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PARAMETRIC MODELLING ON THE RELATIONSHIPS BETWEEN ATTERBERG LIMITS AND COMPACTION CHARACTERISTICS OF FINE-GRAINED SOILS

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ABSTRACT

Compaction is one of the essential engineering techniques, performed to assure the stability of soils based on specified strength. However, in most construction projects such as large scale projects, obtaining the desired compaction characteristics, namely optimum moisture content (OMC) and maximum dry density (MDD), becomes time-consuming. In this case, predicting the compaction characteristics from the Atterberg's limits that involve a more straightforward and quicker method of testing becomes a vital task. This study focused on obtaining valid correlations between Atterberg's limit parameters and compaction characteristics of fine-grained soils. A series of laboratory tests for 50 samples conducted for the investigation. Statistical relationships of all the parameters were analyzed. The laboratory test results indicated that both OMC and MDD showed a strong correlation with LL and PL together using multiple linear regressions than with single parameters from single linear regression. Therefore, the study concluded that during the prediction of OMC and MDD from the Atterberg's limits, the combined parameters of Atterberg's limits should be used rather than single parameters. It is recommended, the result of this research could be applied in different civil engineering practice, directly related to the parameters to be known.

KEYWORDS: *Fine-grained soils, Compaction, Atterberg's limits, Correlation, Regression.*

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1. INTRODUCTION

Most of the time, Geotechnical engineers confronted with handling large volumes of soil, where the soil itself, used as a construction material. Soil compaction for all structures, where is to be built, is necessary to achieve the desired strength, compressibility, and permeability characteristics of existing soils, which had been understood ever since for any project construction [1].

Every human-made structure resting on the ground needs safe and stable soil. To attain this safety and stability requirements, the engineering properties of the soil beneath the structure or on the structure must be properly identified. However, obtaining these engineering properties of soils requires relatively more time and expense. Moreover, most engineering properties of soils depend upon their index properties. Hence, by obtaining the index properties of soils that involves a more straightforward and quicker method of testing, the engineering properties can be predicted satisfactorily from empirical correlations [2]. Compaction is the process of mechanically pressing the soil particles together into a closed state of contact with the air being expelled from the soil. In this process, both the number and size of voids in a given soil mass will be reduced, and therefore, the density of the soil increases and the engineering property changes significantly. Compaction characteristics of soils are expressed in terms of maximum dry density (MDD) and Optimum moisture content (OMC). Determining MDD and OMC, especially in large scale projects, is both time-consuming and costly. Hence, predicting MDD and OMC from index properties becomes important [3].

In this study, the Index properties and Compaction characteristics of fine-grained soil of Jimma town had been determined, which involved parametric modeling in establishing the correlations between the Atterberg's limits. The developed correlation equations would be a manageable statistical tool in assessing the suitability of fine-grained soils from compaction related purposes at the study locations. From the developed correlations, one could be in a situation to predict compaction characteristics from Atterberg's Limits for some locations. The developed correlations can contribute to minimizing the time, cost, and effort to be incurred in carrying out laboratory compaction tests by predicting the compaction characteristics from Atterberg's limits.

2. METHODS

2.1 Study area

Samples are collected from the soils within Jimma Town. The study location is located 335km by road southwest of Addis Ababa. Its geographical coordinates are in between 7° 13‘- 8° 56N latitude and 35°49‘-38°38‘E longitude with an estimated area of 19,506.24ha. The town is found in an area of average altitude, of about 1780 m above sea level. It lies in the climatic zone, locally known as Woyna Daga [2].

2.2 Sample size and Sampling procedures

2.2.1 Sample Size

There were 30 samples taken from 15 locations within Jimma town. The quantities of the materials required were determined by laboratory tests that are conducted as well as the number repetition of the tests. Accordingly, one test pit performed at each site, considering 1 sample at 1m depth, and another 1 sample at a 2.0m depth of about 40kgs.

2.2.2 Sampling procedures

Precise and accurate data are required to describe the soil profile and sample locations [3]. Test pits were excavated using hand tools carefully with a plan area of 1m by 1m, and representative samples were extracted. The samples properly handled and preserved using a plastic bag to prevent contamination by foreign material and to ensure that the in-situ soil conditions are preserved. The preserving and transporting of the samples was performed according to ASTM D-4220-95 (standard Practice for Preserving and Transporting of Soil samples).

2.3 Laboratory tests

Several laboratory tests had been undertaken to produce model equations. All laboratory tests are conducted according to ASTM. Based on the samples retrieved from the different sites, laboratory tests for all 30 samples were performed at Jimma Institute of Technology soil laboratory. The following different kinds of tests were performed.

2.3.1 Grain Size Distribution

Grain size analysis is a process in which the proportion of material of each grain size present in a given soil is determined. In this study, two types of testing were used: sieve analysis and hydrometer as follows:

2.3.1.1 Sieve Analysis Test

Mechanical sieve analyses were performed on each sample based on ASTM D6913-04 for grain size distribution determination. Sieve analysis used U.S. Sieve sizes No's. 4, 10, 20, 40, 60, 100 and 200. A sample of soil was dried in the oven at a temperature of 105 ^{0}C–110 ^{0}C overnight. It was allowed to cool and its weight recorded. The samples placed in the nested sieves are arranged in order to reduce the sieve with a hole on top, followed by the others. Subsequently, the mass retained on each sieve established.

2.3.1.1 Hydrometer analysis

For this particular study, Hydrometer analysis used to determine the grain size distribution of fine-grained soil having particles sizes smaller than 75µm using Hydrometer.

2.4 Specific Gravity

The specific gravity of selected samples measured in accordance with ASTM D 854-98 (Standard Test Method for Specific Gravity of Soils). The mass of a clean, dry Pycnometer was obtained. The pycnometer filled with clean water weighed, and the temperature was measured. The water was then poured out until the flask half-full and oven-dried soil of a known mass carefully placed in the Pycnometer. The contents allowed to be free from any trapped air. After removing all the air, distilled water was carefully added, making sure that no air was reintroduced to the contents. For each type, the specific gravity of soil determined according to ASTM D-854 "Standard Test Method for Specific Gravity of Soils."

2.5 Atterberg's Limits

Laboratory tests performed to determine the Plastic Limit(PL) and Liquid Limit(LL) of the soil samples. The experiment conducted using ASTM D4318 -98 (Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils). Approximately 200 grams of soil passing No.40 (0.425mm) sieve are needed to complete the Atterberg limits test. Water added to the soil samples and the soil sample covered and placed for 16 hours. The sample split into two areas. Approximately 20 grams was set aside for the plastic limit determination, while the rest used for determining the liquid limit. Four separate water content determinations made between 15 and 35 blows using the Casagrande apparatus. Once these data plotted, the liquid limit will be determined by locating the water content at 25 blows. For plastic limit determination, 1/3 of the 20 grams were taken and rolled into a 3mm thread on the glass plate. This step repeated until the soil crumbled when the thread is reached 3mm diameter. Water content determination performed. The average of the two water contents recorded as the plastic limit.

2.6 Compaction test

Laboratory compaction tests provided the basis for determining the percent compaction and water content required to obtain the engineering properties, and for controlling construction to assure the required compaction and water contents. The testing procedure, according to ASTM D698-98, is summarized as follows: A soil at a selected water content placed in three layers into a mold of given dimensions. Each layer compacted by 25 blows of 24.5kN rammer dropped from a distance of 305mm, subjected the soil to a total compaction effort of about 600 kN/m2. The resulting dry unit weight of the sample was determined. The procedure repeated for a sufficient number of water contents to establish a relationship between the dry unit weight and the water content.

2.7 Data Processing and Analysis

There are many methods that we can use to check the validity of the relationships between two or more variables [22]. However, in this study, the two common methods are used, namely: Scatter plot and Linear regression analysis. The study variables are separated into independent and dependent variables. The compaction test parameters (OMC and MDD) are dependent variables, while the parameters from Atterberg's limit test (LL, PL, and PI) are independent variables. Before the analytical method introduced, some important terms are discussed below:

- ***T-test value***: The probability of making a mistake to reject a hypothesis when it happens to be true at the level of significance. In practice, it is usual to use the 5% level of significance. This means that we are 95% confident that we can make the right decision and we cannot go wrong with a probability of 5%, and you can get the *t-value* by dividing the standard error of the coefficient through its independent variables.
- ***P-value:*** It is the most important term in the opinion of the statistical significance of the independent variables. It also represents a significant predictive power of the model. *P-value* is simply the ratio of the model mean square error to the mean square.
- ***Standard error:*** The average error of each measurement sample points on the line of best fit. Out of all the curves, the best-fit curve through the standard error smaller, and it is important because it is used to calculate other measures, such as confidence intervals and margin of error.
- ***The correlation coefficient (R):*** correlation coefficient (sometimes called the regression coefficient) is the act of the linear correlation between two variable x and y, between +1 and -1 for sale inclusive. R = 1 indicates a perfect linear correlation and linear regression perfect, R = 0 is no correlation, and R = -1 total negative correlation.

2.7.1 Scatter Plots

In developing correlations, a first step is creating a scatter plot of the data obtained, to visually assess the strength and form of some type of relationship [22].

- If all points in the scatter plot are very close to each other, a fairly good correlation can be expected between the dependent and independent variables. Likewise, if those points are widely scattered, a poor correlation of data can be expected between them.
- If the points are scattered and they reveal no upward or downward trend, then we say the variables are uncorrelated.
- However, If there is an increasing trend from the lower left-hand corner and going upward to the upper right-hand corner, the correlation indicated 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

2.7.2 Regression analysis

Regression analysis provides a statistical technique for modeling and investigating the relationship between two or more variables [22]. A variable whose value is predicted is called the dependent variable or response. A variable used to predict the value of the dependent variable is termed independent called multiple regression models. Alternatively, the Regression model containing one independent variable is termed as a simple regression model. A few techniques can be used to indicate the adequacy of a multiple regression model; some of these are standard error and the coefficient of regression (R2) values. The standard error of a statistic gives some idea about the precision of an estimate or predictor variable.

3. LABORATORY TEST RESULTS, ANALYSES, AND DISCUSSIONS

3.1 Laboratory test results

Table 1 indicated the locations and samples collected from different depths, including the corresponding values for Atterberg's limits, compaction test, and specific gravity test results.

Table 1: Summary of Laboratory test results

No	Sample Location	Atterberg's Limits			Compaction test		Specific Gravity (Gs)
		LL	PL	PI	MDD	OMC	
1	Ajipp @ 1m	94	48	46	1.30	36	2.65
2	Ajipp @ 2m	95	55	40	1.27	37	2.68
3	Kitto Campus @ 1m	90	45	45	1.38	34	2.66
4	Kitto Campus @ 2m	94	46	48	1.31	36	2.63
5	Bosa Kitto @ 1m	80	44	36	1.37	34	2.67
6	Bosa Kitto @ 2m	81	39	42	1.38	34	2.61
7	Bosa Addis @ 1m	76	33	43	1.41	32	2.76
8	Bosa Addis @ 2m	78	42	36	1.39	33	2.74
9	Merkato @ 1m	84	44	40	1.35	34	2.71
10	Merkato @ 2m	85	45	40	1.34	34	2.70
11	Awetu @ 1m	79	40	39	1.38	32	2.80
12	Awetu @ 2m	82	43	39	1.39	33	2.82
13	Seto Semero @1m	84	49	35	1.32	34	2.70
14	Seto Semero @ 2m	86	51	35	1.33	35	2.72
15	Kochi @1m	90	51	39	1.29	36	2.79
16	Kochi @ 2m	88	53	35	1.32	35	2.78
17	Ginjo Guduru @1m	95	48	47	1.25	37	2.70
18	Ginjo Guduru @ 2m	93	58	35	1.29	37	2.72
19	Ginjo @1m	88	45	43	1.33	35	2.62
20	Ginjo @2m	87	48	39	1.34	35	2.61
21	Becho Bore @1m	101	58	43	1.22	39	2.62
22	Becho Bore @2m	103	59	44	1.21	40	2.61
23	Mentina @1m	94	59	35	1.28	38	2.76
24	Mentina @ 2m	96	51	45	1.26	38	2.77
25	H-mentina @1m	91	49	42	1.30	37	2.76

26	H-mentina @ 2m	93	59	34	1.29	37	2.74
27	Hirmata @1m	87	40	47	1.34	35	2.65
28	Hirmata @ 2m	85	38	47	1.36	34	2.63
29	H-Merkato @1m	89	45	44	1.32	35	2.71
30	H-Merkato @2m	90	44	46	1.31	36	2.70

3.2 Correlation and Regression Analysis

3.2.1 Scatter Plot and Best-Fit Curve for the primary data

The scatter plots of OMC with LL, PL, and PI, And MDD with LL, PL, and PI for the 30 primary data were done by using Ms. Excel, and the plots are presented below.

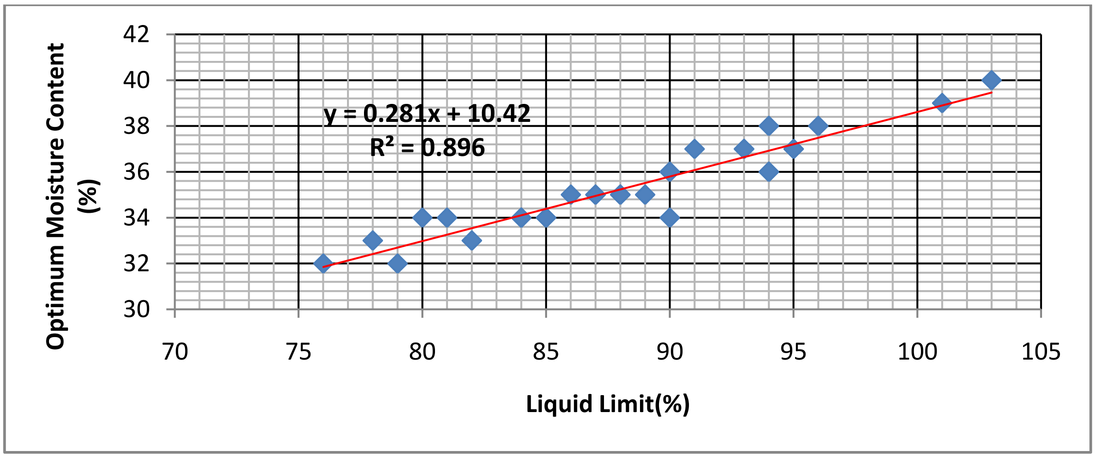

Figure 1: Scatter plot and the best-fit curve of liquid limit and OMC.

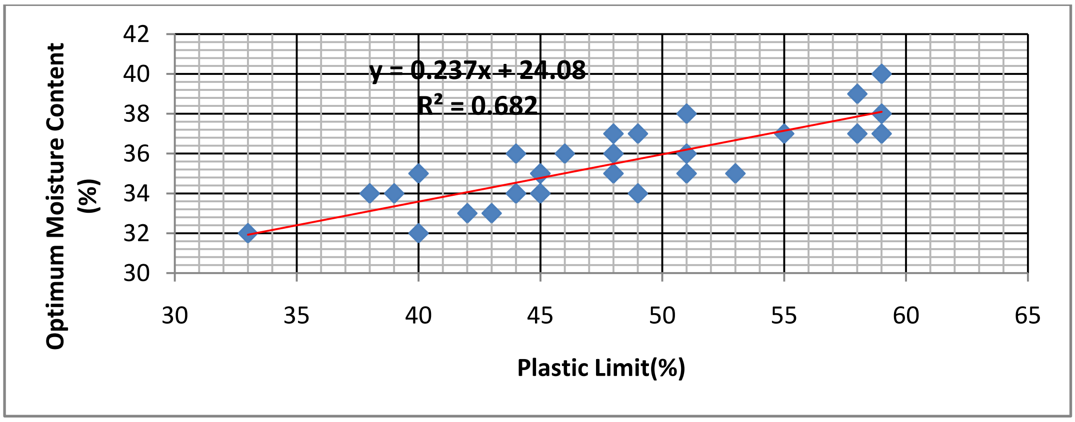

Figure 2: Scatter plot and best-fit curve of plastic limit and OMC

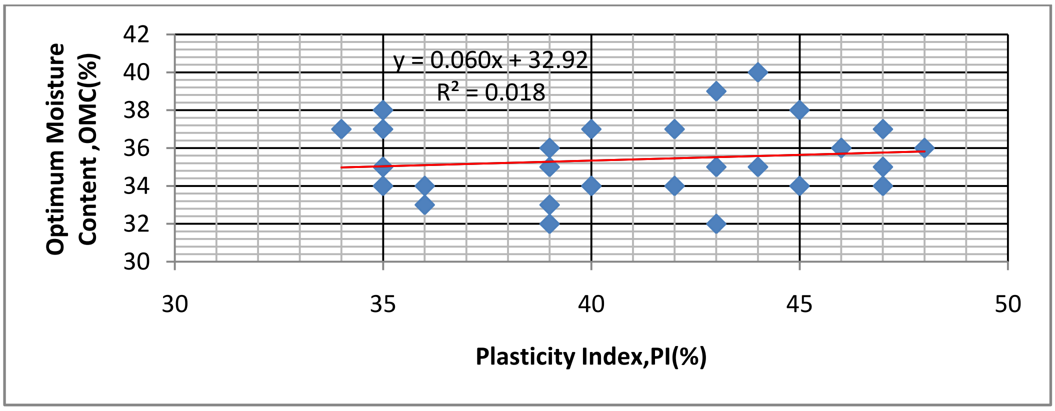

Figure 3: Scatter plot and best-fit curve of the plasticity index and OMC

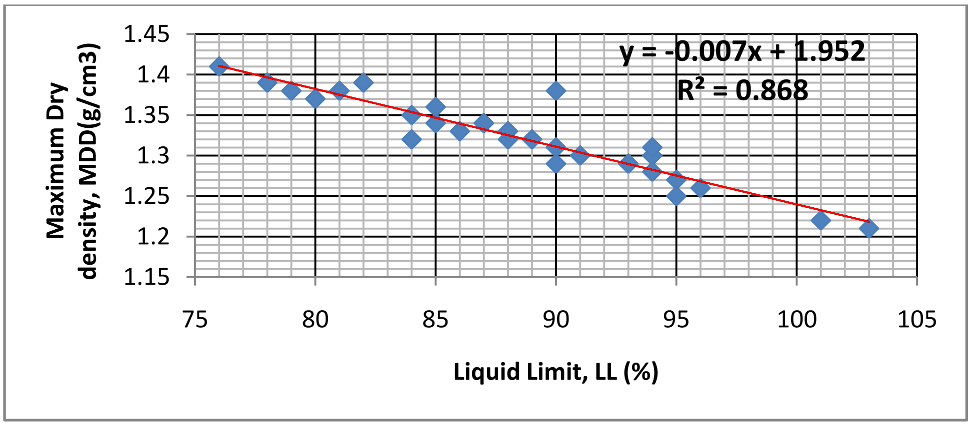

Figure 4: Scatter plot and best-fit curve for liquid limit and MDD

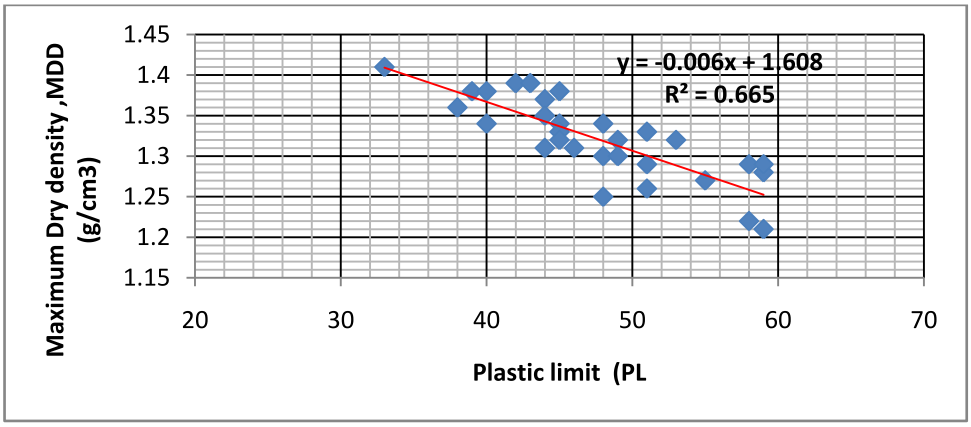

Figure 5: Scatter plot and best-fit curve for plastic limit and MDD.

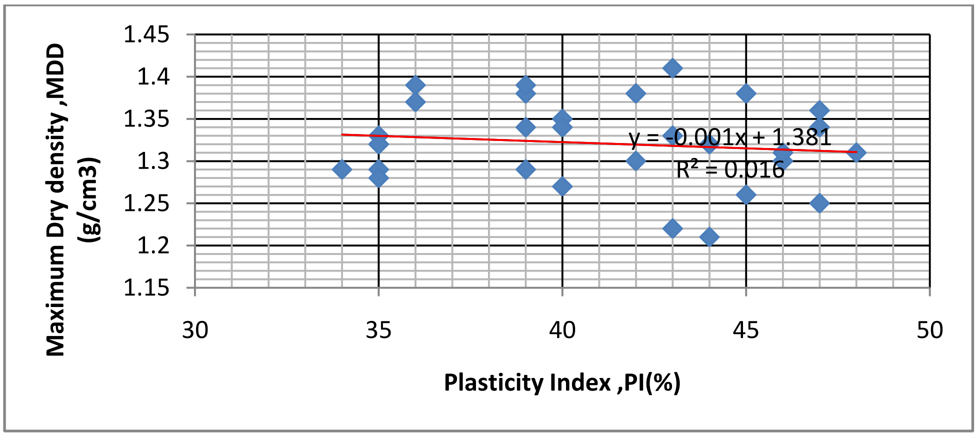

Figure 6: Scatter plot and best-fit curve for plasticity Index and MDD.

3.2.2 Scatter plots for the primary plus(+) secondary data

The scatter plot of OMC and MDD with LL, PL, and PI for the 50 primary plus(+) secondary data were done by using Excel, and the plots are presented below.

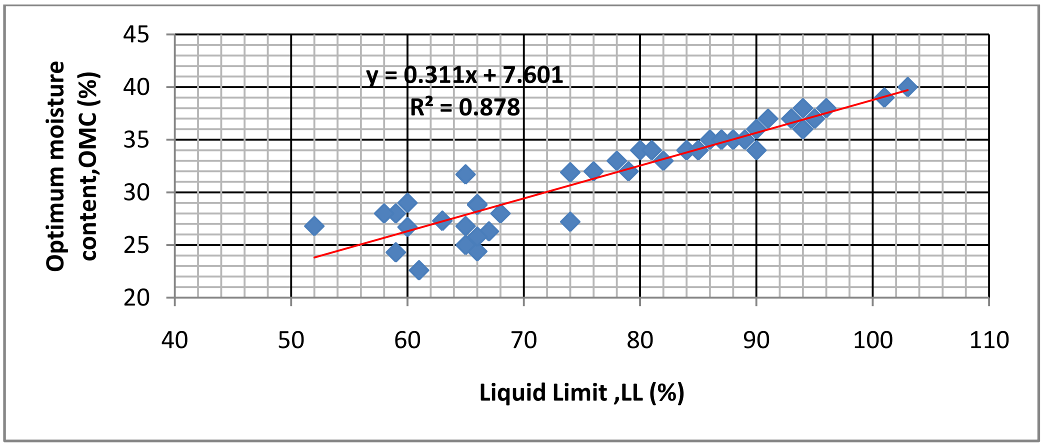

Figure 7: Scatter plot and best-fit line for liquid limit and OMC.

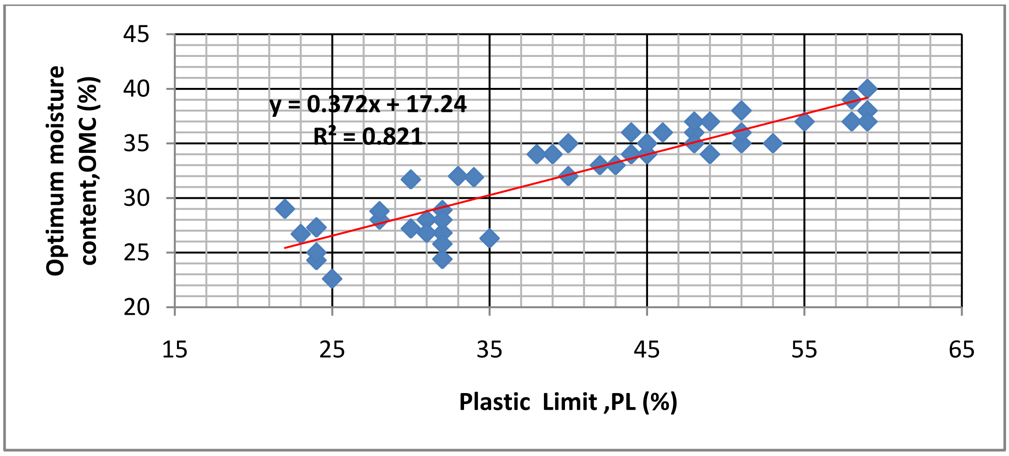

Figure 8: Scatter plot and best-fit curve for plastic limit and OMC.

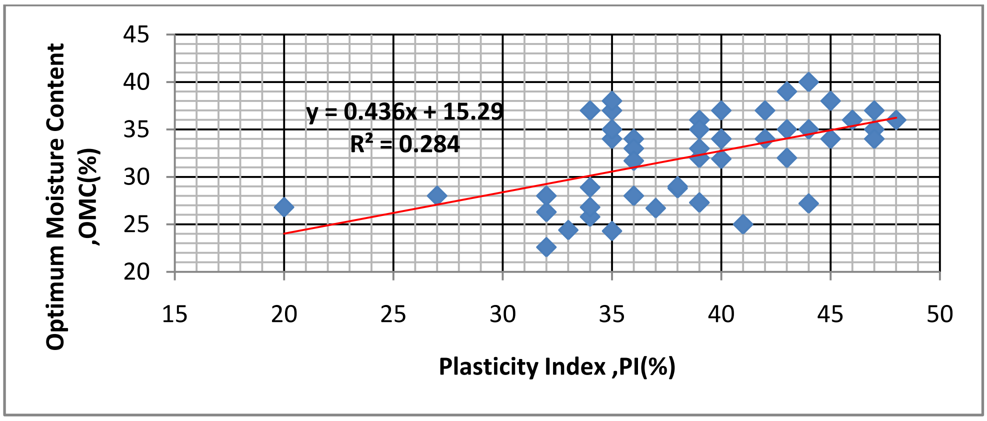

Figure 9: Scatter plot and best-fit curve for plasticity Index and OMC.

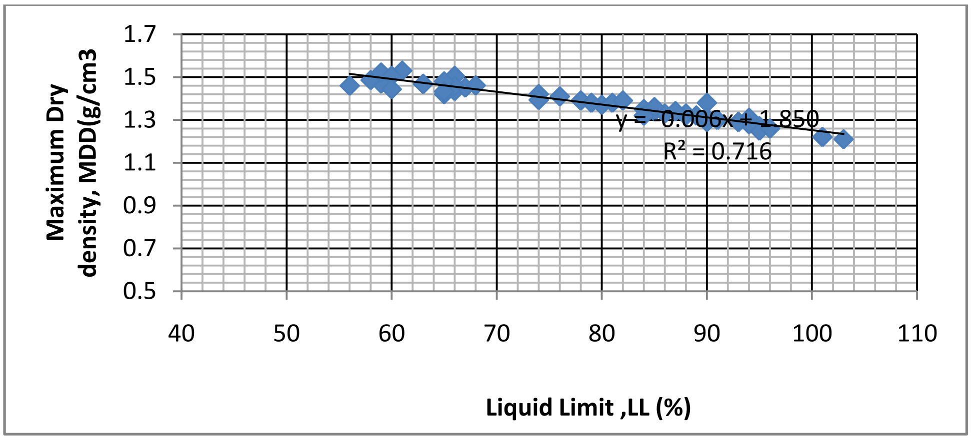

Figure 10: Scatter plot and best-fit curve for liquid limit and MDD.

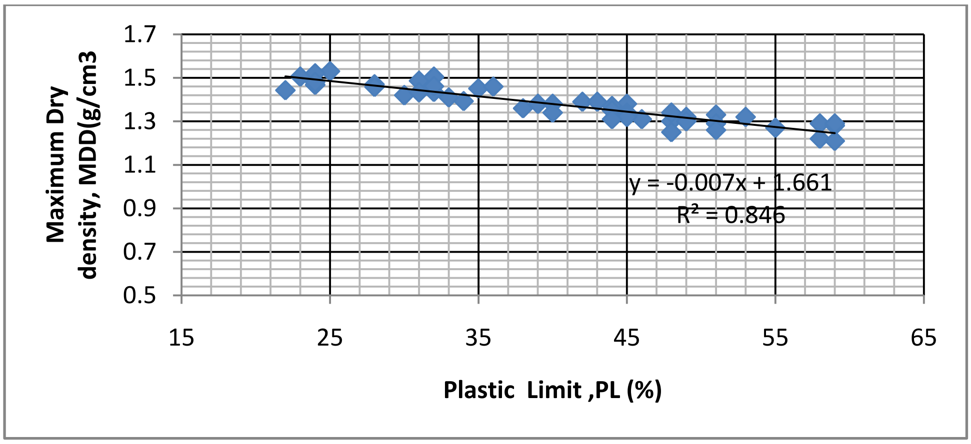

Figure 11: Scatter plot and best-fit curve for plastic limit and MDD.

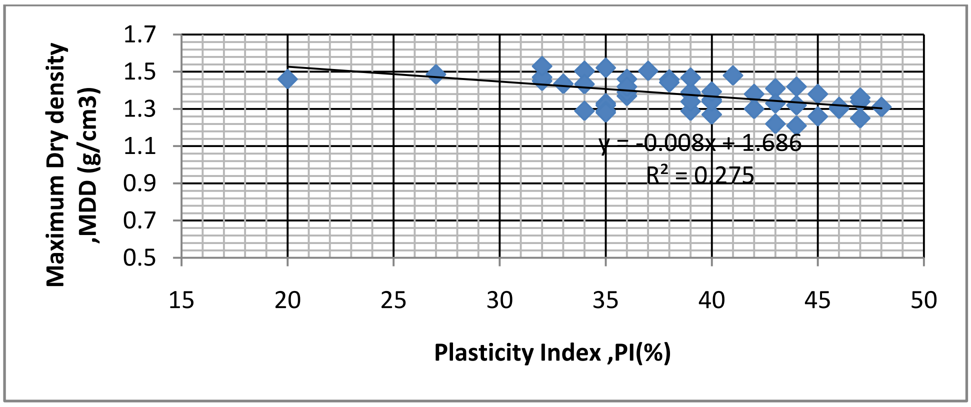

Figure 12: Scatter plot and best-fit curve for plasticity Index and MDD.

3.3 Regression analysis

3.3.1 Univariate Analysis

Table 2: Summary of Univariate Analysis.

Regression	**From primary data: Developed equations**	**Coefficient of regression (R2) values for each equation**
OMC from LL	OMC = 10.427 + 0.282 LL -------(1)	R^2=0.897
OMC from PL	OMC= 24.088 + 0.237 PL -------(2)	R^2=0.682
OMC from PI	OMC = 32.923 + 0.06 PI -------(3)	R^2=0.019
MDD from LL	MDD = 1.953 - 0.007 LL -------(4)	R^2=0.868
MDD from PL	MDD = 1.608 - 0.006 PL --------(5)	R^2=0.665
MDD from PI	MDD = 1.381 - 0.001 PI --------(6)	R^2=0.017
	From Primary plus(+) Secondary data: Developed equations	
OMC from LL	OMC = 7.601 + 0.312LL ---------(7)	R^2= 0.879
OMC from PL	OMC = 17.243 + 0.372 PL ---------(8)	R^2= 0.821
OMC from PI	OMC = 15.297 + 0.436 PI ---------(9)	R^2= 0.285
MDD from LL	MDD = 1.861 - 0.006 LL ---------(10)	R^2= 0.7296
MDD from PL	MDD = 1.683 - 0.007 PL ---------(11)	R^2= 0.7216
MDD from PI	MDD = 1.678 - 0.008 PI ---------(12)	R^2= 0.188

3.3.2 Multivariate Analysis

It was established two sets of data where the point of interest lies in either evaluating how one variable relates to a few numbers of other variables in predicting one variable from the others. The analysis supported by using SPSS statistical analysis software. The multiple linear regression analysis is listed below.

Table 3: Summary of Multiple Linear Regressions.

Regression	**From primary data: Developed equations**	**Coefficient of regression (R2) values for each equation**
OMC from LL & PL	OMC = 11.2943 + 0.244262 LL + 0.0528714PL ---------(13)	R^2 =0.9370
MDD from LL & PL	MDD = 1.9481 - 0.00649493 LL - 0.00113083 PL --------(14)	R^2 =0.9283
	From Primary plus(+) Secondary data: Developed equations	
OMC from LL & PL	OMC = 9.743 + 0.226 LL + 0.114 PL ------ --- (15)	R^2= 0.891
MDD from LL & PL	MDD = 1.788- 0.003 LL - 0.004 PL ---------- (16)	R^2= 0.749

3.4 Discussions on the Developed Equations

3.4.1 Discussion on Single linear regression

After carefully evaluating the data on the scatter plot and different models, it was discovered that OMC is highly influenced by LL by achieving a coefficient of determining value (R^2) of 0.897 and 0.879 in primary, and in primary plus(+) secondary data respectively. While, the MDD has a reasonable correlation with LL with a coefficient of determination of 0.868 and 0.7296 in primary plus(+) secondary data, respectively. The results indicated that the MDD provided a good correlation with Liquid limit (LL) and Plastic Limit (PL).

3.4.2 Discussion on Multiple linear regressions

For a summary of multiple linear regressions (Table 3), it showed there is a good correlation between OMC and MDD with LL and PL, rather than correlating the parameters within itself. Generally, the difference in the equations, and on the values of the coefficient of determinant, basically obtained from primary and from primary plus(+) secondary data due to the number of samples used. It can be argued that these factors affected compaction efforts and workmanship. This study, however, showed the existence of a relatively good correlation of the Atterberg's Limits (LL and PL) and compaction characteristics (OMC and MDD) from the test results.

3.3.3 Validation of the developed equations

In this section, the developed equations validated using four (4) control tests. The sample data used for the control test, which are derived from different tests such as compaction, Atterberg's limits, and sieve analysis tests collected from Merkato and Sari's soil sites. Summary of laboratory test results is as follows:

Table 4: Summary of laboratory results for the control test.

No.	Sample name	Atterberg's limits			Compaction characteristics	
		LL	PL	PI	OMC (%)	MDD (g/cm^3)
1	Merkato @ 1m (Control test)	82	41	41	33	1.38
2	Merkato @ 2m (Control test)	88	43	45	34	1.35
3	Saris @ 1m (Control test)	76	39	37	32	1.37
4	Saris @ 2m (Control test)	80	41	39	34	1.34
5	Technic @1m (Control test)	78	38	40	36	1.41
6	Technic @ 2m (Control test)	77	36	41	38	1.43
7	Matric @1m (Control test)	88	44	44	34	1.37
8	Matric @ 2m (Control test)	90	41	49	36	1.33
9	Ajip @ 1m (Control test)	81	37	44	33	1.43
10	Ajip @ 2m (Control test)	83	39	44	36	1.42

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

1) OMC = 9.743 + 0.226 LL + 0.114 PL ----------------(17)

   Where: R^2= 0.891

2) MDD = 1.788- 0.003 LL - 0.004 PL ----------------(18)

   Where: R^2= 0.749

Substituting the values of the PL and PI in the above equations, the OMC and MDD are predicted. By looking at the validation of the developed equations (table 5), it can be seen that the exact values of OMC and MDD cannot be obtained, but a good approximation can be produced.

Table 5: Validation of the developed equation.

Sample location	OMC Actual (%) A	OMC Predicted (%) B	Variation / ((A-B)/A)*100/ (%)	MDD Actual (g/cm^3) C	MDD Predicted (g/cm^3) D	Variation / ((C-D)/C)*100/ (%)
Merkato @ 1m	33	32.95	0.15	1.38	1.39	0.14
Merkato @ 2m	34	34.53	1.57	1.35	1.33	1.12
Saris @ 1m	32	31.37	1.98	1.37	1.40	1.74
Saris @ 2m	34	32.80	4.42	1.34	1.38	2.52
Technic @1m	36	31.70	3.93	1.41	1.40	1.96
Technic @ 2m	38	31.25	2.35	1.43	1.41	2.55
Matric @1m	34	34.65	1.90	1.37	1.35	1.61
Matric @ 2m	36	34.76	3.45	1.33	1.35	1.80
Ajip @ 1m	33	32.27	2.22	1.43	1.40	2.31
Ajip @ 2m	36	32.95	8.48	1.42	1.38	2.61

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Based on the results of the study, it was found that there exist of relationships between the compaction parameters; maximum dry density and optimum moisture content with the liquid limit, plastic limit, and plasticity index. However, the results showed that there was a weak correlation between compaction parameters; maximum dry density and optimum moisture content with plasticity index as compared to liquid limit and plastic limit. Therefore, the Plasticity Index (PI) was not a good predictor for the compaction parameters. Also, It was proven by previous studies undertaken by Tesfamichael et al. (2017), and Atsbea (2012). Besides, it was found that the maximum dry density (MDD) and optimum moisture content (OMC) correlated well with the liquid limit (LL) for a single relationship. In addition, the statistical relationships on the analyses, it can be concluded that multiple relationships are better than a single relationship.

4.2 Recommendation

In this research study, it is observed that there is a strong correlation between Atterberg's limits and compaction characteristics of fine-grained soils found in Jimma town. Likewise, to get a more interesting and reliable correlation in the future,

- It is recommended to collect more data to get a better correlation between the Atterberg's limits and compaction parameters to cover wide ranges in Ethiopia.
- It is recommended develop correlation equations for the soil by clustered or grouped into different ranges of variables such as particle size, compaction parameters, and Atterberg limits.
- It is essential to identify lateritic soil, and the effect of the test procedure should be considered for further study.

The developed model equations relating between the Atterberg's limits and compaction characteristics of soils are a more flexible tool in assessing the suitability of fine-grained soils for some locations, which provides ease of determining the OMC and MDD.

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