Eng. & Tech. Journal , Vol.30, No.18 , 2012

Improving Collapsibility and Compressibility of Gypseous Sandy Soil Using Bentonite and Kaolinite

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Received on: 31/1/2012 & Accepted on: 7/6/2012

ABSTRACT

The sandy soil which covers the surface layer for the investigated area consists of high gypsum content (50%). The soil was found to be a "collapsible" soil. Thus bentonite and kaolinite have been used as an improving agents for such soil. The essential idea of this study represents an investigation of the possibility of using these materials as additives with different percents (5%, 10%, 15%, and 20%) to enhance these soils. A testing program was conducted on 9 models of untreated and treated gypseous soil specimens to study the behavior of such mixes as well as their effects on physical properties, collapsibility and compressibility characteristics. It was concluded that a significant reduction in collapsibility reaching 80 to 82 % for the 10 percent mixed kaolinite and bentonite respectively. Lowest compression index (C_c) and recompression index (C_r) have been obtained using the same percentages of mixed additives. Generally, best improving results have been obtained using bentonite additive (specially the ratio 10%) for its finer grains than those of kaolinite.

Keywords: Gypseous soil; Bentonite ; Kaolinite ; Additives; Collapsibility; Compressibility

تحسين انهيارية وانضغاطية التربة الرملية الجبسية باستخدام البنتونايت والكاؤلينايت

الخلاصة

تغطي التربة الرملية الطبقة السطحية لمنطقة الدراسة والتي تتصف بمحتواها الجبسي العالي (50%). وجدت هذه التربة "انهيارية". لذا استخدم البنتونايت والكاؤلينايت كعوامل مضافة لتحسينها. وتتمثل الفكرة الأساسية لهذه الدراسة في التحري عن مدى امكانية استخدام هذه المواد كمضافات وبنسب مختلفة (5 ,10, 15, 20 %) من اجل تحسين هذه التربة. تم عمل برنامج الفحص على 9 موديلات لنماذج التربة الجبسية المعاملة وغير المعاملة من أجل دراسة سلوك هذة الخلطات فضلا عن تأثيراتها على الخواص الفيزياوية وخصاص الانهيارية والانضغاطية. أستنتج بان هنالك تقليل مهم في الانهيارية يصل ما بين 80 الى 82 % لنسبة الخلط 10 % لكل من الكاؤلينايت والبنتونايت على التوالي. وتم الحصول على أقل القيم لمعامل الانضغاطية (C_c) ولمعامل اعادة الانضغاطية (C_r) باستخدام نفس نسبة المضافات المخلوطة. على العموم،

https://doi.org/10.30684/etj.30.18.3
2412-0758/University of Technology-Iraq, Baghdad, Iraq

تم الحصول على أفضل نتائج تحسين باستخدام البنتونايت (خصوصا ذو النسبة 10%) بسبب حبيباتها الأنعم مقارنة بتلك الخاصة بالكاؤلينايت.

INTRODUCION

Gypseous soils are considered as collapsible soils, which consist of hydrated calcium sulfate ($CaSO_4.2H_2O$). Gypsu`m, whether in massive or particular form, dissolves due to water table fluctuation or water infiltration into gypseous soils causing the soil to be soft and highly compressible leading to severe foundation problems due to collapse of soils structure and the formation of cavities [1]. Gypseous soil is hard with high bearing capacity unless the water attacks it, but when the water arrives to the soils, gypsum will soften and dissolve. The dissolution of gypsum depends on many factors such as gypsum content, temperature, atmospheric pressure and others [2]. As a result of salt migration (gypsum), new voids will be developed in gypseous soils; afterwards the soil responds to this changing and begins to settle due to re-arrangement of its particles [3, 4].

Gypsum present in soil structure acts as a binder (cementing material) between soil particles and causes the soil to be very hard when it is dry. However, the intrusion of water through rainfall, raise in ground water table, leakage through canal lining or pipe works may result into dissolution and softening of gypseous soils. This can cause serious damage and even collapse of the structures founded on or in such soils [5]. The quantity of soluble salts in soils is a relevant feature for soil behavior under the impact of seepage through an earth fill embankment and/or through soil foundation. The effect of dissolving soluble salts is dependent on the kind of salts and their solubility in conjunction with soil permeability and thus the amount of water passing through the soil, but also with chemical characteristics of seepage water. Therefore, the percentage of soluble salts in a soil is only an indication of the possible effect on behavior [6, 7].

The reason for the lack of information on many of these soil deposits is that they are located in predominantly arid regions with limited economic development in the developed countries. In the last years, many damages were recorded in strategic projects in Iraq due to presence of gypseous soils underneath the base of foundation. Investigation proved that most of these projects were constructed on gypsum stratum or soil containing an amount of gypsum. Problems associated with structures constructed on gypseous soils can be summarized as: settlement; collapse due to soaking, collapse due to leaching; delayed compression and shear failure [6].

The present article investigates the effect of using bentonite and kaolinite, as improving additives, on the behavior and the characteristics of soil represented by its physical properties, collapsibility and compressibility.

EXPERIMENTAL WORK

Location and Preparation of Natural / Mixed Soil Samples

Natural gypseous soils were brought from Al-Qarma site which is located in the east of Al-Falluja city in Al-Anbar Governorate about 50 km west of Baghdad. Disturbed samples were taken from about 1 m below the natural ground surface.

Then these soils are transported to the Soil Mechanics Laboratory, University of Technology where soil test has been conducted for this work. The samples of soils were air dried, pulverized and mixed thoroughly. After that, the soil becomes homogenous and ready for testing. Commercial bentonite and kaolinite brought from a construction company were used. Tap water was used in the experimental work. In this study, compacted soil samples at field unit weight (14.26 kN/m^3) were used. The soil was placed loosely in the mould (or ring) of consolidation cell (by using trial and error) as layers with metal scoop and each layer was gently leveled out under compaction using wooden disk to achieve the required unit weight. Before placing soil sample in the mould (or ring), the inner side of mould was coated with grease oil to avoid friction and to prevent the water from seeping through voids at the interface between the soil sample and inner surface of the mould (or ring). To study soil characteristics and its mechanical behavior, different tests have been carried out such as; soil classification, chemical, physical and mechanical tests included collapsibility and consolidation tests.

Besides, bentonite and kaolinite can be used as grouting materials to improve such gypseous soil characteristics, so they were used as additives to study their effects on soil properties. Eight mixtures (4 for each additive) were prepared with different percents (5, 10, 15 and 20 % by weight) added to the natural soil. These additions are represented as percentages of the total weight of the mixes. The same procedure of preparation was carried out for the mixed soil specimens. A testing program was conducted on each of the 9 models of the untreated (one specimen) and treated (8 specimens) gypseous soils to study the behavior of such mixes as well as their effects on physical properties, collapsibility and compressibility characteristics.

Determination of Gypsum Content

As the determination of gypsum content is complicated so several methods and techniques have been suggested [8]. One of these is the hydration method of Al-Mufty and Nashat (2000) [9] which is used to determine the gypsum content of the natural soil in this study. The hydration method can be summarized as follows: The sample is oven dried at 45°C temperature until the sample weight remains constant. This weight is recorded as W_{45^oC}. Then the same sample is dried at 110°C temperature for 24 hrs and the weight is recorded as W_{110^oC}. Gypsum content (χ) is then calculated according to the following equation:

$$c = \left[\frac{w_{45^o C} - w_{110^o C}}{w_{45^o C}} \right] \times 4.778 \times 100 \qquad ......(1)$$

where:

W_{45^oC} = weight of sample at 45°C temperature.

W_{110^oC} = weight of sample at 110°C temperature.

Physical Properties and Chemical Tests

All results of chemical and physical properties besides the grain size analysis of the tested natural soil are summarized in Table 1 and Figure 1 respectively.

The grain size distribution of the gypseous soil was carried out directly on natural soil without any treatment. Wet sieving was conducted according to BS 1377 [10]. The grain size distribution curve of the soil sample is shown in figure 1. The figure clearly shows that the soil sample is classified as poorly graded sand (SP) according to Unified Soil Classification System (USCS). Thus the soil has no consistency limits (liquid and plastic limits).

The specific gravity was determined according to BS 1377, but kerosene is used instead of water to avoid the dissolving of gypsum in water [10].

The unit weight and water content were determined according to BS 1377 [10]. The maximum dry unit weight was 16.2 kN/m^3. The water content was determined at drying temperature of 45^oC in order to overcome gypsum dehydration [9]. Whereas, the optimum moisture content (OMC) using the standard Proctor test was 12.6%.

The chemical tests Table (1) that have been carried out on the natural soil include gypsum content determined by using the hydration method recommended by Al-Mufty and Nashat (2000)[10]; and sulphate content (SO_3) determined according to BS 1377 test No. 1 [10].

The results of X-Ray Diffraction test analysis indicate the presence of aluminum oxide (Al_2O_3), sulfur oxide (SO_3), silicon oxide ($Si_{36}O_{72}$), cristobalite (SiO_2), gypsum (calcium sulfate hydrate, $CaSO_4.2H_2O$), calcium oxide (CaO) and periclase (magnesium oxide, MgO). Gypsum and quartz are the dominant non- clay minerals.

Single Collapse Test (SCT)

Collapse potential is determined by single collapse (or single oedometer) test using oedometer cell and the procedure stated by Knight (1963)[11]. In this test, vertical static load increments were applied at regular time intervals (24 hr) and the pressure load was doubled with each increment up to the required maximum (25, 50, 100, 200, 400 and 800 kPa). After the application of a stress of 200 kPa and waiting for 24 hrs, water was added to the cell and left for 24 hrs. The additional thickness changes (ΔH) were recorded. The collapse potential (C_p) is calculated using equation 2 [12].

$$C_p = \frac{\Delta e}{1+e_o}\times 100 = \frac{\Delta H}{H_o}\times 100 \qquad .....(2)$$

where: Δe = difference in void ratio before and after soaking.

e_o = initial void ratio.

ΔH = difference in height of soil specimen before and after soaking.

H_o = initial height of soil specimen.

The test was continued as in the conventional consolidation test. Then, unloading process was conducted and the consolidation readings were taken. This procedure of loading and unloading was repeated for each specimen of the 9 mixes.

RESULTS AND DISCUSSION

The physical and engineering properties of Al-Qarma gypseous soil (with 50% gypsum content) have been investigated Table (2). The dry unit weights included within the table were determined from phase relationships. The higher values of specific gravity for mixed soils may be attributed to the fact that clay minerals are too fine that fill the voids within the soil structure resulted in voids decrease and better interlocking. To study the collapsibility and compressibility of such soil, a single collapse test was carried out for such soil in its natural state and after treatment. The relationship between the void ratio and log stress for natural (or untreated) gypseous soil is shown within Figures (2) to (7) and their results are summarized in Tables 2 and 3. It can be seen that the collapse potential for normal Al-Qarma gypseous soil is 6.1 % at stress 200 kPa, therefore, this soil can be classified as problematic soil (Trouble) according to the classifications suggested by Jennings and Knight (1975) [13] and Clemence and Finbarr (1981) [14]. The sudden decrease in void ratio is indicated by the vertical line appeared in the aforementioned figures. This line refers to the sudden collapse of soil structure when water is added under stress level 200 kPa due to the dissolution of gypsum in water leading to an increase in the volume of voids because of bonds breaking between soil particles. Therefore, rearrangement of soil particles takes place and the settlement of soil sample occurs under constant load. This was also observed by Seleam (1988) [15]; Nashat (1990) [3]; Al-Abdullah (1995) [16]; Al-Busoda, (1999) [17]; Al-Neami (2000) [18]; Al-Ahbabey (2001) [19]; Al-Obaidi (2003) [20]; and Fattah et.al. (2008)[21].

Experimental results showed that the addition of bentonite (or kaolinite) led to a reduction in void ratio and increasing dry unit weight and specific gravity depending on the quantity of the added improving material (Tables (2) and (3). The void ratio for untreated gypseous soil (zero% improving material) was 0.732 and decreased for treated soil with 5% bentonite/ kaolinite, then it was slightly reduced with increasing the additive material percent reaching maximum decrease for treated soil with 10%. Then, an increase was noticed for treated soil with 20%. The values of void ratio of soil at different bentonite/ kaolinite percentages may reflect that the global void ratio of the soil can no longer be used to describe the behavior of the soil when a granular soil (sandy) contains fines (bentonite/ kaolinite). This is because, up to a certain fines content, the fines only occupy the void spaces, and do not significantly affect the mechanical behavior of the soil-bentonite/ kaolinite mixture [22]. A reverse behavior has been shown by the dry unit weight and specific gravity values, they were slightly increased with increasing additive material in the 10% limit. This phenomenon is attributed to the fact that the improving materials affected the particle orientation which acts as a cohesive bond between soil particles and to provide a water proofing coat around the gypseous soil particles.

Typical results of single collapse test are shown in the form of e_o– logarithm stress curves. Figures (2) to (5) illustrate the collapse test for normal soil and a particular percentage of bentonite or kaolinite mixed soil, while Figures (6) and (7) represent the collapse test for normal and all percentages for each of bentonite and kaolinite respectively. The results of collapse tests show vertical line which refers to immediate collapse that occurs suddenly when the soil specimen was flooded with water at constant stress level of 200 kPa. The loading period for this line is 24 hrs. The change in strain upon flooding in water points out that the soil is collapsible. The bonds start losing strength with the increase of the water content and at a critical degree of saturation, the soil structure collapses [14, 23]. A summary of data is given in Tables (3) and (4). It can be noticed that the collapse potential (C.P.) increases with the increase of initial void ratio. Treatment results give a considerable reduction in void ratio, increase in dry unit weight and specific gravity hence a significant reduction in collapsibility (or an increase in Collapse Reducion Factor CRF) reaching 80 to 82 % for the 10 % mixed kaolinite and bentonite respectively. This improvement in collapse potential is a result of filling the voids between soil particles by the fine particles of these clay minerals which work as a cohesive bond (filler material) filling the voids between soil particles and provide a water proofing coat around the gypseous soil particles and makes the soil structure more stable to collapse due to water added.

The increase in collapse potential again for 15 and 20 % mixed bentonite/ kaolinite may be attributed to the increase in the compressibility as a result of the increase in fine contents (bentonite and kaolinite). Considering consolidation test, the results exhibit a significant decrease in void ratio especially at high stress level of 800 kPa. The addition of aforementioned percents results in a reduction in void ratio by 19 to 23 % for bentonite and 28 to 41 % for kaolinite. The higher reduction values in void ratio for kaolinite addition may be attributed to its finer particles. Besides, it is noticed that a negative effects on void ratio may be attributed to increase in the compressibility as a result of the increase in fine contents. Also, it is found that the 10 % mixed additives give the lowest compression index (C_c) ranging between 0.118 for bentonite and 0.133 for kaolinite. In the behaviour of the soil tested in the rebound consolidation, slightly increase in void ratio is noticed indicating permanent strain condition. It is found that the 10 % mixed additives give the lowest recompression index (C_r) ranging between 0.022 for bentonite and 0.023 for kaolinite (Tables 2 and 3). This may be attributed to the increase of fine particles that fill the voids within the soil structure and the decrease in voids and the limited gypsum dissolution process by fine particles of such additives.

Finally, it can be said that best improving results have been obtained using bentonite additive (specially the ratio 10%) for its finer grains than those of kaolinite. Besides, by examining the degree of severity of the problem, it seems that the treatment process by the additives agents resulted in non-problematic for 10% bentonite mixed soil and moderate problematic soil for the others instead of problematic natural soil (collapsible soil).

CONCLUSIONS

Based on the results, the following conclusions can be drawn:

1- Bentonite and kaolintie may be used as improving agents for highly gypseous soil (with 50% gypsum content) from Al-Qarma site.
2- The addition of bentonite and kaolinite results in improving the characteristics of the gypseous sandy soil represented by its physical properties, collapsibility and compressibility.

3- Significant reduction in collapsibility (improvement %) reaching 80 to 82 % for the treated gypseous soil with only 10 % mixed kaolinite and bentonite respectively.
4- Best improving results have been obtained using bentonite additive (specially the ratio 10%) for its finer grains than those of kaolinite.
5- Examining the degree of severity of the problem, it seems that the treatment process by the additives resulted in non-problematic for 10% bentonite mixed soil and moderate problematic soil instead of problematic natural soil (collapsible soil).
6- Sufficient reduction is noticed in compressibility characteristics of gypseous soil upon treatment with these additives. Lowest compression index (C_c) and recompression index (C_r) have been obtained using 10 % mixed additives.

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Table (1) Results of physical and chemical properties tests for natural soil.

Physical and Chemical property	**Value**
Specific gravity	2.47
Liquid limit %	NP
Plastic limit %	NP
Plasticity index %	NP
Maximum dry unit weight (kN/m^3)	16.2
Field unit weight (kN/m^3)	14.26
Optimum moisture content	12.6
Gravel (≥4.75mm.) %	10.0
Sand (4.75mm to 0.075mm)%	88.0
Silt and clay (≤0.075mm.) %	-
D_{10} , mm	0.17
D_{30} , mm	0.23
D_{60} , mm	1.0
Coefficient of uniformity, C_u	5.8
Coefficient of curvature, C_c	0.339
Soil classification (USCS)	SP
SO_3	23.8
Gypsum content %	50.0

Table (2) Results of collapse tests for untreated and treated gypseous soils with bentonite.

Soil Property	**0% Bentonite**	**5% Bentonite**	**10% Bentonite**	**15% Bentonite**	**20% Bentonite**
e_o	0.732	0.715	0.718	0.742	0.731
γ_d (kN/m^3)	14.26	15.45	19.21	17.81	16.26
G_s	2.47	2.65	3.3	3.103	2.813
Collapse Potential C.P%	6.10	2.14	1.09	1.65	2.43
Collapse Reduction Factor CRF %	0.0	65	82.0	73.0	60.0
Severity of problem according to Jennings and Knight (1975); and Clemence and Finbarr (1981)	Trouble	Moderate Problem	No Problem	Moderate Problem	Moderate Problem
Compression Index C_c	0.149	0.131	0.118	0.154	0.133
Recompression Index C_r	0.058	0.028	0.022	0.025	0.024

Table (3) Results of collapse tests for untreated and treated gypseous soils with kaolinite.

Soil Property	0% Kaolinite	5% Kaolinite	10% Kaolinite	15% Kaolinite	20% Kaolinite
e_o	0.732	0.702	0.682	0.663	0.721
γ_d (kN/m^3)	14.26	18.22	18.8	17.43	16.85
G_s	2.47	3.10	3.19	2.9	2.9
Collapse Potential C.P %	6.10	3.70	1.22	5.27	4.32
Collapse Reduction Factor CRF %	0.0	40.0	80.0	14.0	29.0
Severity of problem according to Jennings and Knight (1975); and Clemence and Finbarr (1981)	Trouble	Moderate Problem	Moderate Problem	Trouble	Moderate Problem
Compression Index C_c	0.149	0.149	0.133	0.166	0.138
Recompression Index C_r	0.058	0.036	0.023	0.027	0.026

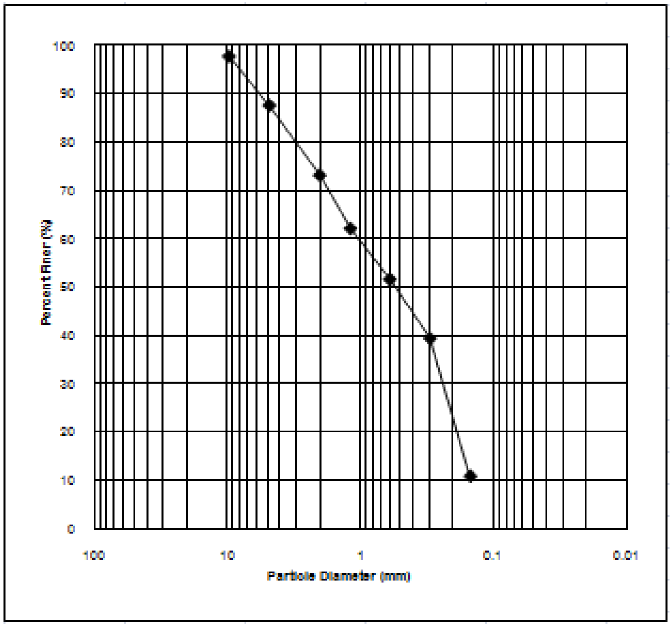

Figure (1) Grain size analysis.

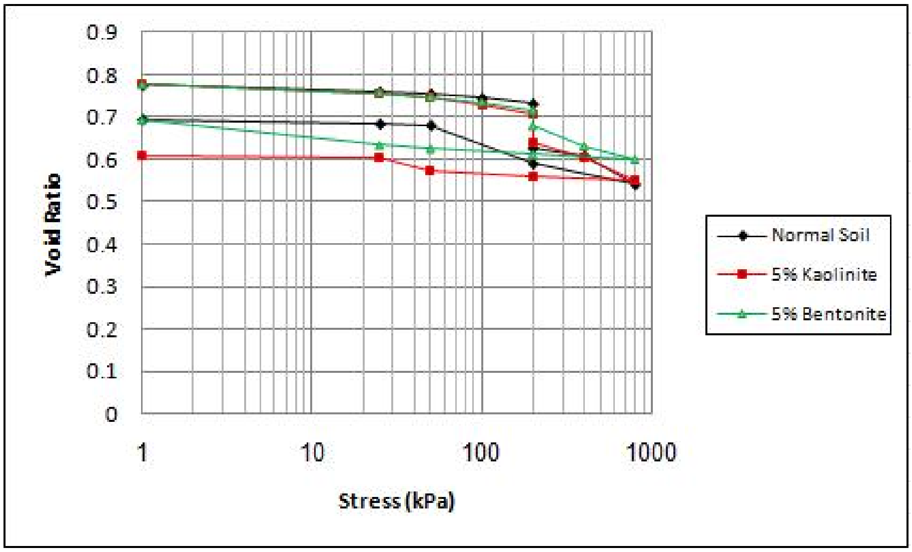

Figure (2) Single collapse test for normal and 5 % bentonite/ kaolinite mixed soils.

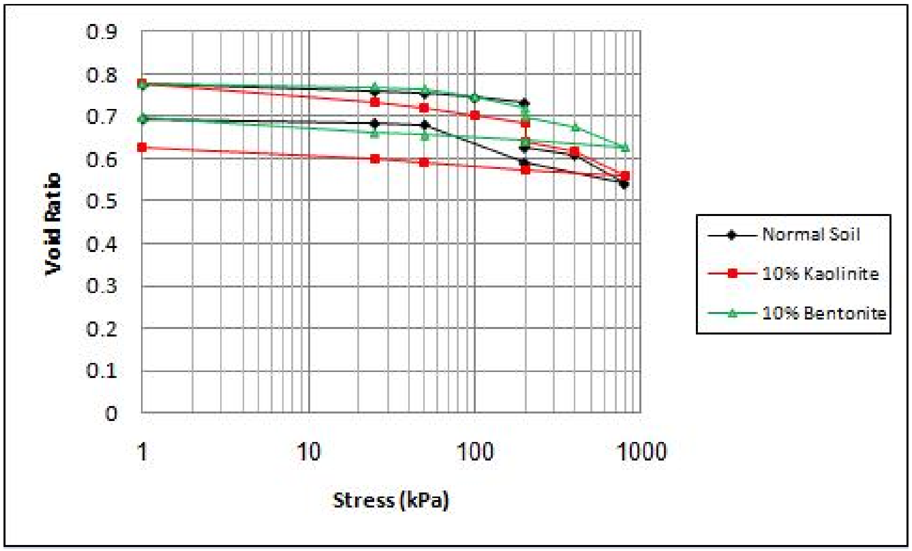

Figure (3) Single collapse test for normal and 10 % bentonite/ kaolinite mixed soils.

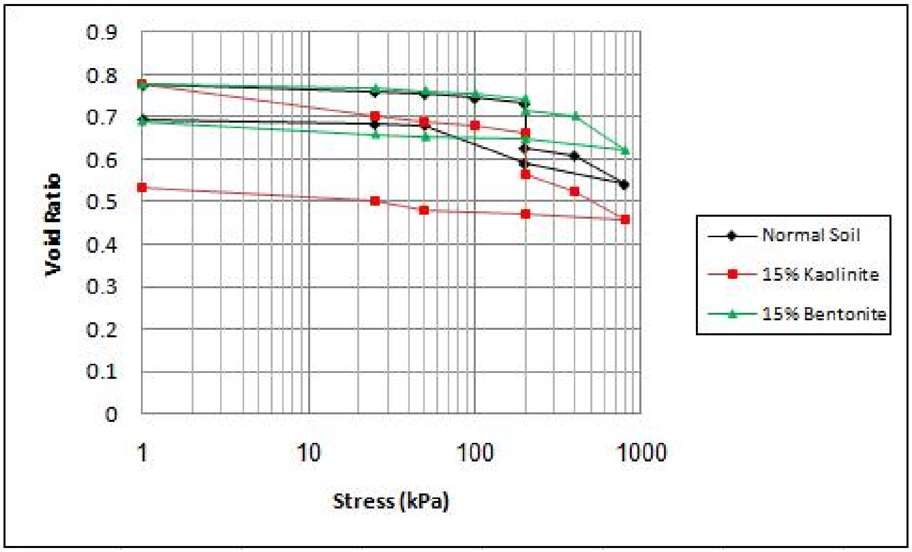

Figure (4) Single collapse test for normal and 15 % bentonite/ kaolinite mixed soils.

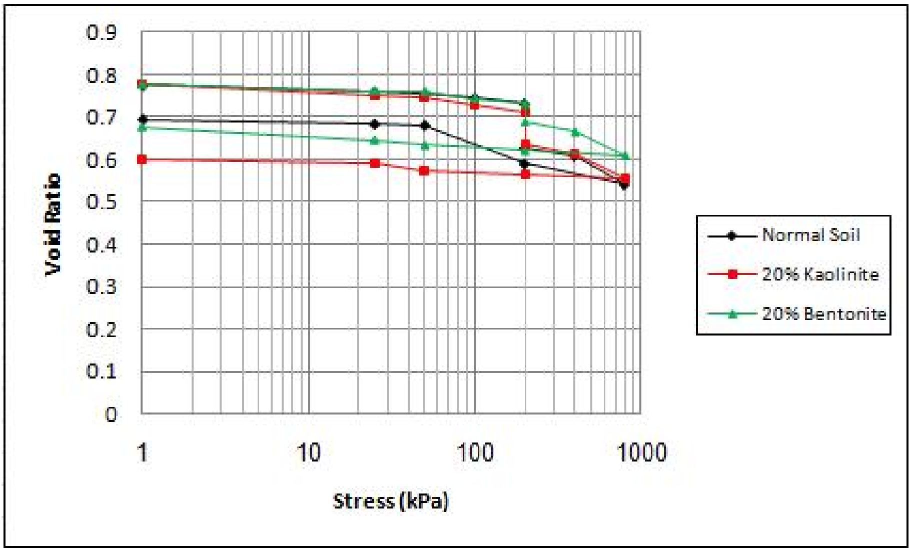

Figure (5) Single collapse test for normal and 20 % bentonite/ kaolinite mixed soils.

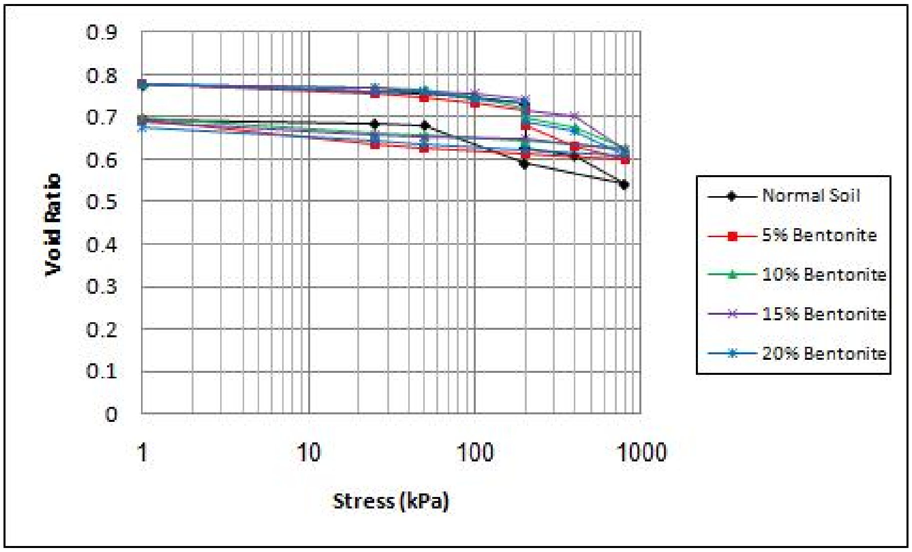

Figure (6) Single collapse test for normal and bentonite mixed soils.

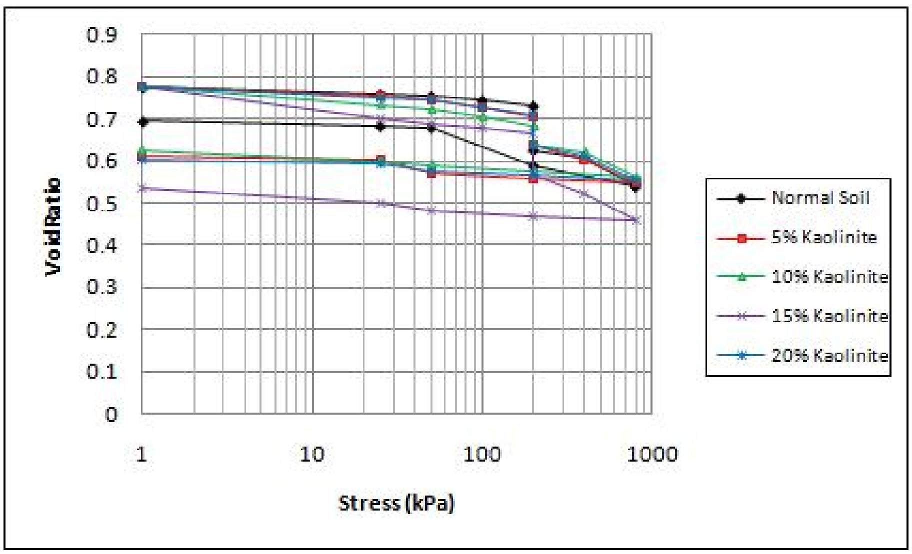

Figure (7) Single collapse test for normal and kaolinite mixed soils.