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SETTLEMENT-TIME BEHAVIOR OF STEEL PILES IN GYPSIFEREOUS SAND - A MODEL PROTOTYPE STUDY

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ABSTRACT: - There are a lot of studies conducted on gypseous soils dealing with the effect of collapsibility on the general behavior of the soil concerning its strength properties, settlement indexes, volume-mass relationship and permeability. To get rid of the bad soil properties then one goes into another subject as dealing with the aspects of soil improvement or replacement and the like. This study is devoted to settlement investigation of a small prototype pile erected into gypsifereous soil, loaded to 70% of its ultimate bearing load, socked for two hours and then leached with water for seven days. In preparing testing soil, well graded sand is mixed with pure gypsum in ratios of gypsum content of 10, 20, 30, 50, 70%. The loading frame is locally manufactured as to apply loads and to record settlement of pile. The results revealed that when gypsum is less than 10% or 20%, settlement recorded is small. The settlement-time curves show a convetional “S” shape in a semi-log scale. Maximum settlement obtained is for gypsum content of 70% and is about 30% of pile diameter. Finally, three additional socking and leaching tests are also conducted by using 5% concentration of CH_3COOH (acid), grade-60 viscosity oil, and kerosene for specimens containing 50% of gypsum. Specimen socked and leached by oil shows very little settlement, while the specimen treated with kerosene shows less settlement as compared with water. The specimen treated with 5% concentration of CH_3COOH shows 50% increase in settlement.
Keywords: Collapsible soil, pile, settlement.

A PREVIEW OF THE PROBLEM

Piles, in general, may be used for the following purposes, 1-to transfer loads through water or soft soil to a suitable bearing stratum, 2-to carry the foundation through the depth of scour to provide safety in the event the soil is eroded away, 3-to anchor down the structures subjected to uplift due to hydrostatic pressure or overturning moment, 4-to resist large horizontal or inclined forces, 5-to compact granular soils (Teng, 1962) [(1)]. A lot of problems arise in choosing the type of foundation. The choice depends very much on the financial support available and many other factors.

The problem of interaction between deep foundation and soil is a very complex one. It is characterized by large variation in the magnitude and distribution of the induced reactive forces which depend on the type and shape of the foundation, on the method of its construction and on the type and consistency of the soil in which it is founded. Therefore, the general solutions of the problem are not available and that the existing practical solutions are based on very simplified assumptions, usually applicable only to a specific set of boundary conditions (Wilun and Starzewski, 1975).[(2)]. The ultimate bearing capacity and settlement of piles in sands depend mainly on the density index of the sand. However, if a pile is driven into sand the density index adjoining the pile is increased by compaction due to soil displacement (except in dense sands, which may be loosened) (Craig, 2004)[(4)].

Gypseous Soils are one of the main problematic soils available in Iraq. It is concentrated in the region extending from north of Baghdad to north of Mousel, but mainly in high concentrations of gypsum content (probably more than 70%) in the discrete of Tikreet and Beiji. Most of them are sandy gypseous soils. These soils are very dependable for foundation bearing stress when they are dry. But once water can find its way to these soils very large almost immediate settlement (called collapse) will eventually take place even if there was little or no load at all. There are fortunately, large number of studies that provided us with very good knowledge and comprehensive results about the behavior of gypseous soils, in the sense, of their strength properties. Although some of these studies differ in some conclusions and results between each other, but in totality they agree in the general behavior and their potential collapsibility. If a structure is built over these soils then certainly this structure will suffer great distress, cracks, misalignment problems, and the like, due to the large instantaneous settlement (collapse) that may occur upon wetting of soil. There are, as well, large numbers of studies insuring these facts.

This study is concerned in studying the collapse behavior of a small prototype model of steel pile founded into gypsifereous sand. It is intended to study, in precise, the settlement-time relationship for such piles founded into a gypsum-sand soil mixture when subjected to socking and then to leaching periods. Thereafter, the gypsum-sand soil is changed in the sense of the gypsum content.

MODELING OF SOIL.

There are two alternatives for choosing the soil in the model;

1. To use a natural gypseous-sand soil obtained from several locations in Iraq provided each type obtained of soil consists of same (at least in approximate matter) soil structure and type but with different amount of gypsum content. That is to study the effect of gypsum content of the settlement-time curves for different gypsum contents, but not different soil structures.
2. To prepare our own soil by mixing specified sand with different amounts of gypsum contents. That is to have gypsifereous sands instead of a natural-gypsum-sand soil mixture.

The first choice gives better settlement-time relationships since the soil used is realistic. The soil fabric structure is “somehow” preserved and the only errors in the experiments are the size and test representation approaches. But on the other hand, due to the circumstances of the country, it is rather difficult to circle around in order to have a representative soil samples. Also, searching for such soils and finding the most suitable ones for the study needs lots of laboratory works and much of finance due to transportation expenses. These entire purposes make the first choice nearly impossible to have a go on, leaving the second choice for study and, of coarse, the author must admit that the soil in second choice will not meet the author’s will to have a close-to-reality study as much as possible one can get.

Unfortunately, there is a major difference between the gypsifereous and gypseous soil, that is, the fabric structure of gypseous soil is rather complicated and consists mainly of sands or much of silt grains bounded by what is so called “bridges” of gypsum working as “connectors. Upon wetting, those bridges or connectors would suddenly and eventually break down due to dissolution to cause a total collapse of the soil structure. On the other hand, the gypsifereous soil consists of natural soil mixed with powder of gypsum. There are no connectors, only soil (sand) grains and powder of gypsum filling the pore space in between. Now if this soil is wetted or leached, the gypsum starts to dissolve into the fresh pore water thus increasing the voids between interparticle-spacing, triggering the sand particles to move closer gradually or suddenly depending on the sand structure of packing. This phenomenon will cause settlement. As can be seen that the two types of soils (gypseous and gypsifereous sands) have two different mechanisms of behavior and gypsifereous sands is thus by far does not simulate the actual field conditions whereas the gypseous sands are more realistic and do represent the natural behavior of gypseous sands.

In spite of these differences, many researchers kept using the gypsifereous soils instead of using the natural gypseous soils for there are, better control on soil strength properties, difficulties in finding appropriate soils, finance problems, and the like.

How much differences are there in the behavior of the two types of soils? The answer is difficult to be represented by simple words; rather, actual experiments need to be conducted to tell the story!

TESTING AND RESULTS

There are too many possibilities for choosing the figures of the setup, since there are many provisions for the size of it; that is, it should not be large to be not practical and not too small to lose the sense of simulation. The dimensions of the individual parts are as follows, Figure (1) and the photos in Figure (2) illustrate the setup assembled for tests.

Technically, two hard plastic containers are used; the smaller has a diameter of 0.3m and depth of 0.3m, while the bigger has a diameter of 0.5m and depth of 0.45m. In the small container gypsifereous soil is compacted to a dry density of 16 to 17 kN/cu.m (depending on the amount of gypsum content) with molding water content of 5%. The steps for modeling and testing are as follow,

1. A layer of 4cm of dry sand is laid down at bottom of small container. This layer of sand is considered essential for the drainage of the gypsifereous soil during leaching. Drain holes are made through the bottom of the plastic container in order to let water or any liquid to drain out of the container. So no water is perched into the container.
2. The gypsifereous soil is prepared outside the container and mixed thoroughly with 5% of water. A small steel tube (having diameter of 1cm and length of 15cm) representing the prototype pile is placed into the center of the small container. Soil mixture is pored into the container in three layers, each of 9cm and are compacted (while the pile in the middle) using the standard Proctor tamper. Eventually the thickness of the gypsifereous soil is about 25cm.
3. Now, the small plastic container with the gypsifereous soil prepared into it, is placed into the bigger container and both are placed near a large steel table. The steel loading frame is fixed to the steel table and the magnetic holder of dial gauge is attached to the table as well.

4. The loading frame is placed on the steel pile with weights attached on it as to supplement load on pile. The dial gauge is leveled to an initial reading representing the zero point, and readings for settlement are begun to be recorded.
5. Now, water is added carefully to both containers, and the period of soaking (for two hours) and leaching (for one week) are begun. As in the last step, settlement readings are recorded until the settlement of pile is nearly stopped. The big container is provided with drain holes that can be controlled and it is used for soaking and leaching processes. It is worth to mention here that it is better approach to collect the water leached in suitable intervals of time to measure the amount of dissolved gypsum and to measure as well the amount of gypsum content remained in soil after the end of each test. Unfortunately, there were no facilities available in laboratory to carry out such tests.
6. The steps mentioned are repeated for all test procedures.
7. There are socking with fluids other than water, i.e. kerosene, oil, and 5% concentration of CH_3COOH, but the testing procedure is the same elsewhere.

The angle of shearing friction φ obtained using the direct shear box is as follows, please care for Table (1):

Sand alone=33 degrees, (best fit for three tests).

Sand with 50% gypsum=about 29 degrees, tested on dry bases, (best fit for six tests).

The gypsum mixed with the sand is an ordinary commercial powder brought from the local market in Baghdad, while the sand used is “well graded sand-SW” brought out from Al-akheidher/ Kerbala, but contains 3% fines (passing 200 sieve). No Proctor test is conducted, but the soils in container is heavily compacted. It should be stated here that author himself could not figure out why there was too much scattering when testing gypsifereous soil with the direct shear box to get the angle of friction φ although the author himself owns good testing experience. The equipment used (the shear box device) was in a very good condition. Nevertheless, in spite of these drawbacks, the average value of φ for the six tests is used to predict the ultimate bearing load of the prototype pile. Due to the availability of the friction angles in sand and in the gypsifereous soil, and the density of soil, a simple calculation leads to the theoretical ultimate bearing load of pile. The load applied to all piles through testing is believed to be 70% of its ultimate bearing load, and it does not necessary reflect reality of actual field condition but it is so chosen for research purposes. Table (2) shows the test results of five containers, having gypsum contents of 10, 20, 30, 50, and 70%. Figure (3) shows results drawn into a semi-log scale. The results are presented as log time versus S/B%, where S is the settlement and B is the pile width which in this case is 1cm. The curves show an "S" shape similar to the consolidation Casagrande curves, but the situation here is collapse and not dissipation of pore water pressure, so we are talking about two totally different phenomena. It seems that when the gypsum contents are 10 and 20%, the settlement is rather low, but when the gypsum content is higher the settlement becomes rather high. Also, the settlements during socking period of 120 minutes are rather small, but as soon as the leaching begins, the settlement rates increase and eventually after the third day become rather small in rate. These results show directly that piles may suffer of collapsibility problems same as footing founded on sypseous soils. *Thus same precautions must be taken into account when constructing on/into soil containing large amount of gypsum content regardless of type of foundation that is going to be used.*

Table (3) and Figure (4) show the test results of socking and leaching 50% gypsum content soil with kerosene, oil, and 5% concentration of CH_3COOH acid. As can be seen that the "S-shapes" are rather clear. It must be emphasized that there were much problems when dealing with liquids other than water. They are summarized as follows,

1. The test in oil specimen is stopped actually after 9 days. Author considers results obtained out of this test are not indicative. The oil did not penetrate more than 6-7cm of soil. This is so because the test was conducted outdoors, and ambient temperature was between 1 to 12^{o}C, in winter. That means that the viscosity of oil was high. And since the soil was heavily compacted the oil did not preclude to the whole soil in container. That is why results show small settlement records.
2. The test of soil container treated with CH_3COOH acid solution was successful and the results are conclusive. It show that this acid is really effective more than water in causing potential collapse settlement. Thus if an engineering facility is to be built on gypseous soil and the trend is to motivate the soil collapsibility in advance, then one can think of using this method and, ofcorse, taking into account the financial support available.
3. The test with kerosene show less settlement than using water. The preparation and testing by flammable material is quit dangerous and author does not recommend it unless it is done outdoors and special precautions have to be taken. Thus for those who are thinking of using kerosene and oil for soil treatment, the presented results can be used as a reference guide.

COCLUSIONS

1. Modeling soil in laboratory by mixing soil with pure gypsum may give better control on soil parameters than choosing a natural soils with different gypsum contents, in this case soil structure is lost. This is actually a fact and not a result but yet listed for convenience.
2. It is better to make a socking period before leaching as to give time for the water to be absorbed and preclude to soil voids.
3. The two-tank technique used in testing is effective and gives better control of test. And as expected, test results reveal that the higher gypsum content the higher is the collapsibility recorded. The soil mixture with gypsum content less than 20% reveals rather low settlement, collapsibility is more pronounced in soil with gypsum content of 30% and more.
4. The collapsibility of 70% gypsum content soil show more the 0.3 S/B strain. This strain is considered very high and pile constructed in gypseous soil will eventually suffer same problems as footing founded in such soils.
5. When using CH_3COOH acid solution instead of water, the S/B value increases by more than 50% with same testing conditions. Thus a closed door may be opened as to use cheap solution of acids in absorbing soil collapsibility in advance.
6. Oil cannot be used as a treatment agent for soil containing gypsum, i.e. to separate soil from surrounding water. The low permeability of soil may prevent the oil from penetrating voids in soil.
7. Kerosene may give less S/B values of settlement than using water. On the other hand, conducting such like tests need special precautions to be takes into account.
8. Deep foundation as well as shallow foundation in gypseous soil may both suffer same collapse problems.

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Table (1): Results of shear box tests conducted on pure sand and gypsifereous sand in dry bases.

Applied vertical stress	Alakheidher sand		Sand with 50% of gypsum	
	Max. measured horizontal stress	Angle of shearing resistance Φ	Max. measured horizontal stress	Angle of shearing resistance Φ
50	35	35	31.2	32*
100	65	33	57.7	30*
200	120	31	93.3	25*

Notes:

** Each test is an average of two tests.*

All stresses are measured in kPa.

Table (2): Measured values of collapsibility presented in S/B% – socking and leaching with water for one week.

Time(zero=start of socking)	% Gypsum contents				
	10	20	30	50	70
10 minutes	0	0.5	0.5	1	2
Half an hour	0.5	0.5	1.2	2	2.2
One hour	1	1	2	2.5	2.9
2 hours/ start of leaching.	1	1.5	3	4	5
Three hours	1.2	1.8	4	5	6.3
Four hours	1.2	2	5	6.3	7.7
Five hours	1.3	2	6	8	9.5
Six hours	1.5	2.2	7	9.5	11
Seven hours	1.5	2.2	7.5	11	14
Ten hours	1.7	2.5	8.8	16	22
Fifteen hours	1.8	2.7	9.6	20.5	26.5
One day	2	3	10.3	22.5	28.1

Two days	2	3.5	11	24	29.7
Three days	2.2	3.8	11.3	24.5	30
Four days	2.3	4	11.5	24.6	31
Five days	2.4	4.2	11.7	25	32
Six days	2.4	4.2	12	25.5	32
One week	2.6	4.4	12.1	26.1	33

Table (3): Measured values of collapsibility presented in S/B% – socking and leaching with 5% acid solution of CH_3COOH, kerosene, and oil, for one week- gypsum content = 50% for all.

Time(zero time means start of socking)	Type of liquid used for socking and leaching		
	Solution ofCH_3COOH	kerosene	Oil
10 minutes	1	0.5	0
Half an hour	3.5	1	0
One hour	6.5	1.7	0
2 hours/ start of leaching.	11.3	3.2	0.5
Three hours	17.1	4.2	0.5
four hours	22.2	5.5	0.5
Five hours	25.1	6	0.6
Six hours	26.6	6	0.6
Seven hours	28	6	0.8
Ten hours	31	10	1
Fifteen hours	31	12	1.2
One day	35	15.2	1.4
Two days	36.5	18	1.8
Three days	36.5	18.5	2
Four days	37	19	2
Five days	37	19	2.1
Six days	38	20	2.2
One week	40	20	2.2

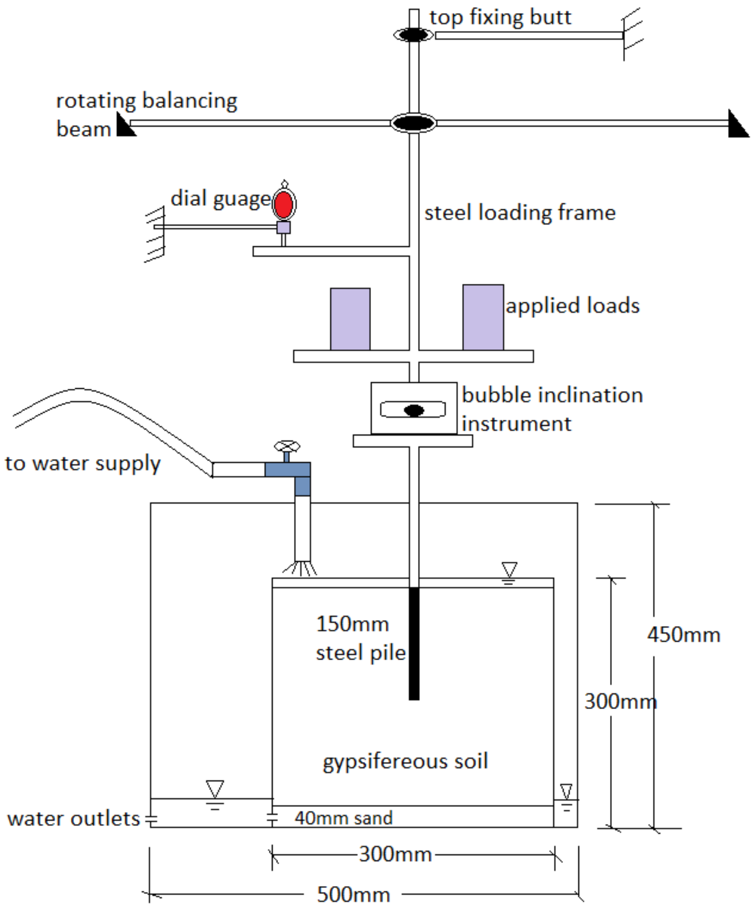

Figure (1): Representative drawing showing testing assembly and loading frame.

Figure (2-a): Photos showing footing assembly.

Figure (2-b): Photos showing footing assembly

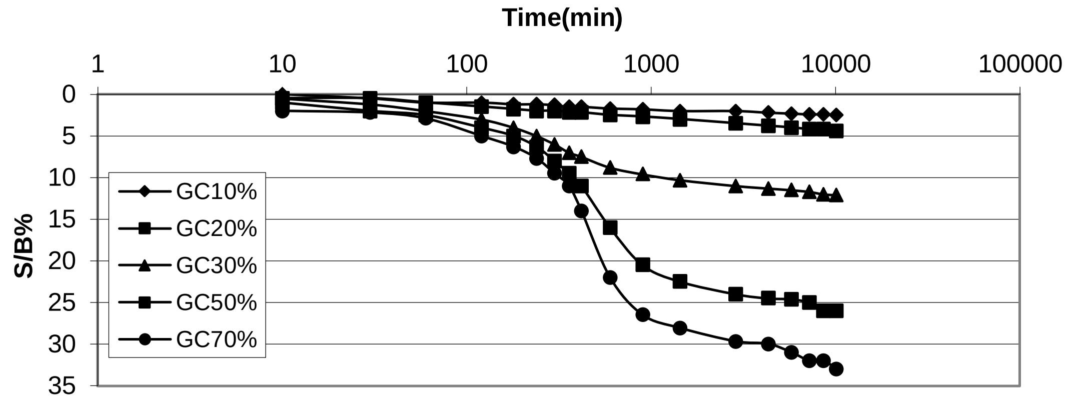

Figure (3): Relationship between time and S/B% for different gypsum contents

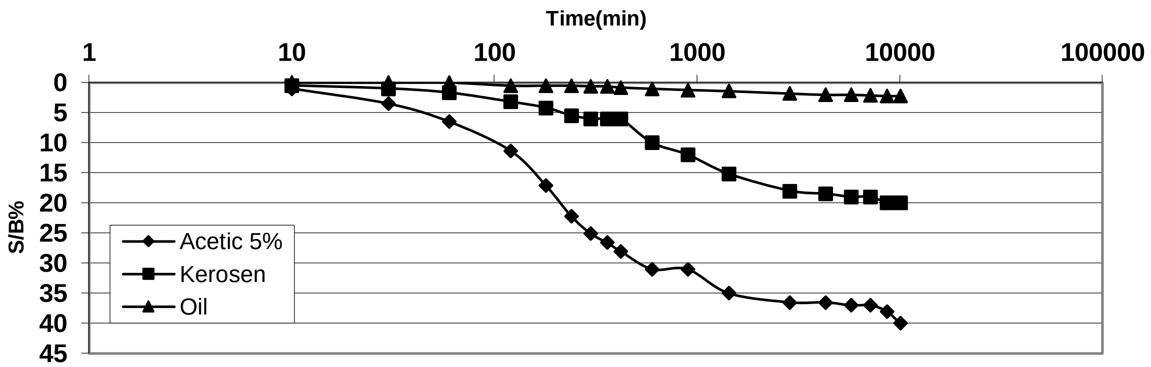

Figure (4): Relationship between time and S/B% for different leaching liquids

دراسة سلوك الهبوط مع الزمن للركائز الحديدية المثبتة بالتربة الرملية الجبسية-دراسة بموديل رياضي

وعد عبدالستار زكريا

مدرس

كلية الهندسة/ جامعة ديالى/ العراق

الخلاصة

توجد العديد من الدراسات التي تم إجراءها على التربة الجبسية والتي تتعامل مع تأثير الانهيارية على التصرف العام للتربة من حيث خصائص القوة ومعاملات الهطول والعلاقة بين الكتلة والحجم وأخيرا النفاذية. ولغرض التخلص من خصائص التربة الغير مرغوب فيها فيكون على الباحث الدخول في موضوع مفاهيم وطرق تحسين خصائص التربة الضعيفة أو طرق استبدال هذه الترب. إن هذا البحث مخصص لدراسة علاقة هطول- زمن لنموذج مصغر للركائز الحديدية تم إنشاءه في تربة جبسية ذات خصائص معدة سلفا ومن ثم تحميل هذه الركيزة المصغرة إلى 70% من طاقة تحملها الأقصى والمحسوب نسبة الى خصائص التربة المفحوصة سلفا. بعد هذه العملية يتم غمر النموذج ألمختبري مع التربة الجبسية لمدة ساعتين ومن ثم غسل النموذج لمدة أسبوع. في عملية تحضير التربة لغرض الفحص تم استخدام رمل من نوع SW ومزجه مع الجبس بنسب 10, 20, 30, 50, 70%. إن جهاز التحميل مع ملحقاته تم تصنيعه محليا لكي يمكن استخدامه لغرض تسليط أي حمل وبنفس الوقت تسجيل الانفعال الحاصل للركيزة مع الزمن. أثبتت التجارب المختبرية إنه عندما تكون نسبة الجبس في الرمل اقل من 10 أو 20% فأن الهطول المسجل بشكل عام قليل. إن الشكل العام للعلاقة بين الهطول ولوغاريتم الزمن هو حرف S التقليدي. أعلى نسبة هطول مسجلة هي لنسبة جبس 70% وكانت حوالي 30% قطر الركيزة. وفي البحث أيضا تم غمر وغسل ثلاثة نماذج مختبرية بالخل بتركيز 5% والكيروسين وزيت المركبات. أثبتت النتائج المسجلة أن النموذج المختبري المعامل بمحلول الخل يعطي انهياريه 50% أكبر مما في حالة الماء. أما الغسل بالكيروسين فأعطى نتائج أقل من الماء. الهطول المسجل في حالة الزيت كان الاقل.