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Application of Atterberg Limits for Predicting Soil Compaction Characteristics

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Abstract

Compaction of soil at engineering construction sites is essential to enhance its geotechnical properties. Laboratory Standard and Modified compaction tests have been used to determine compaction characteristics namely Optimum Moisture Content OMC and Maximum Dry Density MDD. However, these tests are relatively time consuming, require considerable efforts and large soil quantities to evaluate the suitability of soils used in different engineering works. The current study aims to correlate soil compaction characteristics and their Atterberg Limits (Liquid LL and Plastic Limit PL) for soil samples collected at 1-1.25m depth from the campus site of University of Diyala, Baqubah City. Such correlations are advantageous to predict OMC and MDD needed to control field compaction specifications. Grain size analysis, specific gravity, LL, PL, standard Proctor compaction tests were carried out according to American Society for Testing and Materials ASTM Standards. The laboratory results showed that, based on Unified Soil Classification System USCS, the soil at the site is of CL type (clayey soil of low plasticity). Compaction tests revealed that OMC and MDD values were ranged from (15.8-18.4%) and (1.65-1.73)gm/cm3, respectively. MDD and OMC were correlated with their LL and PL. It was found that MDD correlates very well with LL and PL with high R^2 equals to 0.8665 and 0.9189, respectively, and OMC correlates with LL and PL with less R^2 equals to

0.4781 and 0.6882, respectively. The presented models were validated using the laboratory results. Correlations established in this work are useful for the preliminary evaluation of soil compaction parameters using Atterberg Limits for future engineering constructions in the study area.

Keywords: Compaction, Atterberg Limits, Optimum Moisture Content, Maximum Dry Density

تطبيقات حدود اتربرغ للتنبؤ بخصائص دمك التربة

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الخلاصة

ان دمك التربة في مواقع المشاريع الهندسية ضروريا لتحسين خصائصها الجيوتكنيكية. فحوصات دمك بروكتر القياسي والمحور تستخدم عادة لتحديد خصائص الدمك (محتوى الرطوبة المثالي والكثافة الجافة القصوى). لكن هذه الفحوصات تتطلب وقتا وجهدا كبيرين وكميات كبيرة من التربة لتقيم مدى ملائمة استخدام التربة للاعمال الهندسية المختلفة تهدف الدراسة الحالية الى مقارنة خصائص دمك التربة بحدود اتربرغ لنماذج من التربة من موقع جامعة ديالى مأخوذة على عمق (1 الى 1.25 م). هذه العلاقات مفيدة لتقدير خصائص الدمك الضرورية لمراقبة دمك التربة في المواقع الهندسية.تم اجراء فحوصات حجم الحبيبات، الوزن النوعي، حد السيولة، حد اللدونة، وفحص الدمك القياسي مختبريا حسب المواصفات الامريكية. بينت نتائج الدراسة ان تربة المنطقة هي تربة طينية قليلة اللدونة اعتمادا على التصنيف الموحد للتربة وان محتوى الرطوبة المثالي يتراوح بين (15.8 – 18.4 %) والكثافة الجافة القصوى بين (1.65 – 1.73 غم/سم^3) تم التوصل الى علاقة جيدة بين الكثافة الجافة القصوى وحد السيولة واللدونة للتربة وبمعامل ارتباط (0.8665 -0.9189) ايضا تم التوصل الى علاقة اقل جودة بين محتوى الرطوبة المثالي وحد السيولة واللدونة للتربة وبمعامل ارتباط (0.4781 -0.6882) على التوالي وتم التحقق من هذه العلاقات باستخدام نتائج الفحوصات المختبرية. ان الموديلات المقدمة في هذه الدراسة مفيدة في التقييم المبدئي لخصائص الدمك باستخدام حدود اتربرغ في الاعمال الهندسية المستقبلية في منطقة الدراسة.

الكلمات المفتاحية: الدمك، حدود اتربرغ، المحتوى الرطوبي المثالي، الكثافة العظمى الجافة.

Introduction

Soil compaction is a common practice used in different engineering earthworks to achieve the desired geotechnical properties. Compaction enhances shear strength and load bearing capacity characteristics of soil, reduces its permeability and settlement at the construction sites.

Compaction characteristics, OMC and MDD, are usually derived using compaction curves obtained from laboratory standard and modified Proctor tests, and used as criteria to evaluate the field compaction specifications [1]. Determination of OMC and MDD of soils is significant to assess their engineering suitability to avoid future settlement and to reduce future mitigation costs. However, laboratory compactions tests need considerable time, efforts and large soil quantities to assess the suitability of soils used in engineering works such as highways, earth dams, embankment, etc. Therefore, it can be useful to correlate OMC and MDD of soils with their simple Atterberg limits (LL and PL). These relationships can be used for initial evaluation of soil suitability for different engineering projects [2], [3].

In the literature, several authors have correlated compaction characteristics MDD and OMC with LL and PL (e.g. [4], [5], [6]). These correlations revealed that MDD decreases with increasing LL and PL, while OMC increases with increasing LL and PL with different correlation coefficients and data scatter. However, Sridharan and Nagaraj (2005) [7] stated that OMC and MDD do not correlate well with LL while PL does. Hama Ali et al., 2019 [8] concluded that neither PL nor LL gave a satisfactory correlation with OMC and MDD. Verma and Kumar, (2020) [3] reviewed the existing relationships in the literature. They concluded that OMC and MDD of fine grained soils rely on Atterberg limits and new correlations are still needed to cover soils of wide ranges of index properties.

Therefore, this work represents an attempt to explore the relationships between compaction characteristics of soil samples collected from the campus site of the University of Diyala and their Atterberg Limits. First, grain size distribution and index properties were used to characterize the soil at the site. Second, standard Proctor compaction tests were performed to determine the compaction characteristics. Finally, correlations between OMC and MDD and LL and PL were presented and validated.

Materials and Methods

Ten soil samples were manually augured at depth 1-1.25m depth using hand auger from the campus site of the University of Diyala, south of Baqubah city, Figure (1). The area is flat and covered by recent quaternary deposits [9]. Based on the geotechnical information of a borehole drilled in the area, the soil profile is consisted of a layer of 13.m thickness of a low plasticity, light to dark brown Clay soil (CL) above a layer of dark gray Silty Sand (SM) [10]. The study area is currently proposed for building of new educational facilities. Therefore, soil characterization is needed for future geotechnical design and construction. Once recovered, soil samples were secured properly and transformed to the laboratory for analysis.

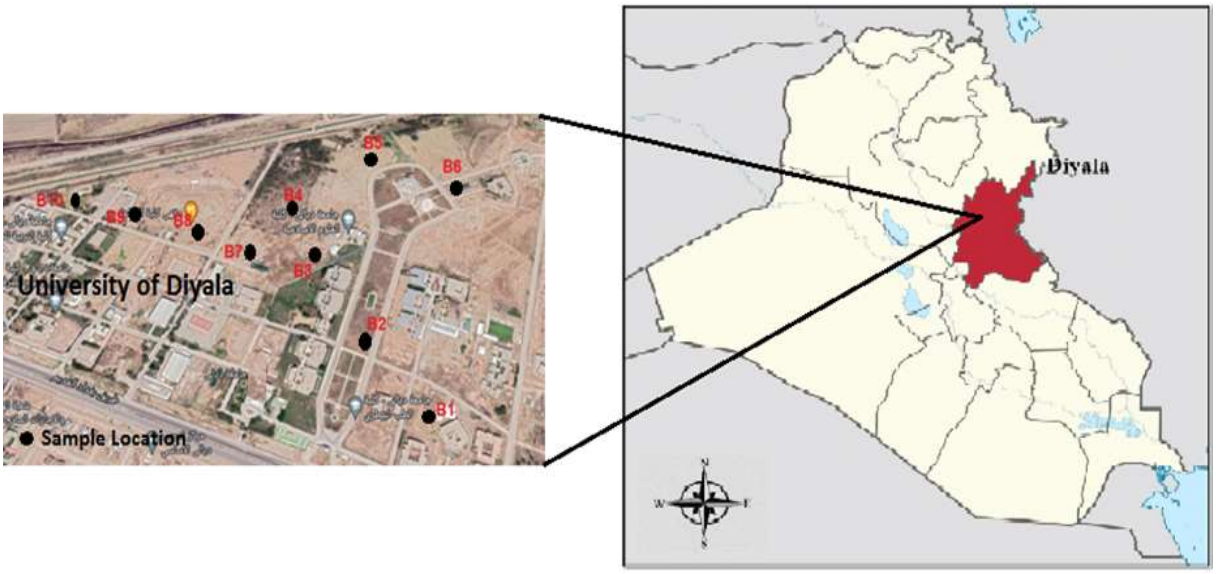

Figure 1: Distribution of soil samples in the study area

All laboratory tests were carried out in this work-based ASTM standards listed in Table (1). Drying oven is used for water content determination, Standard US sieves to perform grain size analysis, Pycnometer to determine soil specific gravity, Casagrande tool for liquid limit determination, and ASTM mold to carry out soil compaction test.

Table 1: Laboratory tests performed and the corresponding ASTM standards

Laboratory Test	ASTM Standard
Water Content	ASTM D2216 [11]
Grain size Analysis	ASTM D422 [12]
Specific Gravity	ASTM D854 [13]
Liquid Limit	ASTM D4318 [14]
Plastic Limit	ASTM D4318 [14]
Standard Proctor Compaction	ASTM D698 [15]

Index properties tests were carried out firstly to characterize the soil in the study area, Figure (2. a). Secondly, compaction tests were conducted in a standard 101.6 mm diameter mold, Figure (2. b) to produce compaction curves from which compaction parameters, OMC and MDD, are derived. Finally, these parameters are correlated with the corresponding LL and PL limits, and the presented models were validated using the laboratory results.

Figure 2: (a) Index properties tests (b) Standard Proctor compaction test

Results and Discussion

Results of laboratory tests are summarized in Table (2). Grain size distribution analysis presented in Figure (3) showed that the soil in the study area is fine grained with Percentage Fines (soil particles passing through US #200 sieve) was ranged from 57.2% to 67.3%. Specific gravity (Gs), was ranged between 2.67 and 2.75. The narrow range of Gs indicates that Gs depends mainly on the soil mineralogical content according to [1].

LL values were ranged between 24% and 27.6%. PL values were ranged between 17.2% and 20.4%. PI values were ranged between 6.3% and 7.8%, which indicate a low plasticity soil according to [1].

The soil in the study area is classified based on plasticity chart, Figure (4), and USCS classification, as type CL (inorganic clayey soil with low plasticity), as PI values fall within (5-20) % range and LL<50% [16].

Table (2) Physical properties and soil classification results.

Sample no	Grain- size distribution			G_S	L.L %	P.L %	I.P	MDD $gm./cm^3$	OMC %	Soil type
	Gravel %	Sand %	Finer %							
BH1	0	34.77	65.22	2.74	24.2	17.5	6.7	1.715	16.7	CL
BH2	0	36.3	63.7	2.74	24.3	18	6.3	1.704	17	CL
BH3	0	32.7	67.3	2.69	25.8	18	7.8	1.695	16.85	CL
BH4	0	41.5	58.5	2.69	24.3	18	6.3	1.7	17	CL
BH5	0	41.5	58.5	2.68	26	19	7	1.692	17.1	CL
BH6	0	39.6	60.4	2.68	26.5	19	7.5	1.685	16.4	CL
BH7	0	38.4	61.6	2.73	25.2	18.8	6.4	1.7	16.9	CL
BH8	0	42.4	57.6	2.75	24	17.2	6.8	1.73	15.8	CL
BH9	0	33.8	66.2	2.67	27.6	20.4	7.2	1.65	18	CL
BH10	0	42.8	57.2	2.68	27.1	20.2	6.9	1.66	18.4	CL

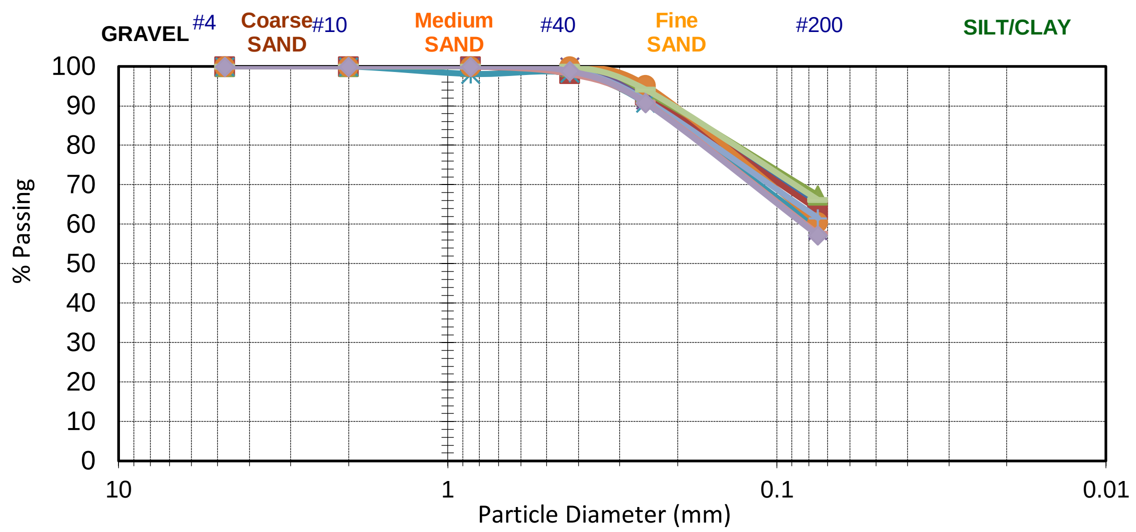

Figure 3: Grain size distribution analysis of soil samples

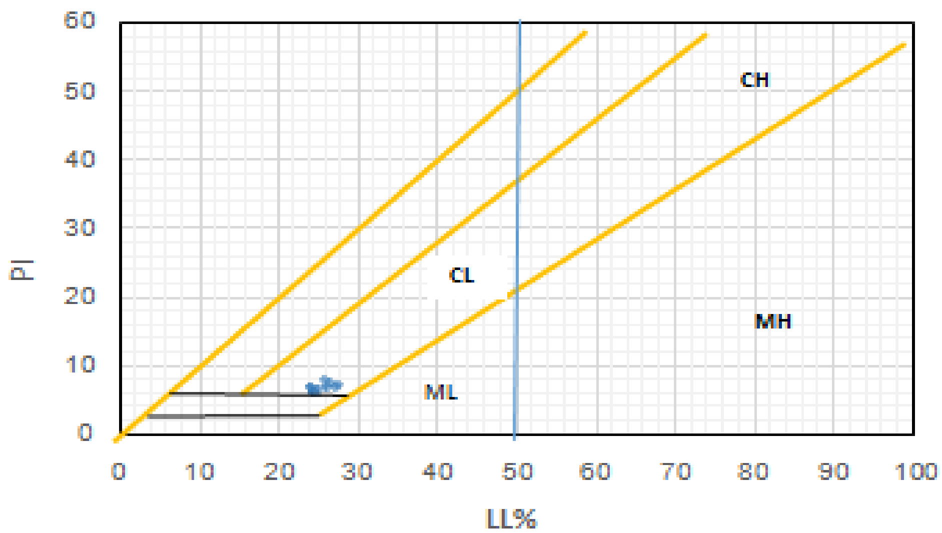

Figure 4: Plasticity chart of soil

Figure (5) depicts compaction curves obtained using standard Proctor method. MDD values were ranged from 1.65gm/cm^3 to 1.73gm/cm^3 while OMC values were ranged from 15.8 to 18.4%.

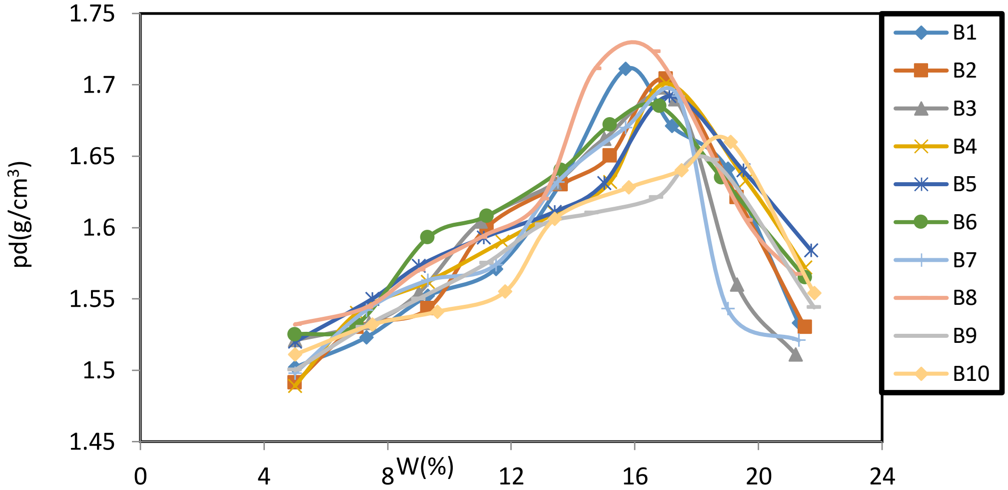

Figure 5: Compaction curves of soil samples

Figure (6) illustrates the relationship between MDD and OMC of soil samples. Increasing MDD decreases OMC linearly. Increasing MDD reduces voids volume, therefore, reduces moisture content required to reach OMC. Similar correlations are reported in the literature [17], [18].

Correlations between Atterberg Limits and compaction parameters are investigated to explore whether these limits can be used to predict compaction parameters to a satisfactory level. Best fit line with correlation or regression coefficient R^2 is adopted to examine the accuracy of correlations (R^2= -1 to +1, and R^2=0 means no correlation). Table (3) shows the accuracy of the correlation coefficient measured by R^2 [19].

Table 3: A measure of correlation accuracy by R^2 [19]

R^2	VALUES ACCURACY
< 0.25	Not Good or Bad
0.25 – 0.55	Relativity Good
0.56 – 0.75	Good
> 0.75	Very Good

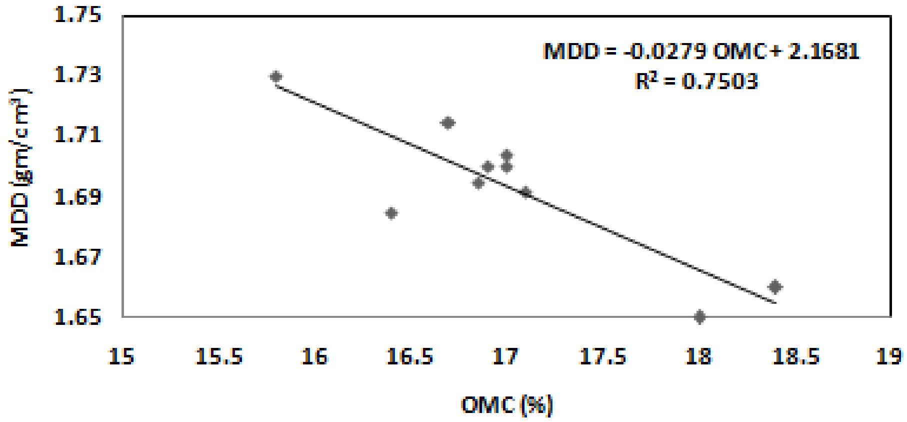

Figure 6: MDD-OMC relationship

Figures (7) and (8) present MDD-LL and MDD-PL relationships, respectively. Increasing MDD decreases both LL and PL of soil with R^2 equals to 0.8665 and 0.9189, respectively. Similarly, Figure (9) and (10) illustrate plots of OMC-LL and OMC-PL relationships, respectively. Increasing OMC increases both LL and PL with R^2 equals to 0.47.81 and 0.6882, respectively. The presented correlations are consistent with similar relationships reported in previous studies (e.g. [4], [5], [6]). However, MDD correlates relatively better with LL and PL than OMC in terms of R^2 values.

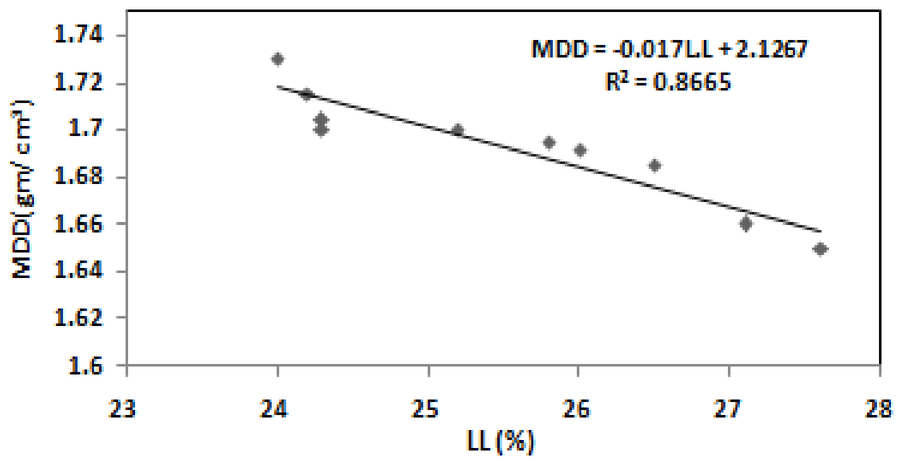

Figure 7: Correlation between MDD and LL

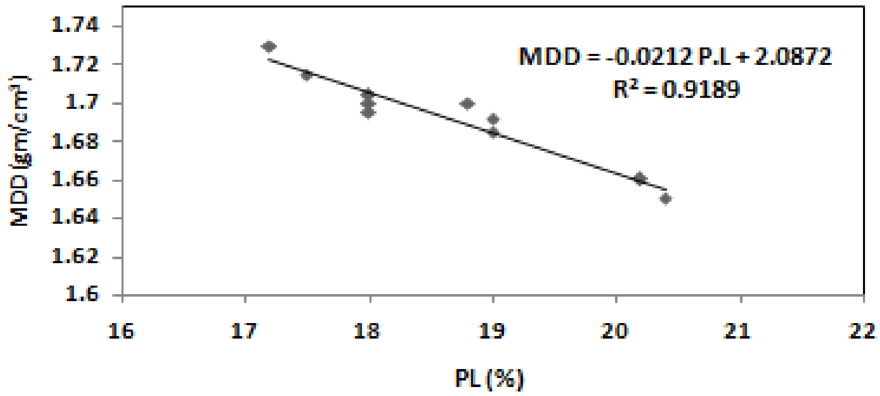

Figure 8: Correlation between MDD and PL

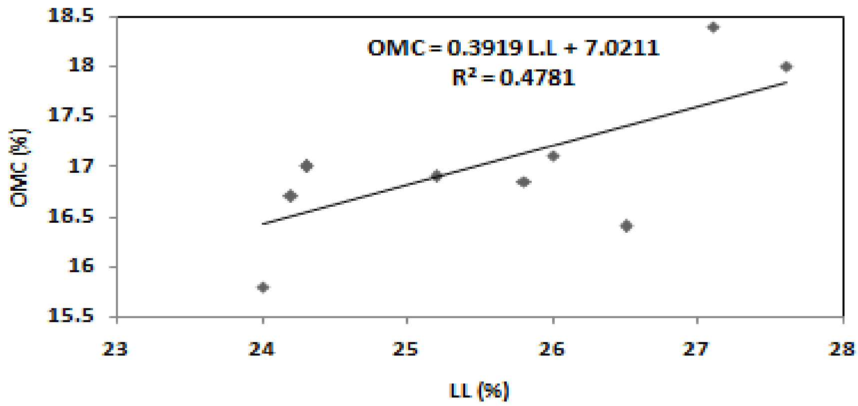

Figure 9: Correlation between OMC and LL

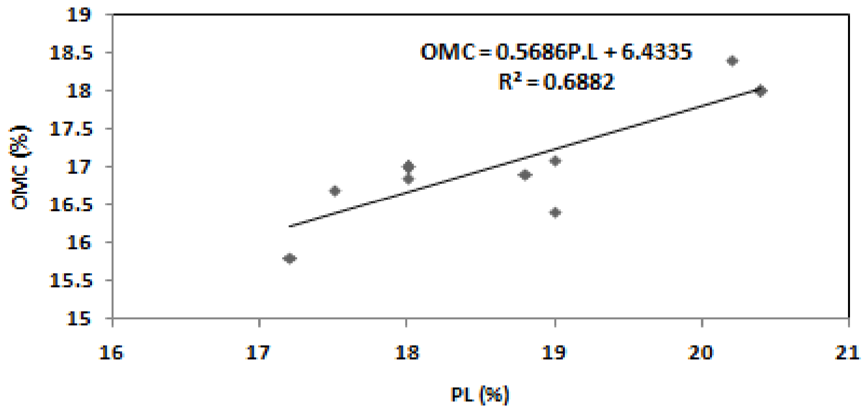

Figure 10: Correlation between OMC and PL

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The best fit equations obtained from MDD correlations with LL and PL can be expressed as follows:

MDD = -0.017LL + 2.1267 .... (1)

MDD = -0.0212 PL + 2.0872 .... (2)

The above models (eq.1 and eq.2) were validated using the laboratory data from Table (2). The measured and predicted MDD are listed in Table (4). It can be noticed that the Absolute Abs. Error between the measured and predicted values of MDD using eq.1 and eq.2 is very low with Mean Abs. Error MAE of 0.0194 and 0.005176, respectively. This suggested that MDD can be predicted very well using Atterberg limits LL and PL.

Table 4: Validation of the MDD-LL and MDD-PL models

MDD g/cm^3				MDD g/cm^3		
Measured		Predicted (eq. 1)	Abs. Error	Measured	Predicted (eq. 2)	Abs. Error
B1	1.72	1.70	0.02	1.72	1.72	0.00
B2	1.70	1.69	0.01	1.70	1.70	0.00
B3	1.70	1.67	0.03	1.70	1.71	0.01
B4	1.70	1.69	0.01	1.70	1.71	0.01
B5	1.69	1.66	0.03	1.69	1.68	0.01
B6	1.68	1.65	0.03	1.68	1.68	0.00
B7	1.70	1.68	0.02	1.70	1.69	0.01
B8	1.73	1.70	0.03	1.73	1.72	0.01
B9	1.65	1.64	0.01	1.65	1.66	0.01
B10	1.66	1.65	0.01	1.66	1.66	0.00

Similarly, the best fit equations obtained from OMC correlations with LL and PL can be expressed as follows:

OMC = 0.3919 L.L + 7.0211 .... (3)

OMC = 0.5686P.L + 6.4335 .... (4)

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The above models (eq.3 and eq.4) were validated using the laboratory data from Table (2). The measured and predicted OMC are listed in Table (5). It can be noticed that the Abs. Error between the measured and predicted values of OMC using eq.3 and eq.4 is relatively low with Mean Abs. Error MAE of 0.4056 and 0.3285, respectively.

Table 5: Validation of the OMC-LL and OMC-PL models

OMC (%)				OMC (%)		
Measured		Predicted (eq. 3)	Abs. Error	Measured	Predicted (eq. 4)	Abs. Error
B1	16.70	16.51	0.19	16.70	16.38	0.32
B2	17.00	16.54	0.46	17.00	16.67	0.33
B3	16.85	17.13	-0.28	16.85	16.67	0.18
B4	17.00	16.54	0.46	17.00	16.69	0.33
B5	17.10	17.21	-0.11	17.10	17.24	-0.14
B6	16.40	17.41	-1.01	16.40	17.24	-0.84
B7	16.90	16.90	0.00	16.90	17.12	-0.22
B8	15.80	16.43	-0.63	15.80	16.21	-0.41
B9	18.00	17.84	0.16	18.00	18.03	-0.03
B10	18.40	17.64	0.76	18.40	17.92	0.48

Conclusions

Soil Index properties and standard compaction tests were conducted on samples collected from the campus site of the University of Diyala, south of Baqubah city. It was found that the soil in the study area is fine-grained type CL of low plasticity. Compaction parameters, OMC and MDD, were determined and correlated with Index properties LL and PL. Increasing LL and PL decreases MDD, while increasing LL and PL increases OMC. The presented correlations are in an agreement with other correlations reported in the literature. Satisfactory correlations were reached particularly between MDD and LL, MDD and PL with high correlation coefficient However, less dependent relationships were found between OMC and LL, OMC and PL. Correlations established in this work provide an initial evaluation of soil compaction parameters using Index properties for the preliminary design of future Engineering projects that require compaction process in the study area.

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