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Evaluation of Geotechnical Properties of Soil at Selected Sites in Al-Nasiriya City

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Abstract

Soil index properties are used to calculate and determine the geotechnical properties of soils and then determine soil suitability for the construction of engineering projects. Most of the geotechnical properties of soil affect each other directly or indirectly, and these properties can be utilized as indicators to calculate other properties.

In the present study, some soil index properties were used to identify the geotechnical properties of soil. According to the unified classification system for soil, most soils were classified as low and high plasticity hilt. In addition, the soils showed a medium to a high degree of expansion according to the values of the Atterberg limit and were generally considered inactive clay soil. Based on the Standard Penetration Test values, consistency index, and compression index, the soil was stiff to extremely stiff and had high to extremely high compressibility. Finally, the results showed the need for soil for some engineering works, such as stabilization and modification, before the construction of engineering projects.

Keywords: Geotechnical Property, Plasticity, Standard Penetration Test, Compression Index, Nasiriya City.

تقييم الخواص الجيوتكنيكية للتربة لمواقع مختارة في مدينة الناصرية

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الخلاصة

تستخدم الخواص الدالة للتربة في تحديد الخواص الجيوتكنيكية لها ومن ثم تحديد مدى ملائمتها في انشاء المشاريع الهندسية. معظم الخواص الجيوتكنيكية للتربة تؤثر على بعضها البعض بشكل مباشر أو غير مباشر كما وتستخدم كمؤشرات لحساب الخصائص الأخرى للتربة. في الدراسة الحالية تم استخدام بعض الخصائص الدالة للتربة للتعرف على خصائصها الجيوتكنيكية. وفقاً لنظام التصنيف الموحد للتربة فأن معظم تربة منطقة الدراسة تصنف على انها تربة غرينية منخفضة اللدونة الى تربة غرينية عالية اللدونة، كما انها صنفت على انها ذات درجة عالية من الانتفاخ وفقاً الى قيم حدود اتيربرغ إضافة الى انها تعتبر غير فعالة. وفقاً الى قيم فحص الاختراق القياسي، دليل القوام ودليل الانضغاط فالتربة تعتبر قوية الى جداً قوية وذات انضغاطية عالية الى جداً عالية. وأخيراً فان نتائج الدراسة الحالية تشير الى ان تربة منطقة الدراسة بحاجة الى بعض الاعمال الهندسية لتحسين خواصها قبل البدء في انشاء المشاريع الهندسية

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1. Introduction

The composition of soils is complex, and their engineering behavior varies from place to place, despite having some similarities in physical or chemical properties. Each soil type is characterized by its unique geological deposition history and originates from a particular rock type with a specific mineral composition found in a region with a distinct climate pattern [1].
Soil is a critical natural resource used in various engineering applications, including the construction of roads, bridges, and buildings. To determine its suitability to such purposes, numerous tests must be conducted to evaluate soil properties [2, 3].

Soil index properties offer insights into the type and condition of soil and are extensively used by geotechnical engineers for analysis purposes; these properties deliver valuable information and indications about the engineering properties of soil, such as shear strength and compressibility [2-6].

Determining soil index properties provides an understanding and sheds light on the soil condition used in civil engineering projects; it also helps predict potential problems and offers necessary solutions for prevention or mitigation [1].
This study investigates the index properties and behavior of Al-Nasiriya soil to assess its suitability for engineering projects in the area.

2. Study Area and Geological Setting

The study area is located in Nasiriya City, the capital city of Thi-Qar Governorate, on the Euphrates River, as shown in Figure 1. The climate of Nasiriya City is characterized by a long, dry and hot summer that changes to cold and rainy in the winter [7].

From a geological point of view, the study area is located in the Euphrates Subzone within the Mesopotamian Zone in the Stable Shelf. The area is covered by Holocene sediments, originating from the floodplain sediments and is characterized by a flat topography [8].

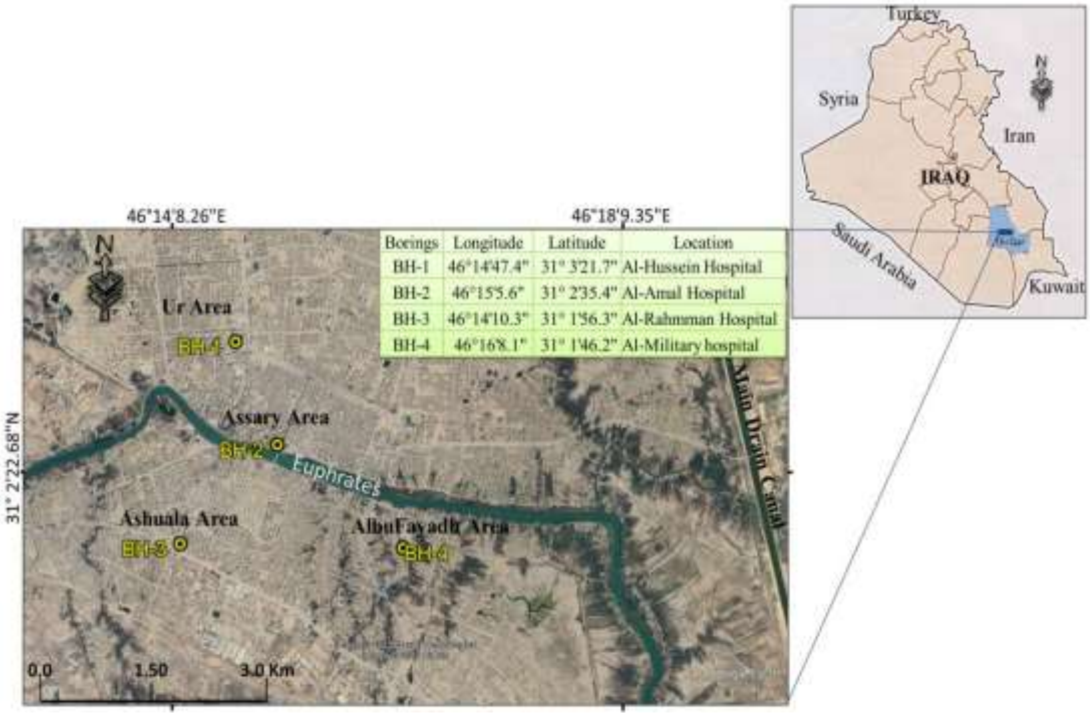

Figure 1: Location map of the study area

3. Materials and Methods

The data were taken from subsurface soil test reports conducted by construction laboratories (The National Center for Construction Laboratories (NCCL)), focusing on subsoil investigations for specific sites: Al-Hussein Teaching Hospital (Site 1), Al-Amal Hospital (Site 2), Al-Rahmman Hospital (Site 3), and a military hospital (Site 4). All tests were conducted according to established standards [9, 10].

The data of physical parameters for the study site, such as grain size distribution (clay (C), silt (M), sand (S), and gravel (G)); water content (Wn), and Atterberg limits (liquid limit (LL), plastic limit (PL), and plasticity index (PI)), are shown in Table 1.

Table 1: Summary of physical properties of the study site

B.H.	Depth (m)	Grain size distribution (%)				Wn (%)	Plasticity index (%)		
		C	M	S	G		LL	PL	PI
1	1.0–3.0	53	46	1	0	38	74	36	38
	3.0–6.0	26	65	9	0	36	44	25	19
	6.0–9.5	51	48	1	0	29	60	29	31
2	1.0–3.0	52	47	1	0	36	64	33	31
	3.0–6.0	52	47	1	0	36	64	33	31
	6.0–9.5	52	46	2	0	30	62	31	31
3	1.0–3.0	65	30	5	0	20	49	35	14
	3.0–6.0	52	40	8	0	22	45	34	11
	6.0–9.5	52	38	10	0	33	49	36	13
4	1.0–3.0	60	33	7	0	29	48	35	13
	3.0–6.0	58	32	10	0	25	40	32	8
	6.0–9.5	56	40	4	0	25	37	26	11

4. Results and Discussion

The grain size has a significant influence on the engineering behaviour of the soil; therefore, knowing the grain size of the soil is very important on the other hand, the deposits composed of different-sized grains have a higher strength than those composed of uniformly graded [11, 12].

As shown in Table 1, the distribution of grain size changes; therefore, there is an increase in the proportion of silt and sand with the increase in depth and on the other hand, there is a decrease in the proportion of clay. In general, the soil of the study area is fine-grained, and the percentage of clay particles are the predominant component (mainly silty clay) in most sites and depths. Therefore, according to Stephen and Ikani, 2012 [13], clay soil is unsuitable for most engineering projects because it has low bearing capacity.

Consistency limits are used as a properties index to identify and classify fine soils. The values of liquid and plastic limits can also provide information about the properties and nature of cohesive soils [14].

On the other hand, the water content in the soil is ranged from 20% to 38% with an average of 30%, as shown in Table 2, and there is no doubt that the presence of a high water amount causes problems in its swelling and shrinkage in addition to its consolidation and it also reduces its cohesion. In general, any change in the water content leads to a change in the physical properties of the soil [15].

The values of liquid limits (LL) ranged between (37-74%) with an average of 53 %, while the plasticity index (PI) ranged between (8-38%) with an average of 21%. Soil plasticity is one of the most important physical properties used in describing and determining its engineering behaviour [16]. Based on the unified soil classification system USCS, the soil can be classified as high plasticity silt (MH), low plasticity silt (ML), high plasticity clay (CH) and low plasticity clay (CL) [17]. The soils classified as CH, MH are considered unsuitable for engineering construction and should be avoided [18].

Table 2: Classification of soil samples according to USCS

B.H.	Depth (m)	Wn (%)	Plasticity index (%) LL	PL	PI	Classification of soil (USCS)	Description of soil
1	1.0–3.0	38	74	36	38	MH	High plasticity silt
	3.0–6.0	36	44	25	19	CL	Low plasticity clay
	6.0–9.5	29	60	29	31	CH	High plasticity clay
2	1.0–3.0	36	64	33	31	MH	High plasticity silt
	3.0–6.0	36	64	33	31		
	6.0–9.5	30	62	31	31		
3	1.0–3.0	20	49	35	14	ML	Low plasticity silt
	3.0–6.0	22	45	34	11		
	6.0–9.5	33	49	36	13		
4	1.0–3.0	29	48	35	13	ML	Low plasticity silt
	3.0–6.0	25	40	32	8		
	6.0–9.5	25	37	26	11		

According to Figure 2, almost soils plot below the A-line, indicating that they are generally high plasticity silt (MH) and low plasticity silt (ML). Based on this and according to Keystone, 2003 [18], the soil at sites 1 and 2 is unsuitable for engineering construction unless treated.

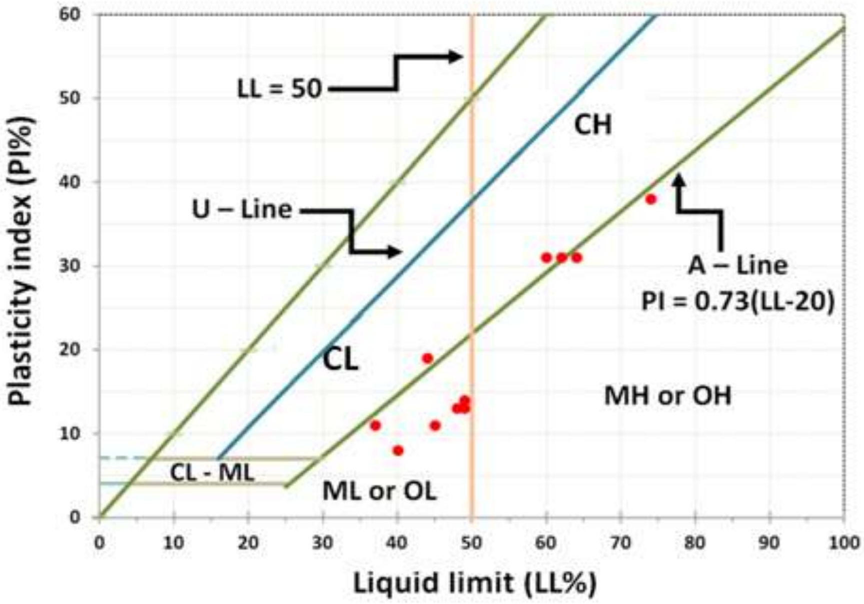

Figure 2: Plasticity chart for soil in the study area

The plasticity of soil depends on both the clay particles and clay mineralogy. However, many clay samples have a variety of percentages of clay fractions but have the same plasticity. Therefore, clay fraction alone is sufficient to measure the plasticity of soil [18].

Consistency indices (liquid limit and plastic limit) were used to classify and describe the plasticity of soil. Based on liquid limit, the soil has intermediate plasticity- high plasticity - very high plasticity. It is described as intermediate – fat – very fat [11]. On the other hand, based on the plasticity index, the soil of the study area has medium plastic to high plastic and based on that, it is described as cohesive silty clay to cohesive clay, respectively [3]. By comparing the results for both methods, we notice that there is a convergence between the results for most samples of soil Table 3 presents a classification of the plasticity of soil based on the consistency index.

Table 3: Classification of soil plasticity according to plasticity index and liquid limit [11] [19]

B.H.	Depth (m)	Bell, 2007 [11]			Roy and Bhalla, 2017 [19]			
		LL	Degree of plasticity	Description	PI	Soil type	Degree of plasticity	Degree of cohesiveness
1	1.0–3.0	74	Very high plasticity	Very fat	38	Clay	High plasticity	Cohesive
	3.0–6.0	44	Intermediate plasticity	Intermediate	19	Clay		
	6.0–9.5	60	High plasticity	Fat	31	Clay		
2	1.0–3.0	64	High plasticity	Fat	31	Clay	High plasticity	Cohesive
	3.0–6.0	64			31	Clay		
	6.0–9.5	62			31	Clay		
3	1.0–3.0	49	Intermediate plasticity	Intermediate	14	Silt clay	Medium plasticity	Cohesive
	3.0–6.0	45			11	Silt clay		
	6.0–9.5	49			13	Silt clay		
4	1.0–3.0	48	Intermediate plasticity	Intermediate	13	Silt clay	Medium plasticity	Cohesive
	3.0–6.0	40			8	Silt clay		
	6.0–9.5	37			11	Silt clay		

Through the comparison between the current study with the previous study conducted by Alfatlawi, 2011 [19] and based on Kerbs and Walker,1971 [20], there is a convergence and agreement between the results of the two studies.

The presence of expansive soil has a significant effect the construction activities. Expansive soils that characterized by the prescience of a large amount of highly active clay minerals, which are responsible for increasing the volumetric change capability of the soil.

The swelling potential determines the ability of soil to expand in addition to swelling pressure parameters. Expansion soil parameter can be directly determined from oedometer tests or indirectly estimated based on the index properties of the soil. The study and identification of expansion soils and prediction of their swelling magnitudes under environmental changes.

There are many criteria to identify and classify expansive soils indirectly, Such as liquid limit, plasticity index and shrinkage limit [21]. Table 4 shows the soil expansivity results predicted by the liquid limit. Based on [22] and [23], the soil has medium expansive – high expansive – very high expansive, but there are differences in the degree of expansion according to each method for the same sites and depths.

Table 4: Soil expansive estimation by liquid limit

B.H.	Depth (m)	LL (%)	Degree of expansion BIS 1498, 1970 [22]	Degree of expansion Chen, 1975[23]
1	1.0–3.0	74	Very high	Very high
	3.0–6.0	44	Medium	High
	6.0–9.5	60	High	
2	1.0–3.0	64	High	Very high
	3.0–6.0	64		
	6.0–9.5	62		
3	1.0–3.0	49	Medium	High
	3.0–6.0	45		
	6.0–9.5	49		
4	1.0–3.0	48	Medium	High
	3.0–6.0	40		Medium
	6.0–9.5	37		

Compared to a study carried out by Khadhim, 2014 [25] and based on liquid limits Seed et al., 1962 [24] for selected sites in the city of Al-Nasiriya, the current study showed a variation in the degree of expansion of the soil while the results based on Khadium, 2014 showed the same degree of expansion for different locations with different depths.

On the other hand, the soil has low expansive – medium expansive – high expansive – very high expansive based on [22, 23, 25] by using the liquid limit index. And the results in most sites and depths were the same, as shown in Table 5. Because of the high degree of expansion in most soil samples, care must be taken into consideration to prevent the damage caused when constructing a shallow foundation [26].

Table 5: Expansion rate classification based on plasticity index

B.H.	Depth (m)	PI	Degree of expansion Holtz and Gibbs, 1956 [25]	Degree of expansion BIS 1498, 1970 [22]	Degree of expansion Chen, 1975[23]
1	1.0–3.0	38	Very high	Very high	Very high
	3.0–6.0	19	Medium	Medium	Medium
	6.0–9.5	31	High	High	High
2	1.0–3.0	31	High	High	High
	3.0–6.0	31			
	6.0–9.5	31			
3	1.0–3.0	14	Medium	Medium	Medium
	3.0–6.0	11	Low	Low	
	6.0–9.5	13	Medium	Medium	
4	1.0–3.0	13	Medium	Medium	Medium
	3.0–6.0	8	Low	Low	Low
	6.0–9.5	11			Medium

Compared to a study carried out by Alfatlawi, 2011 [20] and based on plasticity index [23] [24] for Thi-Qar University soil in the city of Al-Nasiriya, the current study showed a variation in the degree of expansion of the soil while the results based on Alfatlawi, 2011 [20] showed (high) or (medium) degree of expansion based on BIS 1498, 1970 [23] and the same degree of expansion (medium-high) based on Chen, 1975 [24] for different locations with different depths

Table 6 shows the activity of soils for the studied area based on Bowles, 1984 and according to Skempton,1953 [28], there is a direct relationship between the plasticity index of soil to the percentage of clay particles by weight in the soil, which in turn affects soil cohesion with different moisture content[20]. Accordingly, based on values obtained from the studied soils, it can be noticed that the soils have an activity range (0.137 – 0.730) with an average of 0.422, indicating non-active soil, as shown in Figure 3.

Table 6: Soil activity, according to Skempton [27]

B.H.	Depth (m)	PI (%)	Clay (%)	Activity	Interpretation
1	1.0–3.0	38	53	0.716	Inactive
	3.0–6.0	19	26	0.730	
	6.0–9.5	31	51	0.607	
2	1.0–3.0	31	52	0.596	Inactive
	3.0–6.0	31	52	0.596	
	6.0–9.5	31	52	0.596	
3	1.0–3.0	14	65	0.215	Inactive
	3.0–6.0	11	52	0.211	
	6.0–9.5	13	52	0.25	
4	1.0–3.0	13	60	0.216	Inactive
	3.0–6.0	8	58	0.137	
	6.0–9.5	11	56	0.196	

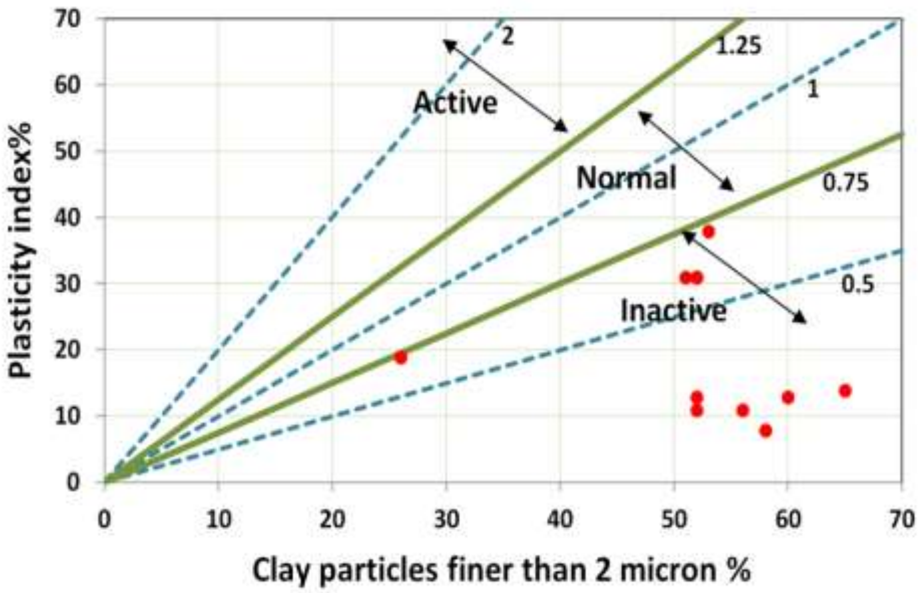

Figure 3: Soil classification based on their activity (Skempton, 1953)

In general, soil activity in this study showed convergence and agreement in some sites with the results of the study conducted by mandhour, 2011 [28] for selected areas in Al-Nasiriya.

On the other side, to determine or estimate the consistency of cohesive soils, The number of blows generated by standard penetration test (SPT N Value) was used according to Rogers, 2006 [29] or by using consistency index according to Bell, 2007 [11]. The values of the number of blows generated by SPT range from (9 – 45) blows, as shown in Table 7, while the consistency index ranges from (0.9-2.09) with an average of (1.25).

According to Rogers (2006), the consistency of cohesive soil is estimated as stiff to very stiff; accordingly, most soils are considered very stiff. The consistency index estimates the soils as soft, stiff and very stiff [11].

Table 7: Consistency of cohesive sols based on consistency index, I_C, and SPT N values

<table>
<tr><th rowspan="2">B.H.</th><th rowspan="2">Depth (m)</th><th colspan="3">Rogers, 2006[29]</th><th colspan="2">Bell, 2007[11]</th></tr>
<tr><th>N_1
SPT
N values</th><th>N_2
SPT corrected N values
$N_2 = 15 + 0.5 (N_1 - 15)$</th><th>Consistency of soil</th><th>I_C</th><th>Consistency of soil</th></tr>
<tr><td rowspan="3">1</td><td>1.0–3.0</td><td>21</td><td>18</td><td rowspan="3">Very stiff</td><td>0.947</td><td>Stiff</td></tr>
<tr><td>3.0–6.0</td><td>35</td><td>25</td><td>0.421</td><td>Soft</td></tr>
<tr><td>6.0–9.5</td><td>45</td><td>30</td><td>1.00</td><td>Stiff</td></tr>
<tr><td rowspan="3">2</td><td>1.0–3.0</td><td>20</td><td>17.5</td><td rowspan="3">Very stiff</td><td>0.90</td><td rowspan="2">Stiff</td></tr>
<tr><td>3.0–6.0</td><td>25</td><td>20</td><td>0.90</td></tr>
<tr><td>6.0–9.5</td><td>22</td><td>18.5</td><td>1.03</td><td>Very stiff</td></tr>
<tr><td rowspan="3">3</td><td>1.0–3.0</td><td>9</td><td>9</td><td rowspan="2">Stiff</td><td>2.07</td><td rowspan="3">Very stiff</td></tr>
<tr><td>3.0–6.0</td><td>13</td><td>13</td><td>2.09</td></tr>
<tr><td>6.0–9.5</td><td>20</td><td>17.5</td><td>Very stiff</td><td>1.23</td></tr>
<tr><td rowspan="3">4</td><td>1.0–3.0</td><td>12</td><td>12</td><td>Stiff</td><td>1.46</td><td rowspan="3">Very stiff</td></tr>
<tr><td>3.0–6.0</td><td>27</td><td>21</td><td rowspan="2">Very stiff</td><td>1.875</td></tr>
<tr><td>6.0–9.5</td><td>22</td><td>18.5</td><td>1.09</td></tr>
</table>

Compression index Cc can express the compressibility of clay soil and the classification of soil type. This term can be obtained by laboratory experiments in consolidation tests (direct method), which are expensive and time-consuming or indirect methods through empirical equations [8, 11, 30, 31]. The compression index ranged between (0.17-0.50) with an average of 0.23, as shown in Table 8.

It can be seen that based on the direct method, the soil, in general, can be classified as clay with high compressibility to soft clay with very high compressibility. According to this classification, most soils were classified as highly compressible clay soil.

On the other hand, soil can be classified according to empirical equations and through the relationship of the compression index to the liquid limit. Therefore, based on the Skempton equation [32], the soil can be classified as clay soil with high compressibility to soft clay with very high compressibility, and the results of this classification are agreed with direct method results, as shown in Table 8. While using Terzaghi and Peck equation [31], the soil can be classified in most sites with different depths into soft clay with very high compressibility, shown below in Table 8.

Table 8. Classification of soil type and degree of compressibility

B.H.	Depth (m)	LL	**Indirect (Based on liquid limit)**				**Direct (Based on the results of the consolidation test)**		
			Skempton, 1944 [32] **Cc = 0.007(LL-10)**		Terzaghi and Peck ,1967 [31] **Cc = 0.009(LL-10)**		Cc	Bell, 2007 [11]	
			Soil type	**Degree of compressibility**	**Soil type**	**Degree of compressibility**		**Soil type**	**Degree of compressibility**
1	1.0–3.0	74	Soft clay	Very high			0.17		
	3.0–6.0	44	Clay	High	Soft clay	Very high	0.17	Clay	High
	6.0–9.5	60	Soft clay	Very high			0.17		
2	1.0–3.0	64					0.50	Soft clay	Very high
	3.0–6.0	64	Soft clay	Very high	Soft clay	Very high	0.17	Clay	High
	6.0–9.5	62					-	-	-
3	1.0–3.0	49					0.27	Clay	High
	3.0–6.0	45	Clay	High	Soft clay	Very high	0.23		
	6.0–9.5	49					-	-	-
4	1.0–3.0	48			Soft clay	Very high	0.20	Clay	High
	3.0–6.0	40	Clay	High	Clay	High	0.20		
	6.0–9.5	37					-	-	-

5. Conclusions

The results of this study can be concluded as follows:

1. All the soil samples are identified as cohesive soil, mainly silty clay.
2. The soils have medium to high expansion degrees, and inactive clays are predominant.
3. Based on the SPT test and consistency index, the soil consistency is stiff to very stiff in most soil samples.
4. Based on the SPT test and compression index, the soils range from clay with high compressibility to soft clay with very high compressibility.
5. The study area needs numerous engineering efforts to improve its physical properties and increase its capacity.

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