Shear Strength of Gypseous Soil under Soaking Conditions

W A Zakaria
University of Diyala, Engineering College, Transportation and Airports Department, Diyala, Iraq.
Email: waadzakariya@yahoo.com

Abstract. Gypseous soil has far been considered one of the metastable soils as it experiences good strength parameters when dry, but upon indentation under goes a sudden-radical decrease in volume, or collapse potential. This will result in great distress in engineering facilities resting on it. This type of soil exists in many regions in world including Iraq, and problems associated with dealing with soil, in general, are numerous in this country. This soil, in its totality, is sandy type, as such its main dominating strength parameter is the friction angle and in special circumstances the apparent cohesion, which may exist. This research is concerned in studying the change in shear strength before and after soaking for gypseous soil. An extensive work is carried out to locate gypseous soil locations in Iraq from available site investigation reports. As such, twelve samples are brought from twelve different locations in Iraq as to be investigated. Test results reveal that there is much data scattering between the soaked and non-soaked angle of friction from one side against the collapsibility and gypsum content for the other side, and the relationship is inversely proportional. There is a decrease of 2-3 degrees in the friction angle as the soil is soaked for 24 hours. The Procter maximum dry density and the specific gravity of soil is inversely proportional to the collapse potential and the data scattering is low. The sieve analysis for the twelve soil samples are sandy in nature.

Keywords. shear strength, angle of friction, gypseous soil, collapse potential.

1. Introduction
Shear strength of soil is a corner stone in foundation engineering, the total capability of soil in its bearing capacity or collapse resistance is based on soil friction and cohesion. The gypseous soil, in general, a sandy soil type in nature since it is formed in arid areas [1], on the other hand Houston, et al [2] confirmed that collapsing soil is not confined to arid zones and have been detected in most parts of the world. This soil is known to experience high strength properties when dry and loses its strength when wetted, this is associated with high settlement [3,4]. The gypseous soil connections between the soils particles (bonding them together) break down as they dissolve when water precludes through soil [5]. They presented as illustration for the mechanism as shown in Figure 1. Large number of researchers went into improving the engineering characteristics by addition of improving materials [6]. Ibrahim and Zakaria [7] studied dynamic effects on such soils. According to them there are shortcomings in FE modelling of gypseous soil.
The gypseous is named the metastable soil [8]. As such, buildings and engineering facilities resting on such soils suffer great distress especially in Iraq [9,10]. The gypseous soil covers 1.5% of total earth crust [11]. The collapsing soils are not confined to arid areas and have been found in most parts of the world. The conditions on arid environment tend to favour the formation of collapsing soils. Also, almost all naturally occurring collapsing soils are either debris flows deposits, or wind deposits (loess). The severity or danger on gypseous soil is detected by many ways, such as the Knight method [12]. This method was by then standardized by the ASTM. The method does not relate the amount of gypsum present into soil to the degree of danger, but instead it relates the collapse potential to be the axis of measure and as shown in Table 1 [13].

| Collapse severity | The Knight method | The ASTM method (D 5333), 2008 |
|-------------------|-------------------|-------------------------------|
| None              | 0-1               | 0                             |
| Slight            | 0.1-2             |                               |
| Moderate          | 1-5               | 2.1-6                         |
| Trouble           | 5-10              |                               |
| Moderately severe |                   | 6.1-10                        |
| Sever             | 10-20             | >10                           |
| Very severe       | >20               |                               |

2. Shear strength of collapsing soil
Criterion for the failure state of sands. For such soils the cohesion usually is practically zero, c = 0, and the friction angle usually varies from 30 up to 45, depending upon the angularity and the roundness of the particles. Clay soil usually has some cohesion, and a certain friction angle, but usually somewhat smaller than sands [14]. The saturated and dry sand experiences same behaviour regarding its shear strength, in other words they have angle of friction [15]. But the case of gypseous soil is different. The presence of gypsum in soil will change the specific gravity (to be less), the angle of friction, the Proctor density (to be less), and triggers the collapse potential phenomenon, and others. Huat et al [16], conducted shear tests on two types of collapsing soils present in Malaysia, in dry and four days soaking conditions. Their results are shown in Table 2;
Table 2. Shear strength parameters [16].

| Residual soil | Apparent cohesion at natural moisture content (kPa) | Friction angle at natural moisture content (°) | Apparent cohesion at wetted condition (kPa) | Friction angle at wetted condition (°) |
|---------------|--------------------------------------------------|---------------------------------------------|---------------------------------------------|----------------------------------------|
| Granitic      | 58                                              | 21                                          | 15                                          | 15                                     |
| Sedimentary   | 75                                              | 33                                          | 20                                          | 34                                     |

Researchers also stated that there was a significant decrease in shear strength for both types of soils. The cohesion (apparent) had reduced by 74% for both soils. Angle of friction had decreased 29% for one soil and remained almost unchanged for the second.

Alawaji [17] conducted a series of shear tests on collapsing arid soils, he reached the following results;

1- The wetting process induced collapse potential increased logarithmically with the normal stress.
2- The angle of friction decreased slightly whereas cohesion (apparent, if any) significantly decreased upon wetting.
3- the collapse potential increased with dry unit weight.

Abbas and Al-Luhaibi [18], in their laboratory study for improving gypseous soils, that there is a decrease in the angle of friction upon soaking such soil into water. And same thing for Zedan and Abbas [19], upon investigating the field bearing stress of gypseous soil, that there was a drop in angle of friction for two samples in case of soaking, from 260 to 130 for sample1 and from 32 to 23 for sample2. On the other hand, Schanz and Karim [20] showed experimentally, that there was a reduction for 12% to 9.2% upon soaking from 6-24 hours. It is worth to mention here that Mahmood [21] attributed this reduction in friction angle. He stated that upon wetting of the gypseous soil, the apparent cementation by the gypsum is lost gradually with time and there is a decrease in friction angle with increasing soaking duration, and ratio of decrease were 3.83% to 12.68% related to soaking period from 2-4 weeks.

Gaaver [22] on studying the strength properties of Egyptian collapsing soils showed that the bearing capacity of such soils decreased by 50% due to soaking process, he recommended using twice the safety factor stated in different codes. He supported the use of compaction to treat the collapsing soil prior to foundation construction. It is worth to mention here, that collapsing soil is sensitive to the rate of strain, as the case of ordinary soils [23]. They showed that shear strength increased with the increase in rate of strain. There was 100% increase in apparent cohesion for an increase in rate of strain from 0.0375 to 3.75 mm/min while only 42% increase in the friction angle was recorded. Taie and Al-Shakarchi [24] provided Figure 2 for the relation between the angle of friction and the relative density, for soaked and dry Baiji collapsing soil. The friction angle is more or less affected by the relative density.

Figure 2. Relationship between relative density and friction angle, [24].
3. Soils used
In this study twelve totally different gypseous soils are brought from three different locations in Iraq, from places known to contain high amount of gypsum content. The locations for the soils are as follows; (1) five different soils are brought from Tikreet city in salahuldeen governorate, 200km north of Baghdad; (2) four different soils from Al-Anbar governorate, 150km west of Baghdad; (3) and three soils from a place south of Mosul city in northern Iraq. The soils in (1) are designated as B1, B2, O1, O2, and H1. Soils in (2) are designated as W1, W2, S, and Y1. And finally that for (3) are Y2, Y3, and Y4, please care for Table 3. The symbols represent location index for local projects.
All soil samples are taken from depths of at least 0.5m below natural ground surface as the top soil is contaminated with some foreign materials. All soil samples obtained are preserved into big plastic jars while transported to Baghdad. Each soil in jar is then remixed as to have a homogeneous soil. It is worth to mention that it is very difficult (next to impossible) to sample in-situ undisturbed specimens since soil is sandy in nature. The locations for soils to be taken are chosen after a thorough study for soil investigation reports for so many engineering facilities projects. The main aim of guide in choosing the soil in concern is to have gypseous soils that varies with their gypsum content. Soils having low content of gypsum are excluded. The intent is to focus on soils with gypsum content say, 20 to 70%.
For each soil the following tests are conducted with the number of tests carried out. The average values are recorded in case of more than one test is conducted;

Table 3. Number and location of soil samples

| Number of specimens | Location | Designations |
|---------------------|----------|--------------|
| 5                   | Tikreet  | B1, B2, O1, O2, H1 |
| 4                   | Alanbar  | W1, W2, S, Y1 |
| 3                   | Mosel    | Y2, Y3, Y4 |

1- Gypsum content (three tests).
2- Dry sieve analysis (one test)
3- Specific gravity (two tests)
4- Proctor density-moisture relationship (one test)
5- Direct shear box test (two tests for dry basis and two tests for soaked basis)
6- Collapse potential (two tests, the Knight method)

4. Experimental results and discussion
Figure 3 show the grain size distribution for six soils only, as all soils are rather sandy and look similar to each other.
Since the dry unit weight has impact on the angle of friction [24], it is important to neutralize this factor to study the pure effect of gypsum. As such, each soil is tested by the standardized direct shear box after compacting the soil up to its maximum Proctor density, the speed of test was fixed to sandy soil mode and the same testing procedure is followed for dry and soaked tests. In case of soaked samples, specimens are left for one day (soaked) then tested ahead. In these cases, the soaked and non-soaked angles of friction are obtained. The tests are conducted with great care as to get accurate results. Figure 4 shows the relationship between the collapse potential and the gypsum content, the data have good convergence as best fitted to a straight line. As expected, the relationship directly proportional, higher gypsum content means higher collapse potential for soil. The soil chosen to have high range of gypsum content and as such a wide range of collapse potential ranging from about 3 to 10. It is worth to mention that author tried to obtain hardly tried to obtain gypseous soils having higher collapsibility but unfortunately, they were far away and hard to reach.
Figure 3. Grain size distribution curves.

Figure 4. Gypsum content versus collapse potential for all soils.

Figure 5 shows the relationship between the dry and soaked angle of friction against the collapsibility. Figure 6 shows the same relationship but against the gypsum content. It is to be mentioned here that there is much scattering in data in these figures. After many trials author believes that the best fit to be obtained are that show in figures. In all shear strength tests no apparent cohesion is measured. But before discussing the data recorded in these two figures it must be emphasized initially that the origin, location,
geological history of all soils are quite different between each other, thus it must be expected to have much divergence and data scattering since soil angle of friction depends of many geotechnical factors, well known in soil mechanics books. In this study the aim is focused on angle of friction as the gypseous soil is soaked (for 24 hours) and compare that for non-soaked basis. For such reasons scattering in data is to be expected in advance. Now returning to figure 5 again, it can be seen linear best fitting for both the dry and soaked specimens is used. The line concerning the non-soaked samples is above that for soaked ones, in other words, there is a reduction in the friction angle in case of soaking process of the gypseous soil. From figure, it is estimated that this reduction is about 2 degrees, regardless of the data scattering. Also, since the two lines have negative slopes (and almost parallel), the angle of friction is inversely proportional the collapsibility, thus as the collapsibility of the gypseous soil increases, both angles of friction (soaked and non-soaked) tend to decrease. The general trend of behavior for the two lines in figure 6 is similar to those in figure 5. Also, increasing the gypsum content leads to a decrease in both the soaked and non-soaked angles of friction. At low gypsum content the difference between soaked and non-soaked angles of friction is about 3 degrees, as the gypsum content increases to more than 70%, this difference goes to 2 degrees, or in other words, the non-soaked angle of friction is higher than that for soaked in value of 2-3 degrees. From figure 6 it can be concluded that the presence of gypsum plays a negative role in decreasing the friction angle of soil.

![Figure 5. Soaked and non-soaked friction angle versus collapse potential.](image-url)
Figure 6. Soaked and non-soaked friction angle versus gypsum content.

Figure 7 shows the relationship between maximum dry unit weight versus the collapsibility. This test is the standard Proctor compaction test. As mentioned earlier, in each shear test, the soil is compacted to its maximum Proctor unit weight. There is a good convergence and less data scattering. The linear best fitting shows negative slope or the two variables are inversely proportional, the less dry density the higher prone to collapsibility. The previous fact is actually obvious since the bulk density of gypsum is less than that for soil.

Figure 7. Proctor maximum dry unit weight versus collapse potential.

Similar to figure 7, same aspects can be said about figure 8, which shows the maximum dry density versus the gypsum content. This is because the relationship between the collapsibility and the gypsum
content is proportional (please care for figure 4). The data scattering is the same in the two figures 7 and 8. Less value of dry density means the higher gypsum content available in soil and, in turn, the higher collapsibility anticipated in the soil. Author opinion is that dry density is a good indicator for collapsibility problems, as data convergence is promising. For instance, a dry unit weight of less than 16 kN/m3 may trigger a settlement having collapse potential of more than 9 or 10 which is a dangerous value for building facilities.

Figure 8. Proctor maximum dry unit weight versus gypsum content.

As a trend to provide good vision for gypseous soil, figures 9 and 10 are presented and show the relation between the specific gravity versus the collapse potential and the gypsum content in soil respectively. Scattering in data in both figures is rather low as the linear best fitting is doing well. The facts in these figure are obvious as increasing the gypsum content in soil (or the collapsibility) will lead to a lower value for the specific gravity. One can say as well that the specific gravity may also be a good indicator for the metastable soil.

Figure 9. Specific gravity versus collapse potential.
5. Conclusions
An extensive work is carried out initially to locate and collect the most appropriate soil samples that can have different content of gypsum, by reviewing so many soil investigations reports. All soil samples are brought from inside Iraq. Finally, the laboratory tests reveal the following points;

1- The relationship between the soaked and non-soaked angle of friction is inversely proportional to the collapsibility and gypsum content. The data are very much scattered as it is best fitted by a straight line, and because of this scattering in data, the linear fitting is found the best in hand. Scatter of data is common in soil mechanics. Also there is a decrease in the friction angle by a value of 2-3 degrees if the gypseous soil is soaked for one day.

2- The gypsum content is directly proportional to the collapse potential value and the data divergence is low. This is obvious since higher gypsum content leads to higher collapse potential value.

3- The relationship between Proctor maximum dry density versus the collapse potential or gypsum content is linearly-inversely proportional and the data scattering is small. The same is said to the relation between the specific gravity versus collapsibility and gypsum content.

4- Test results reveal that the specific gravity and the Proctor maximum dry density can be considered a good guide to detect the collapsibility of soil.

5- The sieve analysis of all the twelve soil samples reveal their sandy nature and no apparent cohesion was measured in direct shear tests.

References
[1] Nashat, I. H. 1990 Engineering Characteristics of Some Gypseous Soil in Iraq Ph.D. Thesis, Department of Civil Engineering, University of Baghdad.

[2] Houston, S. L., Houston, W. N., Zapata C. E., and Lawrence C. 2001 Geotechnical Engineering Practice for Collapsible Soils Geotechnical and Geological Engineering, Department of Civil and Environmental Engineering Arizona State University, 19, 333-355. USA. doi:10.1007/978-94-015-9775-3_6

[3] Clemence, P. S. and Finbarr, A.O. 1981 Design Considerations for Collapsible Soils Journal of Geotechnical Engineering Division, ASCE, Vol. 107, No. GT3, pp.305-317. doi:10.1016/0148-9062(81)91226-2

[4] Noor, S. T., Hanna, A. and, Mashour, I. 2013 Numerical Modelling of Piles in collapsible Soil subjected to Inundation Int. Journal of Geomechanics, 13(5), doi:10.1061/(asce)gm.1943-5622.0000235
[5] Derbyshire E., Dijkstra T, and Smalley I. J. April – 1994 Genesis and Properties of Collapsible Soils Proc. of the NATO Advanced Research Workshop, Loughborough, the United Kingdom. 11-14, doi:10.1007/978-94-011-0097-7

[6] Karim H. H., Samuel Z. W. and Jassem A. H. 2020 Behaviour of Soft Clayey Soil Improved by Fly Ash and Geogrid Under Cyclic Loading Civil Engineering Journal, Vol.6, No.2 doi:10.2899/cej-2020-03091466

[7] Ibrahim S. K. and Zakaria W. A. 2019 Effect of Vibrating Footing on a Nearby Static-Load Footing Civil Engineering Journal, Vol.5, No.8.

[8] Coduto, D. 1994 Foundation Design, Principles and Practices Prentice Hall, Englewood Cliffs, New Jersey, USA, p.796.

[9] Sirwan, K. and Khorshid, N. 1989 Some Properties of Gypsiferous Soils of Al-Door Proc. of the 5th Scientific Conf. of the Scientific Research Council, Vol.4, No.2.

[10] Hormdee D., Ochiai H., and Yusufku N. 2012 Advanced Direct Shear Testing for Collapsible Soils with Water Content and Matric Suction Measurement ASCE, Geo-Frontiers Congress, doi:10.1061/40785(164)25

[11] FAO 1998 World Reference Base for Soil Resources World Soil Resources Report 87, Rome, Italy.

[12] Knight, K. 1963 The Origin and Occurrence of Collapsing Soil Proc. of the 3th Regional conf. of Africa on Soil Mechanics and Foundation Engineering, Vol.1., pp.127-130.

[13] Al-Lamy, M. T. A. 2008 The Use of Acrylate in Grouting Some Iraqi Gypseous soils Ph.D. Thesis, Building and Construction Department. University of Technology. Iraq.

[14] Verruijt, Arnold 2006 Soil Mechanics Delft University of Technology, USA.

[15] Lambe T. William, and Whitman, Robert V. 1979 Soil Mechanics M.I.T., John Wiley and Sons, Chapter 20, page 295.

[16] Haut B. B. K., Aziz A. A., Ali F. H., and Azmi N. A. 2008 Effect of Wetting on Collapibility and Sheat Strength of Tropical Residual Soils EJGE, University of Putra, Malaysia. Vol.13.

[17] Alawaji, H. A. March – 2001 Shear Induced Collapse Settlement of Arid Soils Geotechnical and Geological Engineering, 19(1), 1-19.

[18] [18] Abbas, Jawdat K. and Ai-Luhaibi, Hameed M. A. 2020 Influence of Iron Furnaces and Slag on Compressibility and Shear Strength of Gypseous Soil Tikrit Journal of Engineering Sciences, 27(1), pp.65-71.

[19] [19] Zedan, Adnan J. and Abbas, Heha H. 2020 Experimental Investigation of Square Footing Resting on Sand over Gypseous Soils Tikrit Journal of Engineering Sciences, 27(1), pp.30-39.

[20] [20] Schanz, Tom and Karim, Hussein H. 2018 Geotechnical Characteristics of Some Iraqi Gypseous Soils MATEC Conf.

[21] [21] Mahmood, Mohammed S. 2017 Effect of Time-Based soaking on Shear Strength Parameters of Sand Soil Applied Research Journal, Vol.3, Issue5, pp.142-149.

[22] [22] Gaaver, Khaled E. 2012 Geotechnical Properties of Egyptian Collapsible Soils Alexandria Engineering Journal, Vol.51, Issue, 3, September-2012, pp-205-210, Elsevier. doi:10.1016/j.aej.2012.05.002

[23] [23] Owololabi, Titilayo, and Ola, Samuel A. 2014 Geotechnical Properties of a tropical Soil in South-Western Nigeria EJGE, Volume 19, Bund. H., University of Technology Akure, Nigeria.

[24] [24] Taie, Abbas J, and Al-Shakarchi, Yousif J. 2017 Shear Strength, Collapsibility and Compressibility Characteristics of Compacted Baiji Dune Soil Journal of Engineering Science and Technology, School of Engineering, Taylor’s University, Vol. 12, No. 3, pp.767-779.