

Correlation of Compaction Characteristics with Atterberg Limits for Fine Grained Soils

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Abstract: *Compaction is a process in which the particles of a material, such as soil are compressed to reduce its volume and increase the density. The process often involves applying pressure or mechanical force to the material which forces particles to come closer to each other, reducing the air voids between them. In many Civil Engineering constructions, compaction is commonly used to improve strength, stability and load bearing capacity of soil such as building foundation, roads, highways, airfields, embankments and earthen dam. For conducting this process in laboratory a test called Standard Proctor Compaction and Modified Proctor Compaction are commonly used to determine Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). In large construction projects conducting laboratory test on soil samples from different representative areas/fields takes much time, money and lots of physical efforts. In this paper an effort has been made to conduct the study using Standard Compaction test and tried to develop a correlation of compaction characteristics and Atterberg limits on fine grained soils from central part of India in the state Madhya Pradesh. A total 20 numbers of disturbed soil samples were taken from different trial pits at a depth ranging from 1.0 to 3.0 m. After collecting the samples, samples were taken to CSMRS laboratory for conducting further laboratory tests such as Atterberg Limit, Grain Size Analysis, Specific Gravity and Compaction Test. After conducting these tests, the observed data were analyzed using analytical methods and then correlation of compaction characteristics with Atterberg Limit on soil samples were done using regression analysis. The analysis was done using MS EXCEL software and from the statistical analysis, a good correlation was observed between MDD with LL and OMC with LL. A fair relationship were also observed between OMC with PL and PI and MDD with PL and PI individually.*

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

I.INTRODUCTION

The Geotechnical Engineers are often encounter to handle large amount of soil particularly in case of constructing embankment, highways, roads, dams and building foundations where the soil plays an important role as a construction material. For achieving good bearing capacity, reducing compressibility, minimizing permeability and increasing the shear strength of soil, compaction of soil is very important process in Civil Engineering construction. The process of densifying the soil for various construction purpose have been in existence since long time when the early civilization begun on earth. [1]. To evaluate soil suitability for construction, laboratory compaction tests are performed to determine the maximum dry density

(MDD) and optimum moisture content (OMC). However, these tests are time-consuming and require considerable effort. Instead, Atterberg limits, which define soil consistency and plasticity, provide a simpler means of estimating compaction characteristics.

The suitability of a soil for a large construction project and preliminary assessment of its parameters, the correlation between Atterberg Limits and soil compaction characteristics provides a useful tool. While laboratory compaction tests remain the standard. Atterberg limits offer a quick method to estimate soil behaviors and suitability for construction projects. By utilizing these relationships, geotechnical engineers can optimize soil selection and compaction processes, leading to more efficient and stable infrastructure development.

II. RESEARCH METHODOLOGY

2.1 Study Area

The study was conducted on the representative soil samples collected from central part of India in the state of Madhya Pradesh.

The borrow area locations were identified and representative soil samples were collected from the identified locations. Further laboratory testing was conducted to identify the soil characteristics and other parameters in the lab of CSMRS. The specific location and borrow area trial pits are shown in fig.-1(a) and 1(b). The trial pits were excavated to a depth ranging from 1.0 to 3.0 meter and about 50 Kgs. Samples were taken from each pit and carried to CSMRS laboratory for further lab testing.

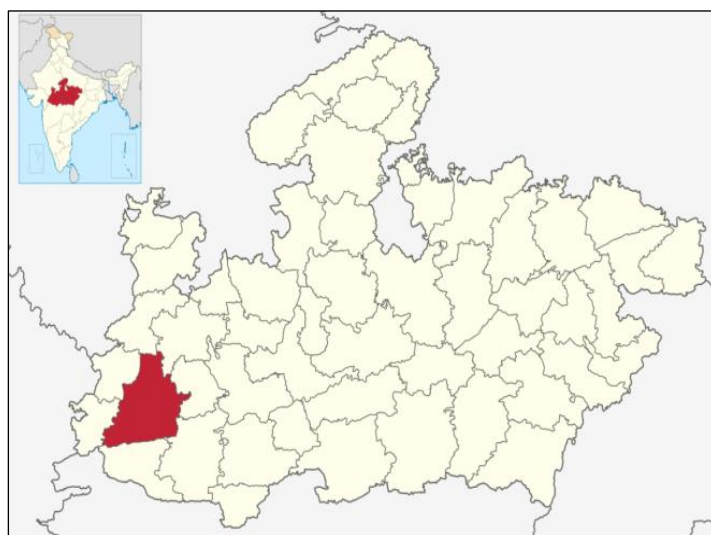


Figure-1(a) Location of Sampling Areas



Figure-1(b) Location of borrows area pits.

2.2 Sources for collection of Data

The essential data required for this study were obtained from the following sources:

1. Primary Sources:
 - Collected samples from each trial pit.
 - Results of various laboratory tests conducted on these samples.
2. Secondary Sources:
 - Relevant Academic Journals and books.

- Books and published articles.
- Reliable websites and online databases.

2.3 Laboratory Tests and Results

A total 20 numbers of laboratory soil samples were selected from particular borrow area locations of certain area of central India and further tested in the Soil Mechanics Laboratory of CSMRS, New Delhi. The tests include Mechanical Analysis, Atterberg Limit, Specific Gravity, Compaction, Consolidation, Permeability, Shrinkage limit and Soil Dispersivity test (Free swell Index, Crumb test and Double Hydrometer Test). However, for conducting this study the test results of Grain size analysis, Specific Gravity, Atterberg Limits and Standard Proctor Compaction Test were utilized.

2.3.1 Grain size Analysis Test (IS: 2720 (Part-4) -1985)

The soil fractions finer than 0.075 mm was determined in accordance with IS: 2720 (Part-4)-1985 “Methods of Tests for Soil (Part-4 Grain Size Analysis).” The test method includes wet sieving of soil particles which are finer than 4.75 mm IS sieve and retained on 75 micron IS sieve. The particle size below 75 micron is determined by Pipette method.

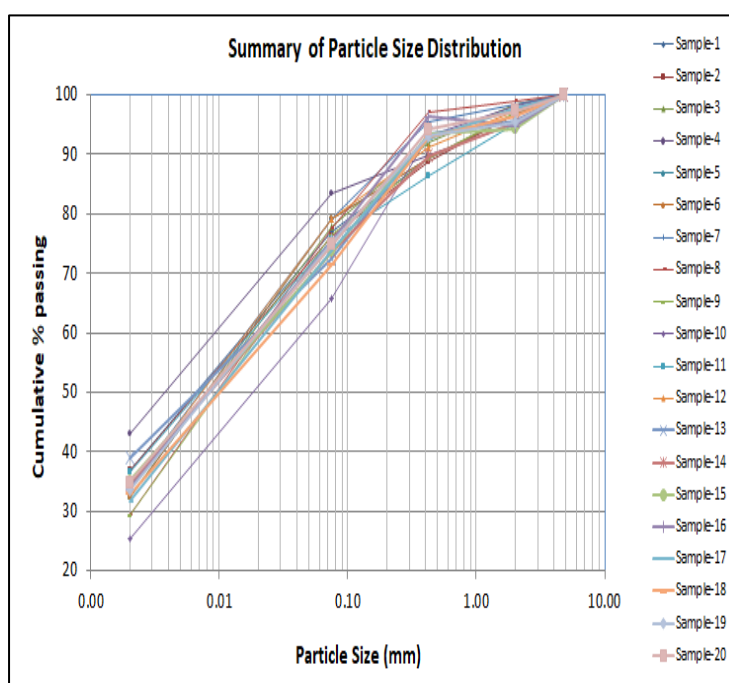


Figure 2: Summary of Particle size distribution curve

2.3.2 Atterberg Limit Tests (IS:2720 (Part-5) -1985)

The liquid limit test for each type of soil is determined accordance with IS: 2720 (Part-5)-1985 “Determination of Liquid and Plastic Limit”

2.3.3 Standard Proctor Compaction Test (IS: 2720 (Part- 7) - 1980)

Dry Density-Moisture content Relationships: The soil samples retrieved from each borrow area locations were initially air dried and then sieved through 4.75 mm IS sieve for testing in IS light compaction machine with mould diameter of 100 mm and capacity of 1000 cm³. The soil samples were placed in the mould in three numbers of layers and each layer was compacted by giving 25 numbers of blows with hammer of 2.60 kg. and 310 mm height of fall. The standard test procedure was followed as per IS:2720 (Part-7)-1980 “Determination of Water Content-Dry Density Relation using Light Compaction”. After compacting each soil samples with incremental percentage increase of water, weight of compacted soil in the mould was taken and bulk density were calculated followed by determining the moisture content of soil by oven drying method for each repetitive steps of compaction process according to IS:2720 (Part-II)-1973 “Methods of Test for Soil-Determination of Water Content.”

Finally, the maximum dry unit weight and corresponding optimum moisture content were computed by plotting the compaction graph representing percentage moisture content on abscissa and dry density as ordinate.

Table 1: Summary of all laboratory results

S. No.	Lab Sample No.	Depth (m)	Soil Classification	Atterberg Limit			Compaction Characteristics		
				LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cc)	MDD (Kg/cum)
1	Sample-1	1.0-3.0 m	CI	49.30	23.45	25.85	18.20	1.723	1723
2	Sample-2	1.0-3.0 m	CI	44.85	21.24	23.61	17.81	1.678	1678
3	Sample-3	1.0-3.0 m	CI	41.30	20.35	20.95	17.60	1.655	1655
4	Sample-4	1.0-3.0 m	CH	58.00	25.65	32.35	18.76	1.770	1770
5	Sample-5	1.0-3.0 m	CI	46.80	22.45	24.35	17.95	1.695	1695
6	Sample-6	1.0-3.0 m	CI	38.85	20.16	18.69	17.45	1.645	1645
7	Sample-7	1.0-3.0 m	CI	42.10	20.95	21.15	17.58	1.668	1668
8	Sample-8	1.0-3.0 m	CI	36.30	18.78	17.52	17.20	1.631	1631
9	Sample-9	1.0-3.0 m	CI	48.60	23.19	25.41	18.20	1.712	1712
10	Sample-10	1.0-3.0 m	CI	42.80	21.54	21.26	17.80	1.688	1688
11	Sample-11	1.0-3.0 m	CI	48.10	21.69	26.41	18.10	1.709	1709
12	Sample-12	1.0-3.0 m	CI	44.75	22.15	22.60	17.86	1.695	1695
13	Sample-13	1.0-3.0 m	CH	53.60	24.15	29.45	18.38	1.742	1742
14	Sample-14	1.0-3.0 m	CH	52.90	23.85	29.05	18.35	1.723	1723
15	Sample-15	1.0-3.0 m	CH	51.78	23.78	28.00	18.32	1.729	1729
16	Sample-16	1.0-3.0 m	CH	52.35	23.56	28.79	18.26	1.740	1740
17	Sample-17	1.0-3.0 m	CH	53.45	23.56	29.89	18.39	1.740	1740
18	Sample-18	1.0-3.0 m	CH	54.38	24.42	29.96	18.48	1.756	1756
19	Sample-19	1.0-3.0 m	CH	53.89	23.83	30.06	18.42	1.750	1750
20	Sample-20	1.0-3.0 m	CH	51.56	23.68	27.88	18.23	1.735	1735

III. ANALYSIS, RESULTS AND DISCUSSION

3.1 General

Correlation is a statistical technique used to determine and analyze the relationship between two variables. In graphical analysis, correlation technique help visualize the degree and direction of association between these variables.

Correlation Analysis involves various methods and techniques used for studying and measuring the extent of the relationship between the two variables. Graphical method of correlation analysis involves:

1. Scatter Plot (scatter diagram): In this a graphical representation of two variables plotted on the X and Y axis. The pattern of data points helps determine the strength and direction of correlation:

- Positive Correlation: If the point slope upward from left to right
- Negative Correlation: If the point slope downward from left to right
- No Correlation: If the points are scattered randomly without a clear trend.

2. Line of Best Fit (Trend Line):_A straight or curved line drawn through the data points in a scatter plot. It indicates the overall trend of the relationship between the two variables.

3. A regression model is a type of statistical or machine learning model used to estimate the relationships between variables and predict continuous outcomes. It analyses how a dependent variable (target) changes in relation to one or more independent variables (features). Alternatively, Regression model containing one independent variable or regressor is termed as a simple regression model.

Scatter plot: For developing the correlations, the first step is to create a scatter plot of the data, to visually assess the strength and the form of some type of relationship. 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 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.

The scatter plot of MDD with LL, PL, and PI, and OMC with LL, PL and PI for the 20 numbers of selected soil sample data were done and the plots are presented below:

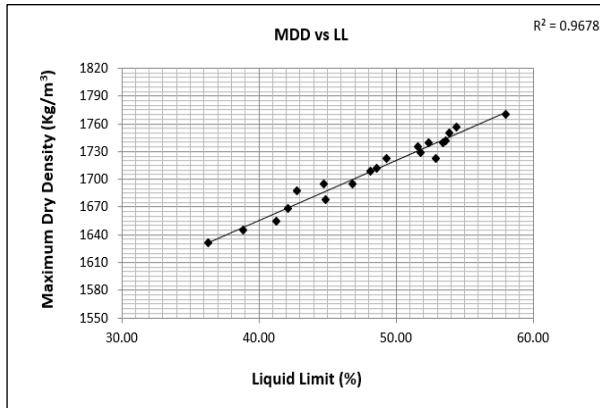


Figure 3.1: Scatter plot of MDD vs. LL

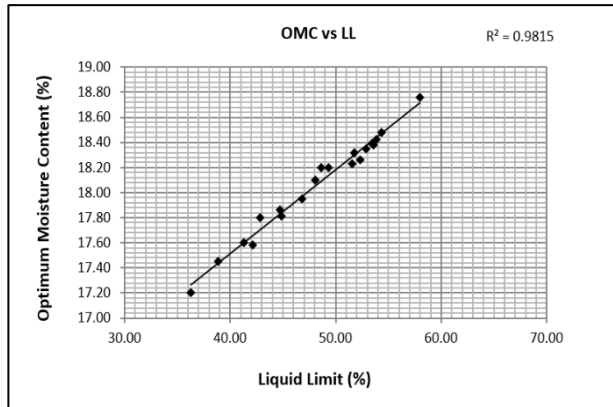


Figure 3.4: Scatter plot of OMC vs. LL

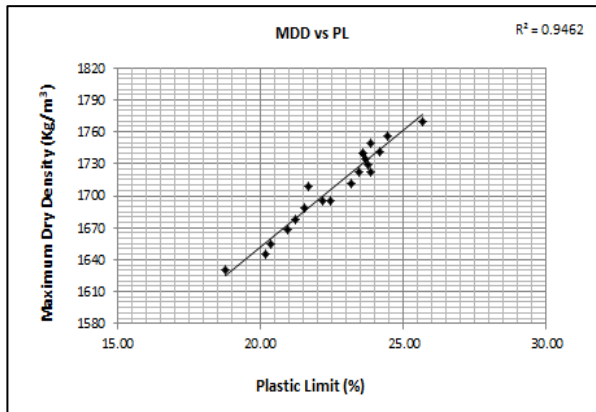


Figure 3.2: Scatter plot of MDD vs. PL

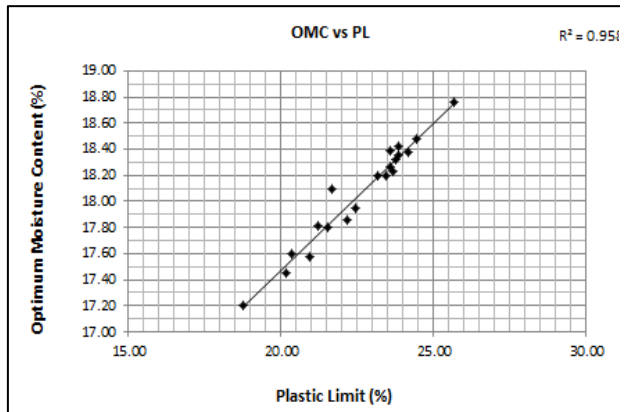


Figure 3.5: Scatter plot of OMC vs. PL

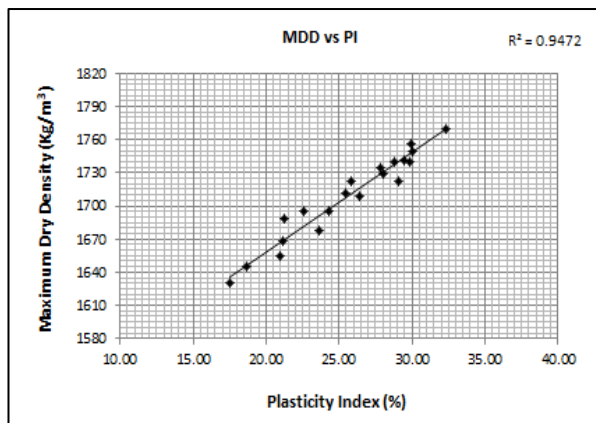


Figure 3.3: Scatter plot of MDD vs. PI

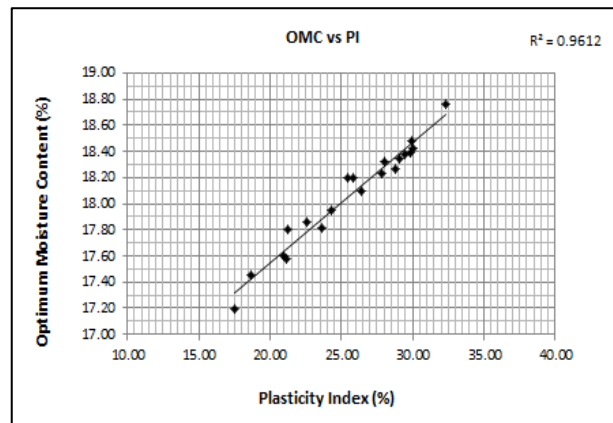


Figure 3.6: Scatter plot of OMC vs. PI

3.2 Regression Analysis:

3.2.1 Simple linear regression: The analysis confirms a linear relationship between independent and dependent variables, represented by a best-fit regression equation. The adequacy of the model is validated by coefficient of determination (R^2), which indicates how effectively the independent variable explains the variations in the dependent variable. Statistically significant regression coefficients demonstrate the reliability of the model, enabling accurate prediction within the tested range. Overall, simple linear regression provides clear, quantitative bases for trend identification and result interpretation.

Table 2: Summary of simple linear regression analysis

Regression	From the selected data
OMC from LL	$0.067 LL + 14.831 ; R^2 = 0.9815$
OMC from PL	$0.2269 PL + 12.935 ; R^2 = 0.9581$
OMC from PI	$0.0923 PI + 15.70 ; R^2 = 0.9612$
MDD from LL	$6.5031 LL + 1395.2 ; R^2 = 0.9678$
MDD from PL	$22.026 PL + 1210.9 ; R^2 = 0.9462$
MDD from PI	$8.9471 PI + 1479.6 ; R^2 = 0.9472$

3.2.2 Discussion on Simple linear regression

The study of scatter plots with different models indicates (Table-2) that Optimum Moisture content (OMC) is highly influenced by the Liquid Limit, with coefficient of determination (R^2) of 0.9815 using selected data. Similarly maximum dry density (MDD) shows a strong correlation with LL, achieving (R^2) value of 0.9678 for the selected data. The correlation between OMC and MDD with the Plastic Limit (PL) and Plasticity Index (PI) resulted in good relationships, indicating these parameters possessing quite strong predictors in this case.

3.2.3 Validation of the developed equations

The validation of developed equation was checked correctly by another five samples. The data from this test is used to confirm the result conducting different tests such as compaction, Atterberg limits. The Summary of a laboratory result for is as follows:

Table 3: Summary of Laboratory results for validation study

S. No.	Lab Sample No.	Depth (m)	Soil Classification	Atterberg Limit			Compaction Characteristics		
				LL (%)	PL (%)	PI (%)	OMC (%)	MDD (g/cc)	MDD (Kg/cum)
1	Sample-21	1.0-3.0	CI	41.20	20.02	21.18	19.60	1.67	1670
2	Sample-22	1.0-3.0	CI	41.00	19.98	21.02	19.20	1.69	1690
3	Sample-23	1.0-3.2	CI	38.55	17.87	20.68	18.50	1.73	1730
4	Sample-24	1.0-3.3	CI	40.20	18.16	22.04	18.90	1.71	1710
5	Sample-25	1.0-3.4	CI	40.70	21.10	19.60	19.40	1.69	1690

Among the developed equations of OMC and MDD corresponding to LL 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 for dependent variable.

1. $OMC = 0.067 \times LL + 14.831 ; R^2 = 0.9815$
2. $MDD = 6.5031 \times LL + 1395.2 ; R^2 = 0.9678$

Table 4: Validation of OMC and MDD based on the Developed Equation

Lab Sample No.	OMC Predicted (%)	OMC Actual (%)	Accuracy of predicted model (%)	MDD Predicted (Kg/cum)	MDD Actual (Kg/cum)	Accuracy of predicted model (%)
Sample-21	17.6	19.6	89.7	1663.1	1670.0	99.6
Sample-22	17.6	19.2	91.6	1661.8	1690.0	98.3
Sample-23	17.4	18.5	94.1	1645.9	1730.0	95.1
Sample-24	17.5	18.9	92.7	1656.6	1710.0	96.9
Sample-25	17.6	19.4	90.5	1659.9	1690.0	98.2
Average	17.5	19.1	91.7	1657.5	1698.0	97.6

Based on the above results, the accuracy of predicted model for optimum moisture content corresponding to liquid limit is 91.7% and for maximum dry density corresponding to the liquid limit is 97.6%. It can also be said that the exact values of optimum moisture content and maximum dry density may not be directly obtained from the developed equation but it could provide a quite reliable approximation.

IV. CONCLUSION

The results of this study demonstrate the feasibility of predicting the compaction characteristics of fine-grained soils with varying proportions of fines. Statistical analysis and discussion indicate a relatively significant correlation between Optimum Moisture Content (OMC) and Liquid Limit (LL). Additionally, a strong correlation is observed between Maximum Dry Density (MDD) and Liquid Limit (LL). And from the regression analysis the following model were found to work satisfactory.

$$\text{OMC} = 0.067 \times \text{LL} + 14.831; R^2 = 0.9815$$

$$\text{MDD} = 6.5031 \times \text{LL} + 1395.2; R^2 = 0.9678$$

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