TJES
ISSN: 1813-162X
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

Settlement and Collapse of Gypseous Soils

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Abstract

The work in this research presents an experimental, theoretical and field study in order to investigate the settlement of Gypseous soils and the effect of water percolation on collapsibility of this soil. In this research, more than five sites where chosen to extract the gypseous soil samples with different gypsum content; the sites located in different regions in Salah Aldeen Governorate. In order to estimate the settlement and collapse of gypseous soils, field tests consist of standard penetration test for depths (1m to 5m) for each site and plate load test were conducted in dry and soaked cases.

The results show that the settlement of gypseous soils in dry condition is less than the same soils that have low values of gypsum in its formation, the settlement value of lightly gypseous soils can be evaluated from the basic equations depending on data of SPT**.**

In soaking case with short term flooding, gypseous soils shows compressible and they are sufficiently reliable soil base, while in the case of long term flooding settlement develops due to dissolution of salts and gypsum. The magnitude and the rate of the settlement depend on initial gypsum content, relative amount of leached salts, the mineralogy and type of soil and soil properties and acting load.

The standard penetration test does not use in calculating the settlement for the soils that have gypsum in its formation in soaking condition**.**

Keywords: Gypseous soils, Settlement, Collapsibility, SPT, PLT.

دراسة الهبوط والانهيار للترب الجبسية

الخلاصة

تنتشر التربة الجبسية وبمساحات واسعة ومناطق متفرقة من العراق. هذه التربة تسببت بفشل اسس المنشات المقامة عليها وخاصة عند جريان الماء وذوبان الجبس في التربة. تضمن العمل في هذا البحث دراسة حقلية ونظرية ومختبرية الغرض منها دراسة الهبوط في الترب الجبسية ومعرفة تأثير جريان الماء على الانهيار لهذه التربة. اختير اكثر من خمسة مواقع لاستخراج نماذج التربة الجبسية وبنسب مختلفة ومن مناطق متفرقة من محافظة صلاح الدين.

تضمنت الاعمال الحقلية اجراء فحص الاختراق القياسي لكل موقع من العمق (1م الى 5م) بالاضافة الى فحص تحميل الصفيحة لربط نتائج تلك الفحوصات مع قيم الهبوط والانهيار للترب الجبسية للحالتين الجافة والمغمورة، كما تم اخذ نماذج مشوشة وغير مشوشة من جميع المواقع وفحصها في المختبر للتعرف على الخصائص الفيزيائية والهندسية لهذه الترب الى جانب فحص الانهيارية والانضغاطية لمعرفة الخصائص الاساسية لتخمين الهبوط والانهيار للترب الجبسية. النتائج بينت ان الهبوط في الترب الجافة يقل كلما زادت محتوى الجبس فيها، كما يمكن ان تستخدم المعادلات الاساسية المعتمدة على بيانات فحص الاختراق القياسي لايجاد الهبوط في الترب ذات المحتوى الجبسي القليل. اما في حالة الغمر للترب الجبسية فان السبب الرئيسي للهبوط يكون الانهيار الذي يحصل في بنية التربة نتيجة لفقدان الاواصر التي توفرها جزيئات الجبس مع التربة اضافة الى ذوبان الجبس نفسه، وبحدوث حالة الجريان ولفترة زمنية فان سبب الهبوط هو ذوبان الجبس والاملاح الاخرى وان قيمة الهبوط تعتمد على المحتوى الجبسي، كمية الاملاح المرشحة، طريقة تكوين المعادن ونوعها اضافة الى خصائص التربة ومقدار الاحمال المسلطة وبالتالي لايمكن استخدام نتائج فحص الاختراق القياسي لحساب الهبوط مباشرة.

الكلمات الدالة: التربة الجبسية، الهبوط، الانهيارية، فحص الاختراق القياسي، فحص تحميل الصفيحة.

Introduction

In Iraqi soils, especially at the north –west and other sparse region, the gypsum forms high percentage in the soils. Gypseous soils were known as reference of most problems that can happen to the structure built on, especially when water soaked and/or leached these soils. This situation leads to dissolve gypsum then creates voids and cavities that will execute to conformation the settlement and collapse. In additional to this, it will generate wateriness apertures that will help in water streaming that will execute to solution more of the gypsum.

Settlement of soil is the gradual downward movement of an engineering structure, due to compression of the soil below the foundation. The problem is widely and ramose, it must be studied in spite of its difficulties.

Many of researchers studied settlement of clay soils [1,2], where other researchers studied settlement of sand soils [3,4,5]. In two cases, the researchers found special equations (laboratory and field) to estimate values of settlement of soils. However, the settlement of gypseous soils has a little attention from the researchers. Thus in this research different sites were chosen where different gypsum content was found in order to carry out the field and laboratory testing.

Collapsible soil can withstand a large applied vertical pressure with small compression, but then show much larger settlement upon wetting, with no increase in vertical stress. This behavior can yield disastrous consequences for structures unwittingly built on such deposits. The process of their collapsing is often called of “hydroconsolidation”, “hydrocompression”, or “hydrocollapse” [6].

It is more useful to list the typical characteristics of a collapsible soil, Gibbs, (1961)[7] was accumulating these characteristics:

1. An open structure
2. A high void ratio
3. A low dry density
4. A high porosity
5. Geologically young or recently altered deposit
6. High sensitivity, and
7. Low inter-particle bond strength.

Standard Penetration Test (SPT)

The SPT can be used for all types of soil, but in general, the SPT is most often used for sand deposits. The SPT can be especially of value for clean sand deposits where the sand falls or flows out from the sampler when retrieved from the ground. Without a soil sample, other types of tests, such as the SPT, must be used to assess the engineering properties of the sand. Often when drilling a borehole, if subsurface conditions indicate a sand strata and sampling tubes come up empty, the sampling gear can be quickly changed to perform SPT [8].

Corrections to the Recorded SPT Value

The actual energy effective in the driving of the SPT equipment varies due to many important factors. The SPT parameter depends on the following factors [9]:

1. *Hammer efficiency, (E_h)*

$$E_h = \frac{E_a}{E_{in}} \times 100\% \quad \text{..................... (1)}$$

Where:

E_h: Hammer efficiency
E_a: Actual hammer to sample energy
E_{in}: Input energy

2. *Length of drill rod*

Correction factors are used for correcting the effects of length of drill rods, (C_d), as shown in Table (1).

Table 1. Correction of Cd

Length(m)	>10	6-10	4-6	0-4
(C_d)	1	0.95	0.85	0.75

3. *Sampler correction factor, (Cs)*

Without liner Cs = 1.00
With liner,
Dense sand, clay = 0.80
Loose sand = 0.90

4. *Borehole diameter, (C_b)*

Correction factors are used for correcting the effects of borehole diameter correction factor C_b, as in Table (2).

Table 2. Correction of C_b

Bore hole diameter(mm)	60-120	150	200
C_b	1	1.05	1.15

5. *Overburden pressure, (C_N)*

Various correction factors for overburden pressure have been suggested by a number of investigators [10].

$$C_N = \left[\frac{95.76}{\sigma_o'}\right]^{0.5} \quad \text{.............................. (2)}$$

$C_N \leq 2.0$

Where:

σ_o': effective overburden in kPa

Then the N_{cor} may be expressed as:

$$N_{cor} = NE_h C_b C_s C_d C_N \quad \text{......................... (3)}$$

N_{cor} is related to the standard energy ratio used by the designer. N_{cor} may be expressed as N_{70} or N_{60} according to the designer's choice.

In Equation (3) C_N is the corrected value for overburden pressure only. The value of C_N as per Equation (3) is applicable for granular soils only, where C_N = 1 for cohesive soils for all depths [11].

Estimation of Settlement

Settlements of structures built on granular soils are generally considered only under two states, that is, either dry or saturated. The stress-strain characteristics of dry sand depend primarily on the relative density of the sand, and to a much smaller degree on the shape and size of grains. Saturation does not alter the relationship significantly provided the water content of the sand can change freely [11].

Settlement Based on Theory of Elasticity

$$\delta_e = q(\alpha B')\frac{1-\mu^2}{E} I_s I_f \text{.............................(4)}$$

Where:

q: net applied pressure on the foundation

μ: Poisson's ratio of soil

E: average modulus of elasticity of the soil under the foundation measured from z = 0 to about *z* = 4*B*

α: number of corners contributing to settlement at the footing center *α*= 4; at a side *α* = 2, and at a corner *α* = 1.

B' = *B*/2 for center of foundation (= *B* for corner of foundation)

I_s: shape factor

I_f: depth factor

Settlement Calculation from Laboratory Data

Settlement can be estimated from the results of confined compression test through the following equation [11]:

$$\delta = H\frac{\Delta e}{1+e_0} \quad \text{..................................... (5)}$$

δ : Settlement in mm.

e_0 : Initial void ratio.

Δe: Change in void ratio.

H: Thickness of layer.

Settlement from SPT Data

There are several methods available for the calculation of footing settlements in field using SPT results. Most of these methods are based on elasticity, and thus focus on determination of soil compressibility, with consideration of footing size. The methods that depended on SPT will widen and explain each method and on what depend all of them.

1- Meyerhof's Method in (1965)

The modified expression for the settlement is [12]:

$$\delta = \frac{1.25q}{N_{60}} C_W C_D \quad \text{for } B \leq 1.22\text{m} \text{ .... (6)}$$

$$\delta = \frac{2q}{N_{60}}\left[\frac{2B}{B+0.3}\right]^2 C_W C_D \quad \text{for } B > 1.22\text{m} \text{ ......(7)}$$

Where:

δ: Settlement of footing in mm.

q: load on base of footing (kN/m^2).

N_{60}: blow count for SPT N-value.

C_W: groundwater table correction

C_D: correction for depth of embedment =1- $\frac{Df}{4B}$

D_f: depth of embedment in m.

B: width of footing in m

2-Meyerhof's Method in (1974)

A quick estimate of the settlement, S, of a footing on sand has been proposed by Meyerhof in 1974 [13]:

$$\delta = \frac{\Delta pB}{2q_c} \text{.. (8)}$$

Where:

Δp: the net foundation pressure

B: the least dimension of the footing

$q_c = 400 \times N$ kN/m^2

N: actual number of blows recorded in SPT

3-Terzaghi and Peck Method in (1948)

A general expression for these relations is [14]:

$$\delta = C\left[\frac{q}{N}\right]\left[\frac{B}{B+1}\right]^2 \quad (9)$$

Where:

δ: settlement in inches.
B: footing width in foot.
q: bearing pressure in Tsf.
N: blows count=N_{60} where N_{60} not corrected for overburden stress.
C: empirical constant =8 for B<4 ft or C=12 for B >4 ft

4-Terzaghi and Peck Modified in (1967)

Settlement can be approximated by the relation [14]:

$$\delta = \frac{3q}{N_{60}}\left[\frac{B}{B+0.3}\right]^2 \quad (10)$$

Where
q: bearing pressure in kN/m^2.
B: width of foundation in m.

5- Burland & Burbidge Method in (1985)

Burland and Burbidge (1985) [15], proposed a semi-empirical method, using the blow counts from standard penetration test [16]. They suggested that the settlement can be estimated in normally consolidated granular soils

$$\delta_{\text{footing}} = q_{\text{net}}\frac{1.71}{N_{60}^{1.4}}\,B^{0.7} \quad (11)$$

In over consolidated granular soils, with pre-consolidation pressure of σ'_p and $q \le \sigma'p$:

$$\delta_{\text{footing}} = \frac{1}{3}q_{\text{net}}\frac{1.71}{N_{60}^{1.4}}\,B^{0.7} \quad (12)$$

$$\delta_{\text{footing}} = \left[q_{\text{net}} - \frac{2}{3}\sigma'p\right]\frac{1.71}{N_{60}^{1.4}}\,B^{0.7} \quad (13)$$

For $q \ge \sigma'_p$

The settlements have to be multiplied by the following factor (fs):

$$f_s = \left[\frac{1.25L/B}{0.25+L/B}\right]^2 \quad (14)$$

The settlements estimated above imply that there is granular soil at least to a depth of z_l. If the thickness (Hs) of the granular layer below the footing is less than the influence depth, the settlements have to be multiplied by the following reduction factor (f_l):

$$f_l = \frac{H_s}{z_1}\left[2 - \frac{H_s}{z_1}\right] \quad (15)$$

Burland and Burbidge (1985) [15], noted some time-dependent settlements of the footings, and suggested a multiplication factor (f_t) given by

$$f_t = 1 + R_3 + R_t \log\frac{t'}{3} \quad (16)$$

Where, R_3 takes into consideration the time dependent settlement during the first three years of loading. Suggested values for R_3 and R_t are 0.3-0.7 and 0.2-0.8 respectively [16].

6-Bowles Method in 1977

Bowles' settlement method is based on the Terzaghi and Peck method, but is modified to produce results that are not conservative. His equations are [14]:

$$\delta = \frac{2.5q_0}{N}\left[\frac{C_W}{C_D}\right] \quad \text{for } B \le 4ft \quad (17)$$

$$\delta = \frac{4q_0}{N}\left[\frac{B}{B+1}\right]^2\left[\frac{C_W}{C_D}\right] \quad \text{for } B \ge 4ft \quad (18)$$

q: is in kips/sf, N is measured in the field, and the settlement is in inches.
The correction factor for water is:

$$C_W = 2 - \left[\frac{D_W}{D_f+B}\right] \le 2.0 \text{ and } \ge 1.0 \quad (19)$$

The correction factor for depth is:

$$C_D = 1 + 0.33\left[\frac{D_f}{B}\right] \le 1.33 \quad (20)$$

7-Peck and Bazaraa Method in 1969

Peck and Bazaraa (1969) method was adopted the Meyerhof's Equation in (1965) replacing N_{60} with $(N_1)_{60}$ blow counts from standard penetration test corrected for overburden stress. The settlement should then be multiplied by water table correction and depth correction [16], thus

$$\delta = C_W C_D \frac{0.53q}{(N_1)_{60}}\left[\frac{2B}{B+0.3}\right]^2 \quad (21)$$

Where:
$C_W = \frac{\sigma}{\sigma'_o}$ at 0.5B below the bottom of the foundation

σ_o:total overburden pressure.
σ_o': Effective overburden pressure

$$C_D = 1 - 0.4\left[\frac{\gamma D_f}{q}\right]^{0.5} \quad \ldots\ldots (22)$$

γ: unit weight of soil
The relationship for $(N_1)_{60}$ are

$$(N_1)_{60} = \frac{4N_{60}}{1+0.04\sigma_o'} \text{ for } \sigma_o' \leq 75\text{kN/m}^2 \quad \ldots\ldots (23)$$

$$(N_1)_{60} = \frac{4N_{60}}{3.25+0.01\sigma_o'} \text{ for } \sigma_o' \geq 75 \text{ kN/m}^2 \quad \ldots (24)$$

8- Peck, Hanson, and Thornburn Method in 1974

This method is based on Terzaghi and Peck settlement method [14].

For intermediate width footings (>2 ft, 0.6m)

$$\delta = \frac{q}{0.11 N_C C_W} \quad \ldots\ldots (25)$$

And for rafts

$$\delta = \frac{q}{0.22 N_c C_W} \quad \ldots\ldots (26)$$

Where q is in tsf.
The correction factor for water is:

$$C_W = 0.5 + 0.5\left[\frac{D_W}{D_f+B}\right] \quad \ldots\ldots (27)$$

for water from 0 to D_f +B

For blow count:

$$N_C = NC_n \quad \ldots\ldots (28)$$

$$C_n = 0.77 log\left[\frac{20}{\sigma_o'}\right] \quad \ldots\ldots (29)$$

Where:
σ_o': Effective overburden pressure for the measured blow count at D_f + (B/2) in tsf (0.25 tsf =24 kPa).

9-Teng Method in 1962

Teng's method for computing settlement is an interpretation of the Terzaghi and Peck bearing capacity chart. Teng included corrections for depth of embedment, the presence of water, and the blow count. The settlement expression is [14]:

$$\delta = \frac{q_o}{720(N_c-3)}\left[\frac{mH}{B+1}\right]^2 \frac{1}{C_W C_D} \quad \ldots\ldots (30)$$

Where: q_o = net pressure in psf
The correction factor for water is

$$C_W = 0.5 + 0.5\left[\frac{D_W-D_f}{B}\right] \geq 0.5 \text{ for water at and below } D_f \quad \ldots\ldots (31)$$

For depth:

$$C_D = 1 + \left[\frac{D_f}{B}\right] \leq 2.0 \quad \ldots\ldots (32)$$

For blow count:

$$N_C = N\left[\frac{50}{\sigma_o'+10}\right] \quad \ldots\ldots (33)$$

Where:
σ_o' = effective overburden at median blow count depth about D_f + B/2, in psi (40 psi, 276kPa)

Settlement Based on PLT

The plate load test can be used to directly estimate the settlement of a footing. For settlement of medium to dense sands caused by an applied surface loading, an empirical equation that relates the depth of penetration of the steel plate S1 to the settlement of the actual footing δ is as follows [8]:

$$\delta = \frac{4S_1}{\left(1+\frac{B_1}{B}\right)^2} \quad \ldots\ldots (34)$$

This test was performed in accordance with ASTM D1194 "Bearing Capacity of Soil for Static Loads on Spread Footing") is used to determine the relationship between settlement and plate pressure q_p [17].

Collapse Potential

A procedure for determining the collapse potential of a soil was suggested by Jennings and Knight in 1975.The collapse potential C_P is then expressed as [11]:

$$C_p = \Delta e_c/1 + e_o \times 100\% \quad \ldots\ldots (35)$$

in which Δe_c is the change in void ratio upon wetting, e_o is natural void ratio.

Settlement of Gypseous Soil having Gypsum Content >10%

Plate Load Test

Dry Condition

This test (PLT) was consider as a refrence to compare between the settlement values that were extracted from standard penetration test and labrotary test for soil in dry condition

Table (3) shows the properties of the soil on which the PLT carried out. The site Al-Qadisiyah site has a high gypsum content about 43.24% that was classified as highly gypsiferous soil according to the Barzanji (1973)[18] classification, therefore it was chosen to carry out the plate load test, standard penetration test and laboratory tests to find the settlment values for all possible methods and then compare between them for two conditions (dry and soaking).

Table 3. Properties of Al-Qadisiyah site

Properties		Value in dry	Value after soaking
Gypsum Content %		43.24	28.65
Moisture content, (ω)%		3.04	24.36
Specific gravity, (Gs)		2.54	2.54
Particle-size distribution		SP	SP
Atterberg limits	Liquid limit (L.L)%	32	---
	Plastic limit(P.L)%	N.P	---
	Plasticity index (P.I)%	---	---
Field unit weight, (γ_f) kN/m³		13.54	18.19

Figure (1) shows the results of settlement values for PLT that was carried out on site Qd1.The results of this site in PLT were considered as a reference to comparison between settlement value for different method of the soil in dry condition . From this figure ,it can be observed that the soil is very strong and have low settlement.

Soaking Condition

As soil is submerged with water, the bonding between particles will be destroyed and the collapse happens. If these soils contain high percentage of gypsum, the collapsibility increases.

The results of the soil that is tested by plate load test after soaking in water shown in Figure (1). The settlement of gypseous soil that has gypsum content about 43.24% after soaking in water for the time about eight days was very high as compared with the settlement of the same soil in dry condition.

Figure (1) shows the results of the settlement for dry and soaking conditions. This large difference in the values of the two conditions expounds to the effect of gypsum in soil at dry condition, then thawing of the gypsum bond in soaking conditions.

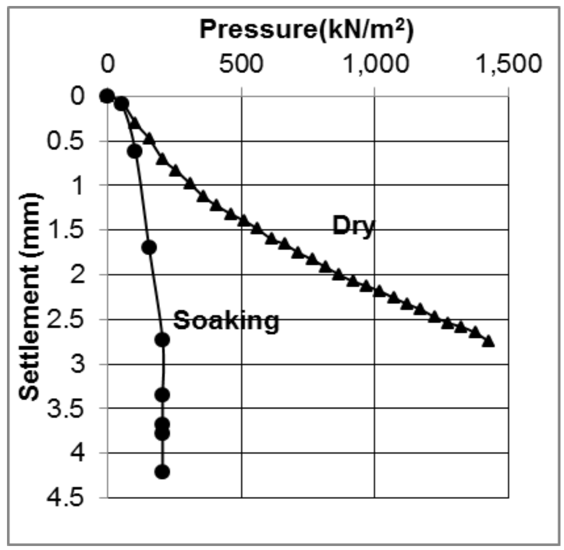

Fig. 1. Comparison between the Results of the PLT in Dry and Soaking Conditions

Laboratory Method

Dry Condition

The results from the laboratory work illustrated in Table (4). The results found from the laboratory tests give higher values than the results extracted from in situ tests. This difference can be attributed to the effect of sample disturbance, and the stress relief of the laboratory samples.

Soaking Condition

Settlement values for gypseous soils in wet condition are extracted from collapse test. Table (4) illustrates the results of settlement values in soaking condition.

Table 4. Results of Laboratory tests

Gypsum Content	Settlement (mm) in dry condition	Settlement (mm) after soaking
60.34	0.304	34.416
43.24	1.51	32.572
38.67	0.76	29.478
33.83	1.092	25.341
28.05	2.01	17.306
24.13	2.42	15.077
19.84	3.4	7.663
5.38	3.96	6.05

Standard Penetration Test

Dry Condition

The standarad penetration test is used in granular soils or cohesionless soil .Gypseous soil is a kind of the granular soil ,therefore the standarad penetration test was carried out on soils that have different gypsum content and found the value of settlement from special equations that depend the number of blow count in finding the settlement.

Trautmann and Kulhawy (1987)[19] used the following relationship for Poisson's ratio

$$\mu = 0.1 + 0.3\emptyset_{rel} \quad \text{.............................. (36)}$$

Where: ϕ_{rel} = relative friction angle =

$$\frac{\varphi_{tc}-25^{\circ}}{45^{\circ}-25^{\circ}} \; (0 \le \varphi_{rel} \le 1) \quad \text{........... (37)}$$

φ_{tc}: friction angle

Table (5) illustrates Poisson's ratio of Al-Qadisiyah site.

Table 5. Results of Poisson's ratio of Al-Qadisiyah site, (Qd1)

Depth (m)	ϕ	ϕ_{rel}	$\mu=0.1+0.3*\phi_{rel}$
1	32.22	0.36	0.21
2	36.17	0.56	0.27
3	27.70	0.14	0.14
4	29.70	0.23	0.17
5	30.71	0.29	0.19

Parameters such as the modulus of elasticity Es and Poisson's ratio for a given soil must be known to calculate the elastic settlement of a foundation. In most cases, if the laboratory test results are not available, these values were estimated from empirical correlations, (Das, 1999)[20]. Many correlations for the modulus of elasticity of sand with the field standard penetration resistance N and cone penetration resistance qc was made in the past. Schmertmann (1970)[2] proposed that:

$$E_s\ (kN/m^2) = 766N_{60} \quad \text{........................ (38)}$$

For sand (normally consolidated)

$$E_s=500(N+15) \quad \text{.............................. (39)}$$

Es in equation (38) will denote E_{s1} and Es in equation (39) denote E_{s2}.

Table (6) illustrates the values of E_{s1} for dry and soaking conditions of Al-Qadisiyah site, and Table (7) and (8) illustrate the values of E_{s2} for dry condition after soaking of Al-Qadisiyah site.

Settlement can be estimated from many equations depending on data obtained by SPT.

Table 6. Results of E_{s1} in dry and after soaking conditions

Depth (m)	N @ 300 mm in dry	Es (kN/m2) in dry	N @ 300mm after soaking	Es (kN/m2) after soaking
1	70	53620	50	38300
2	85	64727	100	76600
3	115	88090	80	61280
4	110	84260	72	55152
5	139	106217	66	50556

Table 7. Results of E_{s2} in dry condition

Depth (m)	N @ 300 mm	N_{60}	N_{55}	E_{s2}
1	70	89	97	56181.82
2	85	108	118	66265.91
3	115	126	138	76276.04
4	110	103	112	63525.19
5	139	112	123	68848.58

Table 8. Results of E_{s2} after Soaking

Depth (m)	N @ 300mm	N_{60}	N_{55}	E_{s2}
1	50	64	70	56830.91
2	100	128	139	67049.45
3	80	102	111	77193.06
4	72	86	94	64272.19
5	66	69	75	69666.56

Using statically analysis, the best method can be chosen. This value chosen was depended by the comparison between the methods and knowing converge degree for each method from the real settlement value.

The recovery settlement value is calculated for each method as follows:

Recovery settlement value =

$$\frac{\text{settlment of any method}}{\text{settlement of Meyerhof method(1965)}} \times 100 \quad \ldots(40)$$

The standard penetration test is carried out on it. Number of blows is taken and entered in special equations to find the settlement values that are given in Table (9) and Figure (2). The settlement was calculateted from the equations for the footing (1*1)m in all methods.

Table 9. Summary of Settlement Values for Qd_1 in Dry Condition

No.	Methods	Settl. (mm)	Recovery of Settl.	Percent error (%)
1	Meyerhof 1965	1.109	98.19	1.81
2	Meyerhof 1974	1.203	106.54	6.54
3	Terzaghi & Peck 1948	1.882	166.61	66.61
4	Terzaghi & Peck 1967	1.575	139.44	39.44
5	Burland & Burbidge 1985	0.627	55.55	44.45
6	Bowles 1977	1.277	113.03	13.03
7	Peck & Bazaraa	1.100	97.37	2.63
8	Peck, Hanson and Thornburn	1.710	151.39	51.39
9	Teng 1962	0.777	68.79	31.21
10	Using Es_1	1.236	109.46	9.46
11	Using Es_2	1.741	154.13	54.13
12	Laboratory method	1.785	157.96	57.96

Soaking Condition

Table (6) shows the results of Es_1in soaking condition. These results are use in finding the settlement values in theory of elasticity.

Tables (7) and (8) illustrate the results of Es_2 that product by using N_{55} in equation (39). Table (10) shows the results of settlement values in soaking condition of Al-Qadisiyah site and these results acts in Figure (3).

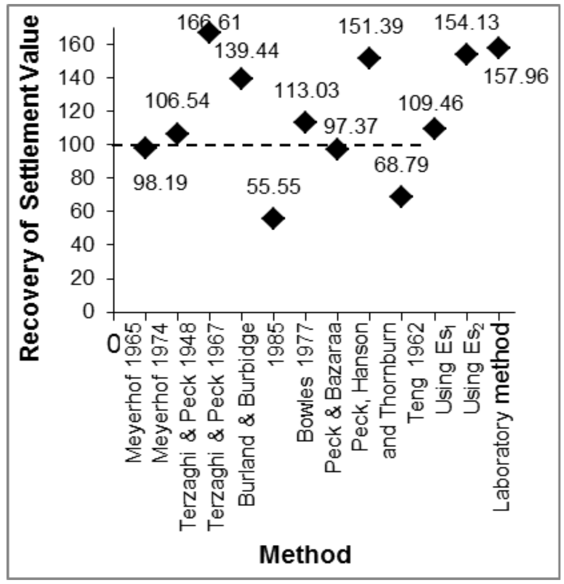

Fig. 2. Results of Settlement for Qd_1 in Dry Condition

The laboratory method can be considered as the best method in finding the settlement value for gypseous soils after soaking condition. Therefore, the results in Table (10) depend on this method in comparison with the field method in finding the settlement that depends on the data from SPT test. The values listed in these tables will illustrate the results of settlement values for twelve methods and recovery settlement values and percent of error for each method for the sites after soaking.

Figure (3) shows the recovery of settlement value and the degree of converge the result of each method with the real settlement value for all methods. These results on laboratory method as best method to find the real settlement value after soaking the soil.

Table 10. Summary of Settlement Values for Qs_1 after Soaking

No.	Methods	Settl. (mm)	Recovery of Settl.	Percent error (%)
1	Meyerhof 1965	2.664	17.27	82.73
2	Meyerhof 1974	1.698	11.01	88.99
3	Terzaghi & Peck 1948	2.656	17.22	82.78
4	Terzaghi & Peck 1967	3.783	24.53	75.47
5	Burland & Burbidge 1985	1.016	6.59	93.41
6	Bowles 1977	3.603	23.36	76.64
7	Peck & Bazaraa	1.987	12.88	87.12
8	Peck, Hanson and Thornburn	4.296	27.85	72.15
9	Teng 1962	1.916	12.43	87.57
10	Using Es_1	1.482	9.61	90.39
11	Using Es_2	1.909	12.38	87.62
12	Laboratory method	1.542	100.00	0.00

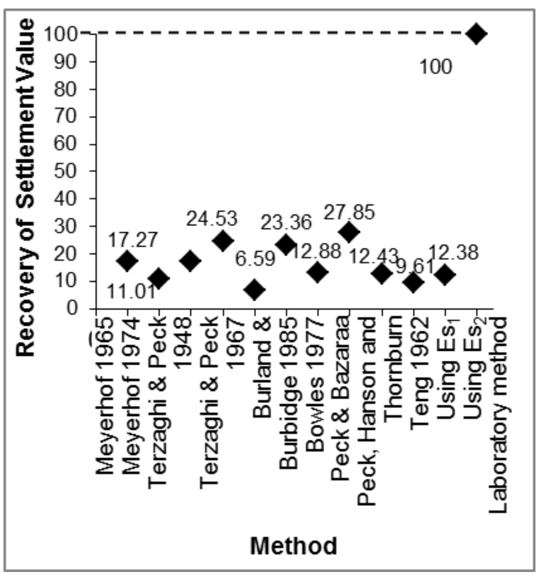

Fig. 3. Results of Settlement for Qs_1 after soaking with water

Settlement of Gypseous Soil Having Gypsum Content<10%

Plate Load Test

The plate load test was carried out on Al-Qadisiyah soil site (2). This site has gypseous soil with gypsum content less than 10%, Table (11) shows the properties of the soil which was tested by PLT.The results for the test are shown in Figure (4).

Table 11. :Properties of Al-Qadisiyah soil site (2) at 1m depth.

Properties		Value
Gypsum Content		7.73
Moisture content, (ω)%		3.65
Specific gravity, (Gs)		2.65
Particle-size distribution		SP
Atterberg limits	Liquid limit (L.L)%	32
	Plastic limit (P.L)%	---
	Plasticity index (P.I)%	---
Field unit weight, (γ_f) kN/m³		14.68

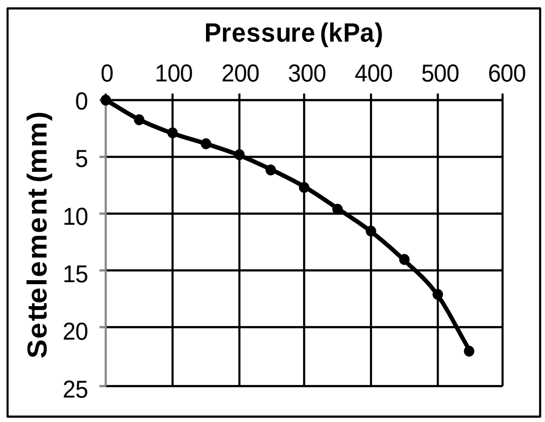

Fig. 4. Results of PLT for Al-Qadisiyah site (2)

The difference between Figure (1) and Figure (4) was very articulate where the settlement, for the soil that has gypsum content low (Al-Qadisiyah site 2), is a high value but the soil ,that has high gypsum content (Al-Qadisiyah site 1), is having a small value .The case was interpreted to entity particle of gypsum that consider as interconnected materail between the partical of soil that will be the soil is very strong when it is dry and the settlement is a very small. When the gypsum content was high in soil formation ,the settlement value was small, this means the direct corrlelation between the gypsum content and the settlement value is opposite if the soil is dry.

Standard Penetration Test

Dry Condition

Table (12) shows physical properties of the soil tested by SPT at Al-Dour city. This soil has low gypsum content (5%). The standsrd penetration test is carried out on it. Number of blow counts are taken and entered in special equations to find the settlement values.

Figure (5) shows the results of the settlement values calculated by different (12) methods .This soil is compared with another soil that has different properties and gypsum content.

Soaking Condition

For this test, the chosen soil was from Al-Dour city with properties shown in Table (12). The SPT was carried out in two conditions (dry and soaking). The settlement at dry condition was drowning and shown in Figure (5) and the wet condition illustrated in Figure (6). A difference in settlement values was notes due to amount of gypsum content, where the percentage of the gypsum in the soil affects the engineering properties of the soil.

Table 12. Properties of Al-Dour site

Properties		Value in dry	Value after soaking
Gypsum Content %		5.01	3.9
Moisture content, (ω)%		17.8	40.81
Specific gravity, (Gs)		2.58	2.58
Particle-size distribution		SP	SP
Atterberg limits	Liquid limit (L.L)%	32	---
	Plastic limit (P.L)%	23	---
	Plasticity index (P.I)%	10	---
Blow count	First 150 mm	8/15	8/15
	Second 150 mm	13/15	10/15
	Third 150 mm	42/15	14/15
Field unit weight, (γ_f) kN/m³		14.8	18.95

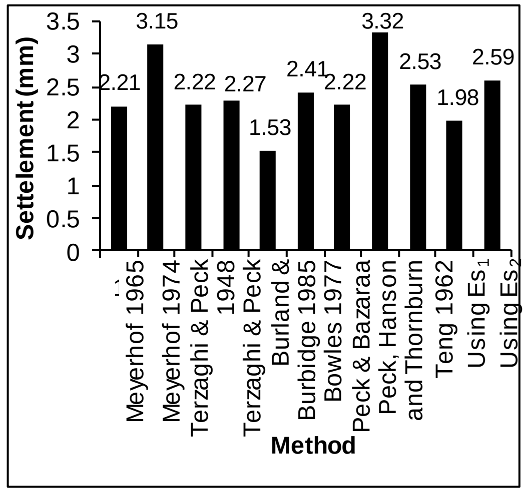

Fig. 5. Results of the Settlement for Al-Dour soil in Dry condition

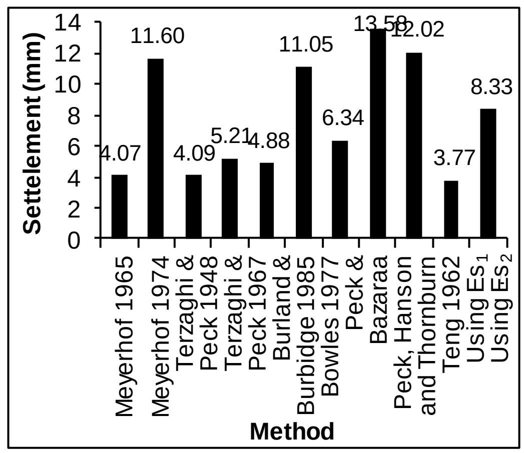

Fig. 6. Results of the Settlement for Al-Dour City soil after soaking with water

Effect of Gypsum Content on the Compressibility

From the test tesults and settlement estimated from different equations a corrllation between the gypsum content and compression index (Cc) was found and shown in Figure (7) where the compression index decreases with gypsum content.

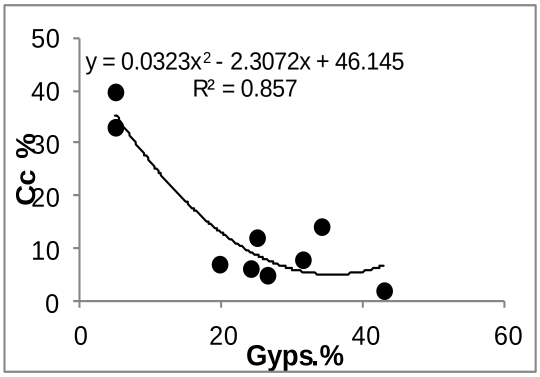

Fig. 7. Correlation between Cc and gypsum content in dry condition

Effect of Gypsum Content on the Collapsibility

Figure (8) shows the results of the collapsibility of the tested soils. The results show that the collapsibility increases with increase of gypsum content

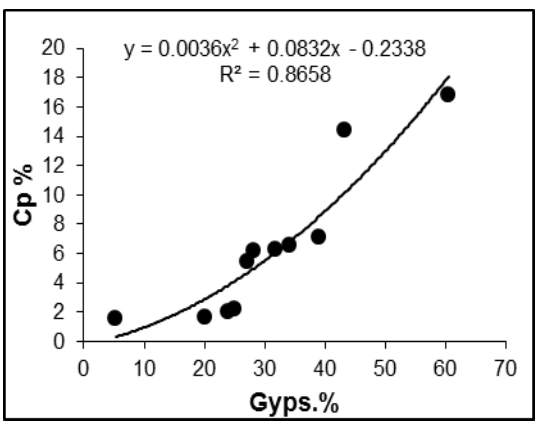

Fig. 8. Correlation between gypsum content and CP%

Conclusions

1- The settlement of gypseous soils in dry condition is less than the same soils have low values of gypsum in there formation.
2-The settlement value of light gypseous soils can be evaluated from the basic equations depending on data of SPT.
3-The standard penetration test is not used in calculating the settlement for the soils that have high gypsum in its formation in soaking condition.
4- If the method that compute the settlement value from field data is old one, the percentage of error will be high ,in addition it was found in many references there is difference in its' formula .Therefore this method does not accredit on its' results.
5-The value of modulus of elasticity for the soils with high gypsum content cannot be found from the unconfined compression test in the laboratory because of the gypseous soils in its' origin are granular soils and don't susceptive for compression. Therefore, the reading of q_c will be very high without access deformation.

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