THE PREDICTION OF FINAL SETTLEMENT FROM 1D-CONSOLIDATION TEST: A CASE STUDY

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ABSTRACT: Consolidation settlement was a major topic discussed by the civil engineers and geologists particularly when dealing with structure design involving foundations. The prediction of long-term settlements can be determined by the soil exploration. In this study, the prediction of settlement for petrol chemical tank reservoir project have been selected and discussed as a case study. Base on thin-wall tube sampler, soil samples from the project were investigated in the laboratory by consolidation test which was done by using the oedometer apparatus. Finally, the consolidation time and settlement can be predicted from the oedometer results which indicate the highest settlement of the project was 0.6m within 1.2 months.

KEYWORDS: Consolidation, settlement, oedometer test

1. INTRODUCTION

Consolidation settlement is a major topic discussed by an engineers and geologists when designing the structures. From past experienced, many case of building problems and failure found that settlements could affect them by continuing settlement for many years with total accumulated settlements being very large. This settlement may due to creep or secondary settlement. There are many method used to predict the settlement such as Casagrande oedometer (Terzaghi, 1923: Casagrande, 1936). We can predict the primary and secondary settlement in laboratory by using 1-D consolidation oedometer test. The reliability of the prediction depends on many factor such as good samples, human, apparatus and others uncertainties especially soils.

A fine-grained soil in saturated condition was subjected to an increasing compressive stress from selected loading and caused the deformation or strain of soil skeleton. Strain is a cumulative effect of grain distortion and particle rolling and slipping. This strain results in a reduction of void ratio or voids volume which can only take place as pore fluid when it displaced. Since a fine-grained soil has a low permeability coefficient, the pore fluid displacement was a rate process, or time dependent. When the compression of a soil mass is a time dependent, it is termed as a consolidation. A soil will be fully consolidated state when its volume remains constant under a constant rate of stress. A soil will be normally consolidated condition when it is currently corresponding to its maximum consolidation pressure. A soil will be over consolidated when the present day overburden pressure is less than the highest historic consolidation pressure.

Terzaghi (1943) suggest the model of one-dimensional consolidation which used the steel spring technique that represents the soil. It is assumed that the frictionless piston was supported by the springs and the cylinder was filled with water. If a load was applied to the piston by the closed valve, the length of the springs will remains unchanged since the water was assumed as incompressible (undrained condition). If the load was induces an increase in total stress of $\Delta\sigma$, then the whole of this consideration must be count initially by an equal increase in porewater pressure Δu. When the valve was opened, excess porewater pressure will cause the water overflow causing the reduction of porewater pressure. Then, the piston will sink as the spring was compressed. Thus, the load was gradually transferred to the springs, causing them to be

shortening until it was carried by the springs. At the final stage, the increasing of effective stress $\Delta\sigma'$ was equal to the increasing total stress resulting the reducing in excess porewater pressure to zero. The rate of compression apparently depends on the extent of which valve was opened; this is due to the analogous to the permeability soil.

2. CASE STUDY

In this study, the proposed Petrol Chemical Tank Reservoir at Shiang Wei PLO 414, Jalan Perak, Kawasan Perindustrian Pasir Gudang, Johor have been selected as a case study. The initial applied load for this project was 140 kPa. The structure was built on a soil which subjected to the settlement. Some settlement is inevitable, depending on the situation and some settlement is tolerable. When we built a structure on a top of soil, some person need to have knowledge of how settlement occurs and predict how much of it and also predict how fast the settlement will occur in this situation. Traditionally, the consolidation behavior has been implemented in the laboratory to determine the consolidation settlement within 90% degree of consolidation and estimation of time to settlement. This project was proposed to Messrs. SHELL Malaysia Trading Sdn. Bhd. LPG Business, Shell Malaysia Trading Sdn. Bhd. Changkat Semantan, Damansara Heinghts, Kuala Lumpur.

A total number of two (2) boreholes were drilled using the rotary drilling machine according to British Standard Code of Practice BS 5930:1981 "Site Investigation". The depth of both boreholes was 6.45m below the ground level. The borehole diameter ranged in size from 76.2mm to 101.6mm. It was advanced by Multi-speed, rotary drilling machine. The rotary wash boring was advanced partly by a chopping and twisting action of a light bit and partly by jetting water which is pumped through the hollow drilled rod and bit. Then, cuttings were removed from the hole by the circulating water. After that, drilled rod and bit moved up and down by pulling and slackening the rope. The soil-laden water from the borehole was discharged into the same reservoir where the coarse materials settled out and from which the so-called 'wet samples' can be secured.

The SPT used a 50mm diameter x 600 long thick-walled split sampler tube which driven into undisturbed soil under the impact of a sliding hammer weighing 65kg with a free fall of 760mm. The penetration resistance of 'N' value was recorded as the number of hammer blows required reached the penetration depth of 300mm. After the finished the job, the sampler tube was removed and dissembled in order to provide a disturbed sample. The SPT was carried out at every 1.50m intervals and at the bottom of every borehole.

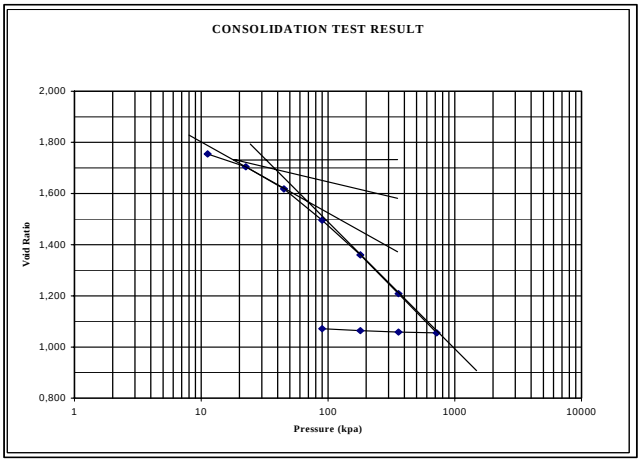
The physical properties observed within the soil layers were a soft to firm and sandy CLAY layer (appendix A). This material was found in each borehole and their color was in a dark grey. The thickness of this CLAY layer was varies from approximately 1.50m to 4.50m and with SPT- N-average of 8. The observed of silty SAND layer found in each borehole was a medium dense to dense. The color was varied from medium red to brown. The thickness of this layer was varies from approximately 4.50m to 6.50m and SPT-N value range from 14 to 36 with an average of 25.

Undisturbed samples were taken from boreholes by using thin-walled tube sampler. The drilling machine forced the thin-walled tube sampler into the undisturbed soil. During a sampling below the water tables, the water was constant at the chasing top until the sampler was removed. Subsequent of these samples, both ends of the sample will be coated with a non-shrinking wax to ensure airtight seal. At this study area, the total of five (5) nos of undisturbed samples has been taken which two (2) nos of them was from the borehole 1 at depth 3.00m and 3.60m and the another three (3) were taken from borehole 2 at depth 1.50m, 2.10m and 2.70m.

3. LABORATORY TESTING

Both disturbed and undisturbed samples were transported to the laboratory for investigation. Several testing were conducted to the samples according to BS 1377:1990. The tests consist of one-dimensional consolidation using oedometer machine.

Borehole No.: **BH1 UD1** Depth : **3.00-3.60** m

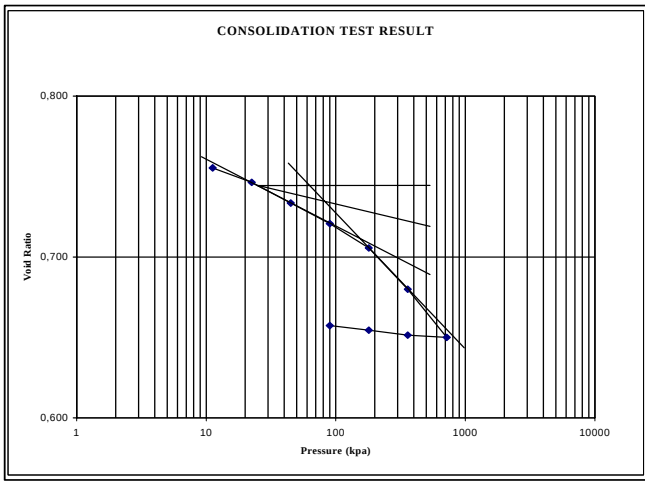


Pressure (kPa)	Void Ratio	Cv (m^2/year)	Mv (m^2/kN)
11,241	1,7547	6,10	
			0,001626780
22,483	1,7043	6,87	
			0,001423902
44,966	1,6177	6,49	
			0,001032770
89,931	1,4961	6,52	
			0,000604690
179,86	1,3604	5,35	
			0,000357390
359,73	1,2087	5,14	
			0,000192869
719,45	1,0554	4,47	

	Initial	Final
Void Ratio	2,0165	1,1085
Sample Height (mm)	20	13,736
Moisture Content (%)	65,80	36,17
Dry Density (Mg/m^3)	1,1427	1,3914
Specific Gravity	2,62	
Coefficient of Compression	0,5090	
Preconsolidation Pressure	40,0 kPa	
Degree of Saturation (%)	85,49 %	

Figure 1: One-dimensional consolidation test result for sample BH1 UD1

Borehole No.: **BH1 UD2** Depth : **3.60-4.20** m

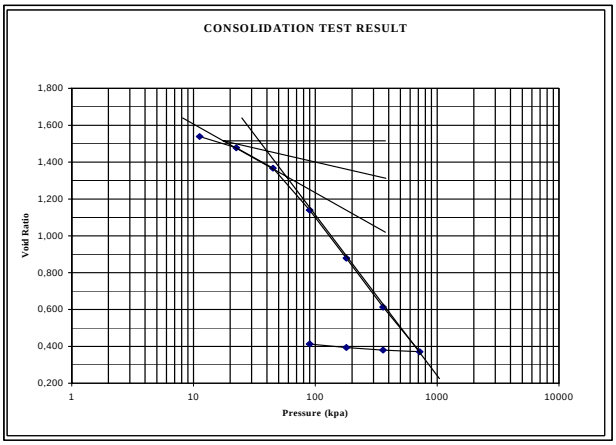


Pressure (kPa)	Void Ratio	Cv (m²/year)	Mv (m²/kN)
11,241	0,7555	8,73	
			0,000458350
22,483	0,7464	8,60	
			0,000327114
44,966	0,7336	8,48	
			0,000164769
89,931	0,7207	8,36	
			0,000097027
179,86	0,7057	8,21	
			0,000083730
359,73	0,6800	7,34	
			0,000049689
719,45	0,6500	7,70	

	Initial	Final
Void Ratio	0,8090	0,2645
Sample Height (mm)	20	18,324
Moisture Content (%)	30,46	9,96
Dry Density (Mg/m³)	1,4522	1,7230
Specific Gravity	2,62	
Coefficient of Compression	0,0998	
Preconsolidation Pressure	80,0 kPa	
Degree of Saturation (%)	98,65 %	

Figure 2: One-dimensional consolidation test result for sample BH1 UD2

Borehole No.: **BH 2 UD1** Depth : **1.50-2.10** m



Pressure (kPa)	Void Ratio	Cv (m²/year)	Mv (m²/kN)
11,241	1,5385	9,44	
			0,002130865
22,483	1,4777	9,90	
			0,001982958
44,966	1,3673	7,62	
			0,002140348
89,931	1,1394	7,23	
			0,001355272
179,86	0,8787	5,72	
			0,000785836
359,73	0,6131	3,49	
			0,000417327
719,45	0,3710	2,82	

	Initial	Final
Void Ratio	1,6554	0,8561
Sample Height (mm)	20	10,644
Moisture Content (%)	61,43	31,77
Dry Density (Mg/m³)	1,1736	1,4378
Specific Gravity	2,62	
Coefficient of Compression	0,8045	
Preconsolidation Pressure	40,0 kPa	
Degree of Saturation (%)	97,23 %	

Figure 3: One-dimensional consolidation test result for sample BH2 UD1

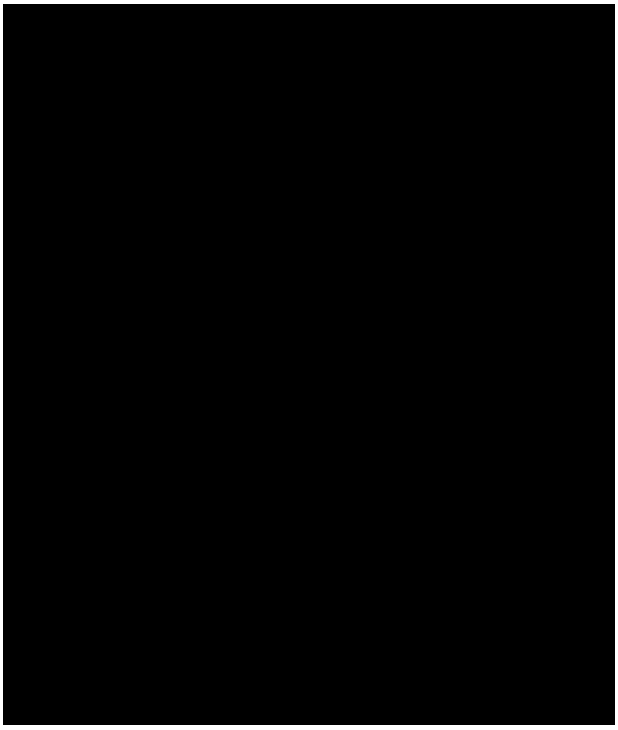
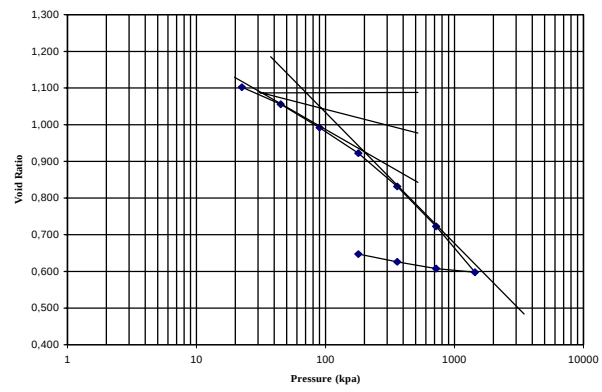


Figure 4: One-dimensional consolidation test result for sample BH2 UD2

Borehole No.: **BH2 UD3** Depth : **2.70-3.30** m

CONSOLIDATION TEST RESULT



Pressure (kPa)	Void Ratio	Cv (m^2/year)	Mv (m^2/kN)
22,483	1,1020	14,41	
			0,000979141
44,966	1,0558	12,16	
			0,000687414
89,931	0,9922	14,68	
			0,000390508
179,86	0,9223	13,70	
			0,000261276
359,73	0,8319	12,57	
			0,000165302
719,45	0,7230	12,92	
			0,000101094
1438,9	0,5977	13,00	

	Initial	Final	
Void Ratio	1,2141	0,8479	
Sample Height (mm)	20	16,692	
Moisture Content (%)	39,30	27,44	
Dry Density (Mg/m^3)	1,3601	1,4866	
Specific Gravity	2,62		
Coefficient of Compression	0,4163		
Preconsolidation Pressure	85,0	kPa	
Degree of Saturation (%)	84,80	%	

Figure 5: One-dimensional consolidation test result for sample BH2 UD3

The result for normally consolidated soil shows the preconsolidation pressure (Pc) for sample BH2 UD3 has the highest value of 85kPa, compare to other samples. The lowest value of preconsolidation pressure (Pc) is 40kPa for sample BH1 UD1 and BH2 UD1. The preconsolidation pressure (Pc) results were determined based on Cassagrande method.

5. RESULTS, ANALYSIS AND DISCUSSIONS

The applied initial load was 140kPa and was calculated as a permanent load of a foundation structure. Information from consolidation test result was applied to determine the consolidation settlement and time to reach 90% degree of consolidation. The discussion of consolidation parameter was only at sandy CLAY layers between depths 0.00m to 4.20m.

The general subsoil condition for BH 1 from 0.00m to 3.60m was a soft soil ground layer and the average water table was 0.8m below the ground level (BGL). The testing parameters for BH 2 are listed in table 1.

Table 1: Parameter Based On One-D Consolidation Test BH1 UD1 3.00-3.60m and BH1 UD2 3.60-4.20m

Parameter	BH 1 UD1	BH 1UD 2
Average initial void ratio, e	2.0165	0.8090
Coefficient of vertical consolidation, Cv	6.10 m^2/year	8.73 m^2/year
Preconsolidation pressure, Pc	40 kPa	80 kPa
Compression index, Cc	0.5090	0.0998
Assume thickness of soft ground layer, H	3.60 m	3.00 m
Assume design structured load, P	140 kPa	140 kPa
Average water level	0.8 m	0.8 m
In-situ stress of middle of soft clay (3.30 m BGL), P'	25.00 kPa	31.00 kPa
Consolidation settlement calculation, Sc	0.4545 m ≃ **0.5m**	0.1083 m ≃ **0.1m**
Time to reach t 90% of consolidation settlement, t90%	0.46 year ≃ **6 months**	0.22 year ≃ **3 months**

The condition of subsoil for BH2 was a soft soil layer from 0.00m to 2.10m BGL and the average water table was 0.8m BGL. The testing parameters for BH 2 were listed in the table 2.

Table 2: Parameter Based On One-D Consolidation Test BH2 UD1 1.50-2.10m, BH2 UD1 1.50-2.10m and BH2 UD3 2.70-3.30m

Parameter	BH 2 UD1	BH 2 UD2	BH 2UD3
Average initial void ratio, e	1.6554	1.3935	1.2141
Coefficient of vertical consolidation, Cv	9.44 m^2/year	8.57 m^2/year	14.41 m^2/year
Preconsolidation pressure, Pc	40 kPa	42 kPa	85 kPa
Compression index, Cc	0.8045	0.4127	0.4163
Assume thickness of soft ground layer, H	2.00 m	1.00 m	2.00 m
Assume design structured load, P	140 kPa	140 kPa	140 kPa
Average water level	0.8 m	0.8 m	0.8 m
In-situ stress of middle of soft clay (3.30 m BGL), P'	18.00 kPa	24.00 kPa	30.00 kPa
Consolidation settlement calculation, Sc	0.54 m ≃ **0.6 m**	0.13 m ≃ **0.13 m**	0.2516m ~ **0.3 m**
Time to reach t 90% of consolidation settlement, t90%	0.1 year ≃ **1.2 months**	0.024 year ≃ **0.3 month**	0.06 year ≃ **0.7 months**

The result for normally consolidated soil shows that the preconsolidation pressure (Pc) for sample BH2 UD3 has the highest value of 85kPa, compare to other samples. The lowest value of preconsolidation pressure (Pc) was 40kPa for sample BH1 UD1 and BH2 UD1. The preconsolidation pressure (Pc) results were determined based on the Cassagrande method.

The sandy CLAY layer was found between 0.00m to 4.20m and the problem will be discuss at this layers. From the 1-D consolidation test, the settlement and time to reach 90% degree of consolidation can be compute. The summary of settlement result was tabulated in table 3. For borehole (BH 1 and BH 2) the average of consolidation coefficient was very high which about 6.10 to 14.41 m^2/year and this indicate that the soil was very high in compressibility. The Preconsolidation pressure, Pc was between 40kPa to 140kPa and this indicates that the soil durability was low and can exhibit a high settlement.

Table 3: Summary of Settlement and Time

SAMPLE	SETTLEMENT (m)	TIME AT U=90% (Months)
BH1/UD1/3.00 – 3.60 m	0.5	6
BH1/UD2/3.60 – 4.20 m	0.1	3
BH2/UD1/1.50 – 2.10 m	0.6	1.2
BH2/UD2/2.10 – 2.70 m	0.13	0.3
BH2/UD3/2.70 – 3.30 m	0.3	0.7

6. CONCLUSION

From the laboratory results, the highest settlement was 0.6m within 1.2 months. These indicate that the soil was very high in settlement and time to reach 90% degree of consolidation was fast. The consolidation settlement and time reach 90% consolidation settlement can be used to evaluate the settlement for soil in order to predict the impact to the foundation.

The field testing using boring machine found a sandy CLAY layer at depth of 0.00m to 4.20m which is lower in 'N' SPT value and this indicate that the soil was very weak in strength. For suggestion, the soil for the proposed site should be improved by some methods before the construction work being implemented or the using of piling foundation must be introduced in the foundation design in order to solve the problems.

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8. APPENDICES

APPENDIX A

Project : SOIL INVESTIGATION WORKS FOR PROPOSED PETROL CHEMICAL TANK RESERVOIR AT SHIANG WEI PLO 414, JALAN PERAK, KAWASAN PERINDUSTRIAN PASIR GUDANG, JOHOR DARUL TAKZIM

Client : MESSRS. SHELL MALAYSIA SDN. BHD.

Borehole No. : BH 1	Date Started :	Coordinate, E :	Final Depth : 6.45m	Boring Dia. : 76.20mm
Reduced Level :	Date Completed :	N :	Final W.L : 1.00 m	Type of Boring : RWB

Depth (m)	Legend	Soil Description & Lithology	Sample Ref.	Depth (m)	Rec. Ratio	75 mm	75 mm	75 mm	75 mm	75 mm	75 mm	'N' Value	Remarks
		Top Soil:											
		Firm, dark grey with a traces of pale grey spotted, sandy CLAY	P1/ D1	1.50 to 1.95	370/450	1	1	2	1	1	1	5	
		Dark grey with a little medium brown mottled, sandy CLAY	UD1	3.00 to 3.60	600/600								
3.60m		Dark grey with a little dark grey mottled, silty SAND	UD2	3.60 to 4.20	600/600								
		Medium dense, medium brownish red, silty SAND	P2/ D2	4.50 to 4.95	390/450	2	3	2	3	4	5	14	
		Medium dense, medium brownish red, silty SAND	P3/ D3	6.00 to 6.45	400/450	2	2	3	3	5	5	16	
6.45m		**END OF BH 1 AT 6.45 m** Final Water Level is 1.00m											

Scale of Strength

Cohesive Soil		Non-Cohesive	
0 - 2	Very soft	0 - 4	Very loose
2 - 4	Soft	4 - 10	Loose
4 -8	Firm	10 - 30	Medium dense
8 - 15	Stiff	30 - 50	Dense
15 - 30	Very stiff	> 50	Very dense
> 30	Hard		

Water Observation

Date	Time	Depth	Casing	W.L

Legend

	: Wash Boring	D	: Disturbed Sample
	: Split Spoon Sample	UD	: Undisturbed Sample
	: Thin Wall Tube Sample	CL	: Cored Length
	: Piston Sample (Ps)	TCR	: Total Cored Recovery
	: Maizer Sample (M)	RQD	: Rock Quality Designation
	: Rock Core Sample	V	: Vane Shear Test
	: Water Level (WL)	Pm	: Permeability Test
P	: Standard Penetration Test	Pr	: Pressuremeter Test

APPENDIX B

Project : **SOIL INVESTIGATION WORKS FOR PROPOSED PETROL CHEMICAL TANK RESERVOIR AT SHIANG WEI PLO 414, JALAN PERAK, KAWASAN PERINDUSTRIAN PASIR GUDANG, JOHOR DARUL TAKZIM**

Client : **MESSRS. SHELL MALAYSIA SDN. BHD.**

Borehole No. : **BH 2**	Date Started :	Coordinate, E:	Final Depth : 6.45m	Boring Dia. : 76.20mm
Reduced Level :	Date Completed :	N:	Final W.L : 1.00 m	Type of Boring : RWB

Depth (m)	Legend	Soil Description & Lithology	Sample Ref.	Sample Depth (m)	Sample Rec. Ratio	SPT 75 mm	SPT 75 mm	SPT 75 mm	SPT 75 mm	SPT 75 mm	SPT 75 mm	'N' Value	Remarks
		Top Soil:											0
													1.1
		Dark grey with a little medium brown spotted, sandy CLAY	UD1	1.50 to 2.10	600/600								
		Pale grey with a traces of medium brown mottled, sandy CLAY	UD2	2.10 to 2.70	600/600								2.2
2.70m		Medium brown with a traces of pale grey spotted, sandy SILT	UD3	2.70 to 3.30	600/600								3.3
4.50m		Medium dense, medium reddish brown with a traces of pale grey mottled, silty SAND	P1/ D1	4.50 to 4.95	400/450	2	3	4	4	5	6	19	4.4
													5.5
6.45m		Medium dense, medium brown, silty SAND	P2/ D2	6.00 to 6.45	410/450	3	4	4	5	5	7	21	
		END OF BH 2 AT 6.45 m Final Water Level is 1.00m											6.6
													7.7
													8.8
													9.9

Scale of Strength

Cohesive Soil		Non-Cohesive	
0 - 2	Very soft	0 - 4	Very loose
2 - 4	Soft	4 - 10	Loose
4 - 8	Firm	10 - 30	Medium dense
8 - 15	Stiff	30 - 50	Dense
15 - 30	Very stiff	> 50	Very dense
> 30	Hard		

Water Observation

Date	Time	Depth	Casing	W.L

Legend

	: Wash Boring	D	: Disturbed Sample
	: Split Spoon Sample	UD	: Undisturbed Sample
	: Thin Wall Tube Sample	CL	: Cored Length
	: Piston Sample (Ps)	TCR	: Total Cored Recovery
	: Maizer Sample (M)	RQD	: Rock Quality Designation
	: Rock Core Sample	V	: Vane Shear Test
	: Water Level (WL)	Pm	: Permeability Test
P	: Standard Penetration Test	Pr	: Pressuremeter Test