Evaluation of the Collapse Behavior of Gypseous Soils in Selected Regions of Iraq

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ABSTRACT

Soil collapse occurs when increased moisture causes a chemical or physical bonds between the soil particles to weaken, which allows the structure of the soil to collapse. In Iraq, gypseous soils cover about (20 to 30) % of its total area concentrated primarily on the west desert and extended to the southern parts and directed towards south west. This paper presents the collapse potential of Iraqi unsaturated gypseous soils under various initial conditions such as initial dry density and the initial degree of saturation. Three types of gypseous soils obtained from different parts of Iraq. Laboratory work included a series of single and double oedometer tests to investigate the collapse behavior of these unsaturated soils and the initial conditions that effected on it. It was found that For each soil, the collapse potential decreases with increases of dry unit weight. The increase of initial water content for each soil will decreases the values of collapse potential. The collapse potential increases with increase of the void ratio for each soil. For each soil, the collapse potential decreases when the initial degree of saturations increases.

INTRODUCTION

Gypseous soil is one of the soils which present a risk for structures, especially with high gypsum content, because of the problem of collapse of soil under the footings. In Iraq soils, especially in the north-west and other sparse regions, the gypsum forms high percentage in the soils which is reference of most problems that can happen to the structure built on when these soils are soaked with water.

A collapsible soil is defined as "any unsaturated soil that goes through a radical rearrangement of particles and great loss of volume upon wetting with or without additional loading" (Clemence and Finbar, 1981).

Jennings and Knight (1957), suggested a collapse test to predict collapse settlement for foundation design purposes which they called "Double Oedometer Test (DOT)". Knight (1963) suggested a laboratory test to calculate the collapsibility of soils called "Single Collapse Test (SOT. The Collapse Potential (CP) is defined as:

$$C.P. = \frac{\Delta H_e}{H_o} x\ 100 = \frac{\Delta e}{1+ e_o} x\ 100 \qquad (1)$$

where:
ΔHe = change in height of sample resulting from wetting,
H_o = initial height of the sample,
Δe = change in void ratio of sample resulting from wetting, and
e_o = natural void ratio.

Jennings and Knight (1975) suggested a procedure to describe the collapse potential of a soil which is mostly a qualitative evaluation. This procedure was subsequently modified by Houston et al. (1988) and standardized by the American Society for Testing and Materials (ASTM) under code number ASTM D5333 (2003).

The amount of collapse in gypseous soils depends highly on the void ratio before wetting and on the permeability of the soil. The higher value of void ratio or the permeability cause a larger amount of collapse potential. The (CP) value is also affected by the gypsum content of the soil. In gypseous soils with high gypsum contents and low void ratio, the collapse may be less than for soils with lower gypsum contents but higher void ratio (Al-Mufty, 2004).
Fredlund and Gan (1995) studied the collapse behavior of a compacted soil testing in the laboratory using a modified conventional oedometer and a tensiometer for the measurement of matric suction. The results shown that collapse is a transient and continuous process.

Al-Mufty (2004) presented a method to compute collapse potential for partly saturated gypseous soils. It was found that the collapse would be insignificant at stresses lower than the preconsolidation stress of the saturated soil and the increase in gypsum content or the void ratio increases the collapse.

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Seleam (2006) proposed three equations to predict the collapse potential of any gypseous soil using only basic soil tests without the need for more elaborated tests. These equations can be considered as a rough estimate of the collapsibility of the gypseous soil.

Abid Awn (2010) designed a modified device to measuring the collapsibility of gypseous soil. The results showed high activity in measuring the collapsibility, in addition to the ability to measure the compressibility of such soil at leaching process at the same time.

Ayadat and Hanna (2012) introduced various methods of predicting collapse from simple and rapidly performed index have been suggested by several workers in the field. In his investigation, most of the well-known collapses identifying criteria are reviewed and evaluated.

Nalini and Kommu (2015) studied the influence of variations in compaction dry density, initial water content, inundation stress, and void ratio on the collapse behavior of the soil and determined the collapse behavior of soils under wetting conditions by using oedometer test and control of collapse behavior of soil.

A comparison was made between the collapse potential predicted form laboratory standard collapse test with filed collapse (coefficient of resolving slump) estimated from plate loading test was made by Fattah et al. (2016). The soil site for investigation was in Rumaila, Basrah Governorate. Results of collapse test carried out on two samples showed that the collapse potential, Ic of the two samples is 5.091% and 3.502%, the soil is considered of moderate degree of collapse. The coefficient of average resolving slump for saline soil was calculated from field plate load test to be 0.94% to 1.2%. The difference in boundary conditions between the two approaches was found clear in the evaluation of collapse potential.

The aim of this study is to investigate the collapse potential of unsaturated gypseous soil obtained from different parts of Iraq with different gypsum contents and to study the relationship between collapse potential of these soils with initial conditions such as water content, density, void ratio and degree of saturation.

PROPERTIES OF SOIL USED

Three different soils obtained from various locations in Iraq were used in this work. These types of soil were employed for testing. The chemical and physical properties of these soils are listed in Tables 1 and 2, respectively.

Table 1: Chemical properties of soil.

No.	Location of source	Symbol	Gypsum content, □ %	Sulphate content (SO_3) %
1	Arar city	GA	12	5.58
2	Ain Al-Tamor, Kerbala city	GK	30	13.95
3	Tikrit city	GT	55	25.58

Table 2: Physical properties of soil.

Physical properties	GA	GK	GT
Specific gravity(Gs)	2.6	2.54	2.38
Optimum moisture content %(O.M.C)	15	14	14
Maximum Dry unit weight ($\square_{dry})_{max}$ (kN/m³)	17.82	17.80	16.9
Void ratio (e) at O.M.C	0.436	0.427	0.408
Coefficient of uniformity (Cu)	2.8	5	4
Coefficient of Curvature (Cc)	0.825	1.033	0.681
Soil symbols according to USCS	SP	SW	SP

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OMC: Optimum moisture content.
USCS: Unified Soil Classification System.

Figures 1 to 3 represent the standard compaction (Proctor test) curves of the soils used in the study, the test was done according to ASTM D 698-12. It can be noticed that that the three soils have approximately the same optimum moisture content (14-15)% and close values of the maximum dry unit weight (16.9-17.82) kN/m^3 irrespective of the gypsum content.

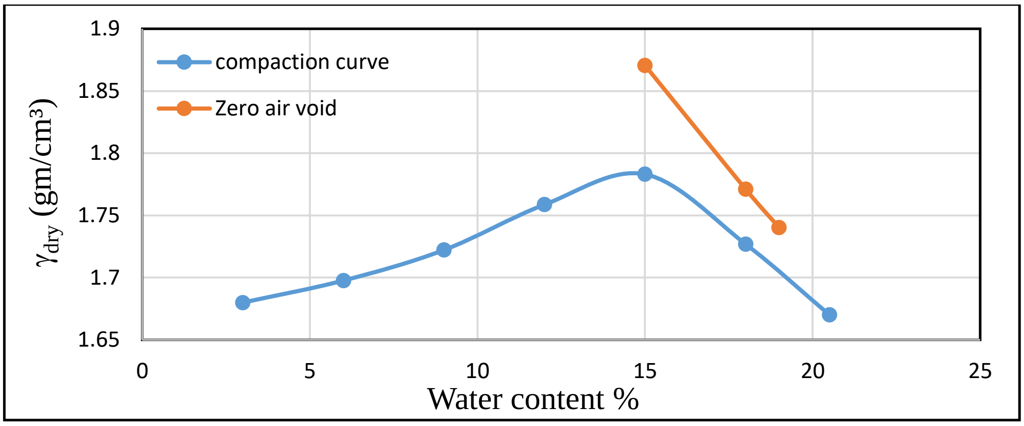

Figure 1: Compaction curve for Arar soil (□=12%).

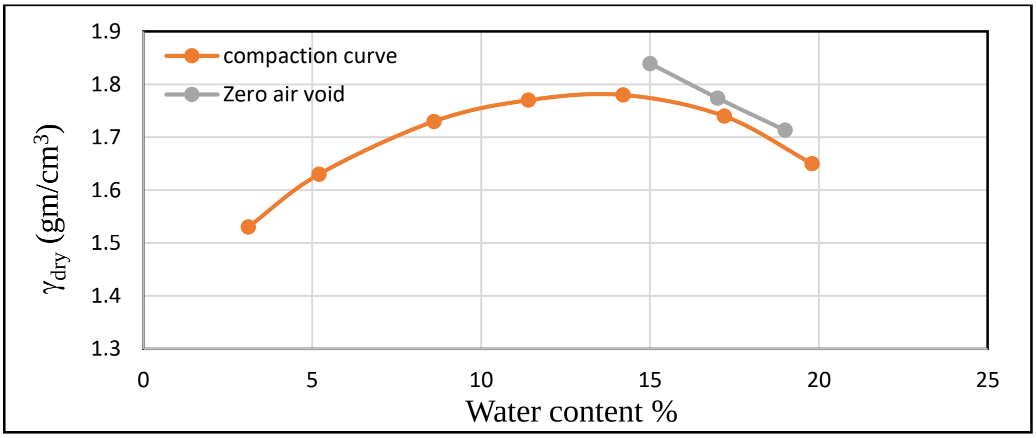

Figure 2: Compaction curve for Kerbala soil (□=30%).

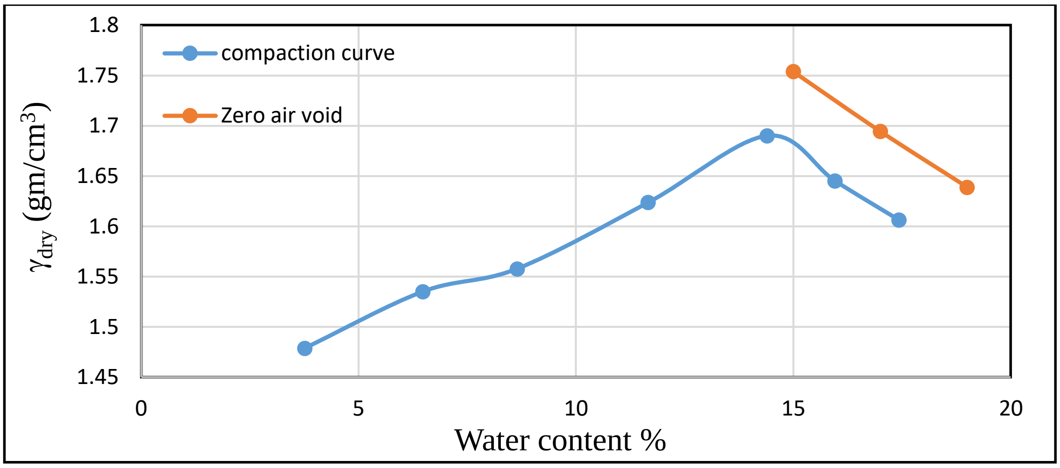

Figure 3: Compaction curve for Tikrit soil (□=55%).

Testing program
Depending on the results of the compaction-curve, three points have been chosen (two from the dry-side and one at the optimum-moisture content) for all types of soil to measure the collapse-potential. The testing program

consisted of single-oedometer and double-oedometer tests on specimens prepared directly in the oedometer rings. Nine soil samples were prepared for single oedometer test, three samples for each soil and 18 samples for double oedometer test performed where water content, dry unit weight and the degree of saturation were varied.

Collapse potential is determined according ASTM D5333-03 by using the conventional oedometer device in a constant temperature and humidity environmental.

Single oedometer test (SOT)
In this test, the soil sample is loaded incrementally at natural condition until the sample reaches a vertical stress of (200 kPa) with load increment ratio (LIR) of 1. Then, the sample is soaked with water for (24 hrs.). The additional settlement is recorded at 200 kPa stress level due to soaking process. Then the test continues by additional loading and unloading as in the conventional consolidation test. The collapse potential (CP) is calculated using equation 1.

Double oedometer test (DOT)
This test can be summarized by using two identical samples, the first sample is tested at its natural water content until the end of the test, while the other sample is soaked at the beginning of the test.

The procedure for testing the two samples was the same as in the conventional consolidation test procedure. The difference between the two curves of (e - log σ_v') represents the soil collapse at any given pressure.

RESULTS AND DISCUSSION

a- Single oedometer test results
Figures 4 to 12 show the results of the single-oedometer test for three types of gypseous soil with different initial values of water content and density. These figures describe the relationship between the vertical stress and void ratio. The summary of the results is given in Table 3.

Table 3: Summary of results for single oedometer tests.

Type of soil	Gypsum content%	Dry unit weight (kN/m^3)	Initial void ratio	Degree of saturation%	C.P.%	Degree of collapse
GA1	12	16.97	0.532	29.32	0.67	Slight
GA2	12	17.6	0.477	54.50	0.44	Slight
GA3	12	18.1	0.436	83.486	0.32	Slight
GK1	30	16.55	0.534	28.54	7.19	Moderately severe
GK2	30	17.55	0.447	56.82	3.02	Moderate
GK3	30	17.80	0.427	83.28	0.97	Slight
GT1	55	15.3	0.555	25.73	5.08	Moderately severe
GT2	55	16.0	0.487	48.87	3.89	Moderate
GT3	55	16.9	0.408	81.66	2.12	Moderate

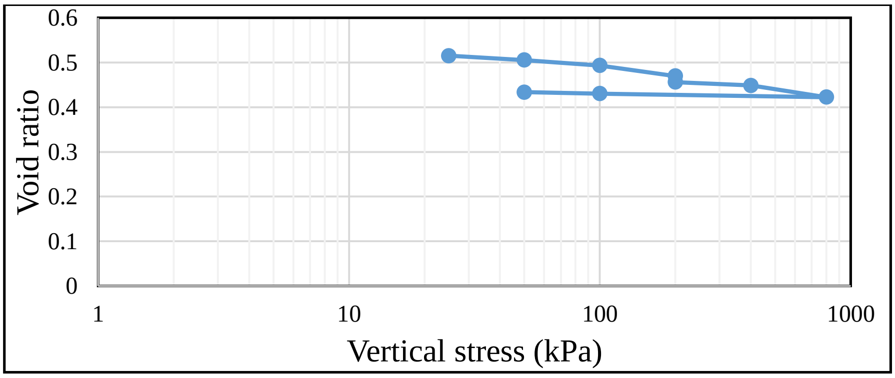

Fig. 4: Variation of void ratio with vertical stress for GA soil prepared at w=6%, γ_{dry}=16.97 kN/m^3 in single oedometer test.

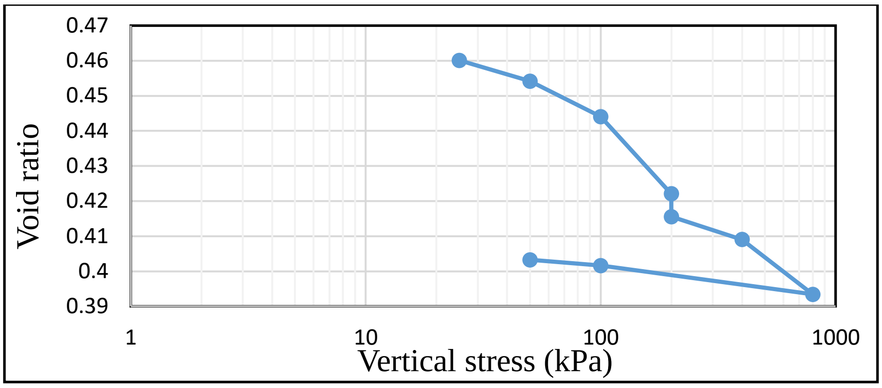

Fig.5: Variation of void ratio with vertical stress for GA soil prepared at w=10 %, γ_{dry}=17.60 kN/m^3 in single oedometer test.

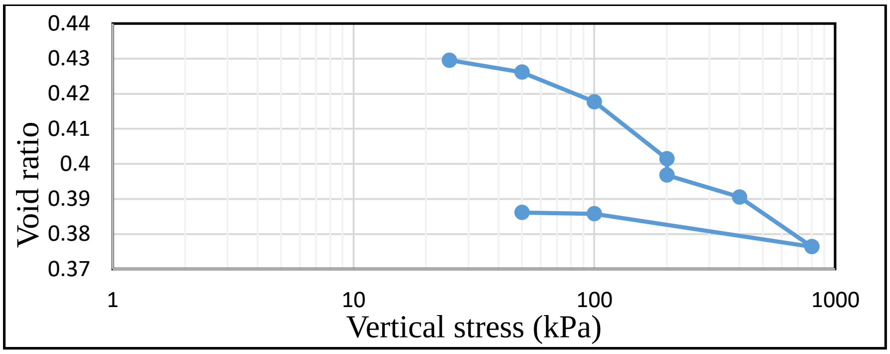

Fig.6: Variation of void ratio with vertical stress for GA soil prepared at w=14 %, γ_{dry}=18.10 kN/m^3 in single oedometer test.

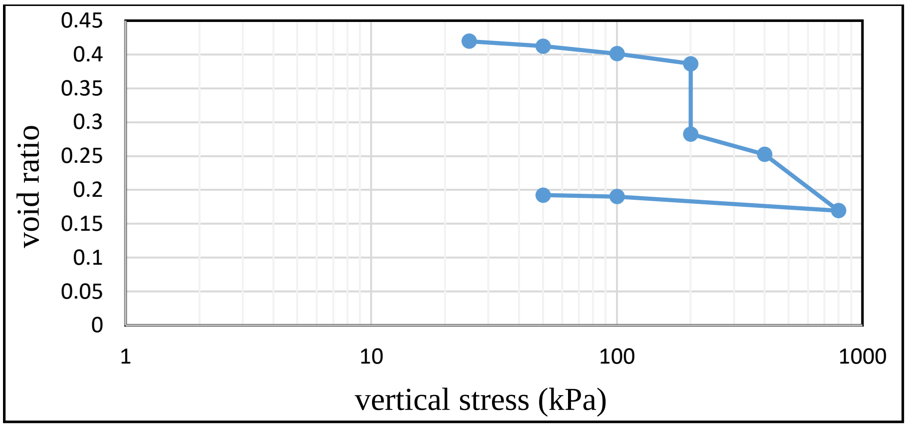

Fig.7: Variation of void ratio with vertical stress for GK soil prepared at w=6 %, γ_{dry}=16.55 kN/m^3 in single oedometer test.

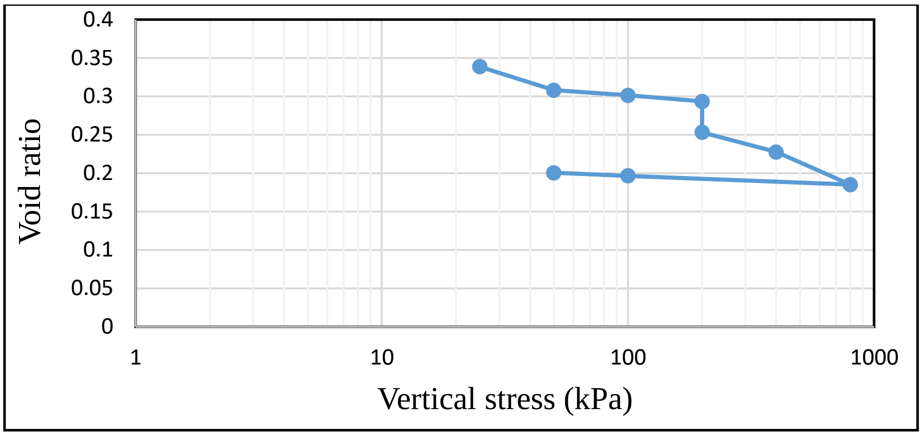

Fig.8: Variation of void ratio with vertical stress for GK soil prepared at w=10 %, γ_{dry}***=17.55 kN/m***^{3} ***in single oedometer test.***

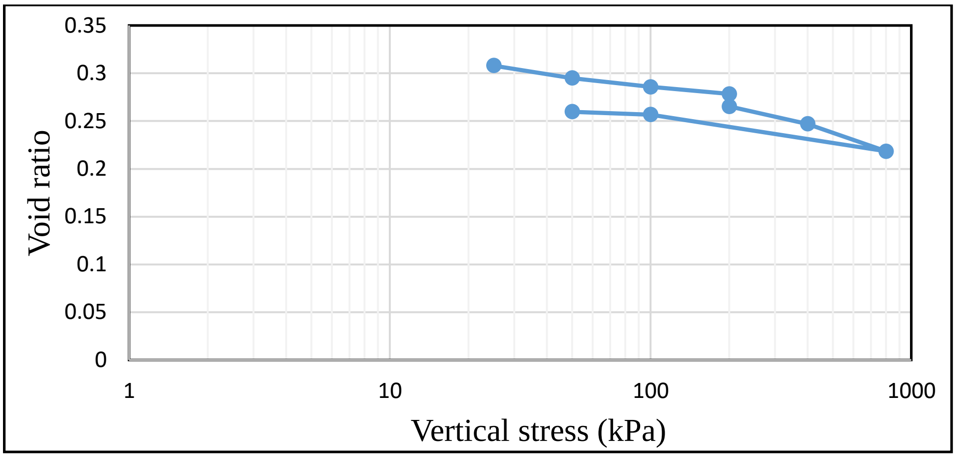

Fig. 9: Variation of void ratio with vertical stress for GK soil prepared at w=14 %, γ_{dry}***=17.80 kN/m***^{3} ***in single oedometer test.***

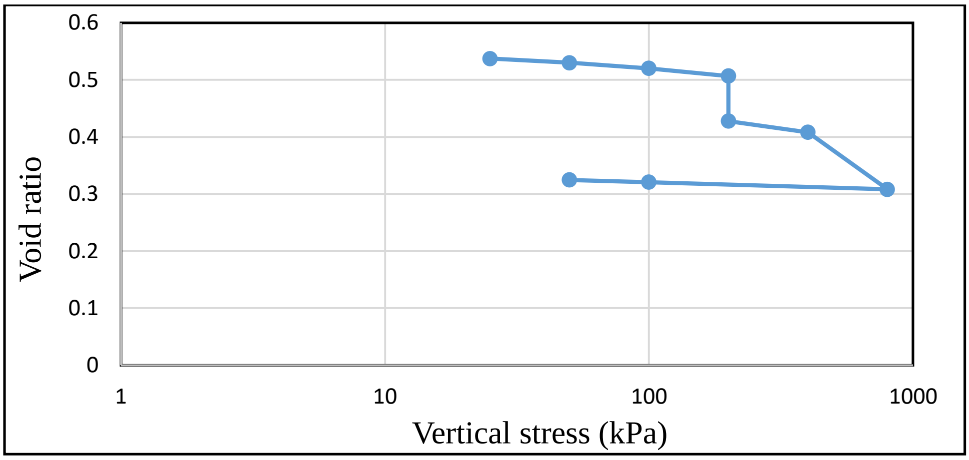

Fig.10: Variation of void ratio with vertical stress for GT soil prepared at w=6 %, γ_{dry}***=15.30 kN/m***^{3} ***in single oedometer test.***

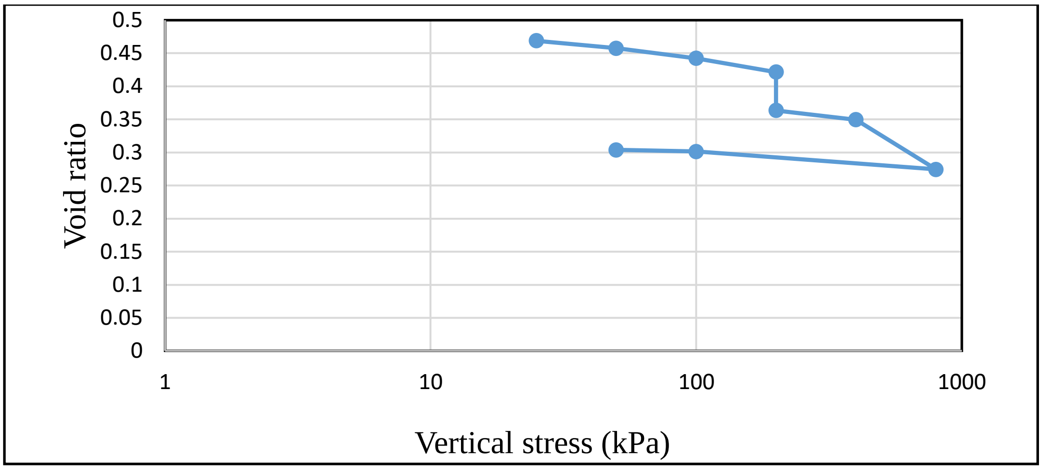

Fig.11: Variation of void ratio with vertical stress for GT soil prepared at w=10 %, γ_{dry}=16.00 kN/m^3 in single oedometer test.

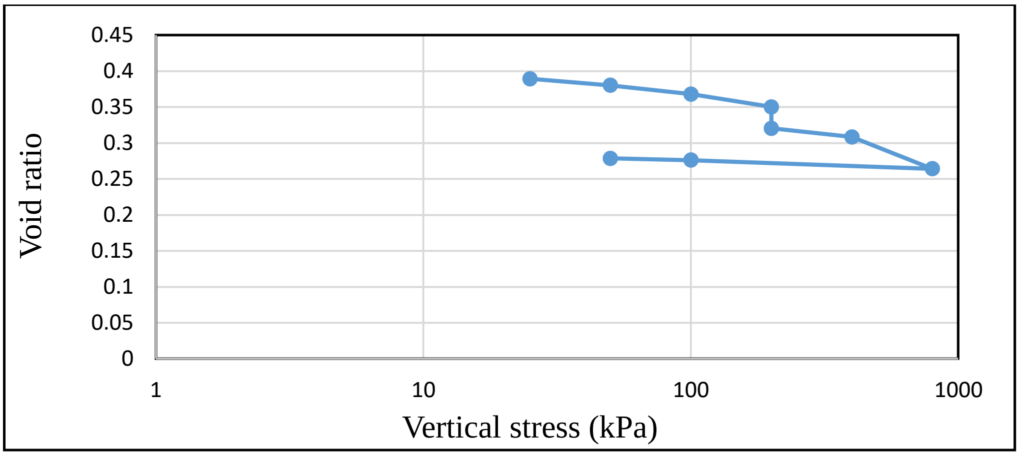

Fig.12: Variation of void ratio with vertical stress for GT soil prepared at w=14 %, γ_{dry}=16.90 kN/m^3 in single oedometer test.

b-Double oedometer test results

Figures 13 to 21 display the relationship between vertical stress and void ratiofor the double-oedometer test for three types of gypseous soil with different initial values of water content and density. Two identical samples of each type of gypseous soil were tested. The first sample was loaded and unloaded at an unsaturated state, while the second was loaded and unloaded at a fully saturated state from the beginning of the test.The summary of the results are given in Table 4.

Table 4: Summary of the results for double oedometer test.

Type of soil	Gypsum content%	Dry unit weight (kN/m^3)	Initial void ratio	Degree of saturation%	C.P.%	Degree of collapse
GA1	12	16.97	0.532	29.32	1.13	Slight
GA2	12	17.6	0.477	54.50	1.55	Slight
GA3	12	18.1	0.436	83.486	0.72	Slight
GK1	30	16.55	0.534	28.54	7.23	Moderately severe
GK2	30	17.55	0.447	56.82	3.01	Moderate
GK3	30	17.80	0.427	83.28	2.85	Moderate
GT1	55	15.3	0.555	25.73	7.25	Moderately severe
GT2	55	16.0	0.487	48.87	3.77	Moderate
GT3	55	16.9	0.408	81.66	0.31	Slight

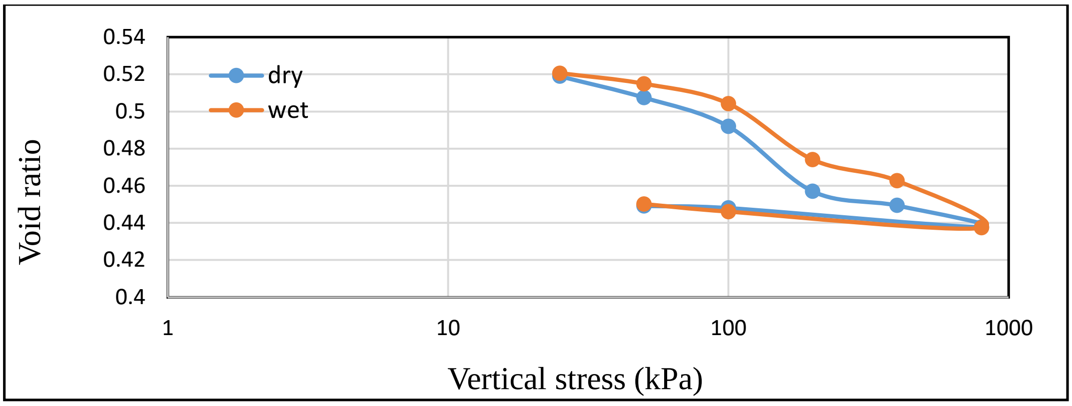

Fig.13: Variation of void ratio with vertical stress for GA soil prepared at w=6 %, γ_{dry}=16.97 kN/m^3 in double oedometer test.

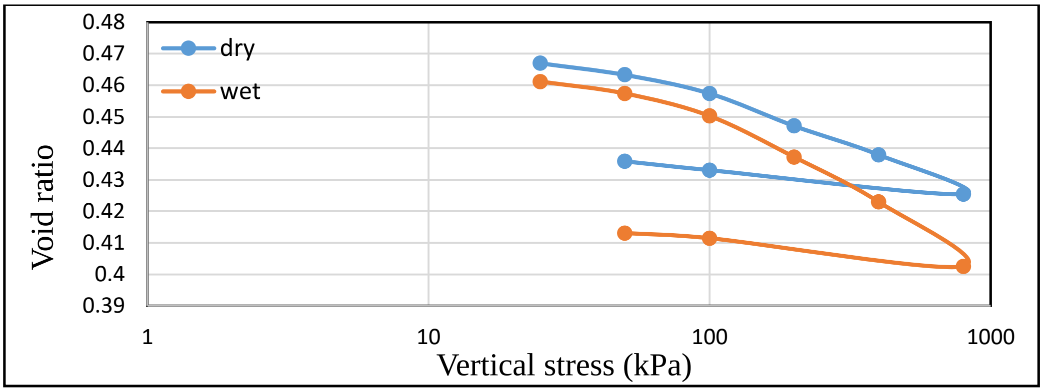

Fig.14: Variation of void ratio with vertical stress for GA soil prepared at w=10 %, γ_{dry}=17.60 kN/m^3 in double oedometer test.

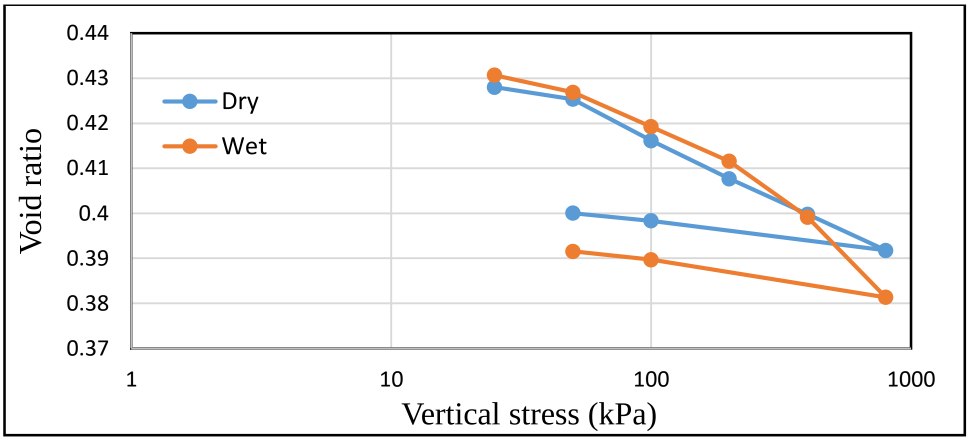

Fig.15: Variation of void ratio with vertical stress for GA soil prepared at w=14 %, γ_{dry}=18.10 kN/m^3 in double oedometer test.

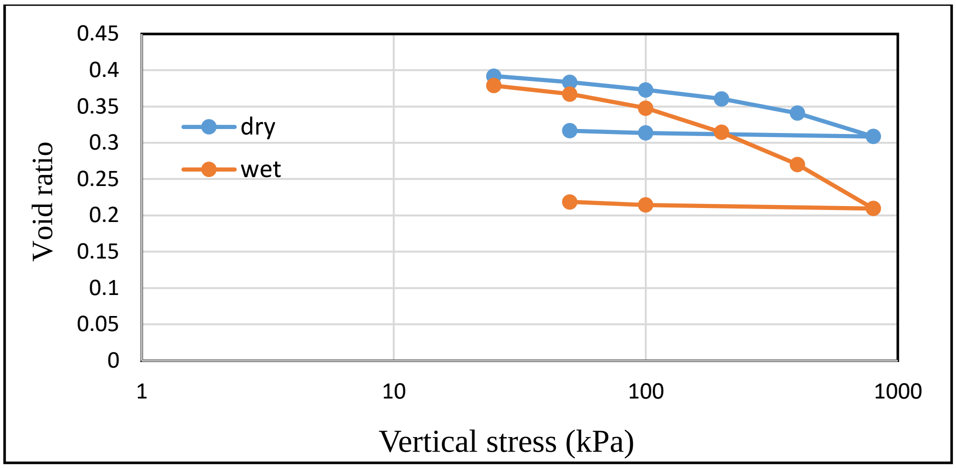

Fig.16: Variation of void ratio with vertical stress for GK soil prepared at w=6 %, γ_{dry}=16.55 kN/m^3 in double oedometer test.

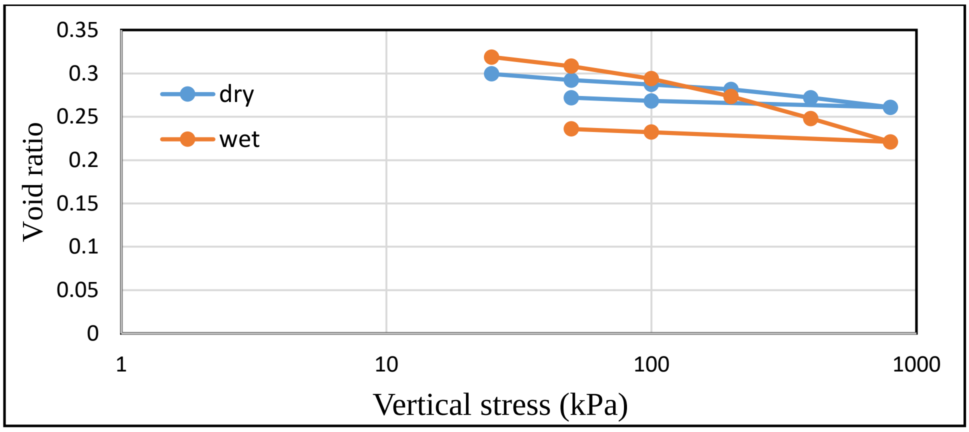

Fig.17: Variation of void ratio with vertical stress for GK soil prepared at w=10 %, γ_{dry}=17.55 kN/m^3 in double oedometer test.

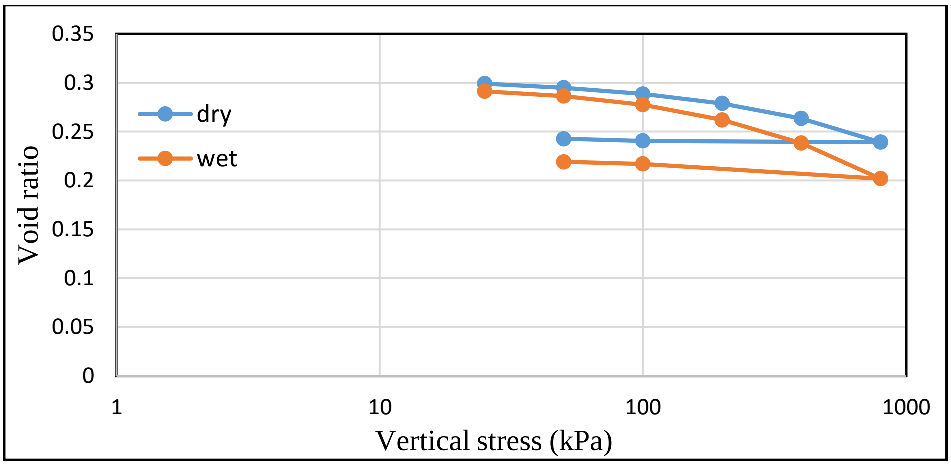

Fig.18: Variation of void ratio with vertical stress for GK soil prepared at w=14 %, γ_{dry}=17.80 kN/m^3 in double oedometer test.

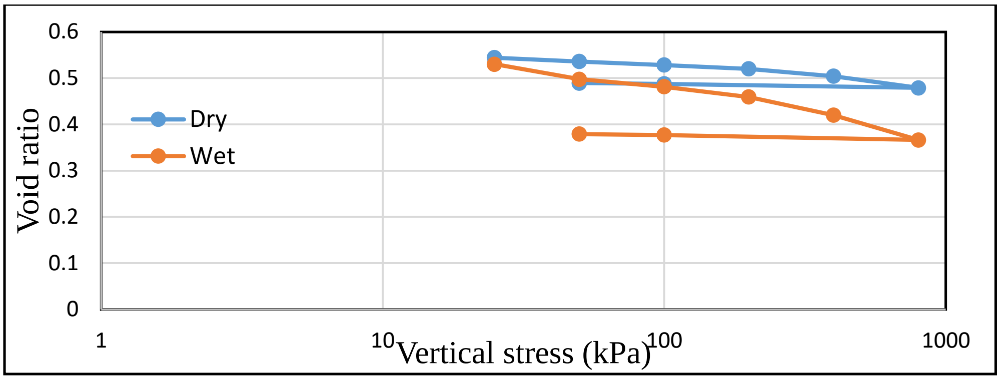

Fig.19: Variation of void ratio with vertical stress for GT soil prepared at w=6 %, γ_{dry}=15.30 kN/m^3 in double oedometer test.

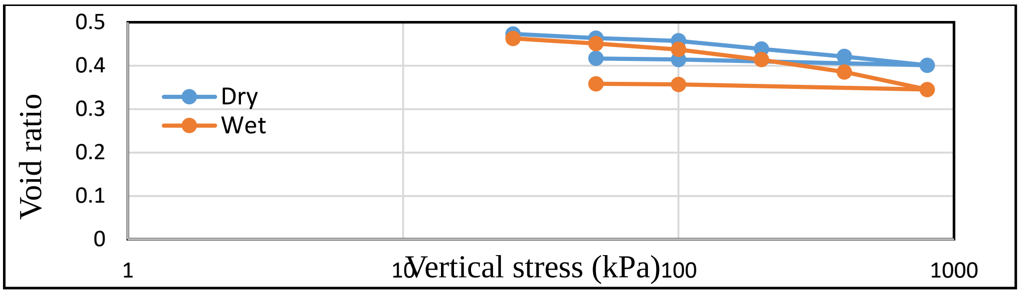

Fig.20: Variation of void ratio with vertical stress for GT soil prepared at w=10 %, γ_{dry}=16.00 kN/m^3 in double oedometer test.

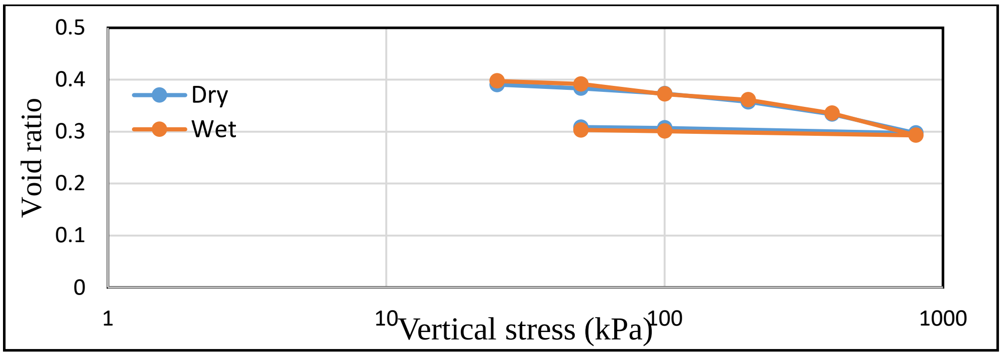

Fig.21: Variation of void ratio with vertical stress for GT soil prepared at w=14 %, γ_{dry}=16.90 kN/m^3 in double oedometer test.

It can be seen that the collapse potential for samples tested in the double oedometer tests are greater than those obtained from collapse test at stress level of 200 kPa. This may be caused by sample preparation, in addition to high gypsum content which may prevent more dissolution of gypsum.

The compressibility of the soil is low when loaded under unsaturated condition. It can be seen that the collapse potential for samples tested in the double oedometer tests under stress level 800 kPa are greater than those obtained from collapse test at stress level of 200 kPa. This may be caused by sample preparation, and high stress level (800 kPa), in addition to high gypsum content which may prevent more dissolution of gypsum under low stress level.

In double oedometer tests, it is difficult to set both specimens at the same initial void ratio. In addition, friction that develops between oedometer ring and soil specimen under equal external stress will be different in dry and wet specimens resulting in a difference in “true” compressive stresses applied to dry and wet specimens. We may then expect the collapse potential obtained from double oedometer tests to be higher than that obtained from collapse test.

The collapse may be caused by break-down of the interparticle bonds under high loads. However, in general, collapsible soils undergo significant volume change prior to reaching saturated state. the triggering mechanism for collapse is attributed to the loss of strength due to reduction in matric suction as a result of wetting. In other words, collapse occurs when there is a change in stress state of the soil as it goes from unsaturated condition towards a saturated condition (Fredlund and Gan, 1995).

The value of CP for GA soil is less than the value of other two soils due to low gypsum content of this soil (12%).

CONCLUSIONS

This paper has presents the results of a series of collapse tests to investigate the collapse potential of unsaturated gypseous soil obtained from different parts of Iraq under various conditions and to study the several parameters affecting the collapsibility of gypseous soil such as water content, initial dry unit weight, initial void ratio and degree of saturations. From the results of this work, the following conclusions can be warranted:

1- The collapse potential for Tikrit and Kerbala soils is higher than the collapse potential of Arar soil because of high gypsum content of these soil (greater than 30%).
2- For each soil, the collapse potential decreases with increases of dry unit weight.
3- The increase of initial water content for each soil will decreases the values of collapse potential.
4- The collapse potential increases with increase of the void ratio for each soil.
5- For each soil, the collapse potential decreases when the initial degree of saturations increases.

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