Correlation Between Compaction Characteristics and Atterberg Limits of Fine Grained Soil found in Addis Ababa

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Abstract: Compaction is a way of eliminating air out of the voids of a soil by mechanical means. Compaction is mandatory in different fields of civil engineering such as in highway, airfield, embankments, and dams; to reduce compressibility and permeability of a soil hence increases the shear strength and bearing capacity of a soil. A laboratory tests called standard Proctor and modified proctor tests were advanced to determine the maximum dry density and optimum moisture content of a soil. In this study standard compaction is used. However, in huge projects, conducting laboratory tests by using proctor tests consume time, money, a lot of effort or energy and required a large quantity of samples. An effort to make a correlation between compaction characteristics and Atterberg limits of fine grained soil found in Addis Ababa, which allows us to estimate the compaction parameters of fine grained soils from Atterberg limits were done in this thesis.To develop the correlation, a total 10 test pits has been excavated and a total of 20 disturbed samples (primary data) was collected from different places, 2 samples from each test pit at different depths ranging from 1.00m to 3.00m. And 36 secondary data (laboratory results) were collected from AACRA. After the samples were collected, they were transported to the Gondwana engineering laboratory and different laboratory tests (Atterberg limits, Grain size analysis, Specific gravity and compaction tests) has been conducted. After the tests were conducted, the recorded data were analyzed using descriptive and analytical methods, and then the correlation between compaction characteristics and Atterberg limits of fine grained soil using regression analysis has been done. Regression analysis was conducted by using EXCEL and SPSS software. From the statistical analysis part one can observe that there is a relatively good correlation between OMC and PL and similarly a good correlation is observed between MDD and LL, PL and PI together. The equations found are listed below.
1. OMC = 0.916 * PL - 0.030 * PI - 0.875, $R^2 = 0.807$
2. MDD = - 0.18* PL - 0.027 * PI + 21.182, $R^2 = 0.835$

Index Terms— Atterberg limits, compaction characteristics, and Fine grained soils

1 Introduction

Most of the time Geotechnical engineers are confronted to handle large volumes of soil, where the soil itself is used as a construction material. The importance of compaction as a practical means of achieving the desired strength, compressibility and permeability characteristics of soils has been appreciated since the time early earth structures were built [1].

Compaction of soil has applications in almost every field of civil engineering involving soil. Thus, for a civil engineer, it is very essential to know the compaction characteristics of natural soils, and thereby assess their suitability. In such situations, to obtain compaction characteristics such as maximum dry density and optimum moisture content, one has to carry out a laboratory compaction test. But laboratory compaction test requires sufficient time and effort. For a preliminary assessment of the suitability of soils required for large project, it is desirable to develop correlations of engineering properties with simple physical properties, namely Atterberg limits, which are obtained through simple tests known as index tests. Correlations making use of the Atterberg limits are fairly common in soil mechanics literature, and can be quite useful [1].

2 Research Methodology

2.1 Study Area

The research is conducted at different places in the Addis Ababa city. Addis Ababa is the capital city of Ethiopia Founded in 1886; it is the largest city in Ethiopia. The city is populated by people from different regions of Ethiopia with a population of 3,384,469 according to the 2007 census with an annual growth rate of 3.8%. This city is found at the elevation of 2355m and at a coordinate of $9^0$1″48′N, $38^0$44″24′E on a well-watered plateau surrounded by hills and mountains. It is a grassland biome located at the foot of mount "Entoto" and forms part of the watershed for "Awash" river. It has sub-tropical highland climate with temperature differences up to 10^0C. Daily maximum temperatures don't usually exceed 23 ^{0}C during dry seasons [2].

The selection of sites for excavation was purposive, they are selected based on Addis Ababa's soil classification map, secondary data that are collected from different organizations and from previous researches that are done on investigation of engineering properties of Addis Ababa soils.

Accordingly soil classified under A-7 is chosen for the study. And to make the sample representative the researcher takes two samples from each Sub Cities and a total of twenty samples are collected.

The specific locations of sampling are AKAKI, BOLE, MEGENAGNA, JEMO, LIDETA,MEXICO, KOLFE, ASKO, MESALEMIA, SHIROMEDA (Fig.3). One test pit was opened at each site and disturbed samples About 50 kg were collected from each pit at a depth ranging from 1.00m to 3.00m. After extracting, the samples were transported to at Gondwana eng. plc. Geotechnical laboratory and different laboratory tests are done.

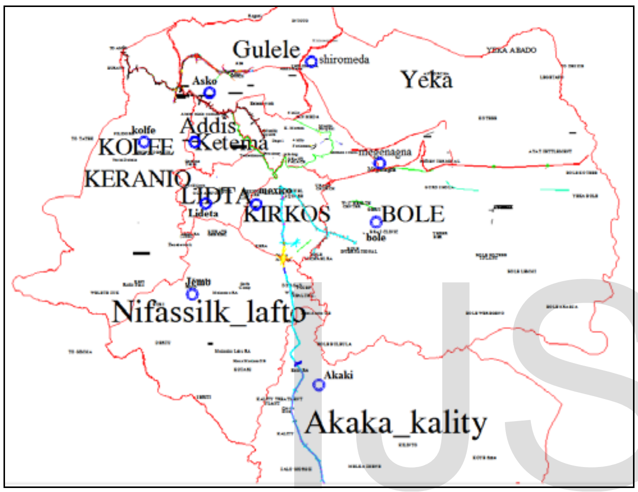

Figure 2.1: Locations of sampling areas [3]

2.2 Data collection process

The data needed for this research were collected from:-

Primary sources: - samples were collected from each test pit, then different laboratory tests were conducted and the results were recorded.

Secondary sources are: AACRA, different journals, previous thesis, books and websites.

2.3 Laboratory Tests and Results

Based on the samples retrieved from the sites, laboratory tests on the twenty one samples were conducted at Gondwana eng. plc. Geotechnical laboratory. Accordingly, the following different kinds of tests have been performed.

2.3.1 Grain size Analysis Test (ASTM D-1140)

The amount of soil materials finer than 0.075mm was determined according to ASTM D-1140"Standard Test Method for Amount of Material in the Soil Finer than the No. 200 Sieve".

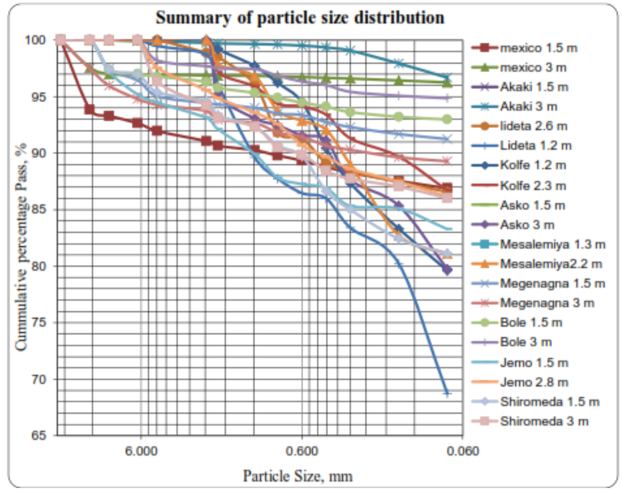

Figure 2.2 Summary of Particle size distribution curve

2.3.2 Specific Gravity of soil (ASTM D-854)

The specific gravity of each type of soil was determined according to ASTM D-854 "Standard Test Method for Specific Gravity of Soils".

Table 2.1 Summary of specific gravity

No.	Sample locations	Depth	Gs
1	Bole	1.5m	2.68
2		3m	2.72
3	Akaki	1.5m	2.65
4		3m	2.67
5	Kolfe	1.2m	2.71
6		2.3m	2.73
7	Lideta	1.2m	2.71
8		2.6m	2.73
9	Megenagna	1.5m	2.67
10		3m	2.65
11	Asko	1.5m	2.74
12		3m	2.78
13	Mesalemiya	1.3m	2.72
14		2.2m	2.74
15	Jemo	1.5m	2.75
16		2.8m	2.77
17	Mexico	1.2m	2.70
18		2.1m	2.73
19	Shiromeda	1.5m	2.69
20		3m	2.71

2.3.3 Atterberg Limit Tests

The liquid limit for each type of soil is determined according to ASTM D-4318 "Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of

ISSN 2229-5518

Soils”.

Table 2.2 Summary of Atterberg Limits

No	Sample locations	Depth	Atterberg limits		
			LL	PL	PI
1		1.5m	97.00	41.00	56.00
2	Bole	3m	93.00	39.00	54.00
3		1.5m	88.15	35.00	53.15
4	Akaki	3m	93.16	37.00	56.16
5		1.2m	62.35	32.00	30.35
6	Kolfe	2.3m	62.90	33.00	29.90
7		1.2m	55.37	27.00	28.37
8	Lideta	2.6m	60.14	29.00	31.14
9		1.5m	87.36	35.00	52.36
10	Megenagna	3m	84.48	34.00	50.48
11		1.5m	60.00	25.00	35.00
12	Asko	3m	59.00	30.00	29.00
13		1.3m	60.00	31.00	29.00
14	Mesalemiya	2.2m	56.39	26.00	30.39
15		1.5m	63.00	26.00	37.00
16	Jemo	2.8m	64.00	24.00	40.00
17		1.2m	73.70	31.00	42.70
18	Mexico	2.1m	66.62	32.00	34.62
19		1.5m	74.80	29.00	45.80
20	Shiromeda	3m	79.20	32.40	46.80

2.3.4 Standard Proctor Test (ASTM D-698)

Moisture-Density Relationships: Each sample extracted from the different sites was sieved over a 4.75mm sieve for testing and compacted into a 101.6-mm diameter mold as described in Procedure “A” of the ASTM D-698. Each sample was immediately tested for water content according to ASTM D-2166 and the moisture content obtained during this procedure was used for generation of a compaction curve according to ASTM D-698.

Finally, the maximum dry unit weight and corresponding optimum moisture content were computed using spreadsheet and charts.

Table 2.3 Summary of OMC and MDD Results

No.	Sample locations	Depth	OMC (%)	MDD (g/cc)
1	Bole	1.5m	37.00	1.25
2		3m	35.00	1.26
3	Akaki	1.5m	30.00	1.33
4		3m	31.00	1.31
5	Kolfe	1.2m	23.50	1.55
6		2.3m	26.00	1.52
7	Lideta	1.2m	25.00	1.46
8		2.6m	25.50	1.46
9	Megenagna	1.5m	32.00	1.27
10		3m	30.00	1.27
11	Asko	1.5m	22.00	1.64
12		3m	25.50	1.54
13	Mesalemiya	1.3m	28.00	1.50
14		2.2m	23.20	1.64
15	Jemo	1.5m	22.00	1.63
16		2.8m	23.00	1.62
17	Mexico	1.2m	25.80	1.44
18		2.1m	26.50	1.46
19	Shiromeda	1.5m	25.10	1.51
20		3m	26.40	1.47

Table 2.4 Summary of all laboratory results

No.	Sample locations	Depth	Soil classification	Atterberg limits			Compaction characteristics			G_s
				LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cc)	MDD (Kg/m3)	
1	Bole	1.5m	A-7-5(64)	97.00	41.00	56.00	37.00	1.25	12.26	2.68
2		3m	A-7-5(63)	93.00	39.00	54.00	35.00	1.26	12.36	2.72
3	Akaki	1.5m	A-7-5(59)	88.15	35.00	53.15	30.00	1.33	13.04	2.65
4		3m	A-7-5(66)	93.16	37.00	56.16	31.00	1.31	12.85	2.67
5	Kolfe	1.2m	A-7-5(27)	62.35	32.00	30.35	23.50	1.55	15.20	2.71
6		2.3m	A-7-5(31)	62.90	33.00	29.90	26.00	1.52	14.91	2.73
7	Lideta	1.2m	A-7-6(19)	55.37	27.00	28.37	25.00	1.46	14.36	2.72
8		2.6m	A-7-6(31)	60.14	29.00	31.14	25.50	1.46	14.35	2.70
9	Megenagna	1.5m	A-7-5(57)	87.36	35.00	52.36	32.00	1.27	12.45	2.67
10		3m	A-7-5(53)	84.48	34.00	50.48	30.00	1.27	12.45	2.65
11	Asko	1.5m	A-7-6(32)	60.00	25.00	35.00	22.00	1.64	16.08	2.74
12		3m	A-7-6(25)	59.00	30.00	29.00	25.50	1.54	15.10	2.78
13	Mesalemiya	1.3m	A-7-5(23)	60.00	31.00	29.00	28.00	1.50	14.71	2.72
14		2.2m	A-7-6(26)	56.39	26.00	30.39	23.20	1.64	16.08	2.74
15	Jemo	1.5m	A-7-6(33)	63.00	26.00	37.00	22.00	1.63	15.98	2.75
16		2.8m	A-7-6(38)	64.00	24.00	40.00	23.00	1.62	15.89	2.78
17	Mexico	1.2m	A-7-5(43)	73.70	31.00	42.70	25.80	1.44	14.12	2.71
18		2.1m	A-7-5(40)	66.62	32.00	34.62	26.50	1.46	14.32	2.73
19	Shiromeda	1.5m	A-7-6(41)	74.80	29.00	45.80	25.10	1.51	14.80	2.69
20		3m	A-7-5(46)	79.20	32.40	46.80	26.40	1.47	14.50	2.71

Table 2.5 Secondary data that are collected from AACRA

No	Sample locations	Soil classification	Atterberg limits			Compaction characteristics		
			LL	PL	PI	OMC (%)	MDD (g/cc)	MDD (Kg/m3)
1	AACRA 1	A-7-6 (40)	48.00	24.00	24.00	17.60	1.69	16.57
2	AACRA 2	A-7-6 (40)	62.00	25.00	37.00	23.00	1.59	15.59
3	AACRA 3	A-7-5(40)	79.00	29.00	50.00	18.70	1.58	15.49
4	AACRA 4	A-7-5(29)	69.00	28.00	41.00	18.70	1.58	15.49
5	AACRA 5	A-7-5 (6)	52.00	24.00	28.00	19.00	1.67	16.38
6	AACRA 6	A-7-5 (12)	53.00	23.00	30.00	20.00	1.57	15.40
7	AACRA 7	A-7-5 (20)	57.00	29.00	28.00	25.00	1.50	14.71
8	AACRA 8	A-7-5 (26)	57.00	30.00	27.00	26.00	1.53	15.00
9	AACRA 9	A-7-5 (21)	55.00	32.00	23.00	28.30	1.55	15.20
10	AACRA 10	A-7-5 (21)	55.00	30.00	25.00	29.00	1.38	13.53
11	AACRA 11	A-7-5 (23)	61.00	28.00	33.00	23.00	1.60	15.69
12	AACRA 12	A-7-6 (20)	54.00	26.00	28.00	22.30	1.71	16.77
13	AACRA 13	A-7-6(30)	77.00	29.00	48.00	24.20	1.51	14.81
14	AACRA 14	A-7-6(40)	83.00	25.00	58.00	21.00	1.47	14.42
15	AACRA 15	A-7-5	47.00	22.00	25.00	15.50	1.76	17.26
16	AACRA 16	A-7-5 (28)	63.00	30.00	33.00	25.00	1.53	15.00
17	AACRA 17	A-7-5	67.00	37.00	30.00	33.00	1.41	13.83
18	AACRA 18	A-7-5 (41)	73.00	28.00	45.00	23.50	1.55	15.20
19	AACRA 19	A-7-6 (21)	45.00	23.00	22.00	21.00	1.60	15.69
20	AACRA 20	A-7-6 (24)	52.00	25.00	27.00	22.00	1.57	15.40
21	AACRA 21	A-7-6(28)	69.00	22.00	47.00	19.60	1.52	14.91
22	AACRA 22	A-7-5(11)	73.00	23.00	50.00	18.50	1.59	15.59
23	AACRA 23	A-7-5(21)	72.00	26.00	46.00	21.00	1.54	15.10
24	AACRA 24	A-7-5(28)	73.00	27.00	46.00	21.00	1.54	15.10
25	AACRA 25	A-7-5(11)	67.00	24.00	43.00	21.00	1.58	15.49
26	AACRA 26	A-7-5(17)	74.00	23.00	51.00	21.00	1.58	15.49
27	AACRA 27	A-7-5 (31)	54.00	26.00	28.00	24.00	1.61	15.79
28	AACRA 28	A-7-6 (31)	57.00	27.00	30.00	24.50	1.58	15.49
29	AACRA 29	A-7-5 (28)	66.00	29.00	37.00	26.50	1.53	15.00
30	AACRA 30	A-7-5	54.00	25.00	29.00	20.50	1.56	15.30
31	AACRA 31	A-7-5(8)	49.00	24.00	25.00	21.00	1.65	16.18
32	AACRA 32	A-7-5 (36)	79.00	28.00	51.00	25.00	1.53	15.00
33	AACRA 33	A-7-6(27)	73.00	32.00	41.00	28.00	1.49	14.61
34	AACRA 34	A-7-6(28)	73.00	29.00	44.00	24.00	1.54	15.10
35	AACRA 35	A-7-5 (23)	77.00	28.00	49.00	20.00	1.71	16.77
36	AACRA 36	A-7-6(25)	69.00	24.00	45.00	17.20	1.61	15.79

3 ANALYSIS, RESULTS AND DISCUSION

3.1 General

The concept of "correlation" is a statistical tool which studies the relationship between two variables. Correlation Analysis involves various methods and techniques used for studying and measuring the extent of the relationship between the two variables. "Two variables are said to be in correlation if the change in one of the variable results in a change in the other variable". There are two important types of correlation. They are Positive and Negative correlation, And Linear and Non – Linear correlation [4].

Regression analysis is concerned with how the values of Y depend on the corresponding values of X. Y, whose value is to be predicted, is known as dependent variable or response and X, which is used in predicting the value of the dependent variable, is called independent or regressor variable. A regression model that contains more than one regressor variable is called multiple

Regression models. Alternatively, Regression model containing one independent variable or regressor is termed as a simple regression model [15].

In carrying out the statistical analysis, both the statistical software program called SPSS and MS Excel spreadsheet are used to determine the Scatter plot, Best fit curve and Regression.

3.2 Scatter plot

In developing correlations, the first step is creating a scatter plot of the data, to visually assess the strength and the form of some type of relationship [15].

- If the points are very close to each other, a fairly good amount of correlation can be expected between the two variables. On the other hand, if they are widely scattered a poor correlation can be expected between them.
- If the points are scattered and they reveal no upward or downward trend, then we say the variables are interrelated.
- If there is an upward trend, rising from the lower left hand corner and going upward to the upper right hand corner, the correlation obtained from the graph is said to be positive. Also, if there is a downward trend from the upper left hand corner the correlation obtained is said to be negative.

3.2.1 Scatter plot for the primary data

The scatter plot of OMC with LL, PL, and PI, And MDD with LL, PL and PI for the 20 primary data were done by using Ms. Excel and the plots are presented below.

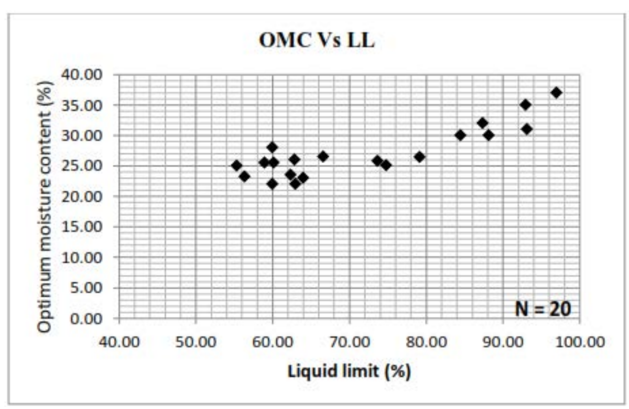

Figure 3.1: Scatter plot of OMC vs. LL

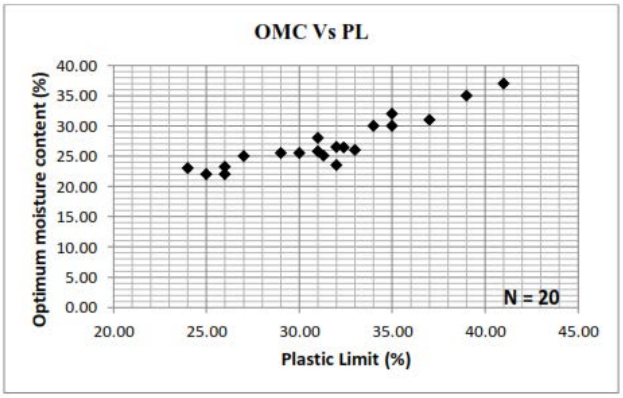

Figure 3.2: Scatter plot of OMC Vs PL

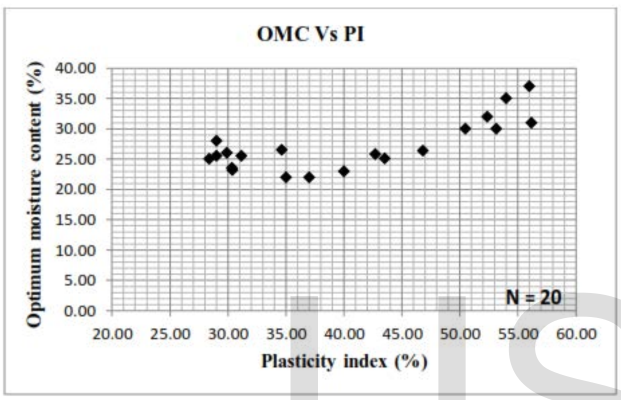

Figure 3.3: Scatter plot of OMC vs. PI

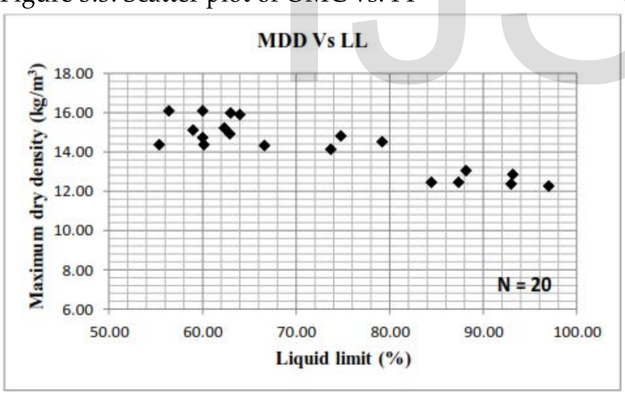

Figure 3.4: Scatter plot of MDD vs. LL

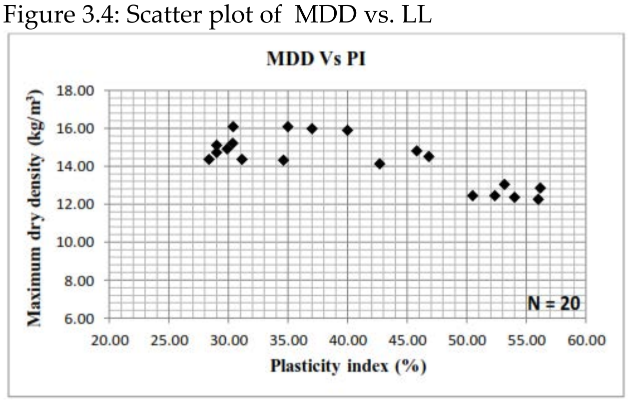

Figure 3.5: Figure 10. Scatter plot of MDD vs. PI

3.2.2 Scatter plots for the primary and secondary data

The scatter plot of OMC with LL, PL, and PI, And MDD with LL, PL and PI for the 56 primary and secondary data were done by using Excel and the plots are presented below.

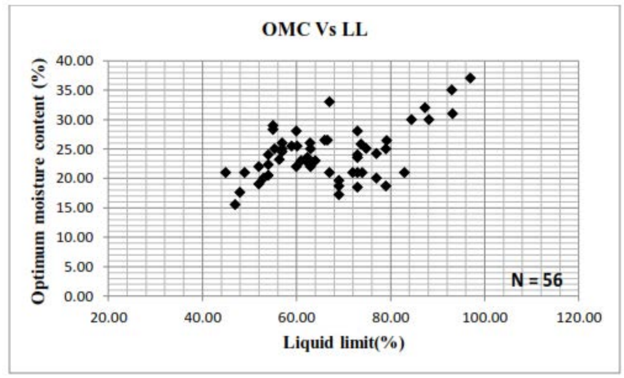

Figure 3.6: Scatter plot of OMC vs. LL

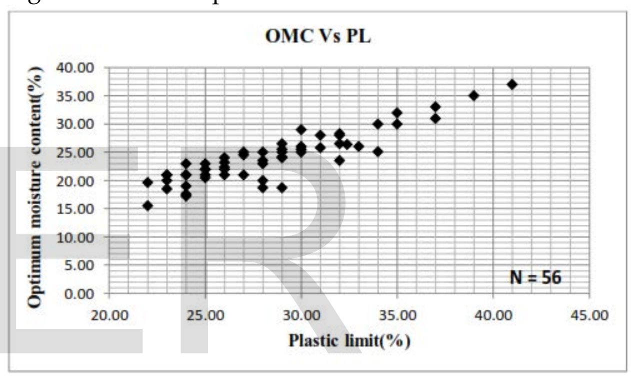

Figure 3.7: Scatter plot of OMC vs. PL

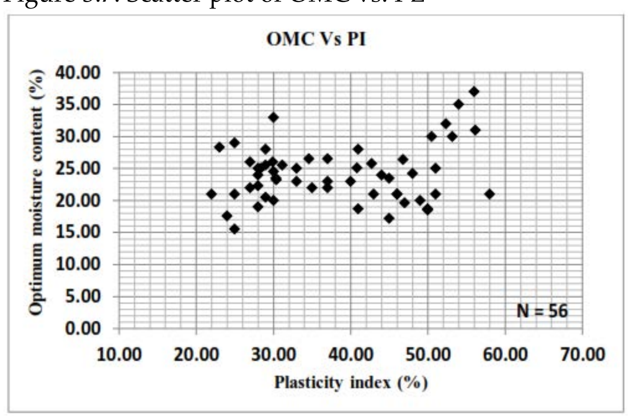

Figure 3.8: Scatter plot of OMC vs. PI

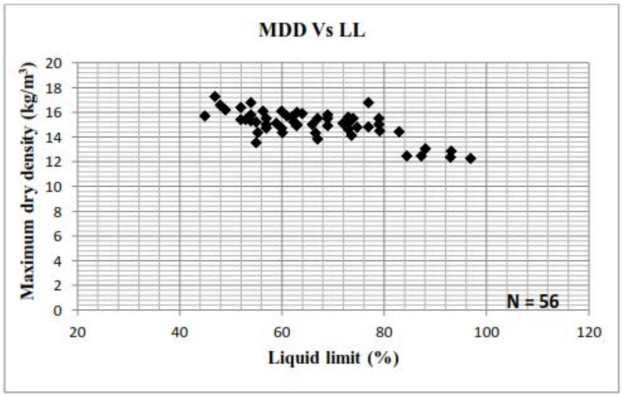

Figure 3.9: Scatter plot of MDD vs. LL

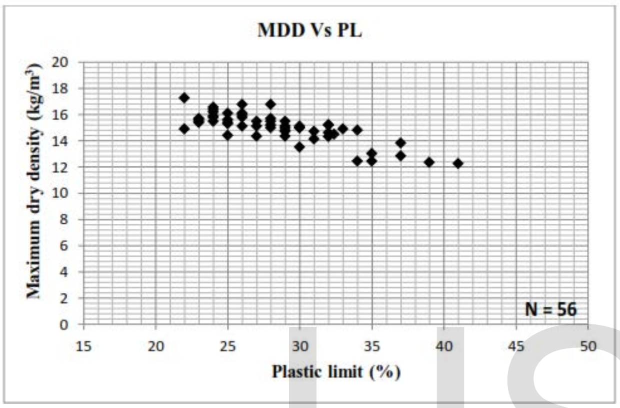

Figure 5.10: Scatter plot and best fit curve of MDD vs. PL

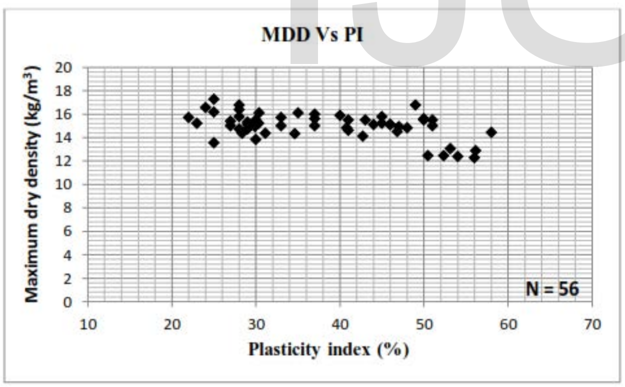

Figure 3.11: Scatter plot of MDD vs. PI

3.3 Regression analysis

3.3.1 Simple Linear Regression

Table 3.1:Summary of simple linear regression analysis

Regression	From primary data	From primary + secondary data
OMC from LL	OMC = 0.258*LL + 8.535, $R^2 = 0.74$	OMC = 0.178*LL – 12.246, $R^2 = 0.25$
OMC from PL	OMC = 0.838*PL + 0.689, $R^2 = 0.85$	OMC = 0.894*PL – 1.384, $R^2 = 0.803$
OMC from PI	OMC = 0.307*PI + 14.684, $R^2 = 0.57$	OMC =0.0944*PI + 20.53, $R^2 = 0.05$
MDD from LL	MDD = -0.081*LL + 20.14, $R^2 = 0.75$	MDD = -0.061*LL + 19.059, $R^2 = 0.47$
MDD from PL	MDD = -0.25*PL + 22.146, $R^2 = 0.78$	MDD = -0.2*PL + 20.713, $R^2 = 0.64$
MDD from PI	MDD = -0.098*PI + 18.25, $R^2 = 0.59$	MDD = -0.052*PI + 16.968, $R^2 = 0.23$

3.3.2 Multiple Linear Regressions

Here, we deal with two sets of data where the interest lies in either examining how one variable relates to a number of others or in predicting one variable from others. The analysis is conducted by using SPSS statistical analysis software. Summary of multiple linear regression analysis is listed below.

Table 3.2:Summary of multiple linear regression analysis

Regression	From primary data	From primary + secondary
OMC from PL and LL	OMC = 1.496 + 0.084LL + 0.624 PL $R^2 = 0.879$	OMC = - 0.03 LL + 0.946 PL - 0.875 $R^2 = 0.807$
OMC from PL and PI	OMC = 1.496 + 0.708PL + 0.084PI $R^2 = 0.879$	OMC = - 0.875 – 0.03PI + 0.916 $R^2 = 0.807$
OMC from LL and PI	OMC = 1.496 + 0.708LL – 0.624 PI R2 = 0.879	OMC = - 0.875 - 0.946PI + 0.916LL $R^2 = 0.807$
MDD from PL and LL	MDD = 21.829 - 0.039LL - 0.15 PL $R^2 = 0.831$	MDD = 21.182 - 0.153 PL - 0.027 LL $R^2 = 0.698$
MDD from PL and PI	MDD = 21.829 - 0.189 PL - 0.039 PI R2 = 0.831	MDD = 21.182 - 0.027 PI - 0.18 PL $R^2 = 0.835$
MDD from LL and PI	MDD = 21.829 + 0.15PI - 0.189 LL R2 = 0.831	MDD = 21.182 - 0.18 LL + 0.153 PI $R^2 = 0.698$

3.4 Discussions on the developed equations

3.4.1 Discussion on single linear regression

After carefully studying the data on the scatter plot and different models, this analysis discovered that OMC is highly influenced by PL by achieving a coefficient of determining value (R^2) of 0.85 and 0.803 in primary and primary plus secondary data respectively. And MDD has a good correlation with PL with a coefficient of determination of 0.78 and 0.48 in primary and primary and secondary data respectively.

This category also shows that the correlation of OMC and MDD with plasticity index and liquid limit in this group gave fair to poor results.

3.4.2 Discussion on multiple linear regressions

From summary of multiple linear regressions, one can say there is a better correlation between OMC and MDD with LL, PL and PI together rather than correlating with each of them.

Generally, the difference in the equation and on the values of the coefficient of determination that are obtained from primary and from primary plus secondary data is because of the number of samples, the factors that affect compaction efforts and workmanship.

This study, however, indicates the existence of a relatively good correlation between index properties

(LL, PL and PI) and compaction characteristics (OMC and MDD).

3.5 Validation of the developed equations

In this section the researcher tries to validate the developed equations by using 1 control test. The data that is used as a control test is found by conducting different tests such as compaction, Atterberg's limits and sieve analysis tests on Akaki soil sample that is found from Gondwana engineering plc. Laboratory. Summary of laboratory results is as follows.

Table 3.3 Summary of laboratory results for control test

No.	Sample name	Soil classification	Atterberg limits			Compaction cxs		
			LL	PL	PI	OMC (%)	MDD (g/cc)	MDD (Kg/m^3)
1	Akaki for validation	A-7-5	95	37	59	33	1.28	12.552

And among the developed equations the following equations are selected for validation by their value of the coefficient of correlation (R^2), i.e. equations with high value of the coefficient of correlation are selected for each dependent variable.

1. OMC = 0.916 * PL - 0.030 * PI - 0.875, R2 = 0.807
2. MDD = - 0.18* PL - 0.027 * PI + 21.182, R2 = 0.835

Table 3.4 Validation of the development equation

Sample location	OMC actual (%) A	OMC predicted (%) B	Variation /((A-B)/A)*100/ (%)	MDD (Kg/m3) C	MDD pridicted (kg/m3) D	Variation /((C-D)/C)*100/ (%)
Akaki (control test)	33.00	32.22	2.35	12.55	12.80	2.00

By seeing the above result one can say that the exact values of OMC and MDD from the development equation cannot be found but a good approximation can be produced.

4 CONCLUSION

From the results of this study the concept of predicting compaction characteristics of fine grained soils containing varied proportions of fines has been made.

From the statistical analysis and the discussion part one can observe that there is a relatively good correlation between OMC and PL, similarly a good correlation observed between MDD and LL, PL and PI together.

And, generally from the regression analysis the following equations were found satisfactory.

1. OMC = 0.916 * PL - 0.030 * PI - 0.875, R^2 = 0.807
2. MDD = - 0.18* PL - 0.027 * PI + 21.182, R^2 = 0.835

The proposed correlation equations between the compaction characteristics of soils with their Atterberg limits are going to be a manageable tool in rapidly assessing the suitability of fine grained soils for compaction related purposes at the study locations.

From the developed correlations one would be in a situation to predict compaction characteristics of the index properties for some locations of Addis Ababa.

Acknowledgment

The authors wish to thank the Jimma Institute of Technology, Jimma University, as well as the Ethiopian Road Authority (ERA) for allowing this research project to proceed. This hard work could not be completed without the joint sponsorship program.

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