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The Estimation of One-Dimensional Collapse for Highly Gypseous Soils

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ABSTRACT

The presence of gypsum in soils has a notable impact on their engineering properties. Since the gypsum dissolved due to water percolation, their properties may change over time. Collapsibility is considered the most significant parameter ruling the characteristics of highly gypseous soils for several decades; standards have tried to find the best formula for expressing the amount of strain in collapsing soils. Starting from the single and double odometer test, coming to the one-dimensional collapse. In this research 21, highly gypseous soil samples were prepared and tested according to three different standards. For different densities, the results indicate that collapse potential values obtained from the single oedometer method are quite similar to those using the double oedometer test under different conditions. Furthermore, the collapse strain estimated by the one-dimensional collapse test gives different values due to the variety of applied pressure at wetting under different conditions. Also, the amount of gypsum dissolved during the tests indicates that the expression of the quantum of collapsibility of gypseous soils (strain) is more satisfactory than the qualitative declaration adopted by the version of the old method.

1. INTRODUCTION

Gypsum soils are both a problem and a puzzle, which is precisely why they deserve attention. The presence of Gypsum accumulations in soils strongly impacts the physical properties, besides, controls the behavior of the soil. Gypsum is the most abundant sulfate mineral in soils and has been described in arid and semiarid soils around the world. Generally, the Gypseous soil is stiff when it is dry, although, most of this stiffness is lost and becomes more compressible upon wetting due to the dissolution of the cementing gypsum, which causes high softening of the soil which forms more pores and significant loss in strength. A sudden increase in compressibility occurs when these soils are fully or partially saturated accompanied by structure collapse of the soil. This can cause severe damage and even collapse of the structures found on or in such soils [1-4].

Gypseous soils are considered metastable or collapsible soils, and a large number of researchers have estimated the collapse potential for high Gypseous soil using the double oedometer test which was proposed by Jennings & Knight (1957) [4-10]. The collapse potential value is correlated with a qualitative collapse classification as shown in Table 1. This method has then been updated and adopted by the American Society for Testing and Materials (ASTM) and standardized under code number D5333 known as the single oedometer test. Many researchers [11-17] used the single oedometer test ASTM D5333-03 [18] to determine the collapse index, results also indicated a qualitative collapse represented by the degree of collapse shown in Table 2.

It is important to note that the ASTM D5333-03 standard was not updated and was withdrawn in 2012, and the available method for calculating the magnitude of soil collapse is the one-dimensional swell or collapse of ASTM D4546-21[19]. However, most researchers still choose to follow the old, withdrawn test method. No papers are yet found to illustrate the collapse determination by the recent method.

The major purpose of this research is to estimate the collapse of highly gypseous soil using three mentioned different methods and compare the results of the three test methods.

Table 1. Collapse severity (After Jennings & Knight 1957) [13]

Collapse potential, C_p (%)	Collapse Severity
0-1	No problem
1-5	Moderate problem
5-10	Trouble
10-20	Severe trouble
>20	Very Severe trouble

Table 2. Classification of Collapse Index [18]

Collapse index, Ie (%)	Degree of collapse
0	None
0.1-2	Slight
2.1-6	Moderate
6.1-10	Moderately Severe
>20	Severe

2. SOIL AND TESTING PROGRAM

The highly gypseous soil samples were taken from the Tikrit University site, Salah Al-Din Governorate. Disturbed samples are collected between 1 and 1.5 meters below the surface of the natural ground. Soil samples are then placed into nylon bags and were brought to the soil mechanics laboratory for testing. Figure 1 shows the accumulations of gypsum in the used gypseous soil.

Figure 1. Accumulations of gypsum in the used gypseous soil

The particle size distribution test was performed based on method B ASTM D6913-17. According to the unified classification system, the soil can be classified as Poorly graded Sand (SP). The graduation curve can be seen in Figure 2. Also, a compaction test was performed in accordance with ASTM D698-21 as shown in Figure 3, The maximum dry unit weight and the optimum moisture content are shown in Table 3. Specific gravity (Gs) was found using ASTM D854-14 expect using kerosene instead of distilled water in the test. The plasticity index in specimens was calculated using ASTM D4318 - 17. Whereas the minimum and maximum index densities were performed in accordance with the ASTM D4254 – 16 and ASTM D4253 – 16 respectively.

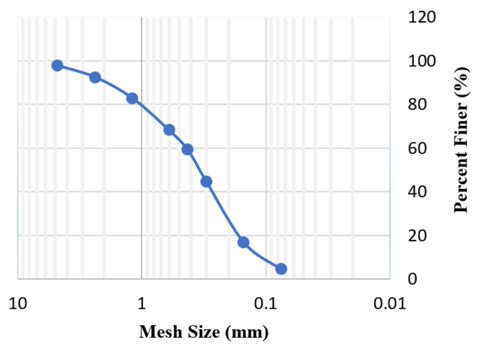

Figure 2. The gradation curve according to ASTM D6913-17, test method B

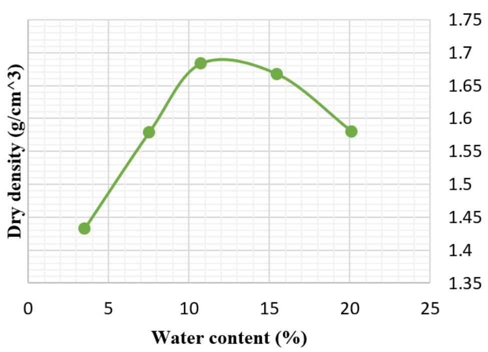

Figure 3. The compaction curve according to ASTM D698-21

The chemical tests were carried out in the Department of Chemical Engineering, College of Engineering, Tikrit University, according to the Earth manual, (1998) and British Standards (BS), (1975). It was found that the gypsum content is 70%. The summary of the physical and chemical soil properties is presented in Table 3.

Table 3. Physical ad chemical properties of the soil

Physical Properties	**Values**
Moisture content (%)	5.2
Specific gravity, Gs	2.4
Minimum unit weight (KN/m^3)	11.77
Maximum unit weight (KN/m^3)	14.05
Liquid limit (L.L) %	26
Plastic limit (P.L) %	NP
Plasticity index (P.I) %	NP
Unified classification system	(SP)
Optimum moisture content % (Standard Procter compaction test)	12
Maximum unit weight (KN/m^3) (Standard Procter compaction test)	16.56
Chemical Properties	**Values**
Gypsum content %	70
Total soluble salt (T.S.S) %	78.11
pH	7.86
Organic Matter (O.M) %	0.10

3. SAMPLES PREPARATION

3.1 Oedometer tests

The test program for the single and double oedometer tests consists of performing a three-test series of the highly Gypseous soil with varying dry densities. Although the one-dimensional collapse test included performing a three-test series with varying stress at wetting and varying dry densities. 21 Soil samples were tested. The procedure for each method is illustrated below.

3.1.1 Double oedometer test

The following procedure is suggested by Jennings & Knight [13] where two soil samples of the highly Gypseous soil are prepared as mentioned above. The first sample is tested in its moisture content by placing the soil sample in the loading device and applying vertical stresses in 25, 50, 100, 200, and 400 kPa increments without adding water to the soil cell. The deformation is recorded every hour before the stress is added. where the second sample is inundated immediately after being placed in the loading device for 24 hours and without applying any load, then the sample is tested by the same method as the dry sample. The stress increments for both samples are 25,50,100,200, and 400 KPa.

3.1.2 Single oedometer test

The test steps are performed according to ASTM D5333-03 [18]. A soil sample is remolded inside the cell ring, after curing, the initial wet mass and the height of the specimen are measured, the specimen is then placed into the loading device and the porous stone is applied to the top and bottom of the specimen ring, seating stress of 5 KPa is applied, and five minutes later, the vertical stresses are applied each hour for increments of 25,50,100,200, and 400 KPa. Dial gauge readings are recorded right before applying any loads, the specimen is inundated at the applied stress of 200 KPa to measure the collapse potential. It is important to point out that the sample is left for 24 hours after inundating with distilled water before adding the 400 KPa pressure.

3.1.3 One dimensional collapse of soils

The procedure is followed in accordance with ASTM D4546-14 [19], test method A is used since the specimens were reconstituted. Four soil samples were prepared and when the specimen is ready for testing, it is placed in the loading device, and seating stress of 1 KPa is applied to the soil specimen represented by the weight of the load plate and the top porous stone. Vertical stresses are applied in increments to achieve various stress levels. The applied stresses for each specimen were 9, 18, 36, 50, 100, 200, 300, 400, and 500 KPa. To prevent specimen dryness, the stress on each specimen is increased in 5-10-minute increments for a total loading interval of no more than one hour. After recording the dial gauge readings that represent the amount of compression, h_1, each specimen is soaked in distilled water for 24 hours, and the wetting-induced collapse is recorded, Δh_2. Knowing that the first specimen was Soaked at the applied vertical stress of 50 KPa, and the second, third, and fourth specimens were Soaked at the applied stresses of 100, 200, and 300 KPa respectively.

4. RESULTS AND DISCUSSIONS

The results of the single oedometer test for different soil states are illustrated in Figure 4. The collapse potential for each specimen of the single oedometer tests was calculated by dividing the deformation induced by the addition of distilled water (i.e. at the applied stress of 200 KPa) over the initial height of the specimen, expressed in percent. The collapse potential for the single oedometer test was compared with the classification of collapsibility index that is shown in Table 2, it's worth knowing that the collapse index is the collapse potential measured at the applied stress of 200 KPa. For soil in a dense state, the degree of collapse is considered moderate. However, the degree of collapse of soil in the loose and medium-dense state is Moderately severe.

It can be noticed that soil in its loosest state has the biggest value of strain, i.e. it compresses more because of the existence of a large number of voids between soil particles, and vice versa for the soil specimen at its densest state. Whereas the behavior of the soil specimen at the medium dense state is intermediate between the loose and dense state.

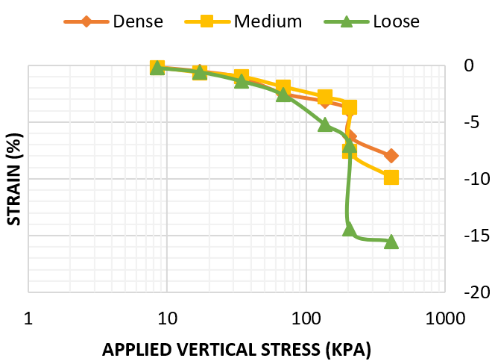

Figure 4. Results for the single oedometer test with different density conditions

Figures 5-7 display the results for the double oedometer test at the dense, medium-dense, and loose states respectively. The collapse potential for the double oedometer tests was determined by subtracting the strain at the applied stress in the soaked specimen from the dry specimen at the same applied stress (200 KPa). The potential of collapse is specified with the values of collapse severity shown in Table 2. Collapse makes no problem in a dense state, but in the medium dense it makes a Moderate problem, whereas it is Trouble in the loose state.

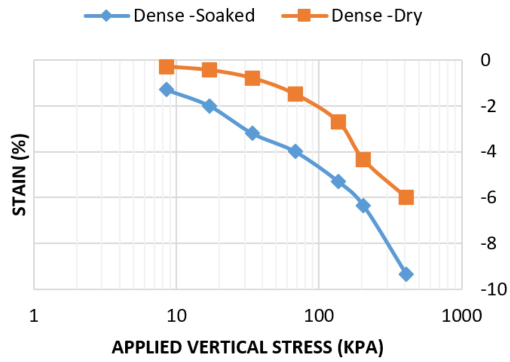

Figure 5. Test result for the double oedometer test at the dense state

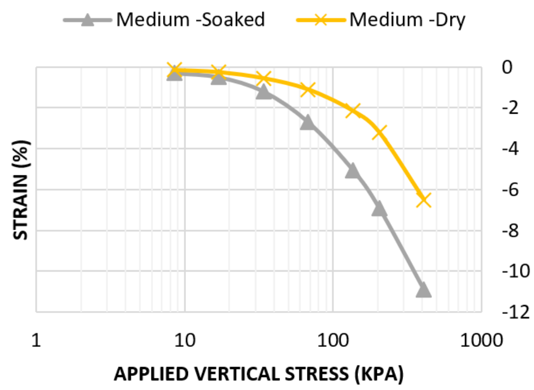

Figure 6. Test result for the double oedometer test at the medium-dense state

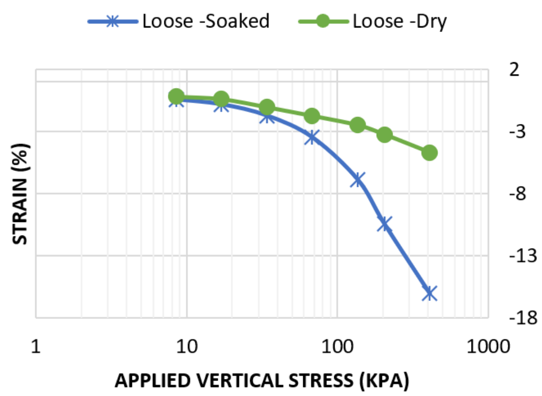

Figure 7. Test result for the double oedometer test at the loose state

The collapse strain Ɛc (%) for the one-dimensional collapse test was calculated as follows:

$$\text{Collapse strain } \varepsilon_c\ (\%) = -100\ \Delta h_2 / h_1 \quad (1)$$

where, h_1=Specimen height immediately prior to wetting; Δh_2=Change in specimen height: Collapse caused by wetting.

As mentioned in the literature, three-test series were conducted using this test method, each series contains 4 samples where the first one is inundated at 50 KPa, and the second, third and fourth samples were inundated at the applied pressure of 100, 200, 300 KPa respectively. Figure 8 shows the test results for the one-dimensional collapse at the loose state.

Figure 9 summarizes the results of the 12 test samples in a brief way, where three curves of the collapse strain (%) versus the applied wetting pressures. it can be seen from this figure for the samples in their dense state the soil tends to collapse the most when the pressure of wetting is 300 KPa. However, the sample at the (100 & 200) KPa wetting pressure has approximately the same value of the collapse strain, while for the pressure of wetting 50 KPa the collapse strain has the minimum value. While the soil at its medium-dense state has a maximum collapse strain at the inundating at the applied pressure of 300KPa, but the collapse strain at the wetting pressure of 100 KPa is larger than the one at the 200KPa. The variation of the collapse strain magnitudes upon different stresses might be attributed to the fact that there is a maximum degree of densification that can be attained, this is caused by the collapse at a certain pressure level.

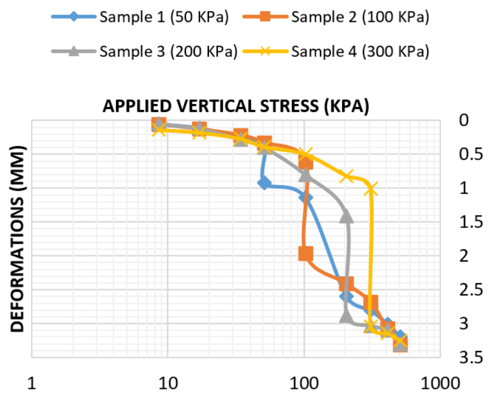

Figure 8. Test results for the one-dimensional collapse at the loose state

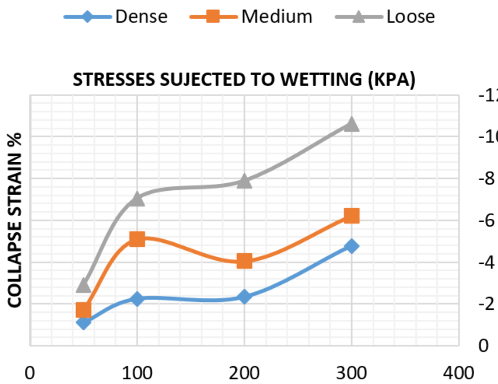

Figure 9. Test results for the one-dimensional collapse test with different density conditions according to different wetting stresses

Nevertheless, the collapse strains in the case of the loose state increase with increasing the pressure at wetting, the values of collapse strain at the loose state are larger than other states. All the available data indicate that the relationship between collapse strain and the applied wetting pressures is predominantly a nonlinear function. Figure 10 demonstrates a comparison of the collapse potential and collapse strain for the three test methods for varying densities.

The values of the collapse potential and collapse strain for the three methods with different conditions of densities are recorded in Table 4, a qualitative collapse potential is obtained when using the single and double oedometer test while using the one-dimensional collapse test a quantitative value of collapse strain is obtained.

Table 4. Test results for the three test methods

State \ Test Method	Single Oedometer test	Double Oedometer test	One Dimensional collapse test			
	Collapse Potential (%) at 200 KPa		Collapse Strain (%) at			
			50 KPa	100 KPa	200 KPa	300 KPa
Dense	Moderate	No problem	-1.10	-2.248	-2.33	-4.78
Medium Dense	Moderately Severe	Moderate problem	-1.7	-5.096	-4.04	-6.21
Loose	Moderately Severe	Trouble	-2.89	-7.05	-7.88	-10.61

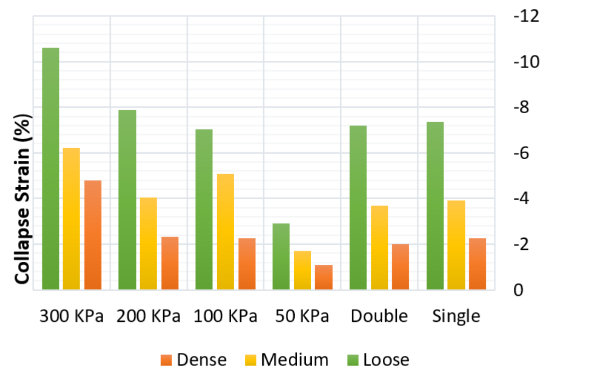

Figure 10. Summary of test results for the three methods

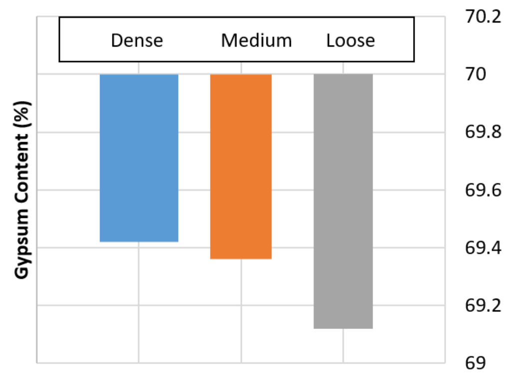

Figure 11. Gypsum content at the end of the single oedometer test

Gypsum content plays an important role in affecting the soil's behavior, especially when it presents in soil with high percentages, one of the reasons behind the variation of highly gypseous soil collapsibility is due to gypsum dissolution. Figure 11 displays the magnitude of the gypsum content at the end of the single oedometer test. The figure indicates that the soil in its loose state dissolved more amount of gypsum during the test, this is due to the fact that this sample has larger voids, thus, during the inundation, these voids are filled with water leading to a larger amount of gypsum to dissolving, as a result of this, collapse potential increased. The soil in a medium dense state dissolved less of gypsum content than the previous one, this is because of having fewer voids, and the same reason for the soil in its dense state which had the least gypsum dissolution.

Further, it was found that the gypsum content at the end of the double oedometer test is the same as in the single oedometer test, the gypsum in the loose sample has dissolved more than the medium dense, and the dense respectively as illustrated in Figure 12.

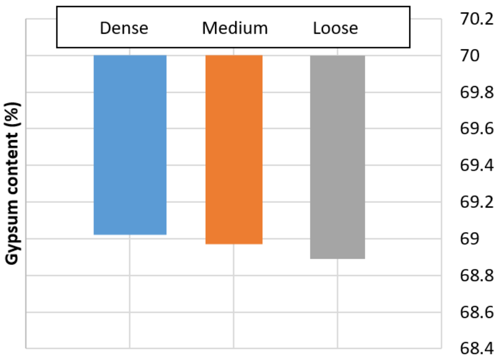

Figure 12. Gypsum content at the end of the double oedometer test

Figure 13 displays the results of gypsum content at the end of one-dimensional collapse tests, For the dense soil samples, maximum gypsum dissolution is when wetting pressure is 50 KPa. This might be explained as the soil under this small stress did not reach the maximum densification, so when it is soaked with water, more particles of gypsum dissolve. Otherwise, the soil sample submerged in 100, 200 KPa dissolved less gypsum because densification becomes better. However, the soil structure of the sample inundated at 300 KPa may break down already prior to inundating causing more new voids, these voids are then filled with water, thus making a larger collapse strain. Same explanation for the loose and medium dense samples except that the soil structure broke down at the applied pressure of 200 KPa as shown in Figure 13.

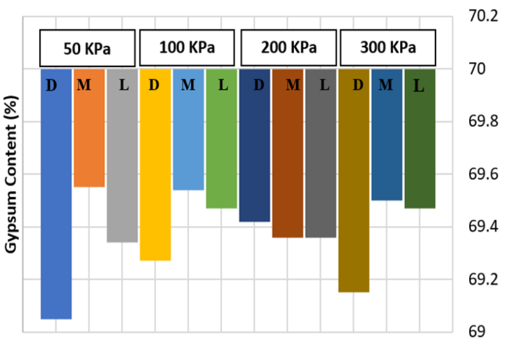

Figure 13. Gypsum content at the end of the one-dimensional collapse test, where D refers to dense, M for medium dense, and L for Loose samples

5. CONCLUSIONS

The results that were carried out in this test indicate that the latest method of estimation collapse (one-dimensional collapse test) provides the best results. The Single and double oedometer tests give a qualitative evaluation of soil collapse potential under vertical stress of 200 kPa, this stress does not represent different foundation pressures or overburden pressures at different depths of a soil profile. Whereas the test method for the one-dimensional collapse of Soils gives various quantitative evaluations of soil collapse under a range of stress values relevant to any project.

The latest test method showed varied results for the collapse strains due to the varying wetting pressure. The variation of the collapse strain magnitudes upon different stresses might be explained by the fact that collapse can cause maximum densification at a particular pressure level. Any additional pressure above this point will, consequently, have a little or opposite effect on the collapse strain.

The gypsum effect has been studied by determining the gypsum content before and after each collapse test. The one-dimensional collapse test method provided variations of collapsibility values for the highly gypseous due to the gypsum dissolution.

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