ISSN: 0067-2904

Geotechnical Assessment of Soil Investigation at Campus Site of College of Science, University of Diyala, Iraq

Asem Ahmed Hassan*, Kareem Khwedim, Abdalratha M Sahaab
Department of Petroleum Geology and Minerals, College of Science, University of Diyala, Diyala, Iraq

Received: 8/6/2021 Accepted: 28/8/2021 Published: 30/5/2022

Abstract

This study aims to evaluate some physical and mechanical properties of soil samples collected from the campus site of the College of Science, University of Diyala, Iraq. All laboratory tests were performed according to ASTM standards. The test results showed that the range of water content *w* was (13.89%-16.34%) and the specific gravity range was (2.58-2.77). Atterberg limits tests showed that the range of Liquid Limit LL, Plastic Limit PL, Plasticity Index PI were (26.20-35.20%), (18.63-23.24%), and (7.57-12.42), respectively. Liquidity Index LI values were ranged from 0.002 to 0.560, while Consistency Index CI values were ranged from 0.271 to 0.998 indicating a plastic state. The average optimum water content (OWC) and maximum dry density (MDD) obtained from the Standard Proctor Compaction test were 10.36% and 1.79g/cm^3, respectively. Shear test results revealed that the cohesion strength range was (5-10) KN/m^2 and the angle of internal friction range was (25-30^o). The compression index derived from the consolidation test was ranged from 0.03 to 0.25, and the calculated values of void ratio (0.94-1.04) and porosity (0.48-0.51) are within the range of clay soils. According to the test results, the soil in the study area is classified as fine-grained soil type CL (i.e. inorganic clay soil of low to medium plasticity) based on USCS classification. The obtained OWC and MDD values from the compaction test can be used as criteria to control future filed compaction practice at the site. The calculated angle of internal friction values is within the range of CL soil. However, the cohesion strength is relatively low due to the high water content, as cohesion of clay soil is affected by water content and fine-grained content. The compression index values reflect the high compressibility of clay soil due to the high fine gained content, which is directly related to the settlement. Therefore, it is suggested to improve soil strength by increasing soil relative compaction not less than 95% to lower its compressibility and subsequent settlement, and increase its load bearing capacity. Finally, geotechnical parameters presented in the current study are discussed and compared well with previous studies. These parameters are helpful for future engineering works scheduled at the campus site of the College of Science, University of Diyala, Iraq.

Keywords: Geotechnical Assessment, Site Investigation, Soil, Tests, Diyala

التقييم الجيوتكنيكي لتحريات التربة في موقع الحرم الجامعي لكلية العلوم، جامعة ديالى، العراق

عاصم احمد حسن*, كريم خويدم, عبد الرضا سحاب
قسم جيولوجيا النفط والمعادن, كلية العلوم, جامعة ديالى, ديالى, العراق

*Email: asem.ahmed@uodiyala.edu.iq

الخلاصة

الهدف من هذه الدراسة هو تقييم بعض الخصائص الفيزيائية والميكانيكية لنماذج من التربة تم جمعها من موقع الحرم الجامعي لكلية العلوم في جامعة ديالى، العراق. اجريت جميع الاختبارات وفق المعايير القياسية للجمعية الامريكية لاختبار المواد. لقد بينت نتائج الاختبارات ان مدى المحتوى المائي للتربة كان (13.89–16.34%) وان مدى الوزن النوعي كان (2.58–2.77) وبيينت اختبارات حدود اتربرغ ان مدى حد السيولة، حد اللدونة، ودليل اللدونة كان (26.20–35.20%)، (18.63–23.24%) و (7.57–12.42) على التوالي. لقد تراوحت قيم دليل السيولة من 0.002 الى 0.560 بينما تراوحت قيم دليل القوام من 0.271 الى 0.998 مؤشرة حالة التربة اللدنة. لقد كان معدل المحتوى المائي المثالي والكثافة الجافة القصوى من خلال فحص بروكتور القياسي للدمك هو 10.36% و 1.79 غرام/سم^3. لقد بينت نتائج فحص القص المباشر ان مدى قوة تماسك التربة كان (5–10) كيلو نيوتن/م^2 وقد كان مدى زاوية الاحتكاك الداخلي (25–30^o). لقد تراوح مدى دليل الانضغاط الذي تم حسابه من خلال فحص الانضمام من 0.03 الى 0.25 كما كانت قيم نسبة الفراغات المحسوبة (0.94–1.04) والمسامية (0.48–0.51) وهي ضمن مدى الترب الطينية. بناء على نتائج الاختبارات فان تربة منطقة الدراسة يمكن تصنيفها على انها تربة طينية نوع CL ذات لدونة واطئة الى متوسطة وفق نظام التصنيف الموحد. ان قيم محتوى الماء المثالي والكثافة الجافة القصوى المحسوبة من اختبار الدمك بمكن الاستفادة منها كمعيار للسيطرة على نسب دمك التربة حقليا. ان قيم زاوية الاحتكاك الداخي المحسوبة هي ضمن مدى التربة نوع CL لكن مقاومة التماسك واطئة نسبيا نتيجة لمحتوى الرطوبة العالي اذ ان تماسك التربة الطينية يتاثر بمحتوى الرطوبة اضافة الى محتوى المواد الناعمة. ان قيم معامل الانضاط يعكس انضغاطية التربة الطينية العالية نتيجة لمحتوى الحبيبات الناعمة فيها والذي يرتبط بشكل مباشر بالهبوط، ولهذا فقد اقترح تحسين مقاومة التربة للهبوط بزيادة دمك التربة النسبي الى ما لايقل عن 95% لتقليل انضغاطية التربة وهبوطها وزيادة سعة تحملها للاحمال الهندسية. اخيرا تم مناقشة ومقارنة المعاملات الجيونكنيكية في هذه الدراسة مع مثيلاتها في الدراسات السابقة في المنطقة. ان هذه المعاملات مفيدة للاعمال الهندسية المستقبلية في موقع كلية العلوم في جامعة ديالى، العراق.

1. Introduction

Engineering site investigation provides a critical geotechnical assessment for soils at proposed construction sites. Geotechnical assessment of soil is required to evaluate soil condition and assess its suitability for safe and economic engineering structures [1].

A number of studies have been presented to evaluate the geotechnical properties of soils of different parts of Iraqi regions in the literature. For example, Al-Naimi (1996) assessed the shear stress and consistency parameters variations of the soil of Baghdad city [2]. Al-Jabban (2014) evaluated the soil properties of Hilla City based on laboratory tests of borehole samples and data from previous laboratory and field studies in the area [3]. Hussein (2016) presented a geotechnical assessment for soil samples taken from different locations in Wasit Governorate [4]. Alzubaydi et al. (2016) evaluated the geotechnical properties of soil in the middle sector of the Al-Massab Al-Aam channel [5]. Al-Baghdadi (2016) presented geotechnical maps for An-Najaf city to determine soil properties variations [6]. Rasheed et al. (2016) evaluated some shallow geotechnical properties of soil by testing stations distributed in the Koya district [7]. Al-Siaede (2019) introduced a new topographical and geotechnical approach developed to calculate the silt volume in Dwerige weir south-east of Missan, southern Iraq [8]. Sayhood and Rashid (2020) evaluated some geotechnical properties of soils samples collected from Euphrates river banks in the cities of Kufa and Mishkhab, middle of Iraq [9]. Al-abboodi et al. (2020) presented a geotechnical evaluation of borehole data distributed over a wide area of Basrah city, southern Iraq [10]. Finally, Al-Talib et al. (2021) used the geotechnical properties of rock samples collected from the Gercus Formation to investigate the impact of erosion and rock Sliding on the Duhok dam reservoir, northern Iraq [11].

Moreover, several studies have dealt with the geotechnical assessment of the subsurface soils of the Diyala Governorate. In this regard, Al-Ani (2001) [12] prepared primary geotechnical maps for selected areas from Diyala Governorate based on the evaluation of soil investigation reports prepared by the National Center for Construction Laboratories (NCCL) and the results of boreholes drilled in Baqubah City. The study showed that most middle and western parts of Diyala Governorate consist of fine-grained soil that varies widely in geotechnical characteristics. Similarly, Alshakarchi and Turkie (2011) [13] constructed geotechnical maps for Diyala and Baghdad, Wasit and Babylon governorates by collecting and analyzing data for some physical and mechanical properties of soils. The authors have noticed wide variations in soil characteristics due to their formation and origin from recent deposits. They found that the soil in Diyala can be considered fine-grained soil according to USCS. Abdullah and Awad (2017) [14] assessed the geotechnical properties of five soil samples collected from selected locations in the Alghlabia area, western Baqubah city. According to USCS and Skempton's classification, the soil was classified as (CL-ML, CL) with low plasticity, and based on the geotechnical test results. The authors concluded that the soil in the area is suitable for engineering construction works.

Recently, an extensive campaign of building new educational facilities has been taken place at the University of Diyala. Therefore, geotechnical assessment of soils is vital to characterize the soil condition and improve the quality control specification of the engineering works. Thus, the work presented in this study aims at evaluating of some physical and engineering properties of soil samples collected from the campus site of the College of Science, University of Diyala, Iraq.

2. Study Area Location and Soil Sampling

The study area is located in Diyala Governorate at the campus site of the College of Science, University of Diyala, Baquba city, 60 km northeast of Baghdad. The study area is relatively flat with a ground elevation of 43m and watertable 1.9m, and according to the geotechnical borehole Figure 1 drilled about 1km south of the studied area is composed of up to13.0m depth of light to dark brown clayey soil. Based on USCS, the soil is generally classified as low plasticity clay (CL) [15]. Locations of soil samples were distributed in a small area proposed to construct new educational buildings. All samples were secured properly using sealed plastic bags for laboratory analysis. Figure 2 shows a location map of soil samples in the study area.

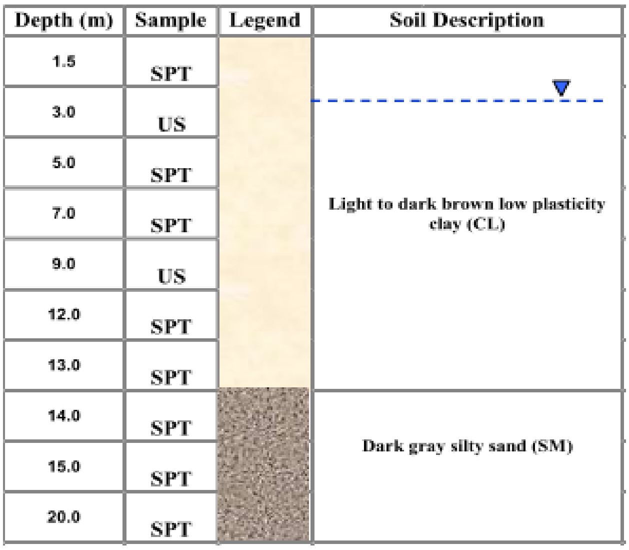


Figure 1-Geotechnical boring log in the study area

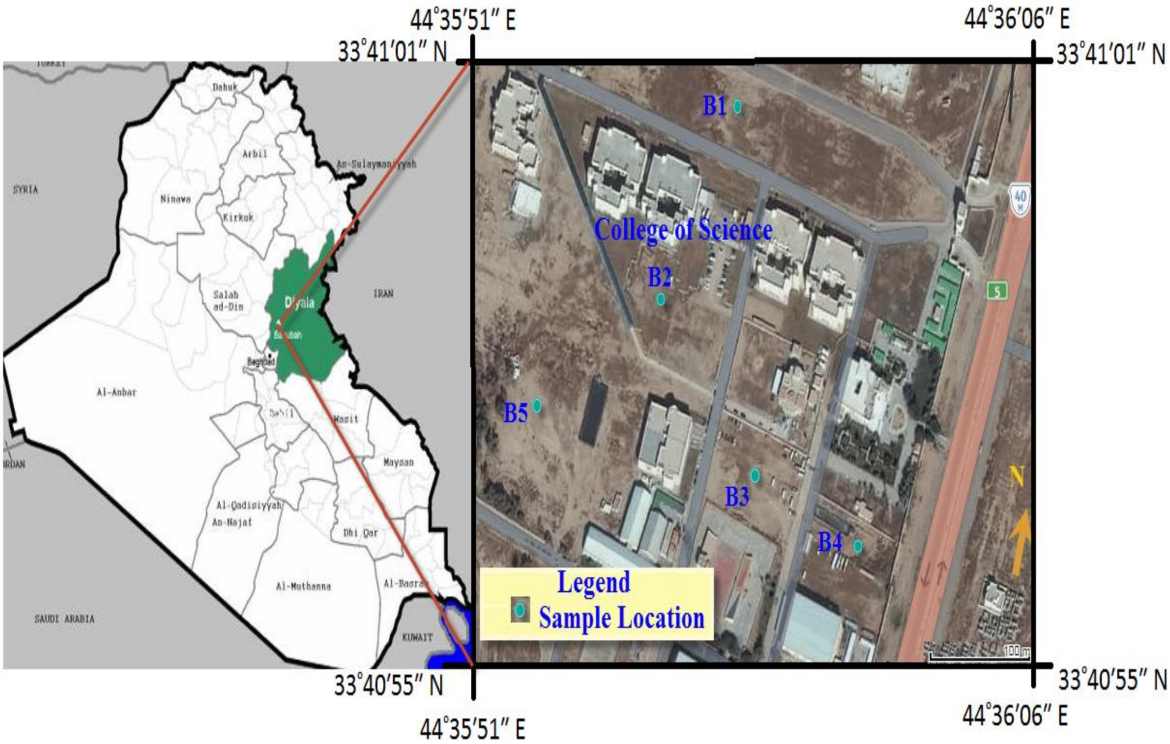


Figure 2-Location map of soil samples

3. Laboratory Tests

Laboratory tests were performed in this study by the authors according to ASTM standards summarized in Table 1.

Table 1- List of the conducted laboratory tests and testing standards

Laboratory Tests	Testing Standard
Physical Tests	
Water Content	ASTM D-2216-05
Specific Gravity	ASTM D-854-05
Liquid Limit	ASTM D-4318-05
Plastic Limit	ASTM D-4318-05
Engineering Tests	
Compaction Test	ASTM D-698-07
Direct Shear Test	ASTM D-3080-04
One Dimensional Consolidation Test	ASTM D-2435-04

3.1 Water Content

The water content of the soil is an important indicator to describe its behavior and consistency characteristics, particularly for fine grained soil [16]. To determine the water content of the soil, the Oven drying method is used [17].

3.2 Specific Gravity

Determination of the specific gravity of the soil is fundamental to determine the phase relationship of air, water, and solids for a given volume of soil. The pycnometer method [18] was implemented to calculate the specific gravity of soil samples. It determines the specific gravity of soil as the ratio of the mass of a unit volume of the soil solids at a particular temperature to the mass of the same volume of water at the same temperature [19].

3.3 Liquid Limit, Plastic Limit, and Plasticity Index

Atterberg Limits (LL, PL, and PI) are important to characterize and classify fine-grained soils. In this study, Atterberg limits [20] were determined and used to classify the soil according to USCS classification. LL of soil can be defined as the water content in percent, at the boundary between the liquid and plastic states, at which it behaves like a liquid. PL of soil can be defined as the water content in percent at the boundary between the plastic and semi-solid states, making it crumble when rolled by hand into threads of 3.2mm diameter. Plasticity Index PI (PI= PL-LL) is the range of water content over which a soil behaves plastically.

3.4 Compaction test

Soil compaction, and densification of the soil through removing air are performed in the laboratory to determine the OWC and MDD of a soil subjected to a certain mechanical effort. OWC and MDD values derived from the compaction test are helpful as criteria to control filed compaction practice. The compaction test is conducted using the Standard Proctor compaction test [21].

3.5 Direct shear test

The Shear strength of soil can be defined as its resistance to shear stresses. Shear strength relays on parameters such as cohesion and friction. It is vital to determine these parameters to analyze the soil stability problems such as bearing capacity, pavement, and slope stability [22]. In this test [23], the relationship between normal stress σ and shear stress τ can be expressed as:

$$\tau = c + \sigma \tan \Phi \qquad (1)$$

Where *C* is the cohesion, and Φ is the angle of internal friction.

3.6 Consolidation test

Consolidation of soil is the reduction of its volume subjected to vertical pressures due to the flow of pore water. This test is conducted to determine the settlement of a structure which is a key parameter for engineering designs [19]. The soil specimen is subjected to different vertical stresses according to [24] standard. From the measured data, the consolidation curve that relates pressure *P* and void ratio *e* can be generated, from which Compression Index (Cc) can be derived as:

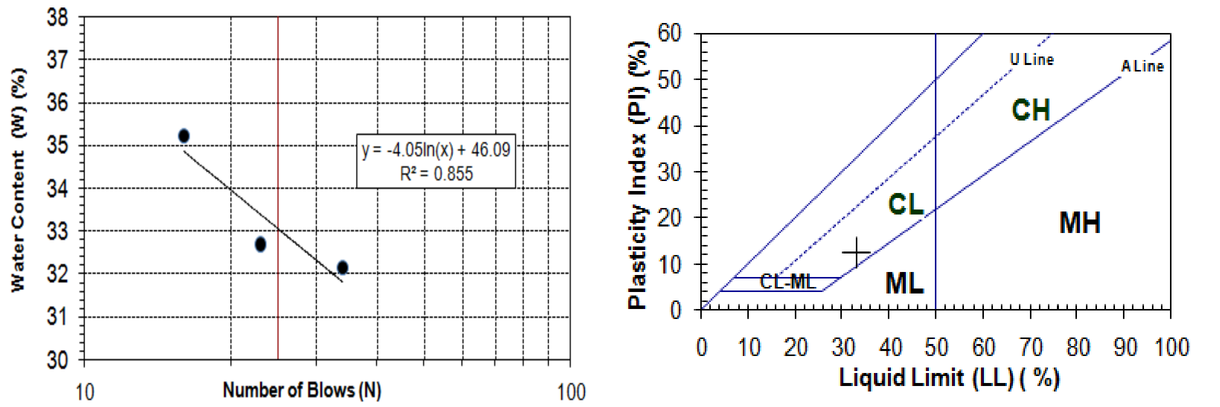
$$Cc = \frac{\Delta e}{\Delta log \mathrm{P}} \qquad (2)$$

C_C is a crucial parameter for evaluating the settlement due to the primary consolidation of clay soils [25], [26].

4. Results and Discussion

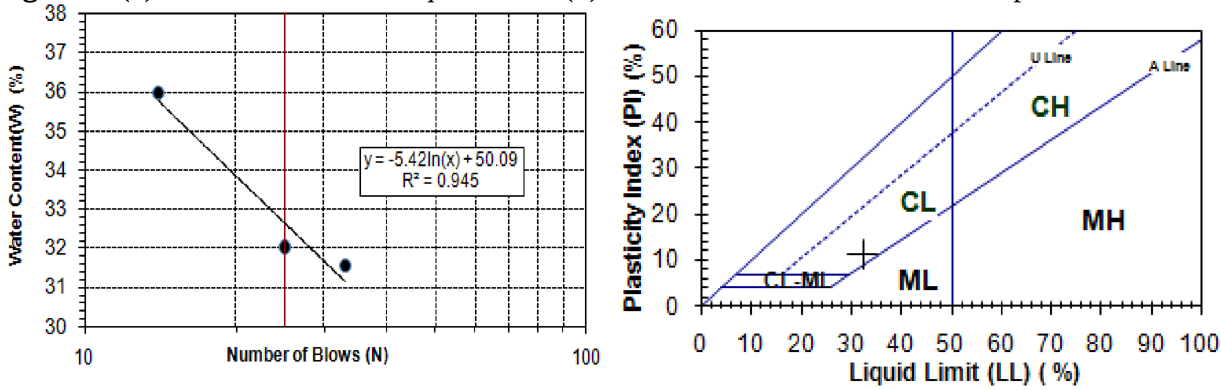
The range of water content of the soil samples was (13.89%-16.34%) with an average of 15.44%. The specific gravity values of the soil in the area vary between 2.58 and 2.77, with an average of 2.66. The narrow range of specific gravity emphasizes that the specific gravity of the soil depends on the mineralogical content of the soil and hence varies slightly [1].

LL was determined and used to classify the soil according to USCS. Figures 3, 4, 5, 6, and 7 show the liquid limit determination and USCS soil classification of the samples (B1), (B2), (B3), (B4), and (B5), respectively. Table 2 summarizes the results of the Atterberg Limits tests.



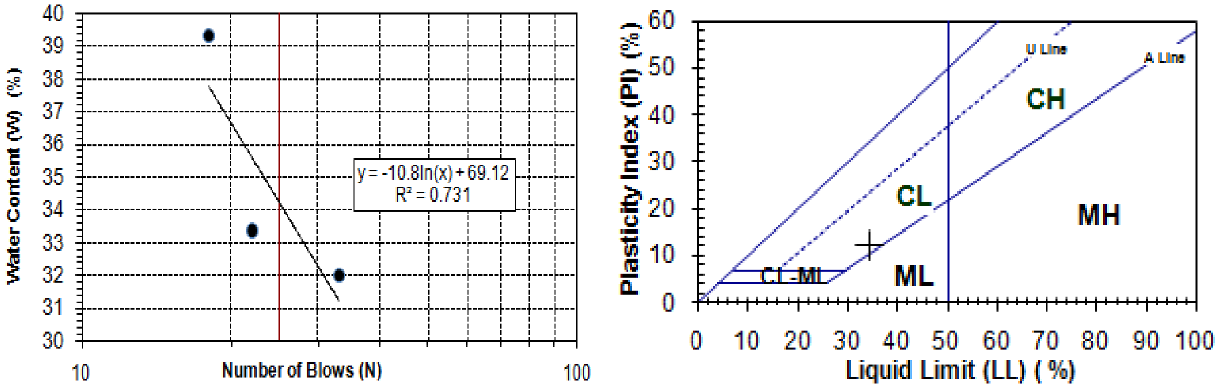
(a) **(b)**

Figure 3-(a) Determination of Liquid Limit (b) USCS soil classification of sample NO B1



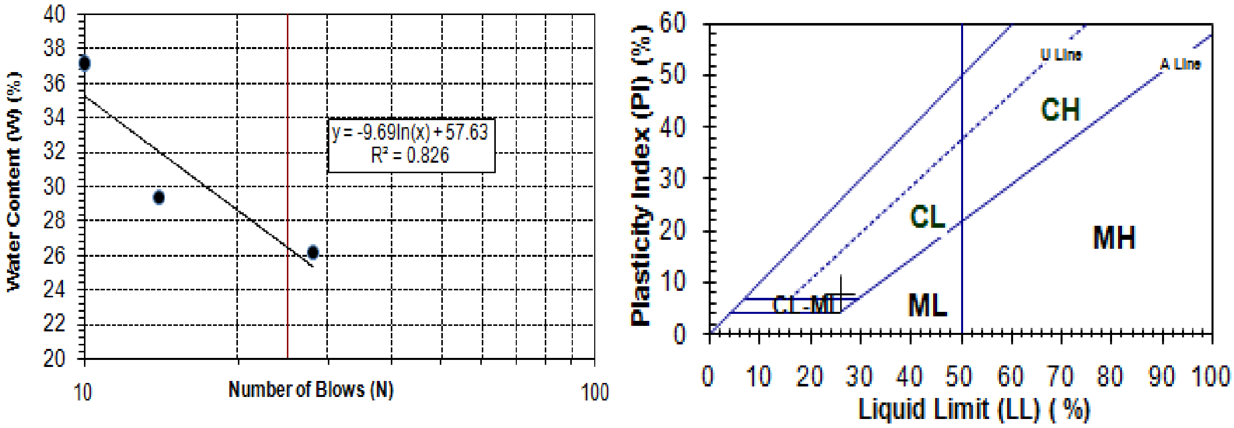
(a) **(b)**

Figure 4-(a) Determination of Liquid Limit (b) USCS soil classification of sample NO B2



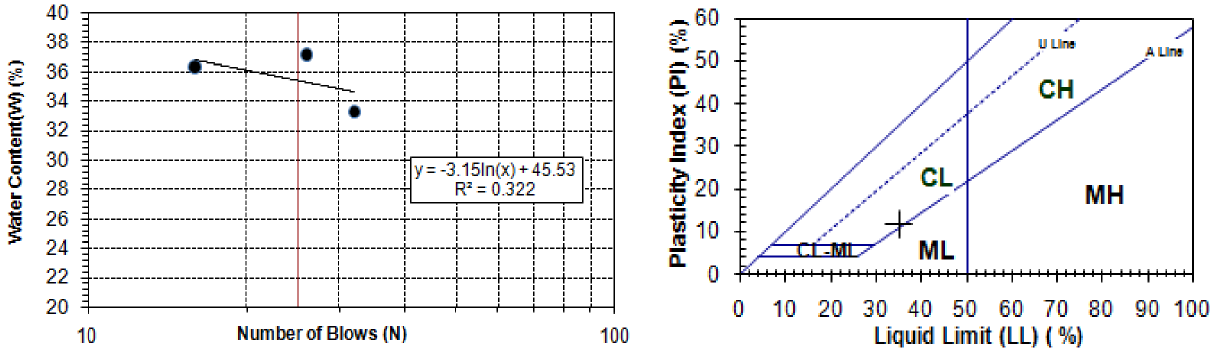
(a) **(b)**

Figure 5-(a) Determination of Liquid Limit (b) USCS soil classification of sample NO B3



(a) **(b)**

Figure 6-(a) Determination of Liquid Limit (b) USCS soil classification of sample NO B4



(a) **(b)**

Figure 7-(a) Determination of Liquid Limit (b) USCS soil classification of sample NO B5

The range of LL was (26.20-35.20%) with an average of 32.22%, while the range of PL was (18.63-23.24%) with an average of 21.06%. The range of PI was (7.57-12.42) with an average of 11.61. According to the test results, the soil can be described as intermediate Liquid Limit [27], and based on USCS classification. The soil can be considered as fine-grained soil type CL. CL soil is inorganic clay of low to medium plasticity, where PI (5-20) and LL<50% [25], [28].

Table 2-Atterberg Limits and USCS soil classification of the samples

Sample NO	Liquid Limit (LL) %	Plastic Limit (PL) %	Plasticity Index (*PI*)	USGS Soil Classification
B1	33.00	20.58	12.42	CL
B2	32.50	21.00	11.50	CL
B3	34.20	21.85	12.35	CL
B4	26.20	18.63	7.57	CL
B5	35.20	23.24	11.96	CL

In addition, the soil state and strength of fine-grained soils can be assessed based on Liquidity Index LI and Consistency Index CI [19]. LI is an indicator of how close the water content of the soil is to LL based on Atterberg limits and soil water content, expressed as:

$$\mathrm{LI} = \frac{\mathrm{w-PL}}{\mathrm{PI}} \tag{3}$$

LI= 1 (or 100%) when the soil at LL (the soil behaves like a liquid) while LI=0 when the soil at PL. CI indicates the consistency of the soil and how close the water content of the soil is to PL based on Atterberg limits and soil water content, expressed as:

$$\mathrm{CI} = \frac{\mathrm{LL-W}}{\mathrm{PI}} \tag{4}$$

CI= 0 when the soil at LL (the soil behaves like a liquid), while CI=1 when the soil at PL.
LI and CI values of the soil samples, shown in Table 3, were calculated using Atterberg limits and the natural water content of the soil samples. LI values were ranged from 0.002 to 0.560, while CI values were ranged from 0.271 to 0.998 indicating a plastic state [19].

Table 3- LI and CI of soil samples

Sample No	B1	B2	B3	B4	B5
Liquidity Index LI	0.010	0.020	0.022	0.560	0.002
Consistency Index CI	0.989	0.980	0.978	0.271	0.998

Figures (8) and (9) present the dry density-water content relationship obtained for samples NO B2 and NO B4, respectively, using the Standard Proctor compaction test. Values of OWC and MDD were, respectively, 9.75% and 1.80g/cm^3 for Sample NO B2, and 11.00% and 1.78g/cm^3 for sample NO B4.

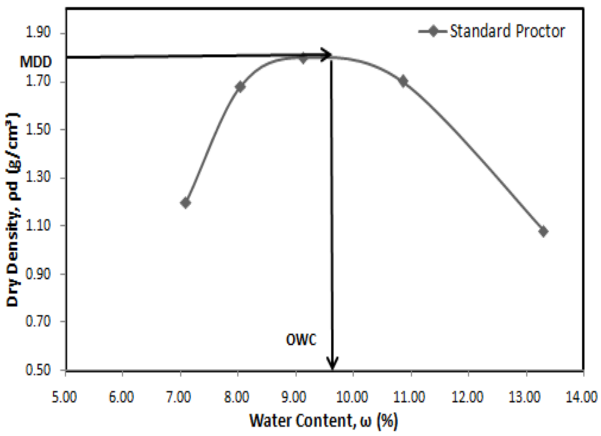


Figure 8-Dry density-water content relationship of sample NO B2

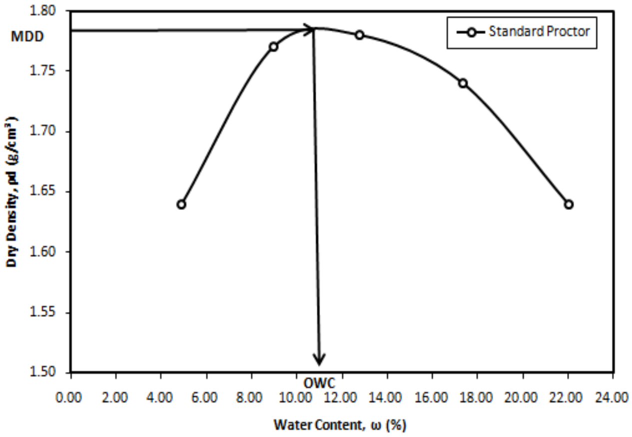


Figure 9-Dry density-water content relationship of sample NO B4

Figures (10), (11), (12), (13), and (14) show, respectively, shear test graphs of samples B1, B2, B3, B4, and B5. Cohesion strength and internal angle of friction values were derived from the graphs and summarized in Table 4. Shear test results revealed that the angle of friction Φ range was (25-30^o) with an average of 29.4^o and the Cohesion Strength C range was (5-10 KN/m^2) with an average of 7.8 KN/m^2.

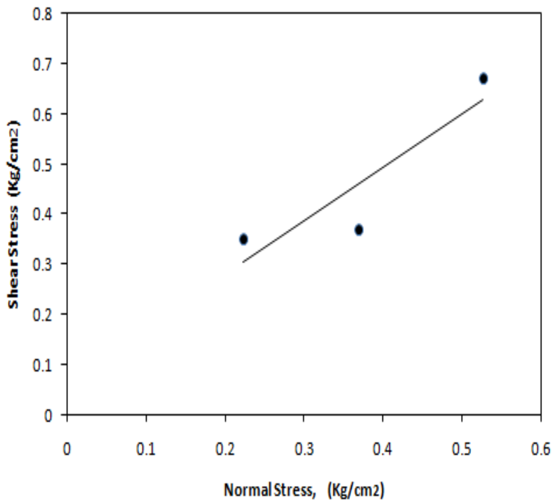


Figure- 10 Shear test of sample NO B1

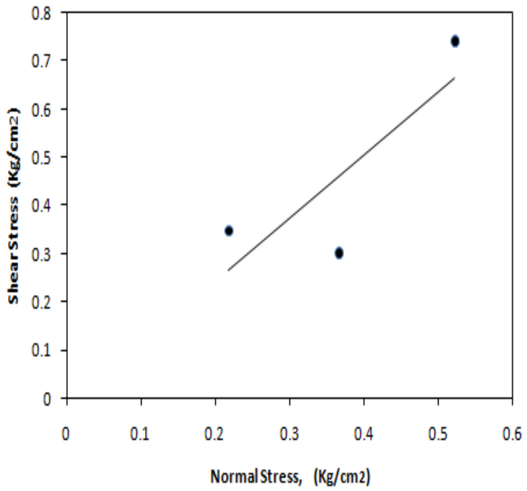


Figure- 11 Shear test of sample NO B2

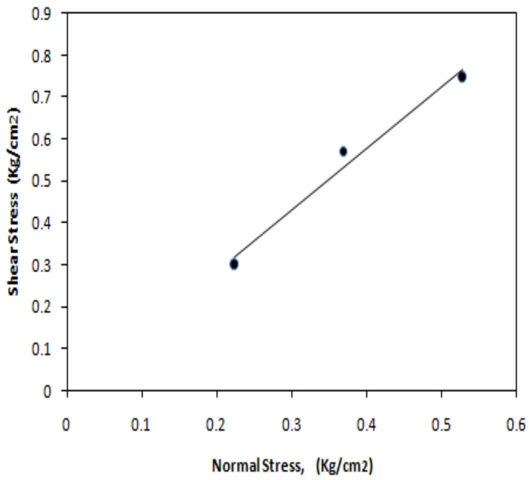


Figure- 12 Shear test of sample NO B3

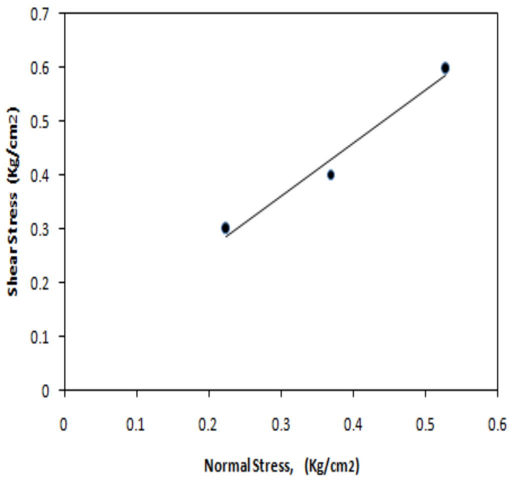


Figure- 13 Shear test of sample NO B4

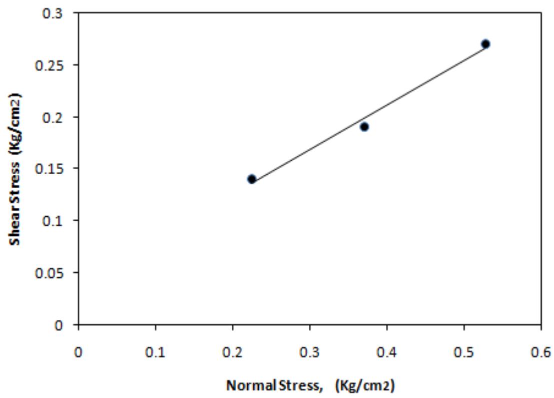


Figure- 14 Shear test of sample NO B5

Table 4- Cohesion and internal angle of friction values derived from shear test graphs

Sample No	B1	B2	B3	B4	B5
Cohesion C (KN/m^2)	10	6	8	10	5
Angle of Friction Φ	25^o	32^o	30^o	29^o	30^o

Figures (15), (16), and (17) depict, respectively, the consolidation curve of soil samples NO B2, B3, and B4.

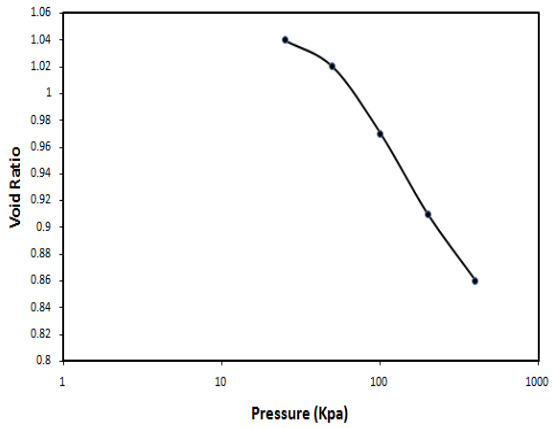


Figure 15-Consolidation test of sample NO B2

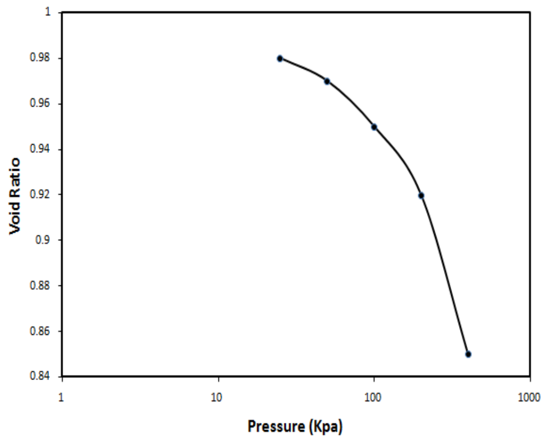


Figure 16-Consolidation test of sample NO B3

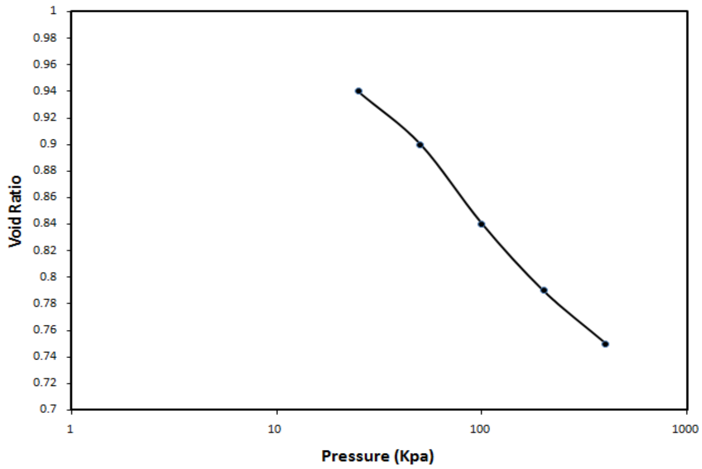


Figure 17-Consolidation test of sample NO B4

In addition, soil porosity *n* was calculated using initial void ratio *e* values. C_c, *e* and *n* values calculated from the consolidation tests are summarized in Table 5.

Table 5-Consolidation test results

Sample No	B2	B3	B4
Compression Index C_c	0.03	0.05	0.25
Void ratio *e*	1.04	0.98	0.94
Porosity *n*	0.51	0.49	0.48

A comparison between the current study and the previous studies:

Results of laboratory tests obtained in this study are compared with the previous studies reported in different parts of the Diyala governorate as shown in Table 6.

Based on the tests results of this work and Table 6, the following remarks can be addressed:

1. Water content of the soil is relatively high. Abdullah and Awad (2017) [14] also noticed a high range of water content in Alghlabia area in the Diyala Governorate. The high water content can be attributed to the low water table below the ground surface and the fine texture of the clay soil that retains water in the voids.
2. Specific Gravity range of the soil is within the range of fine-grained soil [1] and varies slightly as also reported by Abdullah and Awad (2017) [14]. Specific Gravity depends on the mineral composition of the soil rather than other factors; therefore, small variations of specific gravity are expected.

3. According to Atterberg limits and water content tests, the soil in the study area can be classified as fine-grained soil type CL with low to medium plasticity. As a comparison, Al-Ani (2001) [12] showed that the soil in Diyala is fine-grained with low to high plasticity. Similarly, Alshakarchi and Turkie (2011) [13] also reported that the soil, in general, is fine-grained with medium to high plasticity. In the other hand, Abdullah and Awad (2017) [14] noticed that the soil is generally fine grained (with some sand) of low plasticity.
4. Based on shear test results, values angle of friction obtained, which are within the range of clay soil, are relatively high due to the high content fine grained particles (i.e. cohesion increases with increasing fine materials). However, the cohesion strength is relatively low due to the high water content as the cohesion of clay soil is significantly affected by water content [29]. Abdullah and Awad (2017) [14] indicated similar effects of fine grains and water content in the cohesion of clay soils.
5. According to the consolidation test results, compression index values are close to that reported in the surrounding areas [13], [14], which reflect the compressibility of clay soils. Several authors have reported a wide range of compression index for clay soils in the literature. For example, Kumar and Jain (2016) [26] said a range of 0.17 to 0.893, while Widodo and Ibrahim (2012) [30] noticed a range of 0.03 to 1. High compressibility of clay soil is related to the fine grained content. It is vital to consider this parameter in the clay soils as it is directly related to the settlement due to primary consolidation. Moreover, the obtained ranges of void ratio and porosity are within the range of clay soils [14], [31], [32].

Table 6-A comparison between the current study and previous studies in the Diyala governorate

Geotechnical properties/parameters	**Al-Ani (2001) [12]**	**Alshakarchi and Turkie (2011) [13]**	**Abdullah and Awad (2017) [14]**	**Current Study**
Water Content	-	-	% 19 - 22	13.89-16.34%
Specific Gravity	-	-	2.66-2.74	2.58-2.77
Liquid Limit	25-64%	40-65%	29.22-32.87%	26.20-35.20%
Plastic Limit	18-30%	10-43%	23.31-24.10%	18.63-23.24%
Plasticity Index	7-34%	10-43	6.34-8.77	7.57-12.42
Angle of Friction	-	-	21º-3º	25-30º
Cohesion	-	-	16-60 KN/m^2	5-10 KN/m^2
Compression Index	0.09-0.25	0.08-0.25	0.15-0.24	0.03-0.25
Porosity	-	-	0.37-0.45	0.48-0.51
Void ratio	0.47-0.86	0.55-1.07	0.59-0.83	0.94-1.04

5. Conclusions

Some physical and mechanical properties of soil samples collected from the campus site of the College of Science, University of Diyala, Iraq, have been assessed. According to the laboratory tests results, the following points can be concluded:
1. The soil in the study area can be described, based on USCS classifications, as a fine-grained soil type CL (i.e. inorganic clay soil of low to medium plasticity). Previous studies conducted in Diyala reported that the soil, in general is fine-grained of low to high plasticity.
2. Compaction characteristics, namely maximum dry density and optimum water content determined in this work, can be used as criteria to control filed compaction practice. The bell-shaped compaction curves derived are typical of fine-grained soils.

3. Direct shear test results revealed that the measured values of angle of friction are within the range of clay soil. However, the cohesion strength of the soil is relatively low as the cohesion of clay soil is affected by water content.
4. The compression index values derived from consolidation tests indicate the compressibility of clay soils, which should be considered for safe engineering design and works, as it is directly related to soil settlement.
5. Based on tests results, it is vital to improve the engineering properties of the soil in the study area by increasing the relative compaction of the soil to not less than 95%, as recommended. This process can be adopted to enhance the load bearing capacity and reduce compressibility and subsequent soil settlements. Moreover, high water content reduces cohesion and soil strength; therefore, the groundwater should be pumped out as the water table level is relatively close to the ground surface in the area.
6. The obtained tests results are compared well with the results reported in the surrounding areas from the previous studies. It suggested, therefore, preparing geotechnical maps for various regions of the Diyala governorate using the current work and the previous reported studies.
7. The calculated geotechnical parameters in the current study can facilitate suitable designs and remedial measures to protect the engineering foundations of the future educational buildings scheduled at the campus site of the College of Science, University of Diyala, Iraq.

6. Reference

[1] B. M. Das, *Soil Mechanics Laboratory Manual, 6th edition ed., Oxford University press*, 2002, p. 165.

[2] G. A. Al-Naimi, "Evaluation of shear strength parameters of Baghdad soil," M.Sc. Thesis, University of Technology, (unpublished), Baghdad, 1996.

[3] W. J. M. Al-Jabban, "Geotechnical Assessment of Hilla City- Iraq," *Journal of Babylon University/Engineering Sciences*, vol. 22, no. 1, pp. 102-121, 2014.

[4] H. M. Hussein, "Evaluation of geotechnical subsoil properties for Wasit governorate," *Journal of Engineering and Development*, vol. 20, no. 02, pp. 224-238, 2016.

[5] J. H. Alzubaydi, H. A. Alamar and S. N. Al saadi, "Evaluation of Some Geotechnical Properties of Chosen Soils From AlMassab Al-Aam channel Slopes (Middle Sector) of Iraq," *Iraqi Journal of Science*, vol. 57, no. 4A, pp. 2444-2456, 2016.

[6] N. H. Al-Baghdadi, " Geotechnical Mapping of An-Najaf City, Iraq," *Journal of Babylon University/Engineering Sciences*, vol. 24, no. 4, pp. 962-779, 2016.

[7] Z. Rasheed, B. D. Ghafour and H. M. Omar, "Assessment of Shallow Geotechnical Properties, Koya City- North of Iraq," *American Journal of Civil Engineering and Architecture*, vol. 4, no. 2, pp. 67-73, 2016.

[8] R. S. A. Siaede, "A Practical Geotechnical Analysis of in situ Stress Variations and Hydraulic Stability of Small Weirs Using SEEP/W and SIGMA/W Simulation," *Iraqi Journal of Science*, vol. 60, no. 11, pp. 2457-2467, Nov. 2019..

[9] W. H. Sayhood and M. J. Rashid, "Assessment of Some Geotechnical Properties for Soils of Euphrates River Banks (Kufa- Mishkhab), Middle of Iraq," *Iraqi Journal of Science*, vol. 61, no. 12, pp. 3242-3251, Dec. 2020..

[10] I. Al-abboodi, A. Z. Hamoodi and S. M. Salih, "Geotechnical Features of Basrah City, Iraq," *Basrah Journal for Engineering Sciences*, vol. 20, no. 2, pp. 1-7, 2020.

[11] S. A. Al-Talib, A. S. Al-Jawadi and A. S. Al-Sanjari, "Impact of Gercus Formation Erosion and Rock Sliding on Duhok Dam Reservoir – Northern Iraq," *Iraqi Journal of Science*, vol. 62, no. 5, pp. 1562-1569, May 2021.

[12] H. Al- Ani, "Primary Geotechnical Maps Of Soil Of Selected Sites In Diyala Governorate," M. Sc. Thesis, University Of Baghdad – College of Science (Unpublished), Baghdad, 2001.

[13] Y. J. Alshakarchi and M. A. Turkie, "The Geotechnical Maps For The Soil Of The Governorates Baghdad, Diyala, Wasit And Babylon," *Journal of Engineering*, vol. 17, no. 3, pp. 87-104, 2011.

[14] K. A. Abdullah and M. N. Awad, "Geotechnical Properties for Soil Alghlabia Area in Diyala Governorate," in 16th Iraqi Geological Conference , Baghdad, 26-27 April 2017.
[15] Al-Ebdaa Company for Soil Investigation and Piles , "Soil Investigation Report for the New Buildings of Diyala University- Part II, Report No., ESR-015-08," April 2015.
[16] D. G. Fredlund and H. Rahardjo, *Soil mechanics for unsaturated soils, New York: John Wiley & Sons*, 1993, p. 567.
[17] ASTM D2216-05, "Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass," ASTM International, West Conshohocken, PA, USA., 2005.
[18] ASTM D854-05, "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer," ASTM International, West Conshohocken, PA, USA, 2005.
[19] J. E. Bowles, *Physical and Geotechnical properties of soils, 2nd ed., MeGraw-Hill International Book Company*, 1984, p. 250.
[20] ASTM D4318-05, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils," ASTM International, West Conshohocken, PA, USA, 2005.
[21] ASTM D698-07, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3))," ASTM International, West Conshohocken, PA, USA, 2007.
[22] C. R. Scott, *An Introduction to Soil Mechanics and Foundation, 2nd ed., Applied science, Ripple Road, Essex. England*, 1974, p. 361.
[23] ASTM D3080 - 04, "Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions," ASTM International, West Conshohocken, PA, USA, 2004.
[24] ASTM D 2435– 04, "Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading," ASTM International, West Conshohocken, PA, USA, 2004.
[25] K. Terzaghi, R. B. Peck and G. Mesri, *Soil Mechanics in Engineering Practice, 3rd ed., New Yourk: John Wiley & Sons*, 1996, p. 664.
[26] R. Kumar and P. K. Jain, "Prediction of Compression Index (Cc) of Fine Grained Remolded Soils from Basic Soil Properties," *International Journal of Applied Engineering Research*, vol. 11, no. 1, pp. 592-598.
[27] R. D. Kerbs and R. D. Walker, *High Way Material, USA: McGraw-Hill Book Inc*., 1971, p. 428.
[28] T. W. Lambe and R. V. Whitman, *Soil Mechanics, New York: John Wiley & Sons Inc*, 1969, p. 553.
[29] M. A. Dafalla, "Effects of Clay and Moisture Content on Direct Shear Tests for Clay-Sand Mixtures," *Advances in Materials Science and Engineering*, vol. 2013, pp. 2-8, 2013.
[30] S. Widodo and A. Ibrahim, "Estimation of Primary Compression Index (Cc) Using Physical Properties of Pontianak Soft Clay," *International Journal of Engineering Research and Applications*, vol. 2, no. 5, pp. 2232-2236, 2012.
[31] R. D. Holtz and W. D. Kovacs, *An Introduction to Geotechnical Engineering, New Jersey, USA: Prentice Hall, Englewood cliffs*, 1981, p. 733.
[32] J. F. Poland, ,*Guidebook to Studies of Land Subsidence due to Groundwater withdrawal, Vol. 40 of UNESCO studies and Reports in Hydrology, Paris, France,: United Nations Educational Scientific and cultural Organization*, 1984, p. 305.