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BEHAVIOR OF SQUARE FOOTING RESTING ON GYPSEOUS SOIL AND SURROUNDED BY A SHEET PILE WALL

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Abstract

Laboratory model is used in this study to investigate the behavior of centrally loaded square footing resting on gypseous soil, and surrounded by a sheet pile wall at a distance of 2B from the footing edge and extend in depth to 2B as well. During this study the soil were subjected to ten cycles of saturation and drainage at one-week interval to simulate heavy rainfalls or floods. It should be noted that the soaking water were added only outside the area surrounded by the sheet pile. Four points were chosen to detect gypsum solubility, three of them below the footing edge at different depths and one outside the sheet pile wall for comparison. It has been found that the dissolved gypsum below the footing is significantly less than the one outside the sheet pile wall. For each cycle of saturation-drainage the gypsum content is found to be reduced by 3 % and 0.8 % for the outsider point and for average of the three points respectively. Settlement during first cycle of saturation – drainage was twice as the second cycle and about four times of the third cycle. However, this first cycle settlement is about 25 % of the settlement of footing where no sheet pile wall is used. To sum up, the sheet pile wall found to be an effective protection to reduce the collapsibility of gypsum soil and to reduce footing settlement.

Keywords:

Collapsible soil,
Square footing,
Gypseous soil,
Gypsum,
Sheef Pile.

1 Introduction

The gypseous soil is unique in its properties in comparison to other non-gypsum soils. The gypseous soil is usually stiff and stable when it is dry but upon wetting, it losses significant part of its strength and sometimes it collapses if it is soaked with water. The gypsum in soil dissolves in water and consequently, there will be cracks, cavitation, settlement and sometimes collapse of the engineering structure.

Gypseous soil can cause many structural and geotechnical problems for engineering structures. Here is a list of examples seen in different locations in Iraq:

1) Formation of empty spaces underneath the foundations known as cavitationCavitation at Tikrit General Hospital at Tikrit city.
2) The collapse of a hotel in Samarra city.
3) Cliff collapse in residential compounds in Al-Qayara refinery – Nineveh Governorate.
4) Cavitation in the State Company for Detergents in Baiji city.
5) Cavitation in production units at Baiji refinery, Baiji city.

Gypsum content has significant effect on soil properties such as compaction characteristics, soil plasticity, compressibility, and shear strength. Al-Ani [1] concluded that the maximum dry density and the optimum moisture content decrease with the increase in gypsum content. While Al-Dilaimy [2] reported that the addition of gypsum up to 5 % causes an increase in both the maximum dry density and the optimum moisture content. He also found that the higher the gypsum content the higher the liquid limit the lower the plasticity index.

Zakaria [3] observed that the permeability at the beginning of leaching stage is relatively high, then it reaches a steady state condition due to enlargement of voids at the beginning of leaching. This

permeability is reduced upon loading due to the collapse of soil structure under applied pressure. Al-Jumaily et al. [4] showed that the soil shearing strength increases as the percentage of gypsum increases up to a certain level beyond that a drop in shearing strength has been observed. Al-Busoda [5] concluded that the gypseous soil exhibits significant reduction in cohesion upon leaching, while the angle of the internal friction remains approximately constant. The soil becomes more compressible when subjected to leaching, while it is relatively hard when it is dry. Similar results were observed by Al-Neami [6]. The formation of cavities due to leaching of gypsum from regions surrounding the water ways represent major problem. These cavities if not filled by some other soils they become larger until sudden collapse take place. So, special considerations must be taken when dealing with cavitation possibility like gypseous soil [7].

Several studies have sought the improvement of gypseous soils using different methods such as additives, washing or grouting. However, very few studies tackled the problem by isolating the gypseous soil from its main weakness (i.e. wetting). Hence, in this study, a sheet pile wall is used to protect the gypseous soil that carries a square footing. The sheet pile works as a barrier prevents the water from reaching the soil directly underneath the footing. It should be mentioned that it is possible that water can reach the soil below the footing by capillary, but the existence of the sheet pile will make longer water path. Consequently, the water will have relatively high gypsum concentration by the time of reaching the soil under the footing. In this case, this will considerably reduce the dissolution process.

2 Test set up

2.1 Test equipment

The loading equipment consists of a thick wall box-like steel container 1.0 m × 1.0 m × 0.8 m opened from the top as shown in Fig. 1. A steel loading frame is used to apply central loading on a square footing. The container is almost filled with gypseous soil in form of layers maintaining field density. Dial gauges and strain gauges were used to measure applied load and settlement respectively. The footing is surrounded by a sheet pile wall at a distance of 2B from the footing edge and extend in depth to 2B as well. The water was added using inlet valve and allowed to infiltrate outside the sheet pile. Four points P_1, P_2, P_3, and P_4 are chosen to test the gypsum content, see Fig. 1.

2.2 Footing model

Square footing with dimensions of 100 mm x 100 mm was used. The footing is made of iron metal with thickness of 12.5 mm. The load is transfer to the footing by use of loading arm. The settlement of soil under footing was computed through deformation dial gauge.

2.3 Sheet pile model

A sheet pile wall made of stainless steel forming a square cross section 0.5 m x 0.5 m and height of 0.4 m was inserted in the soil surrounding the footing model. It should be mentioned that only 0.2 m of its depth were inserted in the soil, the remaining height is kept above the soil working as a barrier for the soaking water, see Fig. 1. As mentioned earlier, a distance of 2B is kept between the footing edges and the sheet pile.

It should be noted that there are constraints on the results due to the scale and boundary effects.

3 Material used

3.1 Soil

The natural gypseous soil was taken from the city of Tikrit in the governorate of Salah Al-Dean from the site of the University of Tikrit at a depth of 3 m below the natural ground surface after the top layer of soil was removed. The physical tests include the specific gravity, Atterberg limits, particle size analysis, field and maximum unit weight are shown in Table 1. The chemical tests results shown in Table 2 are conducted in the laboratories of the Department of Chemical Engineering at Tikrit

University. These tests include: gypsum content and the percentage of other dissolved salts. Gypsum content was computed by using [8] method according to the following relationship:

$$x\ CasO_4 2H_2O = \frac{W^1{}_{s,45^0C} - W_d}{W^1{}_{s,45^0C}} \text{ x } \frac{136+18\,\varepsilon}{36} \text{ x } 100\ , \quad (1)$$

where:

$$\varepsilon = \frac{2(W_{s,45^0C} - W_d)}{W^1{}_{s,45^0C} - W_d}\ , \quad (2)$$

where:
$xCasO_4 2H_2O$ - the gypsum content in %,
ε - number of moisturizing water molecules in wet calcium for sulfur particles,
$W_{s,45^0C}$ - weight of soil model after drying for 24 hours in the oven at a temperature of 45 ^{o}C,
$W^1{}_{s,45^0C}$ - weight of the soil model after dissolving in distilled water and drying it in the oven at a temperature of 45 ^{o}C for 24 hours,
W_d - weight of the soil model after drying in the oven for 24 hours at a temperature of 105 ^{o}C.

3.2 Water

The water used for laboratory experiments was taken from the Tigris river pH = 7.8 - 8.2, except for procedure that requires distilled water.

Cohesion of soil *c* and internal friction angle of ϕ was found by using a laboratory direct shear test using undisturbed soil samples extracted according to ASTM Designation: D7015 – 13 [9]. The value of *c* was 8 kPa and the value of ϕ was 32^o.

Table 1: Results of the physical tests.

Properties	Value
Specific gravity	2.673
Liquid limit [(%])	20
Plastic limit [%](%)	Non plastic
Gravel [%](%)	6.5
Sand [%](%)	88.7
Silt and clay [%](%)	4.8
Classification of soil according to (USCS)	SP
Field dry unit weight [(kN/m$^{3]}$)	15.22
Max dry unit weight [(kN/m^3]) using the standard method	19.97
Field moisture content [%](%)	5.72
Optimal moisture content [%](%)	13.38
Coefficient of gradation (C_c)	0.89
The uniformity coefficient (C_u)	5.26

Table 2: Results of chemical tests.

Parameter	Value	Reference
Gypsum content [%](%)	48.22	[8]
Total soluble salts [%](%)	63	[10]
PH	7.3	[11]
Sulfur content (SO_3) [%]%	22.19	[11]
Percentage of organic matter (O.M) [%]%	0.102	[11]
Chloride salts (CL) [(mg/l])	0.07	[10]

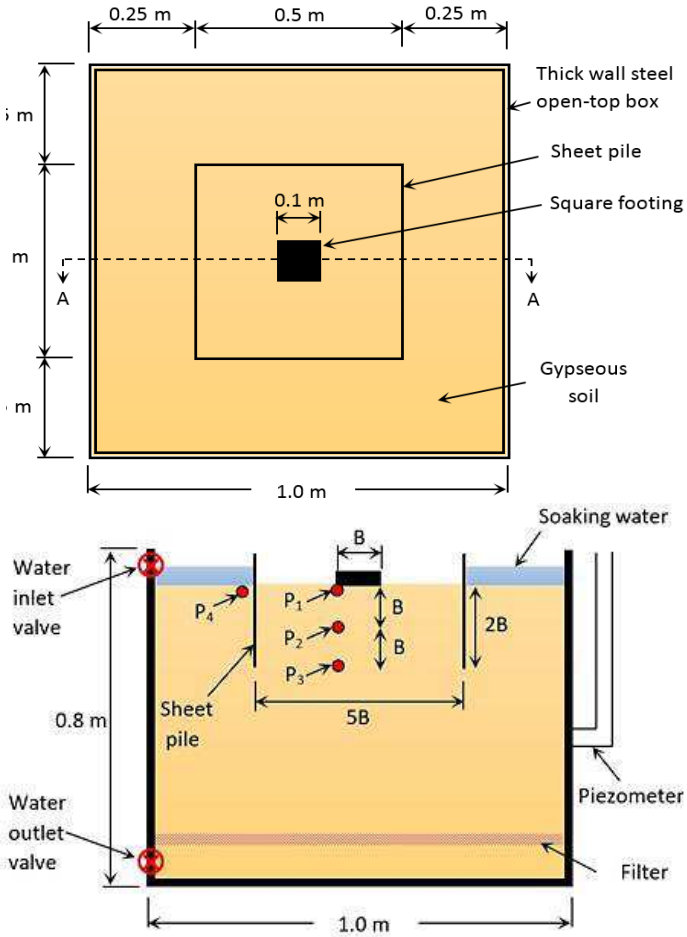


Fig. 1: Schematic drawing for the laboratory set up: top - shows the top view of the set; bottom - shows the cross section A-A illustrated with points P_1, P_2, P_3, and P_4 are the points at which the gypsum content is tested.

4 Test procedure

In the present study, the required tests have been carried out in three stages in order to study the behavior of the footing under vertical loads resting on gypseous soils surrounded by sheet piles. The gypsum ratio is approximately 50 %. The stages of the work are summarized as follows:

4.1 Stage one of three

The soil was placed and compacted inside the box with field unit weight and moisture content in the form of layers, the thickness of each layer is 0.1 m. The sheet pile has not fully driven into soil to prevent water from direct infiltration to the soil under the footing. The footing was placed on soil surface and a stress of 600 kPa [12] was applied taking into account the weight of the arm and the weight carrier. The initial settlement of the footing was measured.

4.2 Stage two of three

Water was added outside the sheet pile wall through a water valve and the soil was saturated for a period of 15 days. The saturation of the soil was observed by a peizometer. During this time, the vertical settlement of the footing is recorded.

4.3 Stage three of three

The water addition is stopped and the valve opened at the bottom of the box to allow water drainage within 7 days. Four samples were taken to measure the percentage of gypsum. The first one is directly at the footing edge, the second is at a depth of B under the footing's edge and the third is at a depth of 2B same line. The fourth sample is taken outside the sheet pile wall at soil surface as

shown in Fig. 1. The samples were taken using a two halves (1-inch) tube, which are inserted into the soil, extract the sample and opened outside. The taken soil sample leaves a cylinderical hole that were refilled with sand to ensure minimum effect on the footing behavior. After the water is drained, the lower valve is closed.

The same steps mentioned in the stages two and three are repeated for ten cycles of saturation and drainage with measuring the amount of settlement of the footing and the percentage of gypsum.

5 Results and discussion

From the data collected from the footing model and the gypsum content during ten cycles of saturation and drainage, the following results was obtained:

5.1 Vertical settlement

The vertical settlement of the footing at stage two of the first cycle was 7.22 mm, which is relatively high. The reason behind this settlement is the dissolving of gypsum and the rearrangement of soil particles under the footing. This value of settlement, i.e. 7.22 mm is found to be about 18 % and 25% from the vertical settlement in the case of submerging the soil under the footing without using sheet piles [13] and [14] respectively. For subsequent cycles of saturation and drainage, the value of the vertical settlement is getting less compared with the corresponding previous cycle. This may due to the residual moisture content for the soil under the footing because 7 days of drainage wouldn't be enough to make the soil dry. So, this would reduce the capillary of fresh water of the subsequent saturation hence reducing the solubility of gypsum. Table 1 and Fig. 2 show the value of vertical settlement for the ten cycles of the saturation and drainage. It is noted that great reduction takes at cycle 2 with respect to cycle 1 (48.1%) and after that the reduction slightly changed.

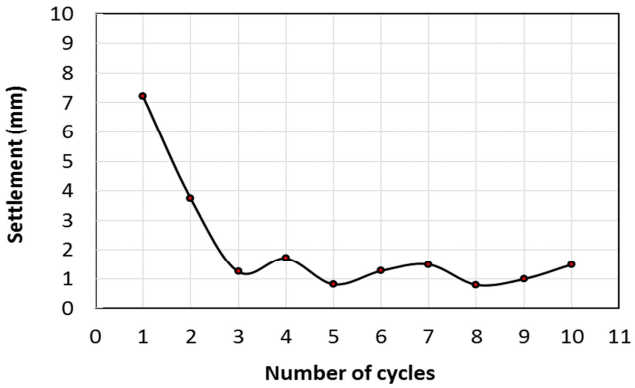


Fig. 2: Relation between the vertical settlement and the number of cycles of saturation and drainage.

5.2 Gypsum dissolution ratio

The ratio of gypsum dissolution is different according to the location where the gypsum content is tested in each cycle of saturating and drainage. There are four points at which the gypsum content was monitored, (see Fig. 1). The first point P_1 is directly at the footing's edge, the second point P_2 is at a depth of B below the first point, the third point is at a depth of 2B under the footing's edge and the fourth point is chosen outside the sheet pile and on the surface of the soil as shown in Fig. 1.

The dissolving ratio of gypsum in the first point P_1 was the least among the four points. The reason is that the water that reaches the soil under the footing may be saturated with gypsum salts during its moving through gypseous soil before reaching the footing. For the second point P_2 which at a depth of B under the footing and inside the box sheet piles, the gypsum content increased initially because of the concentration of gypsum and it is descending from the upper soil with water. Because of drying, gypsum has been concentrated in some locations and the gypsum content gradually began to decrease with the increase of saturating and drainage cycles.

In the third point P_3 which at a depth of 2B below the footing, the increase in the ratio of gypsum is highly obvious as the dissolving of gypsum salts in the soil and descending with the movement of water during the drainage cycle and it concentrated in the bottom layers of soil.

In the fourth point P_4 which is outside the sheet pile and on the surface of the soil, the ratio of gypsum dissolving has also been clear. This is because of the water that reaches directly into the soil

which is not saturated with gypsum and this leads to dissolve the gypsum by water and descending it to the lower layers of soil. The variation of gypsum content with number of cycles for the four points are shown in Table 3 and Fig. 3.

Table 3: Gypsum content at four points for the ten cycles of saturating and drainage.

No. of cycles	Gypsum content			
	Point 1 (P_1)	Point 2 (P_2)	Point 3 (P_3)	Point 4 (P_4)
1	45.16	48.66	49.35	39.85
2	44.82	47.96	48.91	37.80
3	44.12	45.0	48.70	34.92
4	42.90	45.20	48.70	30.51
5	42.81	43.20	46.12	25.60
6	42.31	41.0	45.20	21.60
7	42.30	40.16	44.0	19.05
8	41.0	40.0	44.o	17.0
9	40.54	40.0	43.37	16.20
10	39.0	40.0	42.0	14.0

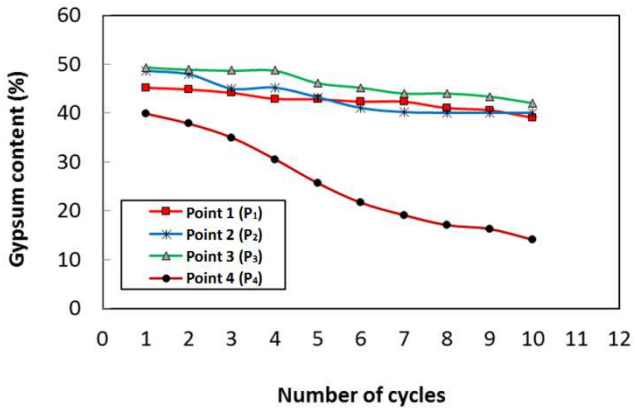


Fig. 3: Variation of gypsum content with the number of cycles of saturation and drainage.

6 Conclusions

From the model tests on the soil during ten cycles of saturation and drainage. It has been found that the dissolved gypsum below the footing is significantly less than the one outside the sheet pile wall. For each cycle of saturation-drainage the gypsum content is found to be reduced by 3% and 0.8% for the outsider point and the for average of the three points respectively. Settlement during first cycle of saturation – drainage was twice as the second cycle and about four times of the third cycle. Nevertheless, this first cycle settlement is about 25 % of the settlement of footing with no sheet pile wall. The sheet pile wall found to be an effective protection to reduce the collapsibility of gypsum soil and to reduce footing settlement.

The foundations of old buildings (e.g. building of cultural inhertance) that constructed on gypsum soil can be protected from the risk of dissloved gypsum by inserting a sheet pile wall surronding the whole building. This will reducde the access of water movment to the gypsum in soil under the foundations hence redusing the settlement and maintian soil stability.

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