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Evaluation of Sabkha Soil Bearing Capacity by Plate Load Test in Al Muthanna Province

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ABSTRACT

For projects such as airports and road paving, an appropriate foundation must be developed in Sabkha soil, which requires a trustworthy assessment of soil-bearing capacity. When heavy traffic is expected to result in substantial wheel loads throughout pavement construction and maintenance, the plate load test helps solve these issues with subgrade and sub-base layer design. This work aims to investigate and assess the geotechnical behavior regarding soil strata from one area in southern Iraq: Sabkha. Conversely, a comparison is made between subgrade response modulus and soil-bearing capacity determined by field plate load tests and traditional laboratory investigations. The data demonstrated that the values related to Ks in the consolidation test rose as a ratio of pre-consolidation pressure of 45% and dramatically dropped with an increase in applied stress that is vertically applied below pre-consolidation stress. Furthermore, PLT data demonstrated that when pressure was applied, the modulus of the subgrade reaction did not follow a regular pattern. At the beginning of the loaded stage, after the pre-consolidation stress, Ks values at testing points 2 and 3 were high. After that, Ks abruptly decreased, particularly when the applied pressure surpassed the pre-consolidation stress before being constant again. A detailed discussion is given on the effects of stress distribution and test conditions on the elasticity stress curve's shape and the subgrade reaction modulus.

Keywords: Sabkhasoil, Bearing capacity, Plate load test.

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حساب سعة تحمل التربة السبخة بواسطة فحص تحميل الصفيحة في محافظة المثنى

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الخلاصة

عند تصميم أساس ثابت في تربة السبخة لمشاريع مثل رصف الطرق والمطارات ، من الضروري إجراء تقدير دقيق لقدرة تحمل التربة. يساعد فحص تحميل الصفيحة في حل مشكلات التصميم لطبقات التربة الطبقة السفلية والقاعدة السفلية حيث من المتوقع وجود أحمال كبيرة على العجلات بسبب حركة المرور الكثيفة أثناء إنشاء الرصيف وعمر الخدمة. تهدف هذه الدراسة إلى تقصي وتحليل ومناقشة السلوك الجيوتقني لطبقات تربة السبخة المختارة من موقع واحد جنوب العراق. من ناحية أخرى ، يتم إجراء مقارنة بين قيم قدرة تحمل التربة ومعامل رد فعل الطبقة السفلية كما تم الحصول عليها من خلال التجارب المعملية التقليدية واختبارات تحميل الصفيحة الحقلية. وقد أشارت النتائج بوضوح إلى أن قيم Ks في (اختبار الانضمام) هي: يتناقص بشكل كبير مع زيادة الضغط الرأسي المطبق تحت ضغط ما قبل الانضمام ثم يزداد بنسبة 45% من الضغط المسبق كنقطة مرجع . كما أظهرت نتائج PLT اتجاهًا غير موحد لمعامل رد فعل الطبقة التحتية فيما يتعلق بالضغط المطبق ، حيث تكون قيم K عالية في البداية من مرحلة التحميل (أي أقل من ضغط ما قبل الانضمام) لنقطتي الاختبار 2 و 3. بعد ذلك حدث انخفاض حاد في Ks خاصة عندما تجاوزت قيمة الضغط المطبق قيمة ضغط ما قبل الانضمام ، ثم تثبت. كما تمت مناقشة تأثير توزيع الإجهاد وظروف الاختبار على معامل رد فعل الطبقة التحتية وشكل منحنى إجهاد المرونة بالتفصيل.

الكلمات المفتاحية:التربة السبخة,فحص تحميل الصفيحة ,سعة التحمل,

1. INTRODUCTION

The term " Sabkha" comes from the Arabic word " Sabkha," which refers to saline flats that have been underneath by silt, sand, and clays and are frequently encrusted by salt **(Al-Homidy etal.,2017)**. The evaporative environment has created such soils. The two main Sabkhas formations are continental and coastal Sabkhas, with equilibrium geomorphic surfaces. Earlier cycle marine sediments form Continental Sabkhas, while the depositional off-lap of intertidal, sub-tidal, and supratidal marine sediment forms coastal Sabkhas. Inadequate restrictions are placed on soil study efforts for foundation construction **(Mase and Farid, 2020).**Many experts have conducted numerous investigations on the properties of the soil in Bengkulu City's coastal areas. According to **(Mase, 2020; Mase et al., 2021)**, poorly graded sand (SP), silty sand (SM), gravelly sand (SG), clayey sand (SC), and well-graded sandy (SW) make up the majority of soil in coastal areas. According to **(Shukla and Baah, 2018; Sethy et al., 2020)**, sandy soil has a low bearing capacity and frequently experiences severe displacement in building foundations. Thus, a thorough investigation of the soil's bearing capacity and foundation displacement is required to prevent the collapse of buildings constructed near the coast. The finite element approach is one way to assess a soil's bearing capacity. Concerning the analysis of stability issues in geotechnical engineering, like railway embankment **(Likitlersuang, 2018)**, underground excavation

(Likitlersuangand Chheng, 2018), active trapdoors **(Likitlersuang andKeawsawasvon, 2021)**, spatial variability **(Likitlersuang and Nguyen, 2021),** slope stability at riverbank **(Petchkaewetal., 2021)** and 3D stability analysis **(Mase, 2022)**, many researchers have presented using finite element simulation. According to these researchers, the application of this technology is acceptable and dependable because the analysis's findings align with actual geotechnical engineering scenarios. The primary reason for such issues is the Sabkha soils' limited bearing capacity. Sabkha soils are also quite vulnerable to moisture. When they come into contact with water, total failure and a reduction in bearing capacity are expected **(Xiao et al., 2015).**
Sabkha soils have a permeable, loose texture that ranges from sandy to gritty. Typically, an encrusted surface comprises the hygroscopic salt types**(Mohamedzien and Al-Rawas,2011)**. Since the modulus of the sub-grade reaction goes up as the applied pressure goes up, the stress-settlement curve for plate load tests on compacted sub-base soil layers (with relative compaction reaching 95%) has a concave upward shape. On the other hand, the curve goes down for cohesive soils as the pressure increases, which means that the modulus of the sub-grade reaction is getting smaller**(JahanGer et al., 2010)**. Horizontal variabilities of the Sabkha soil are associated with its proximity to the shoreline, whereas vertical variations signify phases inthe Sabkha cycle's development **(Sethy etal.,2020**)**.**TheSabkha soil is one of the soils that have very complex and numerous geotechnical problems. Due to the Sabkha soil's high salt content and the fact that it is not ordinary soil, it is susceptible and has a lower density than typical soils. The soil's dissolution causes these geotechnical problems.
The result of such bearing capacity and loss of strength is a failure. When designing subgrade and subbase layers, soil mechanics must be used to comprehend the subsurface material's stress distribution and geotechnical properties. A precise assessment of the soil bearing capacity is required to design a stable foundation during the service life and construction of a pavement on Sabkha soil. One of the primary methods indicated below could be utilized to determine the bearing capacity because damage might result from both foundation failure and excessive settlement: (1) using the Terzaghi equation with a modification supplied by (**Sivakugan and Das, 2018)**, (2) from the Standard Penetration Test (SPT), and (3) from the direct technique using a field plate load test, The plate load test approach was used. The plate load test method is used explicitly for light-load constructions to avoid time-consuming and costly in-depth geotechnical exploration. However, geotechnical engineers could immediately use the plate load test findings to determine the soil carrying capacity. The plate load test is still useful for design problems with shallow depth, like wheel loads on pavement subgrades. The plate load test results, on the other hand, are typically connected to the precise measurement of the modulus of subgrade reaction (Ks) when the Ks parameter serves as the primary input for designing a rigid pavement. Field plate load tests are frequently used to determine the modulus of subgrade reaction since there isn't a straightforward laboratory approach. Nonetheless, several stiffness tests can be used as an indirect method to estimate the Ks value where the service loads act over smaller. Many studies have been documented by investigators, including: site tests and laboratory tests. These studies are summarized below:
(Ahmad et al., 2009) discovered that the bearing capacity values of shallow soil layers were identical between the laboratory test utilizing the Terzaghi equation and the field plate load test. The bearing capacity and subgrade reaction modulus values in relation to subbase layer thickness and relative compaction**.(Mohammed and Al-Obaidi, 2017)** found that a smooth rise in bearing capacity and subgrade reaction modulus resulted from increasing layer

thickness and relative compaction. Through simulating the leaching activity regarding salty soils with different salt contents exposed to surcharge as well as water head at a particular time with different boundary and initial conditions, a numerical model employing the 2-D finite element method is used.
Additionally, the effect of exposed surface area regarding the soil sample on leaching strain was examined **(Karkush et al.,2008).** A series of model loading studies have been conducted using salty soil which was modified by substituting dune sand for it, utilizing geogrid and geotextile under varying values of eccentricity and soaking conditions (**Hussein and Albusoda, 2013)**. The homogenous soil used for testing was partly replaced with salty soil by dune sand reinforced with a geotextile reinforcement layer at the interface. After the salty soil is replaced and reinforced, the bearing capacity rises to 2.5–3.0 times. The low bearing capacity and stiffness of Sabkha soil at shallow depths due to including volume changes, dissolved salts, corrosive behavior, and low strength**(Abbas,2019).**
This study aims to investigate, analyze, and discuss the geotechnical behavior of chosen soil strata from one place south of Iraq. These are interesting aspects of this study. On the other hand, the values of soil's bearing capacity, subgrade response modulus, and elasticity are compared between field plate load testing and traditional laboratory experiments.

2. SITE TESTS ON SABKHA SOIL

Site tests like the California Bearing Ratio (CBR) and the Standard Penetration Test (SPT or N) are particularly beneficial for assessing the stratigraphy and subsurface condition. When saturated with water, the soil at Sabkha is highly brittle and prone to failure., according to the CBR test results. Naturally occurring Sabkha soils were found to have CBR values of 3 to 4, and when Sabkha soil was flooded with water, the values dropped by as much as 50%. It suggests that when flooded with water, Sabkha is prone to failure. The surface crust layer's SPT value was 8, as shown in **Table 1**, indicating that it is loose. The measurements for SPT, cohesiveness, and friction angle show that the Sabkha soil is weak.

Table 1. Relative Density based on SPT (**Das and Sivakugan, 2018**).

Relative density	SPT values
very loose soil	0-4
Loose soil	4-10
Medium soil	10-30
Dense soil	30-50
very dense soil	more 50

3. TYPES OF SABKHA WITHIN IRAQ

Sabkha has been divided into two primary groups based on their origins: Inland Sabkha and Coastal Sabkha. In this area of southern Iraq, there are two significant sea coastal zones, unlike Inland Sabkha, which has never been investigated or documented.

3.1 Formation of the Sabkha

According to **(Al-Homidy et al.,2017),**Sabkha is produced by the continuous interaction of brines with sediment. While minerals and sedimentary topographies are some of the unique characteristics of Sabkha deposits, major topographies are connected to the initial depositional framework. Several variables affect how Sabkha forms, including:

- Temperature, humidity, and wind speed are only a few climate-related variables.
- Geochemical elements like minerals and brine chemistry
- Geomorphologic elements like surface gradients
- Hydrological: this element may be present alone or in conjunction with the other three.
- Burrowers and algal mats are examples of the biological category.

The interactions and occasionally cooperative behavior of the aforementioned elements lead to the behaviors that characterize the Sabkha soil and its environment.

4.METHODS AND EXPERIMENTAL WORK

4.1. Sabkha Soil Layers' Conditions

Samawaa-Salman Street was geotechnically investigated to determine the subsurface stratigraphy, groundwater conditions, and engineering qualities of the project site's representative soil profiles. One site, known as South Samawaa (SA), was the subject of the soil investigation. The location is situated in Iraq's Al Muthanna Governorate, roughly 350 kilometers south of Baghdad. The soil investigation entails digging four boreholes along the street to a depth of 10–20 meters, passing through Sabkha soil. Several tests were carried out on the undisturbed soil samples, including classification, compaction, and strength tests. According to the soil profile, the top three meters comprise soft, silty clay soil known as Sabkha soil. After the Sabkha layer, a 6 m layer of very stiff, dense gypsum is mixed with sand. Groundwater was found to be 4 meters below ground level. The variation of SPT-N values with depth, soil type, and physical parameters beneath the planned road are compiled in **Fig. 1** and **Table 2.**

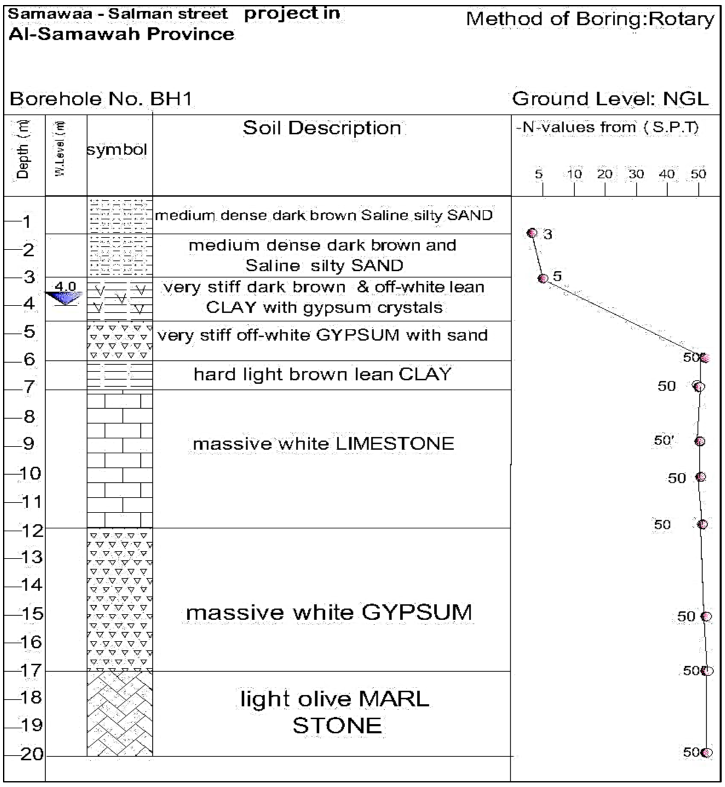

Figure 1. Borehole profile for the first site under the proposed road (Samawaa -Salman Street).

Table 2. Summary of laboratory test results.

Site Name	Dry density (g/cm^3) (Natural	Passing sieve No.200	L.L %	P.L. %	Natural water content (W%)	(Gs)	(qu) kPa	Void ratio (e_o)	Pc (kN/m^2)	Cc	Cs
SA1	1.431	91	68	38	39	2.7	29	0.9	31	0.24	0.03
SA2	1.411	89	53	26	36	2.68	33	0.9	30	0.14	0.05
SA3	1.442	93	50	21	33	2.7	55	0.87	30	0.11	0.03
SA4	1.401	90	57	26	39	2.69	26	0.91	31	0.31	0.08

4.2. Full-Scale Plate Load Test

The basic techniques for evaluating bearing capacity are:
(1) From the Standard Penetration Test,
(2) from the Terzaghi equation with modifications proposed by **(Das and Sivakugan,2018)** and based on geotechnical soil parameters (SPT),
(3) A direct approach utilizing a plate loading test.
In particular, the loading plate test method is used for light-load constructions to avoid costly and time-consuming full geotechnical research. On the other hand, geotechnical engineers could use the results of plate loading tests to assess the soil's bearing capacity rapidly. The plate load test is still useful for shallow-depth design problems when the service loads act over a limited region involving wheel loads on pavement subgrades. The plate loading test (PLT) standard approach developed by the American Society for Testing and Materials (ASTM) is used in this study **(Al-Obaidi, 2017)**. In PLT, one test point is carried out for each site. The test was carried out on a natural ground surface in a natural state (wet condition). A gradual load is given to the bearing plate on the ground. A sufficient amount of time is allowed for settlement to occur following adding an incremental load. In the case when there is no longer any discernible settling of the bearing plate, the next incremental load is applied. This approach yields a load-settlement plot. Based on the theories discussed in the paragraph "Theories equations for bearing capacity," the modulus of subgrade reaction and elasticity determined by plate loading tests were computed. In this study, the test conditions and equipment listed below are utilized, as illustrated in **Fig. 2**:

1. Loading Plate: it uses circular steel bearing plates with a minimum thickness of 2.5 cm, a diameter of 60 cm, and an area of 2000 cm^2.
2. Hydraulic Jack with stress Gauge: it takes a hydraulic jack with a large enough stress gauge to support a maximum vertical load of 200 KN.
3. Settlement-Recording Devices: Three dial gauges are utilized to measure the settlement of test plate with a minimum precision of 0.01 mm.
4. Miscellaneous Apparatus: like steel stands and loading columns.

Plate load tests were done on a layer of Sabkha soil to ensure the requisite design capacity under the loads. The Sabkha layer was 3 meters thick. There were two stages to load the application: loading in the first stage and unloading in the second. A 200-ton hydraulic jack reacting against a large weight was used to apply the load. As demonstrated in **Fig. 3** and **Table 4**, the load test results are shown in load-settlement forms.

(a) (b)

Figure 2. Plate bearing Test: a) Loading system,b) loading steel plate with three settlements.

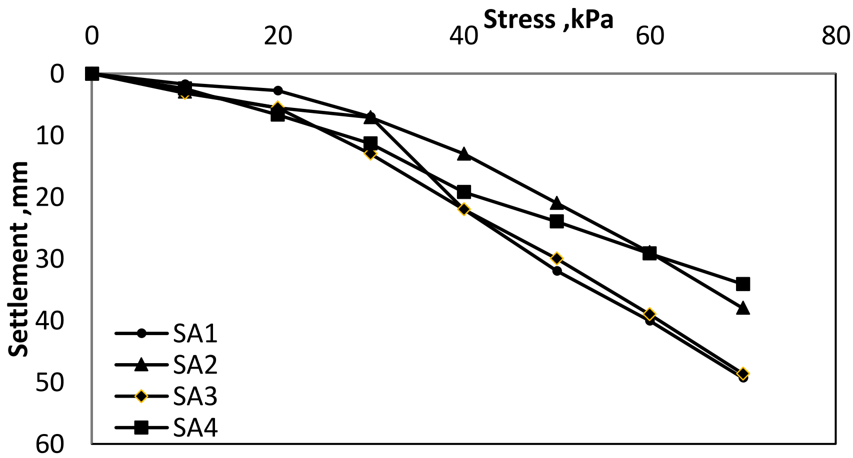

Figure 3. Settlement variation with Stress and for four sites of Sabhka soil.

4.3. Theories Equations for Bearing Capacity

A foundation is a crucial component of any structure built with civil engineering. All building structures, including highways, tunnels, bridges, and canals, are built above ground, and any applied weights are dispersed to the earth. Two types of foundations are used in applications: deep and shallow **(Das, 2006)**. One type of foundation that fits into the shallow foundation category is strip footing. An independent foundation called strip footing transfers column loads to the ground **(Alwalan, 2018)**. Low- to medium-rise buildings typically use strip footing **(Pender, 2005)**. In geotechnical engineering, the soil's bearing capacity is a key consideration when planning foundations. One of the first topics covered in the geotechnical field was soil-bearing capacity. Many approaches were used extensively **(Keawsawasvong et al., 2021; Acharyya, 2019)**. Those procedures can be used analytically or experimentally. Limit equilibrium analysis, slip line approximation, numerical analysis, boundary analysis, and limit analysis combined with numerical analysis are all part of the analytical technique **(Abu-Farsakh and Chen, 2015; Ray et al., 2021)**. Analytical methods have been applied extensively up to this point. The most prevalent techniques are those developed by Meyerhof and Terzaghi **(Dey and Acharyya, 2021; Aboshio and Akagwu, 2016; Benmebarek, 2012)**. According to **(Alencar et al., 2021;Yahia-Cherif et al., 2017)**, ultimate bearing capacity is the highest load per unit area that the soil can withstand without collapsing. Various geotechnical professionals have given up on using classical theory to do soil-bearing capacity analyses in the present day. The finite element method has become the approach of choice for many scholars.

Equations from **(Das and Sivakugan,2018)** are used to figure out the soil samples' ultimate and allowable bearing capacities (qu and qa), elasticity (Es), modulus of subgrade reaction (Ks), and other geotechnical properties.

$$qu = C\ Nc + q\ Nq + 0.5B\ \gamma\ \ N\gamma \tag{1}$$

Where:
qu is the ultimate bearing capacity (kPa)
Nc, Nq, and $N\gamma$ are the parameters of Bearing capacity
C *is* Soil cohesion (kPa)
q is the overburden pressure (kPa)
B *is* foundation width (m)
γ *is* soil density (kN/m^3).

$$qa\ =\ \frac{KS}{40FS} \tag{2}$$

where:
qa is allowable bearing capacity (kPa)
FS is the factor of safety taken as 3,
Ks is the initial tangent modulus of the subgrade reaction (kPa/m).
Eq.(2) is based on the total deformation settlement of ΔH = 25 mm; for ΔH = 6, 12, and 20 mm, the constant 40 can be adjusted to 160, 83, and 50, respectively.

$$KS = \frac{\Delta\sigma}{\Delta_{settl.}} \tag{3}$$

where:
$\Delta\sigma$ is the differentiation between two sequential vertical pressures(kPa)
$\Delta_{settl.}$ is the difference between two successive vertical displacements (m).

$$Ks = \frac{Es}{B(1-\mu^2)} \tag{4}$$

where: B is the width of the foundation (m), it is considered as 0.6 m corresponding to the width of the loading plate. Es is modulus of elasticity
μ is Poisson's ratio, which is taken as 0.4 for the saturated silty Clay according to **Tables 2 to 8 (Das and Sivakugan,2018)**.

Table 3. Summary of site plate loading test results.

Site symbol	Plate loading test		
	Ks (kPa/m)	Es (kPa)	q_a (kPa)
SA1	10400	4370	86
SA2	4000	1680	33
SA3	4350	1827	36
SA4	2325	977	20

5. RESULTS AND DISCUSSION

The findings of the laboratory testing and the field plate load tests will be reported in this section, along with a thorough explanation. **Tables 2 and 3** show a summary of the outcomes from the field and laboratory experiments. **Fig.4** presents the measured results for the Sabkha soil under compressive loads.

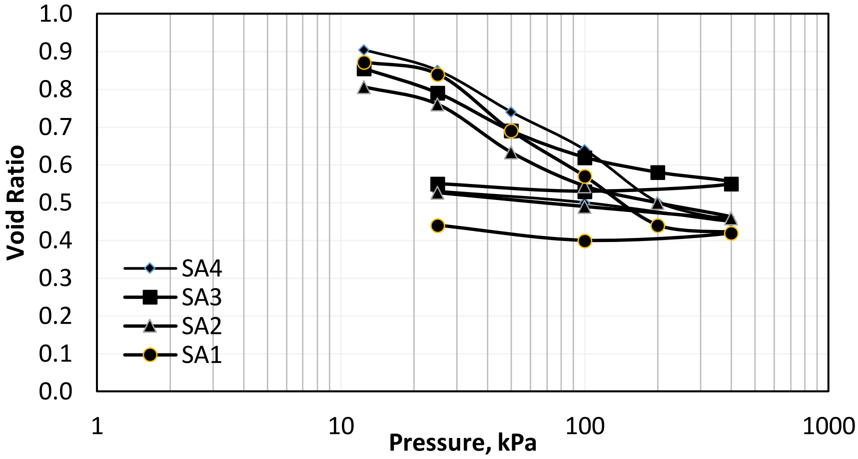

Figure 4. Soaking consolidation test results for four sites of Sabkha soil.

The Sabkha soil layers' computed and measured settlements demonstrate good agreement with the theoretical prediction and the results of the field load test. The soil test results from both laboratory and field experiments are discussed below: The physical, classification, and consolidation tests displayed in **Table 3** and **Fig. 4** show that the four soil samples have a very high initial void ratio. They are, therefore, challenging to pack away. **Figs. 5and6** show that the vertical stress from the consolidation and plate bearing tests is related to the modulus of subgrade reaction (Ks).

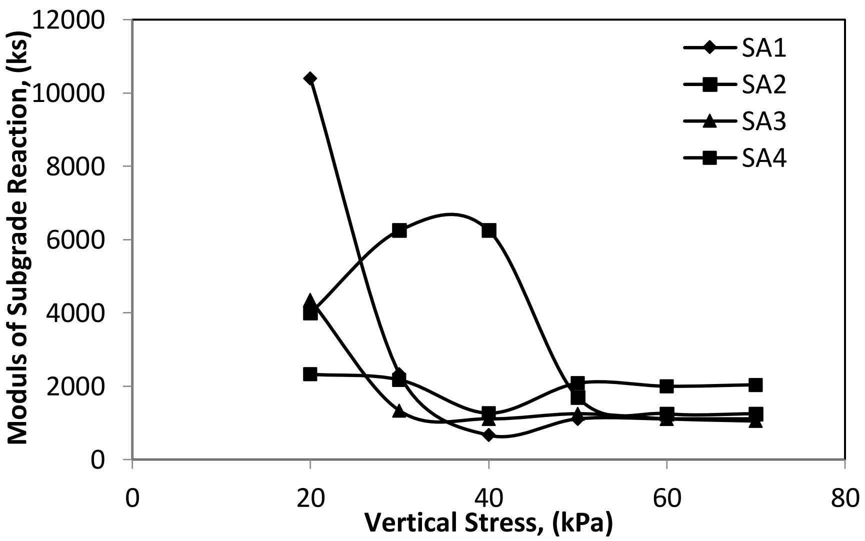

Figure 5. The vertical stress from the plate load test is related to the subgrade reaction (Ks) modulus.

From the consolidation test of the four sites of Sabkha soil shown in **Fig. 6**, it is clear that as the applied vertical pressure is raised below the pre-consolidation pressure, then increased, and then stays the same, the Ks values decrease by a large amount. This behavior is expected since the void ratio has declined, the salts in the soil have been dissolved, and the soil's bindings have been broken, leading to a more dense structure of the soil mass. These results are similar to those obtained by **(Abbas,2019)**. Also, under conditions of saturated two-way drainage, a homogeneous soil sample is subject to regular vertical stress, which is related to the constant change in the modulus of subgrade reaction. As shown in **Fig. 5**, the subgrade reaction's modulus didn't changein the same way as the pressure did. For example, the Ks values for test points 2 and 3 were high at the start of the loading stage, after the pre-consolidation stress. After that, Ks began to climb and then abruptly fell, especially when applied pressure exceeded pre-consolidation pressure. The nature, transformation, and tendency of the imposed stresses on a partially saturated and non-homogeneous subgrade soil layer on a large scale account for this behavior. The stiff response of the soil layer to instantaneous applied pressure is seen nonetheless as a result of short increases in the bulk density of the soil. As a result, the soil particles and pore water responded significantly to the applied pressure during the initial loading. Following that, the soil mass underwent consecutive deformations with soil particle rearrangements linked to pore water dissipation, considerably decreasing the Ks values. Also, the Ks values stay pretty constant because the soil structure is stable, and the soil particles interact the same way inside the load distribution zone, which is shaped like a bubble and goes down as far as twice the width of the foundation. Additionally, the soil mass regains its ability to resist vertical stress with gradual increments in the applied pressure and loading duration, and after that, the Ks magnitudes considerably increase.

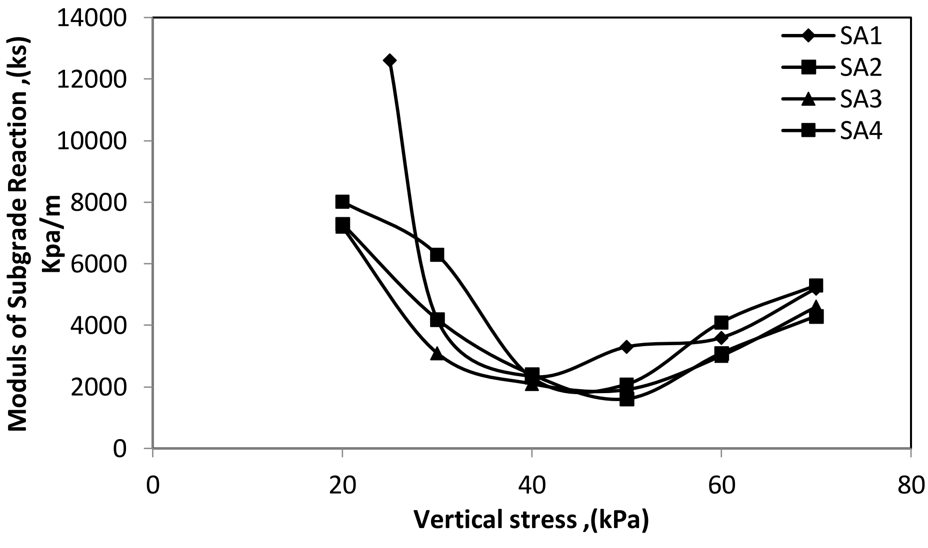

Figure 6. The vertical stress from the consolidation test is related to the modulus of the subgrade reaction (Ks).

6. CONCLUSIONS

Based on the interpretation of the results presented in the previous paragraphs, many conclusions may be expressed herein.

1. The calculated result and the bearing pressure-settlement of the field test were relatively similar. Once calibrated by these field data,
2. Plate load tests are useful for determining the bearing capacity of the sub-grade and sub-base layers and for resolving problems with rigid pavement construction.
3. As the vertical pressure was increased, the values of the modulus of the subgrade reaction from the consolidation test became a ratio of 45% of the pressure before consolidation.
4. The pressure distribution within the soil mass and the test's boundary conditions significantly impact the soil's ability to support a specific amount of weight.
5. The plate load test results for Sabkha soil show that the subgrade response values were significant early on, then dropped sharply until the applied pressure was higher than the pre-consolidation pressure value and then stayed the same.
6. In general, indirect methods, like consolidation tests, are less accurate and reliable than direct methods, like plate load tests, for estimating the modulus of subgrade reaction (ks) of the Sabkha soil layer.

NOMENCLATURE

Symbol	Description	Symbol	Description
$e_{\circ}$	Initial void ratio, dimensionless	Pc	Pre-consolidation pressure, kpa
Es	Modulus of elasticity ,kpa	q_a	Allowable bearing , kn/m^2
F	Factor of safety, dimensionless	q_u	Ultimate bearing , kn/m^2
Gs	Specific gravity, dimensionless	γ	Unit weight , kn/M^3
Ks	Subgrade reaction, kpa/m	μ	Poisson’s ratio, dimensionless
L.L	Liquid limit, %	$\sigma\Delta$	Difference between vertical pressures, kn
P.L	Plastic limit, %	$_{\text{Setll.}}\Delta$	Difference between vertical displacement,m

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Credit Authorship Contribution Statement

Mohammad Fadhil Abbas is responsible for collecting data, executing the experimental and numerical simulations, analyzing and interpreting the writing, and reviewing and editing the manuscript. Haider Mohammad Makkiyah supervised, reviewed, and edited the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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