ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

CORRELATION OF CBR WITH INDEX PROPERTIES OF SOILS IN SULULTA TOWN

A thesis submitted to the School of Graduate Studies of Addis Ababa Institute of Technology in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Geotechnical Engineering)

By

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Contents

SYMBOLS AND ABBREVIATIONS

AASHTO - American Association of Highway and Transportation Officials

ASTM - American Society for Testing and Materials

CH- Inorganic Clay of High plasticity

CBR- California Bearing Ratio

Eqn. - Equation

GPS- Global Positioning System

LI - Liquidity Index

LL - Liquid limit

MDD - Maximum Dry Density

MH – Inorganic Elastic silt

OMC - Optimum Moisture Content

PI - Plasticity index

PL - Plastic limit

PP_{200}- Percent Passing Sieve No. 200 (0.075mm sieve size)

R - Red

R^2 - Coefficient of Correlation

SPSS- Statistical Package for Social Science Software

TP- Test pit

q_u- Unconfined compressive strength

UC - Unconfined compression

USCS - Unified Soil Classification System

Y - Yellow

ω - Water content

α – Standard Significant Error

α_1, α_2, α_3, α_n -Coefficients of the Multiple Linear Regression Equation

β_1, β_2, β_3, βn - Coefficients of the Single Linear Regression Equation

σ^2-Statistical Variance

Ɛ - Statistical Random Error

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ABSTRACT

Soils are the oldest and most complex engineering materials. The California Bearing Ratio (CBR) has been acknowledged as an important parameter to characterize the bearing capacity of earth structures, such as earth dams, road embankments, airport runways, bridge abutments and pavements.

This research presents and discusses the results from a study on the prediction of CBR. In the current study, CBR testswere performed on thirty one samples of fine-grained soils in the laboratory, collected from various locations in Sululta Town. Based on the test results, the soils are categorized in to red clay and black/gray clay soils and the correlationswere done independently for the two categories.

Then various linear relationships between index properties and CBR of the samples were investigated using simple and multiple linear regression analysis, predictive equation estimating CBR from the experimental index values were developed by multiple linear regression analysis and alesser empirical correlation was found with a correlation coefficient R^2 = 0.319for Red clay and satisfactory empirical correlation was obtained with a correlation coefficient R^2 =0.720for black/gray clay of the experimental soils. The equations are developed by using SPSS 23 for windows software. The equations are then tested for two control samples for the two categories. The most important equations are proposed, and applicable with sufficient accuracy for preliminary identification of material for the local area.

1. Introduction

1.1 Background

All civil engineering works such as the construction of highway, building structure, dam and other structure have a strong relationship with soil. All those structures need a strong layer of soil to make sure that the structure is stable. The weakness and failure of soil may lead the structure which builds above it to become weak and collapse or fail. Therefore, the proper analysis of soil is necessary to ensure that these structures remain safe and free endue settling and collapse. Soil conditions vary from one location to another. Hence, it is difficult to predict the behavior of soil. As a result, soil conditions at every site must be thoroughly investigated for proper design.

For applications where the effect of compaction water content on CBR is small, such as cohesion less, coarse-grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort.

The design for new construction should be based on the strength of the samples prepared at optimum moisture content (OMC) corresponding to the Proctor Compaction and soaked in water for a period of four days before testing. In case of existing road requiring strengthening, the soil should be molded at the field moisture content and soaked for four days before testing.

CBR test should be performed on remolded soil in the laboratory. In-situ tests are not recommended for design purpose

CBR test is laborious and time consuming; furthermore, the results sometimes are not accurate due to poor quality of skill of the technicians testing the soil samples in the laboratory. To overcome these difficulties, an attempt has been made in this study to correlate CBR value statistically with the Liquid limit (LL), Plastic limit (PL), Plasticity index (PI), Liquidityindex (LI), andGrain size (PP_{200}) of soil, because these tests are simple and can be completed in less period of time.

1.2Objective of the study

1.2.1 General Objective

The general objective of this research is to find correlation between California Bearing Ratio with index properties of soils found in the study area.

1.2.2 Specific Objective

- To determine the index properties of soils found in SulultaTown.
- To establish relationship between index properties of soils and CBR values for soils found in Sululta town.

1.3Scope of the study

This thesis is intended to address the relationship between the index properties of soil and the CBR value of soil samples recovered in the study area.

With regard to the regression analysis, depending on the trends of the distribution of test results the correlation is analyzed using a linear regression model. The required correlation is carried out by applying a single linear regression model and multiple linear regression models with the aid of SPSS Software. Furthermore, the scope of the developed correlation is limited to the test procedures followed in the subject research work.

1.4 Methodology

Primarily, in order to address the intended objectives of the study, basic theories and descriptions of CBR test in general and in relation to soil index property of subgrade soil reviewed. Subsequently, previous works of different researchers with regard to prediction of CBR value from basic soil index properties were assessed. In order to have satisfactory data for utilizing the correlations, laboratory tests were conducted on samples collected from different parts of Sululta town, so as to get records of test results of CBR values along with the associated soil indices particularly the grain size analysis, Atterberg limits, specific gravity.

Analyses of test results were carried out and correlations were developed and also analyzed to fit the test results. Under the discussions of the obtained results the suitability of the developed correlations were examined. Finally, a generalized conclusion and recommendation were made.

1.5 Organization of the study

The thesis is organized and presented in six Chapters. The first Chapter highlights introduction of the subject. Chapter two deals with review of literatures. Chapter threecovers about description of the study area. Chapter four explains laboratory test results and discussions. In Chapter five, regression analyses and correlations aredone and Chapter six deals with validating andevaluating the obtained correlations. The last chapter presents conclusions and recommendations. Finally, laboratory test results enclosed under appendix section.

2. Literature Review

2.1 General

Roads are necessary for transportation and economic development of country. Most of the road network in ourcountry is consisting of flexible pavement. Flexible pavement consists of different layers such as sub-grade, sub-base, base course and surface layer. California Bearing Ratio (CBR) is one of the methods to determine the sub grade strength. Design and performance of flexible pavement mainly depends on the strength of sub-grade material. The load from the pavement surface is ultimately transferred to sub-grade. The sub-grade is designed such that the stress transferred should not exceed elastic limit. Hence, the suitability and stability of sub-grade material is evaluated before construction of pavement. California bearing ratio (*CBR)* value is considered as strength parameter in design of pavement Structure.

Among the various methods of evaluating the subgrade strength, quick estimate of CBR is very important for highway engineer so a simple test that can be used as an index test was devised. Thus index test is an indirect measure of stiffness modulus or shear strength.

2.2CBR Test Methods

The California Bearing Ratio (CBR) test can be carried out both in laboratory and in field. The CBR is a penetration test for evaluation of the strength of natural ground, subgrades and base courses beneath new carriageway construction. The basic site test is performed by measuring the pressure required to penetrate soil or aggregate with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material. The CBR test is described in ASTM Standards [1] for laboratory-prepared samples.

2.2.1 In-Situ Testing

Field CBR tests are used for evaluation and design of flexible pavement components such as base and sub base and subgrades and for other applications (such as unsurfaced roads) for which CBR is the desired strength parameter. The in situ CBR test is described in ASTM Standards [2] or AASHTO T-193[3] for soils in field.

If the field CBR is to be used directly for evaluation or design without consideration for variation due to change in water content, the test should be conducted under one of the following conditions: (a) when the degree of saturation (percentage of voids filled with water) is 80 % or greater, (b) when the material is coarse grained and cohesion less so that it is not significantly affected by changes in water content, or (c) when the soil has not been modified by construction activities during the two years preceding the test[2]. In the last-named case, the water content does not actually become constant, but generally fluctuates within a rather narrow range. Therefore, the field in-place test data may be used to satisfactorily indicate the average load-carrying capacity.

2.2.2Field CBR test procedure

A circular area of about 30 cm in diameter is trimmed and leveled. Particular care should be taken at the center where the plunger is to be seated. The surcharge load of 15kg is paced on this surface and the plunger is seated properly. The dial gauge to measure the penetration is attached to the plunger from an independent datum frame. A seating load of 4kg is applied and the load and penetration dials are set to zero.

The load is applied to the plunger by means of the screw jack such that the rate of penetration is approximately1.25mm/min. The load readings are noted for at penetrations 0.0,0.5,1.0,1.5,2.0,2.5,3.0,4.0,5.0,7.5,10.0 and 12.5 mm. the load is released and moisture content specimen is taken from underneath the plunger.

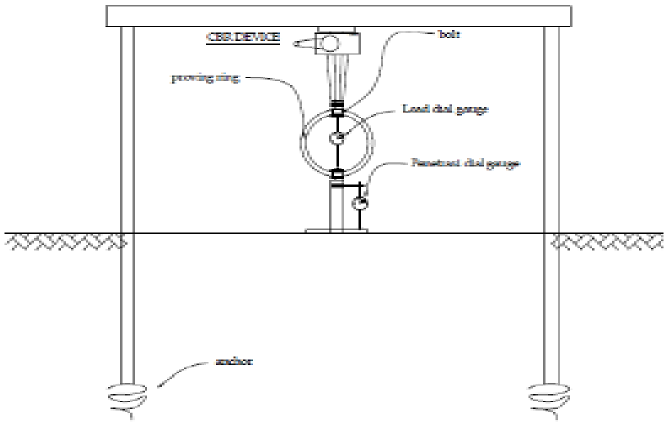

Fig.2.1. Field CBR Apparatus

2.2.3 Laboratory Testing

It is a load-deformation test performed in the laboratory; the results are then used with an empirical design chart to determine the thickness of flexible pavement, base, and other layers for a given vehicle loading. The California bearing ratio is defined as the ratio of the test load to the standard load, expressed as percentage for a given penetration of the plunger.

CBR = (Test load/Standard load) ×100

Generally, CBR decreases as the penetration increases. The test procedure should be strictly adhered if high degree of reproducibility is desired [4].Laboratory CBR test is carried out as per the procedure described in ASTM Standards [1].

Fig.2.2. Laboratory CBR Apparatus

2.3 Index Property Tests

The properties of soils which are not of primary interest to the geotechnical engineer but are inductive of the engineering properties are called index properties [5].The strength and compressibility characteristics of cohesive soils are functions of water content. As such water content is an important factor in understanding the aggregate behavior of cohesive soils [6]. To characterize these behavior parameters like specific gravity, grain size distribution, Consistency limits and moisture-density relationships are used to classify cohesive soils and provide correlation with engineering properties ofsoils [7]

2.4 Existing Correlations

Correlations of CBR with different index properties have been made by different researchers. However, the validity and applicability of such correlations need to be established for their acceptances in general practice. The predicted and experimental values of CBR of various soils have been used to check the applicability and limitations of available methods.

The models developed from Simple Multiple Regression Analysis is given by different investigators as;

CBR_s = f (F, S, G, LL, PL, MDD, and OMC) and a typical Model equation is as follows:

CBRs=0.064F+0.082S+0.033G-0.069LL+0.157PL-1.810MDD-0.061OMC… (2.1) [8]

The validity of the proposed model for prediction of CBR value was verified by data of soil properties reported by few investigators. The results of the predicted and experimental soaked CBR values are presented in Table 2.1. The CBR value was predicted using the proposed regression model given by equation (2.1). It was found that the experimental CBR value and the predicted CBR values are close to each other. The proposed model should only be used along with good judgment and engineering experience for that particular area to provide a rapid and cost-effective method of determining CBR of subgrade soil [9].

2.5 Validity of the Proposed Model

The validity of the proposed model for prediction of soaked CBR value was verified by data of soil properties reported by few investigators. The results of the predicted and observed soaked CBR values are presented in Table 2.1. The soaked CBR value was predicted using the proposed regression model given by equation (2.1). It was found that the observed soaked CBR value and the predicted CBR values are close to each other.

Table 2.1: Validity of Proposed Model by earlier investigators [8]

Investigator	(El-Rawi& Al-Samadi, 1995)	(El-Rawi& Al-Samadi, 1995)	(Mohanty et al., 2011)	(Reddy et al., 2011)
Fines (%)	89	97	92.56	54
Sand (%)	11	3	7.44	43
Gravel (%)	0	0	0	3
LL (%)	52	51	33.45	42
PL (%)	29	24	22.24	22
OMC (%)	22.7	20.5	17	14.6
MDD (g/cc)	1.54	1.67	1.72	1.8
Predicted CBRs Value (%) by Equation 2.1	3.38	2.42	3.57	3.50
Observed CBRs Value (%)	3.8	2.5	3.28	3.8
Ratio of Predicted CBRs to Observed CBRs	0.89	0.96	1.09	0.92

Suitable correlation between CBR valuesand Index properties of subgrade soils in Northern, north-east and north-west parts of Addis Ababa was carried by Leliso Y.[10].

The previous researcher [10] Performed his research on 42 samples of fine grained soils found in Addis Ababa, on the basis of which he has developed a correlation between CBR values and Index properties (liquid limit, plastic limit, plasticity index, grain size).

Single Linear Regression Analysis

Model 1: Correlation between CBR and Liquid Limit (LL) CBR = 16.270 - 0.179*LL, with R2 = 0.458, n = 42
Model 2: Correlation between CBR and Plastic Limit (PL) CBR = 6.737 - 0.025*PL, with R2 = 0.003, n = 42
Model 3: Correlation between CBR and Plasticity Index (PI) CBR = 10.413 - 0.177*PI with R2 = 0.429, n = 42
Model 4: Correlation between CBR and Percent Passing Sieve No. 200 (P200) CBR = -1.366 + 0.089*P200, with R2 = 0.041, n = 42
Model 5: Correlation between CBR and Maximum Dry Density (MDD) CBR = -35.966 + 27.072*MDD, with R2 = 0.384, n = 42
Model 6: Correlation between CBR and Optimum Moisture Content (OMC) CBR = 9.499 - 0.150*OMC, with R2 = 0.06, n = 42

From the developed single linear regression models by the researcher, based on coefficient of determination (R^2), CBR value correlates relatively better with liquid limit and plasticity index.

Multiple Linear Regression Analysis

Model A: Correlation between CBR with PL and PI CBR = 14.580 - 0.197*PI - 0.112*PL, with R2 = 0.494, n = 42
Model B: Correlation between CBR with PI and P200 CBR = 8.302 - 0.190*PI + 6.33*P2005, with R2 = 0.533, n = 42
Model C: Correlation between CBR with LL, PI and MDD or (LL, PL and MDD) CBR = -21.734 - 0.003*LL - 0.137*PI + 20.244*MDD, with R2 = 0.629, n = 42 Or CBR = -21.522 - 0.141*LL + 0.137*PI + 20.244*MDD, with R2 = 0.629, n = 42

From the researcher's findings, Model C indicated that the relationship developed between CBR with LL, PL and MDD is moderately correlated than all the rest models.

Based on critical observation the previous researcher have done correlations of CBR with index properties for fine grained soils, and the current research tried to fill a gap of research similarly on fine grained soils of thirty one samples in the study area in our country.

3. Description of the study area

3.1 Topography, vegetation, Climate and Geologyof the area of study

Sululta is one of special zone surrounding Addis Ababa in the Oromia Region of Ethiopia. It was founded in 1929 E.C. Sululta is bordered on the south by the city of Addis Ababa, on the west by the Mulo and MirabShewa Zone, on the north by SemienShewa Zone, and on the east by Bereh. And it has latitude of (910'59.988"N), longitude of (3845'0.000"E) and an average elevation of 2505meters above mean sea level. And it is about 20 km north of Addis Ababa.

The Town is characterized by the Sululta plain, which is a wide, shallow valley, almost completely surrounded by mountains with numerous small rivers which drain into the Muger. The plain is swampy with some quite large areas of open water in the rainy season, but it reverts to grazing land during the dry months. The surrounding mountainsides were covered with forest dominated by Juniperusprocera, and the lower slopes supported groves of Acacia, but now most of the hillsides are covered with plantations of Eucalyptus with only the odd native tree remaining, except for the groves protected by the presence of a church.

The climate in Sululta town is cold. In summer, there is much less rainfall than in winter. According to Koppen and Geiger, this climate is classified as Cwb (Temperate dry winter warm summer)[11].The average annual temperature in sululta is 14.84^{0}c. The area lies in the medium to high rain fall, the rainfall here averages 1119mm [12].

The geological setting of the study area is generally classified in to two major groups; namely, TertiaryVolcanics (Plateau Basalts) and Quaternary units (Rift Volcanics and Sediments). The classification is based on age of eruptions, special distribution, and mode of occurrences. Tertiary Plateau Basalts are part of the Trap-Series volcanic products consisting huge accumulation of basaltic rocks with minor silicic intercalations, whereas the Quaternary Rift Volcanics and sediments comprise variety of rock units (both acidic and basic) associated to the formation of the Main Rift System during the Quaternary Period. However, each of them has subdivisions; whereby Tertiary Volcanics (Plateau Basalts) consists of Aiba Basalt, Alaji Basalt and Chancho Basalt on the other hand Quaternary units (Rift Volcanics and Sediments) comprises Adama Group and EntotoSilicics. Alaji Basalt situated in gently undulating lands and at surfaces where usually covered by relatively thick soil in plain areas of the study area. Weathered material of the unit virtually looks like volcanic ash of light gray to white and fine-grained soft matrix, with sub rounded weathering remnant boulders of the basalt, which exhibits white weathering. Alaji Basalt directly overlies the AibaBasalt,which in turn is overlain by Chancho Basalts of youngervolcanisms. This unit covers large proportion of the total area of the study area and quarrying activities is undertaken on it. Aiba basalt occurs on the northern part of the study area. The unit underlies younger volcanic products mapped in this work as Alaji Basalt and ChanchoBasalt,with rare basictuff inter layering at top. This unit is characterized by its homogenous in composition and range of thickness from 200 to 600 meters. It is the second larger portion in the study area next to Alaji Basalt. Chancho Basalt is other basaltic unit that accumulated Up to 200m thick, mapped in the study area. The unit is situated as a patch occupying small proportion as per the total area, to thenortheast of the study area. Adamagroup in general consists of fiamme ignimbrites of light greenish gray to reddish brown varieties, and unwelded tuffs. The unit also uncomfortably overlies faulted blocks of Plateau Basalt Formations of Tertiary Volcanics in areas along the Rift Shoulder and it covers relativelysmall part of the study area. EntotoSilicics is situated in the southern fringe of the study area around the Mountain Chain of Entoto that surrounds Addis Ababa City from northwestern, northern and northeastern directions. And the unit covers the least proportion of the study area, it lies up to 200m thick and it is either overlies or cuts troughChancho Basalts and in turn is overlain by younger ignimbrites of Adama Group. See figure 3.1 for detailed information[13].

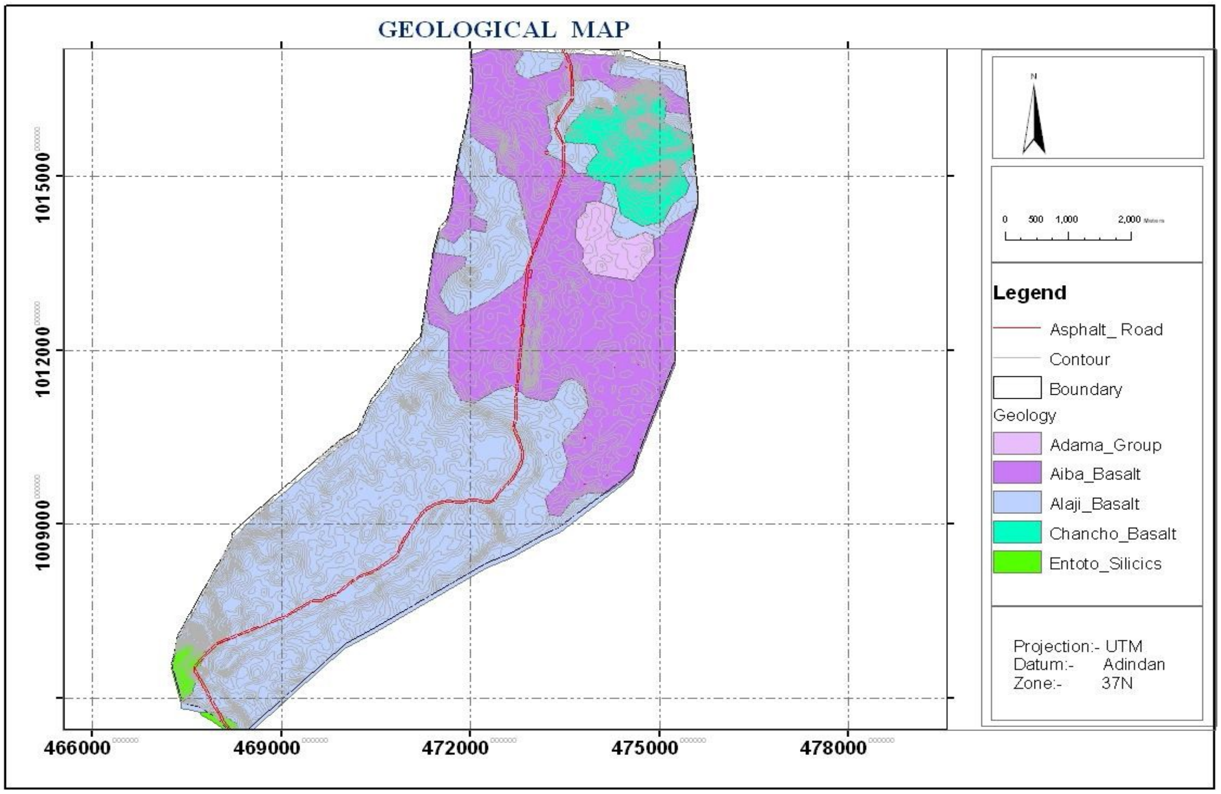

Figure 3.1: Geological map [13]

Based on the above figure 3.1, the dominant geological component in the study area is Alaji basalt which accounts about 56.5%.Aiba basalt is the second dominant component which covers about 33.7% of the study area. The rest of the area is covered by Chancho basalt, Adama group and Entotosilicics.

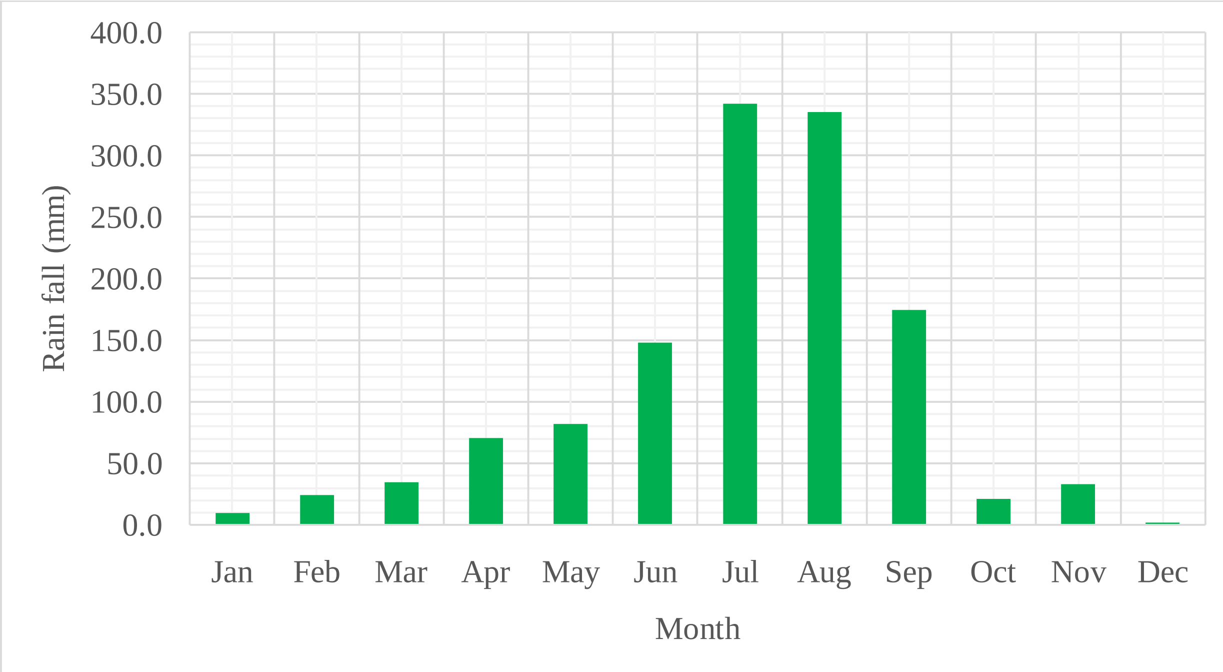

Figure 3.2: Mean monthly rain fall distribution [12]

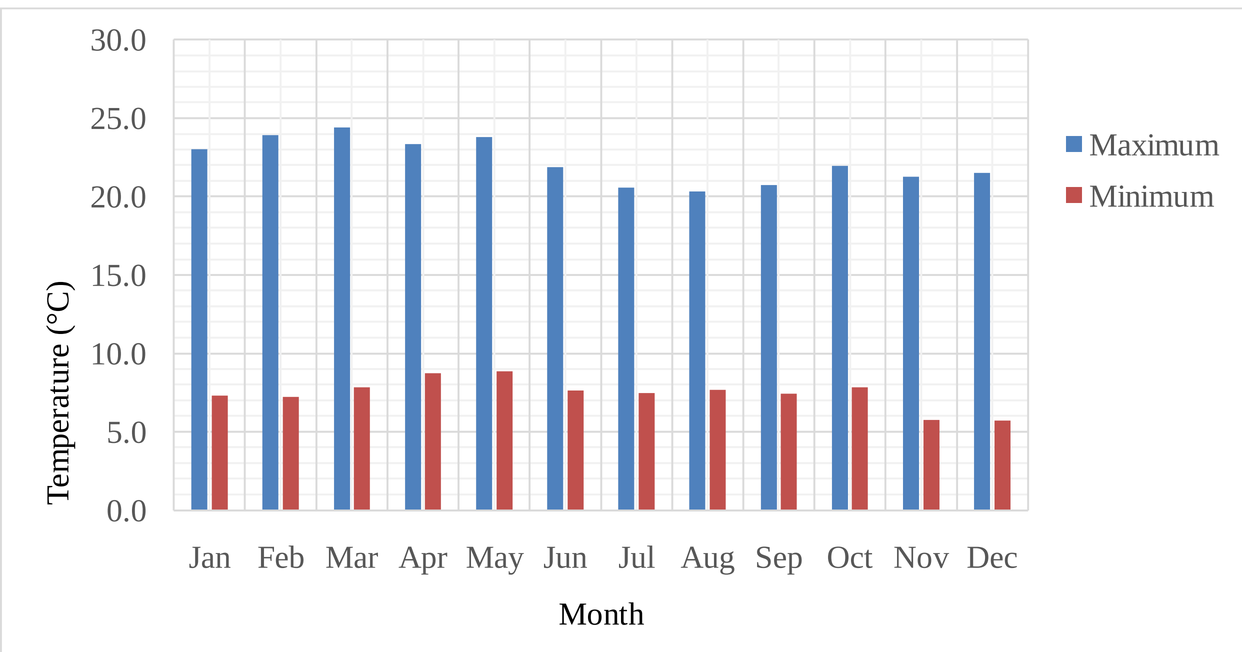

Figure 3.3: Average monthly maximum and minimum Temperature distribution [12]

4. Laboratory Test Results and Discussions

4.1 Laboratory Tests and Results

Based on the samples recovered from the sites both disturbed and undisturbed, laboratory tests on the thirty one samples were conducted in the geotechnical and highway laboratories of Addis Ababa Institute of Technology. Hence, the following Classification and strength tests have been carried out:

Table 4.1 Laboratory Tests and Used Standards

	Types of Tests carried	Standard
1	Grain size Analysis Test	
	a) sieve Analysis	ASTM D6913
	b) Hydrometer Analysis	ASTM D422
2	Specific Gravity Test	ASTM D 854
3	Liquid Limit Test	ASTM D 4318
4	Plastic Limit Test	ASTM D4318
5	Unconfined Compression Test	ASTM D-2166
6	Standard Proctor Test	AASHTO T 99
7	One-point CBR Test	AASHTO T 193

Summary of Laboratory Test Results

In order to analyze the intended correlation, the test results were compiled and summarized as follows in Table 4.2.

Table 4.2 Summary of Laboratory Test results, AASHTO [14] and USCS [15]

		Percent Fractions				**Atterberg Limits**				**Soil Classification**			**Standard Proctor Test**		**CBR Test**				
N0	**Test Pit Location**	**0.075 mm**	**0.002 mm**	**ω (%)**	**Gs**	**LL (%)**	**PL (%)**	**PI (%)**	**LI**	**AASHTO**	**USCS**	**UCS (kPa)**	**MDD (g/cc)**	**OMC (%)**	**No.of Blows**	**Density (g/cc)**	**Load in (MPa) @ 2.54 mm**	**Load in (MPa) @ 5.08 mm**	**CBR @ 100% MDD (%)**
1	TP-1 @ 1.5m	16.04	4.01	22	2.75	55	30	25	-0.32	A-2-7	GC		1.46	26.3	56	1.49	0.4	0.55	6
2	TP-2 @ 1.5m	96.56	58.24	30.3	2.83	76	40	36	-0.27	A-7-5	MH	145	1.26	40	56	1.41	0.06	0.09	3
3	TP-2 @ 3.0m	98.63	64.39	43	2.93	90	32	58	0.19	A-7-5	CH	107	1.35	33	56	1.37	0.11	0.13	3
4	TP-3 @ 1.5m	83.78	23.55	39.8	2.78	67	36	31	0.12	A-7-5	MH	352	1.3	36	56	1.29	0.12	0.14	2
5	TP-3 @ 3.0m	79.12	25.7	40.9	2.88	84	36	48	0.10	A-7-5	CH		1.24	40	56	1.18	0.18	0.21	3
6	TP-4 @ 1.5m	93.29	49.93	34.7	2.77	63	26	37	0.24	A-7-5	CH	108	1.44	34	56	1.44	0.21	0.25	3
7	TP-4 @ 3.0m	94.18	49.42	36.3	2.81	71	28	43	0.19	A-7-5	CH		1.45	31	56	1.46	0.22	0.25	3
8	TP-5 @ 1.5m	75.24	14.69	55.4	2.74	64	33	31	0.72	A-7-5	MH	49	1.33	32.5	56	1.29	0.31	0.45	4
9	TP-5 @ 3.0m	68.53	20.81	57.4	2.77	74	43	31	0.46	A-7-5	MH		1.37	29	56	1.18	0.3	0.38	4

10	TP-6 @ 1.5m	99.55	71.96	48.1	2.63	106	33	73	0.21	A-7-5	CH	90	1.25	32	56	1.28	0.07	0.1	1
11	TP-6 @ 3.0m	96.63	43.64	42.5	2.76	91	33	58	0.16	A-7-5	CH	139	1.19	40	56	1.38	0.05	0.06	1
12	TP-7 @ 1.5m	96.39	51.41	39.6	2.50	106	38	68	0.02	A-7-5	CH	259	1.24	41	56	1.35	0.11	0.13	2
13	TP-7 @ 3.0m	99.34	65.57	45.5	2.74	95	40	55	0.10	A-7-5	MH	129	1.25	36	56	1.38	1.11	1.14	2
14	TP-8 @ 1.5m	95.7	20.84	24.8	2.80	65	36	29	-0.39	A-7-6	MH	618	1.45	29	56	1.44	0.17	0.21	3
15	TP-8 @ 3.0m	96.34	54.61	31.3	2.88	65	32	33	-0.02	A-7-5	CH	387	1.33	35	56	1.51	0.16	0.2	2
16	TP-9 @ 1.5m	88.29	48.31	30.1	2.72	59	25	34	0.15	A-7-5	CH		1.46	27.5	56	1.31	0.25	0.27	4
17	TP-9 @ 3.0m	45.21	7.92	40.2	2.74	51	30	21	0.49	A-7-6	SC		1.36	33	56	1.39	0.2	0.22	3
18	TP-10 @ 1.5m	91.43	44.82	31.2	2.76	53	29	24	0.09	A-7-6	CH	90	1.47	26.3	56	1.5	0.25	0.27	3
19	TP-10 @ 3.0m	93.37	51.25	27	2.88	65	32	33	-0.15	A-7-6	CH	275	1.44	32.6	56	1.52	0.22	0.26	3
20	TP-11 @ 1.5m	94.03	48.57	41.4	2.74	55	32	23	0.41	A-7-6	CH	122	1.45	36.5	56	1.47	0.19	0.23	3
21	TP-11 @ 3.0m	84.93	22.94	46.4	2.81	68	34	34	0.36	A-7-5	MH	72	1.37	28	56	1.26	0.26	0.35	4
22	TP-12 @ 1.5m	95.89	63.12	30.2	2.74	54	27	27	0.12	A-7-6	CH	252	1.47	29	56	1.5	0.57	0.68	4
23	TP-12 @ 3.0m	96.81	58.9	33.5	2.76	64	27	37	0.18	A-7-6	CH	263	1.5	27.5	56	1.45	0.45	0.55	5

24	TP-13 @ 1.5m	95.53	57.77	36	2.79	57	30	27	0.22	A-7-6	MH	114	1.42	32.7	56	1.43	0.19	0.23	3
25	TP-13 @ 3.0m	97.38	60.17	40.2	2.81	56	26	30	0.47	A-7-5	CH	130	1.47	28.5	56	1.37	0.26	0.38	4
26	TP-14 @ 1.5m	96.28	57.8	35.4	2.75	61	28	33	0.22	A-7-5	CH	59	1.43	31	56	1.45	0.21	0.24	3
27	TP-14 @ 3.0m	96.28	56.11	29.7	2.80	59	24	35	0.16	A-7-5	CH	70	1.48	27.5	56	1.4	0.25	0.27	4
28	TP-15 @ 1.5m	96.45	53.92	47	2.72	75	31	44	0.36	A-7-5	CH	56	1.42	32	56	1.32	0.18	0.22	3
29	TP-15 @ 3.0m	93.32	31.84	40.8	2.77	72	34	38	0.18	A-7-5	CH	73	1.34	40	56	1.3	0.17	0.19	2
30	TP-16 @ 1.5m	94.68	49.97	29	2.81	58	26	32	0.09	A-7-6	CH	278	1.51	27.5	56	1.52	0.27	0.36	4
31	TP-16 @ 3.0m	98.64	57.97	37.9	2.83	75	31	44	0.16	A-7-5	CH	281	1.41	34	56	1.42	0.18	0.22	3

5. Regression Analysis and Correlations

5.1 Introduction

Regression analysis is a statistical technique that is very useful in the field of engineering and science in modeling and investigating relationships between two or more variables. The method of regression analysis is used to develop the line or curve which provides the best fit through a set of data points. This basic approach is applicable in situations ranging from single linear regression to more sophisticate nonlinear multiple regressions. The best fit model could be in the form of linear, parabolic or logarithmic trend. A linear relationship is usually practiced in solving different engineering problems because of its simplicity.

Fitting a regression model requires several assumptions. The method of least squares is used in order to choose the best fitting line for a set of data. Estimation of the model parameters requires the assumption that, the residuals (actual values less estimated values) corresponding to different observations are uncorrelated random variables with zero mean and constant variance (σ^2). In most practical situation, the variance (σ^2) of the random error (ε) will be unknown and must be estimated from the sample data [16]. The standard error of an estimate gives some idea about the precision of an estimate. During modeling, a variable that shows the least standard error of estimates is the one to be chosen.

The formation and development of soil structure is very erratic in nature and the CBR value is dependent on the geology, environmental factors, soil characteristics and many other factors which vary from place to place. Therefore equations developed for soils in one place may not work at all if tested on soils of other place of the same region. Hence specific models have to be developed for specific areas in order to give fair evaluations.

These models comprise different soil parameters indifferent combinations. Index properties are the widely used parameters in these models because these properties have significance in indicating the CBR value of a soil. In general, previously developed empirical equations and equations to be developed in the future are not to be expected to determine CBR value precisely and accurately for all soils.

5.2 Scatter Plot and Best-Fit Curve

The MS excel spread sheet is found to be the most powerful and manageable tool for scatter plot analysis and determination of correlation between two variables. In the subject study, the California Bearing Ratio is taken as the dependent variable whereas the liquid limit, plastic limit, plasticity index, liquidity index and grain size (PP200) are independent variables.

However, when determination of the relationships among more than two variables are required (the dependent variable requires two or more independent variables) regression analysis is used and the SPSS software is found to be the most powerful and descriptive tool. Consequently, soils are classified in to red and black or/gray by using Munsell chart.the scatter plot of the same is presented for the Red clay and Black/Gray clay respectively.

5.2.1Scatter plot for red clays

5.2.1.1 CBR Vs. %Passing Sieve No.200 (Red clay)

The best fitting trend line for relationship between CBR and % passing sieve No.200 is CBR = -0.0432*PP_{200}+7.3486, as the strength of this correlation is only 1.65% or has R^2= 0.0165.

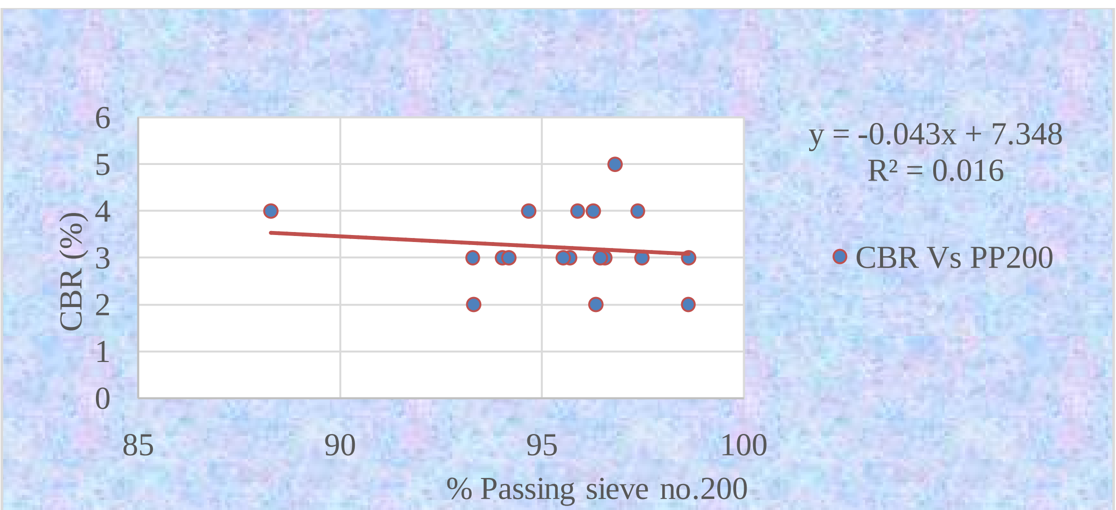

Figure 5-1: Scatter Diagram of CBR vs. %Passing Sieve No.200 the Study Area

5.2.1.2 CBR Vs. Liquid Limit (Red clay)

The best fitting trend line for relationship between CBR and LL is CBR = -0.0469 * LL+ 6.2836, as the strength of this correlation is only 30.44% or has R^2= 0.3044. It is deemed not reliable enough to be used as a predictor for the estimation of the CBR.

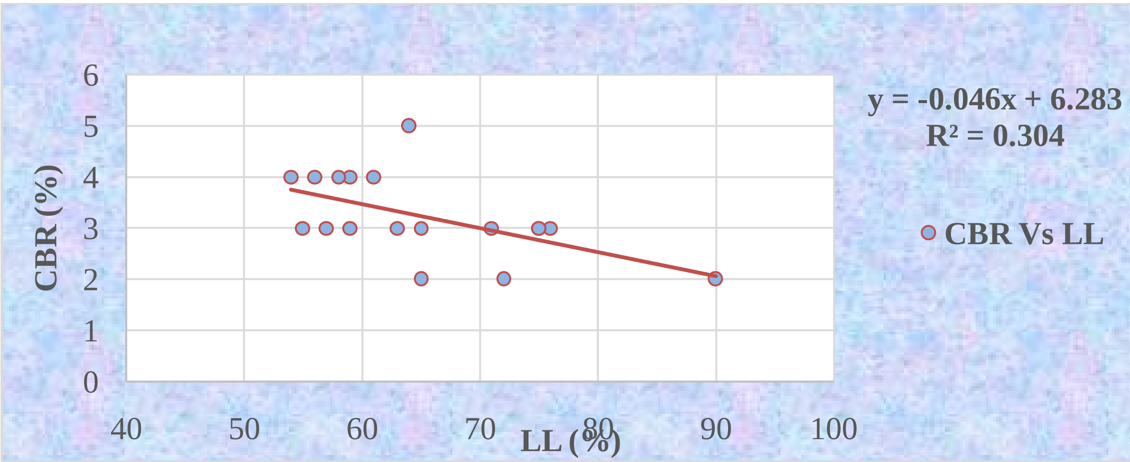

Figure 5-2: Scatter Diagram of CBR vs. Liquid Limit of the Study Area

5.2.1.3 CBR Vs. Plastic Limit (Red clay)

The best fitting trend line for relationship between CBR and PL is CBR = -0.1031 * PL+ 6.2866, the strength of this equation in predicting an outcome from the plastic limit is around 28.66% or has R^2= 0.2866.

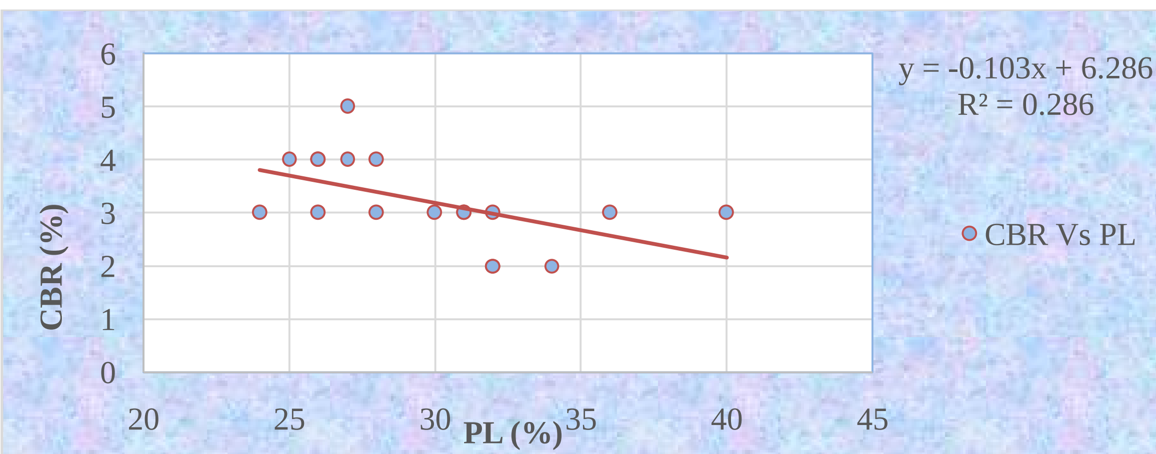

Figure 5-3: Scatter Diagram of CBR vs. Plastic Limit of the Study Area

5.2.1.4 CBR Vs. Plasticity Index (Red clay)

The relationship between the CBR and the plasticity index for the tested samples is shown in figure 5.4. The best fitting trend line for this relationship is CBR = -0.0369 * PI+ 4.5327, the strength of this equation in predicting an outcome from the plastic index is around 13.67 % or has R^2= 0.1367.

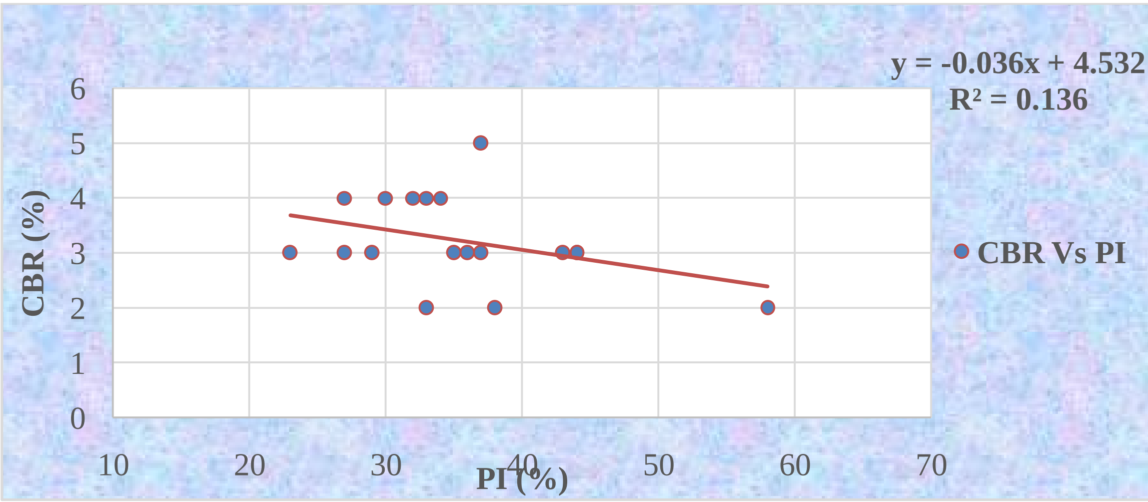

Figure 5-4: Scatter Diagram of CBR vs. plasticity index of the Study Area

5.2.1.5 CBR Vs. Liquidity index (Red clay)

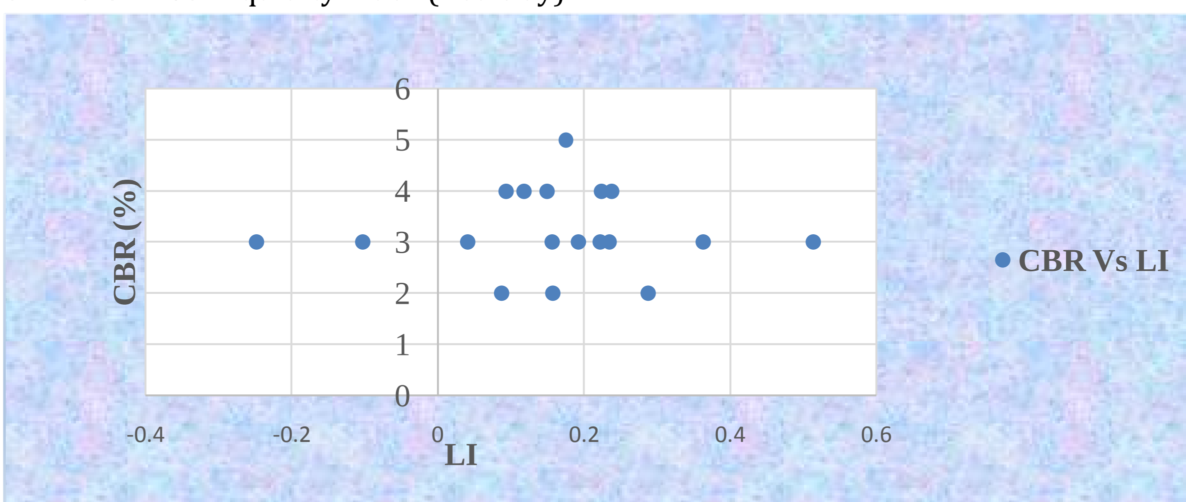

Figure 5-5: Scatter Diagram of CBR vs. liquidity index of the Study Area

5.2.2 Scatter plot for black/gray clays

5.2.2.1 CBR Vs. %Passing Sieve No.200 (Black/Gray clay)

The best fitting trend line for relationship between CBR and % Passing Sieve No.200 is CBR =-0.0462*PP_{200}+6.2669,The strength of this equation in predicting an outcome from the liquid limit is around 70.53% or has R^2= 0.7053.

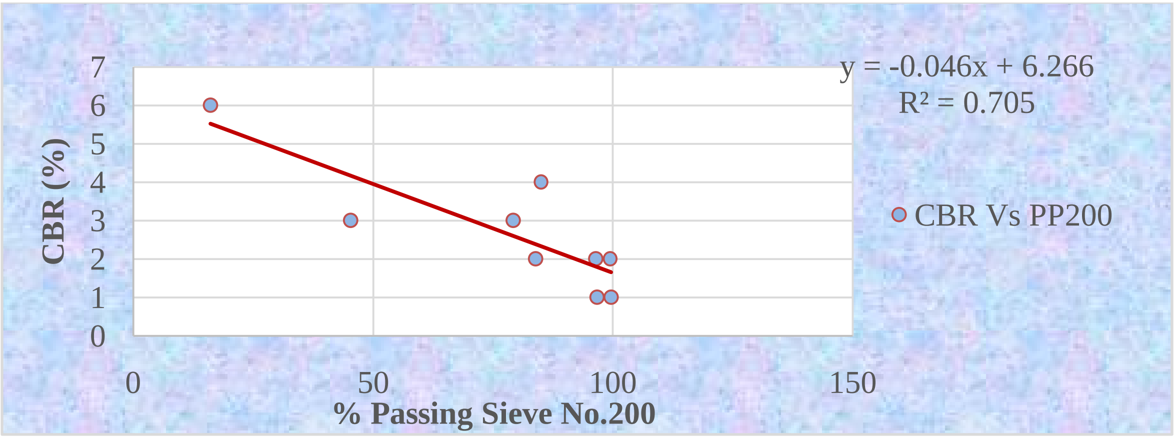

Figure 5-6: Scatter Diagram of CBR vs. %Passing Sieve No.200 of the Study Area

5.2.2.2 CBR Vs. Liquid Limit (Black/Gray clay)

The best fitting trend line for relationship between CBR and LL is CBR =-0.0538 * LL+ 6.9916, the strength of this equation in predicting an outcome from the liquid limit is around 20.61% or has R^2= 0.5061.

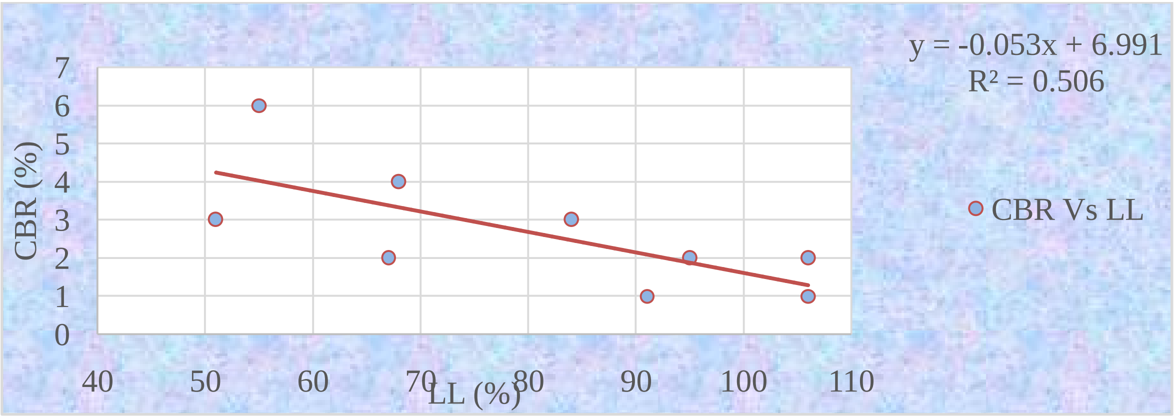

Figure 5-7: Scatter Diagram of CBR vs. Liquid Limit of the Study Area

5.2.2.3 CBR Vs. Plastic Limit (Black/Gray clay)

The relationship between CBR and the plastic limit for the tested samples is shown in figure 5.7. The best fitting trend line for this relationship is CBR = -0.2024PL+9.6386, the strength of this equation in predicting an outcome from the plastic Limit is around 18.89 % or has R^2= 0.1889.Show that the relationship is weak.

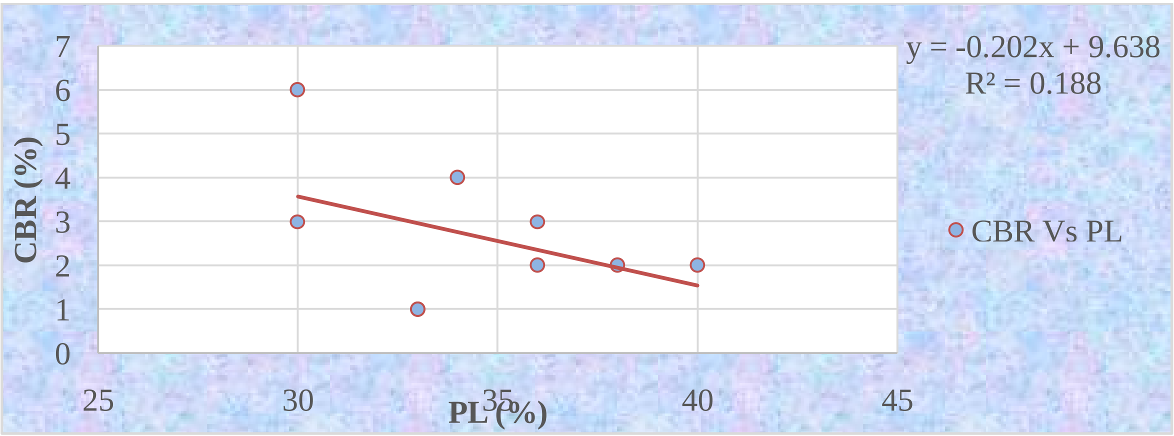

Figure 5-8: Scatter Diagram of CBR vs. Plastic Limit of the Study Area

5.2.2.4 CBR Vs. Plasticity Index

The best fitting trend line for relationship between CBR and PI is CBR = -0.0591PI+5.3466, the strength of this equation in predicting an outcome from the Plasticity index is around 49.07% or has R^2= 0.4907.

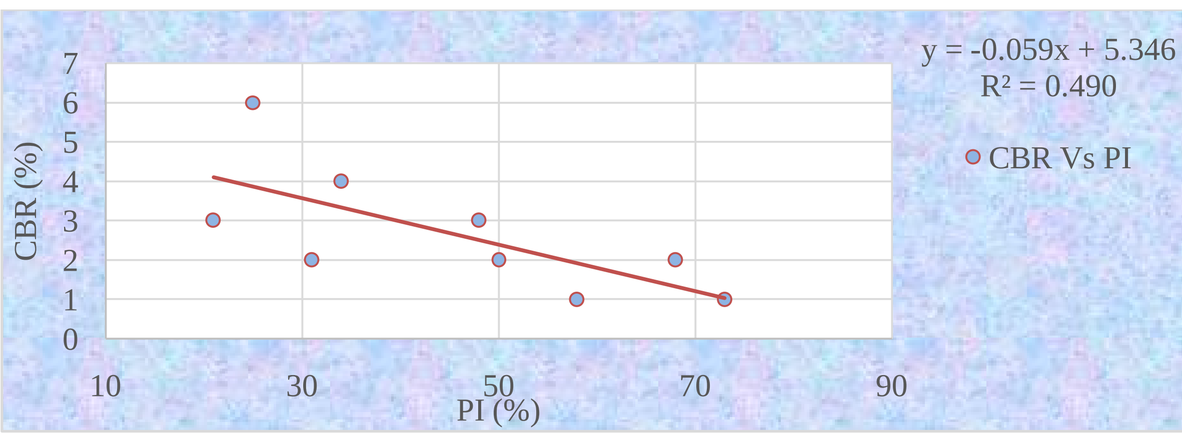

Figure 5-9: Scatter Diagram of CBR vs. Plasticity index of the Study Area

5.2.2.5 CBR Vs. Liquidity Index (Black/Gray clay)

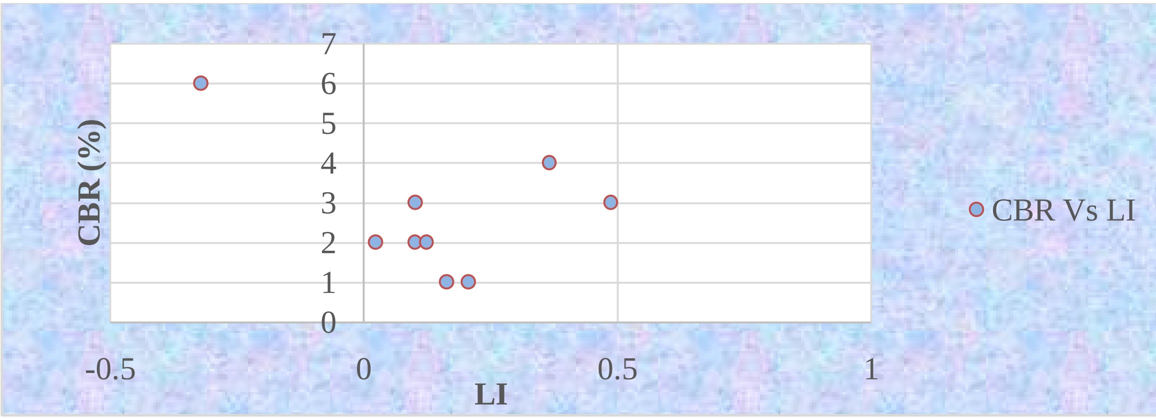

Figure 5-10: Scatter Diagram of CBR vs. Liquidity Index of the Study Area

5.3 Regression Analysis

In this research work, an attempt is made to apply single linear regression model and multiple linear regression models to characterize the strength of subgrade soil from soil index parameters using a statistical approach. The general representation of a probabilistic single and multiple linear regression models are presented in the following forms:

$Y = \beta_0 + \beta_1 x + \varepsilon$ (4.1)

$Y = \alpha_o + \alpha_1 x_1 + \alpha_2 x_2 \ldots + \alpha_n x_n + \varepsilon$ (4.2)

Where, the slope (β_1) and intercept (β_0) of the single linear regression model are called regression coefficients. Similarly, coefficients α_o, α_1, and α2and$\alpha_n$are termed multiple regression coefficients. The appropriate way to generalize this to a probabilistic linear model is to assume that the actual value of Y is determined by the mean value function (the linear model) plus the random error term, ε [16]. The basic assumption to estimate the regression coefficients of the single and multiple regression models is based on the least square method.

Specific to this research, a statistical package for social science software (SPSS) is employed to investigate the significance of individual regressor variables. Out of these equations, equations with higher R^2 values were selected and using these equations the CBR of the study area was calculated. The statistical information's of the test results are presented in Table 5.1 and 5.2.

Table 5.1: Statistical Information of Dependent and Independent Variables (Red clay)

Variable Type	Variable Name	Unit of Measurement	No. of Samples	Ranges		Mean	Standard Deviation
				Min.	Max.		
Dependent	CBR	%	20	1	5	3.25	1.09
Independent	P200	%	20	88.29	98.6	95.15	2.39
	LL	%	20	53	90	64.65	9.17
	PL	%	20	24	40	29.8	3.91
	PI	%	20	23	58	34.85	7.9
	LI	%	20	-0.25	0.51	0.16	0.03

Table 5.2: Statistical Information of Dependent and Independent Variables (Black/Gray clay)

Variable Type	Variable Name	Unit of Measurement	No. of Samples	Ranges		Mean	Standard Deviation
				Min.	Max.		
Dependent	CBR	%	11	1	6	2.91	1.07
Independent	P200	%	11	16.04	99.55	76.8	18.28
	LL	%	11	51	106	78.27	13.7
	PL	%	11	30	43	35.09	2.85
	PI	%	11	21	68	42.73	12.54
	LI	%	11	-0.32	0.722	0.14	0.05

Further to the above Single linear regression Analysis, a number of alternative multiple linearregression analyses that best fit the obtained test results have been carried out. Some typical detail outputs of the SPSS Software for multiple linear regression analysis presented under Appendix A of this thesis and also the summarized correlation results are presented hereafter.

5.3.1 Multiple Linear Regression Analysis

Table 5.3: Input data for SPSS 23 computer program (Red clay)

Location	CBR (%)	LL	LI	%Passing Sieve No 200
TP-9 @ 1.5m	4	59	0.15	88.29
TP-11 @ 1.5m	3	55	0.514	94.03
TP-4 @ 1.5m	3	63	0.235	93.29
TP-4 @ 3.0m	3	71	0.193	93.29
TP-8 @ 1.5m	3	65	-0.248	95.7
TP-8 @ 3.0m	2	65	0.158	96.34
TP-13 @ 1.5m	3	57	0.222	95.53
TP-13 @ 3.0m	4	56	0.238	97.38
TP-12 @ 1.5m	4	54	0.119	95.89
TP-12 @ 3.0m	5	64	0.176	96.81
TP-14 @ 1.5m	4	61	0.224	96.28
TP-14 @ 3.0m	3	59	0.041	97.48
TP-2 @ 1.5m	3	76	-0.103	96.56
TP-2 @ 3.0m	2	90	0.088	98.63
TP-16 @ 1.5m	4	58	0.094	94.68
TP-16 @ 3.0m	3	75	0.157	98.64
TP-15 @ 1.5m	3	75	0.364	96.45
TP-15 @ 3.0m	2	72	0.288	93.32

Table 5.4: Input data for the control sample

Location	CBR (%)	LL	LI	%Passing Sieve No 200
TP-10 @ 1.5m	3	53	0.091667	91.43
TP-10 @ 3.0m	3	65	-0.15152	93.37

The following possible empirical formulas are developed by taking one or more of important parameters (PP200, Liquid Limit, and LI) in different combination as shown in table 5.5.

Table 5.5: Summary of newly developed possible empirical equations (Red clay)

Equations	N	R^2	Eqn.
$CBR = -0.136LI - 0.045PP_{200} + 7.544$	18	0.017	Eqn. 1
$CBR = -0.049LL + 0.026PP_{200} + 3.986$	18	0.309	Eqn. 2
$CBR = -0.049LL - 0.540LI + 6.488$	18	0.316	Eqn. 3
$CBR = -0.050LL - 0.50LI + 0.021PP_{200} + 4.625$	18	0.319	Eqn. 4

Table 5.6: Input data for SPSS 23 computer program (Black/Gray clay)

Location	CBR	LL	LI	%Passing Sieve No 200
TP-9@ 3.0m	3	51	0.48571	45.21
TP-11 @ 3.0m	4	68	0.36471	84.93
TP-1 @ 1.5m	6	55	-0.32	16.04
TP-6 @ 1.5m	1	106	0.20685	99.55
TP-6 @ 3.0m	1	91	0.16379	96.63
TP-7 @ 1.5m	2	106	0.02353	96.39
TP-7 @ 3.0m	2	95	0.1	99.34
TP-5 @ 1.5m	4	64	0.722581	75.24
TP-5 @ 3.0m	4	74	0.464516	68.53

Table 5.7: Input data for the control sample

Location	CBR	LL	LI	%Passing Sieve No 200
TP-3 @ 1.5m	3	67	0.122581	83.78
TP-3 @ 3.0m	3	84	0.102083	79.12

Table 5.8: Summary of Newly developed possible empirical equations (Black/Gray clay)

Equations	N	R^2	Eqn.
$CBR = -0.611LI - 0.048PP_{200} + 6.518$	9	0.677	Eqn. 1
$CBR = -0.030LL - 0.029PP_{200} + 7.540$	9	0.711	Eqn. 2
$CBR = -0.068LL - 1.558LI + 8.754$	9	0.713	Eqn. 3
$CBR = -0.049LL - 0.910LI - 0.015PP_{200} + 8.205$	9	0.720	Eqn. 4

6. Discussion on Correlation Results

The validation of the developed correlation is conducted by using the control sample in order to select the best equation, the CBR value were calculated for both input soil data and control samples soil data using newly developed equations. The results are shown in the following tables.

Table 6.1: Predicted CBR values using newly developed equations (Red Clay)

Test Pit ID	Experimental CBR Value (%)	Predicted CBR Value (%)			
		Eqn.1	Eqn.2	Eqn.3	Eqn.4
TP-9@ 1.5m	4	3.55	3.39	3.52	3.45
TP-11 @ 1.5m	3	3.24	3.74	3.52	3.59
TP-4 @ 1.5m	3	3.31	3.32	3.27	3.32
TP-4 @ 3.0m	3	3.28	2.96	2.90	2.96
TP-8 @ 1.5m	3	3.27	3.29	3.44	3.51
TP-8 @ 3.0m	2	3.19	3.31	3.22	3.32
TP-13 @ 1.5m	3	3.21	3.68	3.58	3.67
TP-13 @ 3.0m	4	3.13	3.77	3.62	3.75
TP-12 @ 1.5m	4	3.21	3.83	3.78	3.88
TP-12 @ 3.0m	5	3.16	3.37	3.26	3.37
TP-14 @ 1.5m	3	3.18	3.50	3.38	3.48
TP-14 @ 3.0m	4	3.15	3.63	3.57	3.70
TP-2 @ 1.5m	3	3.21	2.77	2.82	2.90
TP-2 @ 3.0m	2	3.09	2.14	2.03	2.15
TP-16 @ 1.5m	4	3.27	3.61	3.60	3.67
TP-16 @ 3.0m	3	3.08	2.88	2.73	2.87
TP-15 @ 1.5m	3	3.15	2.82	2.62	2.72
TP-15 @ 3.0m	2	3.31	2.88	2.80	2.84

Table 6.2: Predicted CBR values using newly developed equations for control samples

Test Pit ID	Experimental CBR Value (%)	Predicted CBR Value (%)			
		Eqn.1	Eqn.2	Eqn.3	Eqn.4
TP-10 @ 1.5m	4	3.42	3.77	3.84	3.85
TP-10 @ 3.0m	3	3.36	3.23	3.38	3.41

Table 6.3: Checking accuracy of the newly developed formulas for Control Samples

Test Pit ID	Experimental CBR Value (%)	Variation of CBR with experimental value (%)			
		Eqn.1	Eqn.2	Eqn.3	Eqn.4
TP-10 @ 1.5m	4	14.57	5.85	3.96	3.77
TP-10 @ 3.0m	3	12.10	7.62	12.83	13.72
	Average	13.33	6.73	8.39	8.74

From the values of table 6.3. The percentage variation of newly developed formulas for Control Samples, the accuracy ranges from 6.73% to 13.33%.

Table 6.4: Predicted CBR values using newly developed equations (Black/Gray Clay)

Test Pit ID	Experimental CBR Value (%)	Predicted CBR Value (%)			
		Eqn.1	Eqn.2	Eqn.3	Eqn.4
TP-9 @ 3.0m	3	4.05	4.70	4.53	4.59
TP-11 @ 3.0m	4	2.22	3.04	3.56	3.27
TP-1 @ 1.5m	6	5.94	5.42	5.51	5.56
TP-6 @ 1.5m	1	1.61	1.47	1.22	1.33
TP-6 @ 3.0m	1	1.78	2.01	2.31	2.15
TP-7 @ 1.5m	2	1.88	1.56	1.51	1.54
TP-7 @ 3.0m	2	1.69	1.81	2.14	1.97
TP-5 @ 1.5m	4	2.46	3.44	3.28	3.28
TP-5 @ 3.0m	4	2.94	3.33	3.00	3.13

Table 6.5: Predicted CBR values using newly developed equations for control samples

Test Pit ID	Experimental CBR Value (%)	Predicted CBR Value (%)			
		Eqn.1	Eqn.2	Eqn.3	Eqn.4
TP-3 @ 1.5m	3	2.42	3.10	4.01	3.55
TP-3 @ 3.0m	3	2.66	2.73	2.88	2.81

Table 6.6: Checking accuracy of the newly developed formulas for Control Samples

Test Pit ID	Experimental CBR Value (%)	Variation of CBR with experimental value (%)			
		Eqn.1	Eqn.2	Eqn.3	Eqn.4
TP-3 @ 1.5m	3	19.28	3.35	33.57	18.46
TP-3 @ 3.0m	3	11.40	9.15	3.90	6.36
	Average	15.34	6.25	18.73	12.41

From the values of table 6.6. The percentage variation of newly developed formulas for Control Samples, the accuracy ranges from 6.25 % to 18.73%

6.1 Graphical representation of experimental and predicted values

The following typical graphs are plotted to investigate the approximation of newly developed formulas of the best fitted equation for the red and black/gray soils. The experimental and predicted values are plotted and trend lines are drawn to observe the Variation between the experimental and the predicted values as shown in figure 6.1 to 6.4.

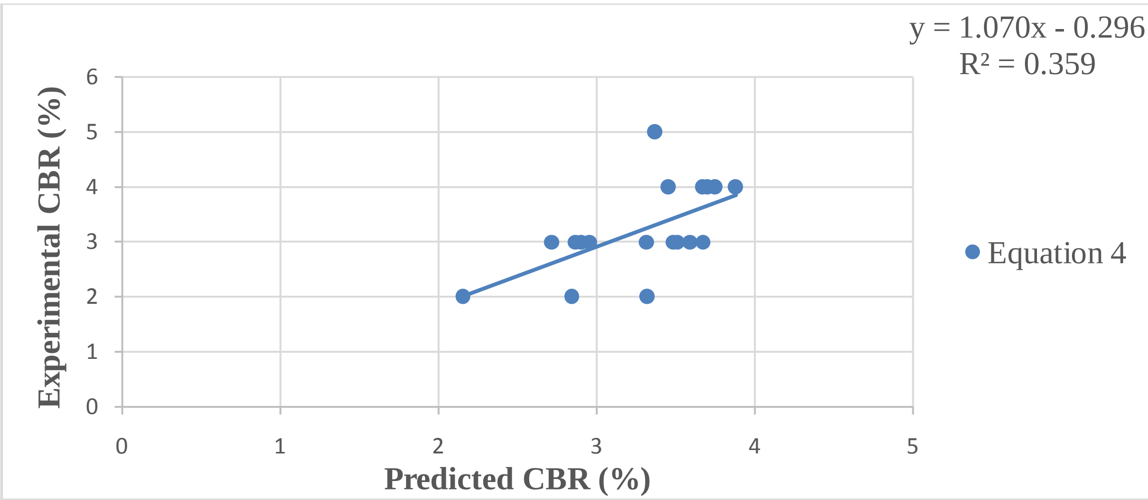

Figure 6.1: Scattered plot of Experimental vs. Predicted CBR based on equation 4(Red Clay.)

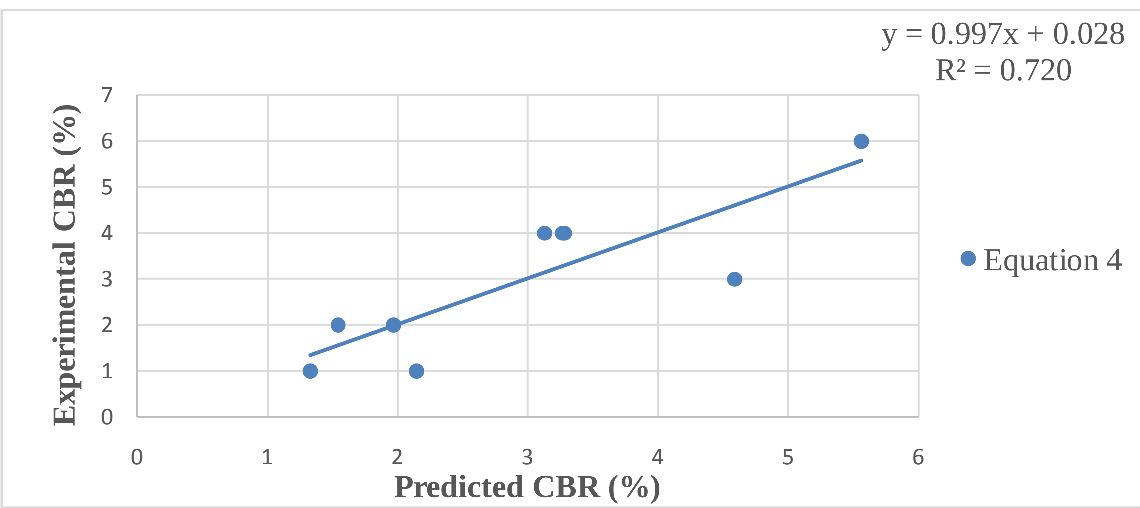

Figure 6.2: Scattered plot of Experimental vs. Predicted CBR based on equation 4 (Black/Gray Clay.

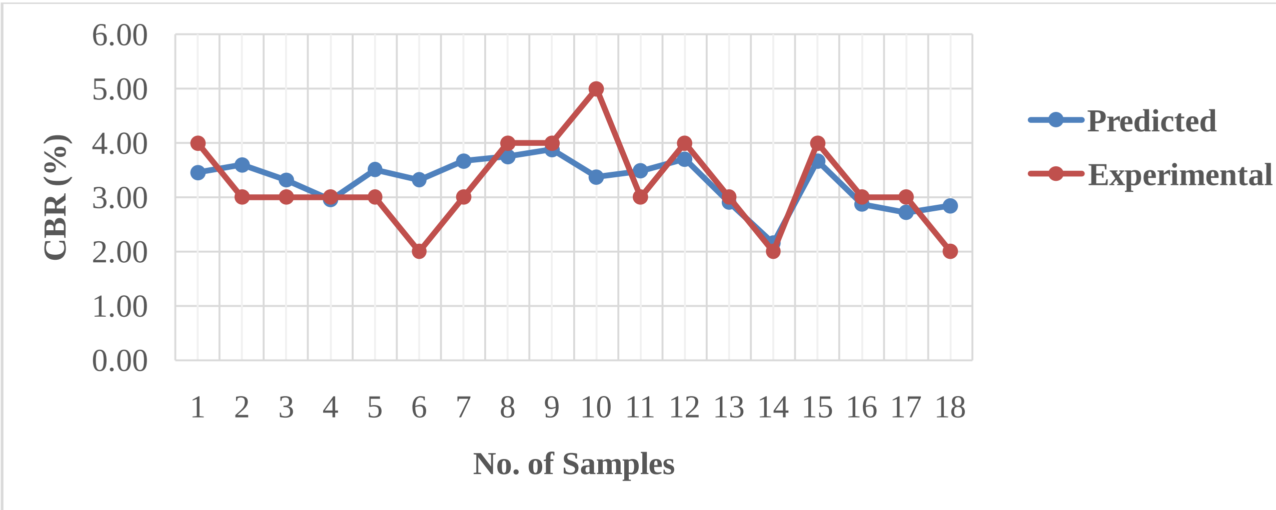

Figure 6.3 Comparison between experimental and predicted CBR value obtained from equation 4 (Red Clay)

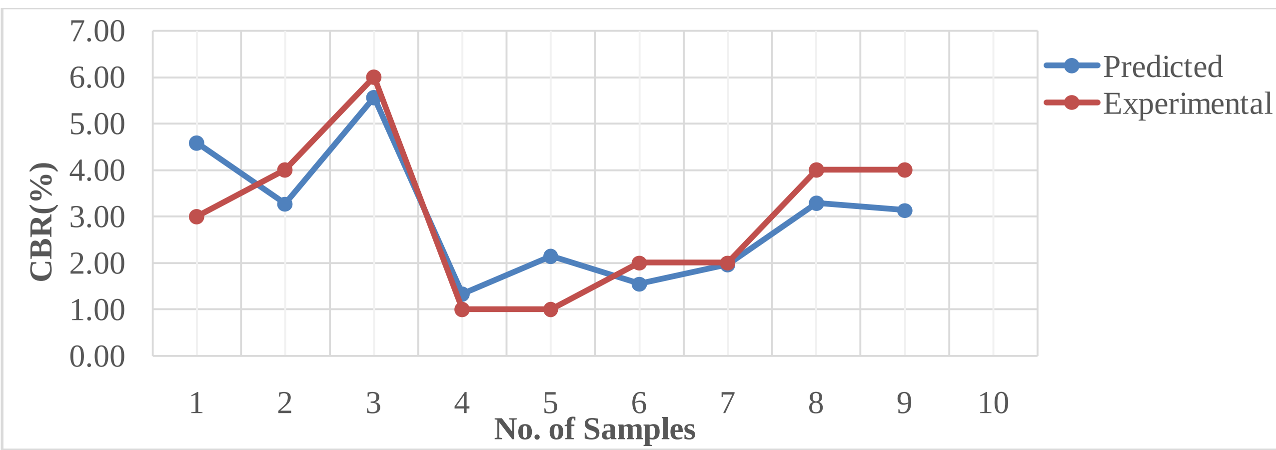

Figure 6.4 Comparison between experimental and predicted CBR value obtained from equation 4 (Black/Gray clay

As can be seen in consecutive Figures, about 67% of the total samples scattered near the straight line, through which the experimental and predictedCBR value is equal, whereas relatively 33%test results slightly deviated from the possible straight line for both red andblack/gray clay soils.

Among the equations for red clay soils, equation 4 describes the relation better than the others. Whereas, equation 4 for black/gray clay soils better describes the relation than the other two equations. This is because, it has good regression analysis with coefficient of determination 0.319 for the red clay whereas 0.720for black/gray clay and also it has parameters which could be easily determined in soil mechanics laboratories and accuracy of experimentalCBR value from predicted CBR value for control sample is 13.33% difference for red clay and 18.73% for black/gray clay. Hence, one may use these suggested equations for the estimation of the CBR valueof the study area.

6.2Evaluation of the Developed and Existing Correlation

The suitability of existing correlations with Leliso Y. along with the developed correlation is examined using test results obtained from the subject study area having similar soil classifications. The calculated results of the correlations which are obtained by using the test results are shown in Table 6.7 for Red clay soils:

Table 6.7: The Developed and Existing Correlations for Red clay

Sample No.	Red Clay Experimental CBR Value [A]	**Developed Correlation**		**Leliso.Y**	
		Predicted CBR Value [B]	Variation (%) [B-A]*100/A	Predicted CBR Value [C]	Variation (%) [C-A]*100/A
1	2	2.15	7.50	2.81	40.5
2	3	3.32	10.67	3.37	12.3
3	4	3.45	13.75	6.73	68.3
4	3	3.59	19.67	4.27	42.3
5	5	3.37	32.60	7.59	51.8
6	4	3.75	6.25	3.72	7.0
7	3	3.48	16.00	3.48	16.0
8	3	2.72	9.33	3.25	8.3
9	4	3.67	8.25	5.83	45.8
Avg	**3.4**	**3.28**	**13.78**	**4.56**	**32.48**

As shown in Table 6.7 the Leliso Y. correlation resulted an average variation of 32.48% from the actual CBR values. On the other hand, the developed correlation predicted the CBR value with average variation of 13.78% for red clay.

In view of the above, it is worth to note that the test results obtained from the subject study area are comparatively suited by the above existing correlation.

6.3 Scattering of test pits in the study area

Thisscattering plot is prepared based on the results from sixteen representative test pits retrieved to a depth of 3.0 meters. By making use of Munsell chart, soils in the study area for a depth of 1.5 meters with GPS coordinates in Table 6.8, are well presented after interpolation of the boundaries between test pits as shown in Figure 6.10. However, the soils in the study area are mainly categorized from engineering point of view into CH (in organic clays of high plasticity) and MH (inorganic silts of high plasticity) based on 1.5m depth investigation. The engineering properties of soils in the study area which are distributed and delineated in the in the scatter plot are presented in the legend. Even though this delineation of soils serves as reference, it has to be updated based on current advanced investigation techniques to enable fellow engineers develop detailed geotechnical map. The distribution of soil is presented in Figure 6.5.

Table 6.8: GPS coordinates of test pits

N0.	Test pit Naming	Test Pit Designation	Easting	Northing	Elevation(m)
1	Health Center	TP-1	473855	1015714	2592
2	Sululta High School	TP-2	472923	1013266	2603
3	Sululta Elementary School	TP-3	473650	1014875	2594
4	KidaneMihiret Church	TP-4	472256	1012894	2620
5	Sululta Stadium	TP-5	474925	1012757	2611
6	Horticulture	TP-6	472623	1011964	2601
7	Primilk	TP-7	473457	1012000	2600
8	Legedima Elementary School	TP-8	472748	1009605	2653
9	Ashewa	TP-9	473138	1010484	2622
10	Shufune	TP-10	471195	1009498	2707
11	Elemtu	TP-11	472070	1009199	2678
12	MizanAtlet Mender	TP-12	469571	1007464	2731
13	MelesAcadamy	TP-13	469481	1006843	2748
14	Near Kenenissa Resort	TP-14	468804	1007034	2754
15	Weserbi Real Estate	TP-15	468688	1005469	2750
16	Weserbi Elementary School	TP-16	468018	1006545	2753

Table 6.9: Colour Designation using Munsell chart

N0.	Specific Location	Colour Designation using Munsell chart							
		When dry				When wet			
		Hue	Value	Chroma	Colour	Hue	Value	Chroma	Colour
1	Ashewa @ 1.5m	10YR	3	2	Very dark grayish brown	10YR	3	1	Very dark gray
2	Ashewa @ 3.0m	5YR	2.5	1	Black	5YR	3	1	Very dark gray
3	ElemtuDiary Farm @ 1.5m	5YR	5	6	Yellowish red	5YR	4	4	Reddish brown
4	ElemtuDiary Farm @ 3.0m	10YR	5	2	Grayish brown	10YR	3	3	Dark brown
5	HealthCenter @ 1.5m	5YR	5	1	Gray	5YR	3	1	Very dark gray
6	Horticulture @ 1.5m	10YR	5	1	Gray	10YR	5	1	Gray
7	Horticulture @ 3.0m	10YR	3	3	Dark brown	10YR	4	2	dark grayish brown
8	KidaneMihiret Church @ 1.5m	5YR	4	3	Reddish brown	5YR	4	3	Reddish brown
9	KidaneMihiret Church @ 3.0m	5YR	3	4	dark reddish brown	5YR	4	3	Reddish brown
10	Legedima Elem. School @ 1.5m	10YR	5	1	dark reddish brown	10YR	3	2	dark Reddish brown
11	Legedima Elem. School @ 3.0m	5YR	3	3	dark reddish brown	5YR	3	3	dark reddish brown
12	MelesAcadamy @ 1.5m	2.5YR	3	4	dark reddish brown	2.5YR	4	4	Reddish brown
13	MelesAcadamy @ 3.0m	5YR	4	6	Yellowish red	5YR	4	4	Reddish brown
14	MizanAtlet Mender @ 1.5m	2.5YR	3	6	dark red	2.5YR	4	4	Reddish brown
15	MizanAtlet Mender @ 3.0m	2.5YR	4	4	Reddish brown	2.5YR	4	4	Reddish brown
16	Near Kenenissa Resort @ 1.5m	5YR	4	4	Reddish brown	5YR	4	4	Reddish brown
17	Near Kenenissa Resort @ 3.0m	2.5YR	4	6	Red	2.5YR	3	4	dark grayish brown

18	Primilk @ 1.5m	5YR	4	1	dark gray	5YR	4	1	dark gray
19	Primilk @ 3.0m	10YR	5	1	Gray	10YR	5	1	Gray
20	Shufune @ 1.5m	5YR	5	3	Reddish brown	5YR	4	4	Reddish brown
21	Shufune @ 3.0m	7.5Y R	4	4	Dark brown	7.5YR	4	4	Dark brown
22	Sululta Elem. School @ 1.5m	5YR	5	3	Reddish brown	5YR	4	4	Reddish brown
23	Sululta Elem. School @ 3.0m	10YR	5	2	Grayish brown	10YR	4	2	dark grayish brown
24	Sululta High School @ 1.5m	7.5Y R	4	2	Dark brown	7.5YR	3	4	Dark brown
25	Sululta High School @ 3.0m	10YR	5	2	Grayish brown	10YR	5	4	Yellowish Brown
26	Sululta Stadium @ 1.5m	10YR	6	1	Gray	10YR	4	1	Dark Gray
27	Sululta Stadium @ 3.0m	10YR	6	1	Gray	10YR	3	2	Very dark grayish
28	Weserbi Elem. School @ 1.5m	7.5Y R	4	4	Dark brown	7.5YR	4	4	Dark brown
29	Weserbi Elem. School @ 3.0m	2.5Y R	3	4	dark reddish brown	2.5YR	3	4	dark reddish brown
30	Weserbi Real Estate @ 1.5m	2.5Y R	4	6	Red	2.5YR	4	6	Red
31	Weserbi Real Estate @ 3.0m	5YR	6	6	Reddish yellow	5YR	4	6	Yellowish red

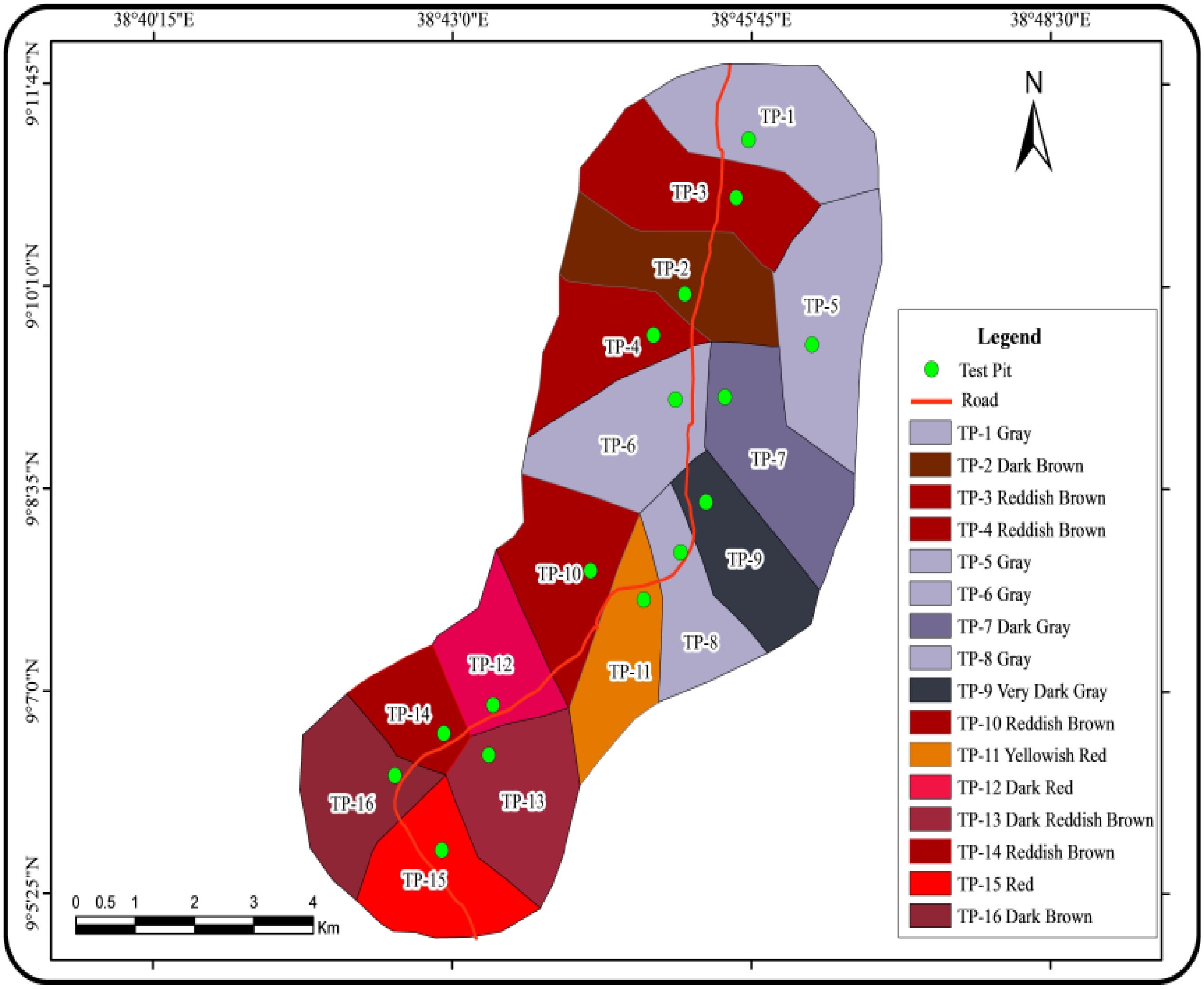

Figure 6.5: Scatter plot oftest pits in the study area at a depth of 1.50m.

7. Conclusions and Recommendations

7.1 Conclusion

The research was conducted to find a localized correlation between CBR value and soil index properties within the scope of the study. Using the obtained Thirty one test results a single and multiple linear regressions were analyzed and a relationship was developed that predicts CBR value in terms of PP_{200}, LL and LI.

The suitability of the developed correlation is evaluated by utilizing a separate control Sample test results. From the results of this study the following conclusions are drawn:

1. From the results of linear and multiple regression analysis, an improved correlation of multiple regressions than the single regression is obtained as given below:

$$CBR = -0.050LL - 0.50LI + 0.021PP_{200} + 4.625$$

R^2=0.319, n = 18 (**for red clay**)

$$CBR = -0.049LL - 0.910LI - 0.015PP_{200} + .046PP_{200} + 8.205$$

R^2=0.720, n = 9(**for Black/ Gray clay**)

2. In light of the above, a combination of soil index properties correlates better with strength characteristic of CBR than individual soil properties.

3. For preliminary design purpose the above correlation might be used, if the predicted CBR value is within the range of 1% to 6%. Otherwise, a detailed laboratory test should be carried out to obtain the actual CBR value.

7.2 Recommendation

1. The equation developed may be further improved by increasing the number of samples.
2. It is advisable to conduct comparative correlations between soaked and unsoaked CBR value with soil index properties
3. One should use these values carefully and based on professional judgment, since the correlation is only of sufficient accuracy for preliminary identification of material.
4. It is also recommended to carry out similar research in other parts of Ethiopia.

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Annexes

Annex A-1: Multiple Linear Regression Analysis **(For Red Clay)**

Equation 9: Correlation between CBR with PL, LI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.733[a]	.537	.438	.60602

a. Predictors: (Constant), Gs, PL, LI

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	28.151	8.339		3.376	.005
	LI	-1.738	.990	-.356	-1.755	.101
	PL	-.092	.038	-.476	-2.439	.029
	Gs	-7.852	3.026	-.528	-2.594	.021

a. Dependent Variable: CBR

Equation 10: Correlation between CBR withPP200, PL, LI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.768[a]	.589	.463	.59252

a. Predictors: (Constant), PP200, LI, PL, Gs

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	25.619	8.389		3.054	.009
	LI	-1.791	.969	-.367	-1.849	.087
	PL	-.095	.037	-.492	-2.573	.023
	Gs	-10.034	3.413	-.675	-2.940	.011
	PP200	.091	.071	.272	1.283	.222

a. Dependent Variable: CBR

Equation 12: Correlation between CBR withPP200, LL, PI, LI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.775[a]	.601	.435	.60793

a. Predictors: (Constant), LI, PI, PP200, Gs, LL

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	23.063	9.634		2.394	.034
	Gs	-9.023	3.898	-.607	-2.315	.039
	PP200	.093	.073	.278	1.276	.226
	PI	.083	.043	.832	1.941	.076
	LL	-.096	.038	-1.124	-2.527	.027
	LI	-1.700	1.006	-.348	-1.690	.117

a. Dependent Variable: CBR

Annex A-2: Multiple Linear Regression Analysis **(For Black/Gray Clay)**

Equation 10: Correlation between CBR withPP200, PL, LI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.857[a]	.734	.556	1.00841

a. Predictors: (Constant), PP200, LI, Gs, PL

Coefficients (a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.014	9.992		.001	.999
	LI	.559	1.199	.103	.466	.658
	PL	.095	.089	.252	1.057	.331
	Gs	1.322	3.459	.086	.382	.716
	PP200	-.054	.015	-.927	-3.641	.011

a. Dependent Variable: CBR

Equation 11: Correlation between CBR withPP200, PL, PI, LI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.859[a]	.737	.475	1.09670

a. Predictors: (Constant), LI, PL, Gs, PP200, PI

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.524	14.302		.176	.867
	Gs	.549	4.728	.036	.116	.912
	PP200	-.047	.031	-.807	-1.547	.183
	PI	-.013	.048	-.152	-.270	.798
	PL	.086	.103	.228	.834	.442
	LI	.275	1.677	.050	.164	.876

a. Dependent Variable: CBR

Equation 12: Correlation between CBR withPP200, LL PL, PI, LI and Gs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.859[a]	.739	.347	1.22326

a. Predictors: (Constant), LI, PL, Gs, PP200, PI, LL

Coefficients (a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.417	15.972		.151	.887
	Gs	.536	5.274	.035	.102	.924
	PP200	-.046	.036	-.783	-1.291	.266
	LL	-.041	.300	-.528	-.138	.897
	PI	.027	.293	.312	.091	.932
	PL	.131	.348	.349	.376	.726
	LI	.187	1.976	.034	.095	.929

a. Dependent Variable: CBR

Annex B: Moisture content test results

Table:- B-1: Determination of moisture content for Test pit (TP-1)

Test Pit, TP-1		
Depth (m)	1.5m	
Container No	6B	2A
Mass of container (m_1), (gm)	15.5	15.8
Mass of container + wet Soil (m_2), (gm)	40.4	42
Mass of container + dry Soil (m_3), (gm)	35.9	37.3
Mass of water (m_2-m_3), (gm)	4.5	4.7
Mass of dry Soil (m_3-m_1), (gm)	20.4	21.5
Moisture Content, (ω %)	22.06	21.86
Average Moisture Content, (ω %)	22.0	

Table:- B-2: Determination of moisture content for Test pit (TP-2)

Test Pit, TP-2				
Depth (m)	1.5m		3m	
Container No	D_3	D_{115}	H_5	102
Mass of container (m_1), (gm)	15.7	15.7	15.5	15.6
Mass of container + wet Soil (m_2), (gm)	63.7	63.1	60.2	61.3
Mass of container + dry Soil (m_3), (gm)	52.4	52.2	46.7	47.6
Mass of water (m_2-m_3), (gm)	11.3	10.9	13.5	13.7
Mass of dry Soil (m_3-m_1), (gm)	36.7	36.5	31.2	32
Moisture Content, (ω %)	30.79	29.86	43.27	42.81
Average Moisture Content, (ω %)	30.3		43.0	

Table:- B-3: Determination of moisture content for Test pit (TP-3)

Test Pit, TP-3				
Depth (m)	1.5m		3m	
Container No	D_{12}	m^2	D4	MA20
Mass of container (m_1), (gm)	15.7	15.5	16	15
Mass of container + wet Soil (m_2), (gm)	61.3	66.5	44.1	42
Mass of container + dry Soil (m_3), (gm)	48.3	52	35.9	34.2
Mass of water (m_2-m_3), (gm)	13	14.5	8.2	7.8
Mass of dry Soil (m_3-m_1), (gm)	32.6	36.5	19.9	19.2
Moisture Content, (ω %)	39.88	39.73	41.21	40.63
Average Moisture Content, (ω %)	39.80		40.9	

Table:- B-4: Determination of moisture content for Test pit (TP-4)

Test Pit, TP-4				
Depth (m)	1.5m		3m	
Container No	H-4	H_5	D_{112}	G-2
Mass of container (m_1), (gm)	15.6	15.6	15.3	15.2
Mass of container + wet Soil (m_2), (gm)	69.1	72.4	70.1	70.4
Mass of container + dry Soil (m_3), (gm)	50.1	53.2	55.6	55.6
Mass of water (m_2-m_3), (gm)	19	19.2	14.5	14.8
Mass of dry Soil (m_3-m_1), (gm)	53.5	56.8	40.3	40.4
Moisture Content, (ω %)	35.51	33.80	35.98	36.63
Average Moisture Content, (ω %)	34.7		36.3	

Table:- B-5: Determination of moisture content for Test pit (TP-5)

Test Pit, TP-5				
Depth (m)	1.5m		3m	
Container No	A20	D11	A2	17
Mass of container (m_1), (gm)	15.4	15.1	15	11
Mass of container + wet Soil (m_2), (gm)	35.7	42	42	55.7
Mass of container + dry Soil (m_3), (gm)	28.4	32.5	32.1	39.5
Mass of water (m_2-m_3), (gm)	7.3	9.5	9.9	16.2
Mass of dry Soil (m_3-m_1), (gm)	13	17.4	17.1	28.5
Moisture Content, (ω %)	56.15	54.60	57.89	56.84
Average Moisture Content, (ω %)	55.38		57.4	

Table:- B-6: Determination of moisture content for Test pit (TP-6)

Test Pit, TP-6				
Depth (m)	1.5m		3m	
Container No	mA-5	8	G_2	2
Mass of container (m_1), (gm)	15.7	15.7	15.1	14.6
Mass of container + wet Soil (m_2), (gm)	62.5	55.2	64.5	60.7
Mass of container + dry Soil (m_3), (gm)	47.4	42.3	49.6	47.1
Mass of water (m_2-m_3), (gm)	15.1	12.9	14.9	13.6
Mass of dry Soil (m_3-m_1), (gm)	31.7	26.6	34.5	32.5
Moisture Content, (ω %)	47.63	48.50	43.19	41.85
Average Moisture Content, (ω %)	48.1		42.5	

Table:- B-7: Determination of moisture content for Test pit (TP-7)

Test Pit, TP-7				
Depth (m)	1.5m		3m	
Container No	m^2E	D_{112}	D_{36}	D_{12}
Mass of container (m_1), (gm)	15.5	15.3	14.7	15.7
Mass of container + wet Soil (m_2), (gm)	68	65	61.1	63.3
Mass of container + dry Soil (m_3), (gm)	53.2	50.8	46.6	48.4
Mass of water (m_2-m_3), (gm)	14.8	14.2	14.5	14.9
Mass of dry Soil (m_3-m_1), (gm)	37.7	35.5	31.9	32.7
Moisture Content, (ω %)	39.26	40	45.45	45.57
Average Moisture Content, (ω %)	39.6		45.5	

Table:- B-8: Determination of moisture content for Test pit (TP-8)

Test Pit, TP-8				
Depth (m)	1.5m		3m	
Container No	MA18	A4	D11	Z1
Mass of container (m_1), (gm)	15.6	15.5	15.1	15.8
Mass of container + wet Soil (m_2), (gm)	59.2	80.2	72.8	57.5
Mass of container + dry Soil (m_3), (gm)	50.5	67.4	59	47.6
Mass of water (m_2-m_3), (gm)	8.7	12.8	13.8	9.9
Mass of dry Soil (m_3-m_1), (gm)	34.9	51.9	43.9	31.8
Moisture Content, (ω %)	24.93	24.66	31.44	31.13
Average Moisture Content, (ω %)	24.80		31.3	

Table:- B-9: Determination of moisture content for Test pit (TP-9)

Test Pit, TP-9				
Depth (m)	1.5m		3m	
Container No	LB	GTT	M14	B3
Mass of container (m_1), (gm)	15.6	15.3	15.5	15
Mass of container + wet Soil (m_2), (gm)	60.3	59.2	50.8	42.8
Mass of container + dry Soil (m_3), (gm)	50.2	48.8	40.6	34.9
Mass of water (m_2-m_3), (gm)	10.1	10.4	10.2	7.9
Mass of dry Soil (m_3-m_1), (gm)	34.6	33.5	25.1	19.9
Moisture Content, (ω %)	29.19	31.04	40.64	39.70
Average Moisture Content, (ω %)	30.1		40.2	

Table:- B-10: Determination of moisture content for Test pit (TP-10)

Test Pit, TP-10				
Depth (m)	1.5m		3m	
Container No	D_{36}	D_{112}	D_{12}	EX
Mass of container (m_1), (gm)	14.8	15.2	15.7	15.5
Mass of container + wet Soil (m_2), (gm)	64.2	71.7	70.4	72.1
Mass of container + dry Soil (m_3), (gm)	52.4	58.3	58.9	59.9
Mass of water (m_2-m_3), (gm)	11.8	13.4	11.5	12.2
Mass of dry Soil (m_3-m_1), (gm)	37.6	43.1	43.2	44.4
Moisture Content, (ω %)	31.38	31.09	26.62	27.48
Average Moisture Content, (ω %)	31.2		27.0	

Table:- B-11: Determination of moisture content for Test pit (TP-11)

Test Pit, TP-11				
Depth (m)	1.5m		3m	
Container No	mA- 2	8	G-2	T-6
Mass of container (m_1), (gm)	15.7	15.8	15.1	15.5
Mass of container + wet Soil (m_2), (gm)	66.9	70.1	69.2	64
Mass of container + dry Soil (m_3), (gm)	52	54.1	52.2	48.5
Mass of water (m_2-m_3), (gm)	14.9	16	17	15.5
Mass of dry Soil (m_3-m_1), (gm)	36.3	38.3	37.1	33
Moisture Content, (ω %)	41.05	41.78	45.82	46.97
Average Moisture Content, (ω %)	41.4		46.40	

Table:- B-12: Determination of moisture content for Test pit (TP-12)

Test Pit, TP-12				
Depth (m)	1.5m		3m	
Container No	B3	L2	G7	MA21
Mass of container (m_1), (gm)	15.1	16	15.5	15.7
Mass of container + wet Soil (m_2), (gm)	51	53	59	61
Mass of container + dry Soil (m_3), (gm)	42.6	44.5	48.1	49.6
Mass of water (m_2-m_3), (gm)	8.4	8.5	10.9	11.4
Mass of dry Soil (m_3-m_1), (gm)	27.5	28.5	32.6	33.9
Moisture Content, (ω %)	30.55	29.82	33.44	33.63
Average Moisture Content, (ω %)	30.2		33.5	

Table:- B-13: Determination of moisture content for Test pit (TP-13)

Test Pit, TP-13				
Depth (m)	1.5m		3m	
Container No	D112	L2	M14	Z1
Mass of container (m_1), (gm)	15.3	16	15.5	15.8
Mass of container + wet Soil (m_2), (gm)	55.4	58.3	66.7	70.4
Mass of container + dry Soil (m_3), (gm)	44.7	47.2	51.5	55.3
Mass of water (m_2-m_3), (gm)	10.7	11.1	15.2	15.1
Mass of dry Soil (m_3-m_1), (gm)	29.4	31.2	36	39.5
Moisture Content, (ω %)	36.39	35.58	42.22	38.23
Average Moisture Content, (ω %)	36.0		40.2	

Table:- B-14: Determination of moisture content for Test pit (TP-14)

Test Pit, TP-14				
Depth (m)	1.5m		3m	
Container No	P23	2B	m_4	H_5
Mass of container (m_1), (gm.)	15.3	15.7	15.6	15.6
Mass of container + wet Soil (m_2), (gm.)	69	69.4	77.4	69
Mass of container + dry Soil (m_3), (gm.)	54.9	55.4	63.3	56.7
Mass of water (m_2-m_3), (gm.)	14.1	14	14.1	12.3
Mass of dry Soil (m_3-m_1), (gm)	39.6	39.7	47.7	41.1
Moisture Content, (ω %)	35.61	35.26	29.56	29.93
Average Moisture Content, (ω %)	35.4		29.7	

Table:- B-15: Determination of moisture content for Test pit (TP-15)

Test Pit, TP-15				
Depth (m)	1.5m		3m	
Container No	2X	D_{112}	T-6	8
Mass of container (m_1), (gm)	15.6	15.4	15.7	15.7
Mass of container + wet Soil (m_2), (gm)	65.8	64.2	73.5	58.7
Mass of container + dry Soil (m_3), (gm)	50.1	48.5	57.2	45.9
Mass of water (m_2-m_3), (gm)	16.2	15.7	16.3	12.8
Mass of dry Soil (m_3-m_1), (gm)	34.5	33.1	41.5	30.2
Moisture Content, (ω %)	46.96	47.43	39.28	42.38
Average Moisture Content, (ω %)	47		40.8	

Table:- B-16: Determination of moisture content for Test pit (TP-16)

Test Pit, TP-16				
Depth (m)	1.5m		3m	
Container No	D12	G2	G7	Z1
Mass of container (m_1), (gm)	15.7	15.1	15.5	15
Mass of container + wet Soil (m_2), (gm)	60.5	57.6	61	59.1
Mass of container + dry Soil (m_3), (gm)	50.4	48.1	48.6	46.9
Mass of water (m_2-m_3), (gm)	10.1	9.5	12.4	12.2
Mass of dry Soil (m_3-m_1), (gm)	34.7	33.0	33.1	31.9
Moisture Content, (ω %)	29.11	28.8	37.5	38.2
Average Moisture Content, (ω %)	29		37.9	

Annex C: Specific gravity testresults (Typical values).

Table:- C-1: Specific gravity test result of TP1 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws}(gm.)	160.8	175.3
Temperature, T_x(^{o}c)	20	20
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.00	159.30
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0001	1.0000
Specific gravity of soil at 20°c.	2.72	2.78
Average specific gravity of soil.	2.75	

Table:- C-2: Specific gravity test results of TP2 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, Wpws (gm.)	161	175.5
Temperature, Tx(oc)	22.5	22
Weight of pycnometer + water at Tx , Wpw(atTx) (gm.)	144.87	159.28
Weight of dry soil , ws (gm.)	25	25
Conversion factor , K	0.9996	0.9998
Specific gravity of soil at 20°c.	2.82	2.85
Average specific gravity of soil.	2.83	

Table: - C-2: Specific gravity test results of TP2 at D=3.0m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	161.8	175.3
Temperature, T_x(^{o}c)	19	20.5
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	144.94	159.27
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	0.9996	0.9996
Specific gravity of soil at 20°c.	3.07	2.79
Average specific gravity of soil.	2.93	

Table:- C-3: Specific gravity test results of TP4 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	161	175.3
Temperature, T_x(^{o}c)	19	19.5
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.02	159.31
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0002	1.0001
Specific gravity of soil at 20°c.	2.77	2.77
Average specific gravity of soil.	2.77	

Table: - C-3: Specific gravity test results of TP4 at D=3.0m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	161.2	175.4
Temperature, T_x(^{o}c)	18	18
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.04	159.34
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0004	1.0004
Specific gravity of soil at 20°c.	2.83	2.80
Average specific gravity of soil.	2.81	

Table: - C-4: Specific gravity test results of TP6 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	160.5	174.9
Temperature, T_x(^{o}c)	21	20
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	144.98	159.40
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	0.9998	1.0000
Specific gravity of soil at 20°c.	2.64	2.63
Average specific gravity of soil.	2.63	

Table: - C-4: Specific gravity test results of TP6 at D=3.0m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	161	175.3
Temperature, T_x(^{o}c)	20	20
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.00	159.40
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1	1.0000
Specific gravity of soil at 20°c.	2.78	2.75
Average specific gravity of soil.	2.76	

Table: - C-5: Specific gravity test results of TP9 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	160.8	175.2
Temperature, T_x(^{o}c)	21	21
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	144.98	159.38
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	0.9998	0.9998
Specific gravity of soil at 20°c.	2.72	2.72
Average specific gravity of soil.	2.72	

Table: - C-5: Specific gravity test results of TP9 at D=3.0m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (g)	160.9	175.3
Temperature, T_x(^oc)	18.5	19
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (g)	145.03	159.42
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0003	1.0002
Specific gravity of soil at 20°c.	2.74	2.74
Average specific gravity of soil.	2.74	

Table: - C-6: Specific gravity test results of TP12 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	160.9	175.3
Temperature, T_x(^oc)	19	19
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.02	159.42
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0002	1.0002
Specific gravity of soil at 20°c.	2.74	2.74
Average specific gravity of soil.	2.74	

Table: - C-6: Specific gravity test results of TP12 at D=3.0m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	160.9	175.4
Temperature, T_x(^{o}c)	19	19
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.02	159.42
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0002	1.0002
Specific gravity of soil at 20°c.	2.74	2.77
Average specific gravity of soil.	2.76	

Table: - C-7: Specific gravity test results of TP15 at D=1.50m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	160.8	175.2
Temperature, T_x(^{o}c)	18	19
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.04	159.32
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0004	1.0002
Specific gravity of soil at 20°c.	2.71	2.74
Average specific gravity of soil.	2.72	

Table: - C-7: Specific gravity test results of TP15 at D=3.0m

Determination No.	1	2
Pycnometer No.	P1	P2
Weight of pycnometer + soil + water, W_{pws} (gm.)	161	175.3
Temperature, T_x(^{o}c)	18	18
Weight of pycnometer + water at T_x , W_{pw}(atT_x) (gm.)	145.04	159.34
Weight of dry soil , w_s (gm.)	25	25
Conversion factor , K	1.0004	1.0004
Specific gravity of soil at 20°c.	2.77	2.77
Average specific gravity of soil.	2.77	

Annex D: Grain size analysis results (typical results)

Table: - D-1: Grain size analysis result of TP1 at D=1.50m

sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	0.0	1126.8	1126.8	0.0	0.0	0.0	100.0
1.5"	37.5	1217.0	1262.7	45.7	1.0	1.0	99.0
1"	25.0	1214.9	2215.9	1001.0	22.3	23.3	76.7
3/4"	19.0	1194.0	1720.2	526.2	11.7	35.0	65.0
1/2"	12.5	1178.7	2051.9	873.2	19.5	54.5	45.5
3.8"	9.5	1157.7	1559.1	401.4	8.9	63.4	36.6
No 4	4.75	1262.1	1816.4	554.3	12.4	75.8	24.2
No 8	2.36	983.5	1198.4	214.9	4.8	80.6	19.4
No 10	2	955.0	983.9	28.9	0.6	81.2	18.8
No 16	1.18	894.8	943.1	48.3	1.1	82.3	17.7
No 30	0.6	831.2	868.5	37.3	0.8	83.1	16.9
No 50	0.3	750.3	773.1	22.8	0.5	83.6	16.4
No 100	0.15	778.4	785.3	6.9	0.2	83.8	16.2
No 200	0.075	274.4	281.8	7.4	0.2	84.0	16.0
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0305	-0.0025	1.0280	8.23	0.0443	87.46	14.03
1	1.0290	-0.0025	1.0265	8.63	0.0392	82.78	13.27
2	1.0265	-0.0025	1.0240	9.29	0.0288	74.97	12.02
4	1.0235	-0.0025	1.0210	10.08	0.0212	65.60	10.52
8	1.0210	-0.0025	1.0185	10.75	0.0155	57.79	9.27
15	1.0185	-0.0025	1.0160	11.41	0.0117	49.98	8.01
30	1.0160	-0.0025	1.0135	12.07	0.0085	42.17	6.76
60	1.0140	-0.0025	1.0115	12.60	0.0061	35.92	5.76
120	1.0125	-0.0025	1.0100	12.99	0.0044	31.24	5.01
240	1.0115	-0.0025	1.0090	13.26	0.0031	28.11	4.51
480	1.0105	-0.0025	1.0080	13.52	0.0022	24.99	4.01
1440	1.0100	-0.0025	1.0075	13.65	0.0013	23.43	3.76

D-1: Grain size distribution curve of TP1 at D=1.50m

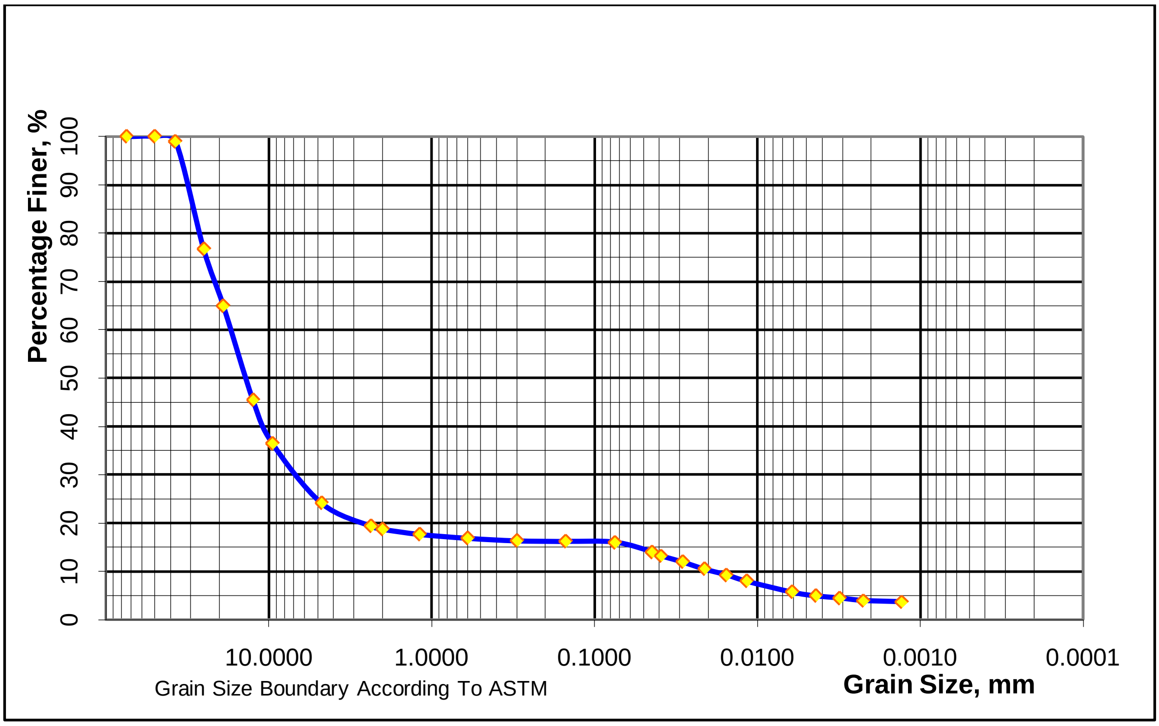


Table: - D-2: Grain size analysis result of TP4 at D=1.50m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1127.3	1127.3	0.0	0.0	0.0	100.0
1.5"	37.5	1217.6	1217.6	0.0	0.0	0.0	100.0
1"	25.0	1215.2	1215.2	0.0	0.0	0.0	100.0
3/4"	19.0	1178.8	1199.3	20.5	0.9	0.9	99.1
1/2"	12.5	1179.4	1183.5	4.1	0.2	1.1	98.9
3.8"	9.5	1158.5	1161.4	2.9	0.1	1.2	98.8
No 4	4.75	1263.1	1264.6	1.5	0.1	1.3	98.7
No 8	2.36	983.9	984.6	0.7	0.0	1.3	98.7
No 10	2	944.1	945.2	1.1	0.0	1.4	98.6
No 16	1.18	894.8	902.0	7.2	0.3	1.7	98.3
No 30	0.6	831.1	844.4	13.3	0.6	2.3	97.7
No 50	0.3	755.0	775.7	20.7	0.9	3.2	96.8
No 100	0.15	780.0	832.5	52.5	2.3	5.5	94.5
No 200	0.075	284.0	311.9	27.9	1.2	6.7	93.3
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0315	-0.0031	1.0284	7.97	0.0440	88.89	82.92
1	1.0295	-0.0031	1.0264	8.50	0.0393	82.63	77.08
2	1.0280	-0.0031	1.0249	8.89	0.0284	77.94	72.70
4	1.0265	-0.0031	1.0234	9.29	0.0206	73.24	68.32
8	1.0260	-0.0031	1.0229	9.42	0.0146	71.68	66.86
15	1.0255	-0.0031	1.0224	9.55	0.0108	70.11	65.40
30	1.0248	-0.0031	1.0217	9.74	0.0077	67.92	63.36
60	1.0232	-0.0031	1.0201	10.16	0.0056	62.91	58.69
120	1.0225	-0.0031	1.0194	10.35	0.0040	60.72	56.64
240	1.0215	-0.0031	1.0184	10.61	0.0028	57.59	53.72
480	1.0202	-0.0031	1.0171	10.96	0.0020	53.52	49.93
1440	1.0190	-0.0031	1.0159	11.27	0.0012	49.77	46.43

D-2: Grain size distribution curve of TP4 at D=1.50m

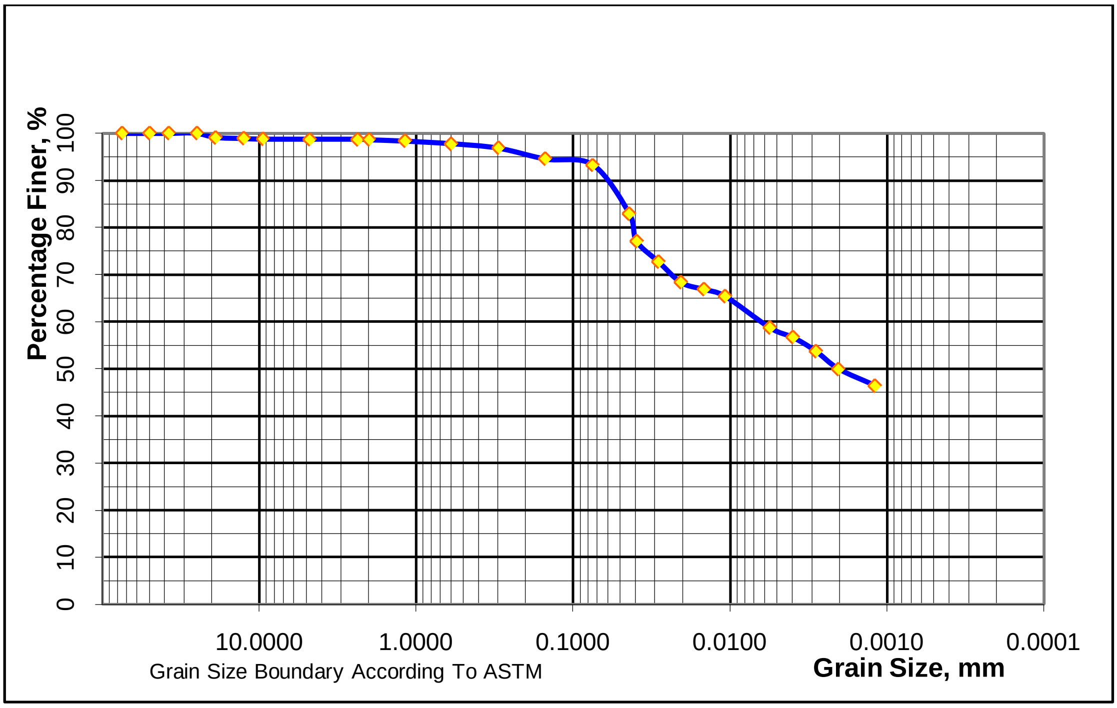


Table: - D-2: Grain size analysis result of TP4 at D=3.0m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1127.3	1127.3	0.0	0.0	0.0	100.0
1.5"	37.5	1217.6	1217.6	0.0	0.0	0.0	100.0
1"	25.0	1215.2	1215.2	0.0	0.0	0.0	100.0
3/4"	19.0	1178.8	1199.3	20.5	0.8	0.8	99.2
1/2"	12.5	1179.4	1183.5	4.1	0.2	0.9	99.1
3.8"	9.5	1158.5	1161.4	2.9	0.1	1.1	98.9
No 4	4.75	1263.1	1264.6	1.5	0.1	1.1	98.9
No 8	2.36	983.9	984.6	0.7	0.0	1.1	98.9
No 10	2	944.1	945.2	1.1	0.0	1.2	98.8
No 16	1.18	894.8	902.0	7.2	0.3	1.5	98.5
No 30	0.6	831.1	844.4	13.3	0.5	2.0	98.0
No 50	0.3	755.0	775.7	20.7	0.8	2.8	97.2
No 100	0.15	780.0	832.5	52.5	2.0	4.8	95.2
No 200	0.075	284.0	311.9	27.9	1.1	5.8	94.2
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0033	1.0297	7.57	0.0431	92.22	86.85
1	1.0315	-0.0033	1.0282	7.97	0.0383	87.56	82.46
2	1.0292	-0.0033	1.0259	8.58	0.0281	80.42	75.74
4	1.0280	-0.0033	1.0247	8.89	0.0202	76.69	72.23
8	1.0272	-0.0033	1.0239	9.11	0.0145	74.21	69.89
15	1.0262	-0.0033	1.0229	9.37	0.0107	71.10	66.96
30	1.0251	-0.0033	1.0218	9.66	0.0077	67.69	63.75
60	1.0235	-0.0033	1.0202	10.08	0.0056	62.72	59.07
120	1.0226	-0.0033	1.0193	10.32	0.0040	59.93	56.44
240	1.0214	-0.0033	1.0181	10.64	0.0029	56.20	52.93
480	1.0202	-0.0033	1.0169	10.96	0.0020	52.47	49.42
1440	1.0195	-0.0033	1.0162	11.14	0.0012	50.30	47.37

D-2: Grain size distribution curve of TP4 at D=3.0m

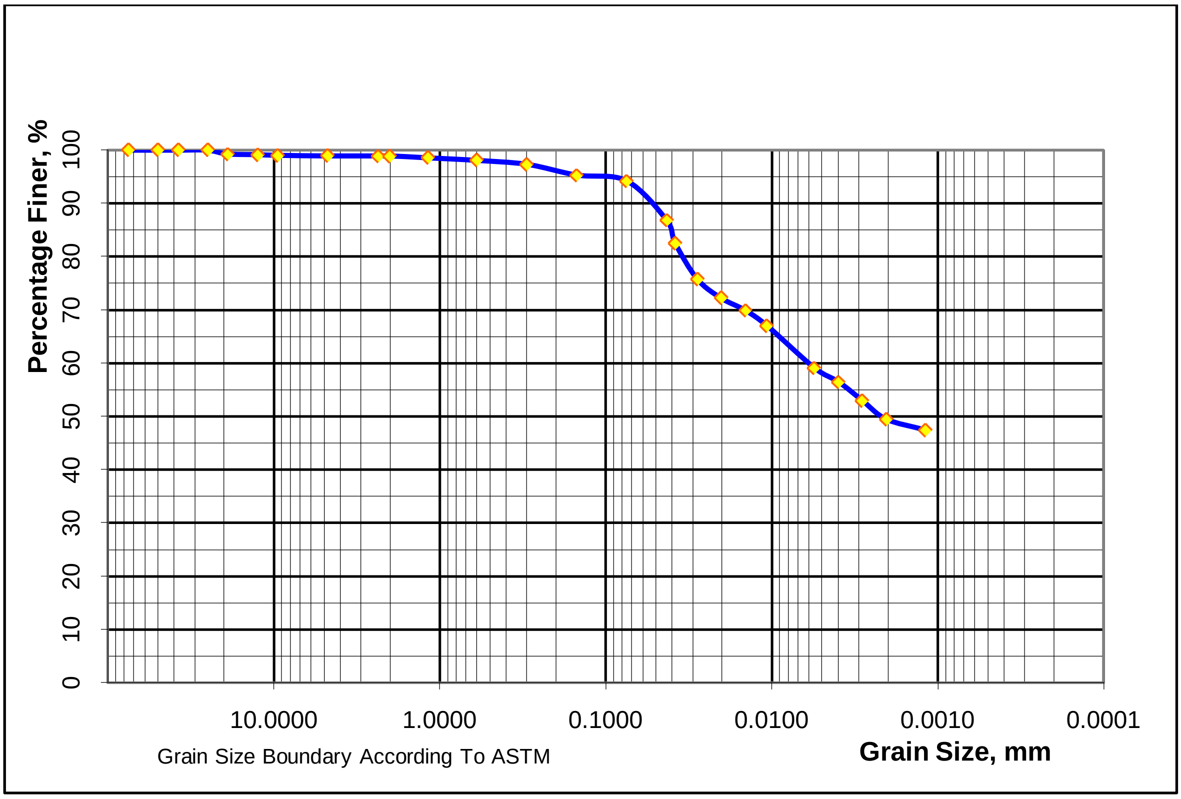


Table: - D-3: Grain size analysis result of TP7at D=1.50m

Sieve No	Opening (mm)	Sieve (g)	Retained soil (g)	Retained soil (g)	Retained (%)	Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1193.9	1193.9	0.0	0.0	0.0	100.0
1/2"	12.5	1178.8	1178.8	0.0	0.0	0.0	100.0
3.8"	9.5	1157.7	1157.7	0.0	0.0	0.0	100.0
No 4	4.75	1262.2	1262.4	0.2	0.0	0.0	100.0
No 8	2.36	983.9	986.6	2.7	0.2	0.2	99.8
No 10	2	955.2	956.4	1.2	0.1	0.3	99.7
No 16	1.18	894.8	900.7	5.9	0.4	0.6	99.4
No 30	0.6	831.3	845.1	13.8	0.9	1.5	98.5
No 50	0.3	750.5	764.8	14.3	0.9	2.5	97.5
No 100	0.15	778.6	790.1	11.5	0.7	3.2	96.8
No 200	0.075	274.5	280.8	6.3	0.4	3.6	96.4
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0305	-0.0025	1.0280	8.23	0.0443	93.33	89.97
1	1.0295	-0.0025	1.0270	8.50	0.0389	90.00	86.75
2	1.0280	-0.0025	1.0255	8.89	0.0282	85.00	81.93
4	1.0265	-0.0025	1.0240	9.29	0.0204	80.00	77.11
8	1.0255	-0.0025	1.0230	9.55	0.0146	76.67	73.90
15	1.0245	-0.0025	1.0220	9.82	0.0108	73.33	70.69
30	1.0230	-0.0025	1.0205	10.22	0.0078	68.33	65.87
60	1.0215	-0.0025	1.0190	10.61	0.0056	63.33	61.05
120	1.0210	-0.0025	1.0185	10.75	0.0040	61.67	59.44
240	1.0195	-0.0025	1.0170	11.14	0.0029	56.67	54.62
480	1.0185	-0.0025	1.0160	11.41	0.0021	53.33	51.41
1440	1.0180	-0.0025	1.0155	11.54	0.0012	51.67	49.80

D-3: Grain size distribution curve of TP7 at D=1.50m

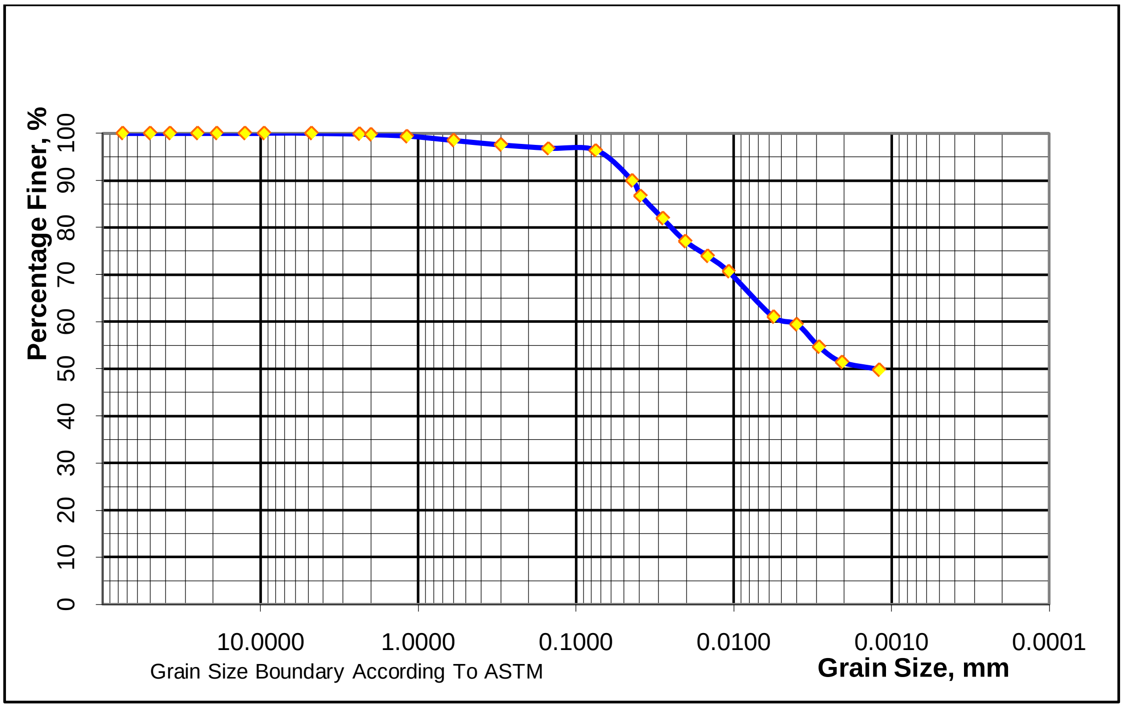


Table: - D-4: Grain size analysis results of TP10 at D=1.50m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1126.8	1126.8	0.0	0.0	0.0	100.0
1.5"	37.5	1217.0	1217.0	0.0	0.0	0.0	100.0
1"	25.0	1214.9	1214.9	0.0	0.0	0.0	100.0
3/4"	19.0	1393.7	1393.7	0.0	0.0	0.0	100.0
1/2"	12.5	1179.6	1179.6	0.0	0.0	0.0	100.0
3.8"	9.5	1158.2	1158.2	0.0	0.0	0.0	100.0
No 4	4.75	1263.0	1264.2	1.2	0.1	0.1	99.9
No 8	2.36	984.0	1007.4	23.4	1.0	1.1	98.9
No 10	2	955.2	971.1	15.9	0.7	1.8	98.2
No 16	1.18	895.2	934.6	39.4	1.8	3.6	96.4
No 30	0.6	831.4	874.8	43.4	1.9	5.5	94.5
No 50	0.3	750.4	778.8	28.4	1.3	6.8	93.2
No 100	0.15	779.9	799.5	19.6	0.9	7.7	92.3
No 200	0.075	275.0	295.0	20.0	0.9	8.6	91.4
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0320	-0.0025	1.0295	7.84	0.0432	90.38	82.64
1	1.0305	-0.0025	1.0280	8.23	0.0383	85.79	78.43
2	1.0290	-0.0025	1.0265	8.63	0.0278	81.19	74.23
4	1.0280	-0.0025	1.0255	8.89	0.0199	78.13	71.43
8	1.0270	-0.0025	1.0245	9.16	0.0143	75.06	68.63
15	1.0255	-0.0025	1.0230	9.55	0.0107	70.47	64.43
30	1.0240	-0.0025	1.0215	9.95	0.0077	65.87	60.23
60	1.0225	-0.0025	1.0200	10.35	0.0055	61.28	56.02
120	1.0210	-0.0025	1.0185	10.75	0.0040	56.68	51.82
240	1.0195	-0.0025	1.0170	11.14	0.0029	52.09	47.62
480	1.0185	-0.0025	1.0160	11.41	0.0021	49.02	44.82
1440	1.0170	-0.0025	1.0145	11.80	0.0012	44.43	40.62

D-4: Grain size distribution curve of TP10 at D=1.50m

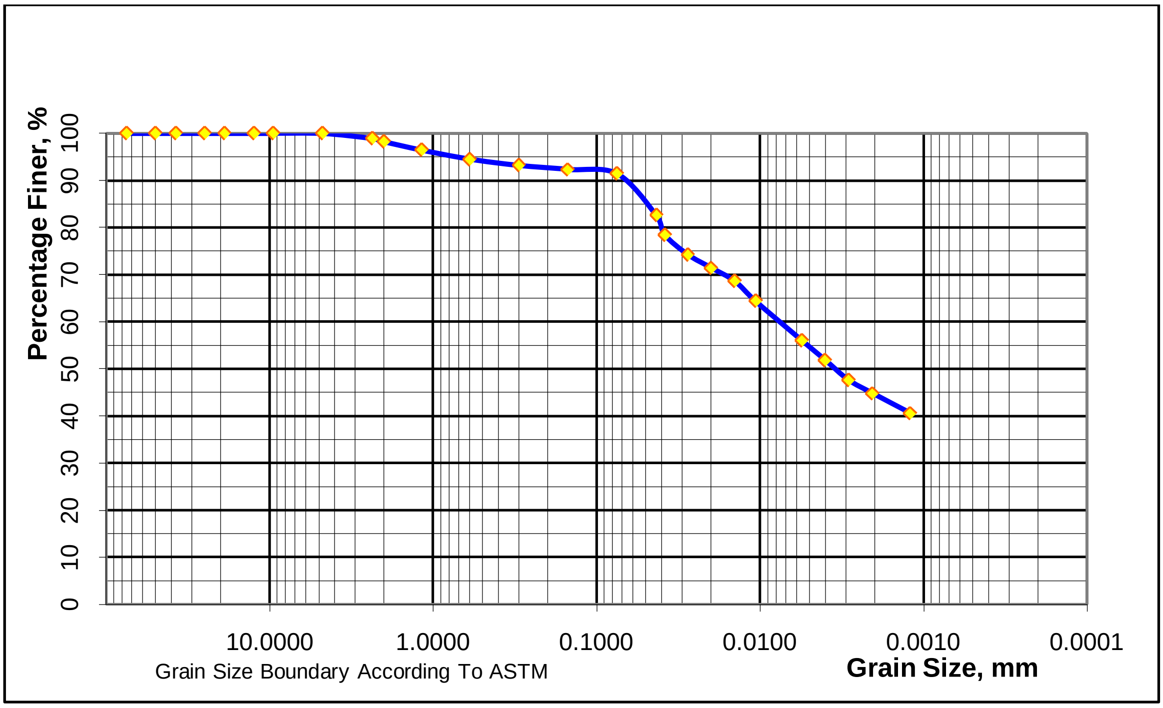


Table: - D-4: Grain size analysis results of TP10 at D=3.0m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1126.8	1126.8	0.0	0.0	0.0	100.0
1.5"	37.5	1217.0	1217.0	0.0	0.0	0.0	100.0
1"	25.0	1214.9	1214.9	0.0	0.0	0.0	100.0
3/4"	19.0	1393.7	1393.7	0.0	0.0	0.0	100.0
1/2"	12.5	1179.6	1179.6	0.0	0.0	0.0	100.0
3.8"	9.5	1158.0	1158.0	0.0	0.0	0.0	100.0
No 4	4.75	1262.5	1268.6	6.1	0.4	0.4	99.6
No 8	2.36	983.8	993.4	9.6	0.6	1.0	99.0
No 10	2	955.1	959.8	4.7	0.3	1.3	98.7
No 16	1.18	895.1	912.3	17.2	1.1	2.4	97.6
No 30	0.6	831.5	858.3	26.8	1.7	4.2	95.8
No 50	0.3	750.4	768.0	17.6	1.1	5.3	94.7
No 100	0.15	778.3	787.3	9.0	0.6	5.9	94.1
No 200	0.075	275.5	287.2	11.7	0.8	6.6	93.4
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0025	1.0300	7.70	0.0428	94.09	87.86
1	1.0315	-0.0025	1.0290	7.97	0.0377	90.95	84.93
2	1.0300	-0.0025	1.0275	8.36	0.0273	86.25	80.54
4	1.0295	-0.0025	1.0270	8.50	0.0195	84.68	79.07
8	1.0280	-0.0025	1.0255	8.89	0.0141	79.98	74.68
15	1.0265	-0.0025	1.0240	9.29	0.0105	75.27	70.29
30	1.0255	-0.0025	1.0230	9.55	0.0075	72.14	67.36
60	1.0240	-0.0025	1.0215	9.95	0.0054	67.43	62.96
120	1.0220	-0.0025	1.0195	10.48	0.0039	61.16	57.11
240	1.0215	-0.0025	1.0190	10.61	0.0028	59.59	55.64
480	1.0200	-0.0025	1.0175	11.01	0.0020	54.89	51.25
1440	1.0180	-0.0025	1.0155	11.54	0.0012	48.61	45.39

D-4: Grain size distribution curve of TP10 at D=3.0m

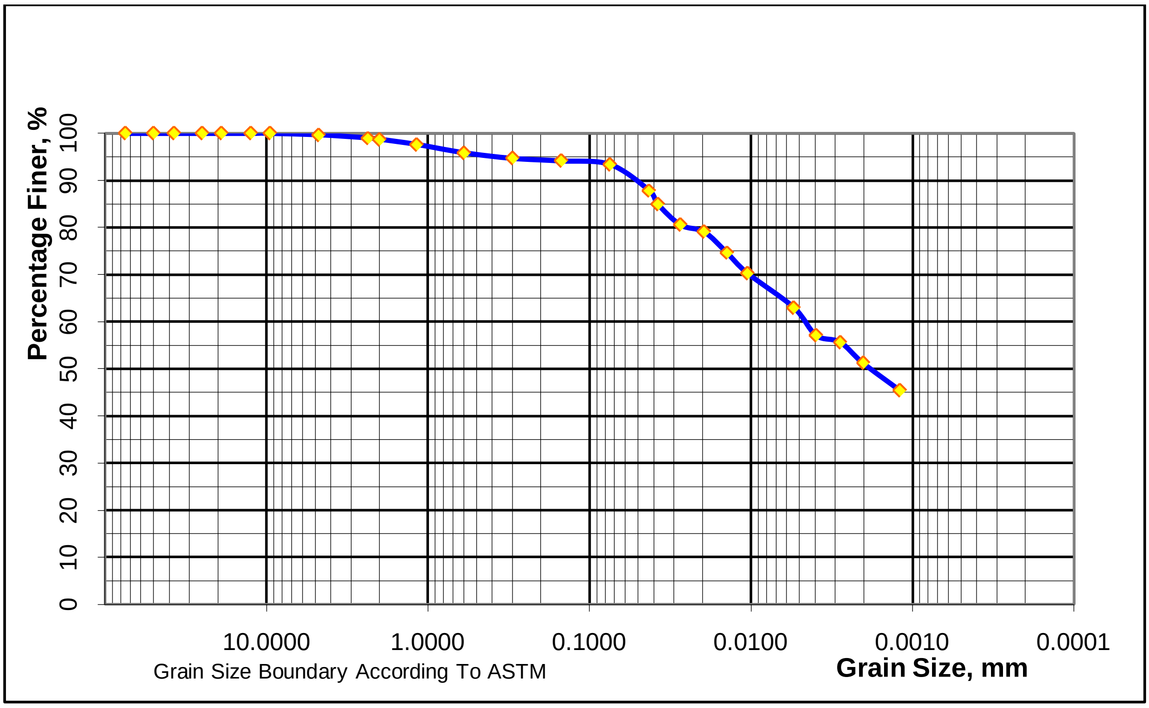


Table: - D-5: Grain size analysis results of TP13 at D=1.50m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1193.9	1193.9	0.0	0.0	0.0	100.0
1/2"	12.5	1178.8	1178.8	0.0	0.0	0.0	100.0
3.8"	9.5	1157.7	1157.7	0.0	0.0	0.0	100.0
No 4	4.75	1263.0	1263.7	0.7	0.0	0.0	100.0
No 8	2.36	983.9	992.2	8.3	0.4	0.4	99.6
No 10	2	944.8	948.5	3.7	0.2	0.6	99.4
No 16	1.18	895.4	904.2	8.8	0.4	1.0	99.0
No 30	0.6	831.4	845.7	14.3	0.7	1.7	98.3
No 50	0.3	754.8	771.0	16.2	0.8	2.5	97.5
No 100	0.15	779.6	802.4	22.8	1.1	3.6	96.4
No 200	0.075	284.1	301.0	16.9	0.8	4.5	95.5
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0031	1.0299	7.57	0.0432	93.21	89.04
1	1.0315	-0.0031	1.0284	7.97	0.0384	88.53	84.57
2	1.0300	-0.0031	1.0269	8.36	0.0278	83.86	80.10
4	1.0292	-0.0031	1.0261	8.58	0.0199	81.36	77.72
8	1.0287	-0.0031	1.0256	8.71	0.0142	79.80	76.23
15	1.0276	-0.0031	1.0245	9.00	0.0105	76.37	72.96
30	1.0265	-0.0031	1.0234	9.29	0.0076	72.95	69.68
60	1.0255	-0.0031	1.0224	9.55	0.0054	69.83	66.70
120	1.0245	-0.0031	1.0214	9.82	0.0039	66.71	63.73
240	1.0235	-0.0031	1.0204	10.08	0.0028	63.59	60.75
480	1.0225	-0.0031	1.0194	10.35	0.0020	60.48	57.77
1440	1.0215	-0.0031	1.0184	10.61	0.0012	57.36	54.79

D-5: Grain size distribution curve of TP13 at D=1.50m

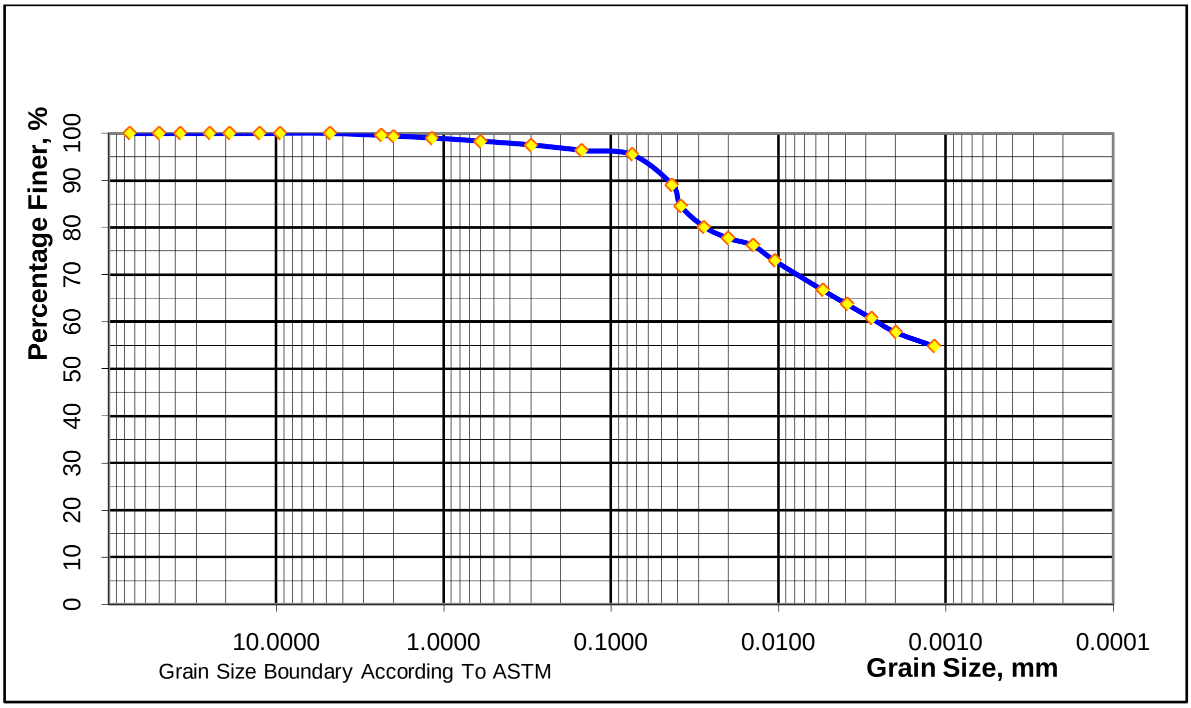


Table: - D-5: Grain size analysis results of TP13 at D=3.0m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1193.9	1193.9	0.0	0.0	0.0	100.0
1/2"	12.5	1178.8	1178.8	0.0	0.0	0.0	100.0
3.8"	9.5	1157.7	1157.7	0.0	0.0	0.0	100.0
No 4	4.75	1263.0	1263.0	0.0	0.0	0.0	100.0
No 8	2.36	983.9	987.6	3.7	0.2	0.2	99.8
No 10	2	944.8	946.6	1.8	0.1	0.3	99.7
No 16	1.18	895.4	900.0	4.6	0.2	0.5	99.5
No 30	0.6	831.4	838.9	7.5	0.4	0.9	99.1
No 50	0.3	754.8	763.7	8.9	0.4	1.3	98.7
No 100	0.15	779.6	792.9	13.3	0.6	1.9	98.1
No 200	0.075	284.1	298.0	13.9	0.7	2.6	97.4
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0031	1.0294	7.70	0.0435	91.29	88.89
1	1.0310	-0.0031	1.0279	8.10	0.0386	86.63	84.36
2	1.0290	-0.0031	1.0259	8.63	0.0282	80.42	78.31
4	1.0282	-0.0031	1.0251	8.84	0.0202	77.93	75.89
8	1.0276	-0.0031	1.0245	9.00	0.0144	76.07	74.08
15	1.0270	-0.0031	1.0239	9.16	0.0106	74.21	72.26
30	1.0260	-0.0031	1.0229	9.42	0.0076	71.10	69.24
60	1.0250	-0.0031	1.0219	9.69	0.0054	68.00	66.22
120	1.0242	-0.0031	1.0211	9.90	0.0039	65.51	63.80
240	1.0235	-0.0031	1.0204	10.08	0.0028	63.34	61.68
480	1.0230	-0.0031	1.0199	10.22	0.0020	61.79	60.17
1440	1.0225	-0.0031	1.0194	10.35	0.0011	60.24	58.66

D-5: Grain size distribution curve of TP13 at D=3.0m

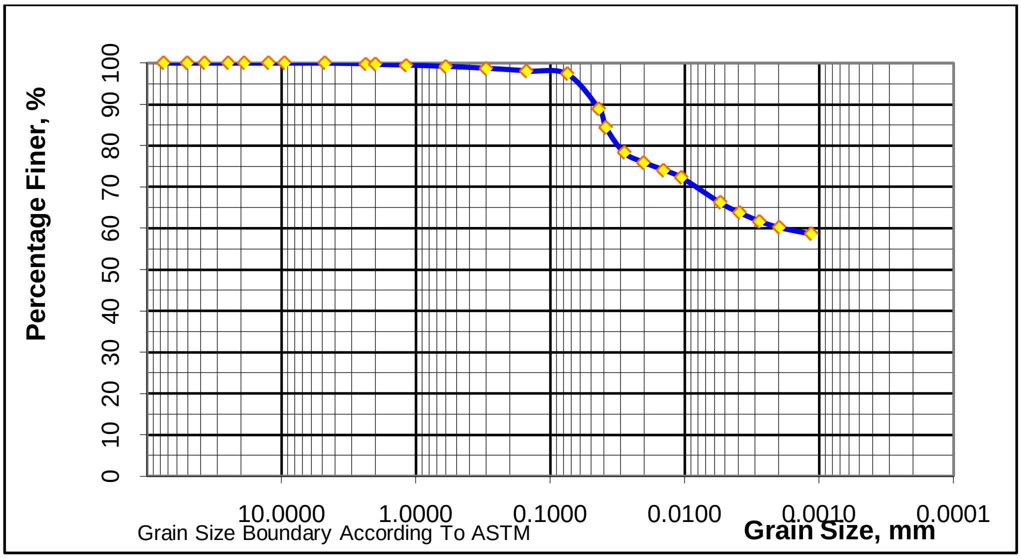


Table: - D-6: Grain size analysis results of TP16 at D=1.50m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1193.9	1193.9	0.0	0.0	0.0	100.0
1/2"	12.5	1178.8	1178.8	0.0	0.0	0.0	100.0
3.8"	9.5	1157.7	1157.7	0.0	0.0	0.0	100.0
No 4	4.75	1263.0	1263.1	0.1	0.0	0.0	100.0
No 8	2.36	984.0	992.0	8.0	0.3	0.3	99.7
No 10	2	955.2	962.3	7.1	0.3	0.6	99.4
No 16	1.18	895.2	916.8	21.6	0.9	1.6	98.4
No 30	0.6	831.4	853.7	22.3	0.9	2.5	97.5
No 50	0.3	750.4	769.1	18.7	0.8	3.3	96.7
No 100	0.15	779.9	798.1	18.2	0.8	4.0	96.0
No 200	0.075	275.0	305.2	30.2	1.3	5.3	94.7
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0025	1.0300	7.70	0.0428	93.15	88.19
1	1.0310	-0.0025	1.0285	8.10	0.0380	88.49	83.78
2	1.0285	-0.0025	1.0260	8.76	0.0280	80.73	76.43
4	1.0275	-0.0025	1.0250	9.03	0.0201	77.62	73.49
8	1.0260	-0.0025	1.0235	9.42	0.0145	72.97	69.08
15	1.0250	-0.0025	1.0225	9.69	0.0107	69.86	66.14
30	1.0240	-0.0025	1.0215	9.95	0.0077	66.76	63.20
60	1.0230	-0.0025	1.0205	10.22	0.0055	63.65	60.26
120	1.0215	-0.0025	1.0190	10.61	0.0040	58.99	55.85
240	1.0205	-0.0025	1.0180	10.88	0.0028	55.89	52.91
480	1.0195	-0.0025	1.0170	11.14	0.0020	52.78	49.97
1440	1.0190	-0.0025	1.0165	11.27	0.0012	51.23	48.50

D-6: Grain size distribution curve of TP16 at D=1.50m

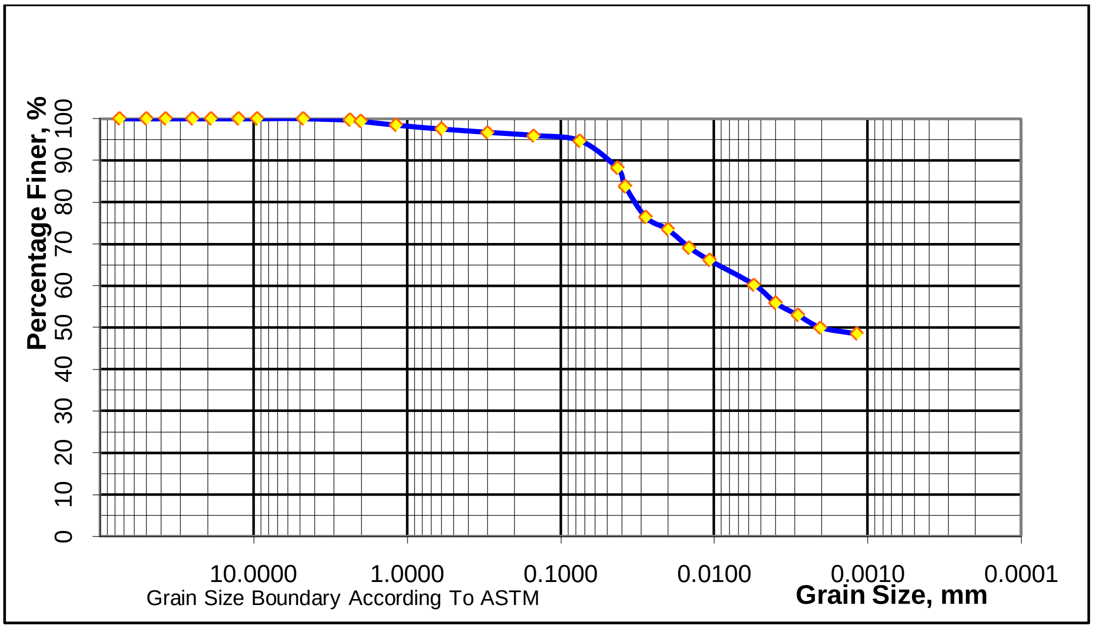
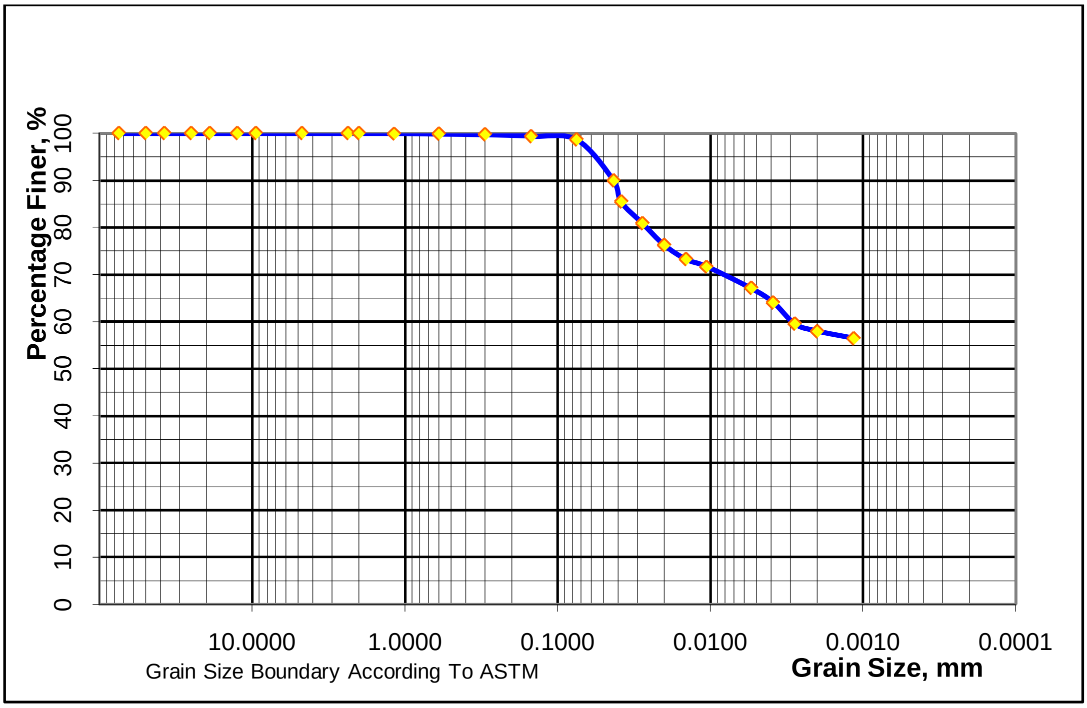


Table:- D-6: Grain size analysis results of TP16 at D=3.0m

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve + Retained soil (g)	Mass of Retained soil (g)	Percentage Retained (%)	Cum. Percentage Retained (%)	Perc. Passing (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	100.0
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	100.0
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	100.0
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	100.0
3/4"	19.0	1193.9	1193.9	0.0	0.0	0.0	100.0
1/2"	12.5	1178.8	1178.8	0.0	0.0	0.0	100.0
3.8"	9.5	1157.7	1157.7	0.0	0.0	0.0	100.0
No 4	4.75	1263.0	1263.2	0.2	0.0	0.0	100.0
No 8	2.36	984.0	984.5	0.5	0.0	0.0	100.0
No 10	2	955.2	955.5	0.3	0.0	0.0	100.0
No 16	1.18	895.2	895.8	0.6	0.0	0.1	99.9
No 30	0.6	831.4	832.9	1.5	0.1	0.1	99.9
No 50	0.3	750.4	753.8	3.4	0.2	0.3	99.7
No 100	0.15	779.9	787.8	7.9	0.4	0.7	99.3
No 200	0.075	275.0	290.6	15.6	0.7	1.4	98.6
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0320	-0.0025	1.0295	7.84	0.0432	91.24	90.00
1	1.0305	-0.0025	1.0280	8.23	0.0383	86.60	85.42
2	1.0290	-0.0025	1.0265	8.63	0.0278	81.96	80.85
4	1.0275	-0.0025	1.0250	9.03	0.0201	77.32	76.27
8	1.0265	-0.0025	1.0240	9.29	0.0144	74.23	73.22
15	1.0260	-0.0025	1.0235	9.42	0.0106	72.68	71.69
30	1.0255	-0.0025	1.0230	9.55	0.0075	71.14	70.17
60	1.0245	-0.0025	1.0220	9.82	0.0054	68.04	67.12
120	1.0235	-0.0025	1.0210	10.08	0.0039	64.95	64.07
240	1.0220	-0.0025	1.0195	10.48	0.0028	60.31	59.49
480	1.0215	-0.0025	1.0190	10.61	0.0020	58.77	57.97
1440	1.0210	-0.0025	1.0185	10.75	0.0012	57.22	56.44

D-6: Grain size distribution curve of TP16 at D=3.0m



Annex E: Atterberg Limits (Liquid limit and Plastic limit test results) Typical Results

Table: - E-1: Liquid limit and Plastic limit test result of TP1 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	Lel-05	LB	G-6	T-6	LC	H5
Mass of container, g	11.00	15.60	15.70	15.60	15.10	15.60
Mass of container + Wet soil, g	30.30	38.90	37.80	37.10	21.50	22.20
Mass of container + Dry soil, g	23.60	30.60	29.70	29.20	20.00	20.70
Mass of water, g	6.70	8.30	8.10	7.90	1.50	1.50
Mass of dry soil, g	12.60	15.00	14.00	13.60	4.90	5.10
Water content, %	53.17	55.33	57.86	58.09	30.61	29.41
No of blows	33	26	20	15	------	------

Liquid Limit, % = 55 Plastic Limit, % = 30 PI, %= 25

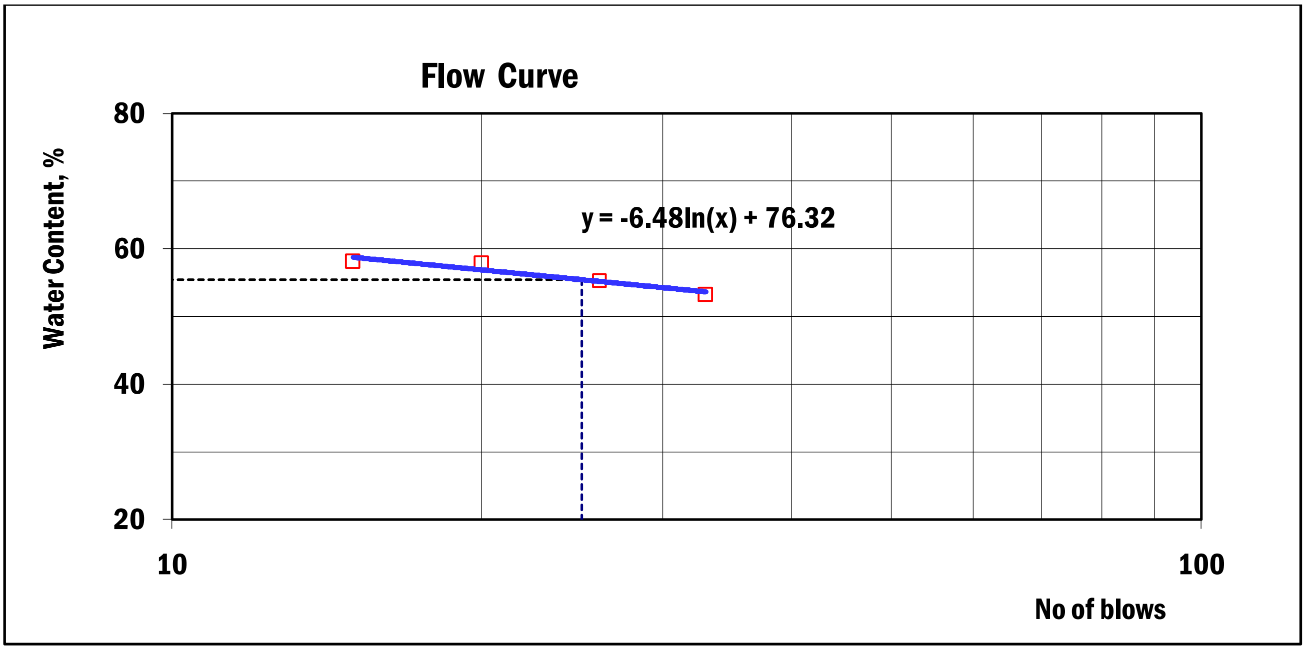


Table:- E-2: Liquid limit and Plastic limit test result of TP3 at D=3.0 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	LC	H5	Lb	PB	TF-1	FL
Mass of container, g	15.20	15.50	15.00	15.60	15.80	14.90
Mass of container + Wet soil, g	38.20	35.50	40.10	39.60	21.10	21.30
Mass of container + Dry soil, g	27.90	26.50	28.60	28.30	19.70	19.60
Mass of water, g	10.30	9.00	11.50	11.30	1.40	1.70
Mass of dry soil, g	12.70	11.00	13.60	12.70	3.90	4.70
Water content, %	81.10	81.82	84.56	88.98	35.90	36.17
No of blows	35	28	21	15	------	------

Liquid Limit, % = 84 Plastic Limit, % = 36 PI, %= 48

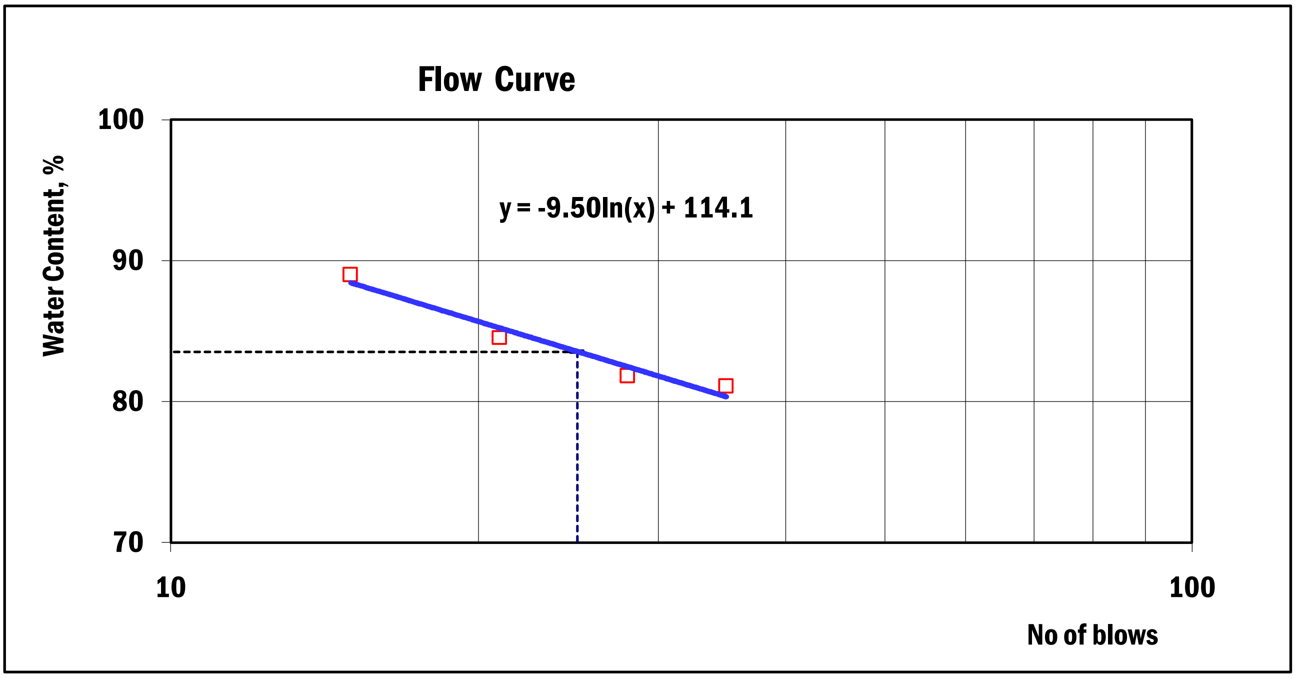


Table: - E-3: Liquid limit and Plastic limit test result of TP6 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	52	A30	2A	L1	T6	D13
Mass of container, g	15.90	15.80	15.80	15.70	15.80	15.50
Mass of container + Wet soil, g	33.70	35.10	35.30	34.50	22.30	22.00
Mass of container + Dry soil, g	24.70	25.20	25.20	24.60	20.70	20.40
Mass of water, g	9.00	9.90	10.10	9.90	1.60	1.60
Mass of dry soil, g	8.80	9.40	9.40	8.90	4.90	4.90
Water content, %	102.27	105.32	107.45	111.24	32.65	32.65
No of blows	34	26	21	15	------	------

Liquid Limit, % = 106   Plastic Limit, % = 33   PI, %= 73

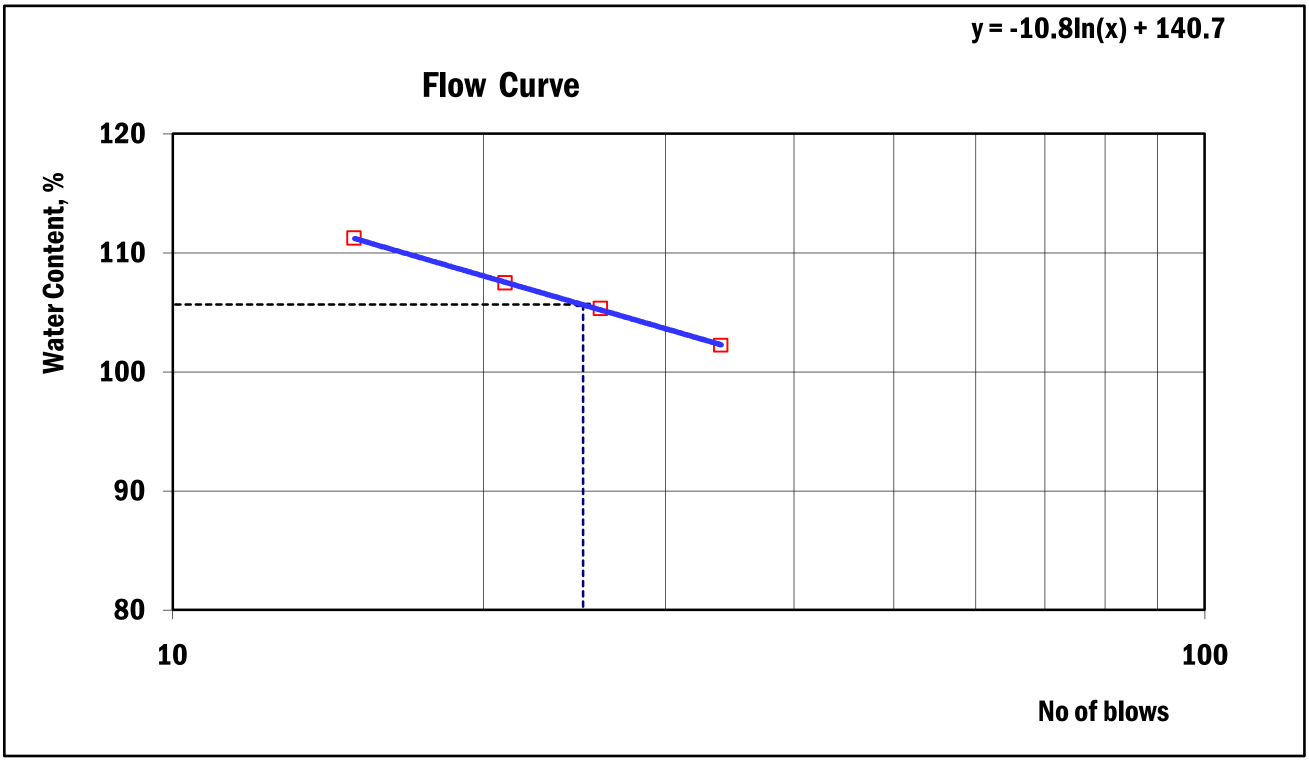


Table: - E-3: Liquid limit and Plastic limit test result of TP6 at D=3.0 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	BC	D5	1J	D15	AN	1A
Mass of container, g	15.80	15.70	15.80	15.50	15.70	11.30
Mass of container + Wet soil, g	39.10	37.10	35.60	33.80	22.40	17.90
Mass of container + Dry soil, g	28.20	27.00	26.10	24.90	20.80	16.20
Mass of water, g	10.90	10.10	9.50	8.90	1.60	1.70
Mass of dry soil, g	12.40	11.30	10.30	9.40	5.10	4.90
Water content, %	87.90	89.38	92.23	94.68	31.37	34.69
No of blows	37	29	22	15	------	------

Liquid Limit, % = 91 Plastic Limit, % = 33 PI, %= 58

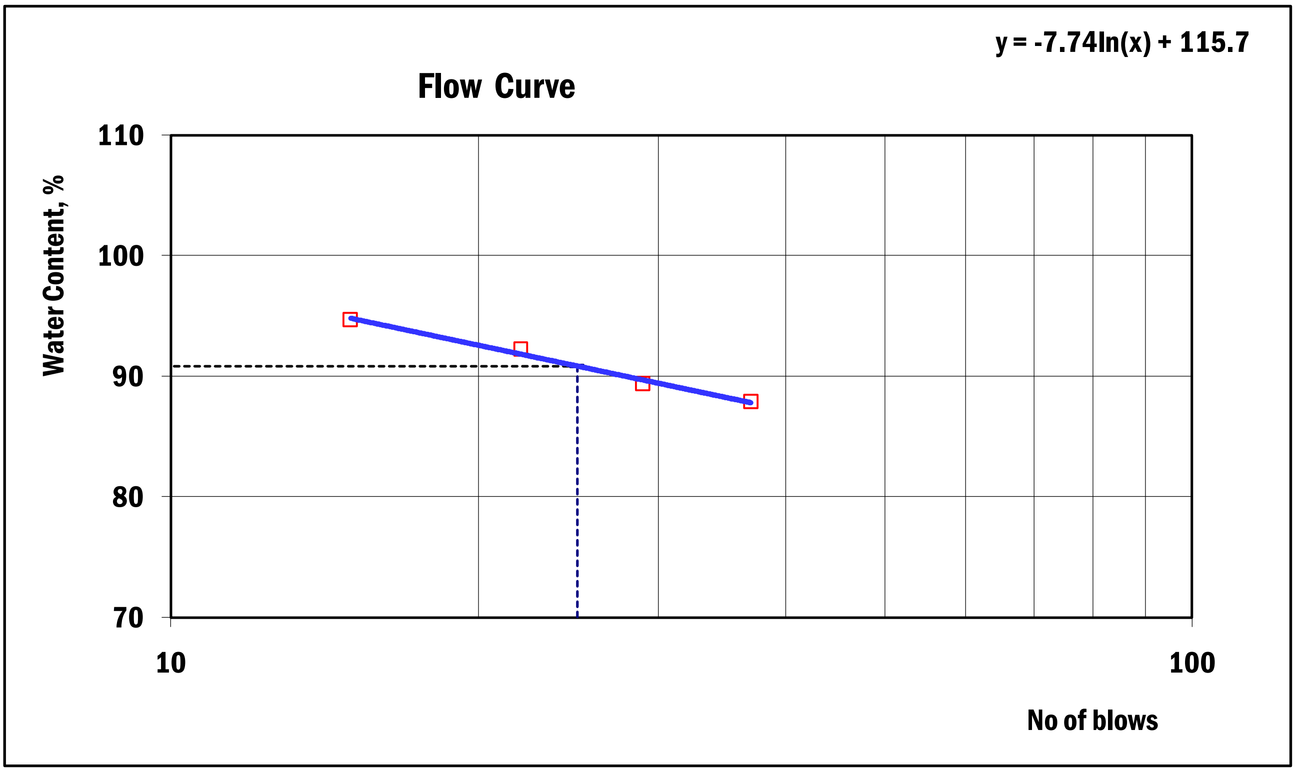


Table:- E-4: Liquid limit and Plastic limit test result of TP9 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	8	28	105	T-6	D-71	TP-23
Mass of container, g	15.80	15.40	15.50	15.50	16.10	15.30
Mass of container + Wet soil, g	35.40	32.90	34.40	34.10	22.60	21.60
Mass of container + Dry soil, g	28.70	26.60	27.30	26.80	21.30	20.30
Mass of water, g	6.70	6.30	7.10	7.30	1.30	1.30
Mass of dry soil, g	12.90	11.20	11.80	11.30	5.20	5.00
Water content, %	51.94	56.25	60.17	64.60	25.00	26.00
No of blows	38	31	23	17	------	------

Liquid Limit, % = 59 Plastic Limit, % = 25 PI, %= 34

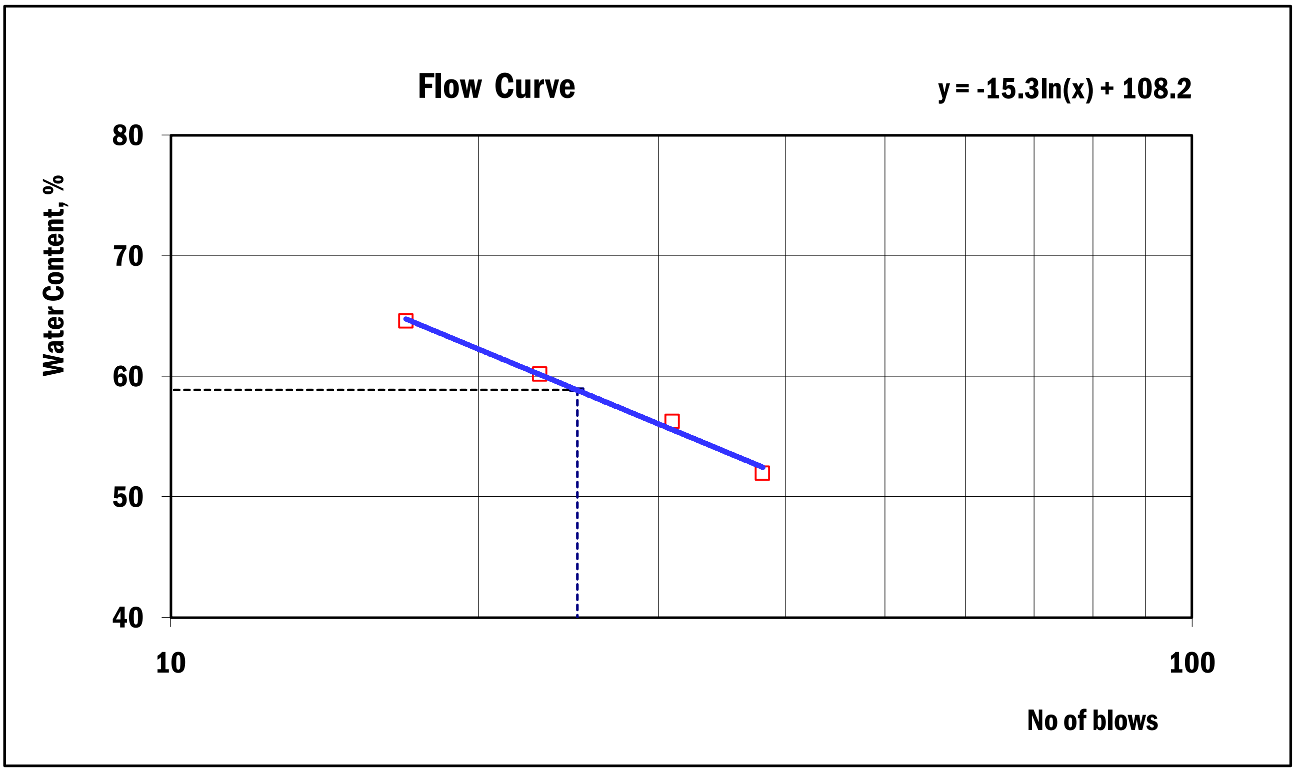


Table:- E-5: Liquid limit and Plastic limit test result of TP12 at D=3.0 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	2AS	1	T-1	2E	AN	MO3
Mass of container, g	15.40	15.70	15.70	15.60	15.50	15.80
Mass of container + Wet soil, g	28.90	33.70	31.70	31.30	21.20	21.40
Mass of container + Dry soil, g	23.70	26.70	25.40	25.10	20.00	20.20
Mass of water, g	5.20	7.00	6.30	6.20	1.20	1.20
Mass of dry soil, g	8.30	11.00	9.70	9.50	4.50	4.40
Water content, %	62.65	63.64	64.95	65.26	26.67	27.27
No of blows	33	27	24	20	------	------

Liquid Limit, % = 64 Plastic Limit, % = 27 PI, %= 37

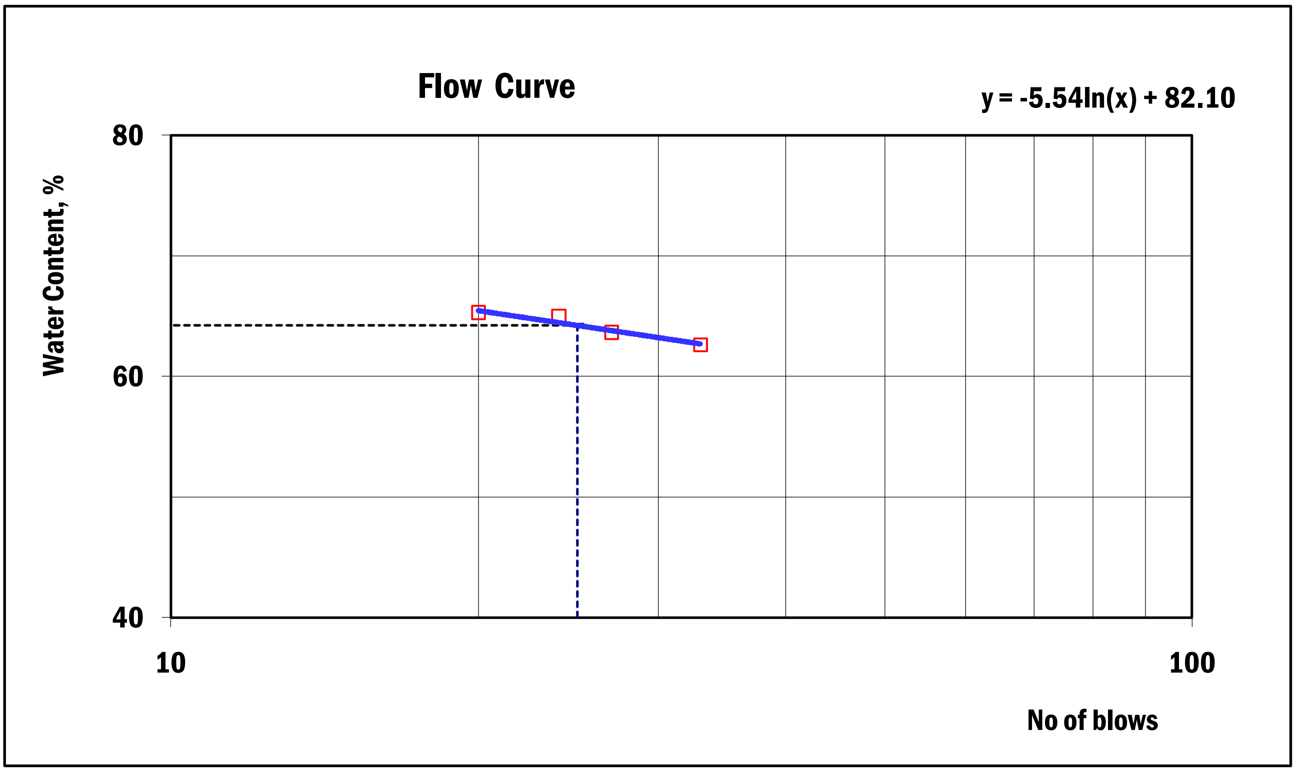
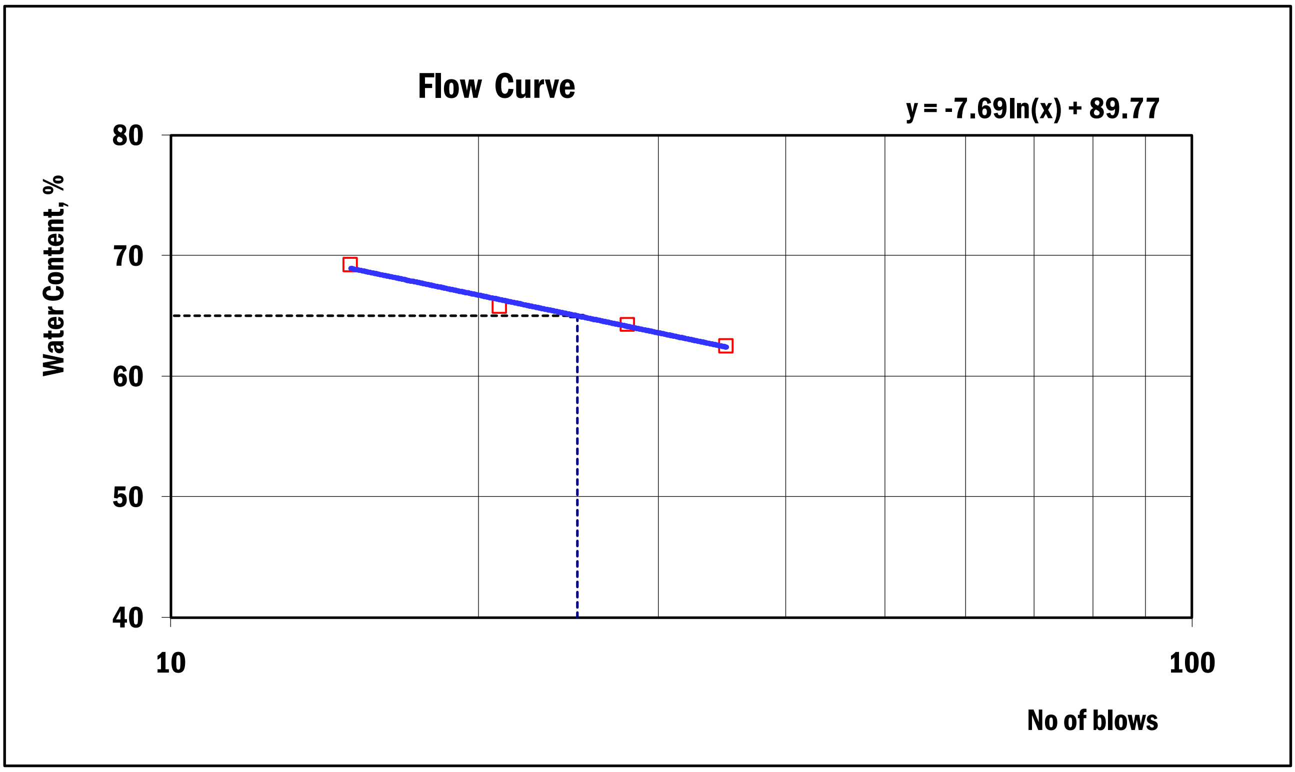


Table: - E-6: Liquid limit and Plastic limit test result of TP15 at D=1.50 m

	Liquid Limit				Plastic Limit	
Trial No	1	2	3	4	1	2
Container No	M-2	M-4	2B	AN	Mo3	1B
Mass of container, g	15.60	15.60	15.70	15.50	15.80	15.70
Mass of container + Wet soil, g	33.80	34.50	34.60	35.30	22.20	22.50
Mass of container + Dry soil, g	26.80	27.10	27.10	27.20	20.70	20.90
Mass of water, g	7.00	7.40	7.50	8.10	1.50	1.60
Mass of dry soil, g	11.20	11.50	11.40	11.70	4.90	5.20
Water content, %	62.50	64.35	65.79	69.23	30.61	30.77
No of blows	35	28	21	15	------	------

Liquid Limit, % = 65 Plastic Limit, % = 31 PI, %= 34



Annex F: Free swell test results

F-1: Free swell test result of TP1 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.5	16.0	15.8	58

F-2: Free swell test result of TP2 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	17.5	18.0	17.8	78

F-2: Free swell test result of TP2 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	24.0	25.0	24.5	145

F-3: Free swell test result of TP3 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.5	15.0	15.3	53

F-3: Free swell test result of TP3 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	17.0	17.0	17.0	70

F-4: Free swell test result of TP4 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.5	15.0	15.3	53

F-4: Free swell test result of TP4 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	16.7	16.0	16.4	64

F-5: Free swell test result of TP5 at D=1.5m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	18.7	19.5	19.1	91

F-5: Free swell test result of TP5 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	17.0	17.7	17.4	74

F-6: Free swell test result of TP6 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	29.0	27.5	28.3	183

F-6: Free swell test result of TP6 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.0	19.0	19.5	95

F-7: Free swell test result of TP7 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	20.5	20.0	20.3	103

F-7: Free swell test result of TP7 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	28.0	24.5	26.3	163

F-8: Free swell test result of TP8 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	15.0	14.5	45

F-8: Free swell test result of TP8 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

F-9: Free swell test result of TP9 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	16.5	16.5	16.5	65

F-9: Free swell test result of TP9 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.5	15.0	15.3	53

F-10: Free swell test result of TP10 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	14.5	14.3	43

F-10: Free swell test result of TP10 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.0	15.0	50

F-11: Free swell test result of TP11 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	16.0	16.3	16.2	62

F-11: Free swell test result of TP11 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	16.0	16.0	16.0	60

F-12: Free swell test result of TP12 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.5	13.5	14.0	40

F-12: Free swell test result of TP12 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	14.5	14.3	43

F-13: Free swell test result of TP13 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	14.5	14.3	43

F-13: Free swell test result of TP13 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	14.0	14.5	45

F-14: Free swell test result of TP14 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	13.5	14.5	14.0	40

F-14: Free swell test result of TP14 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	15.5	15.3	53

F-15: Free swell test result of TP15 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	15.0	14.5	14.8	48

F-15: Free swell test result of TP15 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	13.0	13.5	35

F-16: Free swell test result of TP16 at D=1.50m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	14.5	14.3	43

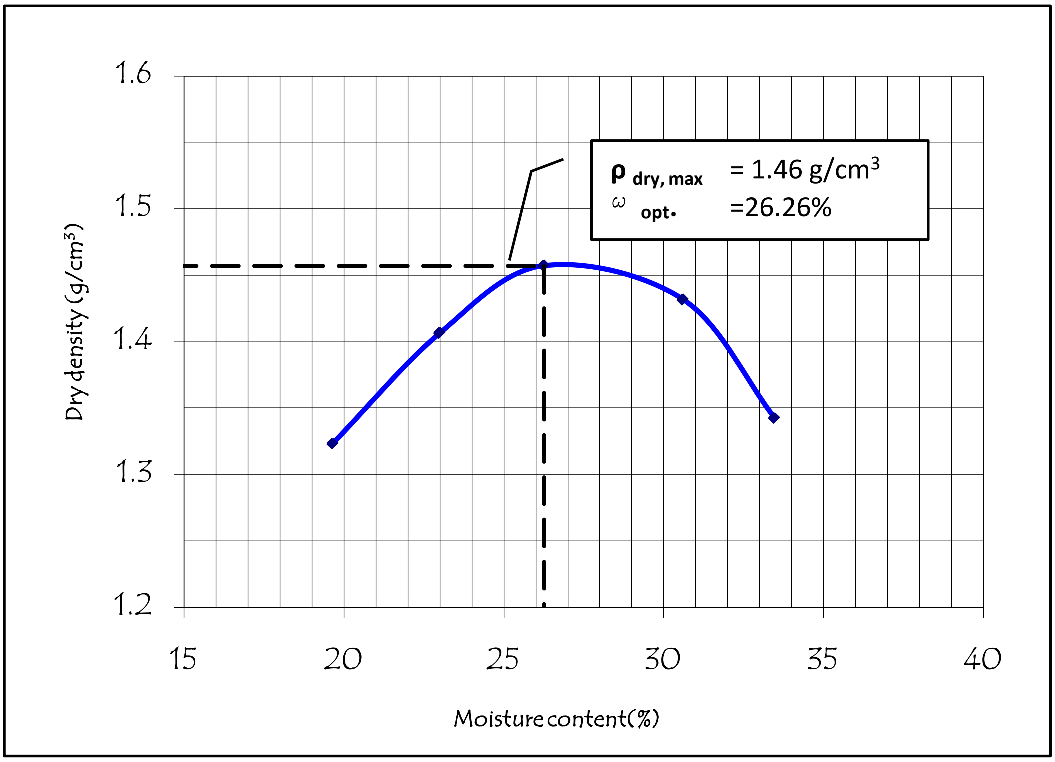
F-16: Free swell test result of TP16 at D=3.0m

Initial Volume (cc)	Final Volume		Average Final Volume (cc)	Free Swell Index (%)
	Sample No.1 (cc)	Sample No.2 (cc)		
10.0	14.0	14.0	14.0	40

Annex G:- Standard Compaction and CBR Test Results.

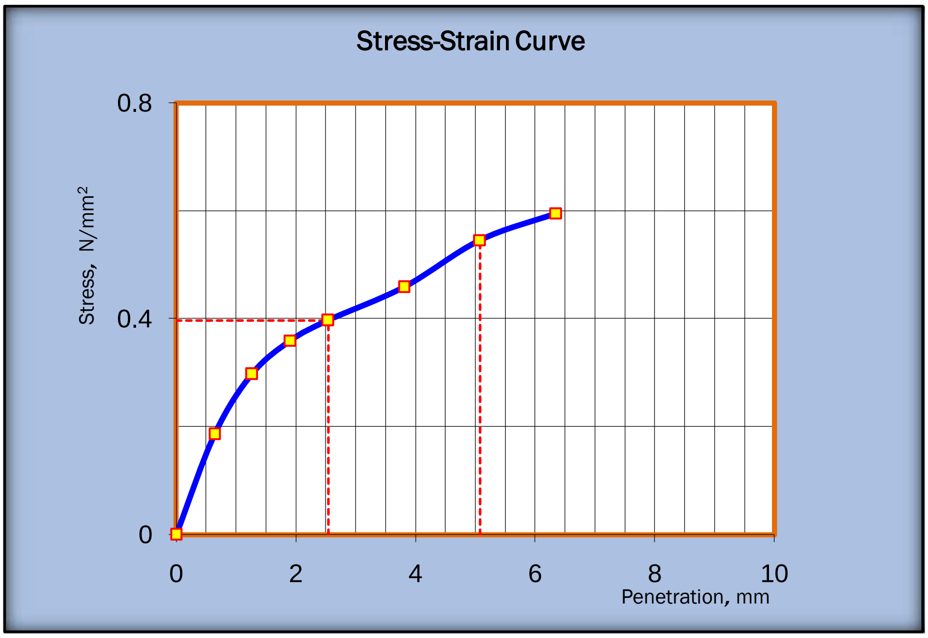
G-1 Moisture content Vs dry density computation table for TP-1 At 1.50m

Determination No.	1	2	3	4	5
Mass of Mold, g	7415	7415	7415	7415	7415
Mass of mold + Compacted Soil, g	10792.8	11105.1	11339.7	11403.7	11237.7
Mass of Compacted soil, g	3377.8	3690.1	3924.7	3988.7	3822.7
Volume of Mold, cm3	2133	2133	2133	2133	2133
Bulk density, g/cm3	1.58	1.73	1.84	1.87	1.79
Water Contenet, %	19.66	22.99	26.26	30.60	33.46
Dry density, g/cm3	1.32	1.41	1.46	1.43	1.34



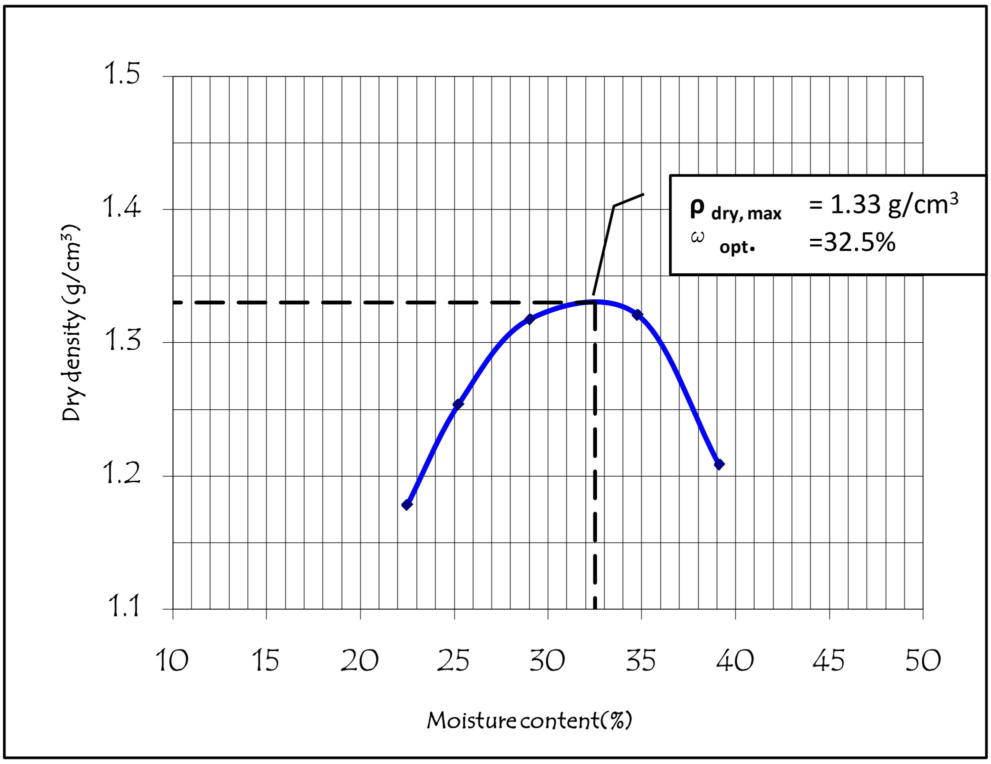
G-2 CBR Computation Table for TP-1 at 1.50m

Blow/ Layer		56/3	Optimum Most. Content (OMC), %		26.3
Swell, %		**0.48**			
Repeated CBR Value, %		**6**	Max. Dry Density (MDD), %		1.46
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	15.0	360	0.19		
1.27	24.0	576	0.30		
1.91	29.0	696	0.36		
2.54	32.0	768	0.40	6.9	5.75
3.81	37.0	888	0.46		
5.08	44.0	1056	0.55	10.3	5.30
6.35	48.0	1152	0.60		



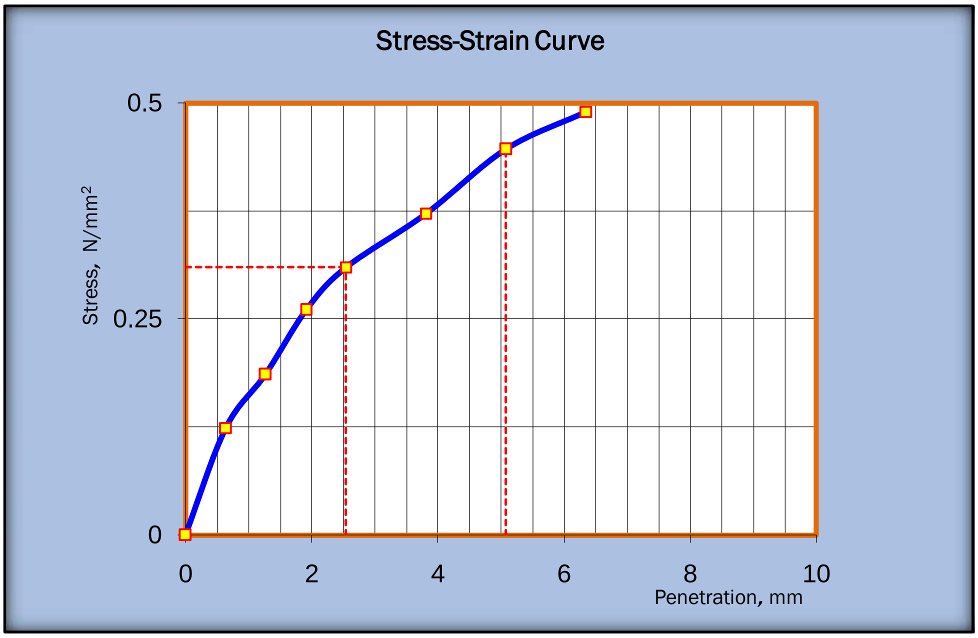
G-3 Moisture content Vs dry density computation table for TP-5 At 1.50m

Determination No.	1	2	3	4	5
Mass of Mold, g	7200	7200	7200	7200	7200
Mass of mold + Compacted Soil, g	10278.6	10548.8	10826.1	10996.7	10785.6
Mass of Compacted soil, g	3078.6	3348.8	3626.1	3796.7	3585.6
Volume of Mold, cm3	2133	2133	2133	2133	2133
Bulk density, g/cm3	1.44	1.57	1.70	1.78	1.68
Water Contenet, %	22.51	25.24	29.03	34.78	39.13
Dry density, g/cm3	1.18	1.25	1.32	1.32	1.21



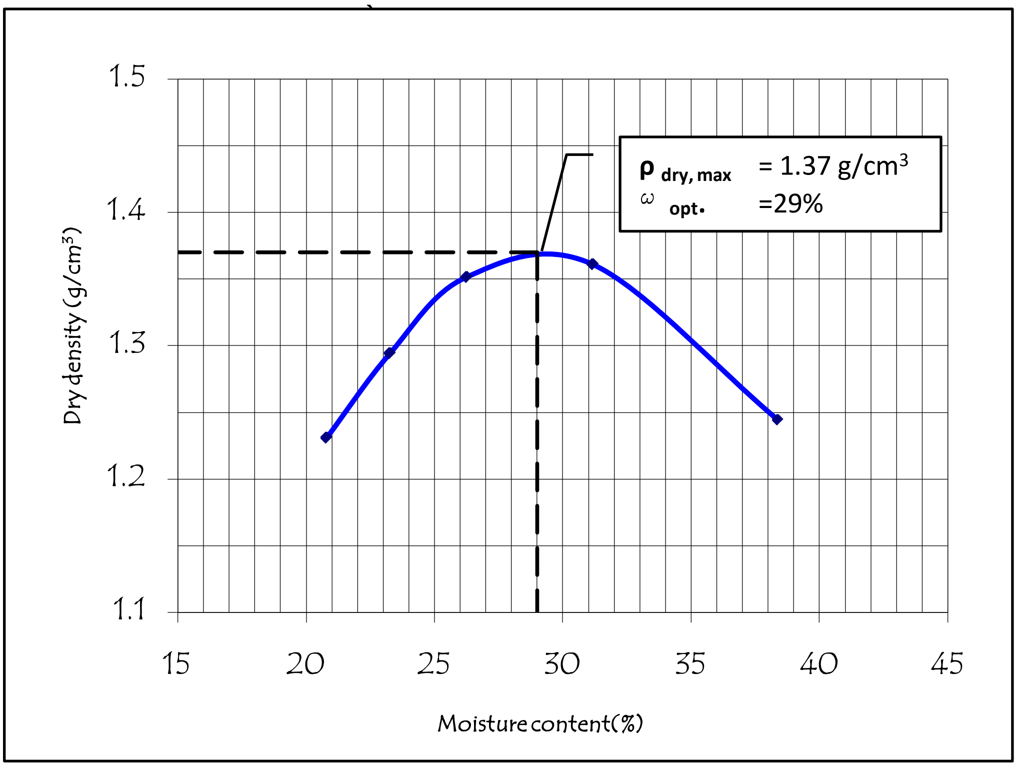
G-5 CBR Computation Table for TP-5 at 1.50m

Blow/ Layer		56/3	Optimum Most. Content (OMC), %		36.0
Swell, %		**2.26**			
Repeated CBR Value, %		4	Max. Dry Density (MDD), %		1.25
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	10.0	240	0.12		
1.27	15.0	360	0.19		
1.91	21.0	504	0.26		
2.54	25.0	600	0.31	6.9	4.49
3.81	30.0	720	0.37		
5.08	36.0	864	0.45	10.3	4.34
6.35	39.5	948	0.49		



G-4 Moisture content Vs dry density computation table for TP-5 At 3.0m

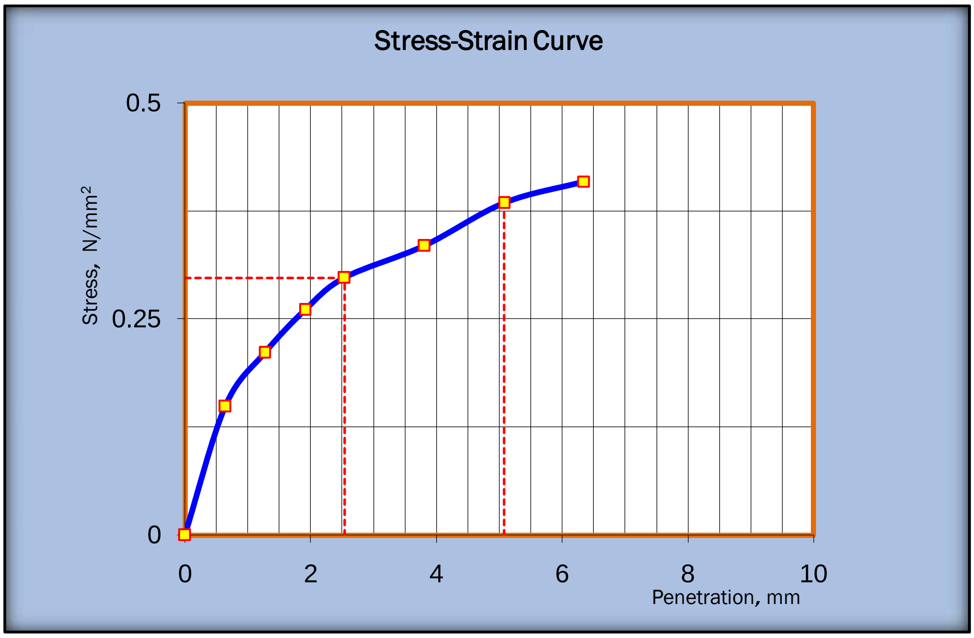
Determination No.	1	2	3	4	5
Mass of Mold, g	7200	7200	7200	7200	7200
Mass of mold + Compacted Soil, g	10356.7	10587	10822	10990	10855.6
Mass of Compacted soil, g	3156.7	3387	3622	3790	3655.6
Volume of Mold, cm3	2123	2123	2123	2123	2123
Bulk density, g/cm3	1.49	1.60	1.71	1.79	1.72
Water Contenet, %	20.79	23.27	26.25	31.17	38.36
Dry density, g/cm3	1.23	1.29	1.35	1.36	1.24



G-6 CBR Computation Table for TP-5 at 3.0m

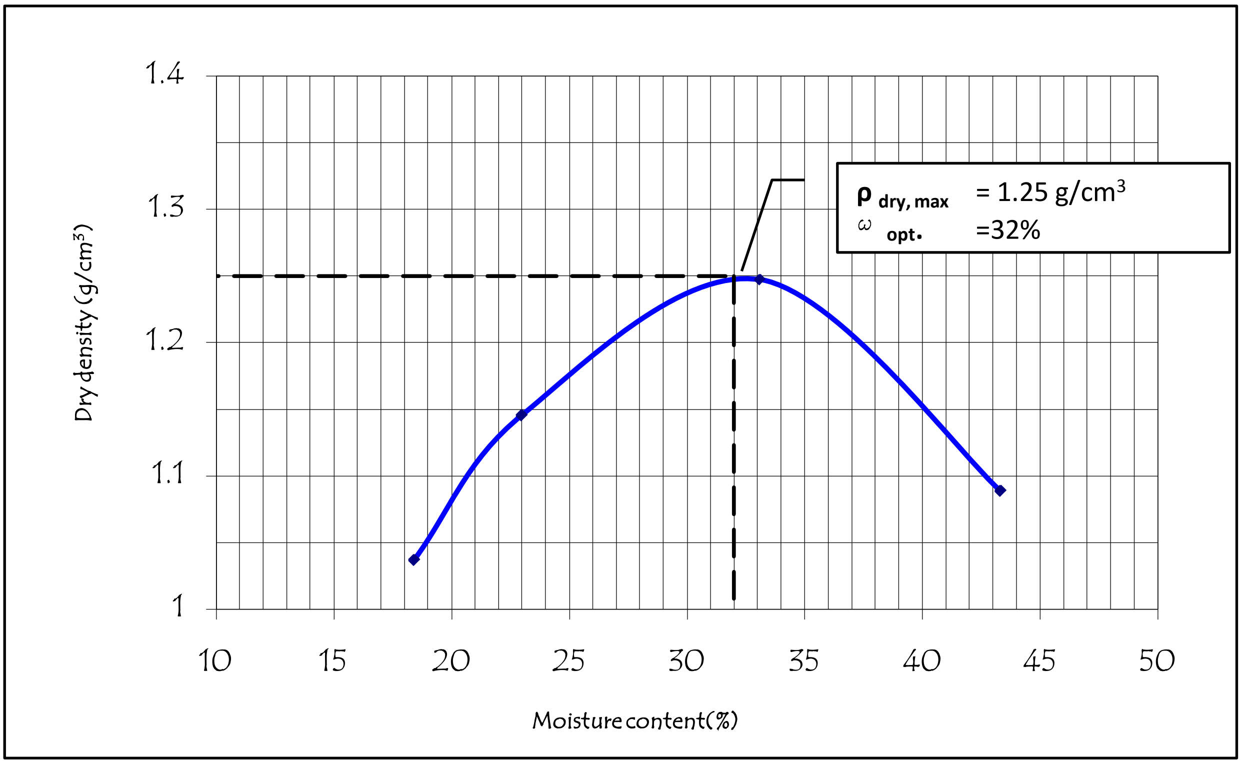
Blow/ Layer	56/3	Optimum Most. Content (OMC), %	43.0
Swell, %	**1.09**		
Repeated CBR Value, %	4	Max. Dry Density (MDD), %	1.15

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	12.0	288	0.15		
1.27	17.0	408	0.21		
1.91	21.0	504	0.26		
2.54	24.0	576	0.30	6.9	4.31
3.81	27.0	648	0.33		
5.08	31.0	744	0.38	10.3	3.73
6.35	33.0	792	0.41		



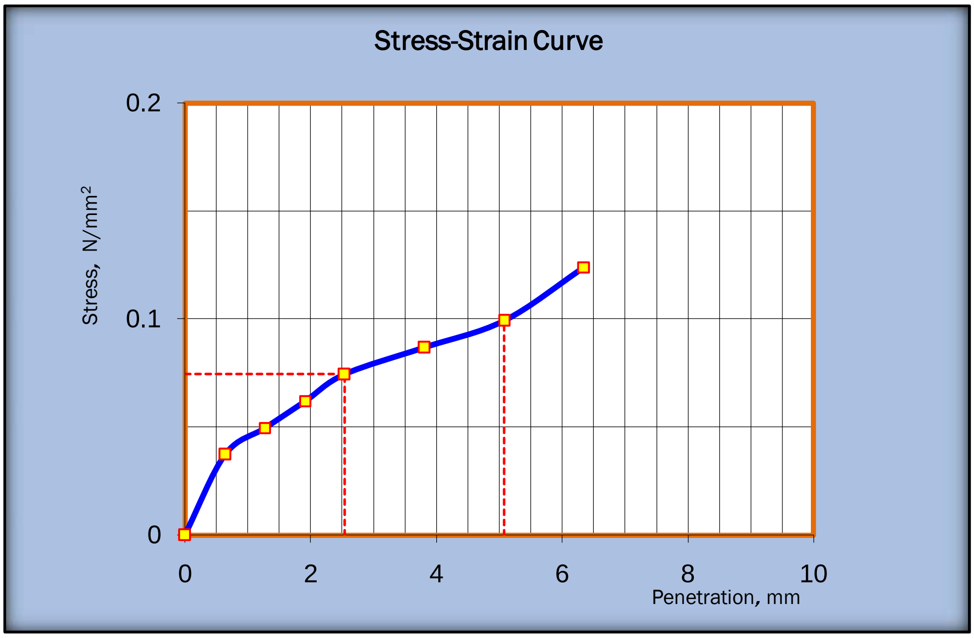
G-7 Moisture content Vs dry density computation table for TP-6 At 1.50m

Determination No.	1	2	3	4
Mass of Mold, g	6774	6774	6774	6774
Mass of mold + Compacted Soil, g	9392.3	9778.9	10314.8	10101.5
Mass of Compacted soil, g	2618.3	3004.9	3540.8	3327.5
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.23	1.41	1.66	1.56
Water Contenet, %	18.41	22.99	33.09	43.32
Dry density, g/cm3	1.04	1.15	1.25	1.09



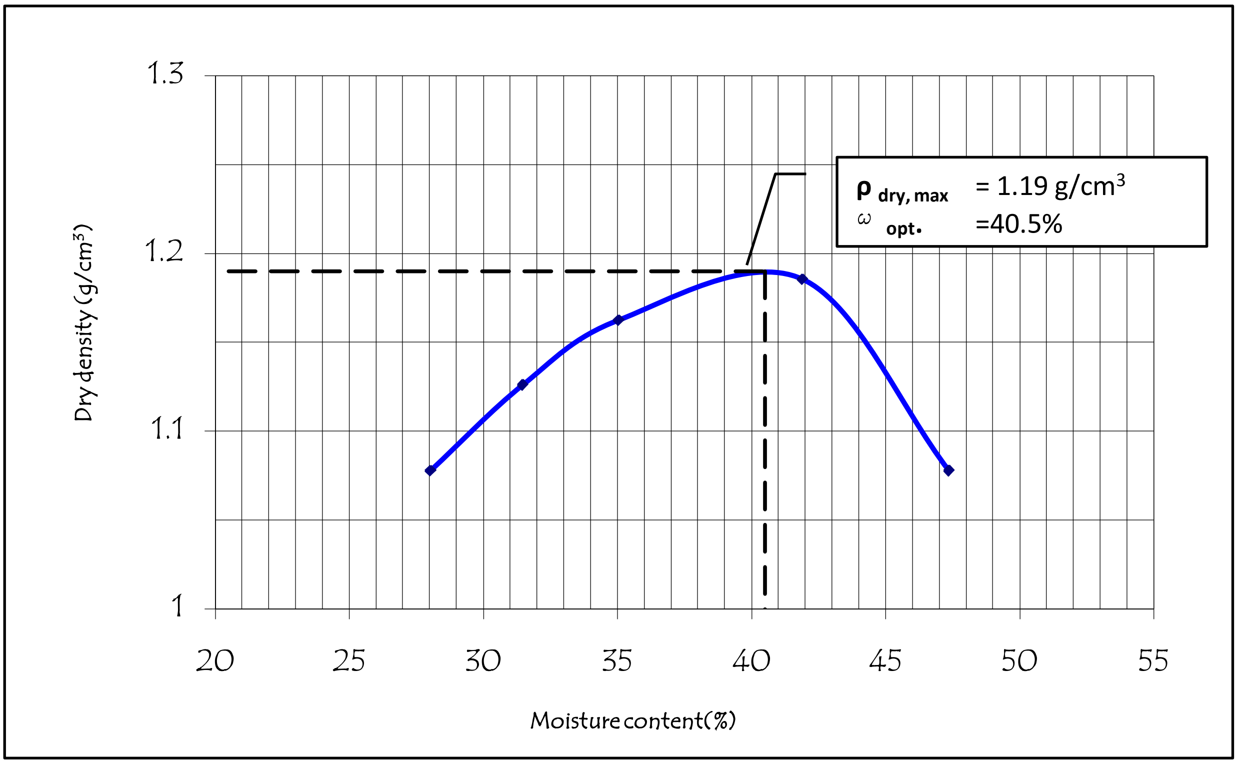
G-8 CBR Computation Table for TP-6 at 1.50m

Blow/ Layer		56/3	Optimum Most. Content (OMC), %		32.0
Swell, %		**9.05**			
Repeated CBR Value, %		**1**	Max. Dry Density (MDD), %		1.25
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	3.0	72	0.04		
1.27	4.0	96	0.05		
1.91	5.0	120	0.06		
2.54	6.0	144	0.07	6.9	1.08
3.81	7.0	168	0.09		
5.08	8.0	192	0.10	10.3	0.96
6.35	10.0	240	0.12		



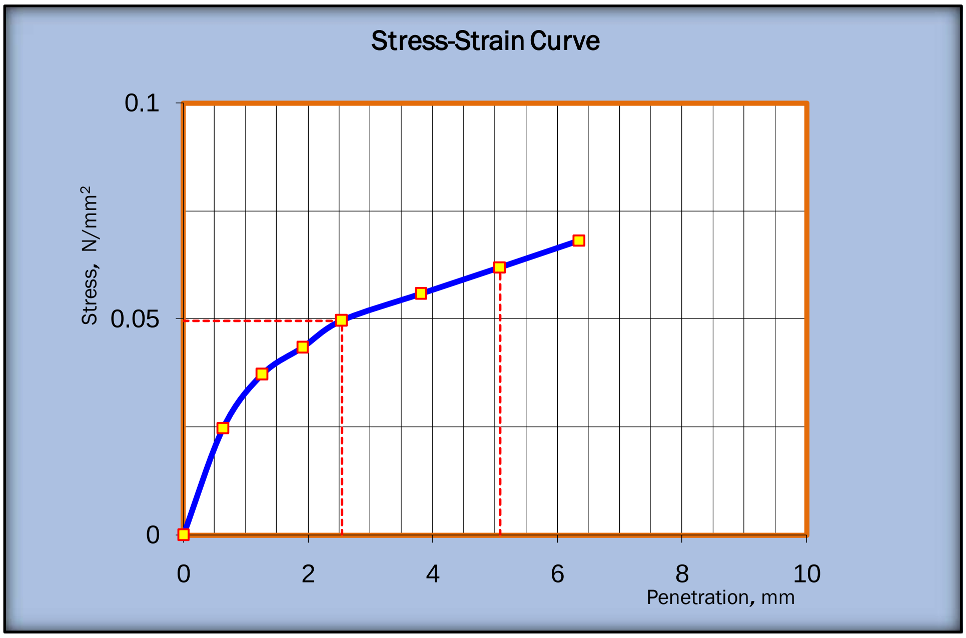
G-9 Moisture content Vs dry density computation table for TP-6 At 3.0m

Determination No.	1	2	3	4	5
Mass of Mold, g	7415	7415	7415	7415	7415
Mass of mold + Compacted Soil, g	10358.5	10571.8	10763.8	11003.2	10802.4
Mass of Compacted soil, g	2943.5	3156.8	3348.8	3588.2	3387.4
Volume of Mold, cm3	2133	2133	2133	2133	2133
Bulk density, g/cm3	1.38	1.48	1.57	1.68	1.59
Water Contenet, %	28.04	31.46	35.05	41.89	47.36
Dry density, g/cm3	1.08	1.13	1.16	1.19	1.08



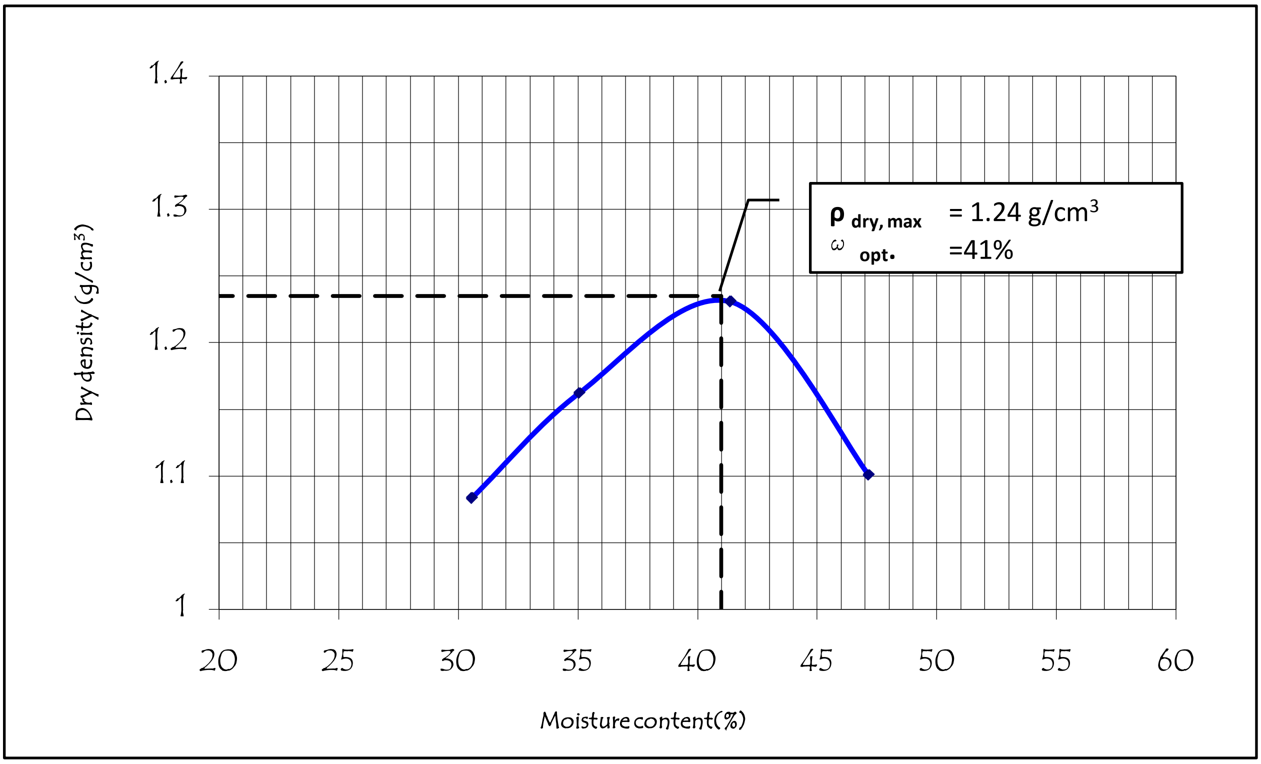
G-10 CBR Computation Table for TP-6 at 3.0m

Blow/ Layer	56/3		Optimum Most. Content (OMC), %		28.0
Swell, %	**10.31**				
Repeated CBR Value, %	1		Max. Dry Density (MDD), %		1.37
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	2.0	48	0.02		
1.27	3.0	72	0.04		
1.91	3.5	84	0.04		
2.54	4.0	96	0.05	6.9	0.72
3.81	4.5	108	0.06		
5.08	5.0	120	0.06	10.3	0.60
6.35	5.5	132	0.07		



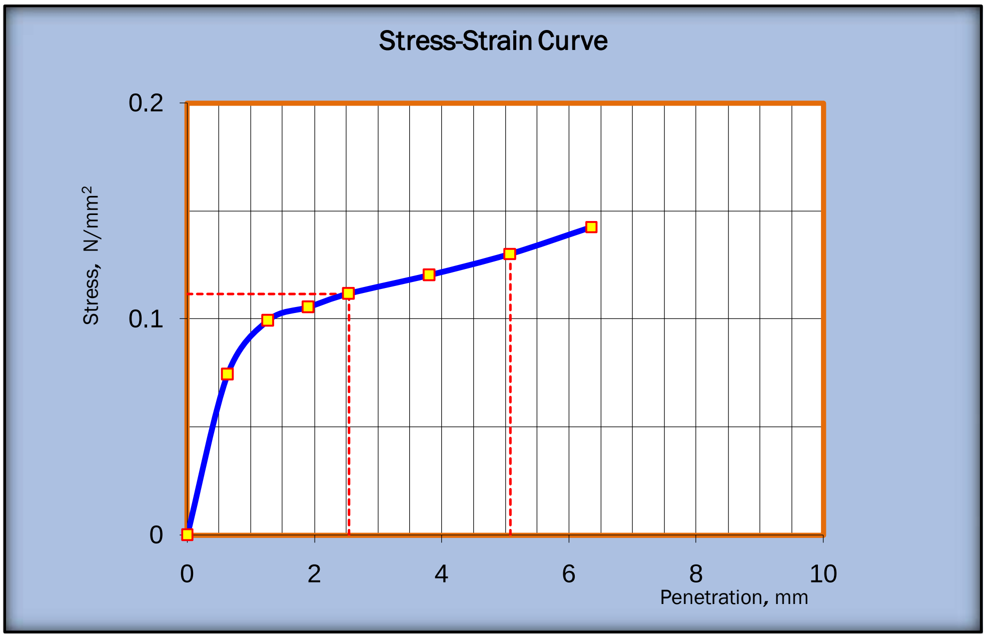
G-11 Moisture content Vs dry density computation table for TP-7 At 1.50m

Determination No.	1	2	3	4
Mass of Mold, g	7435	7435	7435	7435
Mass of mold + Compacted Soil, g	10452.3	10783.8	11146.4	10890.6
Mass of Compacted soil, g	3017.3	3348.8	3711.4	3455.6
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.41	1.57	1.74	1.62
Water Contenet, %	30.57	35.07	41.39	47.15
Dry density, g/cm3	1.08	1.16	1.23	1.10



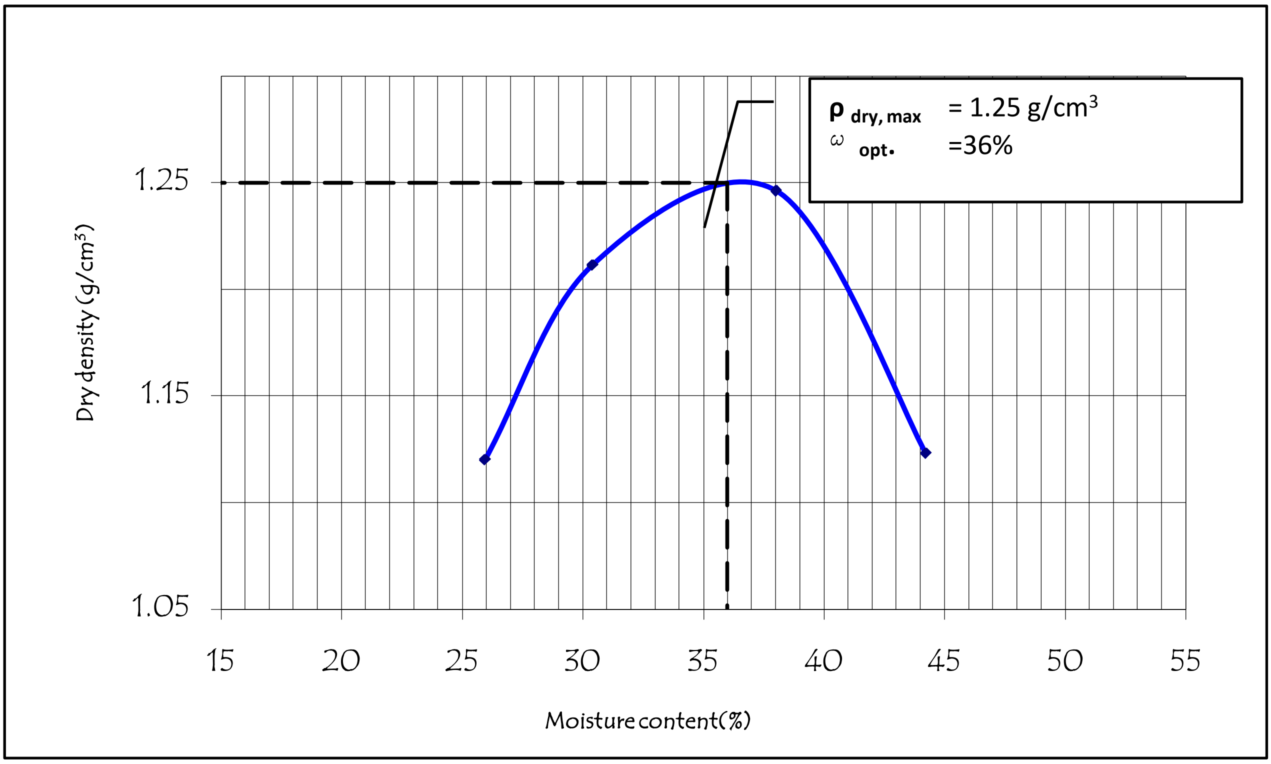
G-12 CBR Computation Table for TP-7 at 1.50m

Blow/ Layer		56/3	Optimum Most. Content (OMC), %		32.5
Swell, %		**5.11**			
Repeated CBR Value, %		2	Max. Dry Density (MDD), %		1.33
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	6.0	144	0.07		
1.27	8.0	192	0.10		
1.91	8.5	204	0.11		
2.54	9.0	216	0.11	6.9	1.62
3.81	9.7	233	0.12		
5.08	10.5	252	0.13	10.3	1.26
6.35	11.5	276	0.14		



G-13 Moisture content Vs dry density computation table for TP-7 At 3.0m

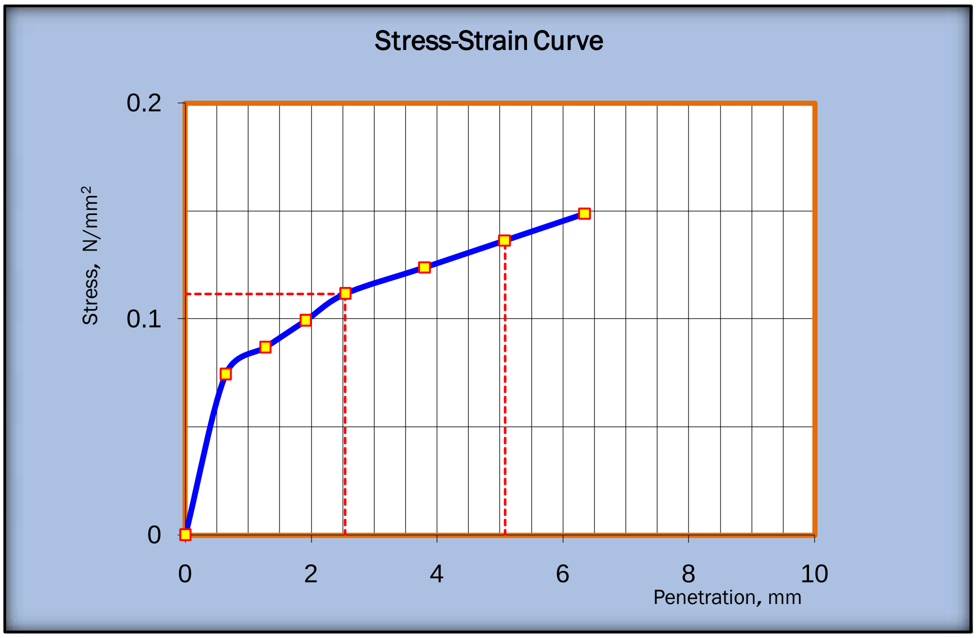
Determination No.	1	2	3	4
Mass of Mold, g	7200	7200	7200	7200
Mass of mold + Compacted Soil, g	10209.5	10570.1	10868.7	10655.5
Mass of Compacted soil, g	3009.5	3370.1	3668.7	3455.5
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.41	1.58	1.72	1.62
Water Contenet, %	25.95	30.41	38.01	44.22
Dry density, g/cm3	1.12	1.21	1.25	1.12



G-14 CBR Computation Table for TP-7 at 3.0m

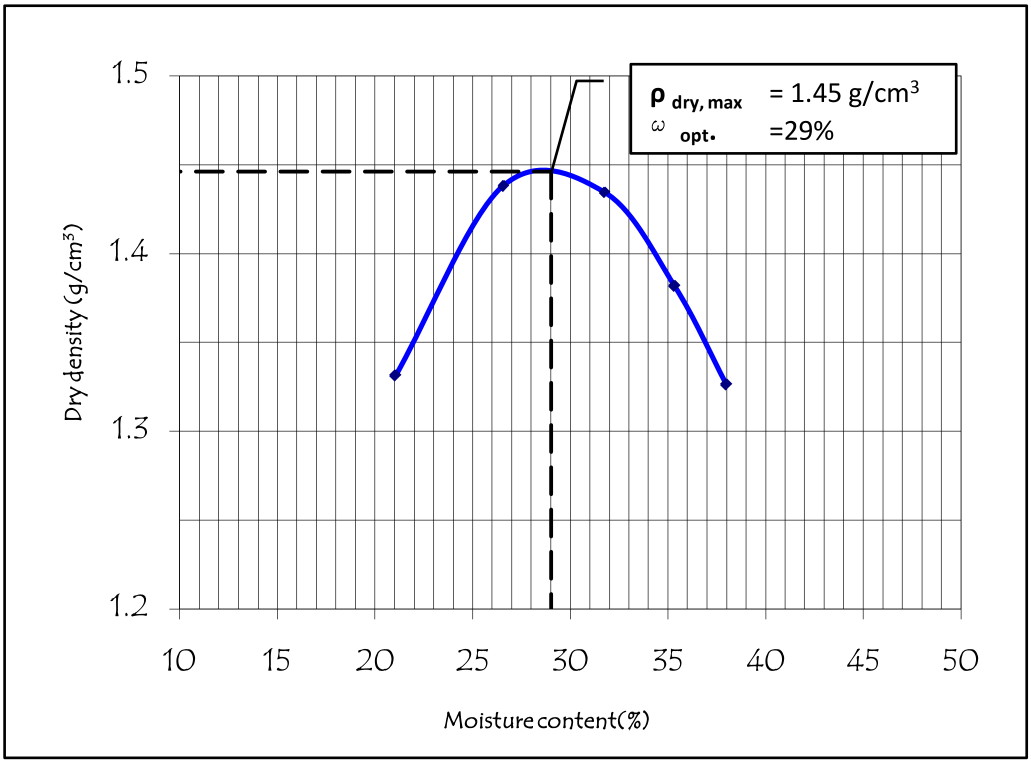
Blow/ Layer	56/3	Optimum Most. Content (OMC), %	29.0
Swell, %	**5.05**		
Repeated CBR Value, %	2	Max. Dry Density (MDD), %	1.37

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	6.0	144	0.07		
1.27	7.0	168	0.09		
1.91	8.0	192	0.10		
2.54	9.0	216	0.11	6.9	1.62
3.81	10.0	240	0.12		
5.08	11.0	264	0.14	10.3	1.32
6.35	12.0	288	0.15		



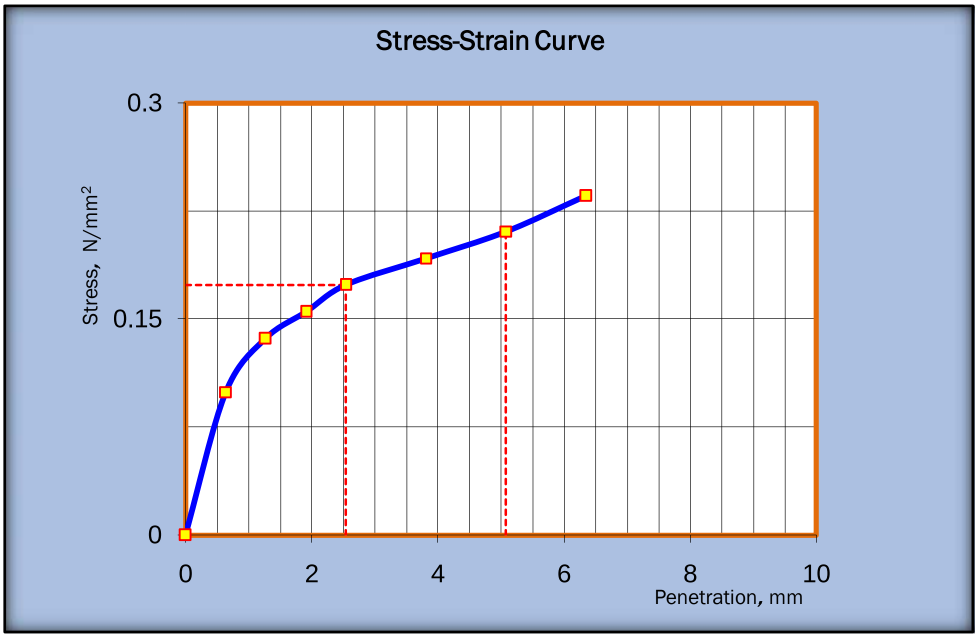
G-15 Moisture content Vs. dry density computation table for TP-8 at 1.50m

Determination No.	1	2	3	4	5
Mass of Mold, g	7200	7200	7200	7200	7200
Mass of mold + Compacted Soil, g	10636.8	11082.1	11231.4	11188.7	11103.4
Mass of Compacted soil, g	3436.8	3882.1	4031.4	3988.7	3903.4
Volume of Mold, cm3	2133	2133	2133	2133	2133
Bulk density, g/cm3	1.61	1.82	1.89	1.87	1.83
Water Contenet, %	21.04	26.56	31.75	35.34	37.98
Dry density, g/cm3	1.33	1.44	1.43	1.38	1.33



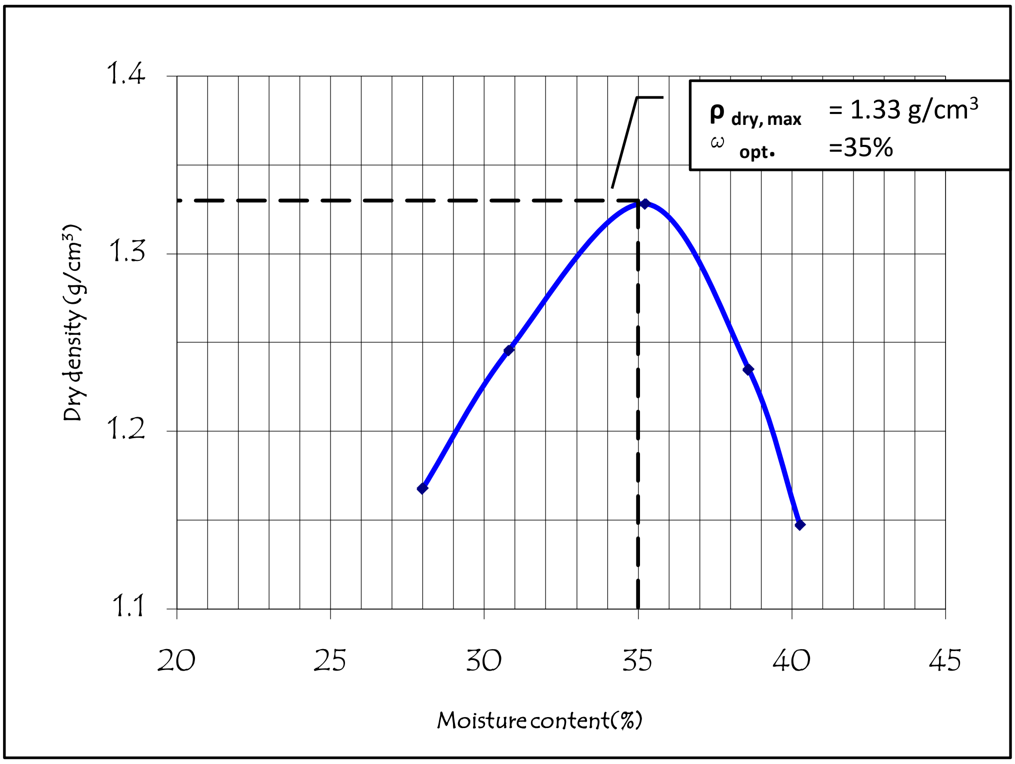
G-16 CBR Computation Table for TP-8 at 1.50m

Blow/ Layer		56/3	Optimum Most. Content (OMC), %		29.2
Swell, %		**0.93**			
Repeated CBR Value, %		3	Max. Dry Density (MDD), %		1.45
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	8.0	192	0.10		
1.27	11.0	264	0.14		
1.91	12.5	300	0.16		
2.54	14.0	336	0.17	6.9	2.52
3.81	15.5	372	0.19		
5.08	17.0	408	0.21	10.3	2.05
6.35	19.0	456	0.24		



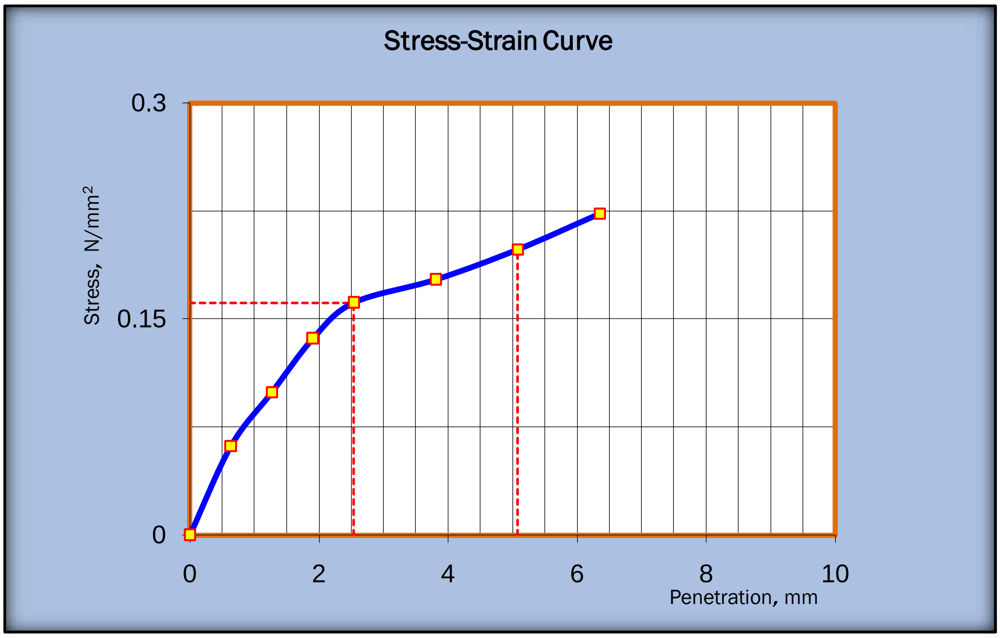
G-17 Moisture content Vs dry density computation table for TP-8 At 3.0m

Determination No.	1	2	3	4	5
Mass of Mold, g	7200	7200	7200	7200	7200
Mass of mold + Compacted Soil, g	10387.5	10674.8	11030.7	10849.5	10632.3
Mass of Compacted soil, g	3187.5	3474.8	3830.7	3649.5	3432.3
Volume of Mold, cm3	2133	2133	2133	2133	2133
Bulk density, g/cm3	1.49	1.63	1.80	1.71	1.61
Water Contenet, %	27.99	30.79	35.23	38.58	40.26
Dry density, g/cm3	1.17	1.25	1.33	1.23	1.15



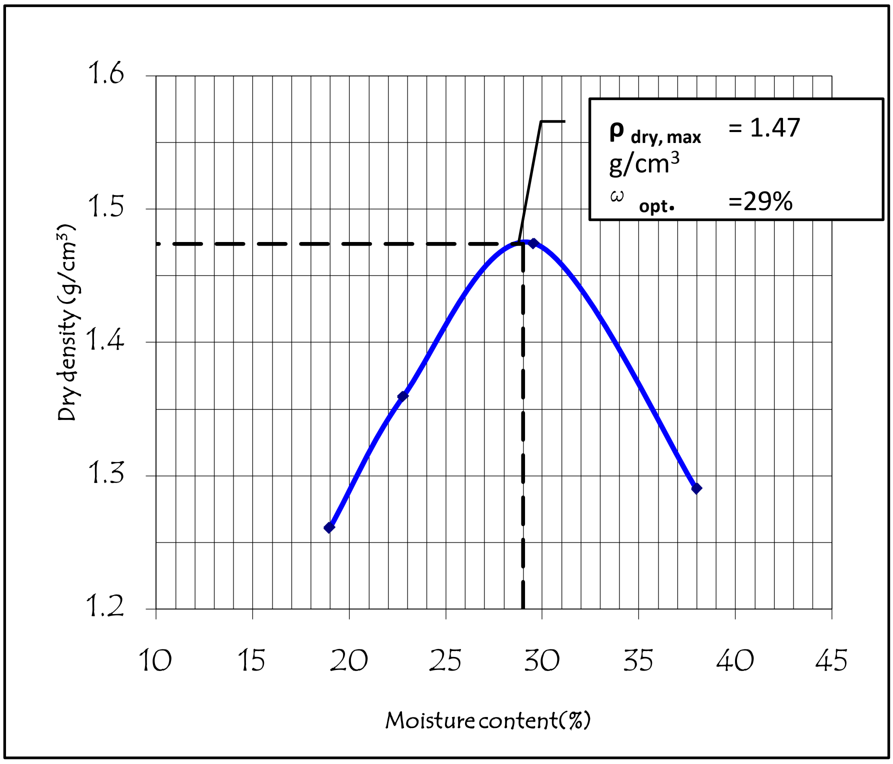
G-18 CBR Computation Table for TP-8 at 3.0m

Blow/ Layer		56/3	Optimum Most. Content (OMC), %		28.5
Swell, %		**6.66**			
Repeated CBR Value, %		2	Max. Dry Density (MDD), %		1.50
Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	5.0	120	0.06		
1.27	8.0	192	0.10		
1.91	11.0	264	0.14		
2.54	13.0	312	0.16	6.9	2.34
3.81	14.3	343	0.18		
5.08	16.0	384	0.20	10.3	1.93
6.35	18.0	432	0.22		



G-19 Moisture content Vs dry density computation table for TP-12 At 1.50m

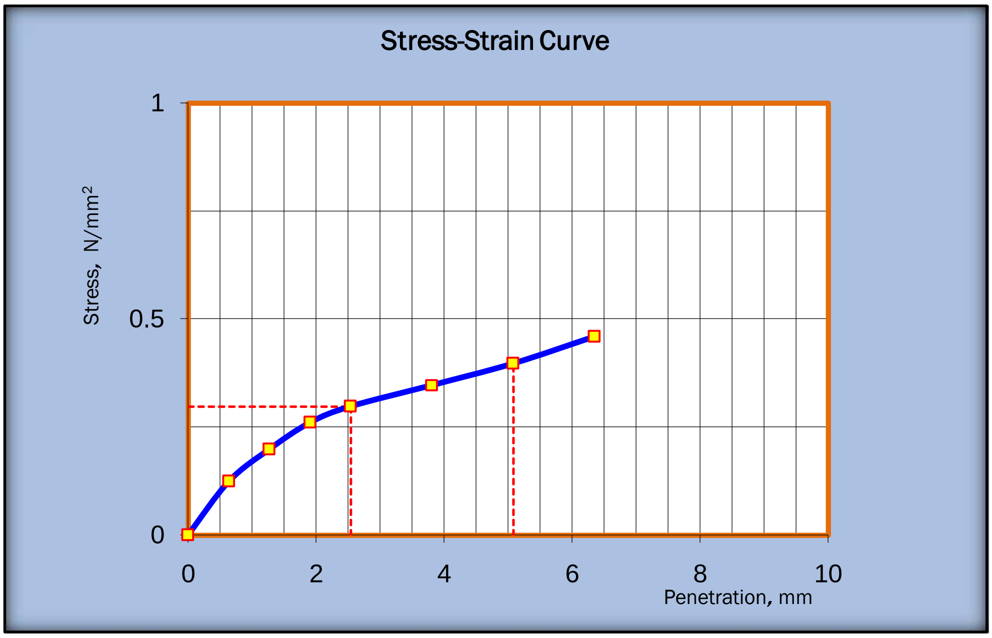
Determination No.	1	2	3	4
Mass of Mold, g	6774	6774	6774	6774
Mass of mold + Compacted Soil, g	9973.5	10334.8	10848	10570.7
Mass of Compacted soil, g	3199.5	3560.8	4074	3796.7
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.50	1.67	1.91	1.78
Water Contenet, %	18.97	22.80	29.56	37.99
Dry density, g/cm3	1.26	1.36	1.47	1.29



G-20 CBR Computation Table for TP-12 at 1.50m

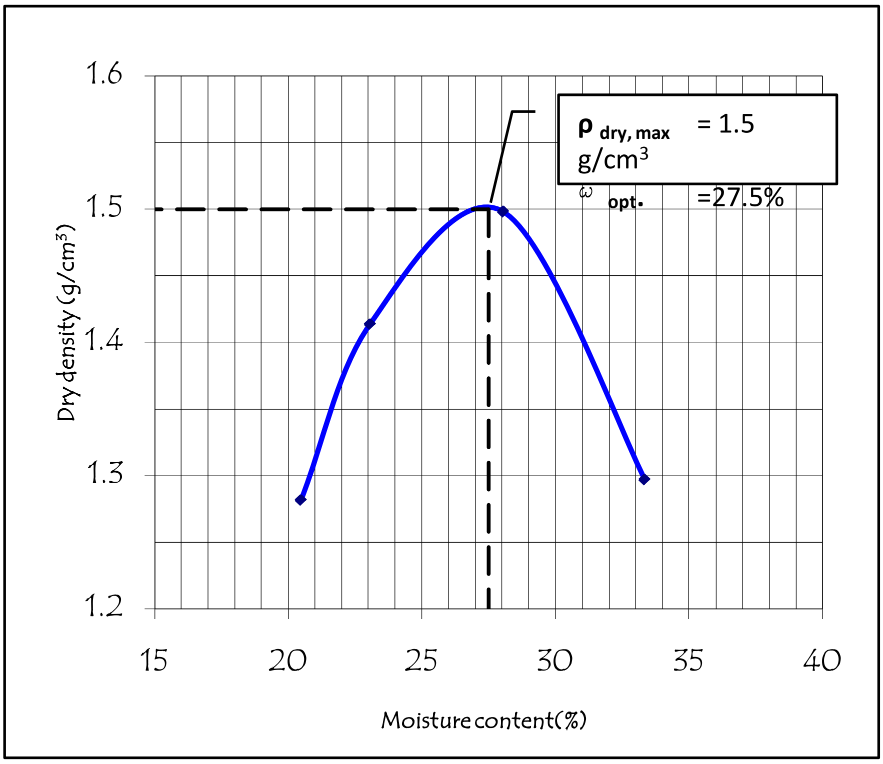
Blow/ Layer	56/3	Optimum Most. Content (OMC), %	29.5
Swell, %	**0.96**		
Repeated CBR Value, %	4	Max. Dry Density (MDD), %	1.47

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	10.0	240	0.12		
1.27	16.0	384	0.20		
1.91	21.0	504	0.26		
2.54	24.0	576	0.30	6.9	4.31
3.81	28.0	672	0.35		
5.08	32.0	768	0.40	10.3	3.85
6.35	37.0	888	0.46		



G-21 Moisture content Vs dry density computation table for TP-12 At 3.0m

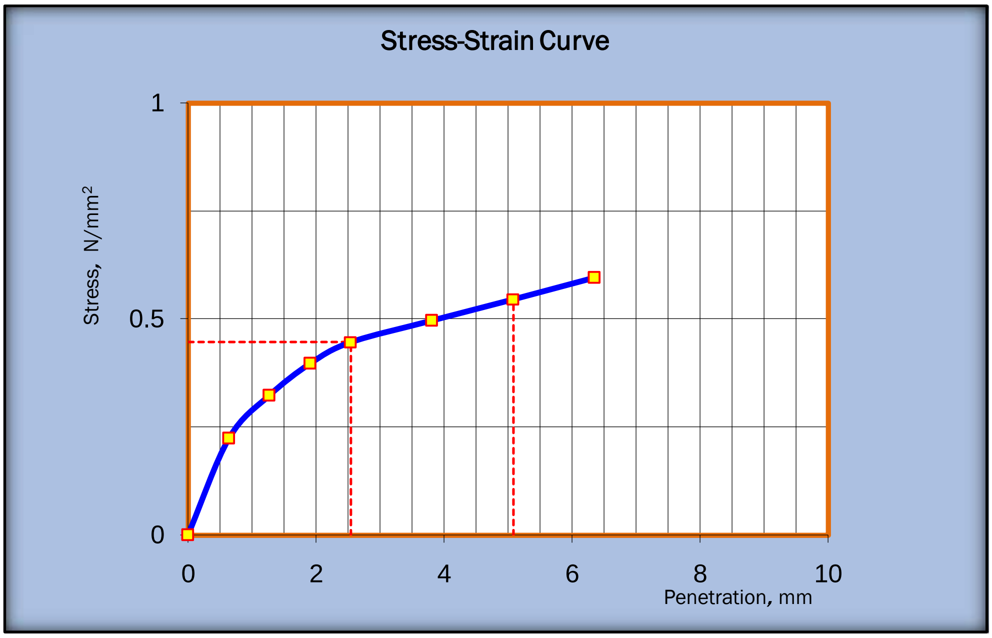
Determination No.	1	2	3	4
Mass of Mold, g	6774	6774	6774	6774
Mass of mold + Compacted Soil, g	10067.4	10484.8	10865.6	10462.7
Mass of Compacted soil, g	3293.4	3710.8	4091.6	3688.7
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.54	1.74	1.92	1.73
Water Contenet, %	20.48	23.06	28.05	33.33
Dry density, g/cm3	1.28	1.41	1.50	1.30



G-22 CBR Computation Table for TP-12 at 3.0m

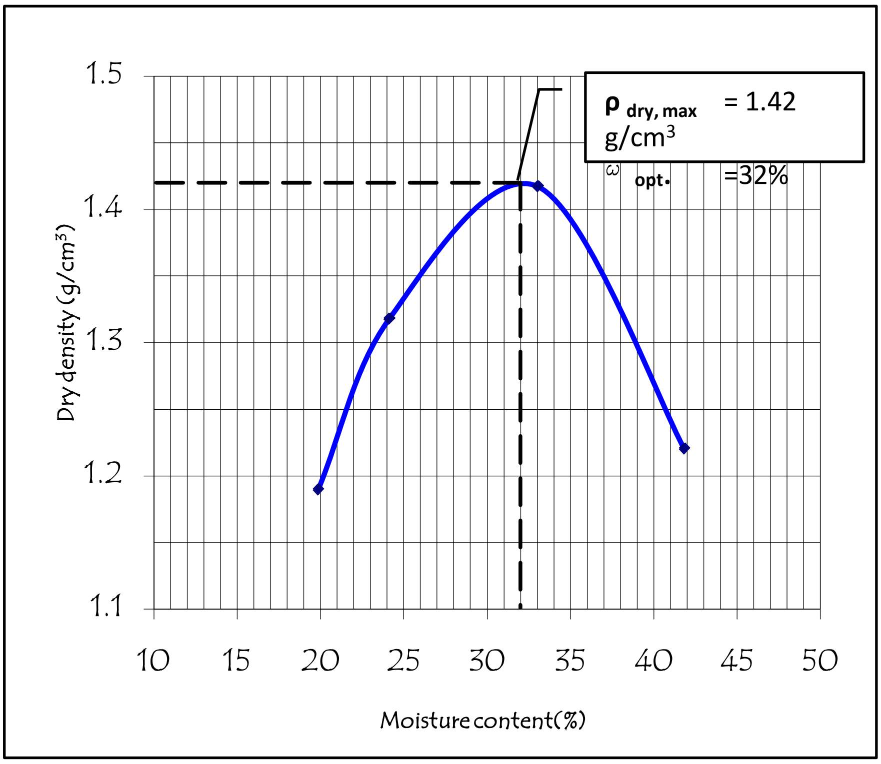
Blow/ Layer	56/3	Optimum Most. Content (OMC), %	32.0
Swell, %	**0.93**		
Repeated CBR Value, %	**6**	Max. Dry Density (MDD), %	1.43

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	18.0	432	0.22		
1.27	26.0	624	0.32		
1.91	32.0	768	0.40		
2.54	36.0	864	0.45	6.9	6.47
3.81	40.0	960	0.50		
5.08	44.0	1056	0.55	10.3	5.30
6.35	48.0	1152	0.60		



G-23 Moisture content Vs dry density computation table for TP-15 At 1.50m

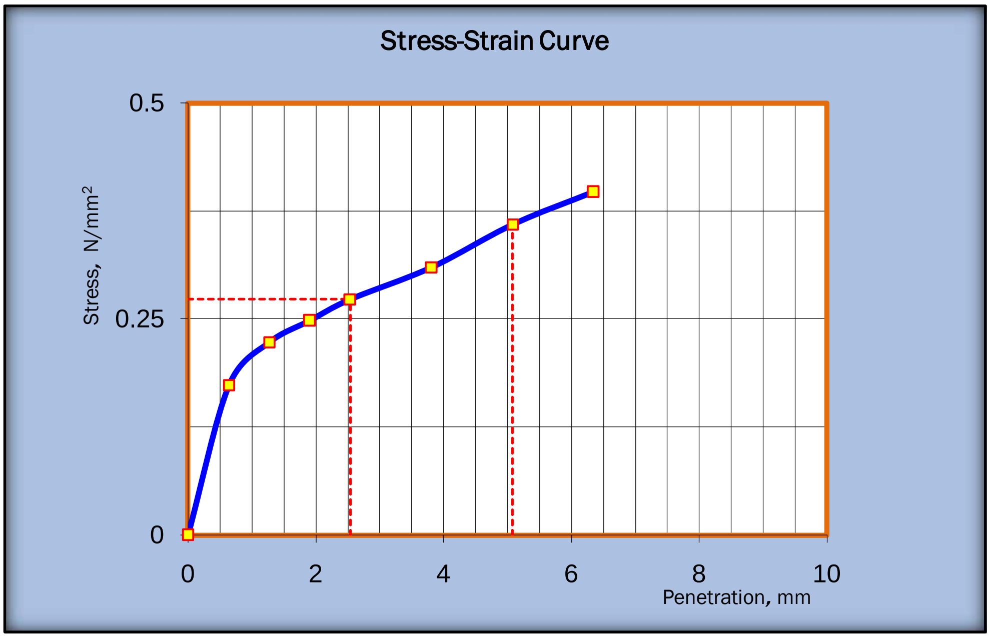
Determination No.	1	2	3	4
Mass of Mold, g	6774	6774	6774	6774
Mass of mold + Compacted Soil, g	9814.8	10262.8	10795.7	10465.6
Mass of Compacted soil, g	3040.8	3488.8	4021.7	3691.6
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.43	1.64	1.89	1.73
Water Contenet, %	19.85	24.13	33.04	41.82
Dry density, g/cm3	1.19	1.32	1.42	1.22



G-24 CBR Computation Table for TP-15 at 1.50m

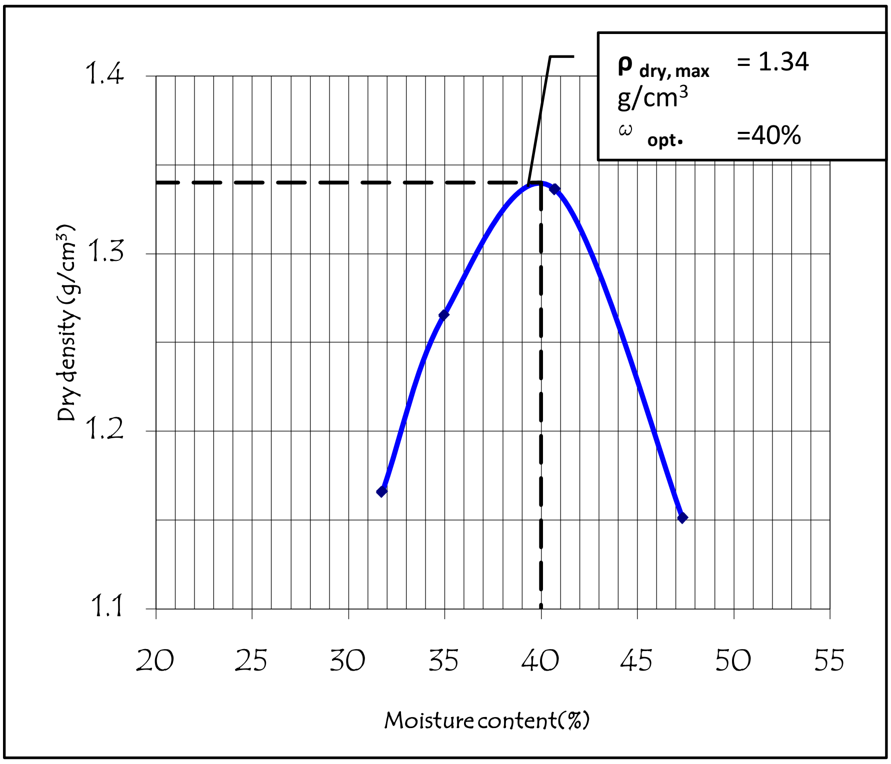
Blow/ Layer	56/3	Optimum Most. Content (OMC), %	32.0
Swell, %	**1.31**		
Repeated CBR Value, %	4	Max. Dry Density (MDD), %	1.30

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	14.0	336	0.17		
1.27	18.0	432	0.22		
1.91	20.0	480	0.25		
2.54	22.0	528	0.27	6.9	3.95
3.81	25.0	600	0.31		
5.08	29.0	696	0.36	10.3	3.49
6.35	32.0	768	0.40		



G-25 Moisture content Vs dry density computation table for TP-15 At 3.0m

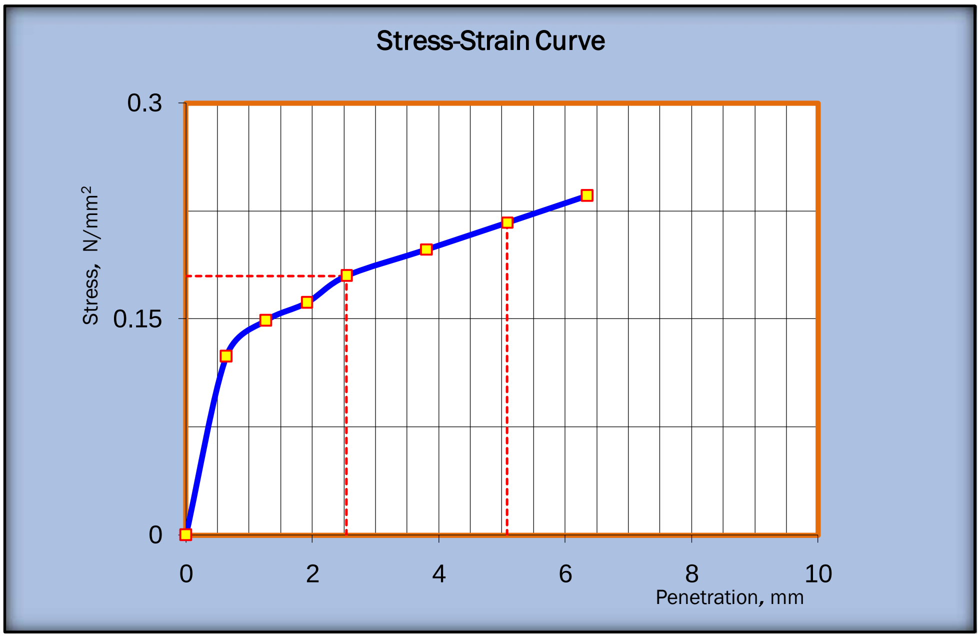
Determination No.	1	2	3	4
Mass of Mold, g	6774	6774	6774	6774
Mass of mold + Compacted Soil, g	10049.6	10415.7	10784.2	10391.4
Mass of Compacted soil, g	3275.6	3641.7	4010.2	3617.4
Volume of Mold, cm3	2133	2133	2133	2133
Bulk density, g/cm3	1.54	1.71	1.88	1.70
Water Contenet, %	31.75	34.95	40.71	47.34
Dry density, g/cm3	1.17	1.27	1.34	1.15



G-26 CBR Computation Table for TP-15 at 3.0m

Blow/ Layer	56/3	Optimum Most. Content (OMC), %	40.0
Swell, %	**0.39**		
Repeated CBR Value, %	3	Max. Dry Density (MDD), %	1.26

Penet. (mm)	Ring Reading (Div.)	Load (N)	Stress (N/mm^2)	Standard stress (N/mm^2)	CBR (%)
0.00	0.0	0	0.00		
0.64	10.0	240	0.12		
1.27	12.0	288	0.15		
1.91	13.0	312	0.16		
2.54	14.5	348	0.18	6.9	2.61
3.81	16.0	384	0.20		
5.08	17.5	420	0.22	10.3	2.11
6.35	19.0	456	0.24		



DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr.-Ing. HenokFikre and has not been presented as a thesis for a degree in any other university, and that all sources of materials used for this thesis have also been duly acknowledged.

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Addis Ababa.

Date of submission: May, 2017