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Effect of Replacement by Subbase on the Bearing Capacity of Fine Grained Soils

A Research

Submitted to the College of Engineering / University of Babylon in partial Fulfilment of the Requirements for the Degree of Higher Diploma in Engineering / Civil Engineering / Geotechnical Engineering

By

Alaa Sami Hadi

Supervised By

Asst. Prof. Dr. Basil Obayd Mahdi

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بسم الله الرحمن الرحيم

وَمَا تَوْفِيقِي إِلا بِاللَّهِ عَلَيْهِ تَوَكَّلْتُ وَإِلَيْهِ أُنِيبُ

صدق الله العظيم

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I certify that the proportion of this research entitled ‘‘**Effect of Replacement by Subbase on the Bearing Capacity of Fine Grained Soils**’’ is prepared by **Alaa Sami Hadi** under my supervision at the College of Engineering, the University of Babylon in partial fulfilment of the requirements for the degree of higher diploma of science in Engineering/ Civil Engineering /Geotechnical Engineering .

Signature

Name: Asst. Prof. Dr. Basil Obayd Mahdi

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Signature:

Name: Asst. Prof. Dr. Ibtihaj Taha Jawad

(Chairman)

Date: 2022/ /

Signature:

Name: Asst. Prof. Ahmed Talib Obeed

(Member)

Date: 2022/ /

Signature:

Name: Asst. Prof. Dr. Basil Obayd Mahdi.

(Member and Supervisor)

Date: 2022/ /

Signature:

Name: Asst. Prof. Dr. Thair J. Mizhir Alfatlawi

Head of the Civil Engineering Department

Date: 2022/ /

Signature:

Name: Asst. Prof. Dr. Hatem Hadi Obeid

Dean of College of Engineering

Date: 2022/ /

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أ.م.د باسل عبيد مهدي

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ABSTRACT

As it is obvious and clear, the importance of the soil in every construction works it is substantial to study the soil properties as an integral part of designing any structure nevertheless it is the most important part. The studying of soil properties will reveal if any problem is existing to make the improvement decision of soil improvement technique represented by replacement of the existing soil by subbase material of a certain thickness. In this study a data was compiled from field tests to ratiocinate a relationship between the thickness of replacement soil layer and the soil bearing capacity in order to conclude to how far the existing soil properties can be improved by this technique. In order to bring out these data; the standard field plate load test was conducted for 4 attempts by changing the replacement thickness, the first was directly on the natural ground while the remaining three tests were conducted with replacement thicknesses of (3, 7.5, 12) cm which represent (0.1, 0.25 and 0.4) of the 30 cm (the plate diameter) used in the test.

The replacement material is subbase manually compacted to 95% compaction ratio (according to the modified compaction test) for each determined thickness.

It is found that replacement of soft fine soil by compacted subbase improves both the ultimate bearing capacity and the settlement at failure.

Briefly and clearly the effectuation of replacement was to increase the bearing capacity by the percent of (95 / 115 / 139) respectively for the replacement of (0.1 , 0.25 , 0.4) of plate diameter and decrease the settlement in a range of (7 to 71) % .

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LIST OF SYMBOLS

SYMBOL	DEFINITION
qu	Ultimate bearing capacity
ɤ	Unit weight of the soil
c'	Cohesion of soil
Nc, Nq, Nɤ	Bearing capacity factors
Ø'	Friction angle
Df	Overburden depth
B	Footing width
Kpɤ	Passive pressure coefficient
Fcs, Fqs, Fγs	Bearing capacity shape factors
Fcd, Fqd, Fγd	Bearing capacity depth factors
Fci, Fqi, Fγi	Bearing capacity load inclination factors
$ɤ_{sat}$	Saturated unit weight of soil
ɤd	Dry unit weight of soil
ɤω %	Unit weight of water
ɤ′	Effective unit weight of soil
ω %	Water content
ωopt	Optimum moisture content
q	Unconfined compressive strength
Cu	Undrained shear strength
ρ	Density
e	Soil void ratio
S %	Degree of saturation
Gs	Specific gravity
u	Hydraulic system pressure
PLT	Plate load test

المقدمة

التربة جزء لا يتجزأ من أي منشـأ بل و هي الجزء الاسـاس و الاكثر اهمية لأخذه بنظر الاعتبار عند الشـروع في تصـميم اي منشـأ ,اذ انه و ضـمن تحريات التربة يجب دراسـة مدى تحمل التربة لأحمال المنشأ المراد تصميمه و تنفيذه بمجرد اعتماد فكرة التصميم . دراسة النتائج و تحديد الحلول المناســبة تعتمد على نتائج تحريات التربة . اذ و لعقود عديدة كان موضـــوع دراسة معالجات التربة من اهم المواضيع المطروحة للنقاش و الدراسة .

يتناول البحث دراسـة مدى تحسـن التربة في حال اسـتبدال التربة الضـعيفة بالسـبيس و مدى تـأثير ذلك على قـابليـة تحمـل التربـة و الهبوط في التربـة و للوقوف على هذه النتـائج و دراستها تم اجراء فحص تحمل الصفيحة بالاضافة الى فحوصات اخرى مهمة تم اجراؤها تباعا اثناء البحث .

حيث تم تجهيز موقع الفحص في الباحة الخلفية من قسـم الهندسـة المدنية في جامعة بابل و تم تجهيزه بتربة رخوة (تم حفر 2.5 * 5 متر و بعمق 1 متر و اســتبدالها بتربة زراعية رخوة) و غمرها بالماء قبل اجراء الفحص بيومين و كلذك من التحضــيرات قبل الفحص هو استبدال التربة بالسبيس المحدول يدوياً بنسبة 95% و حسـب السمك المقرر للفحص , حيث تم احتسـاب سـمك الفحص كنسـبة من قطر صـفيحة الفحص البالغة 30 سـم و اعتماد سـمك طبقة الاستبدال حسب ما يلي (0.1 و 0.25 و 0.4) اي (3 , 7.5 , 12) سم تباعاً مع اجراء فحص على الارض الطبيعية .

حيث اظهرت النتائج من الفحص زيادة قابلية تحمل التربة بحوالي (95% , 115% , 139%) على التوالي لكل فحص بينما نقص هبوط التربة بنسبة تتراوح بين (7 الى 71) .

Chapter One

INTRODUCTION

Chapter One

INTRODUCTION

1.1 General

The bearing capacity and soil settlement can be classified as the most important influential factors on each structure as a proactive step in the structural design and so it has been a serious issue to explore the area for construction in order to find out the soil profile before starting any works in any exploration available way, with knowing the soil profile and soil problems it is important to study the available treatment and improvement to get into the best available result with the most reasonable ways.

1.2 The Aim and Objectives

This work is restricted to:

1- Investigate the effect of the thickness of replacement layer on the bearing capacity by specific trials of field plate load test with different replacement layers.

2- Study the effect of load on the settlement of soil.

3- Find a relationship between the bearing capacity increment and settlement reduction in a specific stress level during the test.

To highlight to what extent the soil replacement under shallow foundation can improve the soil is the target for this research that have been conducted by preparing the test set with providing all the necessary factors that influence the test conditions which includes soft soil and granular material for backfilling with all testing apparatus (that provided from the faculty labs). In another clearly way this work is restricted to the investigation of the effect of replacement of fine soil by compacted subbase on the ultimate bearing capacity and settlement adopting the field plate load test.

1.3 Layout of the Study

This study has been built up from five interconnected chapters as below briefly explained:

Chapter One: Which have been used to show a short brief summarization for the aim of the study with general overview

Chapter Two: Includes a review of the literature and thesis which associated with this study by discussing the soil bearing capacity and the ways of conducting it whether by equations or in field tests.

Chapter Three: Contains a full description of the test methodology and the material used to conduct the results which will be handled in the next chapter.

Chapter Four: From the test results that have been extracted from chapter three, we used to analyze and discuss the results.

Chapter Five: Includes a recommendations for the other researchers that is accompanied with the conclusions of the test results.

Chapter Two

LITERATURE REVIEW

Chapter Two

LITERATURE REVIEW

2.1 Introduction

Bearing capacity is the maximum stress or pressure that a footing can sustain without failure of the soil or rock that is supporting the footing. To design any structure it should be started with the study of the soil bearing capacity as it is a fundamental step to get started with for any design, and led for the importance of studying and calculation of the bearing capacity for the soil.

2.2 Bearing Capacity Equation:

2.2.1 Terzaghi Bearing Capacity Equation:

For decades many attempts have been made to calculate the bearing capacity for soil by several scientists and one of the most popular was Terzaghi with his famous equation and theory which deal with continuous or strip shallow footing and restricted with that the effect of soil located above the foundation bottom line will be considered as a surcharge weight , $q = \gamma Df$ (where γ is the unit weight of the soil and Df is the soil surcharge depth) and the last condition is to consider the failure surface of soil is similar to general shear failure case, with modifications due to foundation shape and shear failure condition. By complying with these conditions Terzaghi equation will be applicable .And to find the value of each term and factors depending on special equations with reference to soil factors and properties.

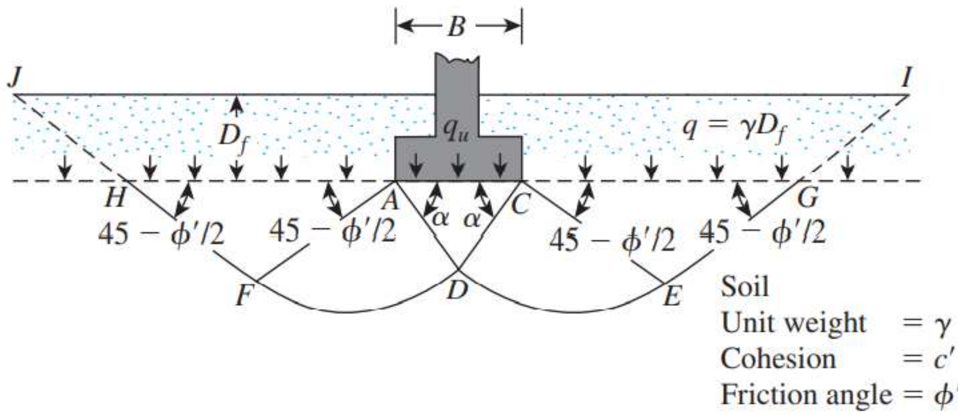

Figure 1. Bearing capacity failure in soil under a rough rigid continuous (strip) foundation (Barja.M.Das (2011)).

1. The triangular zone ACD immediately under the foundation

2. The radial shear zones ADF and CDE, with the curves DE and DF being arcs of a logarithmic spiral

3. Two triangular Rankine passive zones AFH and CEG

The angles CAD and ACD are assumed to be equal to the soil friction angle Note that, with the replacement of the soil above the bottom of the foundation by an equivalent surcharge q, the shear resistance of the soil along the failure surfaces GI and HJ was neglected. Using equilibrium analysis, Terzaghi expressed the ultimate bearing capacity in the form:

$qu = c'Nc + qNq + 0.5\,\gamma\,B\,N\gamma$ ………………………….. (3.1)

Where:

c' = cohesion of soil

ɤ = unit weight of soil

q = ɤ Df

Nc, Nq, Nɤ = bearing capacity factors that are nondimensional and are functions only of the soil friction angle Ø'

The bearing capacity factors and are defined by:

$$Nc = \cot\text{Ø}'\left[\frac{e^{2\left(3\pi/4 - \text{Ø}'/2\right)\tan\text{Ø}'}}{2cos^2\left(\frac{\pi}{4}+\frac{\text{Ø}'}{2}\right)} - 1\right] = \cot\text{Ø}'(Nq-1) \quad \text{….. (3.2)}$$

$$Nq = \frac{e^{2\left(3\pi/4 - \text{Ø}'/2\right)\tan\text{Ø}'}}{2cos^2\left(45+\frac{\text{Ø}'}{2}\right)} \quad \text{……………………………………… (3.3)}$$

$$N\gamma = \frac{1}{2}\left(\frac{Kp\gamma}{cos^2\,\text{Ø}'} - 1\right)\tan\text{Ø}' \quad \text{………………………..……… (3.4)}$$

* Kpɤ = passive pressure coefficient.

To estimate the ultimate bearing capacity of square and circular foundations, Eq. (3.1) may be respectively modified to

$$qu = 1.3\,c'NC + qNq + 0.4\,\gamma\,B\,N\gamma\ (square\ foundation)\ .\ (3.5)$$

$$qu = 1.3\,c'NC + qNq + 0.3\,\gamma\,B\,N\gamma\ (circular\ foundation)\ .\ (3.6)$$

(Barja.M.Das (2011)).

2.2.2 Meyerhof (1951):

In order to deal with other assumption that wouldn't have been treated by Terzaghi equation, And to deal with the fact of rectangular foundations plus to take into account the shearing resistance along the failure surface in soil above the bottom of the foundation finally in case of the load on the foundation may be inclined. For the above mentioned shortcomings Meyerhof dealed with additional 3 empirical factors based on experimental data, these factors are: shape (S), depth (d) and inclination load factor (I) and suggested the following form of the general bearing capacity equation:

$$qu = c'Nc\ Fcs\ Fcd\ Fci + \ qNq\ Fqs\ Fqd\ Fqi + 0.5\ \gamma\ B\ N\gamma\ F\gamma s\ F\gamma d\ F\gamma i$$

Where:

Fcs, Fqs, Fγs: shape factors

Fcd, Fqd, Fγd: depth factors

Fci, Fqi, Fγi: load inclination factors

These factors which can be conducted from the below table :

Table 1. Meyerhof bearing capacity equation factors

Factor	Relationship	Reference
Shape	$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right)$	DeBeer (1970)
	$F_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi'$	
	$F_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right)$	
Depth	$\frac{D_f}{B} \le 1$	Hansen (1970)
	For $\phi = 0$:	
	$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right)$	
	$F_{qd} = 1$	
	$F_{\gamma d} = 1$	
	For $\phi' > 0$:	
	$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'}$	
	$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2\left(\frac{D_f}{B}\right)$	
	$F_{\gamma d} = 1$	
	$\frac{D_f}{B} > 1$	
	For $\phi = 0$:	
	$F_{cd} = 1 + 0.4\underbrace{\tan^{-1}\left(\frac{D_f}{B}\right)}_{\text{radians}}$	
	$F_{qd} = 1$	
	$F_{\gamma d} = 1$	
	For $\phi' > 0$:	
	$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'}$	
	$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2\underbrace{\tan^{-1}\left(\frac{D_f}{B}\right)}_{\text{radians}}$	
	$F_{\gamma d} = 1$	
Inclination	$F_{ci} = F_{qi} = \left(1 - \frac{\beta^\circ}{90^\circ}\right)^2$	Meyerhof (1963); Hanna and Meyerhof (1981)
	$F_{\gamma i} = \left(1 - \frac{\beta}{\phi'}\right)$	
	β = inclination of the load on the foundation with respect to the vertical	

2.2.3 Effect of Water Table on Bearing Capacity:

Due to the effect of water table on the bearing capacity of the soil, modifications have been imperative on the general equation of the bearing capacity as the water table is a non-ignorable factor on the soil properties generally which can be represented by the effect in the bearing capacity equation as explained next .

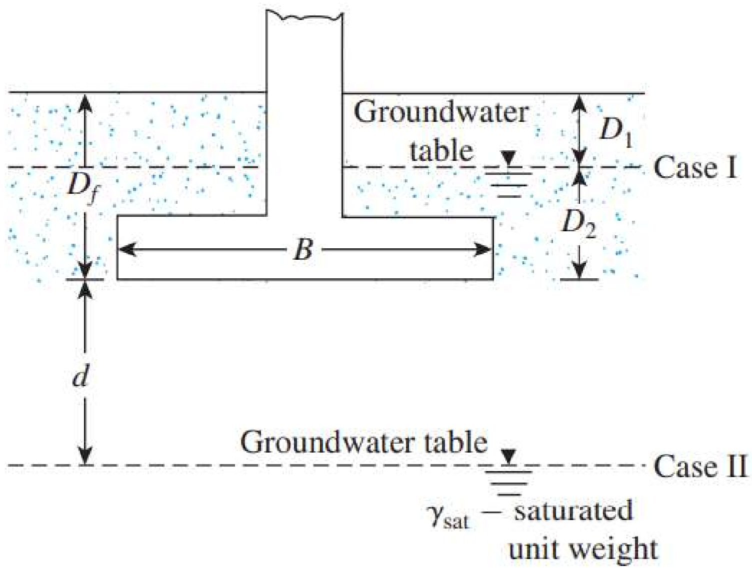

Figure 2. Water effect on bearing capacity equation (Barja.M.Das (2011)).

Case 1: when the water table level in the range of surcharge level ($0 \leq D1 \leq Df$) , the effective surcharge q will be changed to be :

$$q = \text{effective surcharge} = D_1\gamma + D_2(\gamma_{sat} - \gamma_{\omega})$$

Where:

γ_{sat} : saturated unit weight of soil

γ_{ω} : unit weight of water

In addition to that, the third term of the equation will be changed due to the change of the γ value to be $\gamma' = \gamma_{sat} - \gamma_\omega$.

Case 2: when the water table is located in depth which is limited from the bottom face of footing to a depth equal to the footing width ($0 \leq d \leq B$), then: $q = \gamma\ Df$, $\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma - \gamma')$

Case 3: when the water table is located in level that is exceed the footing depth restrict in case 2, ($d \geq B$), then the ultimate bearing capacity will not be affected by the water table.

2.2.4 Bearing Capacity of Footing on Layered Soil:

In the many previous studies in soil bearing capacity equations it was considered that the foundation resting on homogeneous soil layer with constant properties (the cohesion, angle of friction, and unit weight) that extends into a sufficient depth, but in general this is a theoretical case and in realistic case it is naturally stratified soil layers with thickness and height that varies from location to another. And to deal with this situation it was categorized into three general cases (Barja.M.Das (2011)).

Case 1. Footing on layered clay soil with (Ø=0)

Case 2. Footing on layered (Ø-C) soil

And for both case 1 & case 2 it can be sub classified into either the top layer is the stronger than the lower layer or vice versa by being the top layer is the weaker than the lower layer .

Case 3. Will be for the soil layered by sand and clay soil with alternate places (sand overlying clay and clay overlying sand).

In general and in this case we have three variables that are related to each other and together will form the shape of soil failure and the way of determination the ultimate load per unit area (qu) these variables are the footing width (B), effective depth of soil layer that the load is distributing accordingly (H) and the thickness of each layer (D). Which due to the above mentioned variables we will have the cases that:

A. if the (H) is more than (D) for the upper layer so the effect of the load will be spread into the second underlying layer through the first layer and **if** the upper layer is the strongest then punching shear failure will occur while general shear failure will be in the lower layer, in the other probability of the upper layer is weaker than the lower one so the surface failure pattern will be in defined style.

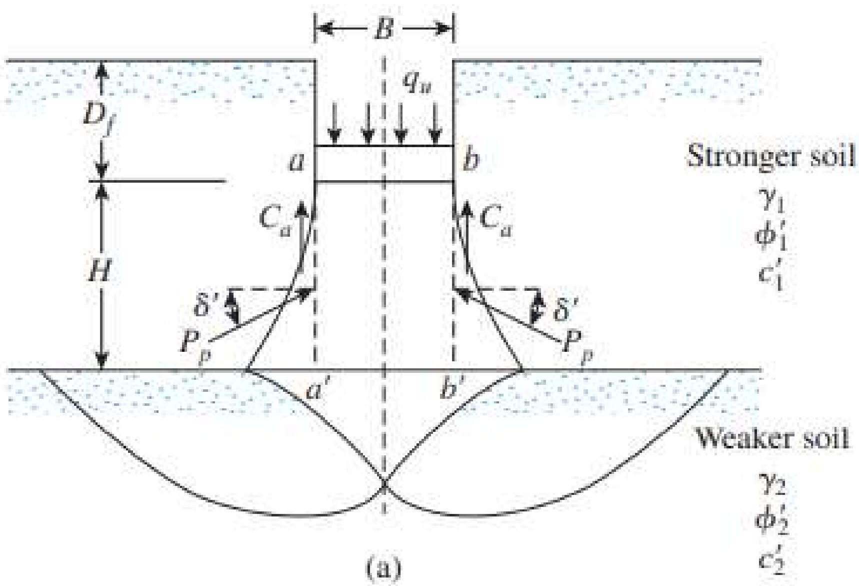

Figure 3. Layered soil effect on bearing capacity (Barja.M.Das (2011)).

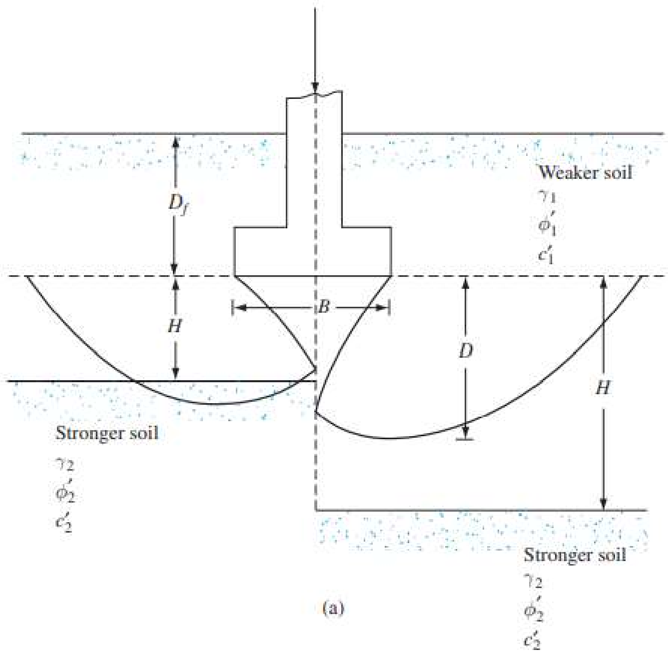

Figure 4. Layered soil effect on bearing capacity - case 2 (Barja.M.Das (2011)).

B. In the other side and if (H) would not cross the limits of (D) so the effect of load will be limited in the upper layer whether it was weaker or stronger.

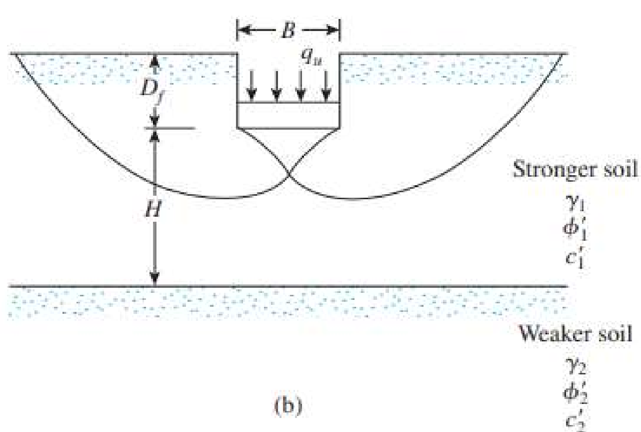

Figure 5. Layered soil effect on bearing capacity - case 3 (Barja.M.Das (2011)).

2.3 Plate Load Test:

As it was mentioned for the importance of bearing capacity in the structure design, beside the theoretical methods there is the plate load test as a practical method to indicate the amount of the soil bearing capacity. (The bearing capacity of a soil is not simply a soil strength parameter, but it also depends on the magnitude and distribution of the load, dimension, and geometry of the loading plate and depth of embedment (or elevation of testing). This bearing capacity can be used in soil investigations and for the design of foundations). (ASTM D 1194)

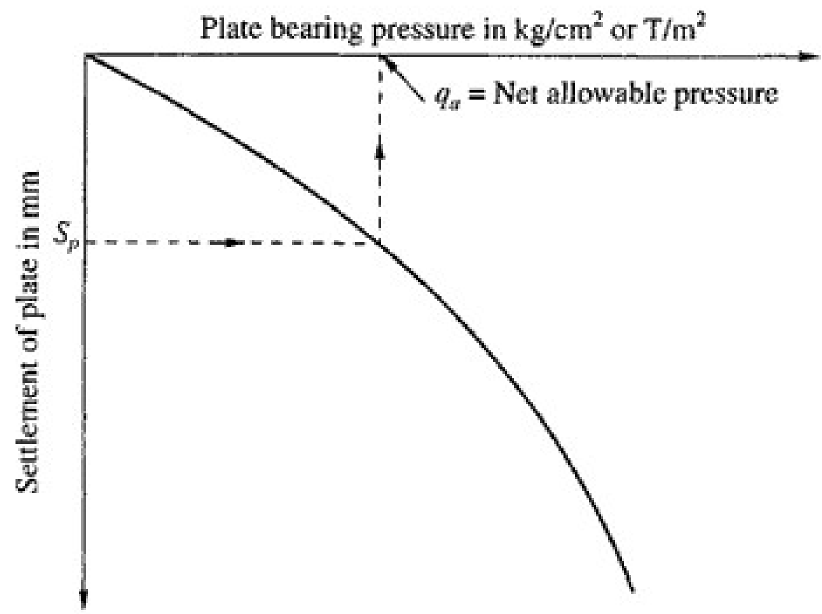

Figure 6. Load-settlement curve in plate load test (V.N.S. Murthy)

It should be considered that the plate load test cannot be useful in cases of:

1- Non-homogeneous soils at least to a depth of 1.5 to 2 times the prototype foundation width.

2- The sandy soils plate load test results for bearing capacity as it will be misleading results. (V.N.S. Murthy)

2.4 Soil Replacement

(Fattah, Al-Neami and Al-Suhaily, 2015) studied the effect of partial replacement with fine grained soil on the bearing capacity of soft clay that is subjected to loading by modeling that is consisted of 2 sets with 4 samples for each set with considering the pattern of replacement is trench and square replacement pattern for each test set respectively, came out with the result that maximum improvement is conducted when using the sampling with properties of (trench pattern with dimension of B and extension of B/2 by depth of 1.5 B) , (consider B as the width of footing) in additional to the fact that the trench soil replacement is more effective that the square replacement by about (10-20)%.

(Malik, Alshameri and Umar, 2020) that pinpointed the depth of replacement as the parameter that is more significant than the replacement width in improving the bearing capacity and the found that (3B,2B) are the optimum width and depth respectively for the square footing while for strip footing it was found that 4B is the optimum depth of replacement with no optimum depth of replacement.

(Mohammed Al-Waily, 2019) Concluded that using crushed concrete as replaced layer for soil improvement is more effective under square footing than under strip footing with the fact that the maximum bearing capacity ratio was conducted in the square footing.

(Elsamee, 2019) Used a numerical modeling to study the behavior of soft clay when using reinforced replacement soil (soft clay below the replacement of different thicknesses of granular soil with many variables such us without or with reinforcement, no. of reinforcement layers and vertical spacing in-between the layers) and came out with the conclusion that the ultimate bearing capacity of soft clay increases with the increase of thickness of replaced layer and geogrid of reinforcement layer.

(Hasanzadeh and Choobbasti, 2016) Found the critical value of improvement in bearing capacity value (that would be by the depth of replacement equal to 0.8 of the diameter of the circular footing) and if increased the depth of replacement to amount that is more than 0.8D will be without any noteworthy changes , to get this conclusion they used numerical analyses to obtain the bearing capacity of circular footing resting on clay soil that stabilized with granular compacted fill with different depth and lengths to show that the granular replacement improvement has significant effect on the bearing capacity value.

Naema. A. Ali (2015) tested the behavior and performance of compacted sand replacement over treated collapsible soil by pre-wetting and compaction by performing the necessary field investigation on the replacement layers which conducted as a percentage of the plate of PLT and has found that the foundation settlement will be reduced by 50% while the bearing capacity increased with 100% for replacement of soil by compacted cohesionless soil

Chapter Three

MATERIALS

AND METHODS

Chapter Three

MATERIALS AND METHODS

3.1 Introduction

This chapter involves the nature and properties of the material encountered in this research:

1- Soil, which can be described as soft soil due to the soil properties revealed by the soil tests.

2- Granular material which had been used as a replacement material (subbase).

The test location has been chosen to be in the backyard of civil engineering department / University of Babylon as it was a clear area that is ready for test with no structures obstacles , and for the replaced granular materials it has brought from outside with making the necessary elective process .

The tests that has been conducted can be simply listed as below:

For subbase:

1. Modified Compaction Test.

For soil:

1. Atterberge limit (liquid limit, plastic limit & plasticity index)
2. Specific Gravity determination test.
3. Particle size distribution.
4. Unconfined Compression test.

Field test:

1. Field plate load test.

3.2 Procedure

3.2.1 Modified Compaction test

A modified compaction test was made on a sample of the subbase according to ASTM D-1517 to determine the compaction parameters.

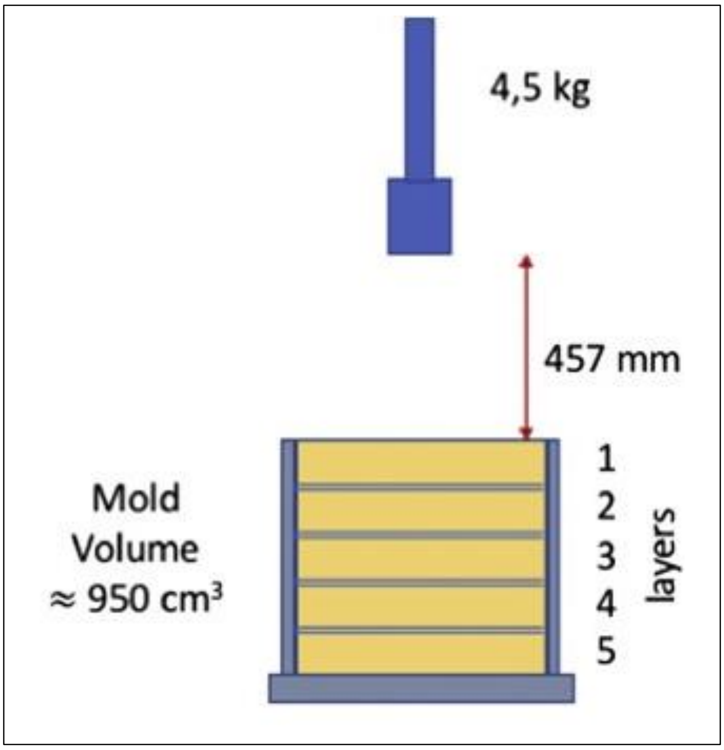

Figure 7. Modified Compaction test apparatus

3.2.2 Plate load test

The Plate Load test is designed to determine the vertical deformation and strength characteristics of soil by assessing the force and amount of penetration with time when a rigid plate is made to penetrate the soil. The method may be used to evaluate the ultimate bearing capacity, the shear strength and deformation parameters of the soil beneath the plate without entailing the effects of sample disturbance. Testing may be carried out at the ground surface, in pits or in trenches (BS 1377-9 (1990). The plate load test is considered to be one of the most frequently employed and suitable method for its purpose on soils especially when the foundation material is such that it is practically impossible to collect undisturbed samples for foundation testing.

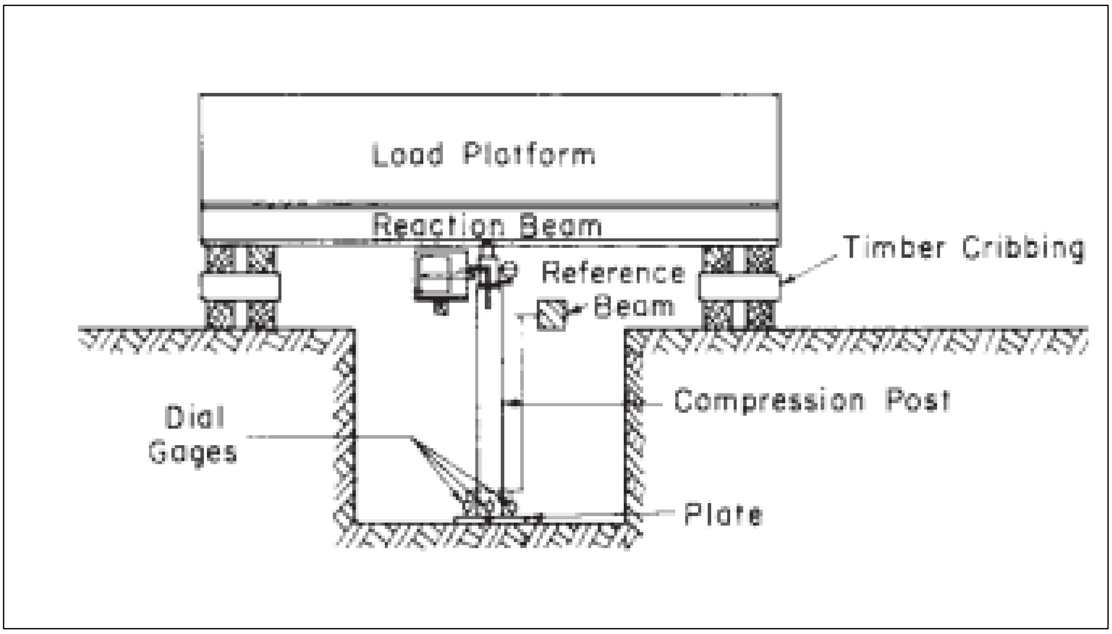

Figure 8. Schematic drawing for the field plate load test set

Firstly it was decided to make the test directly on the natural ground (at the back yard of the civil engineering department building) , the test was firstly started with making an exploration pit with one meter depth to be fulfilled with the soil properties and profile which as shown in the next figure :

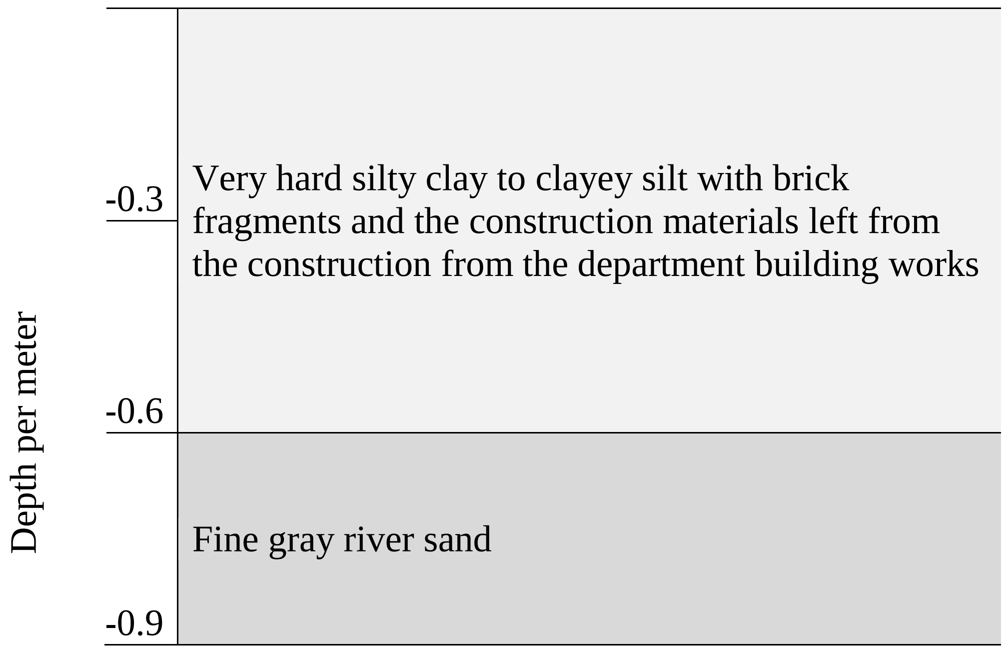

Figure 9. Schematic profile for exploration pit soil properties (the origin soil in the civil engineering department backyard)

After taking samples from each depth, the samples was as the figure below (before drying the samples):

Depth (m)	-0.9	-0.6	-0.3	0.0
ω (%)	28.9	23.9	15.7	11.8

Figure 10. The water content samples for various depths (for the origin soil in the civil engineering department backyard)

The next step was to prepare the site for the plate load test set for test starting by digging a hole of diameter is a little more than the plate diameter:

Figure 11. The first testing attempt hole

Figure 12. The Plate Load test assembly

The first attempt for the plate load test has been done on the natural ground level, And the results revealed that the natural ground is extremely strong and stiff enough and this was not the desired result as the target for the test environment is a soft soil, so it had to make another test conditions that meet the desired one for the test so we had to do a soil replacement procedure to get the location set for our investigation with providing the suitable site conditions as best as it is possible.

So the test procedure was changed to another path comprised in soil replacement as a first step and that was by removing the existing soil for (1.0) m depth in a ditch of (2.5*5) m and replaced it with another clayey cohesive soil with small percentage of sand (comparatively weaker than the origin soil) and worked on flooding the ditch with water before test for many days in the reason of getting a soil with full setting and settlement and to get homogeneous weak normally consolidated soil.

Figure 13. The replaced soil ditch

Figure 14. Flooded (2.5*5) m, (1.0) m depth testing ditch

After setting the desired platform for the test, it was planned to prepare a circular hole of 40cm in diameter with depth that is conducted as a percentage of the circular plate of the PLT diameter (which is 30cm) so the replacement thickness will be (3cm , 7.5cm , 12cm) as the percentage was (0.1d , 0.25d , 0.4d)

To put down an organized description of the work we can enumerate the steps for as below items:

i. The first test was conducted on the natural ground level (of the ditch) without any replacement, it was done with the same procedure as explained next.

ii. The second test was for the replacement thickness (3 cm) started with preparing a circular hole with diameter of 40 cm and depth of 3 cm.

iii. Backfill the hole with a subbase layer with suitable humidity 'that was conducted previously by the modified compaction test to determine the optimum moisture content'.

iv. Flooding the test pit with sufficient amount of water to get ready for the PLT in the next day.

v. First thing in the testing day we had samples for water content and undisturbed samples for the unconfined compression test.

vi. After making all the necessary arrangement and installation steps for the plate load test , we started the loading with (5 bar = 2.395 T/m^2) as a start and record all the readings in through short time intervals to monitor the rapid change in settlement gauge readings and when the readings were almost constant (the soil has been with stable reaction to the load increment) we increased the loading to be (10 bar = 4.79 T/m^2) and start to record all the readings as soon as the load changed , and this procedure was repeated for each load until we got the failure case .

vii. After the load was released the rebound of the soil was recorded (the elastic rebound).

viii. We repeated the previous procedure 3 times with changing the thickness of subbase depending on the percentage of plate diameter (0.1d, 0.25d, 0.4d) so to be (3cm, 7.5cm, 12cm).

ix. So the 3rd test was for the replacement thickness of 7.5 cm and the 4th test was for thickness of 12 cm replacement.

x. We used a water tanker truck to provide the desired reaction.

Figure 15. The first PLT on the natural ground level

Figure 1. The second PLT (with 3 cm replacement)

Figure 2. The third PLT (with 7.5 cm replacement)

Figure 3. Full view of the field plate load test equipment set

3.2.3 Unconfined Compression Stress Test

This test can be classified as one of the simplest and quickest test to obtain the unconfined compression strength *qu* and the undrained shear strength *cu* which can be related with the relation of *(qu=2 cu).*Sample for this test is saturated, undrained 'there is no moisture loss during the test' and without any lateral support, cylindrical sample with dimensions ratio of 2 for the height to diameter "minimum diameter of 30 cm". We extracted an undisturbed saturated sample in each test day before conducting the PLT with dimensions the varies for each test keeping to have the rate of height to dia. ratio of 2 with taking into consideration of cross section area correction due to the reason of the fact that the cross section area is increased with the increase in compression (Ac=A*)

To finally compute the vertical stress at any stage of the test by dividing the total vertical load by the corrected cross sectional area.

Figure 4. The unconfined compression test

3.3 Tests

3.3.1 Water Content Determination:

Due to ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.

3.3.2 Density (Unit Weight) Determination:

Due to D 2937-00 – Standard Test for Density of Soil in Place by the Drive Cylinder Method.

3.3.3 Specific Gravity Determination:

Due to ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

3.3.4 Atterberg Limits Determination:

Due to ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

3.3.5 Unconfined Compression (UC) Test:

Due to ASTM D 2166 - Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.

3.3.6 Modified Compaction Test:

Due to ASTM D 1557 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m^3))[1]

3.3.7 Plate Load Test:

Due to ASTM D 1194 - Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings.

Chapter Four

RESULS AND DISCUSSIONS

Chapter Four

RESULS AND DISCUSSIONS

4.1 Introduction

In this chapter we analyzed the results that we have got from the in situ tests, unconfined compression test and plate load test mainly. For the unconfined compression test we used the digital testing device with almost two site undisturbed samples for each test.

4.2 Modified Compaction Test

Six values of the water content were proposed as it is detailed in the below table:

Table 2. Modified compaction test results

Test no.	1	2	3	4	5	6
Assumed moisture content %	4	6	8	10	10	14
Compacted sample moisture content %	3.81	5.12	6.23	7.56	10.22	13.19
Sample density (gm/cm³)	2.01	2.13	2.26	2.29	2.26	2.22
Dry density of sample (gm/cm³)	1.94	2.03	2.13	2.12	2.05	1.96

The results were then presented graphically to draw the laboratory compaction curve shown in the next below figure.

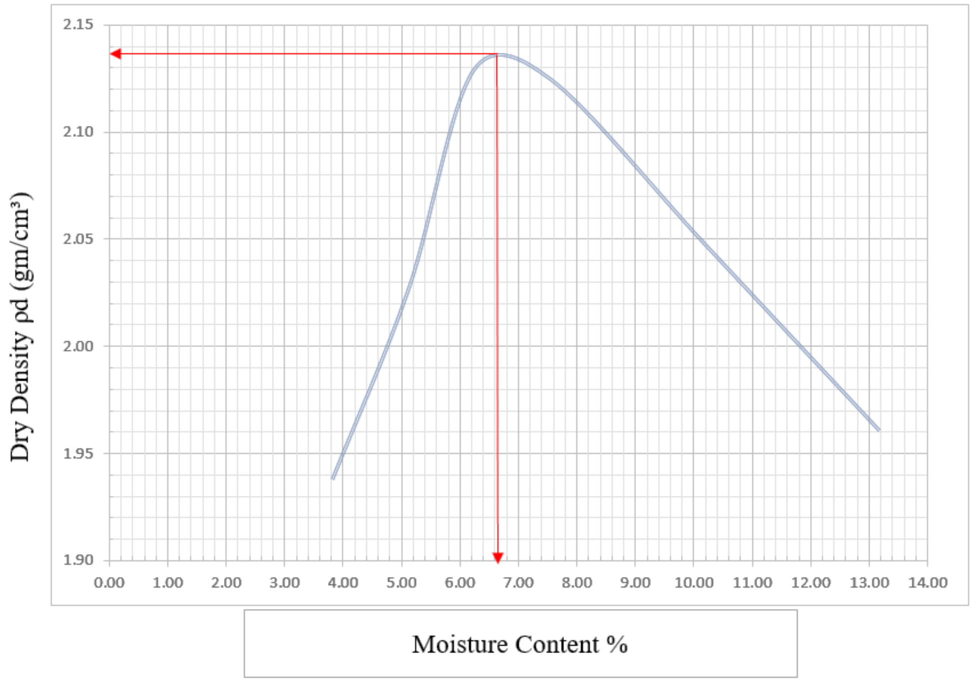

Figure 20. Compaction curve

It was depicted from that curve that the subbase used has the following compaction parameters:

Maximum dry density ρmax = 2.138 gm/cm³
Optimum water content ωopt = 6.8 %

4.3 Atterbege Limit & Specific Gravity

- LL = 32
- PL = 18
- PI = 14
- Gs = 2.66

4.4 Particle Size Distribution.

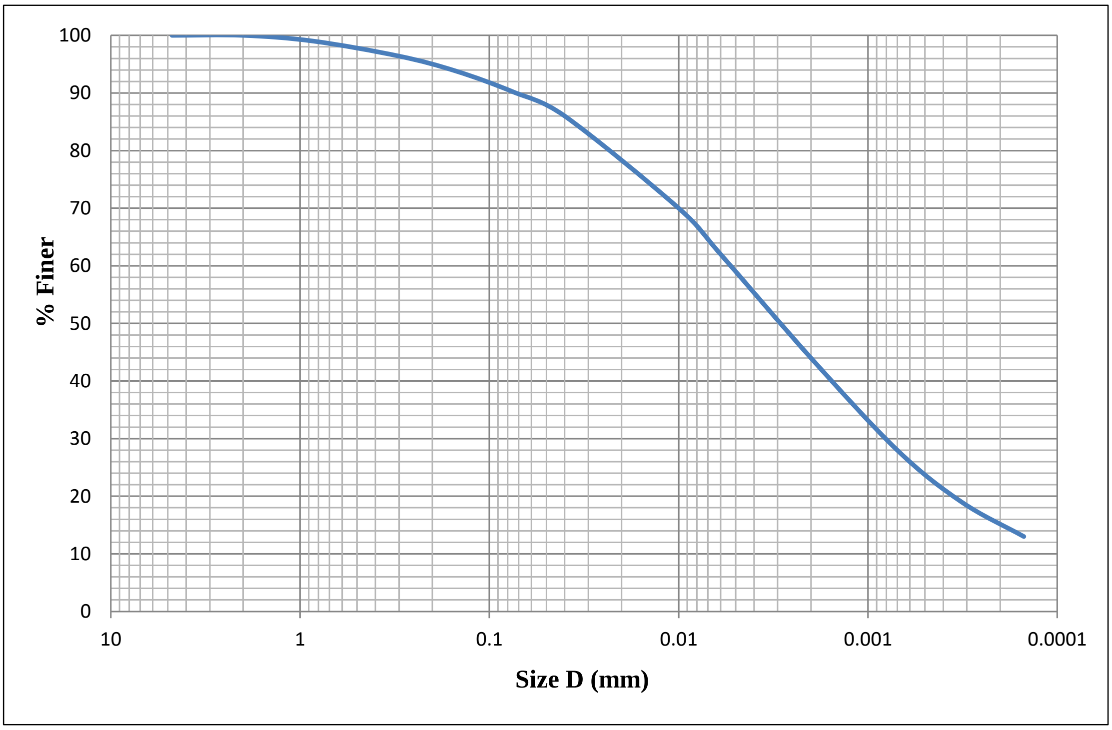

Figure 11. Particle size distribution curve (for soil)

Referred to the above mentioned data (atterberge limit & particle size distribution) the soil (that was used in the test site as explained next in the PLT) can be classified according to the Unified Soil Classification System to be:

CL [Lean Clay]

4.5 Unconfined Compression Test

For the Unconfined compression test the samples were extracted in the morning of each test before the PLT with the cylindrical Shelby tube with the dimension of (35 mm) in diameter and length of almost (75 to 100) mm, with keeping the samples in the same moisture content as possible as it can be to start the test, the results and the calculations can be summarized as the next table no. 3 (the test no. 4 (with 12 cm thickness of replacement layer) selected to show the results and test calculations).

Table 3. Unconfined compression test data

UNCONFINED COMPRESSION TEST

Location : University of Babylon Campus

Test date:	15-09-21	Test No. : (4)	thickness of replacement (mm)	120
Temp.	39º			

SAMPLE DATA :			
diameter (mm)	35	cross section area (A_o)* cm²	9.62
length ℓ (mm)	79.8	density (ρ) gm/cm³	1.94
		Water Content %	26.93

time min.	axial deformation $\Delta\ell$ (mm)	axial strain $\epsilon\ell=\Delta\ell/\ell$	axial load (kg)	corrected area Ac (cm²)	stress kg/cm²	axial strain %
0	0.00	0.000	0.000	9.62	0.00	0.0
0.3	0.20	0.003	0.400	9.64	0.04	0.3
0.5	0.52	0.007	0.600	9.69	0.06	0.7
0.8	0.84	0.011	0.900	9.73	0.09	1.1
1	1.15	0.015	1.000	9.77	0.10	1.5
1.5	1.70	0.021	1.300	9.83	0.13	2.1
2	2.12	0.027	1.500	9.88	0.15	2.7
2.5	2.56	0.032	1.700	9.94	0.17	3.2
3	2.99	0.037	1.800	9.99	0.18	3.7
3.5	3.41	0.043	2.000	10.05	0.20	4.3
4	3.82	0.048	2.200	10.10	0.22	4.8
4.5	4.25	0.053	2.300	10.16	0.23	5.3
5	4.68	0.059	2.400	10.22	0.23	5.9
5.5	5.13	0.064	2.500	10.28	0.24	6.4
6	5.55	0.070	2.600	10.34	0.25	7.0
6.5	5.95	0.075	2.700	10.40	0.26	7.5
7	6.39	0.080	2.800	10.46	0.27	8.0
7.5	6.82	0.085	2.900	10.52	0.28	8.5
8	7.25	0.091	3.100	10.58	0.29	9.1
8.5	7.67	0.096	3.200	10.64	0.30	9.6
9	8.09	0.101	3.200	10.70	0.30	10.1
9.5	8.53	0.107	3.400	10.77	0.32	10.7
10	8.99	0.113	3.400	10.84	0.31	11.3
11	9.43	0.118	3.500	10.91	0.32	11.8
11	10.11	0.127	3.500	11.01	0.32	12.7
12	10.50	0.132	3.700	11.08	0.33	13.2
12	10.92	0.137	3.700	11.15	0.33	13.7
13	11.35	0.142	3.700	11.22	0.33	14.2
13	11.62	0.146	3.700	11.26	0.33	14.6

$$* \; Ac = A * \frac{1}{1-\epsilon l}$$

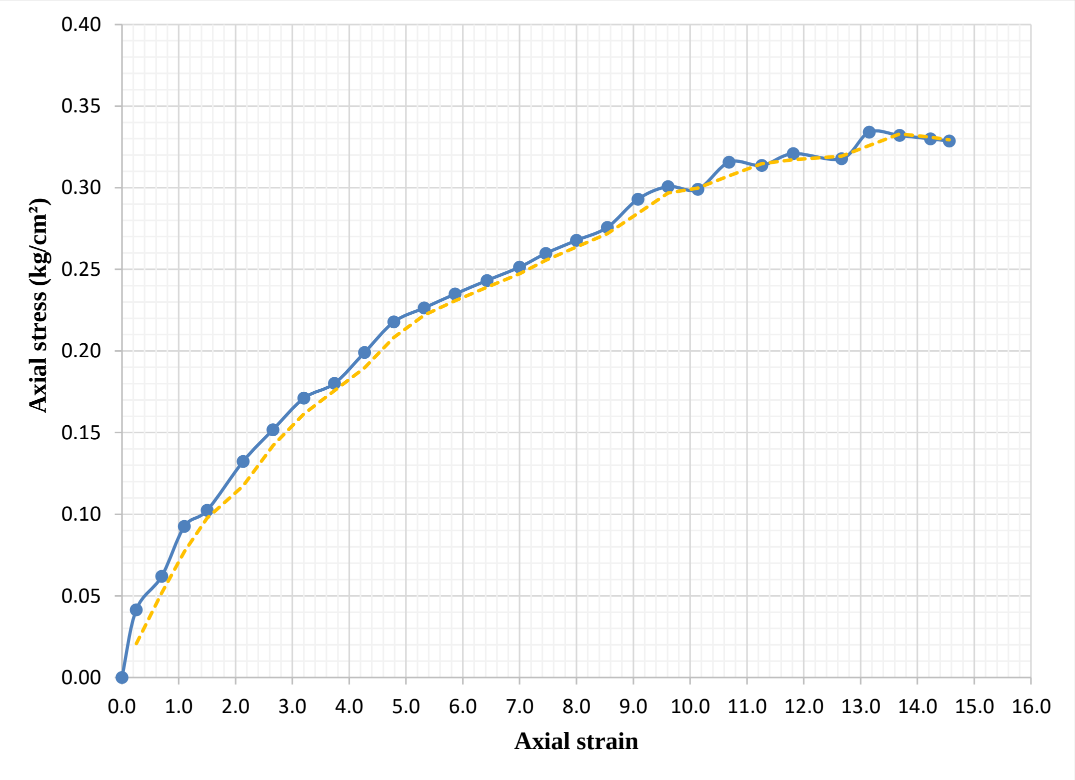

Figure 22. Stress-strain relationship for unconfined compression strength test (for the soft soil)

4.3 Plate load test

Table 4-a. Field plate load test observation data sheet and data calculations for test no. 4

Plate Loading Test Observation Sheet

Location : University of Babylon Campus

Test No.	4		
Date :	15-09-21	Temp. :	39
Starting Time :	9:35 AM		
Thickness of Replacement :	120.0 mm		

Step : 1

Pressure in Hydraulic System u (bar) : 5.00

Plate - soil contact pressure q (T/m²) : 2.40

Elapsed time min.	Settl. Dial guage reading (div.) 0.01 mm/div.				settl. div.	settl. mm	Note	
	A	B	C	Av.				
0	1	18	98	39.00	0.00	0.00	1. Ultimate settlement (mm) =	0.48
0.50	25	40	125	63.33	24.33	0.24	2. Acc. ultimate settlement (mm)=	0.48
1	32	48	132	70.67	31.67	0.32		
2	48	62	151	87.00	48.00	0.48		
3	48	62	151	87.00	48.00	0.48		

Step : 2

Pressure in Hydraulic System u (bar) : 10.00

Plate - soil contact pressure q (T/m²) : 4.79

Elapsed time min.	Settl. Dial guage reading (div.) 0.01 mm/div.				settl. div.	settl. mm	Note	
	A	B	C	Av.				
0	48	62	151	87.00	0.00	0.00	1. Ultimate settlement (mm) =	0.81
0.50	96	120	218	144.67	57.67	0.58	2. Acc. ultimate settlement (mm)=	1.29
1	113	130	226	156.33	69.33	0.69		
2	118	136	232	162.00	75.00	0.75		
3	120	138	233	163.67	76.67	0.77		
4	125	142	236	167.67	80.67	0.81		
5	125	142	237	168.00	81.00	0.81		

Table 1-b. Field plate load test observation data sheet and data calculations for test no. 4

Step :	3						
Pressure in Hydraulic System u (bar) :				15.00			
Plate - soil contact pressure q (T/m²) :				7.19			
Elapsed time min.	Settl. Dial guage reading (div.) 0.01 mm/div.				settl. div.	settl. mm	Note
	A	B	C	Av.			
0	125	142	237	168.00	0.00	0.00	1. Ultimate settlement (mm) = 2.59
0.50	315	334	541	396.67	228.67	2.29	2. Acc. ultimate settlement (mm)= 3.88
1	326	343	549	406.00	238.00	2.38	
2	333	350	537	406.67	238.67	2.39	
3	336	352	539	409.00	241.00	2.41	
4	340	357	544	413.67	245.67	2.46	
5	342	358	544	414.67	246.67	2.47	
6	342	359	545	415.33	247.33	2.47	
7	344	359	545	416.00	248.00	2.48	
8	345	361	567	424.33	256.33	2.56	
9	346	362	568	425.33	257.33	2.57	
10	347	364	568	426.33	258.33	2.58	
11	348	364	568	426.67	258.67	2.59	

Step :	4						
Pressure in Hydraulic System u (bar) :				20.00			
Plate - soil contact pressure q (T/m²) :				9.58			
Elapsed time min.	Settl. Dial guage reading (div.) 0.01 mm/div.				settl. div.	settl. mm	Note
	A	B	C	Av.			
0	348	364	568	426.67	0.00	0.00	1. Ultimate settlement (mm) = 3.21
0.50	651	661	860	724.00	297.33	2.97	2. Acc. ultimate settlement (mm)= 7.08
1	667	676	855	732.67	306.00	3.06	
2	675	687	853	738.33	311.67	3.12	
3	675	691	855	740.33	313.67	3.14	
4	675	691	856	740.67	314.00	3.14	
5	682	696	861	746.33	319.67	3.20	
6	682	699	861	747.33	320.67	3.21	
7	682	699	861	747.33	320.67	3.21	
8	682	699	861	747.33	320.67	3.21	

Table 4-c. Field plate load test observation data sheet and data calculations for test no. 4

Step : 5							
Pressure in Hydraulic System u (bar) :	25.00						
Plate - soil contact pressure q (T/m^2) :	11.98						
Elapsed time min.	Settl. Dial guage reading (div.) 0.01 mm/div.				settl. div.	settl. mm	Note
	A	B	C	Av.			
0	682	699	861	747.33	0.00	0.00	1. Ultimate settlement (mm) = 6.76
0.50	1092	1111	1236	1146.33	399.00	3.99	2. Acc. ultimate settlement (mm)= 13.85
1	1126	1133	1243	1167.33	420.00	4.20	
2	1192	1206	1326	1241.33	494.00	4.94	
3	1206	1223	1341	1256.67	509.33	5.82	
4	1254	1259	1370	1294.33	547.00	5.47	
5	1262	1259	1377	1299.33	552.00	5.52	
6	1266	1272	1381	1306.33	559.00	6.21	
7	1270	1276	1385	1310.33	563.00	6.55	
8	1326	1331	1446	1367.67	620.33	6.20	
9	1337	1343	1452	1377.33	630.00	6.30	
10	1351	1356	1466	1391.00	643.67	6.44	
11	1359	1365	1475	1399.67	652.33	6.52	
12	1365	1371	1480	1405.33	658.00	6.58	
13	1369	1375	1484	1409.33	662.00	6.62	
14	1373	1379	1488	1413.33	666.00	6.66	
15	1376	1382	1490	1416.00	668.67	6.69	
16	1378	1385	1493	1418.67	671.33	6.71	
17	1379	1386	1495	1420.00	672.67	6.73	
18	1381	1388	1497	1422.00	674.67	6.75	
19	1382	1390	1498	1423.33	676.00	6.76	
20	1383	1390	1498	1423.67	676.33	6.76	

Table 4-d. Field plate load test observation data sheet and data calculations for test no. 4

Step :	6						
Pressure in Hydraulic System u (bar) :				30.00			
Plate - soil contact pressure q (T/m²) :				14.37			

Elapsed time min.	Settl. Dial guage reading (div.) 0.01 mm/div.				settl. div.	settl. mm	Note
	A	B	C	Av.			
0	1383	1390	1498	1423.67	0.00	0.00	1. Ultimate settlement (mm) = 15.11
0.50	2020	2030	2240	2096.67	673.00	6.73	2. Acc. ultimate settlement (mm)= 28.96
1	2041	2046	2252	2113.00	689.33	6.50	
2	2048	2055	2260	2121.00	697.33	7.68	
3	2294	2300	2430	2341.33	917.67	9.18	
4	2343	2348	2554	2415.00	991.33	9.91	
5	2392	2400	2607	2466.33	1042.67	10.43	
6	2406	2413	2618	2479.00	1055.33	10.55	
7	2440	2445	2650	2511.67	1088.00	10.88	
8	2450	2457	2660	2522.33	1098.67	10.99	
9	2535	2542	2745	2607.33	1183.67	11.84	
10	2608	2617	2825	2683.33	1259.67	12.60	
11	2631	2637	2841	2703.00	1279.33	12.79	
12	2680	2691	2900	2757.00	1333.33	13.33	
13	2703	2710	2913	2775.33	1351.67	13.52	
14	2714	2720	2914	2782.67	1359.00	13.59	
15	2758	2763	2960	2827.00	1403.33	14.03	
16	2766	2774	2975	2838.33	1414.67	14.15	
17	2766	2782	2983	2843.67	1420.00	14.20	
18	2766	2786	2988	2846.67	1423.00	14.23	
19	2766	2842	3042	2883.33	1459.67	14.60	
20	2766	2845	3054	2888.33	1464.67	14.65	
21	2766	2859	3059	2894.67	1471.00	14.71	
22	2766	2920	3119	2935.00	1511.33	15.11	

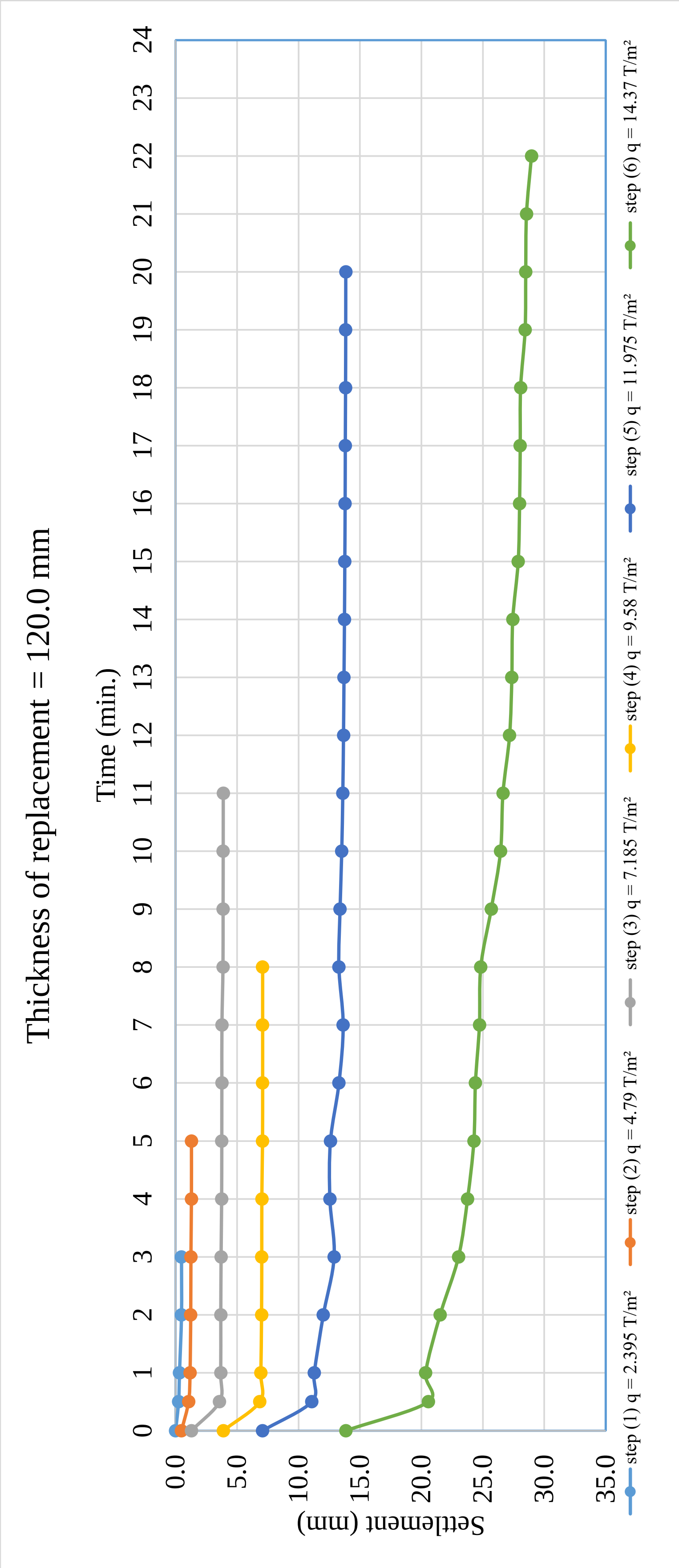

Figure 23. Time-settlement relationship for PLT for test no. 4

From (Butler and Hoy , 1977) who described the “double tangent method” to find the ultimate bearing capacity from the PLT data as shown in the below figure :

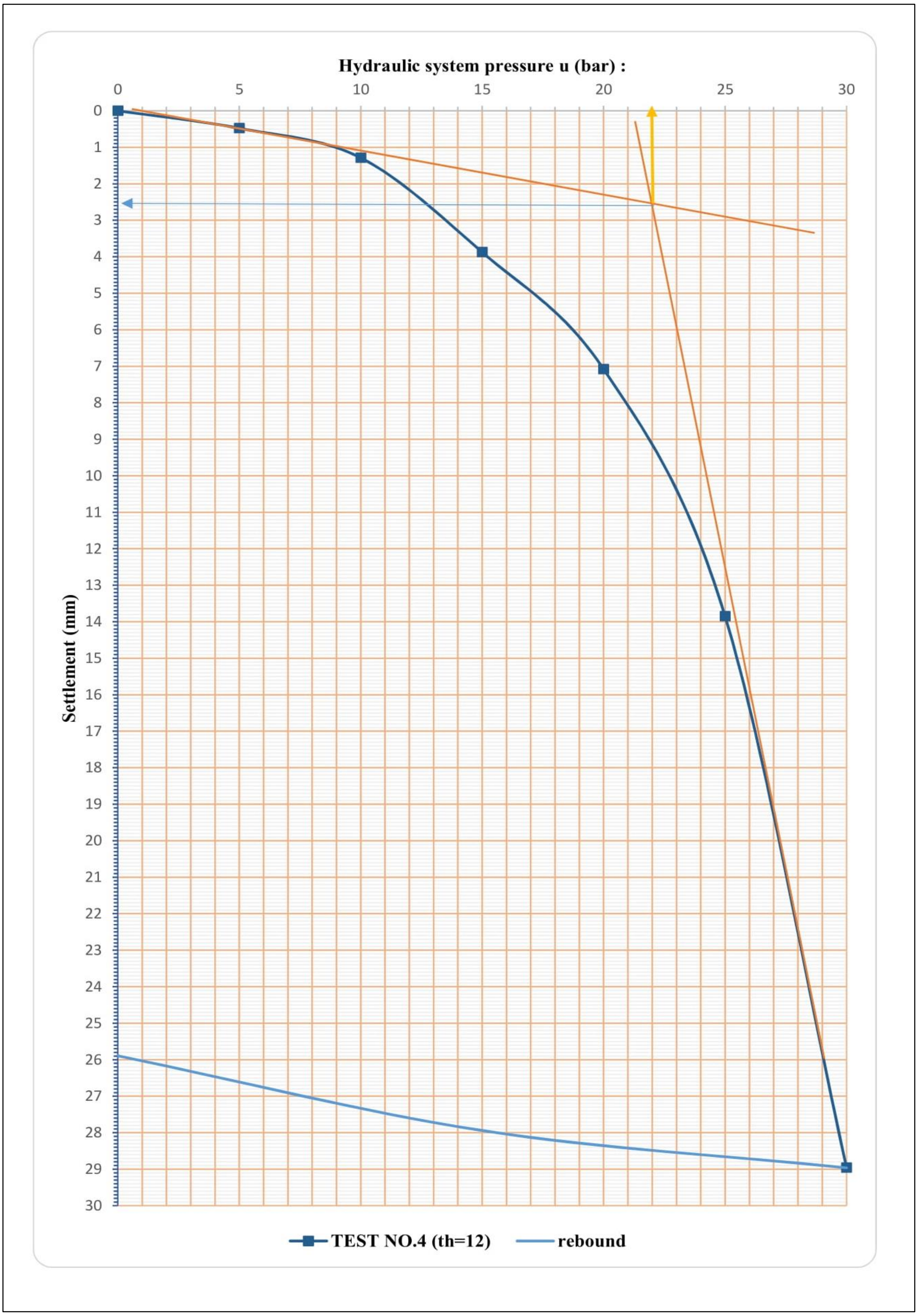

Figure 24. Settlement -pressure PLT relationship, test no. 4 (with 12 cm replacement)

Table 5. Plate load tests summery data

pressure from hydraulic system u (bar)		test no.	1	2	3	4
		Thickness of Replacement (mm) :	0	30	75	120
		load (T/m²)	settlement (mm)			
Loading	0	0	0	0	0	0
	5	2.395	0.84	0.27	0.78	0.48
	10	4.79	3.06	1.35	2.32	1.29
	15	7.185	11.04	3.18	4.8	3.88
	20	9.58	19.02	7.46	7.62	7.08
	25	11.975	28.35	18.37	12.16	13.85
	30	14.37	—	29.50	20.52	28.96
Unloading	15	7.185	—	28.32	19.56	27.94
	0	0	26.74	27.31	16.70	25.89

— out of range (the guage devisions)

Load (T/m²) = u (bar) * 0.479

From this above table it can be observed that the settlement was changed in a range of (7% to 71%) decreasing in accordance with the change of stress level and thickness of replacement.

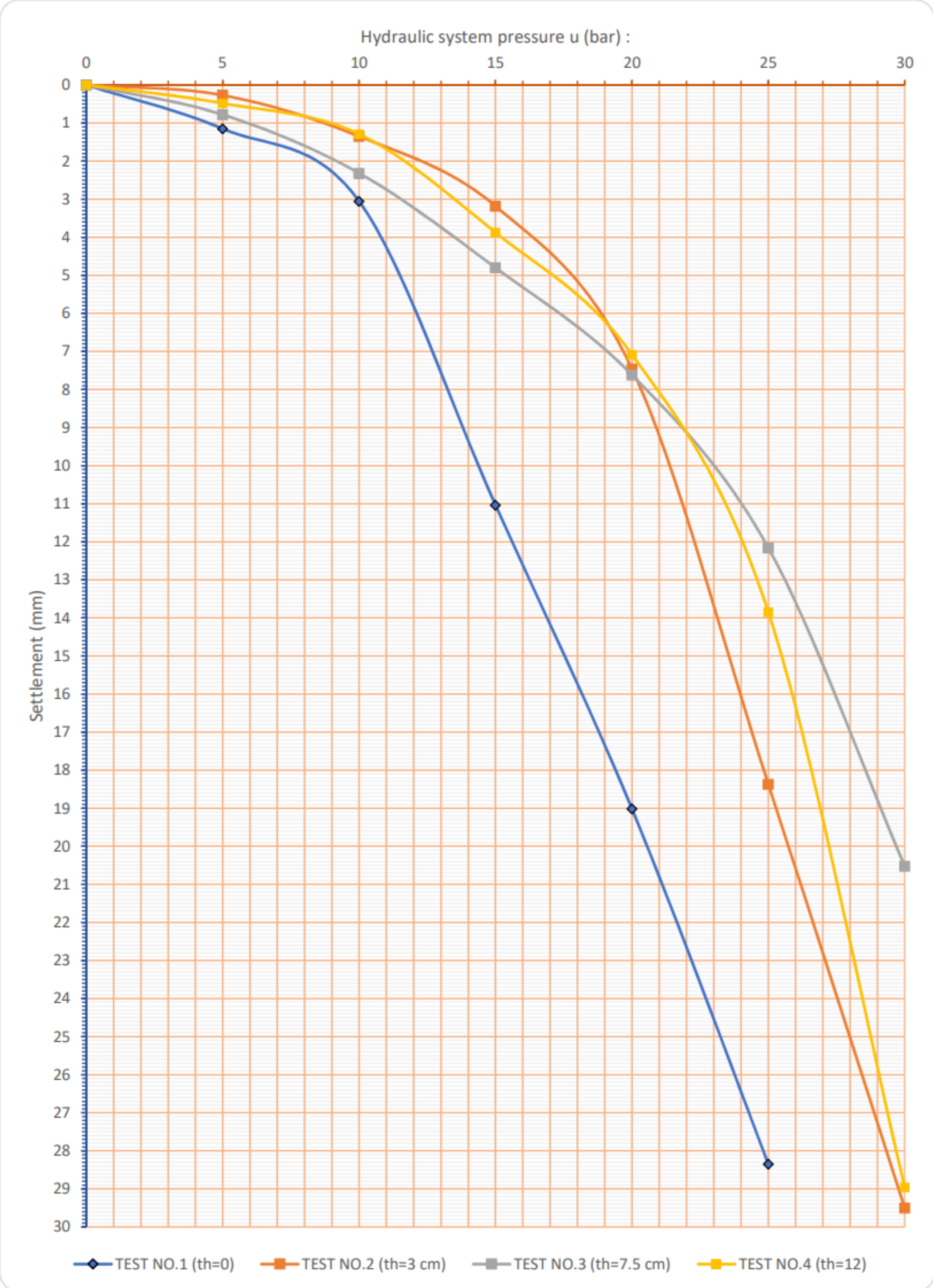

Figure 25. Settlement-Hydraulic system pressure relationship for plate load tests

Table 6. Bearing capacity improvement

test no.	thickness of replacement (mm)	th./D	qu from PLT (T/m^2)	BC improvement ratio	% of improvement BC
1	0	0	4.41	—	0%
2	30	0.1	8.62	1.95	95%
3	75	0.25	9.48	2.15	115%
4	120	0.4	10.54	2.39	139%

D : plate diameter

Figure 26. Relationship of (th./d) and BC% improvement

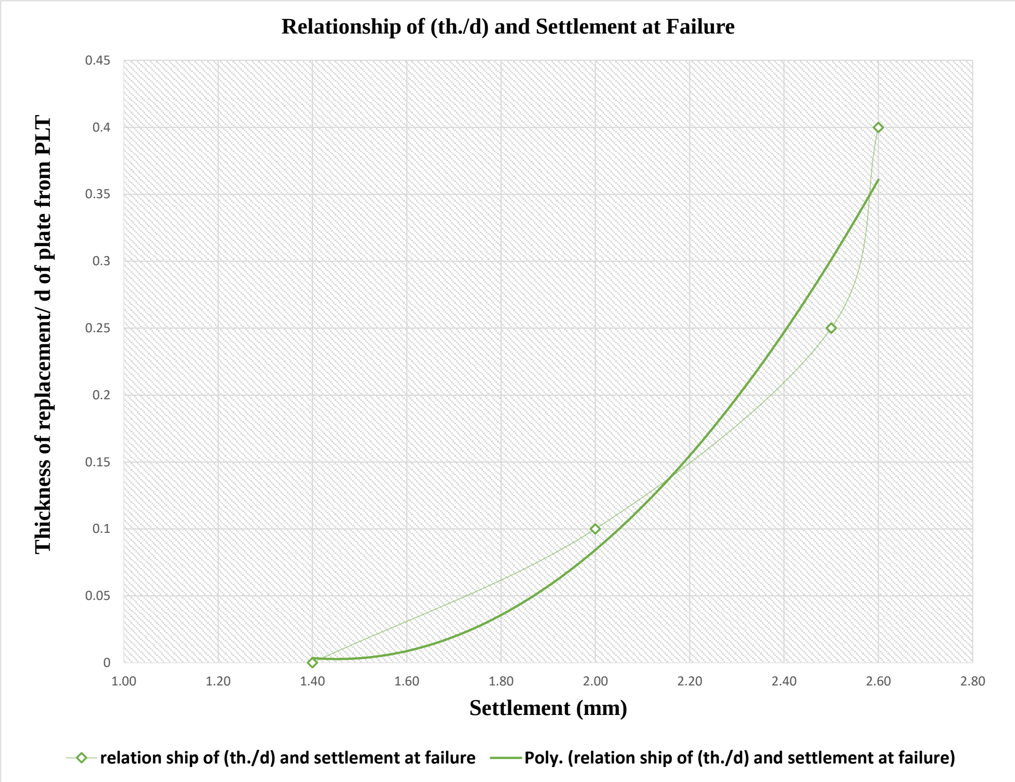

Figure 27. Relationship of (th./d) and Settlement at failure

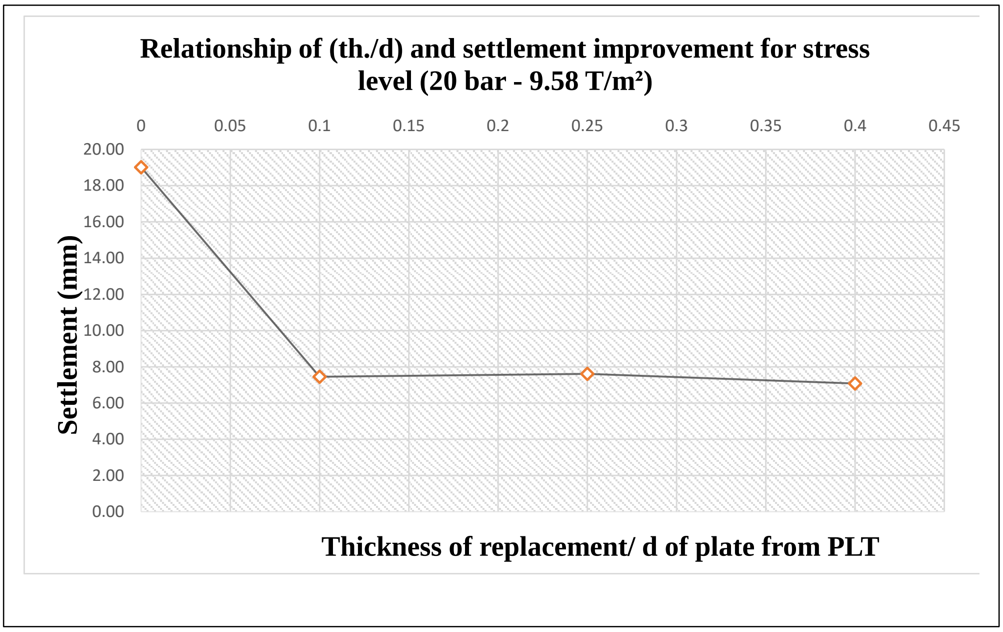

Figure 28. Relationship of (th./d) and settlement improvement for stress level (20 bar/9.58 T/m²)

Table 7. The four tests results summery

Test no.	thickness of replacement (mm)	Ultimat Bearing Capacity qu from plate load test data		settlement (mm)	ω av. %	unconfined compression test		ρ gm/cm³	e	S %	date of the test	temp. during the test C?
		hydraulic system u (bar)	qu (T/m²)			q (T/m²)	Cu T/m²					
1	0	9.2	4.41	1.4	24.8	5.5	2.75	1.95	0.70	93.60	01-09-2021	46
2	30	18	8.62	2	23.4	4	2	1.97	0.67	92.9	02-09-2021	49
3	75	19.8	9.48	2.5	23.62	4.4	2.2	1.950	0.686	91.6	09-09-2021	41
4	120	22	10.54	2.6	26.93	3.3	1.65	1.94	0.741	96.7	15-09-2021	39

*Gs=2.66

*e= (ω+1)*Gs*ρw/ρ

*S=(ω*Gs)/e

Chapter Five

Conclusion and Recommendations

Chapter Five

Conclusion and Recommendations

5.1 Conclusions

Refers to the results that have been discussed in the previous chapter it was obvious the influence of the replacement on both the bearing capacity of soil plus the settlement in such desirable way by increasing the bearing capacity in range of (95%, 115% and 139%) comparing with natural ground bearing capacity and decreasing the settlement of the tested soil with range of (71 to 7) % which can be a significant improving results.

5.2 Recommendations

For the future researchers we can list a few recommendations to be considered:

[1] Try to use different plate diameter in the field plate load test.

[2] Try the field plate load test in different depths from the natural ground level.

[3] Make the field plate load test on the natural ground level with each attempt of various replacement depth.

[4] Conduct the results of the full subbase depth (almost 2 to 2.5 from the plate diameter).

[5] Use different replacement materials.

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