Research Article

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Geotechnical correlations of soil properties in Hilla City – Iraq

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Abstract: In this research, the geotechnical properties of the soil profile in Hilla city within Babylon Governorate in the middle parts of Iraq are described. The geotechnical data at the specific sites were collected from some geotechnical investigation reports performed at some selected locations. This article is devoted to studying the distribution of soil properties (the physical and mechanical) in the horizontal and vertical directions. Moreover, a correlation between different physical and mechanical properties is performed. The correlation is executed using statistical analysis by Microsoft Excel Software (2016). From the regression results, it was found that the nature of the soil is cohesive up to 15 m under the natural ground level, and the soil will change to noncohesive. The new line in the plasticity chart has been drawn parallel to A-line especially for the investigated region, the shear strength parameters depend on the consistency of the soil and the depth, and finally, there is a direct correlation between mechanical and physical parameters. Using these correlations with some available information help to predict the value of shear strength and consolidation parameters.

Keywords: liquidity index, unconfined compressive strength, natural water content, standard penetration test, Microsoft Excel software, Iraq

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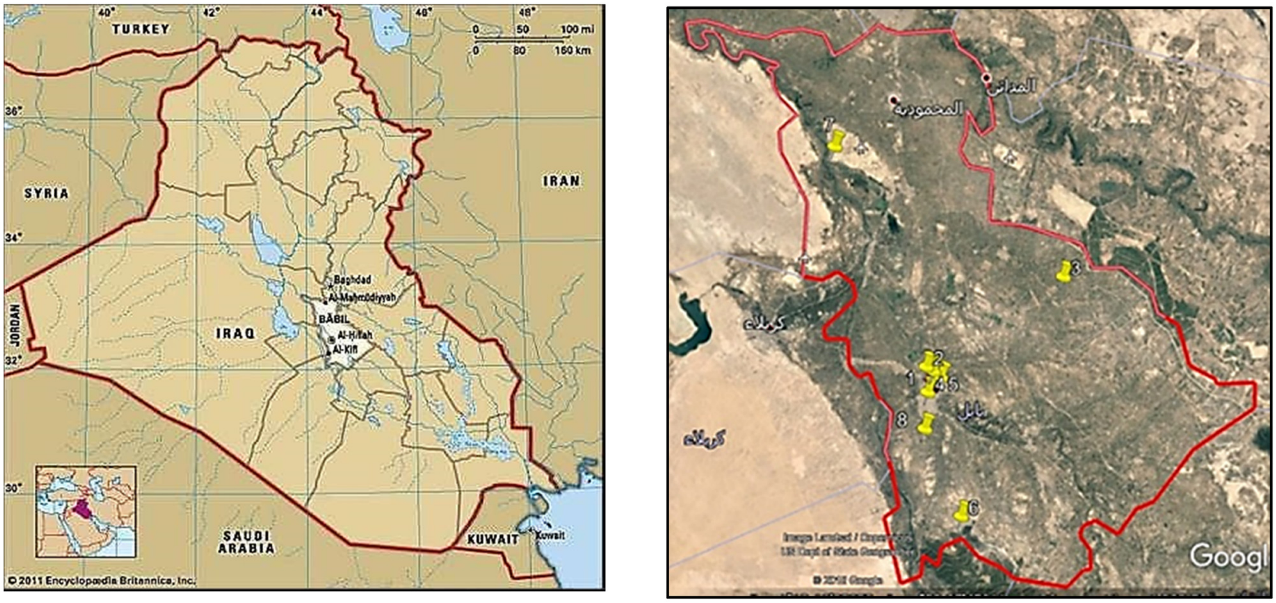
1 Introduction

Babylon Governorate lies between 32° and 33.25° North latitude and 44° to 45° East line of longitude in Iraq. Hilla City lies about 100 km south of Baghdad as shown in Figure 1(a), as well as the Euphrates River crosses this city. Generally and at shoaly depth, the district consists of nonuniform distribution of different stratums. Buringh [1] attributes this nature of distribution to its recent age of sedimentation. The nature of the field is dry to semi-dry, and the average yearly rainfall in that area varies (ranging from 50 mm or less to 200 mm). During summer, temperatures could reach 50°C. In winter, the weather is mild generally [2]. The location of the tested field is shown in Figure 1(b) in the satellite view.

In the last decay, many researches were performed to correlate the mechanical properties with the physical properties. This approach was adopted to save time and reduce the cost of site investigations. In addition, to appoint a preliminary foundation design before performing detailed site investigations. This approach was adopted from the earlier researcher in the field of soil mechanics and foundation engineering. Some of these correlations are listed in the studies by Bowles [3], USDA [4], and Look [5].

The validity of this correlation is mainly dependent on the number of available data and rigorous statistical analysis [6]. Ragab [7] found correlation equations between elements concentration and mechanical properties predicting approximately the element concentration for any soil in the Sultanate of Oman at any time with less cost to evaluate the strength of the material. Hossain et al. [8] carried out a study at the riverbank of the Rupsha River, Khulna, Bangladesh, to investigate the relationships of soil parameters using the most commonly used soil investigating tools such as standard penetration test (SPT) and cone penetration test (CPT). To enhance the precision of mechanical properties for rock, correlations among parameters (physically and mechanically) were conducted on 408 rock specimens by Liu et al. [9]; the correlation between



(a) (b)

Figure 1: Location of Hilla city: (a) the map of Iraq and (b) the satellite image of the field.

elastic Young's modulus and dynamic elastic modulus was found, and also the relationship among shear modulus and dynamic shear modulus.

Fattah et al. [10] investigated the ground response analysis (calculation of site natural periods, amplification of ground motion, and stability analysis) for two sites in Al-Hilla city in the middle of Iraq.

Duan et al. [11] made an intensive study on Mega Project called "Hong Kong-Zhuhai-Macao Bridge." The outcomes were as follows: correlations among soil parameters and piezocone penetration resistance, with special reference to strength, physical, and deformation characteristics, are determined. Dyka et al. [12] presented the results of lab tests, which verify the correlation between the grain-size characteristics of noncohesive soils and the value of the dynamic shear modulus.

Phoon [13] distinguished two major sources of uncertainties in geotechnical parameters. The first comes from the evaluation of shear strength parameters in geotechnical design and the second one is from the models used to calculate the geotechnical parameters. Although several models are simple, it still complexes in some geotechnical application problems such as soil–structure interaction. Abdel-Rahman [14] established a correlation between index tests and the parameters of clay from various places in the Nile valley and Delta region in Egypt. It was shown that clay content influences the liquid limit (LL). The plastic limit (PL), LL, and plasticity index (PI) increase with the increase in the moisture content; moreover, the undrained shear strength of the Egyptian clay increased with the depth.

Fattah et al. [15] investigated the geotechnical characteristics of the soft clays southern Iraq (Garmat Ali).

Al-Khaddar and Al-Ameri [16] performed an intensive study for the correlation of different soil properties in Amarah city within Missan Governorate in the southern parts of Iraq. They made several correlations with enough degree of confidence in the statistical results. Yilmaz [17] used clayey soil, a survey was conducted to evaluate the shear strength, the liquidity index (LI) was used from numerous places in Turkey and was found that

$$c_u = \exp(0.026 - 1.21\, LI)$$
$$\text{with the coefficient of correlation } R^2 = 0.93,$$

where c_u is the undrained cohesion (kPa), LI is the liquidity index, and R^2 is the coefficient of correlations.

Al-Busoda [18] evaluated the properties of cohesive soil in Baghdad, which depend on the unit weight and Atterberg limits. A new line (named Baghdad line) was suggested on the plasticity chart located slightly above the A-line in addition to estimating a new correlation between the total unit weight and the dry unit weight as follows:

$$\gamma_d = 1.20492\, \gamma_{wet} - 7.7961 \text{ with } R^2 = 0.812,$$

where γ_d is the dry unit weight (kN/m^3) and γ_{wet} is the wet unit weight (kN/m^3).

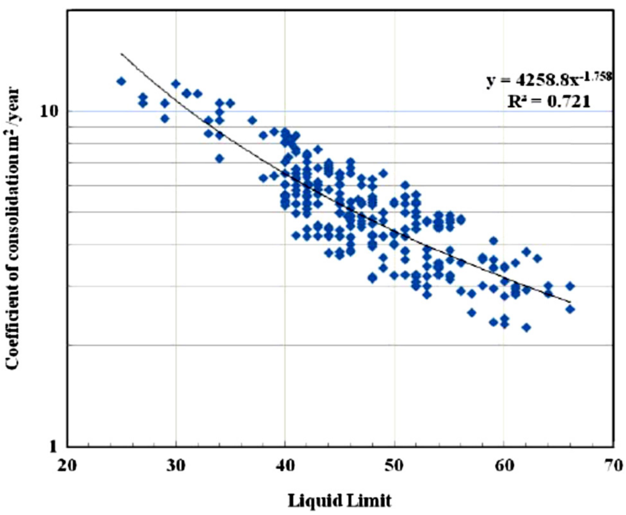


Figure 2: Coefficient of consolidation against LL for Iraqi soils(Al-Tae'e and Al-Ameri [20]).

Khamehchiyan and Iwao [19] carried out an intensive study on the most problematical soil in Japan "Ariak soft clay" and found a correlation between physical and mechanical properties by using the simple regression process, which was enough to estimate some geotechnical properties. Al-Tae'e and Al-Ameri [20] examined the relationship between the water contents and the factor of consolidation for various soils in Iraq. Thus, they concluded that for Middle and South Iraqi soils, the consolidation factor could be calculated when the value of the LL is known, as shown in Figure 2. Al-Taie [21] performed an experimental program at five logistic locations in Basra City (south of Iraq). The research program includes well-defined laboratory tests to identify the constituents of the soil, and then a typical soil profile was introduced.

Roopnarine et al. [22] conducted a detailed study on about 30 soils (Trinidad) to investigate the correlated

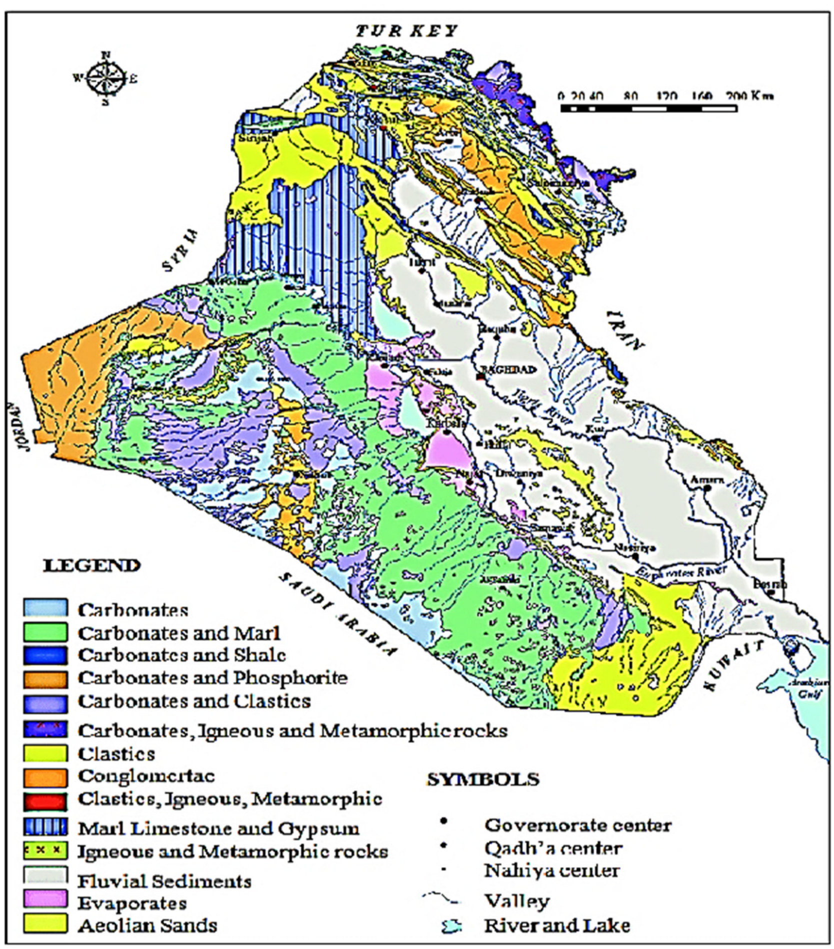


Figure 3: Geological map.

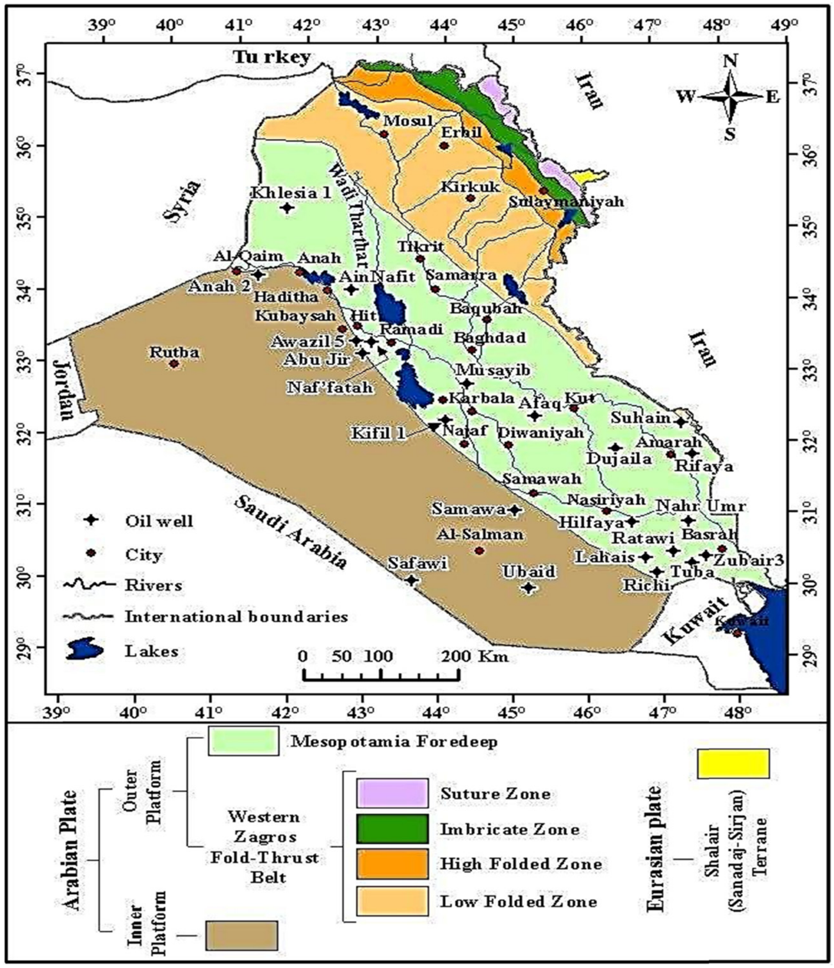


Figure 4: Tectonic map of Iraq.

shear strength and index properties of soil in the slope stability analysis. They concluded that great improvement in the land management and slope stability prediction was achieved throughout the intensive statistical analysis. Al-Jabban [23] performed an assessment study for the soil profile at southern parts of Iraq. The study evaluated the soil profile throughout drilling five boreholes (B.H) at different locations. It concluded that the predominant profile consists of silty clay to clayey silt with a mark of sand at shoaly profundity (about 6 m from the natural ground level). Then, after 6 m, the amount of sand content increases with the increase in the depth. The sand content decreases after 9 m depth. Kadhim and Al-Abody [24] created a geotechnical map for the distribution of the bearing

Table 1: Summary of sites and soil reports

Site name	Site No. on Figure 1(b)	Total No. of B.H
Building of foundation distribution Alforat Medium/Babylon Branch	1	2
Tilal Babylon residential complex	2	12
Supplying and construction of typical slaughter hall	3	6
Construction of two stories building	4	2
Ancient BABYLON site	5	2
Construction of Babylon central prison at Kefil	6	6
AL-KIDER local police station	7	2
Babylon University	8	20

Table 2: The properties of the soil according to laboratory Tests

Soil properties		Range
Physical properties	Void ratio (e_o)	0.563–1.258
	LL%	21–70
	PL%	12–39
	PI%	3–43
	LI	−7.33–2.068
	Natural content of water (ω_n)%	11.21–39
	Global unit weight (γ_t) (kN/m^3)	18.05–22.54
Mechanical properties	SPT, no. of blows	5–50
	Unconfined compressive strength (kN/m^2)	20.8–270
	Compression index (c_c)	0.111–0.443
	Swelling index (c_s)	0.01–0.058

capacity for the soil of Al-Imam area in Babylon in Iraq by using the Geographical Information Systems. It was found that the soil in the Al-Imam area is the stratified soil and consists mainly of cohesive soils of silty clay to clayey silt and sometimes silty sand.

Salih [25] conducted two sets of tests on Barika, Arbat, and Hwana soils in Sulaimani Governorate, Iraq. Their tests were detected to study the possibility of correlation of different soil parameters for shear strength and compressibility requirements. They found that the perfect correlation was obtained among PI and LL with R^2 = 0.874. However, nothing was observed among the coefficient of compressibility, compression index, and consistency properties.

The correlation is not only detected for the laboratory soil parameters but also adopted for field tests. Shahri

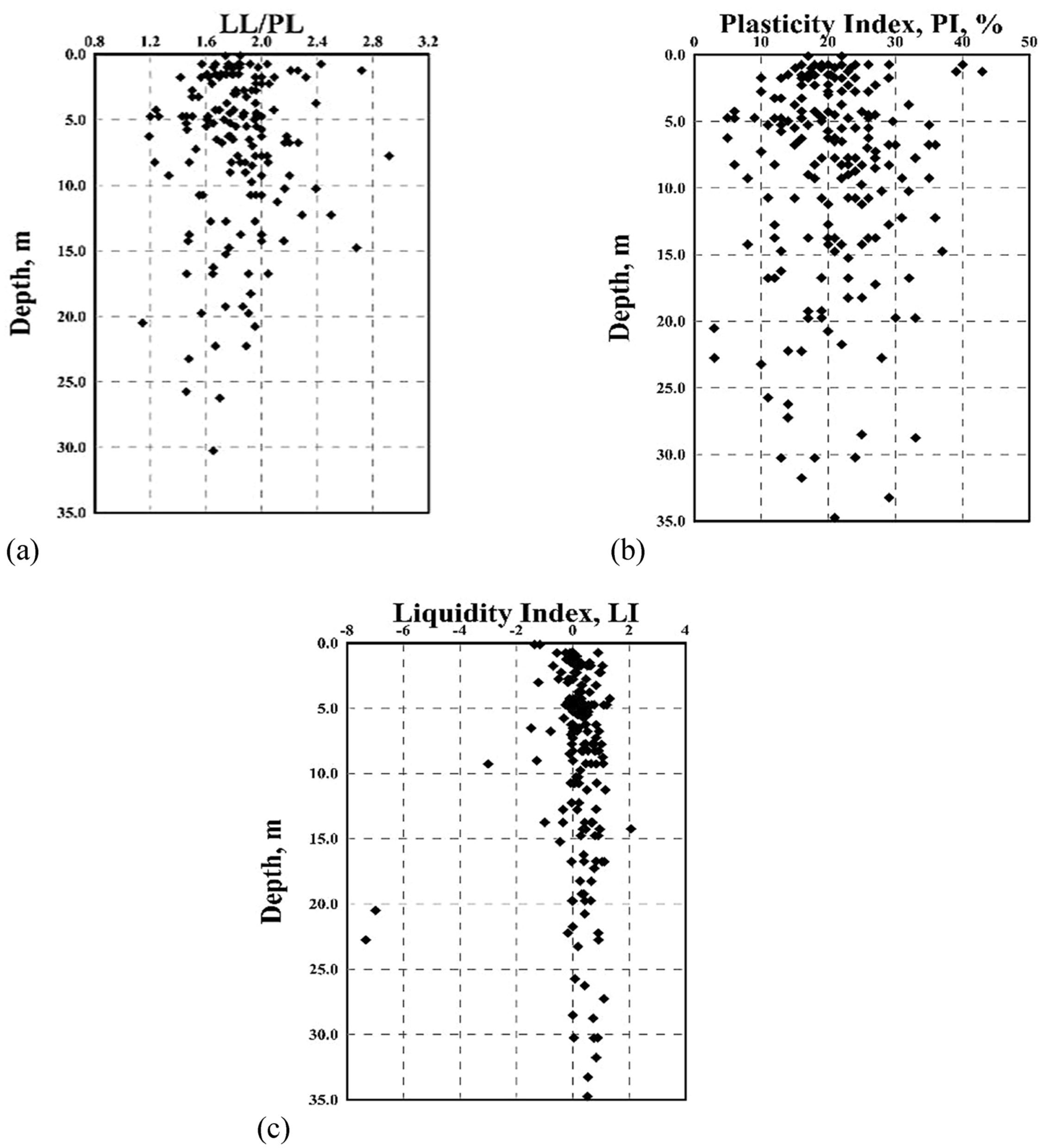


Figure 5: Variation of the Atterberg limits and LI with depth: (a) LL/PL, (b) PI (%), and (c) LI.

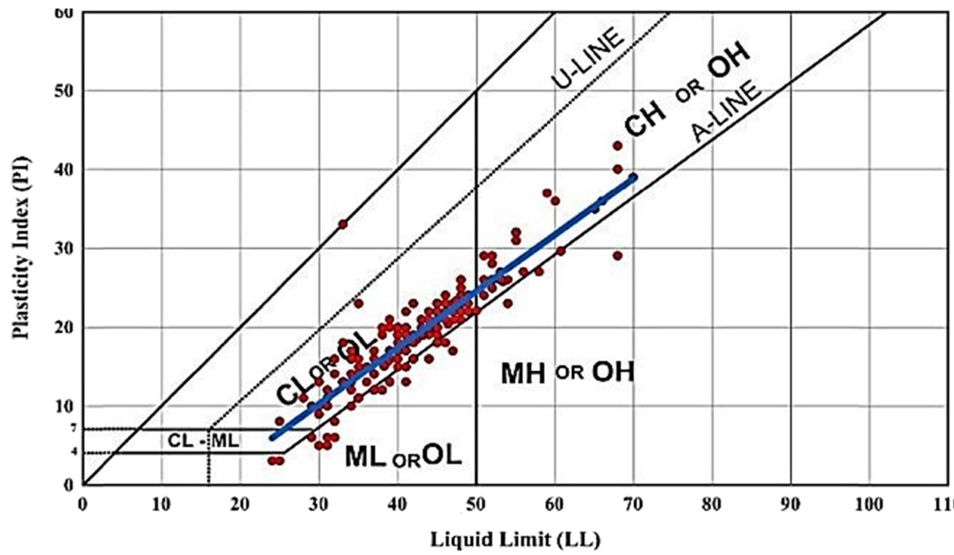


Figure 6: Plasticity chart for the soil samples according to ASTM D2487.

et al. [26] found that the SPT results correlated with CPT results. They found that a high correlation coefficient is obtained for the investigated parameters, and the filtering technique for some data would increase the correlation coefficients.

Mandeel et al. [27] conducted a study on full-scale model shallow foundations on layered soil. From the obtained results, two equations were derived with the use of regression analysis for predicting the ultimate bearing capacity. Fattah et al. [28] determined the shear strength, permeability, and soil water characteristic curve (SWCC) of unsaturated soils. The SWCC is converted to a relation correlating the void ratio and matric suction; the outcomes showed that the undrained shear strength increases with the increase of matric suction, and the coefficient of permeability decreases with the increase of matric suction. Afrasiabi et al. [29] conducted a comparison of alternative soil particle-size distribution models and their correlation with soil physical attributes. Mohammed and Mahmood [30] studied the statistical variations and new correlation models to predict the mechanical behavior and ultimate shear strength of gypsum rock.

Olia et al. [31] investigated the performance of ground-anchored walls subjected to dynamic and pseudo-static

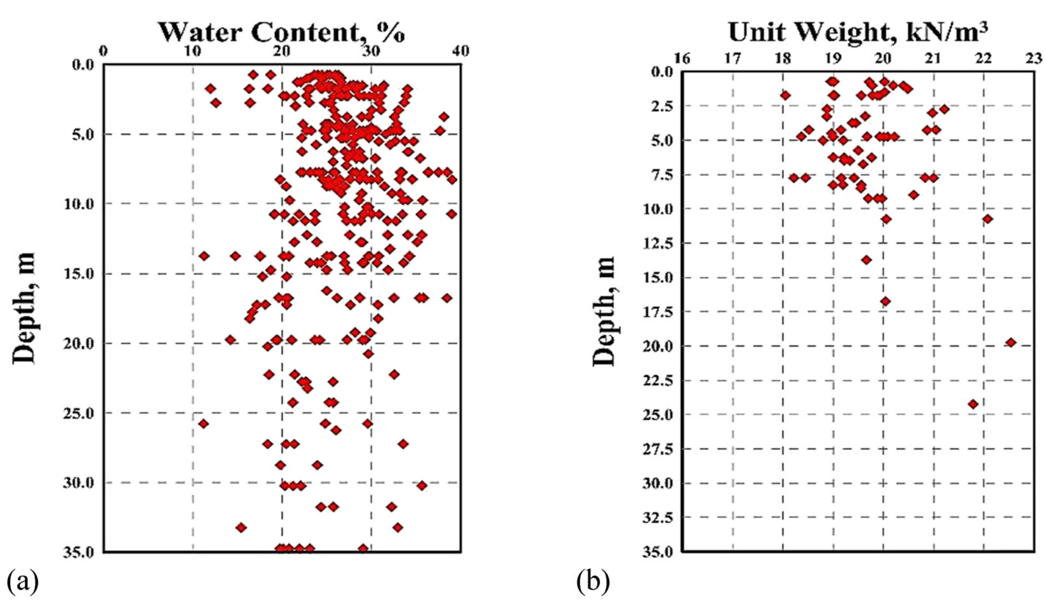


Figure 7: Variance of the water content and the unit weight with depth: (a) water content (%) and (b) unit weight (kN/m^3).

loading depending on predetermined soil parameters at the site. Vali [32] evaluated the effects of the water table on the behaviors of the reinforced marine soil-footing system in Qeshm Island, Iran. The study includes calibration and verification of different soil properties at the site. Arshid [33] studied the prediction of standard penetration resistance of soil using geotechnical database (particle sizes and Atterberg's limits).

This investigation can be employed as a primary source of information to estimate the site characteristics of the region. Also, it can be employed as potential data for city planners, civil and geotechnical designers, and structural constructions.

In this research, an attempt was made to correlate the different soil properties at selected locations within the middle parts of Iraq. The data were collected from 52 geotechnical boreholes and tested in the laboratories of the consulting engineering bureau at the University of Baghdad.

2 Geology of the field

The study area is influenced by geological motions in the region that created an asymmetrical sediment fold with a

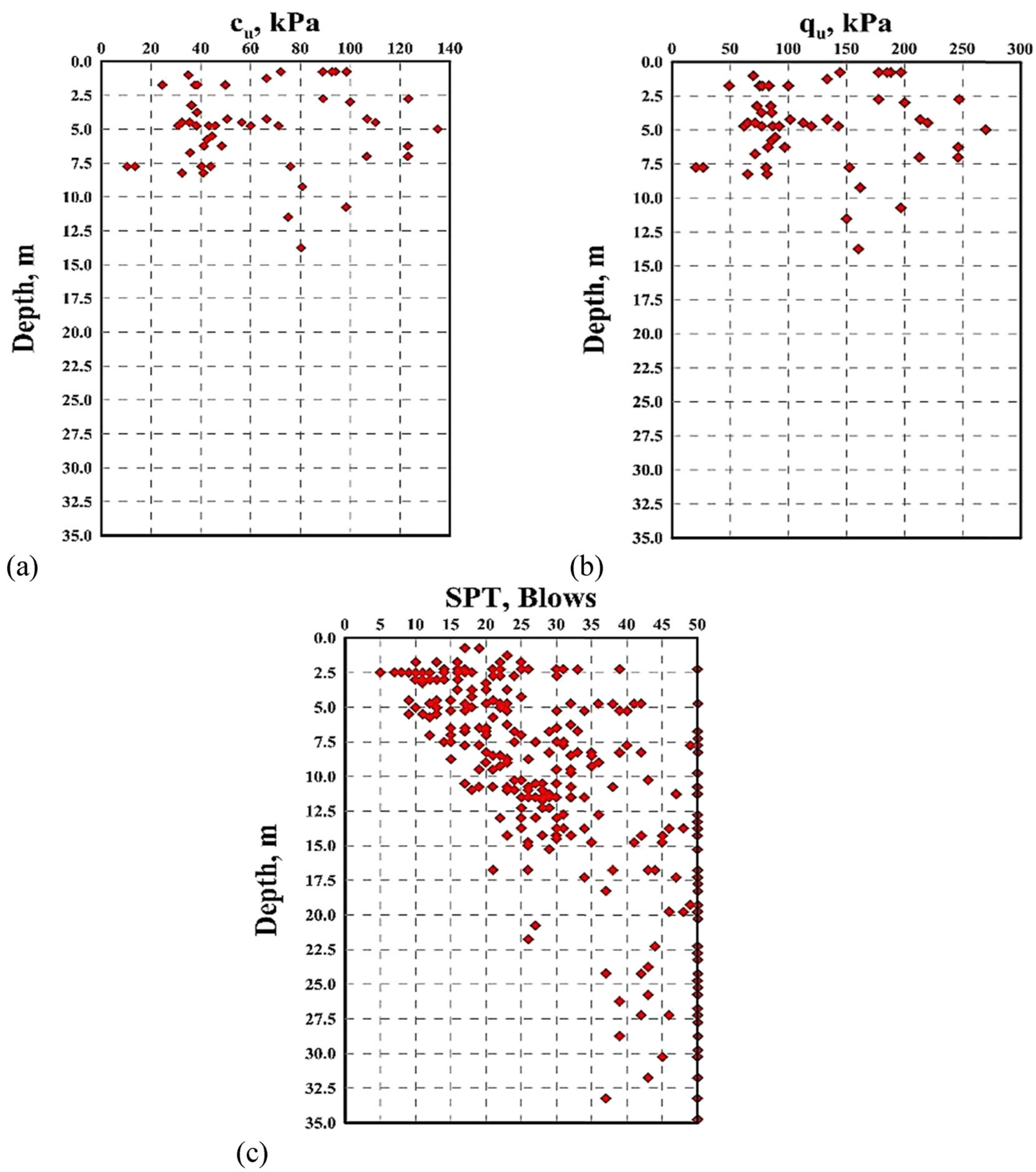


Figure 8: Variation of examined parameters with depth: (a) undrained cohesion (c_u), (b) unconfined compressive strength (q_u), and (c) SPT.

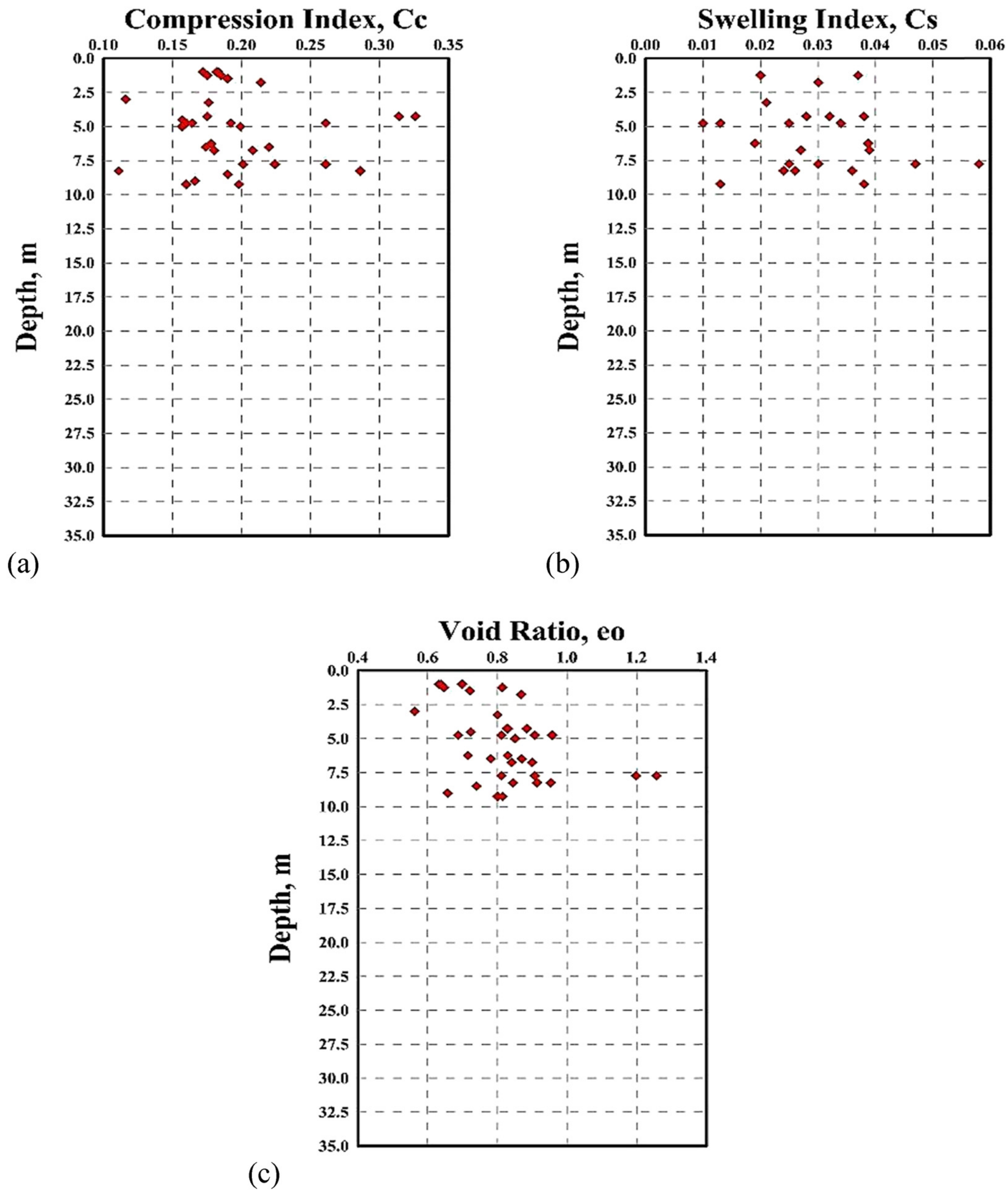


Figure 9: Variation of the c_c, c_s, and e_o with depth: (a) compression index (c_c), (b) swelling index (c_s), and (c) void ratio (e_o).

concave shape level and still fills the trough containing the sediments from the river and more, as shown in Figure 3. In addition, the tectonic map of Republic of Iraq is shown in Figure 4. The study region is located in the plain of alluvium of the new Quaternary leavings in the era of Pleistocene-Holo [1,34]. Geologically, the selected area mainly comprises sediments from the Quaternary of both species (Pliocene to Miocene age). Flood deposits consist of a thin stratum of clay, fine sand and silt, and silt clay with consecutive layers of clay, sand, and rock in the examined area. The investigated area is considered a flat surface level with a 22 cm/km slope. Some sand dunes have been found in some isolated parts "such as southern parts of this study."

3 Methodology of the study

In the present research, the geotechnical properties of the soil collected from 52 geotechnical boreholes were determined, which were collected from various places within the tested area as illustrated in Figure 1(b). Information was taken from soil investigation records conducted by

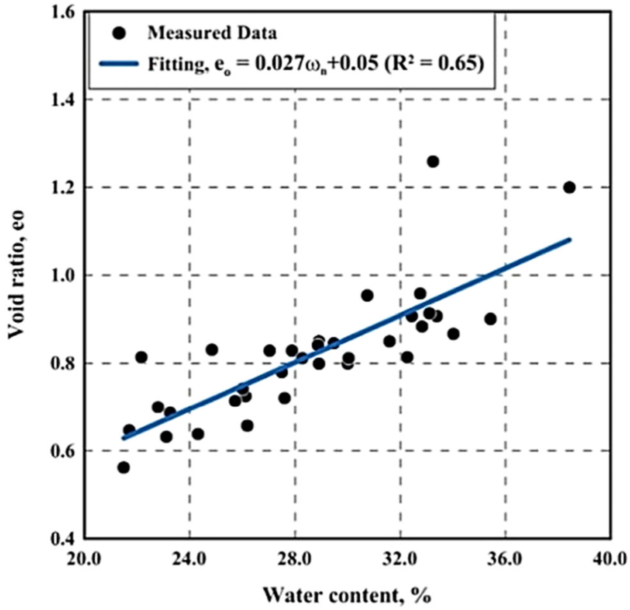


Figure 10: Void ratio versus water content relationship.

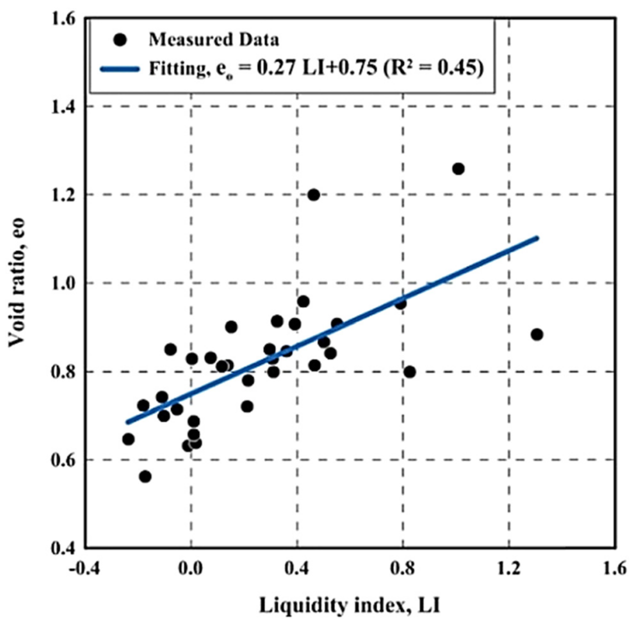


Figure 11: Void ratio versus LI relationship.

the consulting engineering bureau at the University of Baghdad. The sites that have been taken into consideration are listed in Table 1, and their locations are indicated in Figure 1(b). The analysis was performed by using simple regression analysis using Microsoft Excel (2016) Software. Some erratic data were neglected in the statistical analysis. These data may be of very high value or very low value. The elimination of these data depends on local experience in the investigated area.

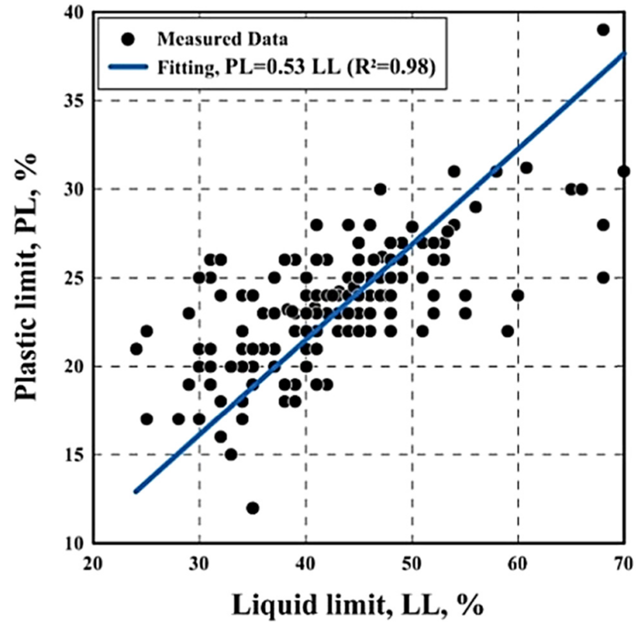


Figure 12: PL versus LL relationship.

4 Variation of the soil geotechnical parameters

All the ranges of the collected physical and mechanical properties of the soil are presented in Table 2. The variations of any soil property would be correlated with the other one according to the target of a certain correlation. Moreover, the statistical analysis includes the correlation between laboratory and field tests.

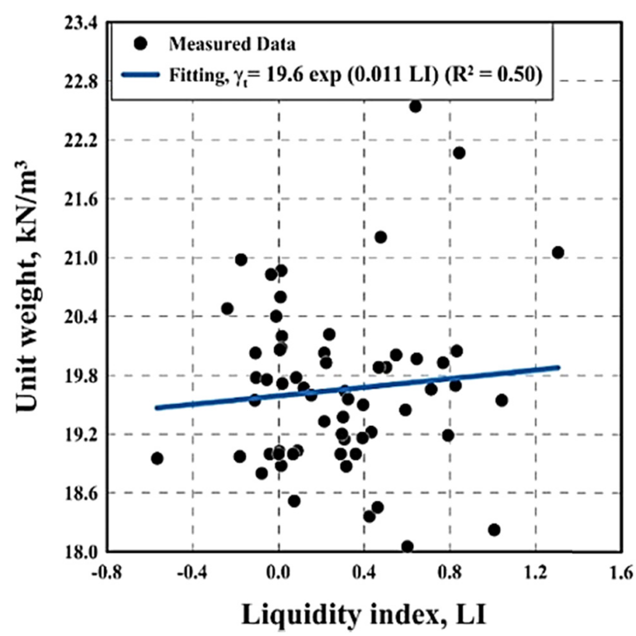


Figure 13: Unit weight versus LI relationship.

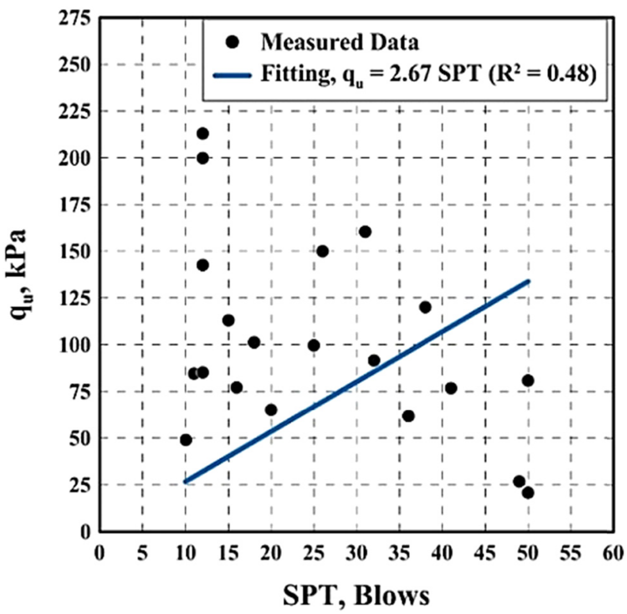


Figure 14: Unconfined compressive strength versus SPT relationship.

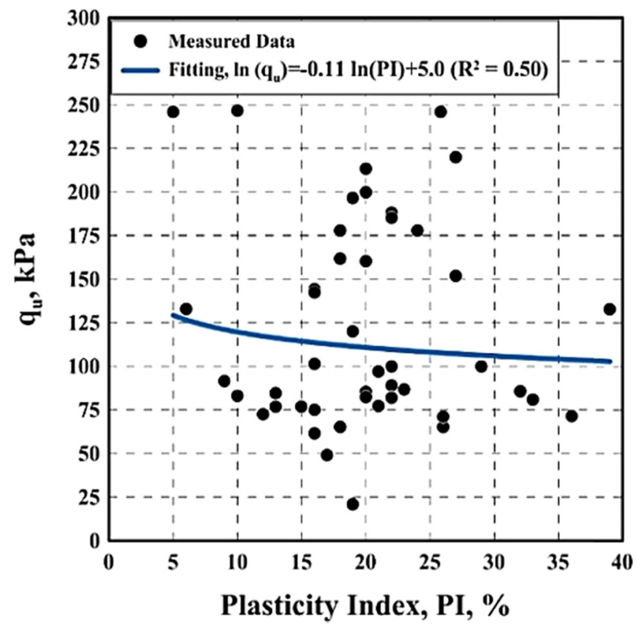


Figure 16: Unconfined compressive strength versus PI relationship.

4.1 Atterberg limits

The variation of liquid limit/plastic limit (LL/PL), PI, and LI with depth is illustrated in Figure 5. It can be seen that the Atterberg limits are almost uniform at the upper 15.0 m, which means that the soil has the little change in the water content of soil and degree of saturation with depth; moreover, about 90% of the LI falls within −1.0 to 1.0. Figure 6 shows the results of the plasticity chart of the investigated soil samples, and the new blue line was drawn depending on the results of PI of soil samples, which was parallel to A-Line of the plasticity chart, and this line can be determined by the equation with R^2 = 0.91:

$$PI_{Hilla} = 0.715\,(LL - 11.255), \tag{1}$$

where PI is the plasticity index (%) and LL is the liquid limit (%).

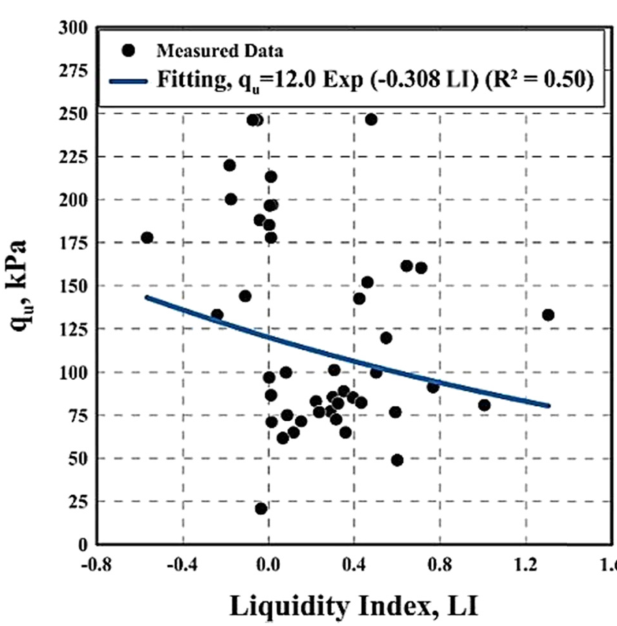


Figure 15: Unconfined compressive strength versus LI relationship.

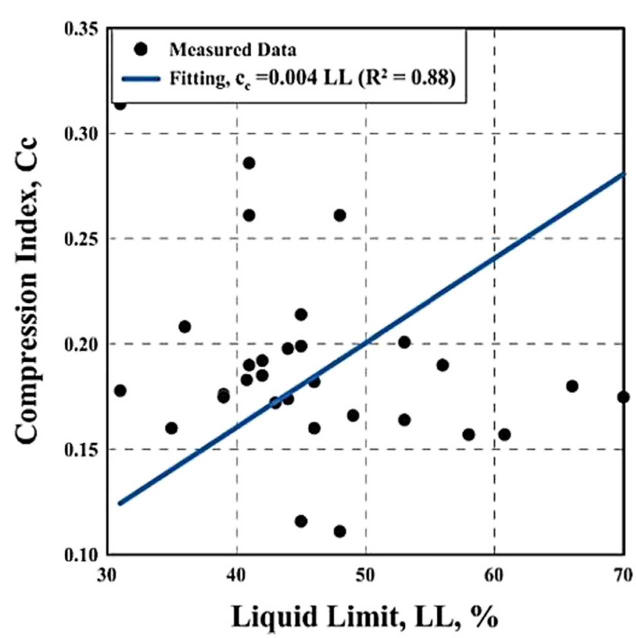


Figure 17: Compression index versus LL relationship.

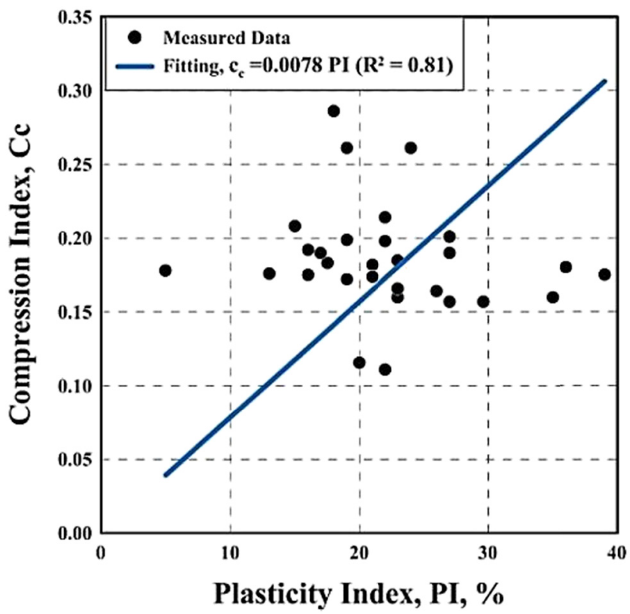


Figure 18: Compression index versus PI relationship.

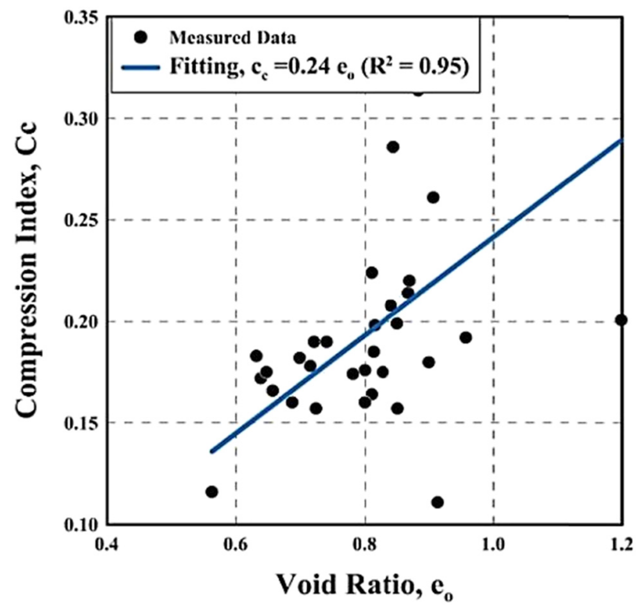


Figure 20: Compression index versus void ratio relationship.

4.2 Water content and unit weights

The distribution of the water content (ω_n) and the total unit weight (γ_t) with depth is shown in Figure 7. It can be noticed that the variance of the water content seems to be uniform. In addition, the water content depends on the presence of groundwater, which means the variance of water content with the depth is very slight because the water table is about 1 m below the surface, while the unit weight increased with the depth. Also, at shallow depths, the values of water content were low due to the climatic conditions in the study area (desiccation).

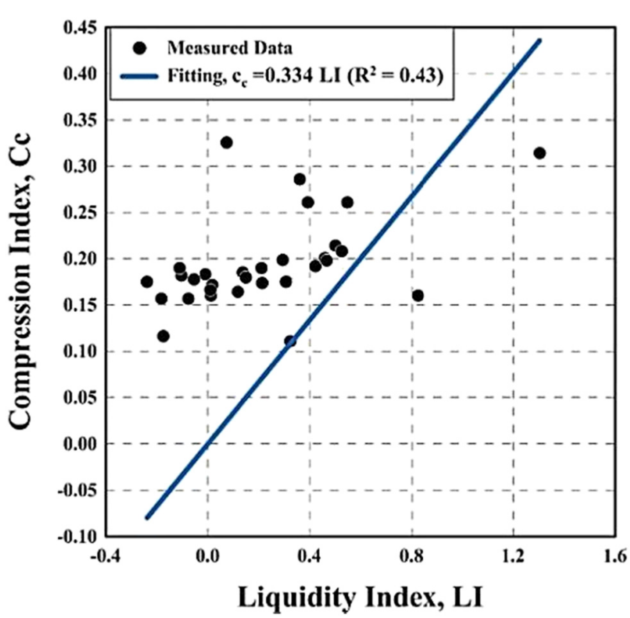


Figure 19: Compression index versus LI relationship.

4.3 SPT and shear strength parameters

The nature of the soil in this research is classified as clay soil. The variation of the shear strength parameters (i.e., undrained cohesion (c_u) and the unconfined compressive strength (q_u)) distribution with depth is shown in Figure 8. Also, the variation of the SPT values with depth is shown in Figure 8. These figures revealed that the shear strength increased with increasing the depth due to the consistency of soil change with depth. At shallow depth, the uniformity of soil is soft or moderate, and with an increase in profundity after 4 m from the natural ground level, the soil will change to stiff or very stiff, and with increasing the depth, the soil becomes hard soil at 7 m; moreover, the soil may change from cohesive soil to noncohesive soil at a depth of more than 15.0 m.

4.4 Consolidation parameters

The variation of the consolidation parameters expressed as compression index (c_c) and swelling index (c_s), and the void ratio with depth is shown in Figure 9. The distribution of the settlement parameters (c_c and c_s) is not

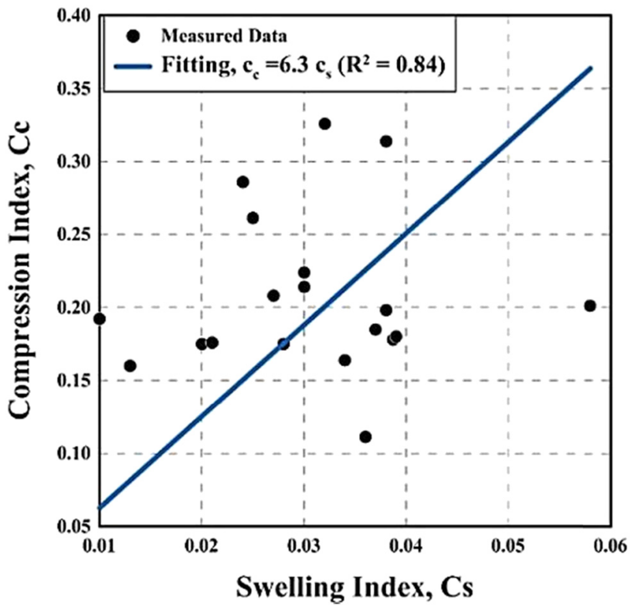


Figure 21: Compression index versus swelling index relationship.

uniform and vary widely in horizontal and vertical directions due to the change in the value of overconsolidation ratio of the site as the site may be under traffic load or may be situated in the empty area. It is important to state herein that in the design stage, the settlement of the clayey layers must be well elaborated before concluding the final bearing capacity of the soil for such site conditions.

5 Correlations of different geotechnical properties

In the engineering practice of geotechnical problems, the designer needs some data that may be missed or unreliable. Hence, the estimation of a certain parameter from others may be required. For this case, a correlation between different physical properties will be performed.

5.1 Physical properties

The relationship among the initial void ratio (e_o), natural water content (ω_n), and LI is shown in Figures 10 and 11. The findings of the statistical fitting simulation are illustrated in the upper legend of each figure. In the same way, the relationship between PL and the LL is illustrated in Figure 12, and the variation of total unit weight (γ_t) with LI is illustrated in Figure 13. A good correlation is obtained when the physical properties are correlated to each other.

5.2 Shear strength properties

The estimation of the shear strength parameters is one of the most important targets of the correlation articles. For this purpose, the relationship between unconfined compressive strength (q_u) with the SPT values, LI, and PI was studied as shown in Figures 14–16, respectively. It can be seen that the coefficient of correlations (R^2) is about 0.5, which considered being good due to the uncertainty in the soil constitutes for different site locations.

5.3 Consolidation properties

The consolidation parameters are used to estimate the settlement and rate of consolidation of cohesive soils. The variation of consolidation parameters (c_c, c_s, and e_o) with different basic physical properties was investigated. The variation of compression index (c_c) with LL, PI, and LI is illustrated in Figures 17–19, respectively. Moreover, the variation of compression index (c_c) with the void ratio (e_o) is shown in Figure 20. Finally, the relationship of the compression index (c_c) with swelling index (c_s) is shown in Figure 21.

All the figures for the consolidation parameters show an excellent relationship through the values of the coefficient of correlations (R^2).

Table 3: Correlations between physical and mechanical properties of clayey soil

Parameter	Correlations	R^2	Eq. No.	Figure No.
e_o	$0.027\omega_n + 0.05$	0.65	2	10
e_o	0.27 LI + 0.75	0.45	3	11
PL	0.53 LL	0.98	4	12
γ_t	19.6 exp(0.011 LI)	0.50	5	13
q_u	2.67 SPT	0.48	6	14
q_u	12.0 exp(−0.308 LI)	0.50	7	15
ln q_u	−0.11 lnPI + 5.0	0.50	8	16
c_c	0.004 LL	0.88	9	17
c_c	0.0078 PI	0.81	10	18
c_c	0.334 LI	0.43	11	19
c_c	0.24 e_o	0.95	12	20
c_c	6.3 c_s	0.84	13	21

6 Summary of the statistical analysis

A summary of findings of the statistical analysis that relates some geotechnical parameters with each other is presented in Table 3. This table includes the correlation between physical parameters with each other in addition to the correlation between physical and mechanical parameters. Also, correlations are good to fair and can be adopted for design and investigation purposes.

7 Conclusion

Through the results of the statistical analysis presented in this study, the following conclusions can be obtained:

1. The soil at the upper 15 m is always cohesive soil, and then, it turns to noncohesive soil.
2. A-line for Hilla soil was suggested, and it was parallel to the original A-line of the plasticity chart.
3. The shear strength of the soil is affected by the soil type and the location. It varies with the consistency of the soil along the depth.
4. The settlement parameters are affected by the nature of the site and location. In general, the values of the compression index and the swelling index were uniform and can be assessed with sufficient accuracy. The settlement parameters increased with the depth for the same soil type.
5. Correlation equations regarding shear strength and consolidation parameters with physical properties were obtained.

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Conflict of interest: Authors state no conflict of interest.

Data availability statement: All data are presented and available in the article.

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