Correlation of Consistency and Compressibility Properties of Soils in Sulaimani City

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Abstract

Compressibility properties of soils are one of the most important properties in geotechnical engineering because of the needs for a safe and economic design for structures foundations. Compressibility parameters are used in the settlement calculations. Direct determination of both compression index (C_c) and recompression index (C_r) are costly, cumbersome and consuming time. These indices require undisturbed soil samples depending on a lot of experiences in the field works. Due to those factors, useful correlations were developed previously to predict compressibility properties. In the current study, the correlations conducted by using consistency properties, which are easy measurable variables. In this study, single (linear equation) and multiple empirical equations were proposed to predict compressibility indices (C_c and C_r) as a function of index properties (LL, PL, PI and SL). The equations were predicted using sixty undisturbed fine-grained soil samples collected from twelve different locations at Sulaimani City in Kurdistan Region of Iraq. Statistical analysis has been carried out by using SPSS software (Version 24). Coefficient of determination (R^2) and root mean square error were used as an evaluation criterion in order to check the calculated empirical correlations equations. The statistical analysis showed that there is a direct and positive correlation among the selected parameters. In addition, accurate correlations were obtained in comparison to the existing relationships.

Key Words : Correlation, Compressibility, Consistency, Fine-grained Soils.

1. Introduction

Most of the foundations of structures are placed on soils. Soil is one of the most important materials used in construction that civil engineers have to study the geotechnical properties of it. Performing subsurface investigation must be undertaken to obtain sufficient number of undisturbed soil samples and then tested in the laboratory to obtain the necessary soil properties such as consolidation parameters (compression C_c and recompression C_r indices). Compressibility properties of fine-grained soils are important for the calculation of consolidation settlement. In addition, determination of these parameters by consolidation test requires a long amount of time and costs. Therefore, a correlation is needed among soils compressibility and consistency properties in order to save time and minimizing the cost of site investigations. Many previous studies were performed to develop correlations among soil parameters as shown in Table 1. More convenient correlation equations between compression index and liquid limit for cohesive soils of different locations in Ammarah City in Messan Governorate-southern part of Iraq were developed by Al- Kahdaar & Al-Ameri (2010).

Compression index with liquid limit and plasticity index were correlated by single empirical equation, which was done by Solanki (2012). The researcher studied 10 zones of Surat City and SUDA (Surat Urban Development Authority). The results showed that the model enables the designer to decide a safe bearing capacity or a permissible bearing capacity. In contrast, the results of Abasi (2013) showed that the liquid limit (LL) could not be related to the compression index (C_c) properly. The study considered 26 samples at three different values of void ratio collected from various sites of Iran.

On the same matter, Akayuli & Ofosu (2013) were used linear regression analysis to correlate compression index with some consistency properties of 60 weathered Birimian phyllites samples from the Kumasi area, Ghanaian. The liquid limit property showed the highest coefficient of determination compared to the plastic limit (PL) and plasticity index (PI).
Dway & Thant (2014) studied an attempt to estimate the compression index as a function of soil index properties. Samples were collected from three locations at depth of 3 - 6 feet in Mandalay. The results showed that the two developed variable equations are reliable to predict the compression index. The other equations with liquid limit and plasticity index cannot be used to accurately predict the compression index.
Cohesive soil samples were considered in some studies such as Shaikh et al. (2014). The established correlations were conducted among compressibility parameters and index properties of the collected samples from 6 places of Khulna City, Bangladesh. The outcomes highlighted that the soil types and their distribution were very complex and usually heterogeneous in both vertical and horizontal directions. The results can play a significant role for planning and designing the structures in the study area.
In addition to undisturbed soil samples, remolded samples were also dealt with in some researches. Lee et al. (2015) studied the undisturbed and remolded samples of Busan clays in Korea. The study was carried out in order to propose empirical correlations to predict the compression index of natural clays using liquid limit and plasticity index. Their results showed negative correlations developed to predict compression index. After a numerous work on soil geotechnical properties correlations, and due to the lack of correlated data on Sulaimani soils, this study generated compressibility properties as a function of index properties in terms of single and multiple empirical equations.

3. Materials and Methods

3.1 Collection of soil samples

In this study, sixty fine-grained soil samples were collected from different locations of Sulaimani City namely: Qerga, Qularaesy, wllwbe, Rapareen, Bakrajo, Swrga, Kellekn, Kenekewe, Kelespy, Homerekwer, Xewete and Dabashan. These locations are shown in Figure 1 and Table 2. Undisturbed soil samples were collected from shallow depths of 1.0-2.0 m from the natural ground level. Undisturbed soil samples were collected for one dimensional consolidation tests, while disturbed soil samples were collected for determination of the Atterberg limits (liquid limit and plastic limit). The collected soil samples were conducted according to ASTM standards.

3.2. One-dimensional consolidation (ASTM D 2435-11)

For conduct of one dimensional consolidation tests, undisturbed soil samples have been trimmed to the size of a mold of 50 mm diameter and thickness of 20 mm. After the sample put in the oedometer apparatus, the pressure was applied in the range of 25 kN/m2 to 800 kN/m2 by sequencing stage for every 24 hours.
3.3 Atterberg limits (ASTM D 4318-10):
Atterberg limits tests (liquid limit, plastic limit) were done on the soils, which were passed sieve No. 40. The liquid limit was measured through the Casagrande liquid limit equipment. For all Atterberg limits, the testing procedures were confirmed accordingly the ASTM D 4318-10. The plasticity index is calculated as the difference between the liquid limit and the plastic limit.
3.4 Linear shrinkage limit (ASTM C 356-10):
Linear shrinkage limit is the proportion of decrease in the length of a soil sample to the original length when the moisture content is reduced from liquid limit (LL) to shrinkage limit (SL). This is after the sample has been subjected to soaking heat for duration of 24 hours and then cooled to the room temperature.

4. Results and Discussions

4.1 Results:

4.1.1 Soil properties and classification

The range of soil characteristics for the study area is shown in Table 3. All the soils are classified according to USCS that's conducted based on ASTM D 2487-00. Plasticity chart shown in Figure 2 shows classification of the selected fine-grained soil samples at Sulaimani City.

4.1.2 Correlations between compressibility and consistency properties

Linear simple regression analysis of the compression index against the consistency properties are presented in Figures 4 to 11. Also, multiple regression analysis was used to correlate the indices with Atterberg limits. The graphs show the predicted relationship among the variables with the coefficient of determination (R^2)

and root minimum square error. Table 4 shows summary of the conducted regression analysis.

4.2 Discussions

Depending on the obtained results presented in the previous section, the discussions have been developed in the following sections.

4.2.1 Relationship between compression index and liquid limit:

In the current study, the compression index significantly correlated with the liquid limit as a single variable. This is noticed from the achieved values of R^2 and RMSE, which were 0.74 and 0.026 respectively. This is accurately proposed as compared to the reported values by: Al- Kahdaar & Al-Ameri (2010), Solanki (2012), Abasi (2013), Akayuli & Ofosu (2013), Shaikh et al. (2014), and Lee et al. (2015).

$\mathbf{C_c = 0.006\ LL - 0.1}$ (No. of Data= 54, R^2 = 0.74, & RMSE = 0.026) (1)

4.2.2 Relationship between compression index and plastic limit

From Figure 4, according to the achievement of the good values of R^2 and RMSE, it was found that the compression index is significantly correlated with the plastic limit as a single variable and much higher than the existing relationship developed by Akayuli & Ofosu (2013), in which R^2 is equal to 0.43.

$\mathbf{C_c = 0.007PL - 0.005}$ (No. of Data= 45, R^2 = 0.75, & RMSE = 0.016) (2)

4.2.3 Relationship between compression index and plasticity index

In the current study, the plasticity index has a sufficiently reliable correlation with the compression index as a single variable equation. This was noticed from the achieved values of R^2 and RMSE as shown in Figure 5. This is very accurate as compare to that reported by Akayuli & Ofosu (2013), Dway & Thant (2014) and Lee et al. (2015) and is very close to the reported value by Solanki (2012) and Shaikh et al. (2014).

$\mathbf{C_c = 0.007\ PI + 0.036}$ (No. of Data = 46, R^2 = 0.72, & RMSE = 0.024) (3)

4.2.4 Relationship between compression index and linear shrinkage limit

The compression index as a function of the linear shrinkage limit was predicted. It was noticed that a sufficiently reliable equation was obtained in accordance to the obtained R^2 and low value of error (RMSE). This correlation was conducted for all selected soil samples in Sulaimani City as shown in Figure 6.

$\mathbf{C_c = 0.014\ SL - 0.024}$ (No. of Data = 51, R^2 = 0.72, & RMSE = 0.02) (4)

4.2.5 Relationship between recompression index with plastic limit, and recompression index with linear shrinkage limit:

In this study, reasonable correlations are developed between C_r with PL and C_r with SL. Those relationships presented as linear equations in Figures 7 and 8 respectively with the coefficient of determination R^2 equal to 0.53 and 0.52 and low values of RMSE, 0.003 and 0.0034 respectively.

$\mathbf{C_r = 0.0011\ PL - 0.012}$ (No. of Data = 50, R^2 = 0.53, & RMSE = 0.003) (5)

$\mathbf{C_r = 0.002\ SL - 0.006}$ (No. of Data = 52, R^2 = 0.52, & RMSE = 0.0034) (6)

4.2.6 Relationship between recompression index and plasticity index:

Reliable correlation to predict the recompression index (C_r) was proposed with R^2 equal to 0.51 is given in Figure 9. Same equation was proposed by Shaikh et al. (2014) with R^2 equal to 0.919, both of those equations indicated an increase of the value of C_r index.

$\mathbf{C_r = - 0.001\ PI + 0.03}$ (No. of Data = 51, R^2 = 0.51, & RMSE = 0.003) (7)

4.2.7 Multiple Regression analysis

A reliable multiple variable empirical equation for predicting the compression index as a function of index properties (LL and PI) was obtained based on the obtained values of R^2 and RMSE, which were 0.72 and 0.015 respectively (Equation 8 in Table 4). In practice, it is clear that compression index depends on soil plasticity due to clay content in that soil. Also, Dway & Thant (2014) proposed same equation with R^2 equal to 0.85.

Both of these equations indicated an increase of the value of C_c index.

C_c **= - 0.11 + 0.01 LL - 0.002 PI** (No. of Data= 60, R^2= 0.72, 7 RMSE= 0.015) (8)

5. Conclusions

From the results of this study, the following conclusions can be drawn:

1- The studied Sulaimani City soils as classified according to the Unified Soil Classification System are found to be clayey or silty soil with low to high plasticity.
2- Compression index can reasonably correlated with the basic soil properties as a single variable equation involving LL, PI, PL and SL. Among them, better correlation between C_c and PL considered the greatest R^2 factor, which is 0.75. The lowest R^2 factor obtained between C_c with PI and SL, which is 0.72. However, for all the graphs, increasing of index properties caused increasing of C_c.
3- Based on the regression analysis to predict the recompression index as a single variable equation the PL resulted in R^2 factor equal to 0.53, PI resulted in R^2 factor equal to 0.51, and SL resulted in R^2 factor equal to 0.52.
4- A reasonable correlation to predict the recompression index as a function of LL and PI was proposed using multiple regression analysis with R^2 factor equal to 0.72.
5- The obtained correlation equation is considered simple, easy and more convenient for estimating swelling index and compressibility index, which may be helpful for the geotechnical engineers for quick determination of compressibility parameters and to predict the magnitude of settlement due to the structures loading.

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ارتباط خصائص تناسق وانضغاط التربة في مدينة السليمانية

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المستخلص :
تعد خصائص الانضغاط للتربة من أهم الخصائص في الهندسة الجيوتكنيكية بسبب الحاجة إلى تصميم آمن واقتصادي للاسس المنشأة . وتستخدم معاملات الانضغاط في حساب الهبوط . الايجاد المباشر لكل من مؤشر الضغط (C_c) ومؤشر إعادة الضغط (C_r) مكلف ومرهق ، ويستغرق الوقت أيضا ، تتطلب هذه المؤشرات عينات من التربة غير مشوهة كما يتطاب الكثير من الخبرات في مجال الاعمال الحقلية . بسبب هذه العوامل ، تم تطوير ارتباطات مفيدة سابقا للتنبؤ بخصائص الانضغاط . تلك الارتباطات التي أجريت باستخدام خصائص الاتناسق (Consistency) ، والتي هي سهلة لأيجاد في المختبر . في هذه الدراسة ، تم اقتراح منفرد (معادلة خطية) ومعادلات تجريبية متعددة للتنبؤ بمؤشرات الانضغاط (C_c و C_r) اعتمادا علي الخصائص الداله (LL ، PL ، PI و SL) . وتوقعت هذه المعادلات باستخدام ستين عينة غير مشوهه من التربة ذات الحبيبات الناعمة تم جمعها من اثني عشر موقعا مختلفا في مدينة السليمانية في إقليم كردستان العراق . لذلك ، تم إجراء التحليل الإحصائي باستخدام برنامج SPSS (الإصدار 24) . تم استخدام معامل التحديد(R^2) ومعامل الارتباط (R) كمعيار تقييم من أجل التحقق من معادلات الترابط التجريبية المحسوبة . وأظهر التحليل الإحصائي وجود ارتباط مباشر وإيجابي بين المعلمات المختارة . بالإضافة إلى ذلك تم الحصول على ارتباطات دقيقة بالمقارنة مع العلاقات القائمة .

الكلمات المفتاحية : الترابط ، الانضغاط ، التناسق ، التربة ذات الحبيبات الناعمة .

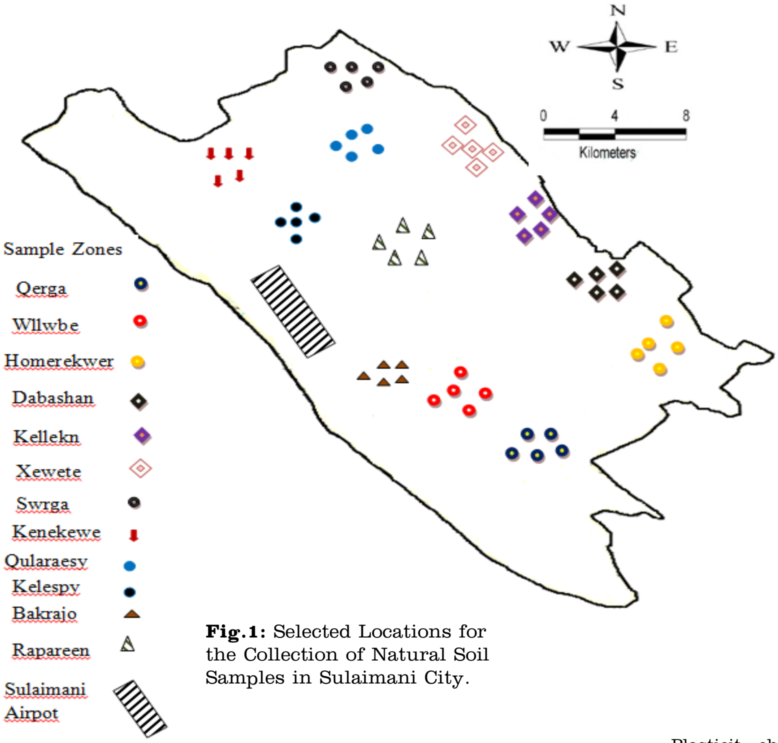

Fig.1: Selected Locations for the Collection of Natural Soil Samples in Sulaimani City.

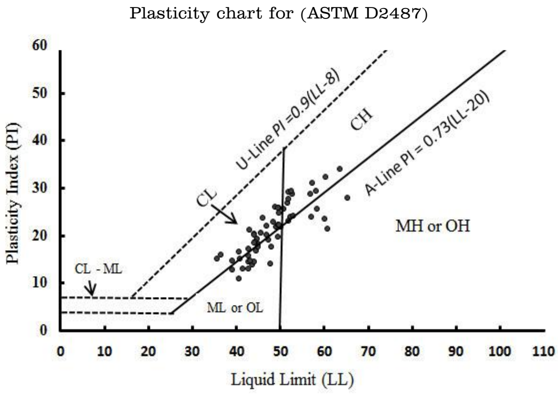

Fig.2: Plasticity chart for Sulaimani City soils.

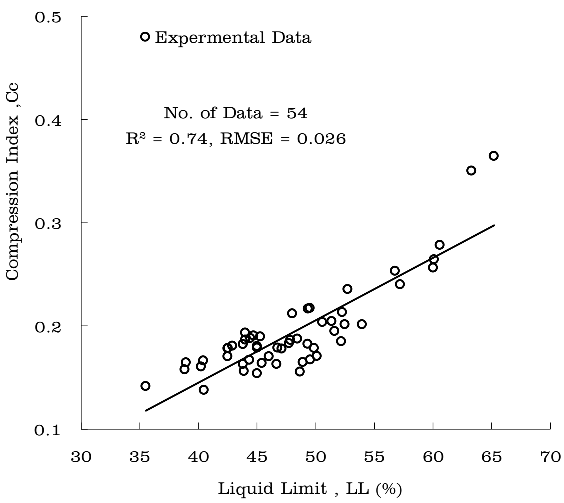

Fig. 3: Relationship of C_c versus LL.

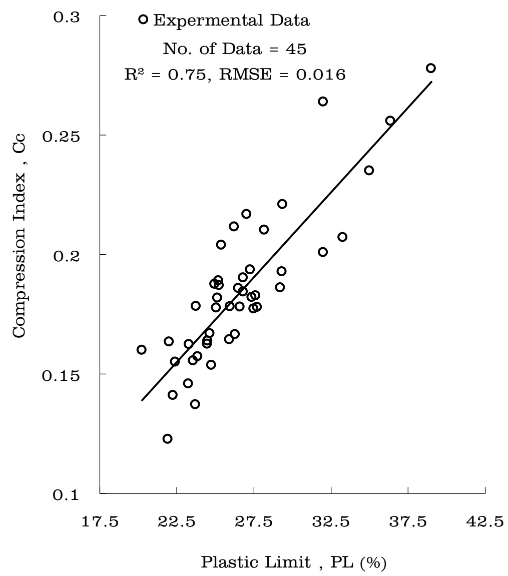

Fig.4: Relationship of Cc versus PL.

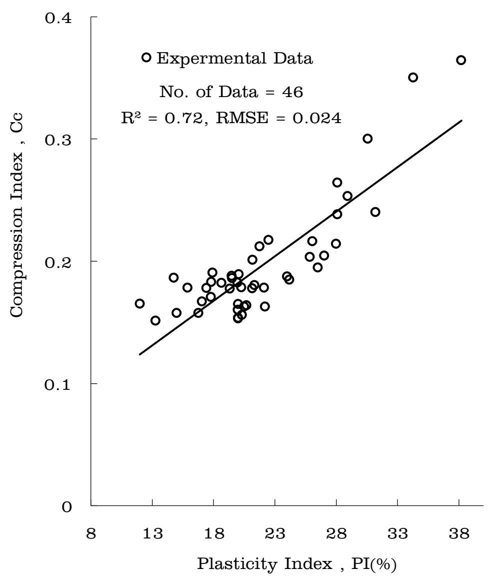

Fig.5: Relationship of C_c versus PI.

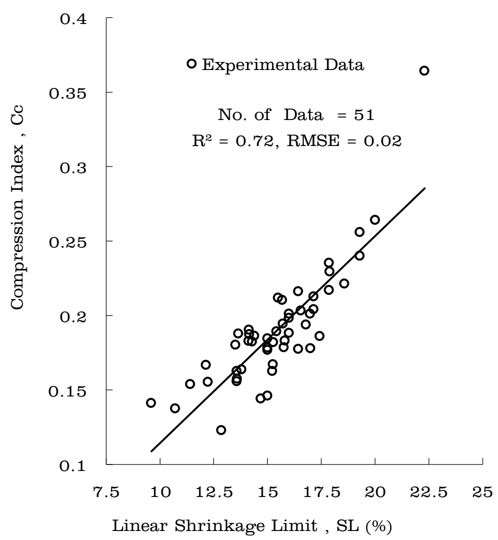

Fig.6: Relationship of C_c versus SL.

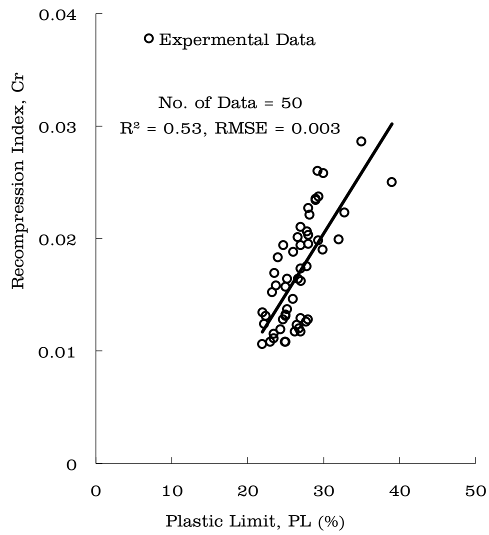

Fig.7: Relationship of Cr versus PL

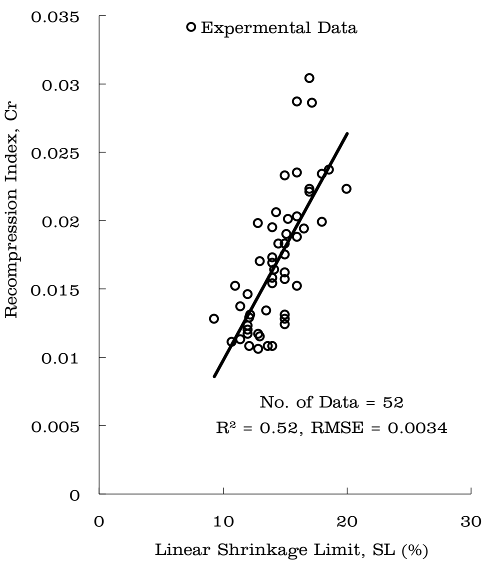

Fig. 8: Relationship of Cr versus SL..

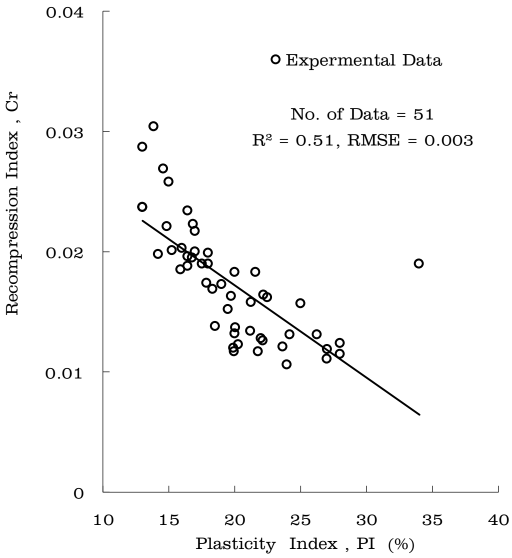

Fig.9: Relationship of Cr versus PI.

Table 1: Compressibility properties equations reported in the literatures.

Reference	Proposed Equations	R^2	No. of Data	Country	Remarks
Al-Kahdaar & Al-Ameri (2010)	$C_c = 0.0056\ LL$	0.86	-	Iraq	Silty clay with low to high plasticity soils, Al-Ammarah Soil in Messan Governorate of Iraq.
Solanki (2012)	$C_c = 0.006\ LL - 0.0024$ $C_c = 0.0082\ PI + 0.0915$	0.41 0.78	-	India	Remolded clays, 10 zones of Surat City and SUDA (Surat Urban Development Authority).
Abasi (2013)	$C_c = 0.007\ LL - 0.043$	0.4	26	Iran	Remolded clays.
Akayuli & Ofosu (2013)	$C_c = 0.004LL - 0.03$ $C_c = 0.003PL + 0.06$ $C_c = 0.007PI + 0.01$	0.78 0.43 0.58	60	Ghanaian	Sixty weathered Birimian phyllites undisturbed samples in the Kumasi area within the Birimian Formation.
Dway & Thant (2014)	$C_c = 0.0027\ LL + 0.2$ $C_c = 0.004\ PI + 0.22$ $C_c = 0.52 - 0.03\ LL + 0.03\ PI$	0.25 0.3 0.85	-	Mandalay	Disturbed soil samples collected from three locations at 3.0 feet and 6.0 feet depths in Mandalay.
Shaikh et al. (2014)	$C_c = 0.011LL - 0.102$ $C_r = 0.002PI - 0.007$ $C_c = 0.017PI + 0.180$	0.82 0.92 0.9	-	Bangladesh	Cohesive soil samples were collected from six places of Khulna city namely: Rupsa, Nirala, NewMarket, Sonadanga, Khalispur, and Goalkhali.
Lee et al. (2015)	$C_c = 0.012(LL+3)$ $C_c = 0.014(PI+20)$	0.38 0.32	-	Korea	Undisturbed and remolded Soil samples for Busan clays in Korea.

Table 2: GPS Data for the Selected Locations of this Study (all Samples Are Collected from Those Locations).

Name of Sample Zones	Sample No.	Latitude	Longitude	Name of Sample Zones	Sample No.	Latitude	Longitude
Qerga	1	35°31'18.35"N	45°28'26.70"E	Bakrajo	16	35°34'4.58"N	45°21'47.74"E
	2	35°31'35.23"N	45°28'18.19"E		17	35°33'39.71"N	45°21'20.34"E
	3	35°31'6.12"N	45°28'2.76"E		18	35°33'37.94"N	45°20'44.41"E
	4	35°31'33.20"N	45°28'49.17"E		19	35°33'27.32"N	45°20'31.24"E
	5	35°30'52.05"N	45°28'0.87"E		20	35°34'11.84"N	45°20'53.43"E
Swrga	6	35°39'18.90"N	45°19'53.69"E	Rapareen	21	35°35'24.40"N	45°20'11.88"E
	7	35°38'43.98"N	45°18'55.95"E		22	35°35'35.05"N	45°20'10.10"E
	8	35°38'20.10"N	45°18'18.62"E		23	35°35'34.51"N	45°19'50.38"E
	9	35°37'57.33"N	45°18'31.67"E		24	35°35'28.39"N	45°19'35.69"E
	10	35°37'38.88"N	45°19'55.79"E		25	35°35'15.90"N	45°19'25.39"E
Qularaesy	11	35°36'58.85"N	45°20'13.56"E	Xewete	26	35°37'34.79"N	45°24'41.94"E
	12	35°36'34.79"N	45°20'27.88"E		27	35°37'27.48"N	45°24'42.19"E
	13	35°36'16.06"N	45°20'23.55"E		28	35°37'21.90"N	45°24'34.78"E
	14	35°36'0.33"N	45°20'26.79"E		29	35°37'11.50"N	45°24'58.97"E
	15	35°36'16.50"N	45°21'16.82"E		30	35°36'51.34"N	45°25'6.92"E

Continued (Table 2)

Name of Sample Zones	Sample No.	Latitude	Longitude	Name of Sample Zones	Sample No.	Latitude	Longitude
Wllwbe	31	35°31'23.34"N	45°25'6.22"E	Homerekwer	46	35°33'9.76"N	45°27'31.10"E
	32	35°31'44.00"N	45°25'27.03"E		47	35°33'5.30"N	45°27'39.24"E
	33	35°31'55.96"N	45°24'53.75"E		48	35°33'7.85"N	45°27'46.58"E
	34	35°32'7.37"N	45°25'10.99"E		49	35°32'52.84"N	45°27'59.11"E
	35	35°32'13.70"N	45°25'19.35"E		50	35°33'3.92"N	45°28'2.96"E
Kellekn	36	35°36'14.51"N	45°25'18.16"E	Kelespy	51	35°34'23.20"N	45°16'24.74"E
	37	35°36'5.72"N	45°25'53.00"E		52	35°34'7.93"N	45°16'25.86"E
	38	35°36'3.53"N	45°26'36.24"E		53	35°33'58.14"N	45°16'23.63"E
	39	35°36'49.21"N	45°27'23.90"E		54	35°33'50.47"N	45°16'7.39"E
	40	35°37'11.19"N	45°25'55.14"E		55	35°34'2.35"N	45°16'11.53"E
Dabashan	41	35°33'47.19"N	45°28'22.69"E	Kenekewe	56	35°35'47.69"N	45°15'33.05"E
	42	35°34'14.99"N	45°28'10.49"E		57	35°35'59.11"N	45°15'25.66"E
	43	35°35'12.50"N	45°27'58.38"E		58	35°35'49.24"N	45°15'23.58"E
	44	35°35'59.93"N	45°27'44.64"E		59	35°35'57.48"N	45°15'14.11"E
	45	35°36'29.48"N	45°28'15.31"E		60	35°35'48.08"N	45°15'10.08"E

Table 3: The geotechnical properties of Sulaimani city soils.

Parameters	Range
Liquid limit (%)	35.5 - 65.2
Plastic limit (%)	20 – 37
Plasticity index (%)	15.26 – 28.2
Linear Shrinkage limit (%)	5.8 - 22
Compression index, C_c	0.12 - 0.36
Recompression index, C_r	0.011 - 0.03

Table 4: Summary of the proposed correlations for this study.

Eq. No.	Proposed Equations	R^2	No. of Data	RMSE	Fig. No.
1	C_c = 0.006 LL - 0.1	0.74	54	0.026	3
2	C_c = 0.007 PL - 0.005	0.75	45	0.016	4
3	C_c = 0.007 PI + 0.04	0.72	46	0.024	5
4	C_c = 0.014 SL - 0.024	0.72	51	0.02	6
5	C_r = 0.0011 PL - 0.012	0.53	50	0.003	7
6	C_r = 0.002 SL - 0.006	0.52	52	0.0034	8
7	C_r = -0.001 PI + 0.03	0.51	51	0.003	9
8	C_c = -0.11 + 0.01 LL -0.002 PI	0.72	60	0.015	-

List of Symbols

Symbol	Description
ASTM	American Society for Testing and Materials
C_c	Compression index
C_r	Recompression index
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
R	Correlation coefficient
R^2	Coefficient of determination
RMSE	Root Minimum Square Error
SL	Linear Shrinkage limit
SPSS	Statistical Package for the Social Science
USCS	Unified Soil Classification System