Correlation of Maximum Laboratory Dry Density and Optimum Moisture Content of Soil with Soil Parameters

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ABSTRACT

The correlation of compaction properties of soil with various soil parameters are investigated in this study. These correlations were derived through graphically analysis. Soils samples were collected from ten cities of Punjab, Pakistan. The maximum dry density and optimum moisture content (O.M.C) are the compaction properties of soil, which is related to many of soil parameters that included Atterberg index (liquid limit (LL), plastic limit (PL), and plastic index (PI)), percentage of fines (silt, sand), coefficient of uniformity (Cu) and coefficient of curvature (Cc). The relationship of maximum dry density and percentage of fines (silt, sand), optimum moisture content and percentage of fines are the most important relations. These relationships provide a key role in the construction of highways. The effect on the maximum dry density of various kinds of soil, quantity of fines, and types of fines and distribution of the grain size become decided through a sensitivity evaluation that measured the effect of those parameters on acquired maximum dry density By measuring these correlations some unique behavioral developments have been analyzed and we conclude that properly graded soils have better dry density than poorly graded when the soils have the equal fines content, further it became discovered that plastic fines have a tendency to boom the maximum dry density.

Keywords: Maximum Dry Density, Optimum Moisture Content (O.M.C), Liquid Limit (LL), Plastic Limit (PL), Plastic Index (PI), Coefficient of Uniformity (Cu), Coefficient of Curvature (Cc).

I. INTRODUCTION

In this study the basic attempt is to develop relationship between soil type and its compaction characteristics of a soil by just carrying out gradation analysis or visual observation. This relation can provide a quick reference of density and soil type. The main purpose of this research is to investigate possible correlations between maximum laboratory dry density, optimum moisture content (O.M.C), coefficient of uniformity (Cu), coefficient of curvature (Cc), plastic limit, liquid limit, plastic index, percentage of sand content and silt content. The availability of correlations between the tests results would reduce the effort and cost by guessing with confidence any compaction properties. In this research, different tests were carried out such that sieve analysis, hydrometer analysis, specific gravity, liquid limit, plastic limit and modified proctor compaction test. The test results are used to evaluate the different soil properties required for investigation of possible correlations between them.

In general compaction is the process in which lessening in volume happens by removal of water under long haul static burdens. It happens when stress is connected to a soil that makes the soil particles pack together all the more firmly, thusly diminishing its mass volume. When this happens in a soil that is immersed with water, water will be pressed out of the soil [1, 3].

Exactly when stress is leaved from a consolidated soil, the soil will bob back; in the consolidation procedure the lost portion of soil volume is recovered. Recompression curve is achieved as describe by recompression index along with consolidation of soil when the stress is applied again. The soil known as over consolidated when load is removed which it had, for example the glaciers on soil before removing. The greatest stress that the soil has supported in past is known as the pre-consolidation stress. [2, 4]

The process of increasing density of soil or unit weight of soil by lessening in air volume is named as compaction, water content usually don’t be altered [17]. The dry density of soil is used to measure the level of compaction too, normally rely on water content and compactive effort (number of blows, weight of hammer, height of free fall, and number of layers). Maximum dry density is achieved at the optimum moisture content. Compaction can be associated with upgrade the properties of a present soil, i.e extend shear quality and bearing breaking point. Extend solidness and along these lines diminish future settlement. [5, 6]

The dry density of soil is more when it consist of different sizes of particles but if it have same size of particles then its dry density might be lower [16]. The dry density of soil is also depends on shape and arrangement of particles which decide...
porosity. Porosity is the amount of air present between the soil particles. More porosity results in lower density. So, it is inversely proportion in relation with density. Rather than porosity, soil texture and organic matter content is also effect the density. If the organic matter content is more in soil, they result in high porosity or void space that causes lower in density of soil. [7]

For the prediction of compaction properties of soil some prediction equations can be established in the literature based on different geotechnical properties such as liquid limit (LL), plastic limit (PL), plasticity (PI) and grain size. Based on compaction results from 10 soils including both natural soils and commercially available soils, Sridharan & Nagaraj et al. developed the prediction model for standard proctor test using only plastic limit [8].

$$\text{Max. Dry Density} = 0.23(93.3-\text{PL})$$  \hspace{0.5cm} (1)

$$O.M.C = 0.92 \text{ (Plastic limit)}$$  \hspace{0.5cm} (2)

On the other hand based on compaction results of 22 clayey soils, Blotzet al. [9] observed that the compaction properties were best correlated with liquid limit and thus introducing the following relationships:

$$\text{MDD} = 17 - 0.16 \text{ LL} + (2.27 \log \text{ LL} - 0.94) \log \text{E}$$  \hspace{0.5cm} (3)

$$O.M.C = 9.2 + 0.67 \text{ LL} + (12.39 - 12.21 \log \text{ LL}) \log \text{E}$$  \hspace{0.5cm} (4)

Where ‘E’ is the compaction energy.

Noor et al. [10] correlated the specific gravity plastic limit and plasticity index to predict the compaction properties and introducing the following relationship:

$$\text{MDD} = 27 - 0.66 \text{ PL}^{0.4} - (1.33 \log \text{G}/2.7$$  \hspace{0.5cm} (5)

$$O.M.C = 0.55 \text{ PL} - 0.36 \text{ PI} - (1.27 \log \text{G}/2.7$$  \hspace{0.5cm} (6)

Hannah & Gnanananda et al. [11] based on compaction results of nine soils including both natural soils and commercially available soils, developed the prediction modeling only plastic limit:

$$O.M.C = 12.001e^{0.0181\text{PL}}$$  \hspace{0.5cm} (7)

K.S Ng et al. [12] developed the prediction model based on the nine soil samples were collected from various sites and thus introducing the following relationship:

$$O.M.C = 1.204\text{PL} - 16.98$$  \hspace{0.5cm} (8)

$$O.M.C = 0.868\text{LL} - 21.61$$  \hspace{0.5cm} (9)

$$O.M.C = 2.72\text{PL} - 27.19$$  \hspace{0.5cm} (10)

$$\text{MDD} = -0.031\text{PL} + 2.537$$  \hspace{0.5cm} (11)

$$\text{MDD} = -0.023\text{LL} + 2.669$$  \hspace{0.5cm} (12)

$$\text{MDD} = -0.073\text{PI} + 2.845$$  \hspace{0.5cm} (13)

The purpose of the this study is to establish few predictive equation based on graphical analysis to roughly estimation of maximum dry density and optimum moisture content without performing standard proctor test.

II. MATERIALS AND METHOD

The research is done on different soil samples. Soil samples from ten different places - Faisalabad (FSD), Sargodha (SRD), Hafizabad (HZF), Chiniot (CHT), Rahim-Yar-Khan (RYK), PindiBhattian (P.B), Bhawalpur (BWP), Jhang (JHN), MianChannu (MC) and Okara (OKR) of Punjab province were extracted for performing tests such as sieves analysis, hydrometer analysis, liquid limit, plastic limit, specific gravity and modified proctor compaction test. Following experiments were performed for determining properties of soil samples taken from above mentioned places. Standard followed for the determination of sieve analysis and hydrometer analysis are (ASTM D 422-63 and ASTM D 422-63) respectively [13]. Liquid limit of soils (ASTM D 4318) and Plastic limits of soil (ASTM D 4318) [14]. These stated codes covers the determination of the liquid limit, plastic limit and plasticity index of soils. From all of measured parameters the most important test is compaction test (Modified AASHTO) (ASTM D 1557) [15].

III. RESULTS AND DISCUSSION

Different test were performed on the different soils samples and results are listed in Table 1. Others test like specific gravity, relative density, liquid limit, plastic limit and moisture content determination were performed in lab in accordance with the ASTM standards.

The soil having plasticity index between 0-3 are classified as non-plastic and the soil having P.I between 3-15 are classified as slightly plastic. Out of ten sample, nine are classified as slightly plastic and one sample is non-plastic. We observed that silt content increases with increasing depth of soil. However, subgrade soil should be taken from a large depth up to 5-10ft. We took our nine (9) soils samples from 3ft depth having less silt content and one sample from 6 feet depth which have maximum 44% silt content. Silt content increased with increase of depth of soil as a result maximum dry density increase.
## Table 1: Properties of Soils

<table>
<thead>
<tr>
<th>Sample City</th>
<th>FSD</th>
<th>SRD</th>
<th>HFZ</th>
<th>CHF</th>
<th>R.Y.K</th>
<th>P.B</th>
<th>BWP</th>
<th>JHNG</th>
<th>M.C</th>
<th>OKR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ce</td>
<td>0.53</td>
<td>0.56</td>
<td>0.44</td>
<td>0.50</td>
<td>0.65</td>
<td>0.50</td>
<td>0.52</td>
<td>0.57</td>
<td>0.60</td>
<td>0.64</td>
</tr>
<tr>
<td>Cu</td>
<td>8.08</td>
<td>10.90</td>
<td>0.41</td>
<td>3.24</td>
<td>4.25</td>
<td>5.90</td>
<td>3.00</td>
<td>1.50</td>
<td>1.00</td>
<td>0.52</td>
</tr>
<tr>
<td>% of Silt</td>
<td>19.20</td>
<td>9.20</td>
<td>3.00</td>
<td>37.80</td>
<td>3.10</td>
<td>11.50</td>
<td>13.00</td>
<td>23.30</td>
<td>44.90</td>
<td>12.23</td>
</tr>
<tr>
<td>% of Sand</td>
<td>80.85</td>
<td>90.30</td>
<td>97.00</td>
<td>62.20</td>
<td>96.90</td>
<td>88.50</td>
<td>87.00</td>
<td>76.70</td>
<td>55.10</td>
<td>87.77</td>
</tr>
<tr>
<td>PI</td>
<td>5.40</td>
<td>5.85</td>
<td>8.24</td>
<td>4.20</td>
<td>6.27</td>
<td>7.52</td>
<td>6.70</td>
<td>6.10</td>
<td>4.47</td>
<td>6.63</td>
</tr>
<tr>
<td>LL (%)</td>
<td>23.85</td>
<td>21.35</td>
<td>21.09</td>
<td>25.45</td>
<td>22.25</td>
<td>20.05</td>
<td>20.85</td>
<td>23.99</td>
<td>24.92</td>
<td>22.08</td>
</tr>
<tr>
<td>O.M.C (%)</td>
<td>11.75</td>
<td>10.85</td>
<td>10.20</td>
<td>13.35</td>
<td>10.75</td>
<td>12.05</td>
<td>12.85</td>
<td>13.35</td>
<td>15.45</td>
<td>12.23</td>
</tr>
<tr>
<td>MDD (g/cc)</td>
<td>2.58</td>
<td>2.55</td>
<td>2.68</td>
<td>2.67</td>
<td>2.52</td>
<td>2.65</td>
<td>2.72</td>
<td>2.71</td>
<td>2.65</td>
<td>2.62</td>
</tr>
</tbody>
</table>

### A. Correlations of dry densities with various parameters

#### a) Relationship between dry density and silt content

To establish the relationship between maximum laboratory dry density and percentage of silt content, a curve between these two variables was drawn. The graph shows that there is an increase in maximum dry density with an increase in silt content. So, for achieving maximum density on field use soil that has maximum silt content. Greater the silt content more will be the dry density.

**Fig. 2. Silt quantity and dry density relation**

\[
\frac{y}{0.0022x + 1.9768}
\]

\[R^2 = 0.9207\]

#### b) Relationship between dry density and sand content

Sand are those particles that are greater than 0.075mm and less than 4.75mm in size. Maximum laboratory dry density decreases with an increase in percentage of sand content and it is inversely proportional to sand content. So, use that soil for subgrade which has minimum sand content to achieve the maximum dry density. Soil having large amount of sand content should be avoided as far as possible.

**Fig. 3. Sand quantity and dry density relation**

\[
\frac{y}{-0.0022x + 2.1919}
\]

\[R^2 = 0.9207\]

#### c) Relationship between dry density and liquid limit

Liquid limit is moisture content below which soils behaves as a plastic material. The maximum laboratory dry density increases with the increase of liquid limit. So, the maximum dry density is directly proportional to liquid limit, as shown in figure 4.

**Fig. 4. Liquid limit and dry density relation**

\[
\frac{y}{0.0022x + 1.9768}
\]

\[R^2 = 0.9207\]
d) Relationship between dry density and plastic limit

Plastic limit is moisture content below which soil is behaves as non-plastic. The maximum laboratory dry density decreases with the increase of Plastic limit. So, the maximum dry density is inversely proportion to Plastic limit, as shown in figure 5.

\[
\text{y} = 0.0098x + 1.8541 \\
R^2 = 0.8684
\]

Fig. 5. Dry density and plastic limit relation

Plasticity index is the difference between the liquid limit and plastic limit. The maximum laboratory dry density increased with the increase of Plasticity index. So, the maximum dry density is directly proportion to plasticity index, as shown in figure 6.

\[
\text{y} = 0.0153x + 1.6702 \\
R^2 = 0.8014
\]

\[
\text{y} = 0.0025x + 1.9664 \\
R^2 = 0.8476
\]

\[
\text{y} = -0.0228x + 2.1552 \\
R^2 = 0.829
\]

\[
\text{y} = 0.0076x + 1.9623 \\
R^2 = 0.8344
\]

Fig. 4. Liquid limit and dry density relation

We concluded from above seven co-relations that the best and most accurate relation for maximum dry density is with the silt content. Equation of this relation is as under,

\[
\text{Maximum dry density} = 1.99 + 0.0018 \text{ (Silt Content)} \quad (14)
\]

having the greatest factor value $R^2=0.92$. This equation was become known to very useful in predicting the maximum dry density of soils in field. Silt contents are the particles passing through standard sieve #200 having size less 0.075mm.

B. Correlations of optimum moisture content (O.M.C) with different soil parameters

a) Relationship between O.M.C and liquid limit

The optimum moisture content increased with the increase of liquid limit. So, the O.M.C is directly proportion to liquid limit, as shown in figure 9.
b) Relationship between O.M.C and coefficient of curvature

The optimum moisture content increases with the increase of coefficient of curvature. So, the O.M.C is directly proportion to coefficient of curvature, as shown in figure 10.

\[ y = 2.0627x + 9.6066 \quad R^2 = 0.8128 \]

Fig. 10. Cc and O.M.C relation

c) Relationship between O.M.C and coefficient of uniformity

The optimum moisture content increases with the increase of coefficient of uniformity. So, the O.M.C is directly proportion to coefficient of uniformity, as shown in figure 11.

\[ y = 0.0907x + 9.7533 \quad R^2 = 0.8273 \]

Fig. 11. Cu and O.M.C relation

d) Relationship between O.M.C and plastic limit

The optimum moisture content increased with the increases of plastic limit. So, the O.M.C is directly proportion to plastic limit, as shown in figure 12.

\[ y = 0.6625x + 5.53 \quad R^2 = 0.9053 \]

Fig. 12. Plastic limit and O.M.C relation

e) Relationship between O.M.C and plasticity Index

The optimum moisture content decreased with the increase of plastic index. So, the O.M.C is directly proportion to plastic index, as shown in figure 13.

Subfigures for figures 9, 10, 11, and 12 are not provided in the text, but they would typically show plots of the relationships described.

Correlations were developed for the Cc, Cu, Liquid limit, Plastic limit and Plasticity index with optimum moisture content, from where we observed that the best and accurate relation of optimum moisture content is with liquid limit. Equation of this relation is

\[ O.M.C = 5.53 + 0.662 \times \text{Plastic Limit} \quad (15) \]

The factor value of \( R^2 = 0.905 \). This value indicates that the correlation with plastic limit is highly significant rather than liquid limit, plasticity index, Cc and Cu. The equation (2) & (7) developed by Sridharan & Nagaraj et al. [8] and K.H Jyothirmayi et al [11] gave almost same result.

IV. CONCLUSION

This investigation has provided useful information about the engineering properties of soil and compaction. It is concluded that maximum correlation can be achieved by putting more efforts in individual soil groups or those within a limited geographic area. In this study, many helpful equations have been developed. So, any prediction situation can be assured by the accuracy of those equations. In soil mechanics and others related fields; this research is a serviceable tool.

Compaction properties maximum dry density and optimum moisture content are very important properties used for the compaction control in field. In this study many correlation are investigated based on the experimental results. These relations can be helpful in the construction of roads and highway sub-
grade material. Many conclusions can be made from this study:

1) Maximum dry density was well correlated with percentage of silt content.

\[ MDD = 1.9768 + 0.0022 \times \text{(\% of Silt content)} \]

With \( R^2 = 0.92 \)

2) Optimum moisture content was best correlated with plastic limit.

\[ O.M.C = 5.53 + 0.662 \times \text{(Plastic Limit)} \]

With \( R^2 = 0.905 \)

The same scenario are discussed by K. H Jyothirmayi et al. [11] and Sridharan & Nagaraj et al. [8]

REFERENCES


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