Correlation Analysis of Geotechnical Soil Parameters: A Case Study in Koya

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Abstract

This paper explores the relationship between liquid and or plastic limits and the compaction characteristics, maximum dry density, and optimum moisture content (OMC) of fine-grained soils. Previous studies have attempted to determine these parameters using simpler soil properties like index soil properties. Some studies found a strong correlation between liquid limit and compaction characteristics, while others observed a correlation with plastic limit. In this research, numerous soil samples were collected from different locations in Koya city, and the necessary tests were conducted. The results were analyzed to determine whether soil index properties could be correlated with compaction characteristics. The findings indicate that neither plastic limit nor liquid limit adequately correlate with maximum dry density and OMC. Surprisingly, contrary to existing literature, liquid limit demonstrates better correlations in this study.

***Key Word*:** Soil properties, maximum dry density, optimum moisture content

1- Introduction

Soil compaction is a necessary process to enhance soil stability by applying mechanical force to densely pack soil particles together. This increases the soil density by reducing the voids between particles, thereby improving soil properties. Consequently, it leads to increased shear strength, modifications in volume change characteristics, reduced settlement, and lower hydraulic conductivity of the soil. In the field, heavy mechanical machinery is typically employed for soil compaction during the construction of earth structures like embankments. Assessing the suitability of the soil in terms of compaction characteristics is crucial for such projects. The compaction characteristics of a soil, namely the maximum dry density (γd max) and optimum moisture content (OMC), are determined through laboratory tests such as the Standard Proctor Test or Modified Proctor Test. The laboratory data on compaction characteristics are then utilized to quantify the degree of compaction for natural soil materials at a satisfactory level (Budhu, 2015, and Powrie, 2014).

While laboratory compaction tests provide a straightforward method for determining compaction parameters, they can be time-consuming due to the requirement of large soil quantities for testing, especially in projects like embankments and roads. Obtaining the specific type of soil needed for testing in a particular area can also pose challenges. It is crucial to assess the suitability of the soil for the intended purpose, but the delay in obtaining test results can have adverse effects on project timelines and the search for suitable soil sources. Therefore, it can be advantageous to utilize correlations between compaction parameters and simpler soil index properties to conduct a preliminary assessment of soil suitability for a specific project (Pillai and Vinod, 2015).

Numerous efforts have been made to establish a correlation between compaction characteristics and the plasticity of soil. Previous studies by McRae (1958), Daniel and Benson (1990), Daniel and Wu (1993), Benson and Trast (1995), Blotz et al. (1998), Gurtug and Sridharan (2004), and Sridharan and Nagaraj (2005) have explored this relationship. Figure 1 illustrates the relationship between the optimum moisture content (OMC) and liquid limit (wL). The plot demonstrates that an increase in wL results in an increase in OMC. However, notable data scatter is evident, particularly at higher values of liquid limit

Similarly, Figure 2 presents a plot depicting the relationship between the maximum dry density (γd max) and liquid limit. It shows a decrease in γd max with an increase in wL, again with a considerable amount of data scatter.

Figure 3 depicts the correlation between the optimum moisture content (OMC) and plastic limit (wP). It is observed that there is a consistent increasing trend in OMC as the plastic limit (wP) increases.

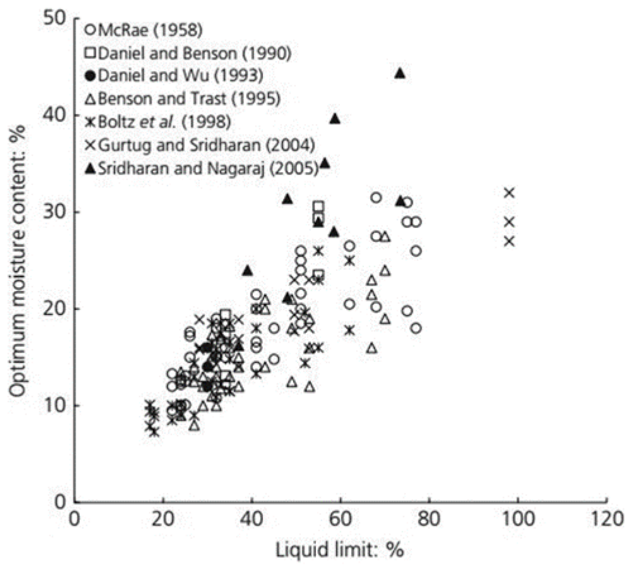

Figure 1: The relationship between optimum moisture content and liquid limit for studies from literature

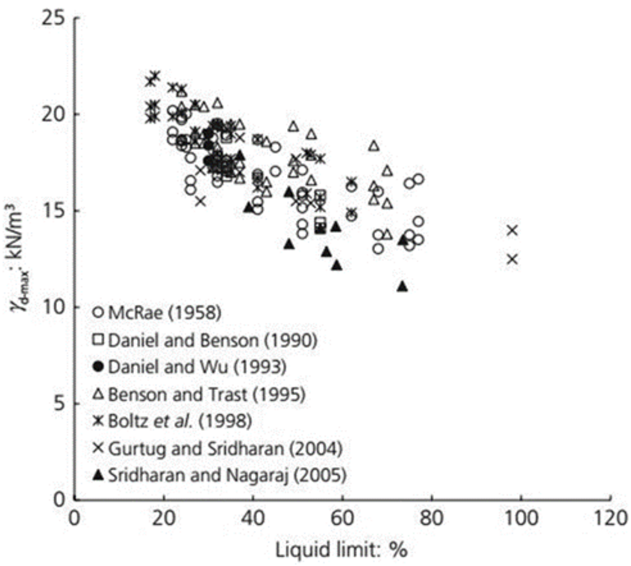

Figure 2: The relationship between maximum dry unit weight and liquid limit for studies from literature

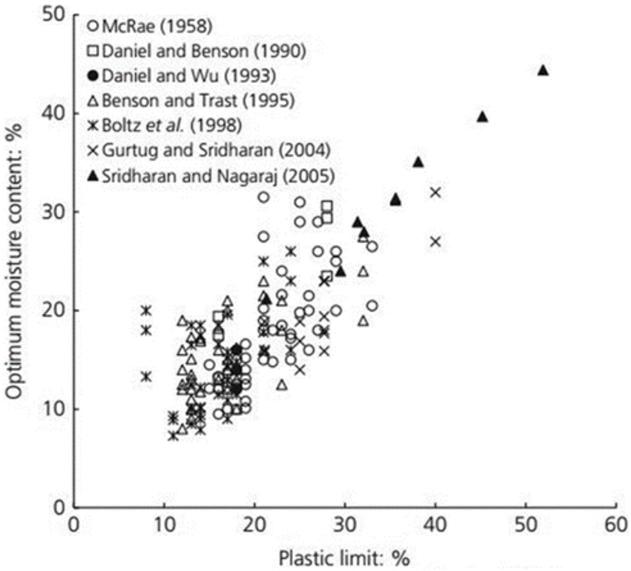

Figure 3: The relationship between optimum moisture content and plastic limit for studies from literature

$$OMC = 0.92\ W_p \qquad (1)$$

$$\gamma_{d\ max} = 0.23\ (93.3 - W_p) \quad (2)$$

They also expressed the best-fitted curve for the relationship between wL – OMC and wL – γ_{dmax} as follows:

$$OMC = 0.37\ (W_L + 12.46) \qquad (3)$$

$$\gamma_{d\ max} = 0.09\ (218 - W_L) \qquad (4)$$

Figures 4 and 5 display the relationship between plastic limit (wP) and optimum moisture content (OMC), as well as between plastic limit (wP) and maximum dry density (γd max), respectively. Although some scatter is still noticeable, the findings suggest that plastic limit (wP) may exhibit a strong correlation with the compaction characteristics in this study.

Nerea (2012) also emphasized the potential for plastic limit to correlate well with compaction characteristics when compared to liquid limit and plasticity index for a specific soil type. It was suggested that plastic limit alone could be used to determine the compaction characteristics. Similarly, Tsegaye et al. (2017) reported a relatively good correlation between OMC and wP, as well as between γd max and both wL and wP combined in the plasticity index.

However, Horpibulsuk et al. (2008) and Pillai and Vinod (2015) concluded that accurately predicting compaction characteristics of fine-grained soil cannot be achieved by considering only one index property (wL or wP). Prasanna et al. (2017) incorporated both wL and wP to establish a strong correlation and achieve more accurate results.

Hence, this study aims to examine samples from various locations to determine whether soil index properties such as plastic limit and liquid limit exhibit significant correlations with the compaction characteristics of fine-grained soils. The objective is to determine which index properties offer stronger correlations compared to others when assessing compaction characteristics.

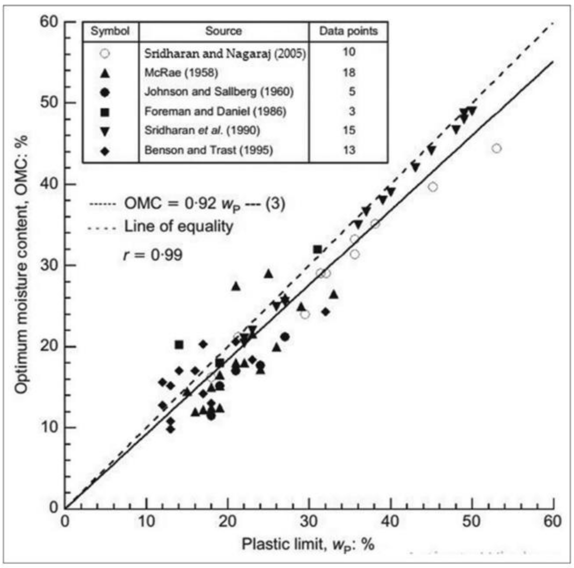

Figure 4: The relationship between optimum moisture content and plastic limit for studies from literature

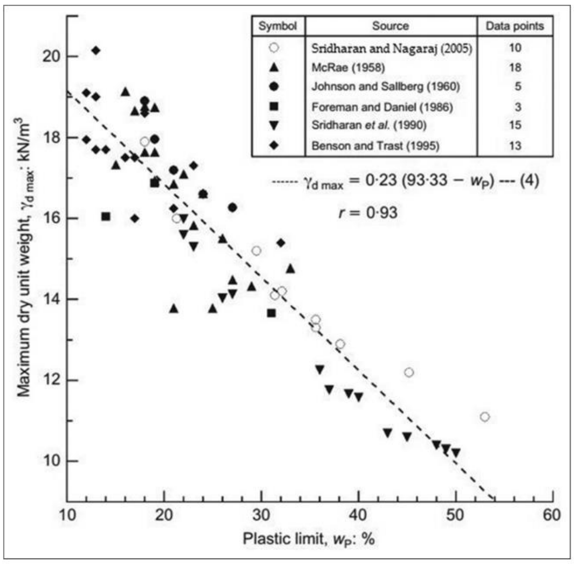

Figure 5: The relationship between maximum dry unit weight and plastic limit for studies from literature

2- Methodology

To achieve the objectives of this study, a total of 27 soil samples were collected from various locations in Koya city. These samples were then transported to the Geotechnical Laboratory at the College of Engineering, Koya University. Approximately 50 kg of disturbed samples were obtained from each pit at depths ranging from 0.50 m to 1.00 m.

Subsequently, sieve analyses were conducted to determine the grain size distribution of the collected samples. Wet sieving analysis (ASTM D2217) was employed to ensure accurate grain size measurements.

The liquid limit, plastic limit, and plasticity index of each soil sample were determined in accordance with ASTM D4318 (Standard Test Method for liquid limit, plastic limit, and plasticity index of soils). The liquid limit test was conducted using the Casagrande apparatus method, with three trials performed for each sample. The plastic limit test utilized the conventional plastic limit test method, with three trials conducted as well.

Following the plasticity tests, each sample was sieved over a 4.75 mm sieve for testing and compacted using the Standard Proctor Test procedure (ASTM D698-07) in a 101.6 mm diameter mold. Three trials were performed for each sample, and the water content was immediately determined according to ASTM D-2166. The obtained water content data was used to construct a compaction curve, from which the maximum dry density and optimum moisture content (OMC) were computed for each sample using a spreadsheet.

Based on the results of the sieve analysis and plasticity tests, the samples were classified, with the majority falling into the category of fine-grained soil, as indicated in Table 1. It is worth noting that despite being collected from different locations in Koya city, the majority of the samples exhibited fine-grained characteristics.

3- Results and discussion

In the previous section, existing data from other research studies were gathered to explore the relationship between compaction characteristics and soil plasticity. This section focuses on the newly obtained data, which are compared with the literature data. The aim is to determine the extent to which the acquired data aligns with the data found in existing literature, particularly in terms of the correlation between index properties and compaction characteristics.

Figure 6 presents a plot illustrating the relationship between optimum moisture content (OMC) and plastic limit (wP). When considering both the literature data and the current data, a significant amount of scatter is observed, making it challenging to establish a definitive relationship. For instance, at a plastic limit (wP) of 30%, a wide range of OMC values can be predicted. Conversely, for an OMC of approximately 20%, there can be several different values of wP. This suggests that a strong correlation between OMC and wP may not be evident. Therefore, it is necessary to find the best-fitted relationship for this data set, which can be expressed as follows:

$$OMC=0.56wP + 5.87 \quad (5)$$

Nevertheless, it is notable that both the literature data and the newly obtained data deviate significantly from the curve that was fitted, particularly when considering high plasticity values.

Table 1: Index properties, compaction characteristics, and grain size distribution of the samples

Sample	wP%	wL%	PI%	Max. dry density (kg/cm^3)	OMC %	F 10%	F 40%	F 200%	Soil classification
1	24	29.1	5.1	1860	16	52.17	15.1	6	Well graded sand
2	32.78	41.2	8.42	1730	22	53.5	12.5	4.1	Silty or clayey sand
3	18.16	27.72	9.56	1772	13.5	39.7	14.5	3.39	Silty or clayey sand
4	26.423	31	4.577	1800	18	53.4	18.35	1.36	Well graded sand
5	15	25.5	10.5	1850	15.5	53.88	20.79	0.16	Well graded sand
6	25.266	35.75	10.484	1750	17	51.66	17.95	7.1	Silty or clayey sand
7	30.297	38.41	8.113	1738	22.5	33.58	9.42	0.69	Silty or clayey sand
8	24.795	30	5.205	1840	17	54	20.9	4	Silty or clayey sand
9	27.448	37.59	10.142	1723	21	86.8	82.4	74.9	Silty soil
10	24.26	34.91	10.65	1920	15	96.99	96.95	96.3	Clayey soil
11	36.45	48.81	12.36	1716.9	19	99.73	99.62	97.3	Clayey soil
12	20.17	33	12.83	1833	19	93.35	90.86	88.5	Clayey soil
13	31.433	36.1	4.667	1861	17.3	99.89	93.1	81.3	Silty soil
14	27.58	35.52	7.94	1861.2	11	99	98.92	93.1	Silty soil
15	24.8	27.9	3.1	1822	15.5	94.9	90.92	86.7	Silty soil
16	32.6	45.4	12.8	1776	16.5	92.64	77.98	32.9	Silty or clayey sand
17	26.65	37.3	10.65	1762.5	17.5	98.9	96.8	90.4	Silty soil
18	29.27	41.6	12.33	1731	22.5	98.56	97.94	95.8	Clayey soil
19	29.2	32	2.8	1950	10	96.45	94.83	58.6	Silty soil
20	20.7	25.3	4.6	2161	13	79.58	75.51	65.4	Silty soil
21	29.6	40	10.4	1723	18.5	98.64	97.43	93.6	Silty soil
22	20.82	26.3	5.48	1669.2	11	97.92	96.93	77.3	Silty soil
23	22.21	26.5	4.29	2040	15	99.74	99.57	97.5	Silty soil
24	22.3	28.2	5.9	2056	11	73.14	70.34	67.6	Silty soil
25	12.84	42	29.16	1645	25	93.33	91.59	88	Clayey soil
26	22.61	33.15	10.54	1789	16.5	84.7	81.54	69	Silty soil
27	26.22	40.1	13.88	1778	20	96.92	95.4	93.2	Clayey soil

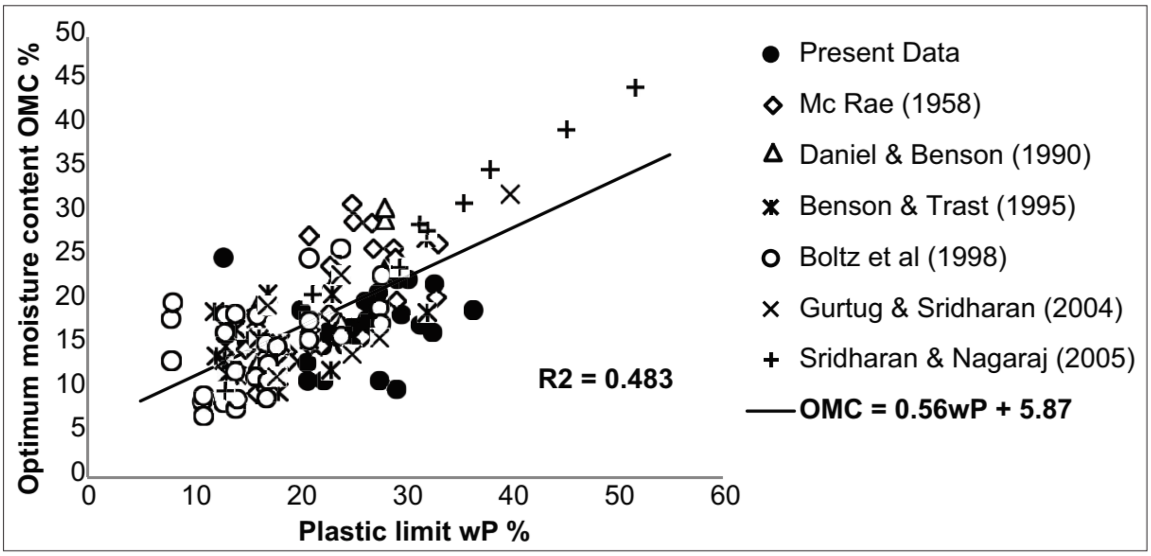

Figure 6: Present data and data from the literature for optimum moisture content and plastic limit

Figure 7 displays a plot of optimum moisture content (OMC) against liquid limit (wL), showing some degree of scatter in the data. However, when comparing the newly obtained data with the literature data, the match is relatively better compared to the relationship between OMC and plastic limit (wP). Combining both sets of data reveals a consistent trend: as wL increases, OMC also tends to increase. It is worth mentioning that a satisfactory relationship between OMC and wL is generally observed for wL values below 60%. However, relying solely on wL to predict OMC may not yield accurate results. The relationship derived from this analysis is as follows:

$$OMC = 0.31wL + 5 \quad (6)$$

Figure 8 depicts a plot of maximum dry density (γd max) against liquid limit (wL). Similar to Figure 7, there is a relatively good correlation between γd max and wL for soils with liquid limits (wL) below 60%. However, there is still a significant amount of scatter in the data, making it insufficient to accurately predict the maximum dry unit weight. Nevertheless, by considering both the present data and the literature data, a new relationship can be established and expressed as follows:

$$\gamma dmax = 21.5 - 0.1wL \quad (7)$$

The correlations proposed by Sridharan and Nagaraj (2005), which assert that plastic limit (wP) is a more reliable predictor of compaction characteristics compared to liquid limit (wL), have been compared with the new data. However, upon examining Figure 9, it is evident that the suggested relationship between optimum moisture content (OMC) and wP does not align well with the new data, as it tends to overestimate OMC values. Similarly, the suggested correlation between maximum dry density (γd max) and wP demonstrates a noticeable discrepancy, with the majority of the new data not aligning with the proposed line by Sridharan and Nagaraj (2005), as shown in Figure 10. This correlation tends to underestimate γd max values. Consequently, these correlations cannot be deemed reliable for predicting the compaction characteristics based on the findings of this study.

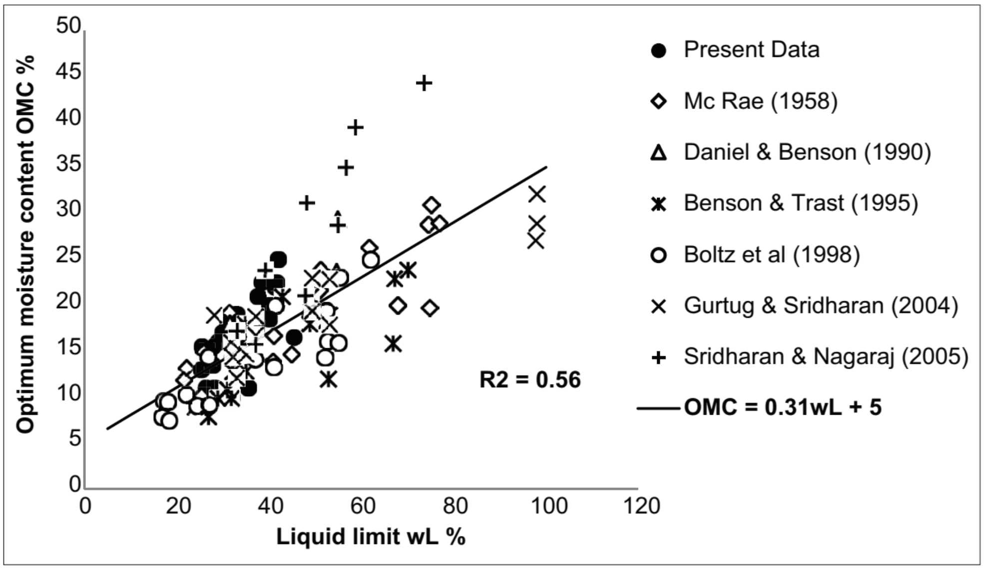

Figure 7: Present data and data from the literature for optimum moisture content and liquid limit

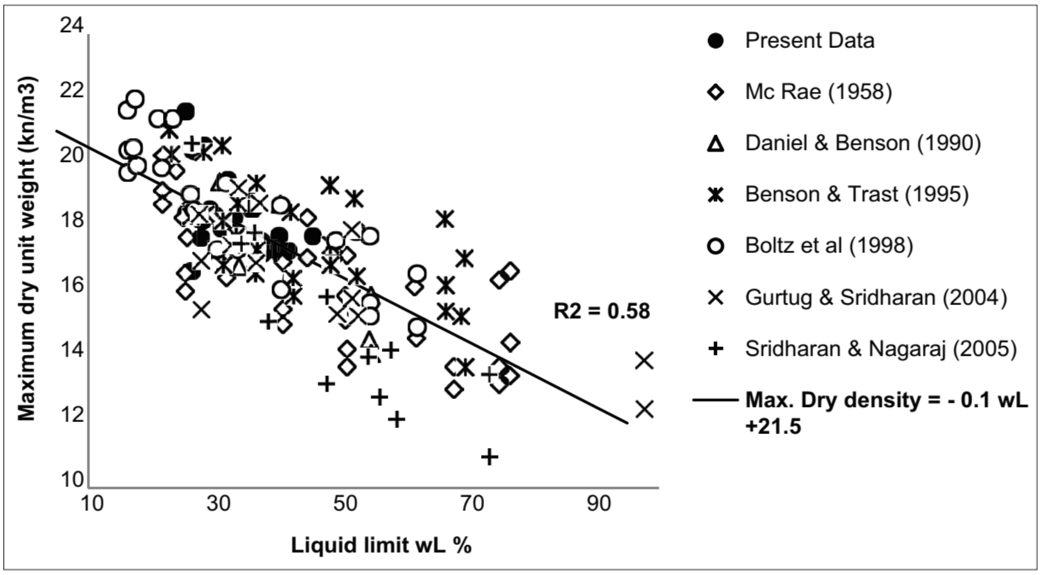

Figure 8: Present data and data from the literature for maximum dry unit weight and liquid limit

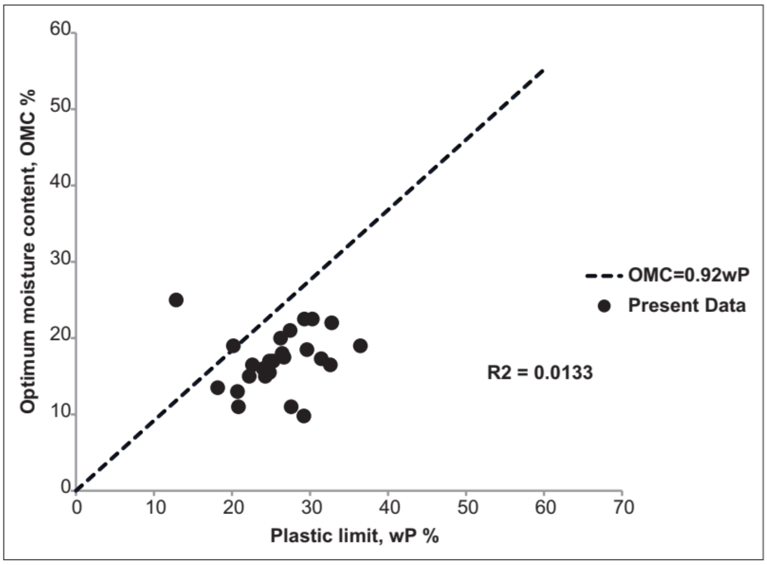

Figure 9: Present data and the proposed correlation for optimum moisture and plastic limit

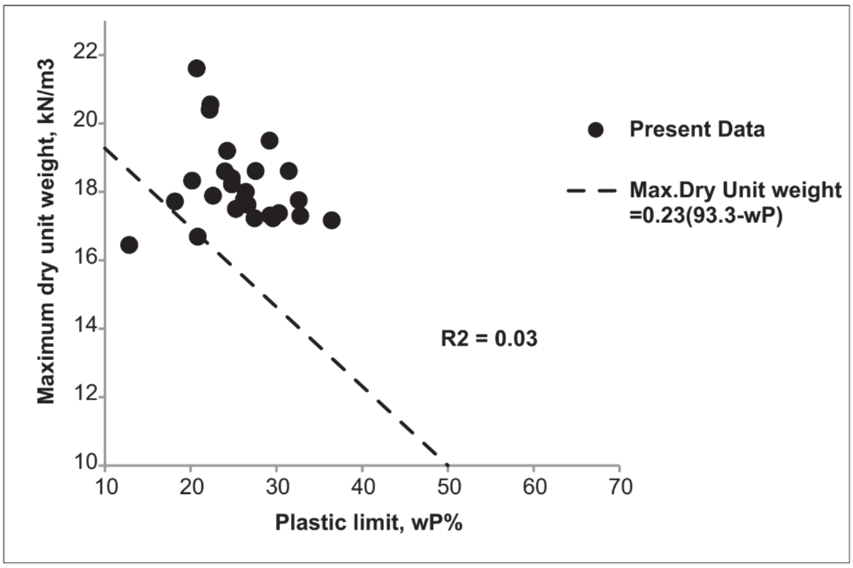

Figure 10: Present data and the proposed correlation for maximum dry unit weight and plastic limit

Additionally, the correlations established by Sridharan and Nagaraj between the compaction characteristics and liquid limit (wL) were also evaluated. Figure 11 illustrates a plot of optimum moisture content (OMC) against wL. It appears that wL exhibits a relatively stronger relationship with OMC compared to wP, although it does not reach a satisfactory level of correlation.

However, there is a weak relationship between maximum dry density (γd max) and wL. Similar to the correlation between γd max and wP, there is a significant amount of scatter between γd max and wL, as observed in the present data. The suggested correlation also underestimates γd max values when compared to the present data, as depicted in Figure 12.

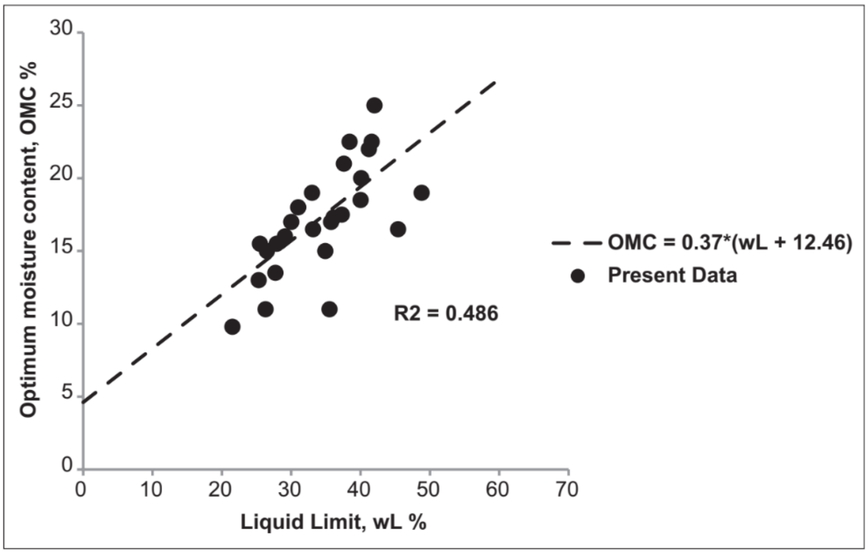

Figure 11: Present data and the proposed correlation for optimum moisture content and liquid limit

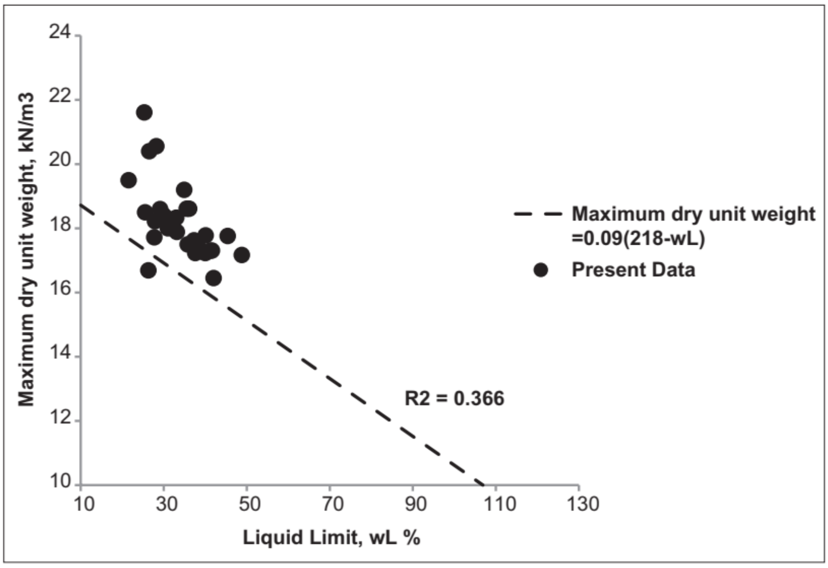

Figure 12: Present data and the proposed correlation for maximum dry unit weight and liquid limit

3- Conclusion

After examining the data from both the literature and the present study, it can be concluded that soil index properties alone cannot provide an accurate estimation of the compaction characteristics. While there is a certain level of correlation between plastic limit and optimum moisture content (OMC), and liquid limit may exhibit some degree of correlation with the compaction characteristics, these relationships do not meet the desired level of accuracy.

The previously established correlations between soil index properties and compaction characteristics suggest that plastic limit has a stronger relationship compared to liquid limit. It is proposed that plastic limit can be used to estimate both OMC and maximum dry density (γd max). However, the findings of this research contradict these assertions, as the results indicate that these correlations are not reliable.

The proposed correlations between OMC and liquid limit (wL), as well as between γd max and wL, demonstrate a relatively better alignment with the newly obtained data, although some scatter is still present.

Furthermore, even when combining the data from the literature and the present study, the correlations between compaction characteristics and soil index properties are insufficient to accurately determine the compaction characteristics solely based on soil index properties.

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