DETERMINATION OF COLLAPSE POTENTIAL OF GYPSEOUS SOIL FROM FIELD AND LABORATORY TESTS

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ABSTRACT: - Collapsible soils are known as problematic soils, which possess considerable strength when dry and lose their strength when inundated experiencing excessive settlements. The soil response to inundation (i.e. landslides or significant soil settlements) could not be predicted beforehand. The irrecoverable volume reduction of collapsible soils takes place fast and sudden and no measurements can be taken to stop the problem once it initiates. The collapse potential increases with time due to soaking and leaching which is attributed to the dissolution and washing out of gypsum.

In this paper, a comparison is made between the collapse potential predicted form laboratory standard collapse test with filed collapse (coefficient of resolving slump) estimated from plate loading test. The soil site for investigation was in Rumaila, Basrah Governorate. Results of collapse test carried out on two samples showed that the collapse potential, Ic of the two samples is 5.091% and 3.502%, the soil is considered of moderate degree of collapse. The coefficient of average resolving slump for saline soil was calculated from field plate load test to be 0.94% to 1.2%. The difference in boundary conditions between the two approaches was found clear in the evaluation of collapse potential.

Keywords: Gypseous soil; collapse; field test; plate load test; collapse test.

INTRODUCTION

Collapsible soils are soils susceptible to large volumetric strains when they become saturated. Numerous soil types fall in the general category of collapsible soils, including loess, a well-known aeolian deposit. Loess is characterized by relatively low density and cohesion, appreciable strength and stiffness in the dry state, but is susceptible to significant deformations as a result of wetting. Gypseous soils are another type of collapsible soils (Lawton et al., 1992).

Deformation behavior of unsaturated collapsible soil under field conditions depends mainly on existing (initial) conditions, wetting and loading history of the soil. The soil can experience a complex volume change reaction depending on the intensity of the applied external load. Thus, compacted soils wetted and subjected to load can swell or collapse depending on their conditions and the value of vertical stress. The clayey soils swell when wetted under low applied stresses and compress when wetted under high stresses. Volume decreases due to surplus of water under the same stresses in loose, partially saturated natural soil layers are termed collapse (Dudley, 1970).

Swelling and collapsing cause damage to many civil engineering structures such as: spread footing, buildings, roads, highways, and earth dams leading to high economic losses. There are many factors affecting collapse behavior of compacted and cohesive soils which are: initial dry unit weight, initial water content, percentage of fines, and the method used in compaction (Lawton et al., 1992).

Collapsible soils settle when saturated under loading. The rapid collapse of soils leads to damages in the structures built on soil. Problematic soils are formed in especial geological conditions. For example, collapsible soils are often found in semi-arid area. Field investigation and laboratory test can be useful to recognize problematic soils. Some properties of soils such as dry unit weight and liquid limit are helpful to estimate collapse potential of soils (Rezaei et al., 2012).

Experiments performed by El Howayek et al. (2011) on two soils included index tests(particle size analysis, specific gravity and Atterberg limits determination), standard compaction (Proctor) tests, and a wide testing program included double odeometer tests to determine the collapse strains upon wetting as a function of level of stress (12.5kPa to 2760 kPa). Soil specimens A and B were compacted maintaining an extensive range of relative compaction values, RC (between 75% and close to optimum) and for moisture contents (between 5–6% points lying in the dry of optimum zone to optimum). The collapse potential was determined following the criterion of the ASTMD5333, which uses the collapse index Ie, the collapse strain measured under a stress of 200 kPa. The collapse was found to increase with decreasing relative compaction, compaction water content and degree of saturation. Significant wetting induced strains were observed even for specimens compacted around 90% RC, in the case of water contents significantly on the dry side of optimum. On the other hand, the collapse strains were noticed to decrease with stress level, in some cases, considerable collapse strains were measured at relatively low stress levels (25–100 kPa), indicating that collapse induced by wetting may be taken into consideration even in case of small thicknesses of soil fill.

It is well recognized that the soil collapsible layers show a high potential for strains collapse strains caused by external loading. Inspection of the collapse potential is, therefore, necessary for calculations of settlement related to the embankment foundations resting on a layer of collapsible soil. The evaluation made by Livneh and Livneh (2012) recommended that the collapse potential depends on the following controlling parameters: (a) plasticy limit, (b) liquid limit, (c) field dry unit weight, (d) in-situ water content, and (e) pressure applied upon saturation in the collapse (single-oedometer) test. Measurement of these parameters, in addition to the water-penetration depth into the underlying soil stratum and the effect of soil partial saturation on the reduction of the collapse potential, was found to enable in the calculation of the magnitude of collapse strain or settlement in a non-homogeneous soil stratum.

Difrent methods have been adopted to decrease collapse effect, such as replacing of the gypseous soil or leveling of the soil (soil grouting or soil improvement). Fattah et al. (2013) carried out tests on four different types of gypseous soils including various properties and different gypsum contents. Tests were implemented on remoulded soil examples to investigate the compressibility of gypseous soil under the effect of varying conditions. The samples were grouted by using acrylate chemical. The treated gypseous soils showed low degrees of collapse potential, where acrylate liquid led to decrease the collapsibility of the gypseous soil by more than 50-60%. The acrylate liquid had affected the shear strength parameters of the gypseous soil through increasing the cohesion and decreasing the angle of internal friction.

Fattah et al. (2014) concluded that the gypseous soil samples revealed a low collapse probable in which the acrylate liquid caused a decrease in the collapsibility of the gypseous soil by more than 50-60%. The grouting with acrylate liquid resulted in the parameters of shear strength of the gypseous soil to be changed; the cohesion increased and the angle of internal friction decreased. For samples uncovered to soaking, it was found that the combination increased and the viewpoint of internal friction relatively decreased. This behavior can be attributed to the soil combination effect, caused by the action of the acrylate solution, and because that the acrylate liquid prevents the contact between soil particles which induced a reduction in interaction.

The objective of the present work is to make a comparison between the collapse potential determined from collapse test and the coefficient of average resolving slump as determined from field plate loading test.

EXPERIMENTAL WORK

A sub-soil investigation was carried in the site of EPP, Rumaila, Basrah Governorate south of Iraq. In general, the site is a wide flat area. The site investigation included drilling of 6 boreholes. Drilling was done using flight auger and rotary drilling. The soil disturbed samples (DS) were gathered from the cutting of auger at different depths. Shelby tubes were used for obtaining undisturbed samples (US). The split spoon samples (SS) were obtained from standard split spoon used in standard penetration test which was performed at different depth intervals depending on the stratifications of the soil.

The underground water table was found in the range of 3.00-3.41 m below the natural ground surface after 24 hours from the drilling termination at time of boring in March 2014.

In general, a series of laboratory tests were performed on selected soil samples included natural water content, density, liquid and plastic limits, sieve analysis and hydrometer, and direct shear test. Atterberg limits tests were carried out on fractions of soil samples passing sieve No. 40 according to ASTM D-4318. Plasticity index indicates the upper soil is non-plastic. Table 1 presents results of physical tests. The results of direct shear test and unconfined compression test are summarized in Table 2.

COLLAPSE TEST

The one-dimensional response-to-wetting test, which is carried out using standard consolidation equipment represents the frequently used laboratory collapse test for determining the collapse potential of the soil (Houston et al., 2001). In oedometer-collapse test, two procedures are commonly followed; single oedometer test (SOT) and double oedometer test (DOT) methods.

The actual collapse potential is determined using the double oedometer test (DOT) method suggested by Jennings and Knight (1975). In this method, two identical samples are prepared and tested individually in oedometer device. One sample is tested at its natural moisture content, while the other is tested under saturated conditions. The same load sequence is used in both cases. The difference between the two stress-strain curves represents the amount of collapse deformation that occurs depending on the stress level.

Jennings and Knight (1975) proposed a procedure to describe the collapse potential of a soil which is mostly a qualitative evaluation. This procedure was subsequently modified by Houston et al. (1998) and standardized by the American Society for Testing and Materials (ASTM) under code number ASTM D-5333 (2003).

Figure 1 illustrates a typical response in which a seating stress of 5 kPa was used to establish an initial state. Any compression under this stress was attributed to sample disturbance. The initial compression curve (points A-B) represents the response of the soil at its in situ water content. Pressure was applied until the stress on the sample was equal to (or greater than) that expected in the field or up to 200 kPa as suggested by Jennings and Knight (1975) and as standardized by ASTM D-5333 (2003).

At point B, the specimen was loaded to reach saturation and left for 24 hours (ASTM D5333,2003). The duration of the load increment following inundation lasted overnight or until primary consolidation was completed (ASTM D2435, 1996). The difference between the strains before and after inundation with water (points B-I) represents the amount of collapse deformation at the specified stress level, after which further loading is undertaken corresponding to points (I-J). The path (J-K) represents the unloading stage of the soil specimen.

According to ASTM D5333 (2003), the following definitions are outlined:

-Collapse: indicates a decrease in the height of confined soil following saturation at a constant applied vertical pressure.

-Collapse index (Ie): refers to the percent-relative value of collapse measured and calculated at 200 kPa.

-Collapse potential (Ic) denotes the percent-relative value of collapse measured at any stress level as follows:

$$I_c = \frac{\Delta h}{h_o} \times 100 \qquad \text{……………………………………………………………….. (1)}$$

Where: Δh = the change in specimen height resulting from wetting, mm, and

h_o = the initial specimen height, mm.

Equation (1) may be rewritten in terms of void ratio as follows:

$$I_c = \frac{e_B - e_I}{1 + e_o} \times 100 \qquad \text{……..…………………………………………………..(2)}$$

where: e_B, e_I = the void ratio at the appropriate stress level before wetting, and

e_o= the initial void ratio.

Based on the oedometer collapse test, the collapse potential can be assessed and used to indicate the problem severity of collapse. Table 3 provides details presented by Jennings and Knight (1975) and ASTM D5333 (2003), showing a slight difference between the two references in the collapse potential range corresponding to problem severity.

Figures 2 and 3 present the results of collapse test carried out on two samples. Based on the collapse potential, Ic of the two samples; 5.091% and 3.502%, the soil is considered of moderate degree of collapse.

PLATE LOADING TEST

The plate loading test is a semi-direct method to evaluate the allowable bearing pressure of soil to exhibit a given amount of settlement. Plates, are almost round, varying in diameter, from 25 to 46 cm and thickness of about 2.5 cm are used for the test. The load on the plate is applied by a hydraulic jack. The reaction of the jack load is taken by a truck. The settlement of the plate is measured by two dial gauges of sensitivity 0.01 mm placed 180° apart. The dial gauges are fixed to an independent support which remains undisturbed during the test. The test is employed essentially according to (ASTM D 1196-93).

The test is basically carried out by applying loads on small steel plates with diameters ranging from 0.3 to 0.75 m or square plates having sides of 0.3 X 0.3 m or sometimes 0.6 X 0.6 m. These plate sizes are generally considered to be so small to extrapolate the results to footings of full size, the size may be 1.5 to 4 or 5 m². A number of reasons cause unreliable extrapolations:

1. The soil at larger depths are subjected to large values of overburden pressure which lead to confine the soil so, it is basically "stiffer" than the soil close to the ground surface. This has considerable effects on the load - settlement relationship used to calculate q_u/t.
2. Previous studies have proved that as the width *B* increases, there is a tendency to a nonlinear increase in q_u/t. It is thought that for small size footings of about, 0.3, 0.45, and 0.6 m, the drawing of *B* against q_u/t is approximately linear (as it is the case of using two footing sizes such as, 2 m and 2.5 m). This requires a wider range of sizes of footings to develop the nonlinear relationship for the soil layer.

Despite these shortcomings, loading tests using the plate loading are sometimes used. The procedure has been considered a standard as ASTM D 1196, which basically requires that a load is positioned on the testing plate, and corresponding settlements are recorded using a dial gauge with an accuracy of 0.25 mm. Observations on a increments of load must be recorded until the settlement rate exceeds the dial gauge capacity. Load increments have to be approximately one-fifth of the predicted bearing capacity of the full footing. The intervals of time of each loading must not be smaller than 1 hour and must be applied approximately at

the same duration for all the increments of load. The test must continue until a total settlement of 25 mm is obtained, or until reaching the load capacity of the testing apparatus. After the load removal, the elastic soil rebound must be recorded for a period of time which must be at least equal to the duration time of the load increment (Bowles, 1997).

COEFFICIENT OF RESOLVING SLUMP FROM PLATE LOADING TEST

To test the value of resolving slump and coefficient of average resolving slump for saline soil foundation (Dongxing et al., 2013)**.** The test equipment is Just like plate load test, but the area of plate is preferred to be 5000 cm^2.

Test steps:
1. Excavating the pit to the depth of test requirement (usually excavating to the depth of foundation buried). The width of pit should be no less than 5 times diameter of plate used in test (W≥5D).
2. 5~10 cm thick gravel sand layer is needed to be paved to dense at the central of test pit. Then the plate is placed on the gravel sand layer.
3. According to the plate load test, incremental loading is applied to the preordain pressure P_0, after every grade of loading, and settlement is recorded at time intervals 10, 10, 10, 15, 15 minutes, and every half hour and once after that, when settlement is less than 0.1 mm after two hours, it is considered to be stable. After stability of settlement, the value of settlement for the plate is recorded.
4. Keeping the pressure P_0 , water is injected (must be fresh water) to the pit, keeping the water head to be 0.3 m, the soaking time is determined by the permeability of soil, which is preferred to be 5~12 days. The settlement of plate is recorded until the settlement becomes stable (standard for stability is that difference value of settlement is less than 1mm after the fifth day). Then the value of resolving slump S$_\square$ is recorded.
5. The stable resolving basement is considered as a new one and the load is increased until it is broken or the settlement reaches 0.01B (for sand) ~ 0.015B (for clayey soil) where B is the width or diameter of plate.

The coefficient of average resolving slump for saline soil S$_\square$ is calculated:

$$\overline{\delta} = \frac{S_\delta}{H_s}$$ ……………………………………………………………………….. (3)

where:

$\overline{\delta}$ is coefficient of average resolving slump,

S_δ is resolving slump value of saline soil layer when it is injected with water as the pressure P on the plate, and

H_s is wetness depth of saline soil under plate.

Two tests were carried out in the field. Test depths are 1.0m and 1.5 m. The test pressure is 200 kPa for P_0 and 400 kPa for the ultimate load. So a total load for more than 20 tones was prepared for this test. Figure 4 shows the results of resolving slump test on sample 1 while Figure 5 traces the variation of settlement with time. Figures 6 and 7 present the results of resolving slump test on sample 2.

The coefficient of average resolving slump for saline soil was calculated from field plate load test to be 0.94% to 1.2%. The difference in boundary conditions between the two approaches was found clear in the evaluation of collapse potential. The collapse potential that results from the complete wetting of the soil layer may not occur in the field, due to the difficulty to maintain full soil saturation state through wetting in a single step. Therefore, the wetting in multi steps procedure is more convenient because of the slow rate of rising of the ground water by the action of capillary forces, especially in regions of low rainfall (Al-Obaidi, 2014).

The dissolution of gypsum in the field is made by brine water rather than by distiiled water which is used in the laboratory. Brine water has an effect on the properties of gypseous soil which was studied by Azam (2000). It was found that the collapse potential increases when the gypseous soil soaking in brine water is twice that when the soaking is by distilled water. In contrast, Al-Farok et al. (2009) found that gypsum dissolution decreases with soaking in brine.

CONCLUSIONS:

1. The coefficient of average resolving slump for saline soil was calculated from field plate load test to be 0.94% to 1.2%, while the results of collapse test carried out on two samples showed that the collapse potential, Ic of the two samples; 5.091% and 3.502%, the soil is considered of moderate degree of collapse.

2. The difference in boundary conditions between the two approaches was found clear in the evaluation of collapse potential.

3. The collapse potential resulted from complete wetting of soil layer may not be achieved in the field, due to the inability to reach full saturation state through a single step wetting. Therefore, the multi-step wetting procedure is more convenient due to the slowly rising of ground water by capillary forces, especially in the low rainfall regions.

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TABLE I. RESULTS OF PHYSICAL TESTS.

Depth, (m) From-to			Specific gravity	Wc, %	Clay %	Silt, %	Sand, %	Gravel, %	Passing #200	Symbol
2.5	-	3.0	2.61	16	-	-	90	3	7	SP-SM
0.5	-	1.0	2.60	17	12	11	70	7	23	SM
2.5	-	3.0	2.61	16	-	-	90	3	7	SP-SM
4.5	-	5.0	2.63	16	-	-	80	8	12	SM
6.5	-	7.0	2.66	10	-	-	77	16	7	SW
8.5	-	9.0	2.65	13	-	-	78	16	6	SP-SM

TABLE II MECHANICAL TEST RESULTS.

Depth, (m)	Mechanical Properties		
	Unconfined compression test	Direct shear test	
	q_t (kPa)	c (kN/m^2)	$\square\square$
2.5 - 3.0	16.8	2.8	42
4.5 – 5.0	18.9	11.1	30
5.5 – 6.0	18.7	0.8	45
8.5 – 9.0	18.0	4.7	40
10.5 – 11.0	18.5	5.8	37

TABLE III: THE SEVERITY OF THE COLLAPSE POTENTIAL.

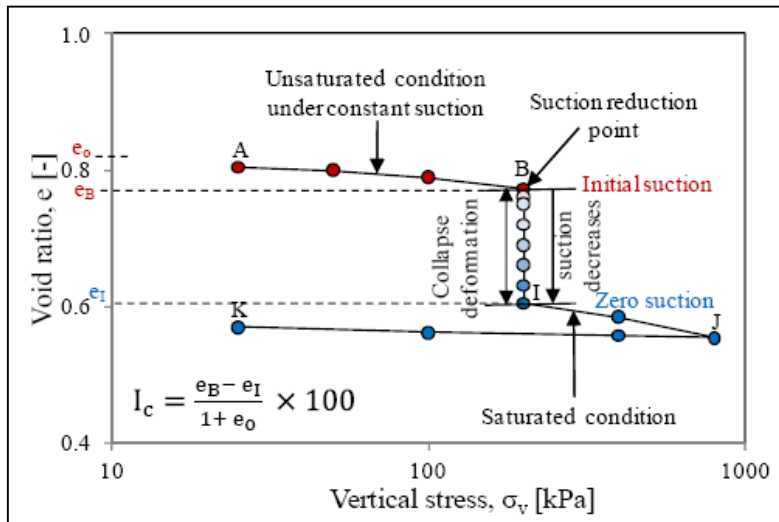| Jennings and Knight, 1975		ASTM (D5333-2003) standard	
I_c, (%) at σ_v=200 kPa	Severity of problem	I_c, (%) at σ_v=200 kPa	Degree of collapse
0-1	No problem	0	None
1-5	Moderate trouble	0.1-2.0	Slight
5-10	Trouble	2.1-6.0	Moderate
10-20	Severe trouble	6.1-10.0	Moderately severe
>20	Very sever trouble	>10.0	Severe

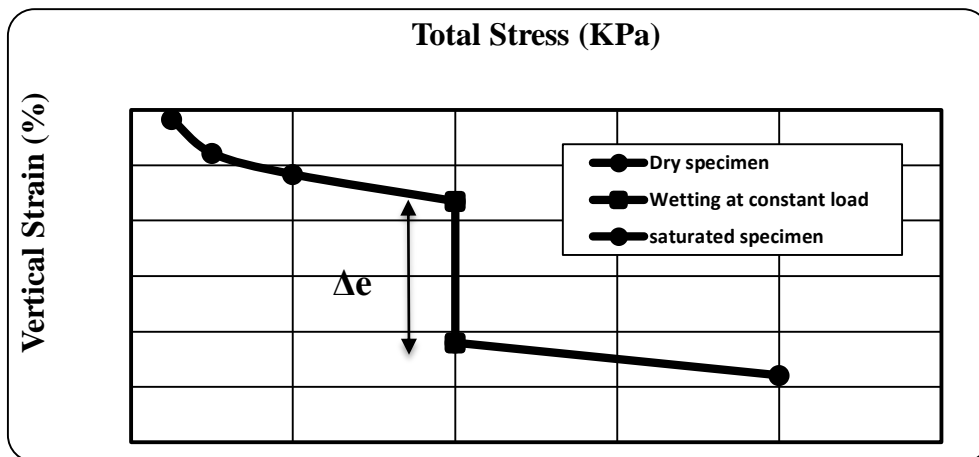Fig. 1: Typical oedometer-collapse test results.

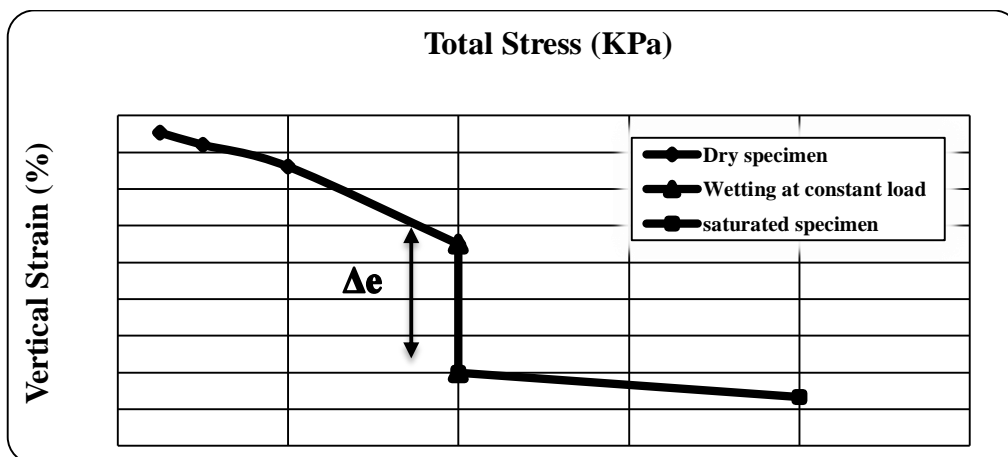Fig. 2: Results of collapse test on sample 1
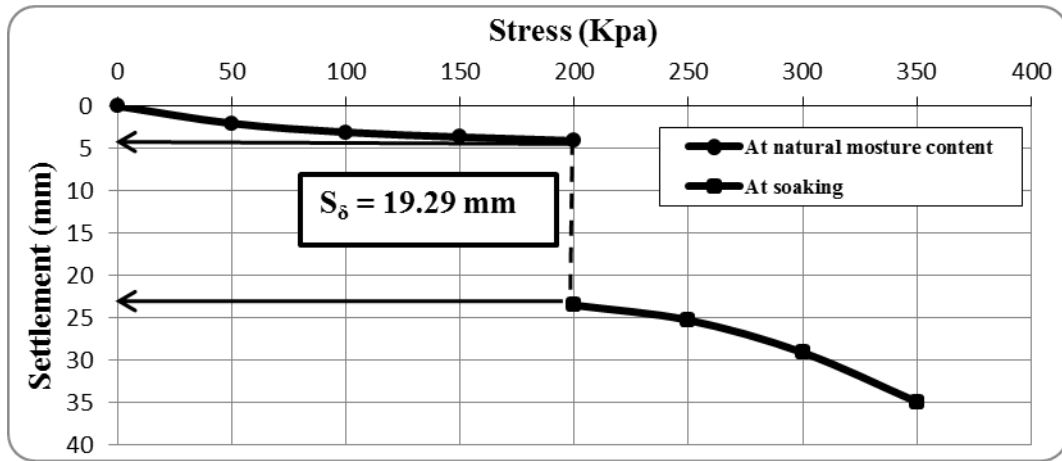

Fig. 3: Results of collapse test on sample 2.

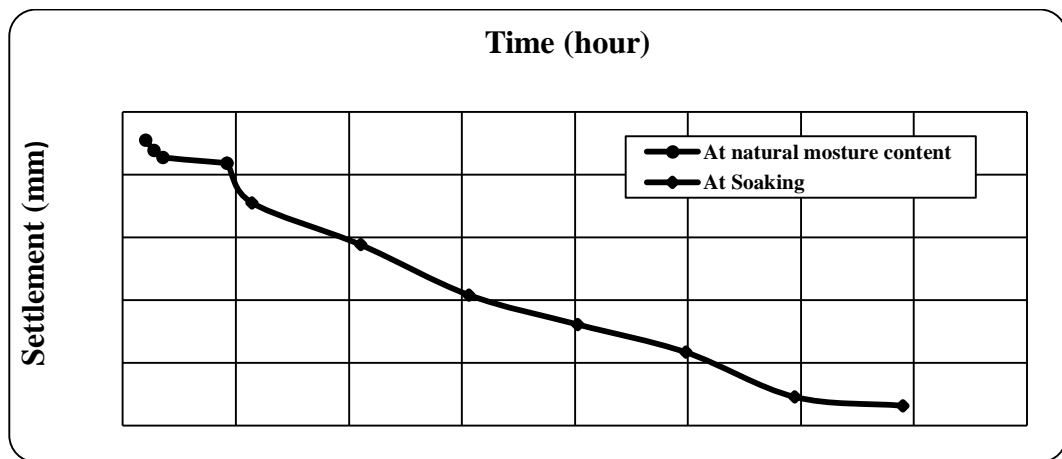Fig. 4: Results of plate load test on sample 1.

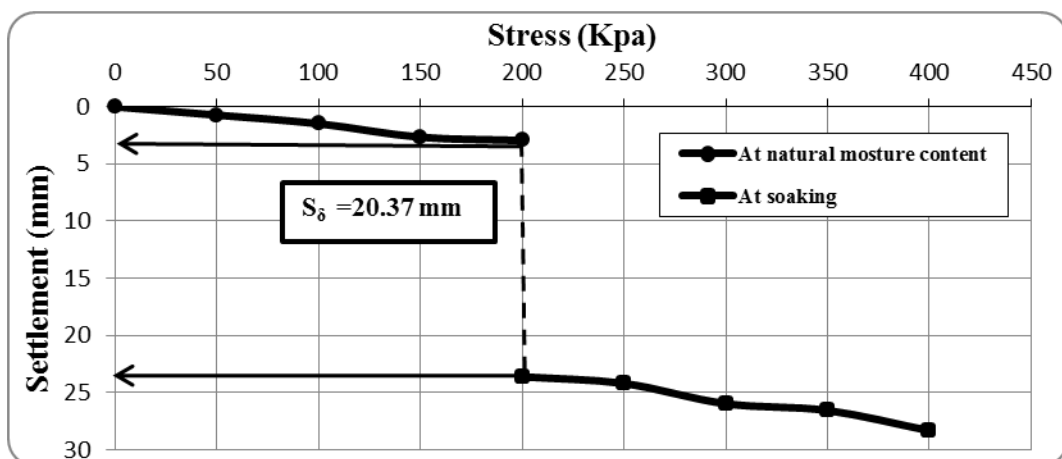Fig. 5: Settlement-time relationship from plate load test on sample 1.

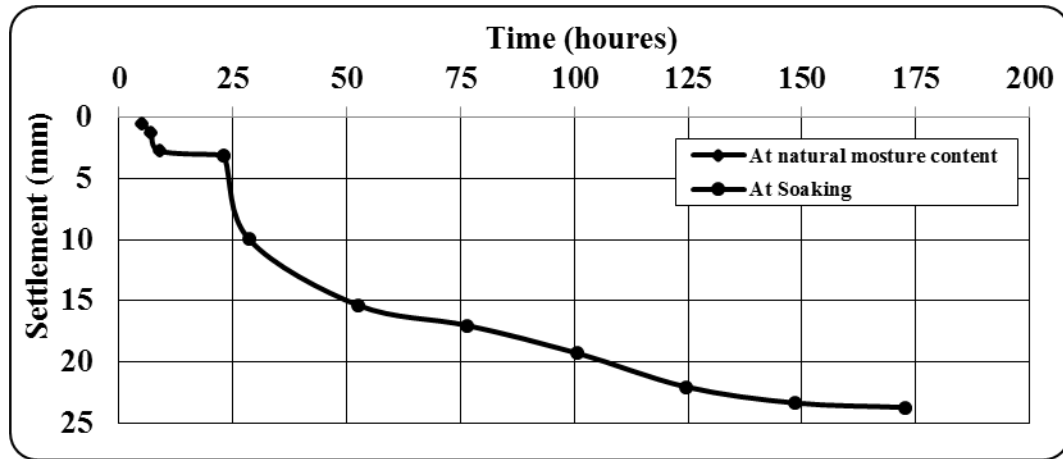Fig. 6: Results of plate load test on sample 2.

Fig. 7: Settlement-time relationship from plate load test on sample 2.

ايجاد احتمال الأنهيار للترب الجبسية حقليا ومختبريا

الخلاصة:

تعرف الترب الأنهيارية بأنها ترب ذات مشاكل وهي تبدي قوة كبيرة عندما تكون جافة وتفقد قوتها عندما تترطب وتبدي هبوطا مفرطا. ان استجابة الترب للأنهيار (مثل الأنزلاقات الأرضية أو هبوطات التربة المهمة) لم يكن من الممكن تخمينها بدقة. ان تقليل الحجم غير المسترجع في الترب الأنهيارية يحدث بسرعة بحيث انه لايمكن تسجيل قراءات أو ايقاف المشكلة عند بداية حدوثها.

ان احتمال الأنهيار يزداد مع الزمن نتيجة الغمر بالماء والغسل والتي تعزى الى ذوبان الجبس وغسله من التربة. في هذا البحث , اجريت مقارنة بين احتمال الأنهيار المخمن من فحص الأنهيار القياسي المختبري مع الأنهيار الحقلي (معامل الهطول المعاد) المخمن من فحص تحميل الصفيحة. موقع التربة الذي تم اختياره في الدراسة هو موقع الرميل في محافظة البصرة . لقد بينت نتائج فحص ألانهيار التي اجريت على نموذجين ان احتمال الأنهيار , (Ic)للنموذجين يبلغ 5.091 % و 3.502 % , حيث تعتبر التربة ذات معدل انهيار متوسط. ان معامل الهطول المعاد للتربة الجبسية تم حسابه ايضا من فحص تحميل الصفيحة الموقعي وقد بلغ 0.94 % و 1.2 %. ان الأختلاف في الشروط الحدودية بين الطريقتين يبدو واضحا في تقييم احتمال الأنهيار.