Assessing the Dynamic Behavior of Asphalt Stabilized Gypseous Soil

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ABSTRACT

The study presents the test results of stabilizing gypseous soil embankment obtained from Al- Faluja University Campus at Al-Ramady province. The laboratory investigation was divided into three phases, the physical and chemical properties; the optimum liquid asphalt (emulsion) requirements (which are manufactured in Iraq) were determined by using one dimensional unconfined compression strength test. In the first phase , the optimum fluid content was 11% (6% of emulsion with 5% water content). At phase two, the effect of aeration technique was investigated using both direct shear and permeability test. At phase three, a laboratory soil model of dimensions 50x50x30 cm was used as a representative of gypseous soil; pure soil, and asphalt stabilized soil have been compacted in five layers after practicing an aeration technique at maximum dry density (modified compaction) cyclic loading test was carried out on four gypseous soil models, two of them were pure soil under (dry and absorbed condition), and the other two were stabilized with emulsion also under (dry and absorbed condition). The impact of charging the hydraulic conductivity due to asphalt stabilization was investigated and the vertical deformations were determined using LVDT.

For the pure soil in dry condition the vertical settlement at the top surface was (7.45 mm) at (157 load cycles), while for pure soil model under absorbed condition, the water was raised to the surface in three days , so the vertical settlement at the top surface was (12.5 mm) at (29 load cycles), this means that the pure gypseous soil under absorbed condition show reduction in strength by(85%).

When the stabilized soil is in dry condition, the vertical settlement at the top surface was (9.75 mm) at (911 load cycles), while the soil was stabilized and subjected to water absorbed for seven days. The water stopped rising at second layer which is the same inlets level from the bottom, and the vertical settlement was (10.47 mm) at (897 load cycles), so there is no change in strength at failure.

Keywords: Gypseous Soil, Emulsion, Water Absorption, Soil Stabilization, Dynamic Behavior of Gypseous Soil.

تقييم التصرف الداينميكي للتربة الجبسية المحسنة بالاسفلت

الخلاصة

التربة الجبسية لهذا البحث احضرت من جامعة الفلوجة مدينة الرمادي, الفحوص المختبرية قسمت الى ثلاث اقسام: القسم الاول ايجاد الخواص الفيزياوية والكيمياوية, والنسبة المثلى لمستحلب الاسفلت المصنوع في العراق التي وجدت من فحص مقاومة الضغط اللامحصور حيث كانت النسبة المثلى للسائل هي 11% (6% مستحلب الاسفلت + 5 % ماء) , وبرنامج تضمن الفحوص العملية ايجاد مقاومة الانضغاط, مقاومة القص المباشر, النفاذية و الانضمام بأتجاه واحد للتربة الجبسية في حالتها الجافة والرطبة. القسم الثاني استعملت تقنية التهوية من خلال فحص القص المباشر , اما القسم الثالث فقد تم تسليط حمل دوري و تم استعمال صندوق بأبعاد (50 * 50 * 30) سم مثقب من الثلث الاسفل للسماح للماء من ملامسة التربة و مقدار موصوليتها للماء وللتربة المحسنة وغير المحسنة.حيث تم عمل خمس طبقات بسمك(6) سم بقيمة الكثافة المحدولة المعدلة و ثم تسليط حمل دوري من خلال موديل مصنع مسبقا وعن طريق جهاز (LVDT) تم قياس الهطول العمودي للترب المحسنة وغير المحسنة تحت تأتير التوصيل الهيدروليكي و ملاحظة ديمومة التربة المحسنة لمنع الماء من الصعود عبر التربة.

وقد وجد ان نسبة التوصيل الهيدروليكي للتربة غير المحسنة الى سطح التربة بمدة قدرها(3) أيام بمعدل هطول (12.5) ملم تحت تسليط حمل دوري قدره 29 دورة تحميل, و بالنسبة للنموذج غير المعرض للغمر فمعدل الهطول (7.45) ملم تحت تسليط حمل دوري (157) دورة تحميل. وقد وجد ان التوصيل الهيدروليكي للتربة المحسنة بمدة قدرها (7) أيام لم يتجاوز فتحات دخول الماء من الثلث السفلي و بمعدل هطول (10.75) ملم تحت تأثير حمل دوري قدره (897) دورة تحميل, اما بالنسبة للنموذج المحسن وغير المعرض للغمر فقد وجد معدل الهطول (9.75) ملم تحت تأثير حمل دوري مقداره (911) دورة تحميل, بملاحظة عدم تغير مقاومة التربة.

INTRODUCTION

The sandy soil with high gypsum content (usually referred to as gypseous soil) covers vast area in south, east, middle and west regions of Iraq, such soil possesses a type of cohesive forces when mixed with optimum amount of water and then compacted, but losses its strength when flooded with water again. Covering the soil particles with thin asphalt layer in a stabilization process will increase the cohesion, limit the negative effect of water by blocking the voids, and reduce the ability of water to traverse the soil layer through capillary action process.

The economic backfill material suitable for such embankments and roads could be the available local soil. When the soil is gypseous, it will be suitable for compaction use in the dry condition. There will always be a possibility for water to penetrate through the pavement cracks to the soil beneath. It may exhibit hazardous situation. Then to prevent the soil from collapsing, the asphalt stabilization could provide a good remedy. For such case, theoretically, each particle of the gypseous soil will be surrounded by a thin film of asphalt which will act as a binding and a damp proofing agent. Stabilization of such soil with liquid asphalt will furnish waterproof layers with extra particles bond to serve for embankment construction.

Two loading types subjected on embankment during the service life are the repeated load by vehicles and static loading due to its self-weight.

BACKGROUND

For the construction of any type of structure resting on problematic soils such as gypseous soils, there are many available methods to improve the behavior of soil. One of these methods is stabilization with asphalt which is used as addition to prevent water penetration that causes collapsibility potential and to improve the characteristics of the soil.

Gypseous soils

In gypseous soils, collapse or compression occurs very quickly when the site is flooded with water during heavy rainfall, irrigation or breaking of sewerage and water pipes which may damage the engineering structures because the element of structure cannot follow the sudden deformation occurs by rearrangement of the inside forces or stresses , **Al-Mohammadi et al. (1987).**

High strength of dry gypseous soil can be obtained, but great losses in strength and sudden increase in compressibility occur when these soils are fully or partially saturated. The dissolution of the cementing gypsum causes high softening of the soil.

The problem becomes more complicated when the ground water flows through the gypseous soil causing leaching and movement of gypsum. In addition to softening, a loss in soil solids takes place. This causes a continuous collapse in the gypseous soil, **(Al-Mufty, 1997).**

Asphalt Emulsion

It is simply a suspension of small asphalt globules in water assisted by an emulsifying agent (such as soap). The emulsifying agent assists by imparting an electrical charge to the surface of the asphalt cement globules. Emulsified asphalts are divided into three major groups, namely, anionic, cationic and nonionic, on the basis of the electrical charges of the asphalt particle in the emulsion. Emulsified asphalts are further classified into three main groups namely, rapid-setting (RS), medium-setting (MS) and slow-setting (SS), on the basis of how quickly the suspended asphalt particles revert back to the asphalt cement, a form in which it is actually needed as a binder **(Olutaiwo et. al., 2008).**

The objective of this paper is to study the effect of change of hydraulic conductivity for gypseous soil stabilized with emulsion asphalt on gypseous soil behavior under cyclic loading.

EXPERIMENTAL WORK

Chemical Tests

The following chemical tests are conducted:

1- Total soluble salts (T.S.S.) (%).
2- Total (CO_3) (%).
3- Total (SO_3) (%).
4- Gypsum content (%).
5- pH value.

The chemical properties of soil are listed in Table (1).

Physical Tests

Classification tests performed on the soil include particle size distribution, specific gravity, Atterberg limits, relative density, and compaction characteristics. Physical tests were conducted as described in Table (2).

Materials Used:

Asphalt Emulsion used in the testing program was locally manufactured by Al- Zahf Al-Kabeer Company with low cost. The specifications as supplied by the manufactured are as given in Table (3).

Design of Gypseous Soil-Asphalt Mixture

To prepare the specimen, the pulverized and homogenous gypseous soil passing sieve No.4 was oven dried at a temperature of (45°C). The optimum moisture content and the maximum dry unit weight of the soil that were found through modified compaction test was 17.7 kN/m^3(95% of modified compaction test) and was selected as a field target in compaction process. Such an issue is mostly considered as an acceptable relative compaction in most engineering requirements. It agrees well with procedure of **(Hamdy, 2010)**, **(Al-Mohammadi et al., 1987)**, **(Al- Mufty, 1997), (Al-Safarani, 2007)**, (Figure1) shows the stress-strain relationship for the unconfined compression test for soil with 11% fluid content.

The test was conducted on soil samples mixed by splitting the optimum moisture content into water and emulsion content which will be referred as to optimum fluid content obtained from modified compaction which was (11%), .The water contents were in a range from 4% to 8% with (1%) increment, while the emulsion was in different percentages of 3% to 7% with (1%) increment. Specimens were allowed to cure for seven days at room temperature of (27± 3) ºC and the average value of the unconfined compressive strength for each duplicate specimen were calculated, and Figure 2 shows the unconfined compression strength – emulsion content (%) relationship.

Absorption Technique

Unconfined compression test specimens were prepared using the same method, size and density as was described in the unconfined compression test. Duplicate specimens having the same fluid content were prepared. Specimens were subjected to seven days curing at air dried condition.

After an absorption period of 7 days, the unconfined compressive strength of specimens was measured, same the results that were obtained by (Ingles and Metcalf, 1972). Table (4) shows effect of hydraulic conductivity on the unconfined compressive strength.

Direct Shear Test

Direct shear test was carried out on eleven groups of different specimens to determine the shear strength parameters, cohesion and angle of internal friction. The dry unit weight was found to be 17.7kN/m^3. The optimum fluid content was determined from the unconfined compression strength test as (5% water + 6% emulsion). The percentage is similar to that carried out by **(Sarsam, 1979)** and **(Sarsam and Ibrahim, 2008)** as shown in Figures (3) to (10).

Aeration of Asphalt Soil

The aeration technique was adopted before compaction by allowing the loose mix to be subjected to atmosphere condition at laboratory temperature of (30 ± 3) ºC for different times. The aeration periods were (30, 60, 90, 120, and 240) minutes respectively with emulsion for direction shear test.

Eleven groups of specimens were tested. The 1st and 2nd groups of specimens are not stabilized, it was pure soil. The specimens were tested in direct shear which was conducted in soaked and unsoaked conditions. The 3rd and 4th group of specimens are stabilized with optimum emulsion content and constructed without aeration then the specimens were left for 7 days for curing. The period of soaking was (3-4) hrs. The 5th ,6th ,7th ,8th and 9th groups of specimens were stabilized with optimum emulsion content and subjected to aeration for different times (30 ,60 , 90, 120, 240) minutes respectively and then the specimens were left for 7 days for curing. The 10th and 11th groups of specimens were stabilized with emulsion and subjected to aeration condition as (120,140) minutes respectively and then tested under soaked condition.

The effect of aeration on shear strength parameters was examined as shown in Figures 9 and 10.

Cyclic Loading Test

In this test, four cyclic loading tests were carried out on gypseous soil mode as shown in Plate (1) and Plate (2). Two of them were pure soil under dry and absorbed model as shown in Plate (3) and the other two were stabilized with emulsion also under dry and water absorption, to compare between the stabilized and pure gypseous soil behavior under absorption condition, and assess the water absorption and extent of stabilized gypseous soil to prevent the water from penetrating the stabilized gypseous soil causing collapse that is considered the big problem of gypseous soil.

The first test was on a non-stabilized gypseous soil model cured for (24) hours in air.

The second test was carried out on a non-stabilized, gypseous soil model cured for (24) hours in air then subjected to capillary rise of water which was added around the box of the model that have inlets surrounding the box to allow the water to touch the gypseous soil and Left for three days. The third test was carried out on stabilized gypseous soil with emulsion under dry condition; the mix has been left for 2 hrs. For aeration before the compaction, then the model was cured for (7) days before test.

The fourth test was on a stabilized gypseous soil with emulsion under absorbed condition; the same procedure was applied for the third test by aeration and curing but the model was left absorbed for 7 days. The results of cyclic loading are shown in Table (5).

Failure Criteria in Soil Model

In several countries, an overly is applied when the rut depth is of the order of (20-30 mm) **(Loo, 1997)** it is recommended to use deflection criterion that should ensure that the rutting is not exceeding (12.5 mm) in depth **(Lister** and **Addis 1972),** The classification of pavement condition as used in T.R.R.L method, **Molenar, (1982)** is shown in Table (6).

Rut depth of (0.5) inch (12 mm) was used as a failure criterion for thickness design in Kentucky, **(Jain, 1980)**. The value of (0.5) inch used as failure in the soil model was based on the depth of rutting made in the top soil due to cyclic loading.

The model of dry pure soil was considered as a reference to the absorbed pure soil model as an improvement percentage, while the model of dry stabilized soil was considered as a reference to the absorbed stabilized model with emulsion as an improvement percentage.

Cyclic Loading Impact on the Pure Soil Model in Dry Condition

The first test of cyclic loading on a dry pure soil model was carried out using five compacted layers. The soil of model was cured in air for (24) hours. The number of cyclic loading versa vertical displacement was (157 blows) with (7.45 mm) as mentioned in Table (5), while the corresponding characteristic curve representing the Log. No. of cyclic loading with vertical displacement behavior is given in Figure (11).

Cyclic Loading Test for the Pure Gypseous Soil Model Subjected to Absorption

The 2nd cyclic loading test was for the pure gypseous soil model with absorbed condition. Hence the model was allowed to face capillary rise of water for (3) days.

The corresponding characteristic curve representing the Log. No. of cyclic loading with vertical displacement behavior is shown in Figure (12).

As observed from the above results , the number of cycles decreased with respect to the dry pure soil, where the No. of cyclic loading was (157 cycles)with (7.45 mm) as shown in Table (5) but when absorbed by water for 3 days, the No. of cyclic loading became (29 cycles)with (12.5 mm), so the No. of cycles at dry pure soil model at(29 cycles) was (1.3 mm), so the reducing in vertical displacement is (85 %).

Test of Cyclic Loading on Stabilized Gypseous Soil Model with Emulsion in Dry Condition

The third test was carried out on a stabilized soil model using emulsion esphalt for stabilization (based on 11 % of stabilizing material by weight, which is (6% emulsion and 5% water). The mix was left for 2 hrs for aeration before the compaction of 5 layers and then the model was cured for (7) days before the test.

In this test, cyclic loading was performed. Table (5) and Figure (13) show the relationship between the No. of cyclic loading with vertical displacement.

The stabilized soil model resists the highest number of load cycles and less vertical displacement as shown in Table (5). The vertical displacement at (911 cycles) was (9.75 mm), the rate of decrease in vertical displacement. This result is a clear example to show that strength and cementation are added by emulsion to the soil, in addition to reducing the voids between soil particles.

Test of Cyclic Loading on Stabilized Gypseous Soil Model under Absorption

The last test of cyclic loading was carried out for the stabilized gypseous soil model. The aeration condition and compaction procedure of the five soil layers were carried out in the same procedure as that held in the previous tests, but the model was allowed to face capillary rise of water for (7) days before test.

The absorption condition for stabilized gypseous soil assessed the hydraulic conductivity and the extent of stabilized gypseous soil prevented the water from penetrating inside the stabilized gypseous soil that cause collapse which is considered the big problem of gypseous soil. Plate (4) shows the flow process through the inlets around the box that are located about 8 cm from the bottom of box to allow the soil to be in touch with water.

From the results of the last test for the absorbed stabilized gypseous soil under cyclic loading , the No. of cycles was reduced a little, as shown in Table (5) and Figure (14), the vertical displacement at (897 cycles) was (10.47 mm), so the rate of decrease in vertical displacement at failure does not show any change for the strength, and this is considered as a clear example to show that the hydraulic conductivity of water was too low where the number of cycles did not change a lot .

CONCLUSIONS

Based on the testing program, the following conclusions could be drawn

1. The unconfined compressive strength of the soil-emulsion mixture under dry and absorption test conditions increases with increasing emulsion asphalt content up to the optimum emulsion asphalt content of 6% and then decreases.
2. For pure gypseous soil tested at dry condition, the cohesion (c) was found to be 41 kPa, when the soil was stabilized by emulsified asphalt without aeration condition; the cohesion was increased to 140 kPa which means an improvement by 250 %.
3. When the soil was stabilized by emulsified asphalt and aerated for two hours and tested under dry condition, the cohesion (c) was found to be 168 kPa, so the cohesion was improved by 21.5% improving on stabilized soil without Aeration.
4. When gypseous soil was tested at absorption condition, the cohesion (c) was found to be 29 kPa, but when the soil was stabilized with emulsified asphalt without aeration and tested at absorbed condition, the cohesion was 53 kPa which means an improvement by 83 %.
5. When the soil was stabilized by emulsified asphalt and aerated for two hours at absorbed condition, the cohesion (c) was found 64 kPa, so the cohesion was improved by 21 %, with respect to non-aerated condition.
6. For the pure soil model under absorbed condition, the water was raised to the surface after three days, so the vertical settlement at the top surface was (12.5 mm) at (29 load cycles), while for the pure soil under dry condition it was (7.45 mm) at (157 load cycles); i.e., the pure gypseous soil under absorbed condition showed a reduction in strength by (85%).
7. The hydraulic conductivity of gypseous soil was changed by asphalt stabilization. When tested in dry condition, the vertical settlement at the top surface was (9.75 mm) at (911 load cycles). While when subjected to absorption condition for seven days, the water raising was stopped at the same level of inlets, the vertical settlement at the top surface was (10.47 mm) at (897 load cycles), so there was no change in vertical settlement or strength at faultier.

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Table (1) Chemical composition of the natural soil.

Chemical Composition	Percentage %
Gypsum content ($CaSO_4$) (%)	49
Carbonate content ($CaCo_3$) (%)	46
Total soluble salts (T.S.S.) (%)	38
Total (SO_3) (%)	22
pH value	7.77

Table (2) Properties of gypseous soil.

Physical property	Test result
Specific gravity, G_s	2.48
Atterberg Limits: Liquid limit (%) Plastic limit (%) Plasticity Index (%)	 24 Non plastic Non plastic
Standard compaction properties : Maximum dry unit weight(kN/m^3) Optimum moisture content (%)	 17.17 14
Modified compaction properties: Maximum dry unit weight(kN/m^3) Optimum moisture content (%)	 18.67 11
Maximum dry unit weight (kN/m^3)	15.5
Minimum dry unit weight (kN/m^3)	11.7
Coefficient of curvature	1.5
Coefficient of uniformity	6.2
according to Unified Classification System Classification	SP-SM

Table (3) Properties of asphalt emulsion.

Property	Test result
Particles charge	+ve
Viscosity CSt	45
Cement Mixing	1.2
Settling Time (hrs.)	19
Coating ability and water resistance	Good
Coating dry & wet aggregate	Fair

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Table (4) Effect of hydraulic conductivity on the unconfined compressive strength.

Emulsion content (%)	Unconfined compressive strength(kPa) with dry condition	Unconfined compressive strength(kPa) under absorbed condition	Percent changing Unconfined compressive strength
4	497	73	-85.31
5	645	80	-87.59
6	690	85	-87.68

Table (5) Results of settlement and number of cyclic loading test.

Model Type	Total No. of cycles loading	Total vertical settlement (mm)
Pure soil at dry condition	157	7.45
Pure soil under absorbed condition	29	12.55
Emulsion stabilized soil at dry condition	911	9.75
Emulsion stabilized soil under absorbed condition	897	10.47

Table (6) The Rut depth (Molenar, 1982).

Rut depth	Less than 10 mm	10-20 mm	Greater than 20 mm
condition	Sound	Critical	Failed

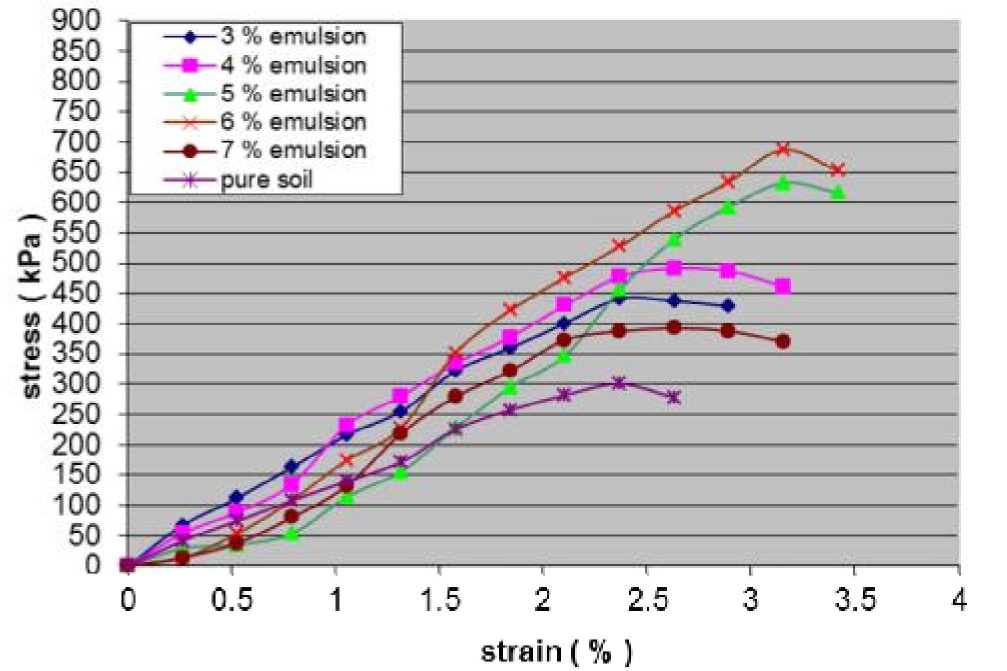

Figure (1) Stress-strain relationship for the unconfined compression test for soil with 11% fluid content.

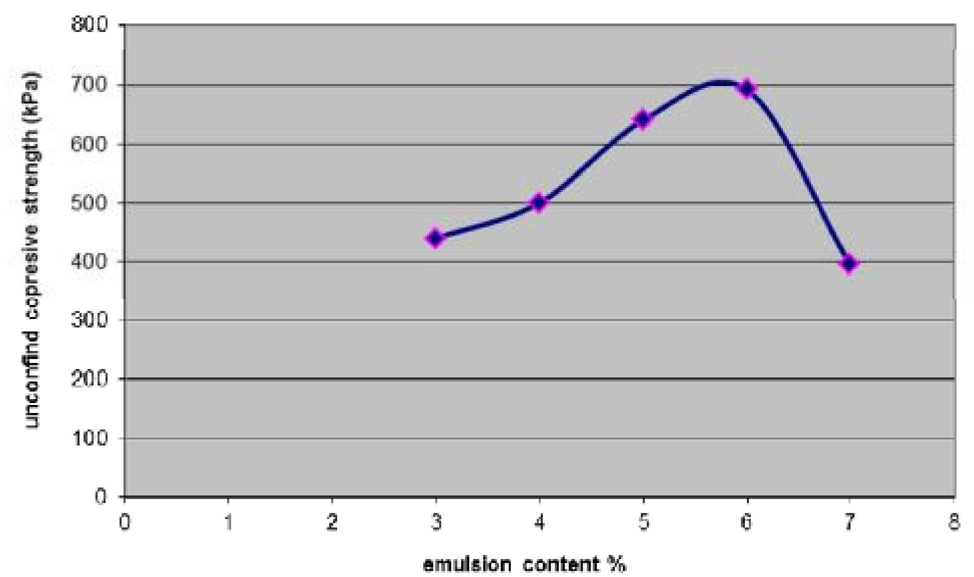

Figure (2) Unconfined compressive strength – emulsion content (%) relationship.

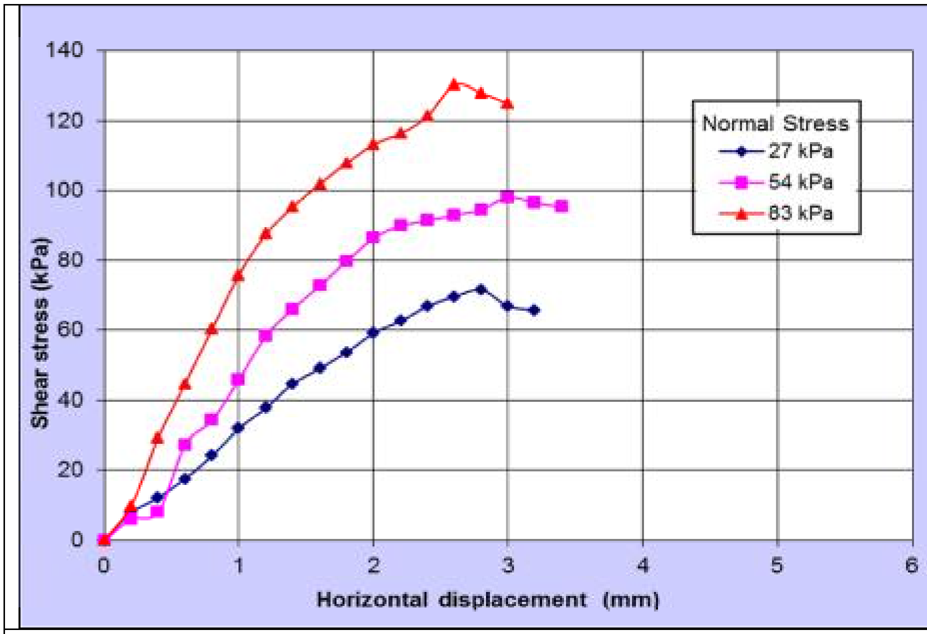

Figure (3) Shear stress- horizontal displacement relationship for non-stabilized gypseous soil (dry condition).

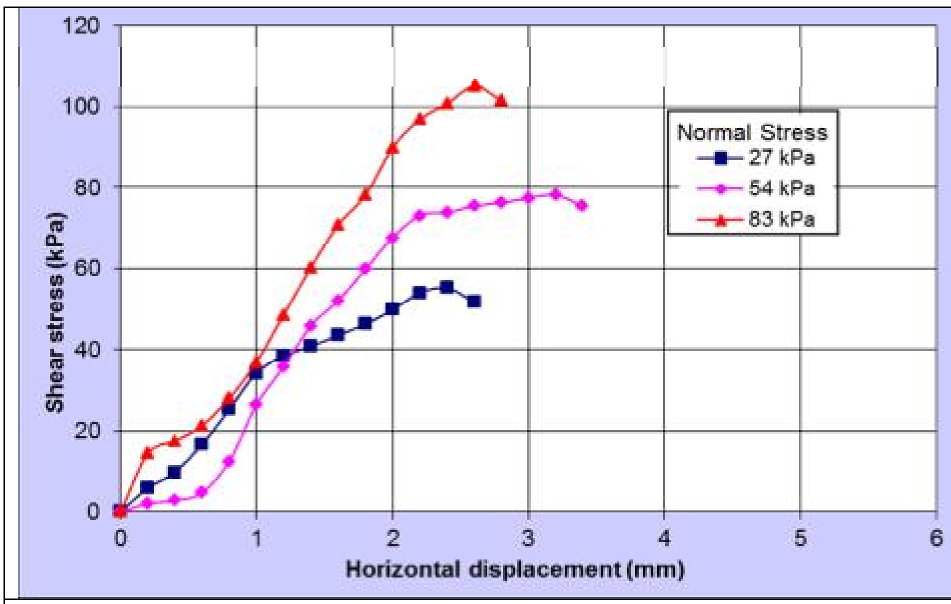

Figure (4) Shear stress- horizontal displacement relationship for non - stabilized gypseous soil (soaked condition) period time (3-4) hrs.

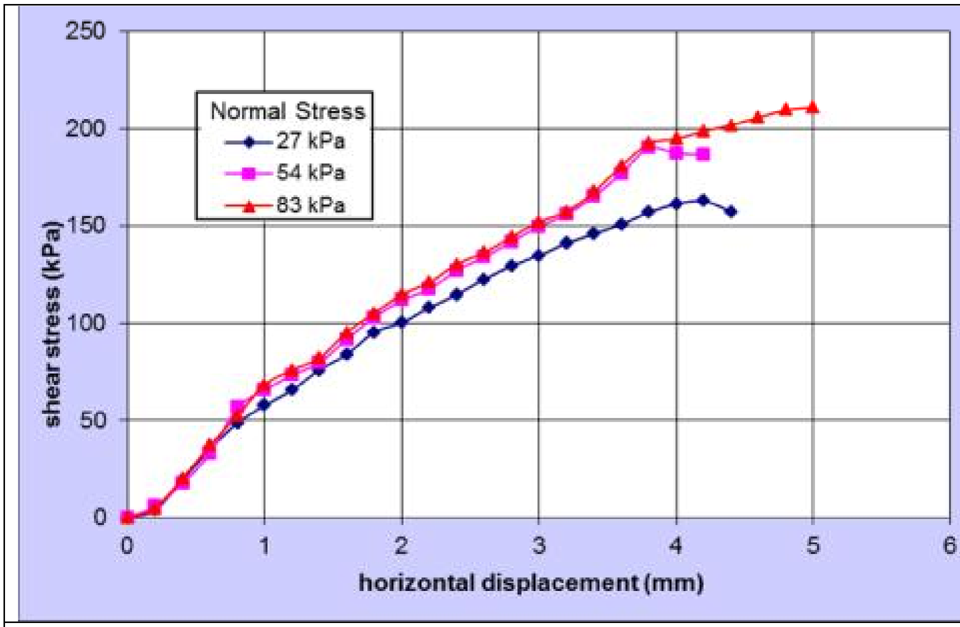

Figure (5) Shear stress- horizontal displacement relationship for stabilized gypseous soil with emulsion (dry condition), "zero aeration".

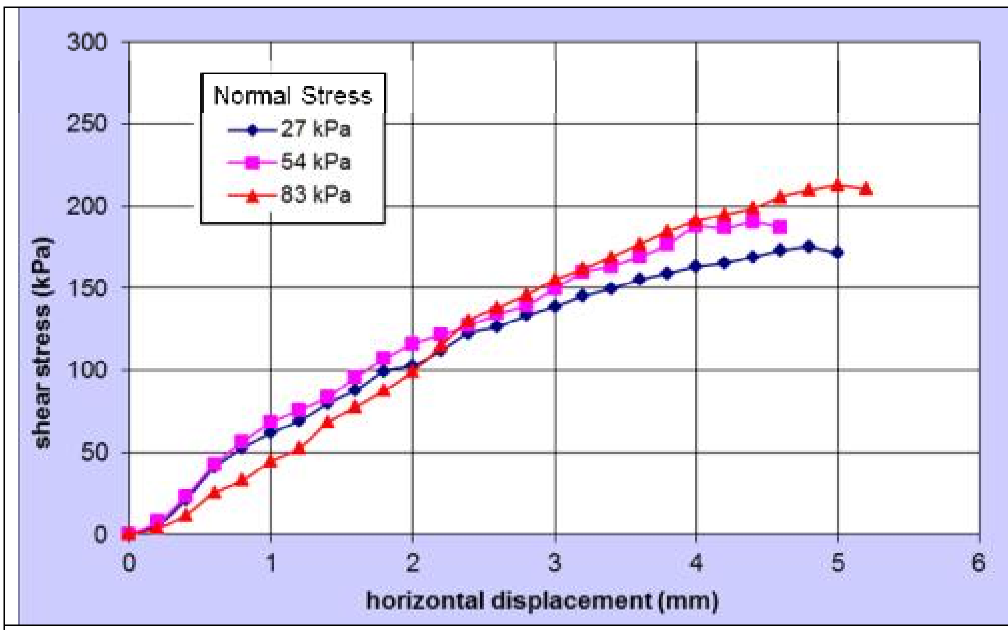

Figure (6) Shear stress- horizontal displacement relationship for stabilized gypseous soil with emulsion (dry condition), "½ hr. aeration".

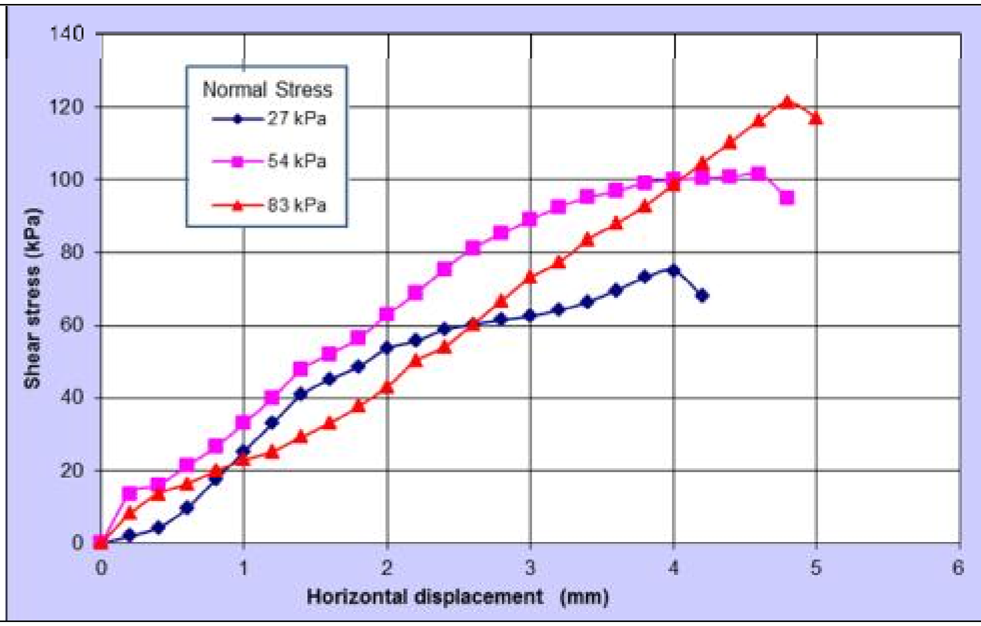

Figure (7) Shear stress- horizontal displacement relationship for stabilized gypseous soil with emulsion (soaked condition), "zero aeration".

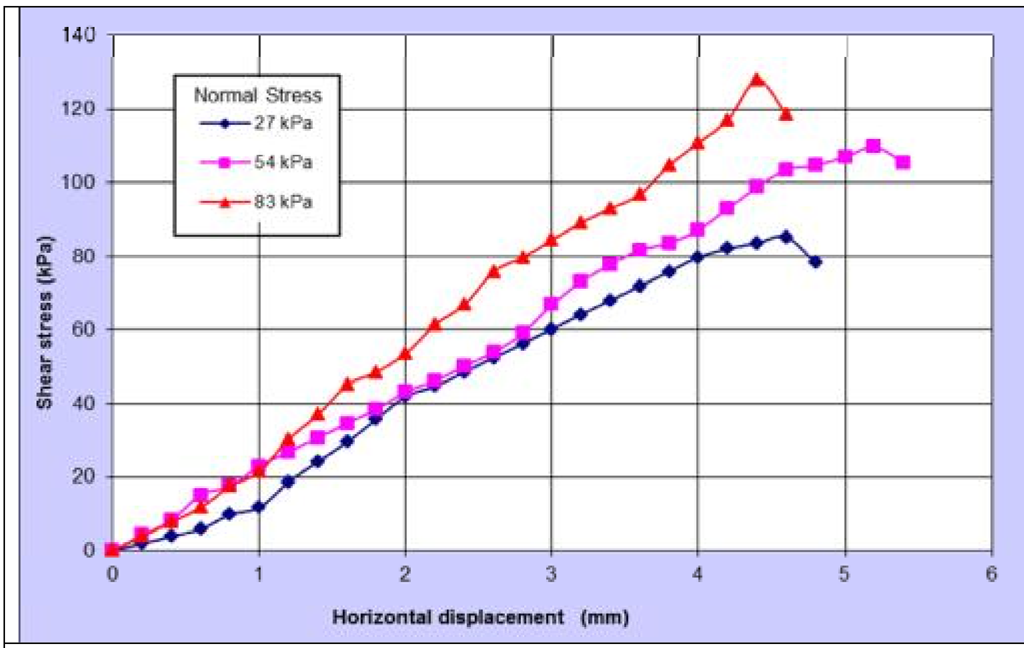

Figure (8) Shear stress- horizontal displacement relationship for stabilized gypseous soil with emulsion (soaked condition), "2 hrs. aeration".

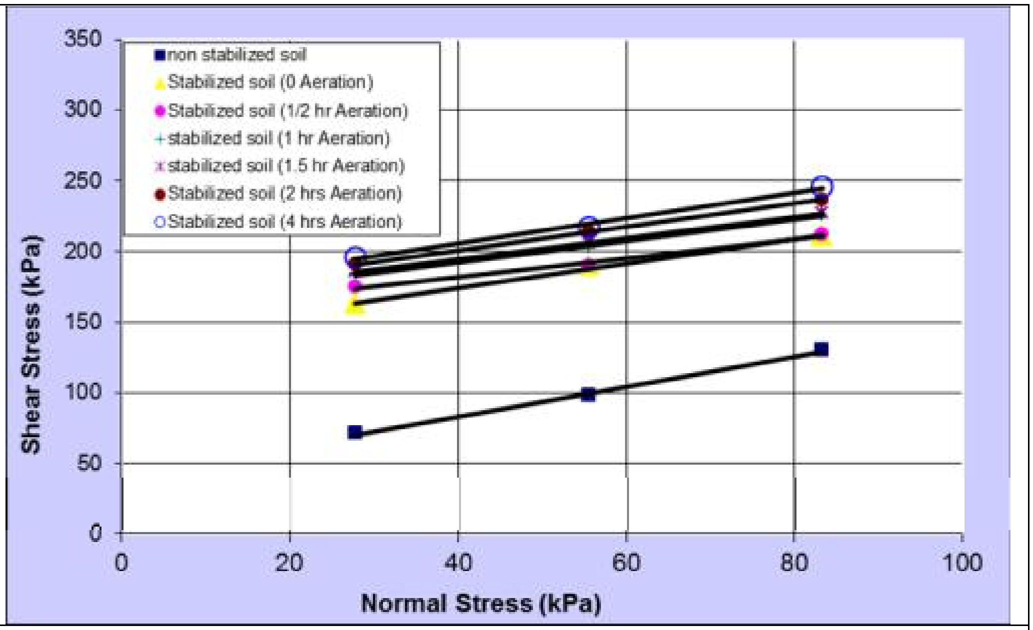

Figure (9) Direct shear test results for stabilized and non-stabilized soil.

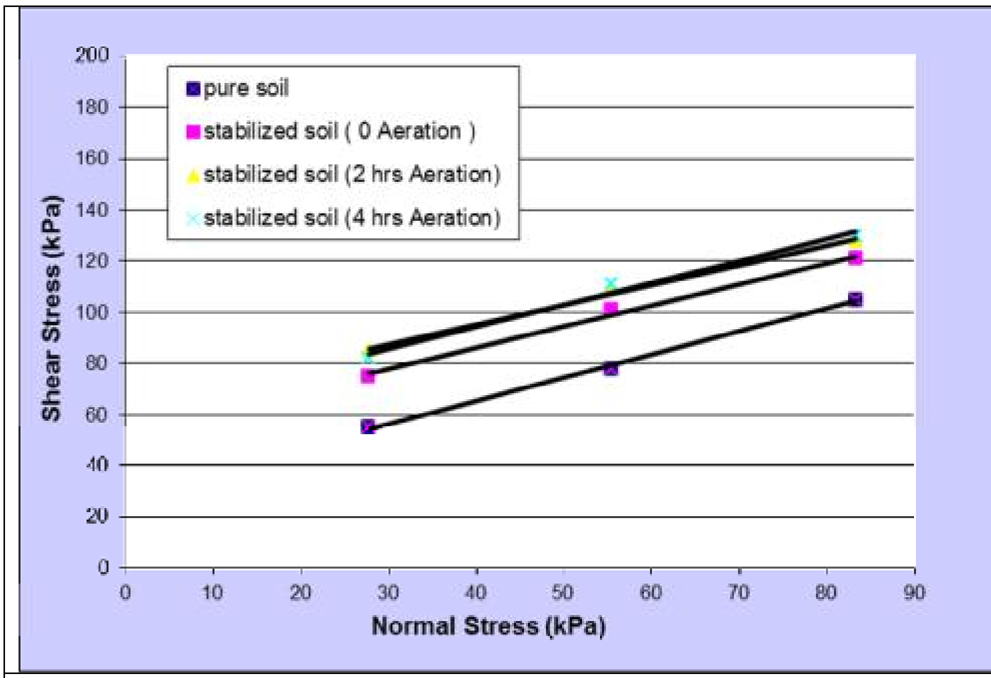

Figure (10) Direct shear test results for stabilized and non-stabilized gypseous soil under soaked condition with aeration technique.

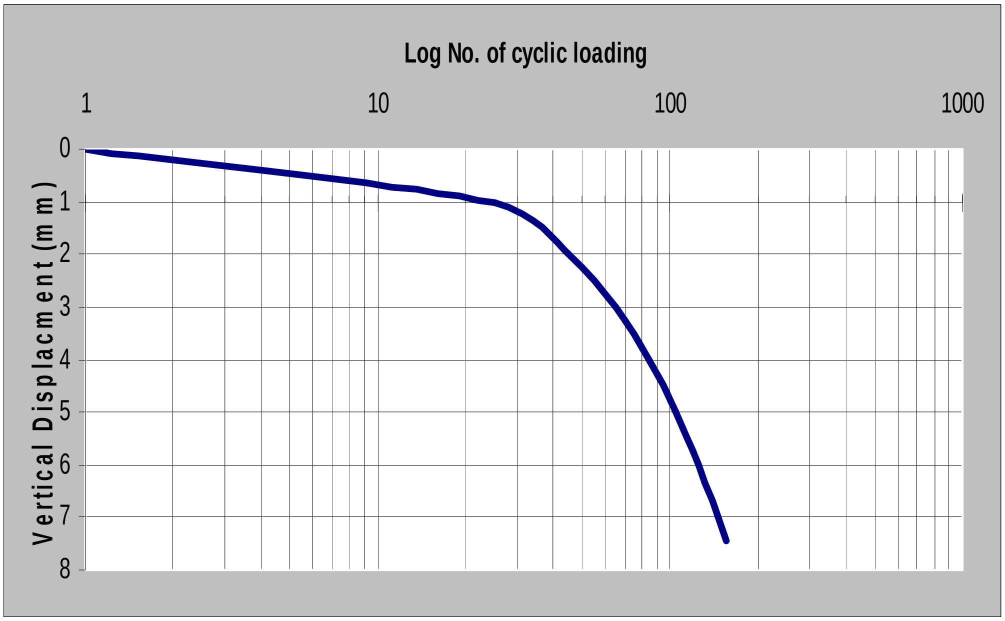

Figure (11) Relationship between vertical displacement with log No. of loading cycles for pure gypseous soil model at dry condition.

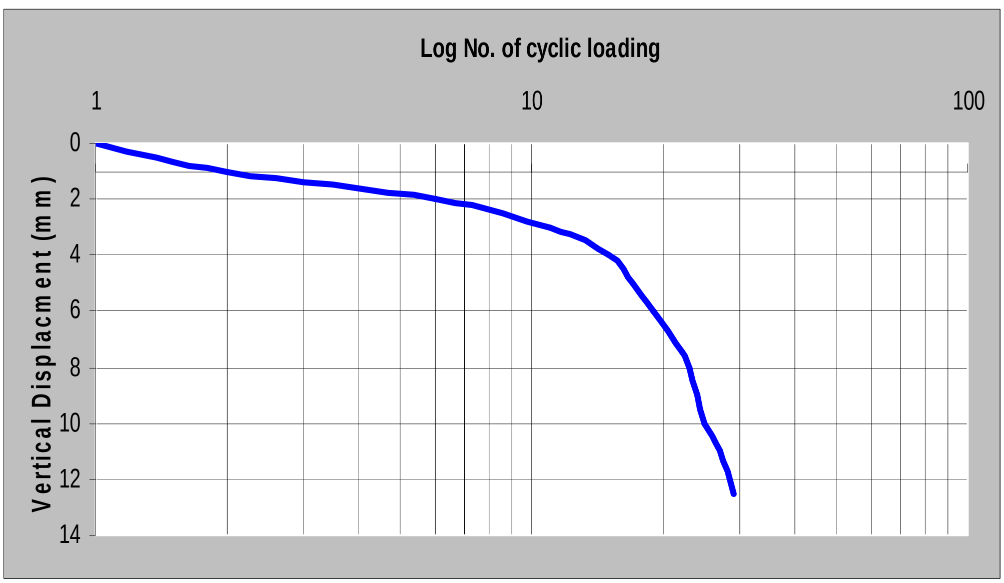

Figure (12) Relationship between vertical displacement and log No. of loading cycles for absorbed pure soil model.

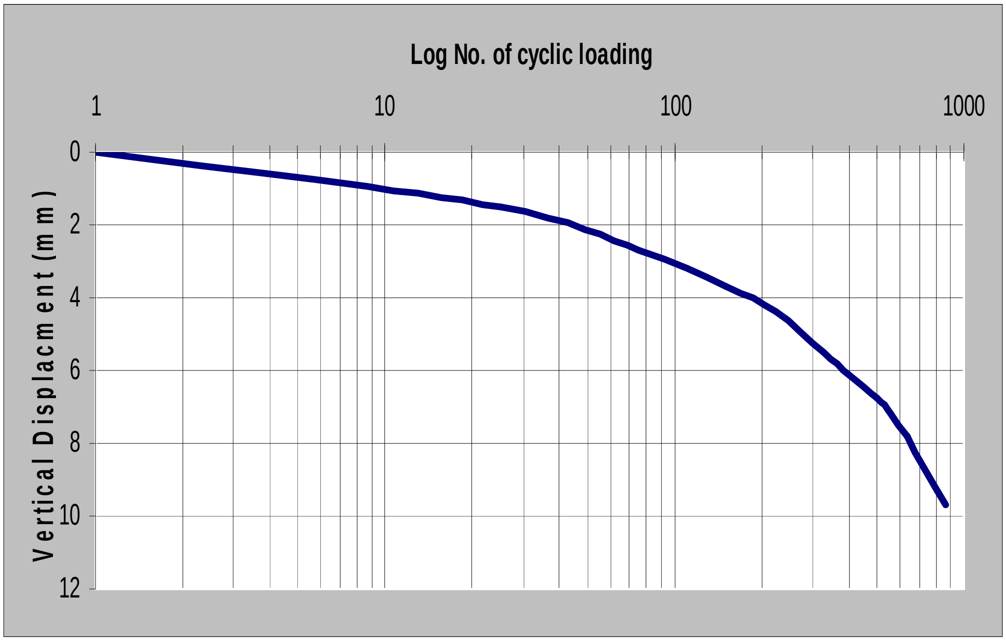

Figure (13) Relationship between No. of loading cycles with vertical displacemen for stabilized gypseous soil at dry condition.

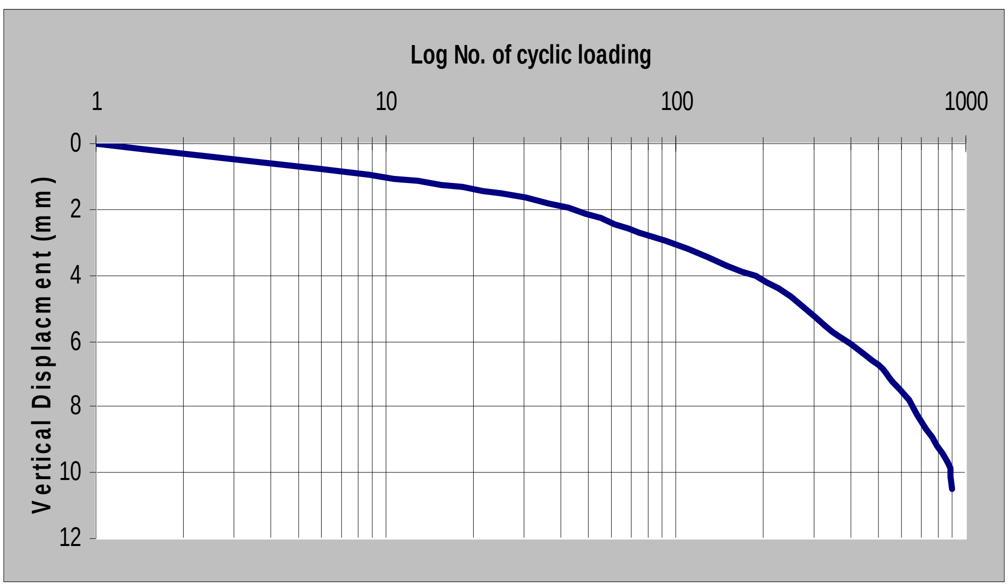

Figure (14) Relationship between No. of loading cycles with vertical displacement for stabilized gypseous soil at absorbed condition.

Plate (1) Model box of cyclic load.

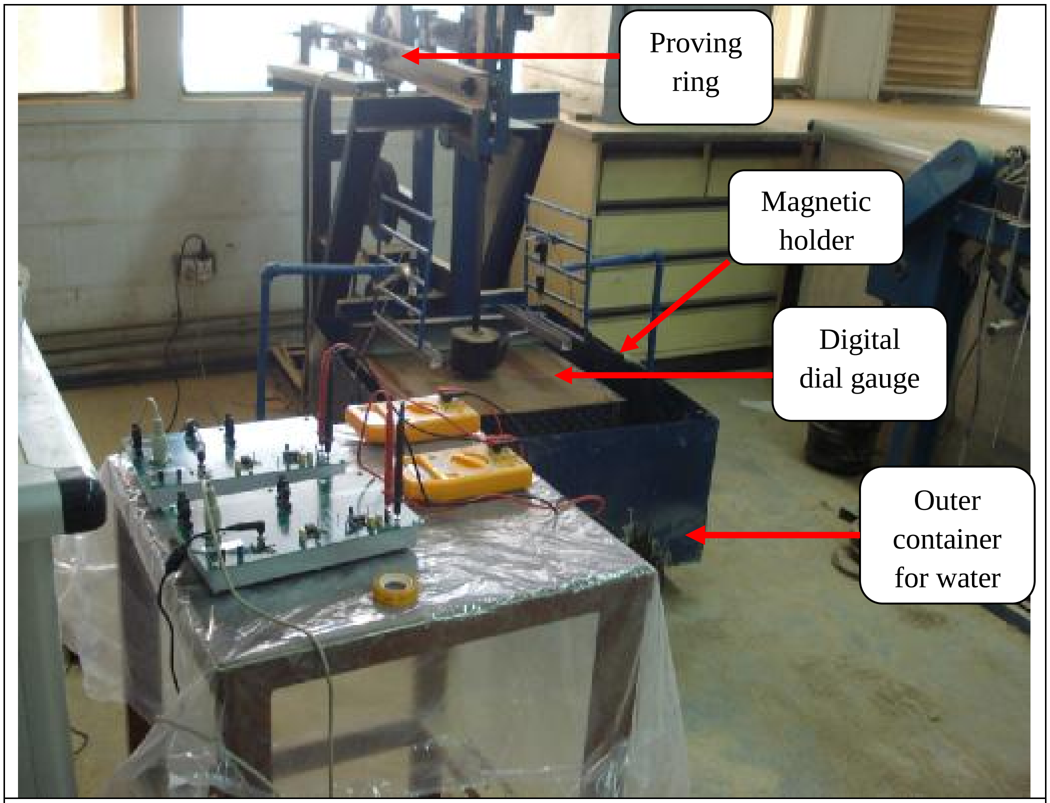

Plate (2) Cyclic loading setup on the soil model.

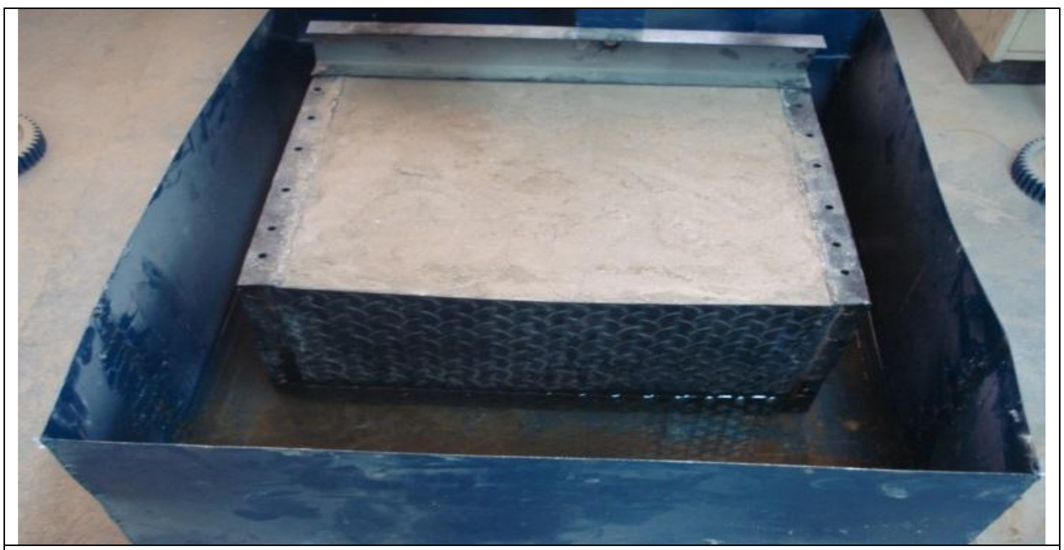

Plate (3) Soil model subjected to water absorption.

Plate (4) Effect of flow on capillary rise of water through the soil model.