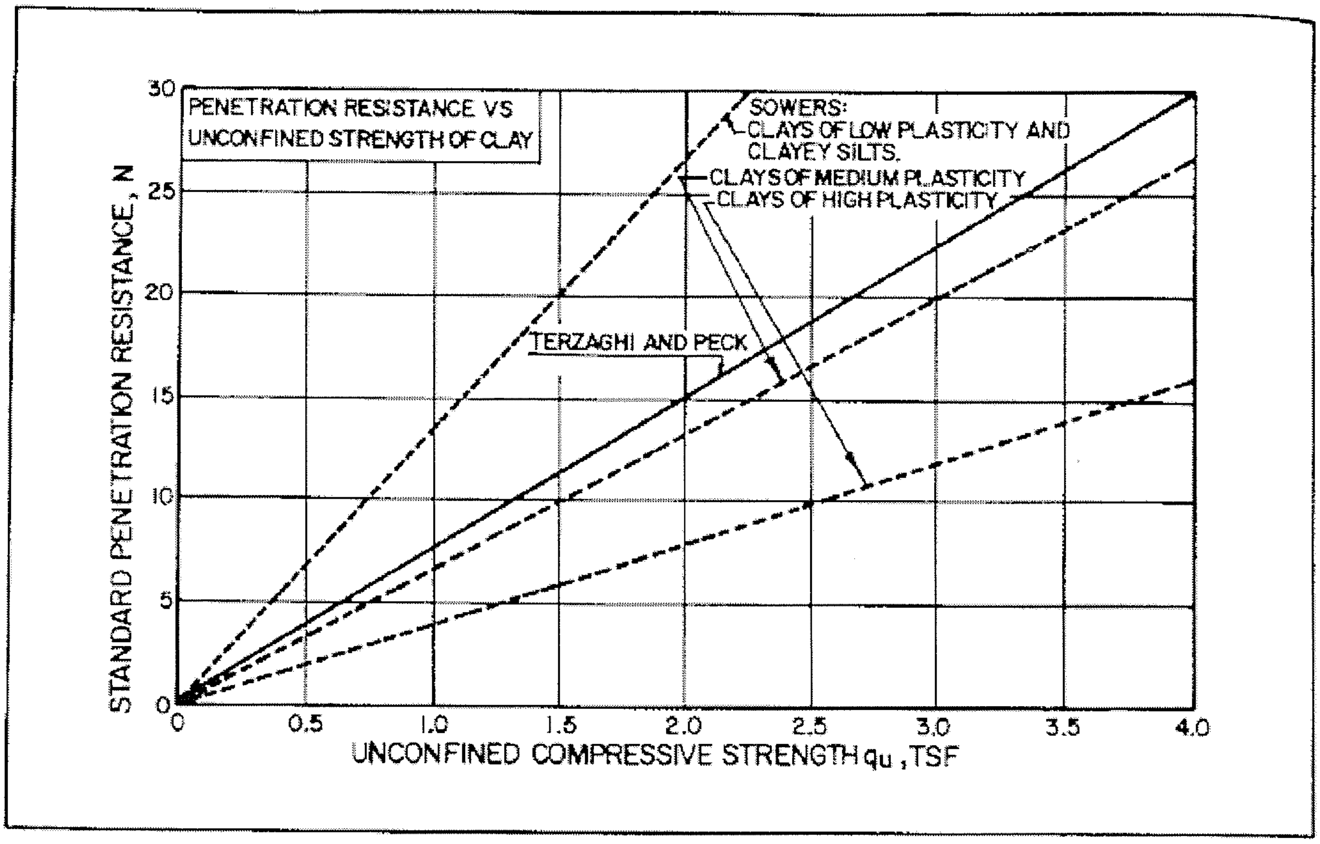


FIGURE 4
Correlations of Standard Penetration Resistance

Fig.1 Relationship between blow count N and unconfined compressive strength q_u cohesive soils. (NAVFAC DM 7.1, 1982) → $c_u = q_u/2$

1 TSF = 107.3kPa

b) Selection of Soil Design Parameters - c_u

Borehole G1

Layer Ia:

(GC)	Selected values	c_u =15kPa, φ_u = 0°

Layer I:

(GC)	From chart NAVFAC	c_u =35kPa
N_{SPT}=6	From laboratory test results	c_u =269kPa (not accepted)
	Selected values	c_u =40kPa, φ_u = 10°

Layer II:

(CL), (SC)	From chart NAVFAC	c_u = 100kPa
N_{SPT}=19	From laboratory test results	c_u = 26kPa, 58kPa, 64kPa
	Selected values	c_u =70kPa, φ_u = 5°

Borehole G2

Layer I:

(SM)	From chart NAVFAC	c_u = 35kPa
N_{SPT}=6	From laboratory test results	c_u = 21kPa, 20 kPa
	Selected values	c_u =40kPa, φ_u = 5°

Layer II:

(SM), (MH)	From chart NAVFAC	c_u = 100 kPa
N_{SPT}=19	From laboratory test results	c_u = 39 kPa
	Selected values	c_u =70kPa, φ_u = 5°

Layer IIa:

(GC), (SM)	From chart NAVFAC	c_u = 200 kPa
N_{SPT}=40	From laboratory test results	c_u = -
	Selected values	c_u =150kPa, φ_u = 5°

Borehole G3

Layer I:

(SM)	From chart NAVFAC	c_u = 35 kPa
N_{SPT}=6	From laboratory test results	c_u = 23 kPa
	Selected values	c_u =40kPa, φ_u = 5°

Layer IIa:

(SM)	From chart NAVFAC	c_u = 100 kPa
N_{SPT}=30	From laboratory test results	c_u = 33kPa
	Selected values	c_u =100kPa, φ_u = 5°

Borehole G4
Layer I:

(SM)	From chart NAVFAC	c_u = 40 kPa
N_{SPT}=8	From laboratory test results	c_u = 23 kPa, 45 kPa, 79 kPa
	Selected values	c_u =50kPa, φ_u = 5°

Borehole G5
Layer I:

(SM), (CL)	From chart NAVFAC	c_u = 40 kPa
N_{SPT}=7	From laboratory test results	c_u = 25 kPa
	Selected values	c_u =40kPa, φ_u = 5°

Layer II:

(GC)	From chart NAVFAC	c_u = 125 kPa
N_{SPT}=26	From laboratory test results	c_u = 81 kPa
	Selected values	c_u =120kPa, φ_u = 5°

Layer IIa:

(GC), (CL), (SC)	From chart NAVFAC	c_u = 150 kPa
N_{SPT}=40	From laboratory test results	c_u = 43 kPa
	Selected values	c_u =150kPa, φ_u = 5°

Borehole G6
Layer Ia:

(ML), (MH), (CL)	From chart NAVFAC	c_u = 0 kPa
N_{SPT}=0	From laboratory test results	c_u =8kPa, 19kPa
	Selected values	c_u =10kPa, φ_u = 0°

Layer II:

(CL)	From chart NAVFAC	c_u = 125 kPa
N_{SPT}=19	From laboratory test results	c_u = - kPa
	Selected values	c_u =100kPa, φ_u = 0°

Layer IIa:

(GC), (CL)	From chart NAVFAC	c_u = 150 kPa
N_{SPT}=40	From laboratory test results	c_u = 35 kPa, 88 kPa, 79 kPa, 63 kPa
	Selected values	c_u =150kPa, φ_u = 5°

Borehole G7
Layer I:

(CL), (ML)	From chart NAVFAC	c_u =15kPa
N_{SPT}=2	From laboratory test results	c_u =43kPa, 104kPa
	Selected values	c_u =20kPa, φ_u = 0°

Layer II:

(GC), (SM), (SC)	From chart NAVFAC	c_u = 80kPa
N_{SPT}=17	From laboratory test results	c_u = 30kPa
	Selected values	c_u =60kPa, φ_u = 10°

Borehole G8

Layer Ia:

(SM)	Selected values	c_u =15kPa, φ_u = 0°

Layer I:

(SM), (ML)	From chart NAVFAC	c_u =20kPa
N_{SPT}=4	From laboratory test results	c_u =5kPa, 8kPa
	Selected values	c_u =20kPa, φ_u = 5°

Borehole G9

Layer Ia:

(SM)	Selected values	c_u =15kPa, φ_u = 0°

Layer I:

(SM)	From chart NAVFAC	c_u =35kPa
N_{SPT}=6	From laboratory test results	c_u =40kPa
	Selected values	c_u =40kPa, φ_u = 5°

Borehole G10

Layer Ia:

	Selected values	c_u =15kPa, φ_u = 0°

Layer I:

(SM)	From chart NAVFAC	c_u =35kPa
N_{SPT}=6	From laboratory test results	c_u =31, 18kPa
	Selected values	c_u =40kPa, φ_u = 5°

A1.3 Oedometer Modulus E_{oed}

a) General Relationships

Table 4

TABLE 5-6

Equations for stress-strain modulus E_s by several test methods

E_s in kPa for SPT and units of q_c for CPT; divide kPa by 50 to obtain ksf. The N values should be estimated as N_{55} and not N_{70}. Refer also to Tables 2-7 and 2-8.

Soil	SPT	CPT
Sand (normally consolidated)	$E_s = 500(N + 15)$ $= 7000\sqrt{N}$ $= 6000N$ — — — ‡$E_s = (15\,000 \text{ to } 22\,000) \cdot \ln N$	$E_s = (2 \text{ to } 4)q_u$ $= 8000\sqrt{q_c}$ — — — $E_s = 1.2(3D_r^2 + 2)q_c$ *$E_s = (1 + D_r^2)q_c$
Sand (saturated)	$E_s = 250(N + 15)$	$E_s = Fq_c$ $e = 1.0 \quad F = 3.5$ $e = 0.6 \quad F = 7.0$
Sands, all (norm. consol.)	¶$E_s = (2600 \text{ to } 2900)N$	
Sand (overconsolidated)	†$E_s = 40\,000 + 1050N$ $E_{s(OCR)} \approx E_{s,nc}\sqrt{OCR}$	$E_s = (6 \text{ to } 30)q_c$
Gravelly sand	$E_s = 1200(N + 6)$ $= 600(N + 6) \quad N \le 15$ $= 600(N + 6) + 2000 \quad N > 15$	
Clayey sand	$E_s = 320(N + 15)$ $\approx E_{oed}$	$E_s = (3 \text{ to } 6)q_c$
Silts, sandy silt, or clayey silt	$E_s = 300(N + 6)$	$E_s = (1 \text{ to } 2)q_c$
	If $q_c < 2500$ kPa use $\quad$ §$E_s' = 2.5q_c$ $2500 < q_c < 5000$ use $\quad E_s' = 4q_c + 5000$ where $E_s' = \text{constrained modulus} = \dfrac{E_s(1-\mu)}{(1+\mu)(1-2\mu)} = \dfrac{1}{m_v}$ $\approx E_{oed}$	
Soft clay or clayey silt		$E_s = (3 \text{ to } 8)q_c$

(Bowles, 1996)

b) Selection of Soil Design Parameters - E_{oed}

Borehole G1

Layer I:

(GC)	From empirical equations	E_{oed}= 250*(N+15)=5250kPa
N_{SPT}=6	From laboratory test results	E_{oed}=12000kPa
	Selected values	E_{oed}=6000kPa

Layer II:

(CL), (SC)	From empirical equations	E_{oed}= 320*(N+15)=10880kPa
N_{SPT}=19	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=11000kPa

Borehole G2

Layer I:

(SM)	From empirical equations	E_{oed}= 250*(N+15)=5250kPa
N_{SPT}=6	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=6000kPa

Layer II:

(SM), (MH)	From empirical equations	E_{oed}= 300*(N+6)=7500kPa
N_{SPT}=19	From laboratory test results	E_{oed}=12000kPa
	Selected values	E_{oed}=11000kPa

Layer IIa:

(GC), (SM)	From empirical equations	E_{oed}= 300*(N+6)=13800kPa
		E_{oed}= 320*(N+15)=17600kPa
N_{SPT}=40	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=18000kPa

Borehole G3

Layer I:

(SM)	From empirical equations	E_{oed}= 250*(N+15)=5250kPa
N_{SPT}=6	From laboratory test results	E_{oed}=5800kPa
		E_{oed}=6000kPa
	Selected values	E_{oed}=6000kPa

Layer IIa:

(SM)	From empirical equations	E_{oed}= 300*(N+6)=10800kPa
N_{SPT}=30	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=11000kPa

Borehole G4

Layer I:

(SM)	From empirical equations	E_{oed}= 250*(N+15)=5750kPa
N_{SPT}=8	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=6000kPa

Layer IIa:

(GC), (CL), (SC)	From empirical equations	E_{oed}= 320*(N+15)=17600kPa
N_{SPT}=40	From laboratory test results	E_{oed}=21000
	Selected values	E_{oed}=18000kPa

Borehole G5

Layer I:

(SM), (CL)	From empirical equations	E_{oed}= 250*(N+15)=5500kPa E_{oed}= 320*(N+15)=7040kPa
N_{SPT}=7	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=6000kPa

Layer II:

(GC)	From empirical equations	E_{oed}= 320*(N+15)=13120kPa
N_{SPT}=26	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=12000kPa

Layer IIa:

(GC), (CL), (SC)	From empirical equations	E_{oed}= 320*(N+15)=17600kPa
N_{SPT}=40	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=18000kPa

Borehole G6

Layer Ia:

(ML), (MH), (CL)	From empirical equations	E_{oed}= 300*(N+6)=1800kPa
N_{SPT}=0-1	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=1000kPa

Layer II:

(CL)	From empirical equations	E_{oed}= 320*(N+15)=10880kPa
N_{SPT}=19	From laboratory test results	E_{oed}=-
	Selected values	E_{oed}=11000kPa

Layer IIa:

(GC), (CL)	From empirical equations	E_{oed}= 320*(N+15)=17600kPa
N_{SPT}=40	From laboratory test results	E_{oed}=11000kPa
	Selected values	E_{oed}=18000kPa

Borehole G7

Layer I:

(CL), (ML)	From empirical equations	E_{oed}= 300*(N+6)=2400kPa
N_{SPT}=2	From laboratory test results	E_{oed}=3700kPa
	Selected values	E_{oed}=2500kPa

Layer II:

(GC), (SM), (SC)	From empirical equations	E_{oed}= 320*(N+15)=10240kPa
N_{SPT}=17	From laboratory test results	E_{oed}=9000kPa
	Selected values	E_{oed}=10000kPa

Borehole G8

Layer I:

(SM), (ML)	From empirical equations	E_{oed}= 250*(N+15)=4750kPa
N_{SPT}=4	From laboratory test results	E_{oed}=2100kPa
	Selected values	E_{oed}=3000kPa

Borehole G9

Layer I:

(SM)	From empirical equations	E_{oed}= 250*(N+15)=5250kPa
N_{SPT}=6	From laboratory test results	E_{oed}=4000kPa
	Selected values	E_{oed}=6000kPa

Borehole G10

Layer I:

(SM)	From empirical equations	E_{oed}= 250*(N+15)=5250kPa
N_{SPT}=6	From laboratory test results	E_{oed}=9500kPa
	Selected values	E_{oed}=6000kPa

A2. DESIGN PARAMETERS FOR ROCK FORMATIONS

A2.1 General Relationships

a) Generalised Hoek & Brown criterion (2002)- GSI

Sheets A-17 to A-21

Summary of Selected Values

- **Marl Layer III**

c'=50kPa
φ'=28° to 34°
γ=21kN/m^3
E_m=400 – 800 MPa

- **Marly Limestone Layer IV -**

c'=100kPa
φ'=29° to 32°
γ=22.5kN/m^3
E_m=1000 – 1500 MPa

GENERALISED HOEK-BROWN CRITERION AND EQUIVALENT MOHR-COULOMB

MALTA - DELIMARA OFFSHORE

Formation: **Marl Layer III**

Facts

σ_{ci}=	5 MPa	Weathering degree=	W3	GSI=	20
γ=	0,0210 kN/m³	m_i=	6	GSI=RMR$_{89}$-5 για RMR>23 με Υπεδαφικό Νερό=15 και Προσανατολισμό Ασυνεχειών=0	
Depth	7 m	JRC=	3 Επιπεδη Τραχεία	Angle of Discon=	45°
D=	0,2	degree of disruption (due to surfacial weathering-excvation)			

Results

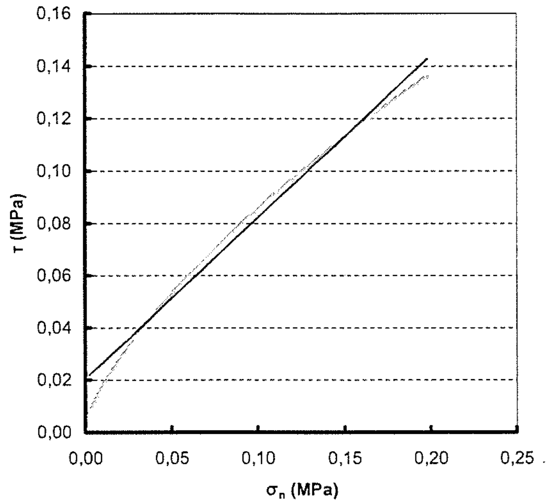
m_b=	0,251	s=	0,0001	a=	0,544
$\sigma_{tensile\ m}$=	-0,001 MPa	σ_n=	0,147 MPa	ρ=	2140,67 kg/m³
σ_c=	0,028 MPa	σ_{cm}=	0,259 MPa	σ_{ci}/σ_{cm}=	19,30

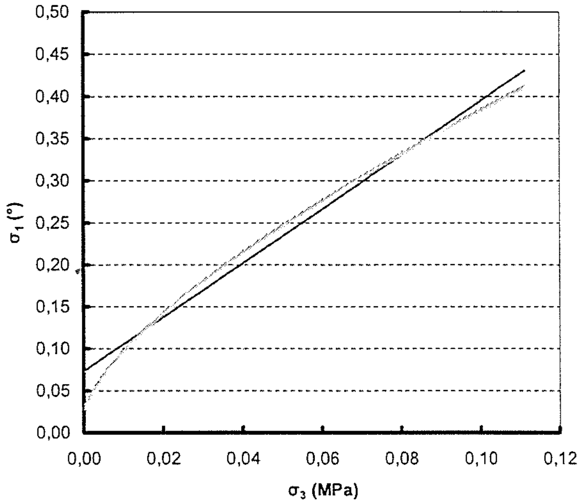
Generalised (foundations)

σ'_{3max}=	1,2500 MPa	σ_{3n}=	0,25	c'=	0,098 MPa
				φ'=	15,62°

Slopes

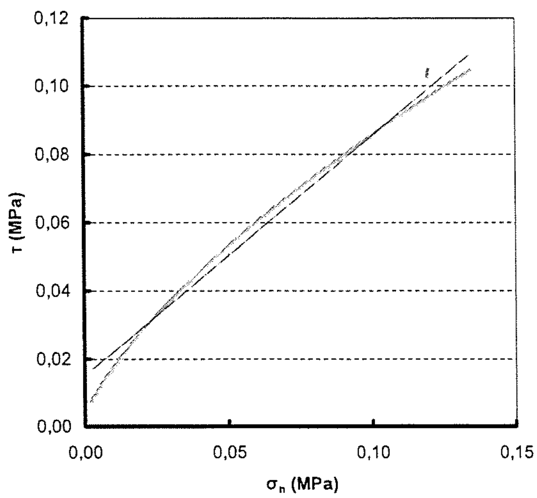
σ'_{3max}=	0,1114 MPa	σ_{3n}=	0,022	c'=	0,020 MPa
				φ'=	31,66°

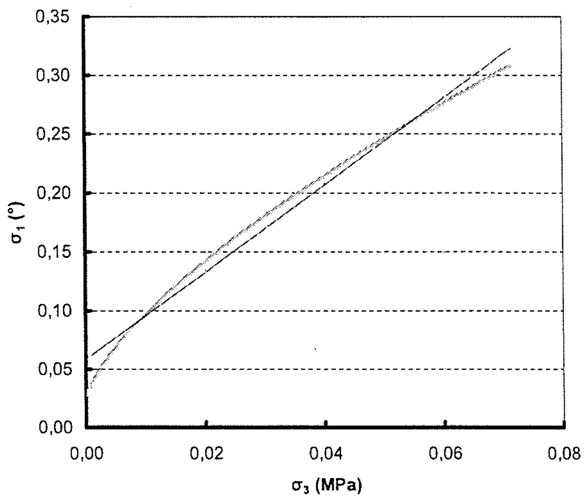




Tunnels

σ'_{3max}=	0,0715 MPa	σ_{3n}=	0,014	c'=	0,015 MPa
				φ'=	35,04°





Modulus of compressibillity

Jacky's Formula			*Sheorey (1994)*				
v=	0,32		v=	0,38			
k_0=	0,48		k_0=	0,61		E_m=	357,87 MPa
G=	135	MPa	G=	130	MPa		
E_{oed}=	516	MPa	E_{oed}=	666	MPa		

Summary of Results

Project: MALTA - DELIMARA OFFSHORE

Formation: **Marl Layer III**

Unconfined compressive strength σ_{ci}=	5,000	MPa
Strength of intact rock σ_c=	0,028	MPa
Compressive strength σ_{cm}=	0,259	MPa
Unit weight γ=	0,0210	MN/m^3
Density ρ=	2140,67	kg/m^3
Factor m_i=	6	
Degree of weathering=	W3	
GSI=	20	
JRC=	3	
Angle of discontin=	45°	
Depth of computation=	7	m
Degree of disruption D=	0,2	

Indexes and Moduli

Modulus of elasticity E_m= 358 MPa — Recommended value **E_m=400-800kPa**

	Jacky's Formula	*Sheorey (1994)*
Shear Modulus G=	135 MPa	130 MPa
Stress-strain modulus E_{oed}=	516 MPa	666 MPa
Poisson's ratio v=	0,32	0,38
k_0=	0,48	0,61

Mohr-Coulomb parameters

	Foundations	**Slopes**	**Tunnels**
Cohesion c'=	98 kPa	20 kPa	15 kPa
Angle of internal friction φ'=	16°	32°	35°

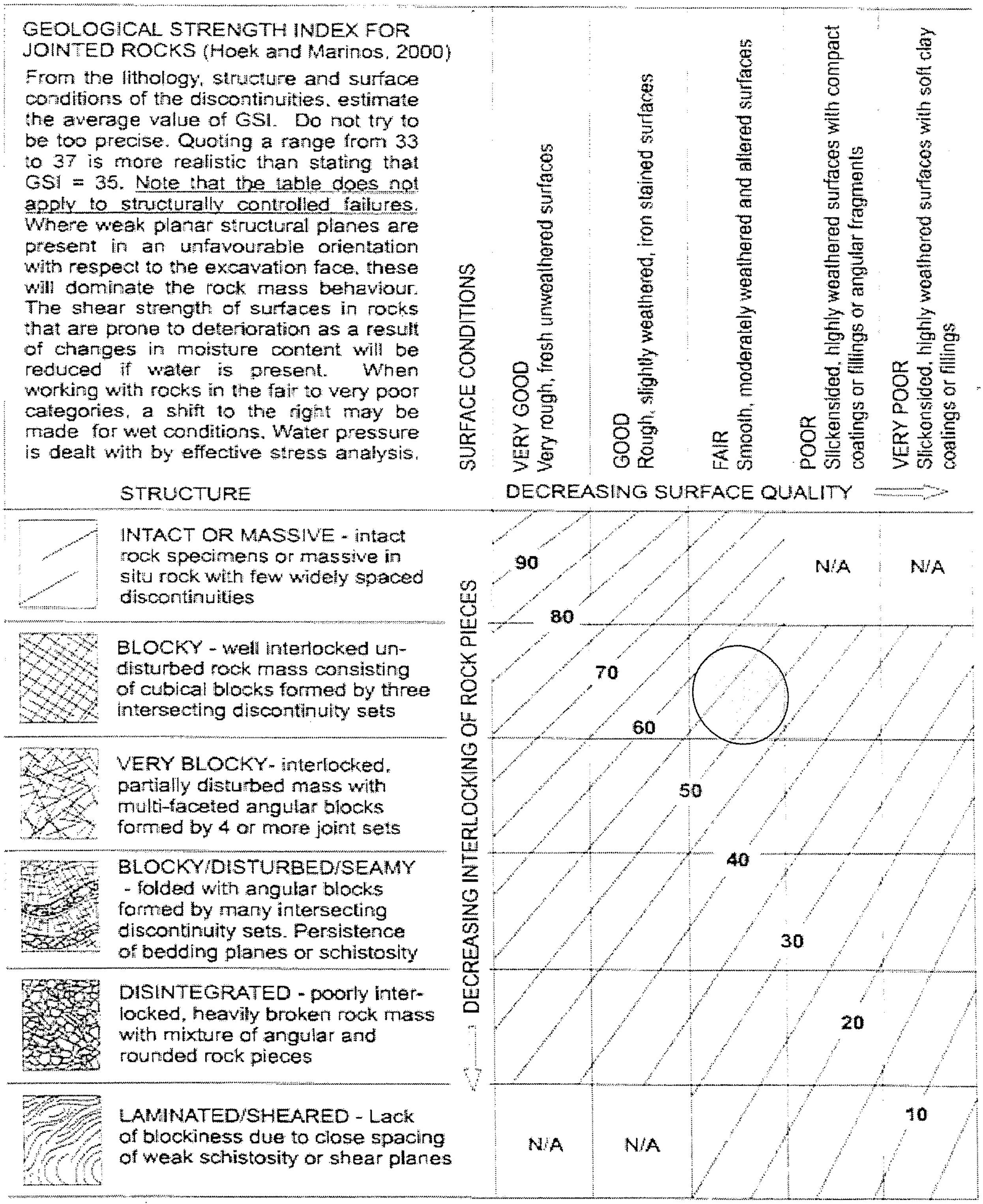
Recommended value **c'=50kPa** **φ'=30°**

Mohr-Coulomb parameters for Discontinuities

	Depth of computation		
	7,0 m	**3,0 m**	**0 m**
Cohesion c'=	3 kPa	1 kPa	0,13 kPa
Angle of internal friction φ'=	18°	19°	22°

Geological Strength Index

Project : Malta - Delimara Offshore		**Rock Description :** Marly Limestone **Layer IV**
Geologist:	**Date :**	**Geological Strength Index (GSI):** 45-60 **Chosen value 55**



GENERALISED HOEK-BROWN CRITERION AND EQUIVALENT MOHR-COULOMB

MALTA - DELIMARA OFFSHORE

Formation: **Marly Limestone Layer IV**

Facts

σ_{ci}= 10 MPa	**Weathering degree=** W2	**GSI=** 50
γ= 0,0240 kN/m^3	m_i= 8	GSI=RMR$_{89}$-5 για RMR>23 με Υπεδαφικό Νερό=15 και Προσανατολισμό Ασυνεχειών=0
Depth 44 m	**JRC=** 3 Επιπεδη Τραχεια	**Angle of Discon=** 45°
D= 0,6	degree of disruption (due to surfacial weathering-excvation)	

Results

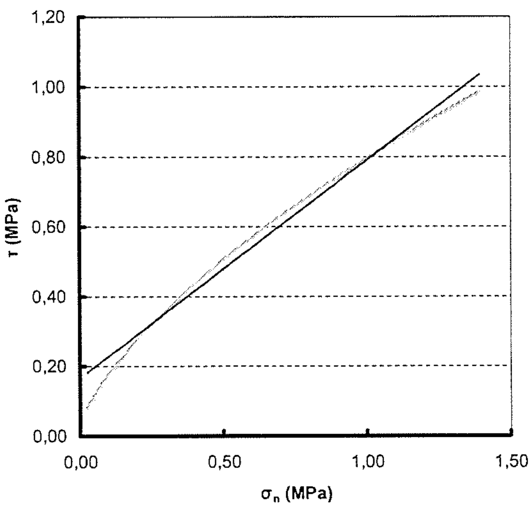
m_b= 0,624	s= 0,0010	α= 0,506
$\sigma_{tensile\ m}$= -0,015 MPa	σ_n= 1,056 MPa	ρ= 2446,48 kg/m^3
σ_c= 0,298 MPa	σ_{cm}= 1,046 MPa	σ_{ci}/σ_{cm}= 9,56

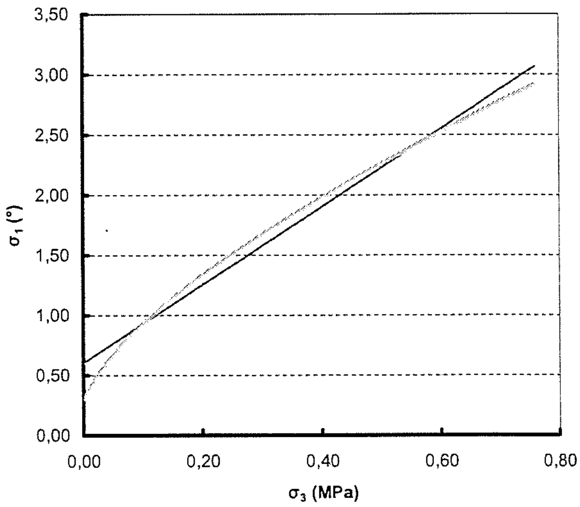
Generalised (foundations)

σ'_{3max}= 2,5000 MPa	σ_{3n}= 0,25	c'= 0,349 MPa φ'= 22,66°

Slopes

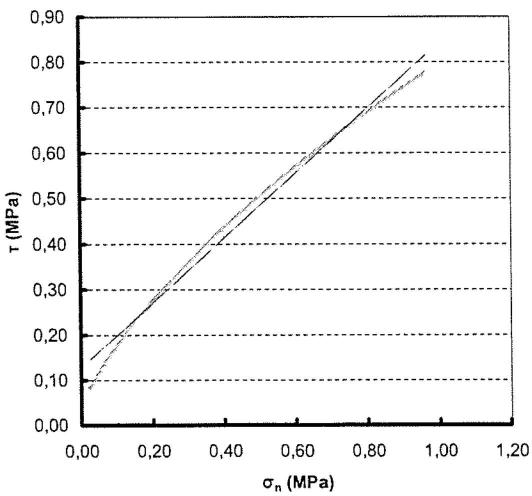
σ'_{3max}= 0,7597 MPa	σ_{3n}= 0,076	c'= 0,167 MPa φ'= 31,91°

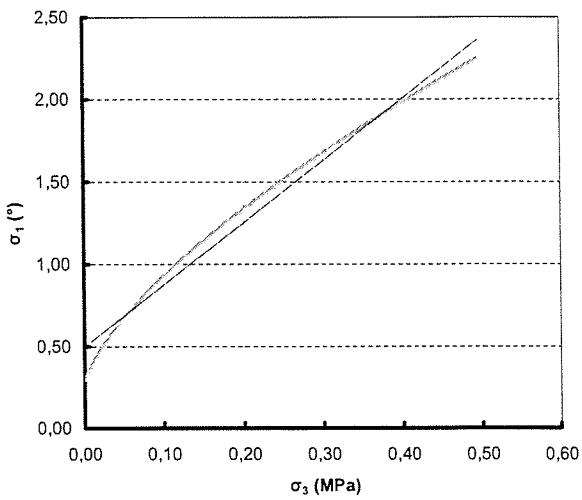




Tunnels

σ'_{3max}= 0,4960 MPa	σ_{3n}= 0,050	c'= 0,129 MPa φ'= 35,40°





Modulus of compressibillity

Jacky's Formula	*Sheorey (1994)*	
ν= 0,32	ν= 0,38	
k_0= 0,47	k_0= 0,62	E_m= 2213,59 MPa
G= 838 MPa	G= 801 MPa	
E_{oed}= 3172 MPa	E_{oed}= 4190 MPa	

Summary of Results

Project: MALTA - DELIMARA OFFSHORE

Formation: **Marly Limestone Layer IV**

Unconfined compressive strength σ_{ci}=	10,000	MPa
Strength of intact rock σ_c=	0,298	MPa
Compressive strength σ_{cm}=	1,046	MPa
Unit weight γ=	0,0240	MN/m^3
Density ρ=	2446,48	kg/m^3
Factor m_i=	8	
Degree of weathering=	W2	
GSI=	50	
JRC=	3	
Angle of discontin=	45°	
Depth of computation=	44	m
Degree of disruption D=	0,6	

Indexes and Moduli

Modulus of elasticity E_m= 2214 MPa — Recommended value **E_m**=800-1500MPa

	Jacky's Formula	*Sheorey (1994)*
Shear Modulus G=	838 MPa	801 MPa
Stress-strain modulus E_{oed}=	3172 MPa	4190 MPa
Poisson's ratio v=	0,32	0,38
k_0=	0,47	0,62

Mohr-Coulomb parameters

	Foundations	**Slopes**	**Tunnels**	
Cohesion c'=	349 kPa	167 kPa	129 kPa	Recommended value **c'**=100**kPa**
Angle of internal friction φ'=	23°	32°	35°	**φ'**=32°

Mohr-Coulomb parameters for Discontinuities

	Depth of computation		
	44,0 m	**17,8 m**	**0 m**
Cohesion c'=	21 kPa	8 kPa	0,17 kPa
Angle of internal friction φ'=	23°	24°	30°

b) Relationship between RQD and modulus reduction ratio

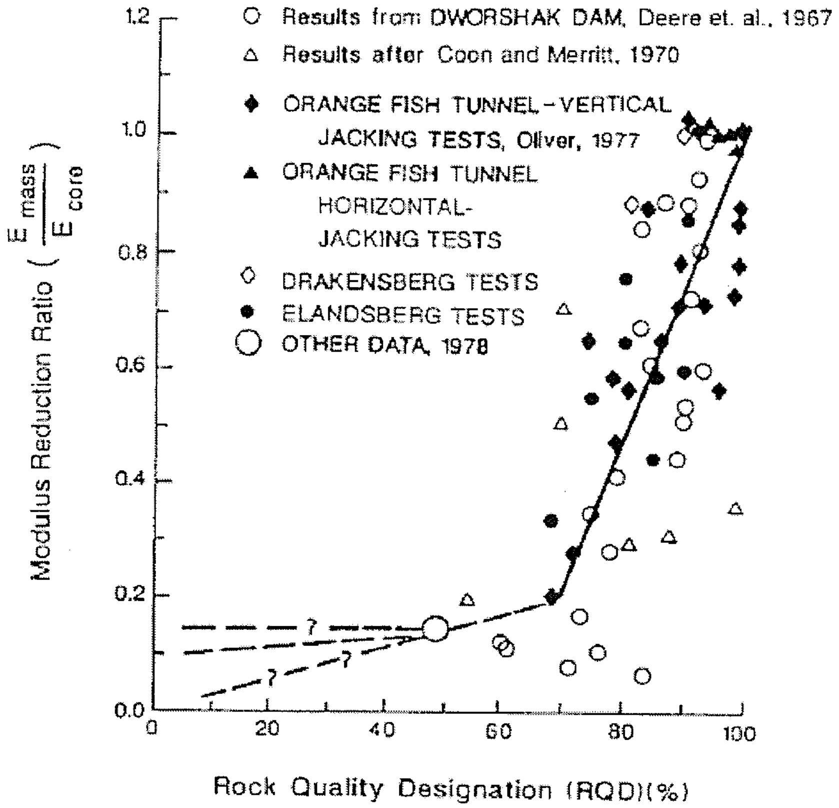


Fig. 3.12. Modulus Reduction Ratio as a Function of RQD (From Bieniawski, 1984)

Fig.1 Relationship between Rock Quality Designation and Modulus Reduction Ratio. (Bieniawski, 1984).

Castor Ltd
GEOTECHNICAL ENGINEERING CONSULTANTS

PROJECT MALTA – DELIMARA - OFFSHORE INVESTIGATION
SUBJECT Geotechnical Design Parameters
DATE December 2014

COMPUTED BY S.G.N
CHECK BY I.L.M
SHEET No. 23 OF 28

c) Summary of laboratory test results – selected σ_c & E_m values

BOREHOLES	Formations	RQD (%)	Laboratory Values Is_{50} (MPa)	Laboratory Values σ_c (MPa)	Mean Values σ_c (MPa)	Selected Values σ_c (MPa)	Laboratory Values E_{core} (MPa)	Mean Values E_{core} (MPa)	E_m/E_{core}	Mean Values E_m (MPa)	Selected Values E_m (MPa)
G1	Clay Marl		0.2-0.5	5	5	5	1700	1700	0.24	400	400
	Marly Limestone		0.4-1.6	11-16	14	14	2900-7600	5250	0.2	1050	1000
G2	Clay Marl		0.5-7.4	-	-	5	-	-	-	-	400
	Marly Limestone		0.9-2.2	14-15	14	14	2800-12000	6000	0.2	1200	1200
G3	Clay Marl		0.1-0.3	4-6	5	5	1200-1800	1400	0.64	900	800
	Marly Limestone		0.2-0.9	5-14	9.5	10	2100-5200	4000	0.25	1000	1000
G4	Clay Marl		0.2-0.3	8	8	6	2400	2400	0.2	480	400
	Marly Limestone		0.7-1.8	9-16	13	13	1500-6300	2800	0.3	840	1000
G5	Clay Marl		-	-	-	5	-	-	-	-	400
	Marly Limestone		0.5-2.2	10-17	13.5	14	2200-5800	3700	0.3	1100	1000
G6	Clay Marl		-	9.5	9.5	7	2200	2200	0.22	480	400
	Marly Limestone		0.7-1.4	13-16	13.5	14	1000-1400	1200	0.8	960	1000
G7	Clay Marl		0.3-0.5	5-12	8	8	500	500	0.8	400	400
	Marly Limestone		0.7-1.8	13-18	14.5	14	2000-2200	2100	0.9	1900	1500
G8	Clay Marl		-	-	-	4	-	-	-	-	400
	Marly Limestone		0.3-3.5	2-14	8	10	900-1400	4200	0.3	1260	1000
G9	Clay Marl		0.7-1.5	3-4	3.5	4	-	-	-	-	400
	Marly Limestone		0.4-3.2	10-13	11	11	1600-4100	2650	0.5	1325	1200
G10	Clay Marl		-	-	-	4	-	-	-	-	400
	Marly Limestone		0.2-3	7-17	10	12	2000-5800	3250	0.6	1950	1200

E_m=Rock mass elasticity modulus
E_{core}=Uniaxial test,elasticity modulus

A3.2 Selected Rock Parameters

a) Layer III, Clay Marl

Borehole G1

RQD= 60% σ_{ci} = 5MPa
c´ = 50kPa γ = 21kN/m^3
φ´ = 30° E_m = 400MPa

Borehole G2

RQD= 70% σ_{ci} = 5MPa
c´ = 50kPa γ = 21kN/m^3
φ´ = 30° E_m = 400MPa

Borehole G3

RQD= 90% σ_{ci} = 5MPa
c´ = 50kPa γ = 21kN/m^3
φ´ = 30° E_m = 800MPa

Borehole G4

RQD= 70% σ_{ci} = 6MPa
c´ = 50kPa γ = 21kN/m^3
φ´ = 32° E_m = 400MPa

Borehole G5

RQD= 80% σ_{ci} = 5MPa
c´ = 50kPa γ = 21kN/m^3
φ´ = 30° E_m = 400MPa

Layer III, Clay Marl

Borehole G6

RQD= 70% σ_{ci} = 7MPa
c′ = 50kPa γ = 21kN/m^3
φ′ = 33° E_m = 400MPa

Borehole G7

RQD= 80% σ_{ci} = 8MPa
c′ = 50kPa γ = 21kN/m^3
φ′ = 34° E_m = 400MPa

Borehole G8

RQD= 30% σ_{ci} = 4MPa
c′ = 50kPa γ = 21kN/m^3
φ′ = 28° E_m = 400MPa

Borehole G9

RQD= 30% σ_{ci} = 4MPa
c′ = 50kPa γ = 21kN/m^3
φ′ = 28° E_m = 400MPa

Borehole G10

RQD= 40% σ_{ci} = 4MPa
c′ = 50kPa γ = 21kN/m^3
φ′ = 28° E_m = 400MPa

b) **Layer IV, Marly Limestone**

Borehole G1

RQD=	60%	σ_{ci} =	14MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	32°	E_m =	1000MPa

Borehole G2

RQD=	70%	σ_{ci} =	14MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	32°	E_m =	1200MPa

Borehole G3

RQD=	60%	σ_{ci} =	10MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	29°	E_m =	1000MPa

Borehole G4

RQD=	70%	σ_{ci} =	13MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	31°	E_m =	1000MPa

Borehole G5

RQD=	60%	σ_{ci} =	14MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	31°	E_m =	1000MPa

Borehole G6

RQD=	85%	σ_{ci} =	14MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	31°	E_m =	1000MPa

Layer IV, Marly Limestone

Borehole G7

RQD=	100%	σ_{ci} =	14MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	32°	E_m =	1500MPa

Borehole G8

RQD=	75%	σ_{ci} =	10MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	29°	E_m =	1000MPa

Borehole G9

RQD=	90%	σ_{ci} =	11MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	30°	E_m =	1200MPa

Borehole G10

RQD=	85%	σ_{ci} =	12MPa
c´ =	100kPa	γ =	22.5kN/m^3
φ´ =	30°	E_m =	1200MPa

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BOREHOLE G1

±0.0

16.0m

Elevation

-16.0 Sea bottom - Soil surface

Layer Ia (GC) ≈1m

E_{oed} = 3000kPa c_u = 15kPa

-17.0 φ_u = 10° γ = 18kN/m^3

Layer I (GC) 5.5m

N_{SPT}= 6

c´ = 5kPa c_u = 40kPa

φ´ = 30° φ_u = 10°

-22.5 γ = 18kN/m^3 E_{oed} = 6000kPa

Layer II (CL), (SC) 18.5m

N_{SPT}= 19

c´ = 10kPa c_u = 70kPa

φ´ = 30° to 32° φ_u = 5°

γ = 19kN/m^3 E_{oed} = 11000kPa

-41.0

Layer III CLAY MARL 3m

RQD= 60% σ_{ci} = 5MPa

c´ = 50kPa γ = 22kN/m^3

φ´ = 28° E_m = 400MPa

-44.0

Layer IV MARLY LIMESTONE

RQD= 60% σ_{ci} = 14MPa

c´ = 100kPa γ = 22.5kN/m^3

φ´ = 30° E_m = 1000MPa

kv = 1000000kN/m^3

End of Borehole

Fig. A1 (no scale)

Legend

- c_u= Undrained shear strength
- φ_u= Undrained friction angle
- c´ = Effective cohesion
- φ´ = Effective internal friction angle
- σ_{ci} = Uniaxial Compressive Strength
- γ = Wet unit weight
- E_{oed} = Oedometer modulus
- RQD= Rock quality index
- E_m= Rock deformation modulus
- N_{SPT} = SPT , blow counts/30cm

BOREHOLE G2

±0.0

17.1m

Elevation

-17.1 Sea bottom - Soil surface

Layer Ia (SM) — ≈1m

-18.0

E_{oed} = 1000kPa, c_u = 15kPa

φ_u = 0°, γ = 17kN/m^3

Layer I (SM) — 3m

N_{SPT}= 6

c′ = 5kPa, c_u = 40kPa

φ′ = 28°, φ_u = 5°

γ = 18kN/m^3, E_{oed} = 6000kPa

-21.0

Layer II (SM), (MH) — 8m

N_{SPT}= 19

c′ = 5kPa, c_u = 70kPa

φ′ = 30° to 32°, φ_u = 5°

γ = 19kN/m^3, E_{oed} = 10000kPa

-29.0

Layer IIa (SM), (GC) — 10.7m

N_{SPT}= 40

c′ = 5kPa, c_u = 150kPa

φ′ = 37°, φ_u = 5°

γ = 19.5kN/m^3, E_{oed} = 18000kPa

-39.7

Layer III CLAY MARL — 6.5m

c′ = 50kPa, σ_{ci} = 5MPa

φ′ = 28°, γ = 22kN/m^3

RQD= 70%, E_m = 400MPa

-46.2

Layer IV MARLY LIMESTONE

c′ = 100kPa, E_m = 1200MPa

φ′ = 30°, σ_{ci} = 14MPa

kv = 1000000kN/m^3, γ = 22.5kN/m^3

RQD= 70%

End of Borehole

Fig. A2 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c′ = Effective cohesion

φ′ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

BOREHOLE G3

±0.0

8.7m

Elevation

-8.5 Sea bottom - Soil surface -8.7

Layer Ia (SM) (≈1m)

-9.5	E_{oed} = 1000kPa	c_u = 15kPa
	φ_u = 0°	γ = 17kN/m^3

Layer I (SM) (9.0m)

N_{SPT}= 6	
c′ = 5kPa	c_u = 40kPa
φ′ = 28°	φ_u = 5°
γ = 18kN/m^3	E_{oed} = 6000kPa

-18.5

Layer IIa (SM) (2.5m)

N_{SPT}= 30	
c′ = 5kPa	c_u = 100kPa
φ′ = 34°	φ_u = 5°
γ = 19.5kN/m^3	E_{oed} = 11000kPa

-21.0

Layer III CLAY MARL (5.0m)

c′ = 50kPa	σ_{ci} = 5MPa
φ′ = 28°	γ = 22kN/m^3
RQD= 90%	E_m = 800MPa

-26.0

Layer IV MARLY LIMESTONE

c′ = 100kPa	E_m = 1000MPa
φ′ = 30°	σ_{ci} = 10MPa
kv = 1000000kN/m^3	γ = 22.5kN/m^3
RQD= 60%	

End of Borehole

Fig. A3 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c′ = Effective cohesion

φ′ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

BOREHOLE G4

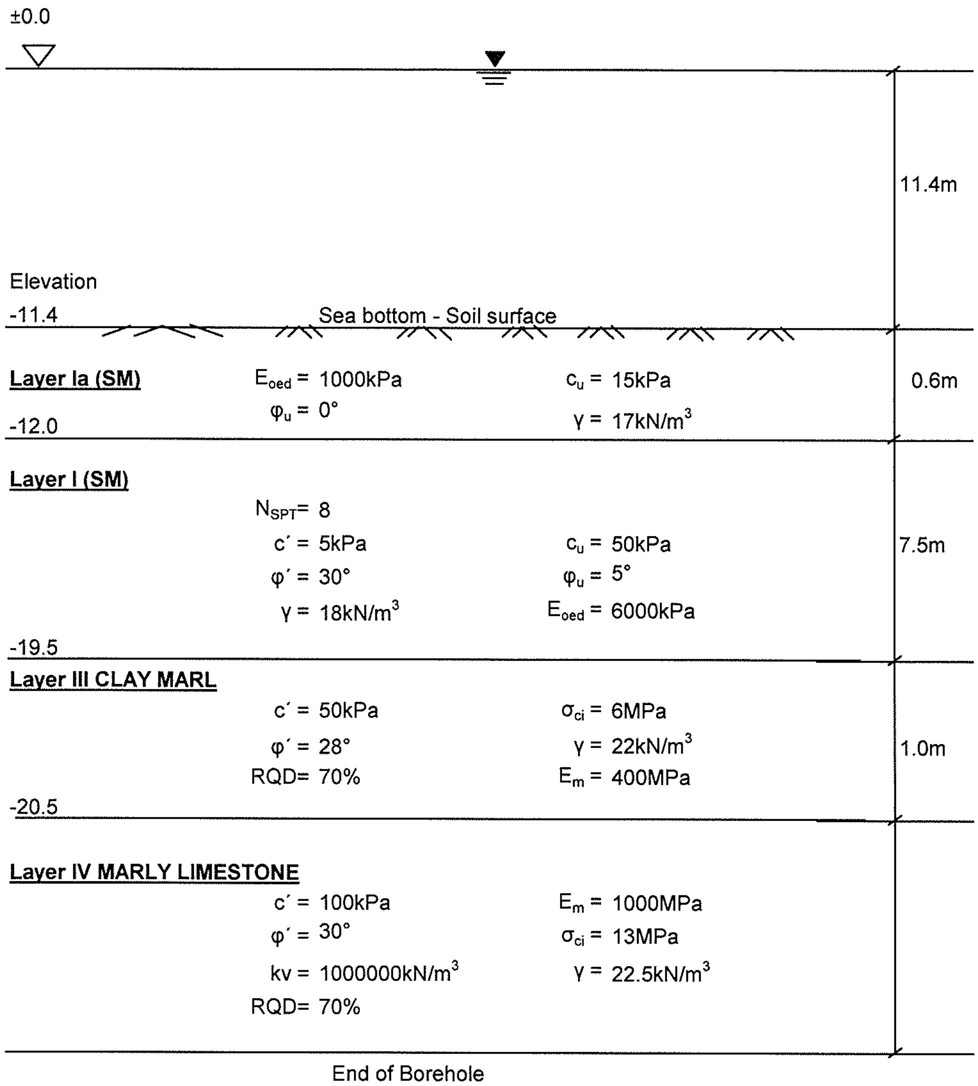

Fig. A4 (no scale)

Legend

c_u= Undrained shear strength
$φ_u$= Undrained friction angle
c´ = Effective cohesion
φ´ = Effective internal friction angle
$σ_{ci}$ = Uniaxial Compressive Strength
γ = Wet unit weight
E_{oed} = Oedometer modulus
RQD= Rock quality index
E_m= Rock deformation modulus
N_{SPT} = SPT , blow counts/30cm

BOREHOLE G5

±0.0

17.1m

Elevation

-17.1 Sea bottom - Soil surface

Layer Ia (SM) ≈1m

E_{oed} = 1000kPa
c_u = 15kPa
φ_u = 0°
γ = 17kN/m^3

-18.0

Layer I (SM), (CL) 9m

N_{SPT}= 7
c′ = 5kPa
c_u = 40kPa
φ′ = 30°
φ_u = 5°
γ = 18kN/m^3
E_{oed} = 6000kPa

-27.0

Layer II (GC) 4.0m

N_{SPT}= 26
c′ = 10kPa
c_u = 120kPa
φ′ = 32°
φ_u = 5°
γ = 19kN/m^3
E_{oed} = 12000kPa

-31.0

Layer IIa (SC), (CL), (GC) 11.3m

N_{SPT}= 40
c′ = 10kPa
c_u = 150kPa
φ′ = 37°
φ_u = 5°
γ = 19.5kN/m^3
E_{oed} = 18000kPa

-42.3

Layer III CLAY MARL 3.2m

c′ = 50kPa
σ_{ci} = 5MPa
φ′ = 28°
γ = 22kN/m^3
RQD= 80%
E_m = 400MPa

-45.5

Layer IV MARLY LIMESTONE

c′ = 100kPa
E_m = 1000MPa
φ′ = 30°
σ_{ci} = 14MPa
kv = 1000000kN/m^3
γ = 22.5kN/m^3
RQD= 60%

End of Borehole

Fig. A5 (no scale)

Legend

c_u= Undrained shear strength
φ_u= Undrained friction angle
c′ = Effective cohesion
φ′ = Effective internal friction angle
σ_{ci} = Uniaxial Compressive Strength
γ = Wet unit weight
E_{oed} = Oedometer modulus
RQD= Rock quality index
E_m= Rock deformation modulus
N_{SPT} = SPT , blow counts/30cm

BOREHOLE G6

±0.0

15.0m

Elevation

-15.0 Sea bottom - Soil surface

Layer Ia (ML) — ≈1m

E_{oed} = 1000kPa | c_u = 15kPa

φ_u = 0° | γ = 17kN/m^3

-16.0

Layer Ia (ML), (MH), (CL) — 4.5m

N_{SPT}= 0-1

c´ = 0kPa | c_u = 10kPa

φ´ = 22° | φ_u = 0°

γ = 17kN/m^3 | E_{oed} = 1000kPa

-20.5

Layer II (CL) — 2m

N_{SPT}= 19

c´ = 10kPa | c_u = 100kPa

φ´ = 32° | φ_u = 0°

γ = 19kN/m^3 | E_{oed} = 11000kPa

-22.5

Layer IIa (GC), (CL) — 12.3m

N_{SPT}= 40

c´ = 15kPa | c_u = 150kPa

φ´ = 37° | φ_u = 5°

γ = 19.5kN/m^3 | E_{oed} = 18000kPa

-34.8

Layer III CLAY MARL — 2.0m

c´ = 50kPa | σ_{ci} = 7MPa

φ´ = 28° | γ = 22kN/m^3

RQD= 70% | E_m = 400MPa

-36.8

Layer IV MARLY LIMESTONE

c´ = 100kPa | E_m = 1000MPa

φ´ = 30° | σ_{ci} = 14MPa

kv = 1000000kN/m3 | γ = 22.5kN/m^3

RQD= 85%

End of Borehole

Fig. A6 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

BOREHOLE G7

±0.0

11.7m

Elevation

-11.7 Sea bottom - Soil surface

Layer Ia (ML) — 0.8m

E_{oed} = 1000kPa | c_u = 15kPa

-12.5

φ_u = 0° | γ = 17kN/m^3

Layer I (ML), (CL) — 9.5m

N_{SPT}= 2

c′ = 0kPa | c_u = 20kPa

φ′ = 24° | φ_u = 0°

γ = 17kN/m^3 | E_{oed} = 2500kPa

-22.0

Layer II (GC), (SM), (SC) — 11.5m

N_{SPT}= 17

c′ = 5kPa | c_u = 60kPa

φ′ = 31° | φ_u = 10°

γ = 19kN/m^3 | E_{oed} = 10000kPa

-33.5

Layer III CLAY MARL — 1.0m

c′ = 50kPa | σ_{ci} = 8MPa

φ′ = 28° | γ = 21kN/m^3

RQD= 80% | E_m = 400MPa

-34.5

Layer IV MARLY LIMESTONE

c′ = 100kPa | E_m = 1500MPa

φ′ = 30° | σ_{ci} = 14MPa

kv = 1000000kN/m3 | γ = 22.5kN/m^3

RQD= 90%

End of Borehole

Fig. A7 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c′ = Effective cohesion

φ′ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

BOREHOLE G8

±0.0

5.7m

Elevation
-6.5 Sea bottom - Soil surface

Layer Ia (SM) (0.8m)

E_{oed} = 1000kPa c_u = 15kPa

-7.3 φ_u = 0° γ = 17kN/m^3

Layer I (SM), (ML) (10.2m)

N_{SPT}= 4

c´ = 0kPa c_u = 20kPa

φ´ = 28° φ_u = 5°

-17.5 γ = 18kN/m^3 E_{oed} = 4000kPa

Layer III CLAY MARL (8.5m)

σ_{ci} = 4MPa

c´ = 50kPa γ = 22kN/m^3

φ´ = 28° E_m = 400MPa

RQD= 30%

-26.0

Layer IV MARLY LIMESTONE

c´ = 100kPa E_m = 1000MPa

φ´ = 30° σ_{ci} = 10MPa

kv = 1000000kN/m^3 γ = 22.5kN/m^3

RQD= 75%

End of Borehole

Fig. A8 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

BOREHOLE G9

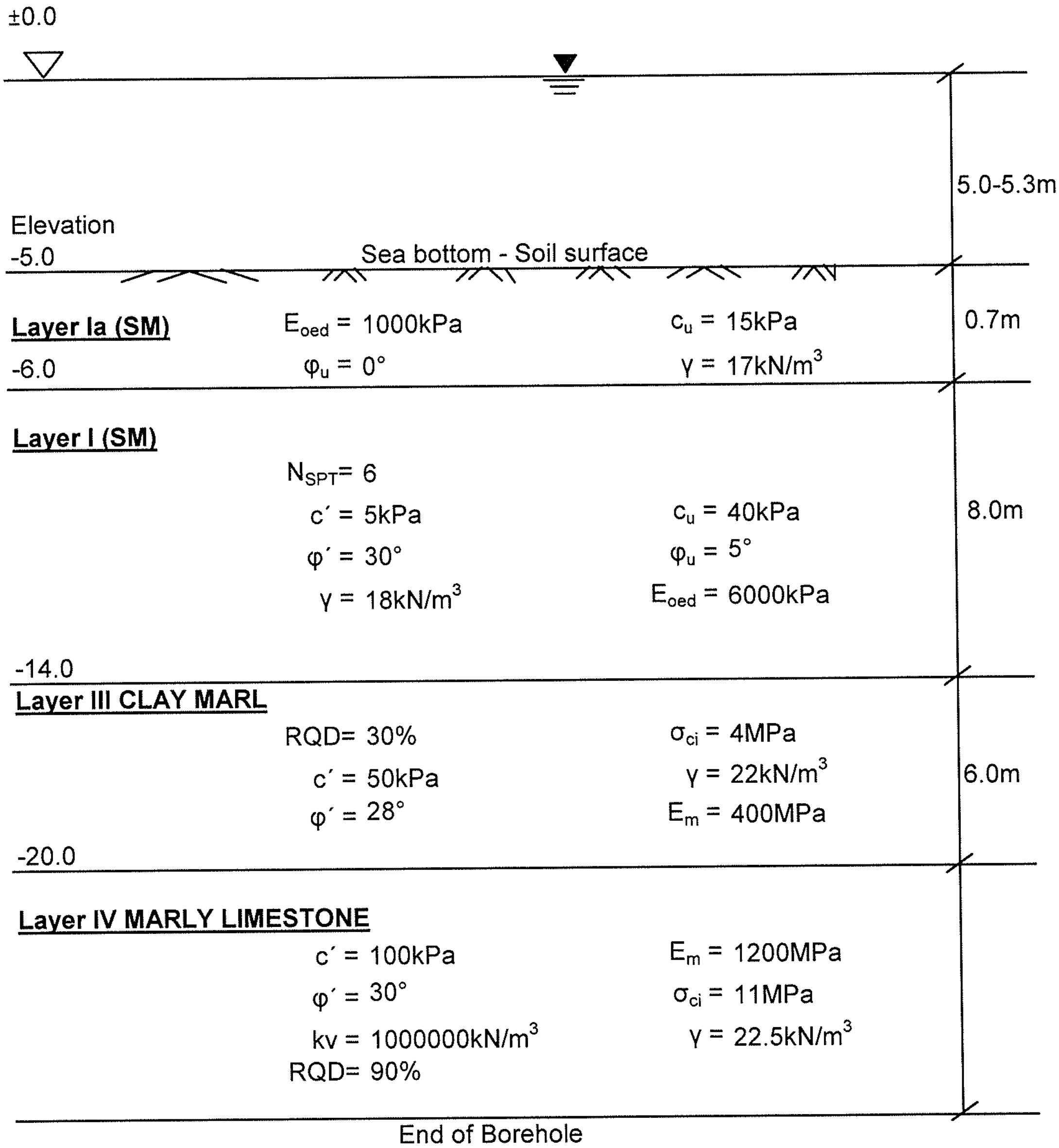

Fig. A9 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c´ = Effective cohesion

φ´ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

BOREHOLE G10

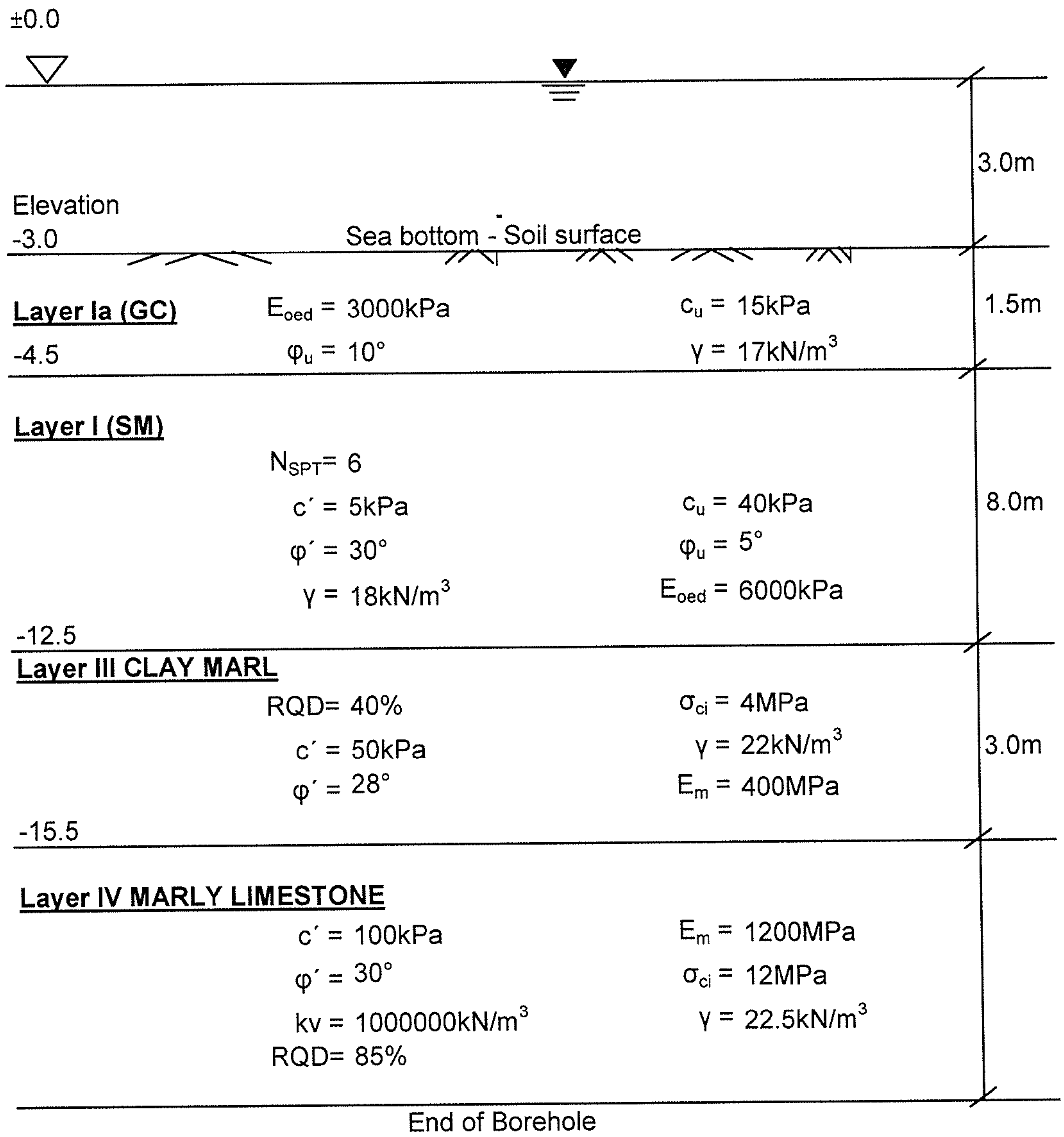

Fig. A10 (no scale)

Legend

c_u= Undrained shear strength

φ_u= Undrained friction angle

c′ = Effective cohesion

φ′ = Effective internal friction angle

σ_{ci} = Uniaxial Compressive Strength

γ = Wet unit weight

E_{oed} = Oedometer modulus

RQD= Rock quality index

E_m= Rock deformation modulus

N_{SPT} = SPT , blow counts/30cm

APPENDIX B

PHOTOGRAPHS OF THE BARGE AND THE DRILLING RIG


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