Improvement of Gypseous Soil Using Cutback Asphalt

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ABSTRACT

Gypseous soils are widely distributed and especially in Iraq where arid area of hot climatic is present. These soils are considered as problematic soils; therefore this work attends to improve the geotechnical properties of such soil and reduce the dangers of collapse due to wetting process. In this research, undisturbed soil sample of 30 % gypsum content from Karbala city is used. The Single Oedometer collapse test is used in order to investigate the collapse characteristics of natural soil and after treatment with 3%, 6%, 9%, 12% and 15% of Cutback Asphalt. Moreover, two selected additive percentages (9% and 12%) are used to evaluate the suitability of using the Cutback Asphalt for improvement of the bearing capacity of gypseous soils. A steel model box is used for this purpose, the treatment depth is equal to one and twice the footing width. The tests results showed that the total settlement of 25 mm of treated soil with (MC-30) material can be achieved at vertical stress lower than that value required for natural soil. Also, thickness of treated layer with (MC-30) material below the proposed foundation has a significant effect on the value of bearing capacity of the soil. The rate of salt dissolved (C.V) is extremely decreased especially at all percentages of Cutback Asphalt. The best bearing improvement ratio is found at 9% asphalt and at a depth equal to foundation width. However, the Cutback Asphalt can be successfully used by 12% for collapse potential treatment while it is not suitable for improvement of the bearing capacity of gypseous soils.

Key words: gypsum soil, cutback asphalt, collapse potential.

تثبيت التربة الجبسية بأستخدام الاسفلت السائل

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ألخلاصه

تنتشر الترب الجبسية بمناطق محددة من العالم بشكل عام وبالعراق على وجه الخصوص حيث تتواجد المناطق القاحلة ذات المناخ الحار.
تعتبر هذه الترب من الترب ذات المشاكل الهندسية الانهيارية لذلك يهدف هذا البحث الى محاولة تحسين خصائص هذه التربة وتقليل خطر الانهيار عند تعرضها للترطيب .
في هذا البحث تم استخدام نموذج التربة من محافظة كربلاء بنسبه جبس30% وتم التحري عن الطاقة الانهيارية للتربة باستخدام فحص الاودوميتر المفرد .
الدراسة اقترحت معالجة مشكلة الانهيار في هذه التربة باستخدام مادة (Cutback Asphalt) (MC-30) بنسبة 3%,6%,9%,12%,15% وباعماق مساوية لعرض الاساس وضعف عرض الاساس .نتائج المعالجة بينت تصنيف الترب الجبسية بانها تربة ذات مشكلة هندسية من النوع الخطر بسبب ارتفاع قيمة طاقة الانهيار الى 10%. أوضحت النتائج انه يمكن استخدام ماده الاسفلت نوع (MC-30) بنجاح في تحسين خصائص الانهيار للترب الجبسية ولغاية محتوى امثل للاسفلت في التربة وبنسبة 12% . بناء على ذلك فانه تنخفض قابلية التحمل للتربة الجبسية بزيادة نسبه الاسفلت المضاف بصورة تدريجية .
لقد اظهرت نتائج الفحص ان التربة المعالجة بمادة الاسفلت (MC-30) تصل الى الهبوط الكلي البالغ 25 mm تحت اجهاد عمودي اقل من قيمة الاجهاد العمودي المطلوب للحصول على نفس مقدار الهبوط للتربة الطبيعية . كما ان سمك الطبقة المعالجة بماده الاسفلت (MC-30) تحت الاساس لها تاثير كبير على مقدار قابلية التحمل للترب الجبسية .ان معدل ذوبان

الاملاح ينخفض كثيرا بصورة خاصة عند زيادة نسبة الاسفلت المضاف. من خلال دراسة النتائج وجد ان احسن نسبة لتحسين في قابلية التحمل هي 9%من مادة الاسفلت عل عمق مساوي الى عرض الاساس. بينت نتائج الفحوص ايضا بأن مادة الاسفلت نجحت بشكل كبير في تحسين خصائص الانهيار لكنها غير ملائمة لتحسين قابلية التحمل للترب الجبسية.

1. INTRODUCTION

Gypseous soils are of the most complex materials that challenge the geotechnical engineers. It is a well-known fact that gypseous soils demonstrate high bearing capacity and very low compressibility when they are in the dry state. Conversely sudden collapsible disposal was reported when the gypseous soils are exposed to water. The collapsibility of gypseous soils scores from the direct contact of water. The rate of dissolution of gypsum depends primarily on environmental changes in moisture content generating from fluctuation of ground water table and/or surface water, permeability and state of flow conditions in addition to the type and content of gypsum**, Al-Saoudi et.al, 2013.** The dissolution of gypsum particles within the soil mass due to wetting can cause many problems to the engineering structures and road network the structure of gypseous soil can be transformed from stable condition to unstable when undergo to increase in moisture content. The gypseous soil is defined as soil that contains sufficient quantities of gypsum (calcium sulphate)**, FAO, 1990.** This soil is commonly formed at dry state particularly due to the cementation of the soil particles by gypsum, but the issue turnoff intricate when the water flow through the gypseous soils causing nominate and reasonable collapse behavior in the soil structure. Many studies have been conducted on gypseous soils in Iraq because they are covering a wide area of nearly 31.7% of the surface sediments of Iraq with gypsum content ranging between 10-70%**, Ismail, 1994,** and are 0.6% of the world**, Alphen and Romero, 1971.** Gypsiferous soils have been studied in the past within the classical framework of soil mechanics that is related to saturated condition. As such, they are characterized as collapsible, problematic soils that suffer large settlement and have significant loss of strength under long term of flooding**, Khalid, 2013.** When salt firmness soils are undergoing softening due to raising in moisture content can cause degeneration of same gypsum. Practically softening can occur in various ways like local shallow wetting, deep local wetting. Many problems have been notified on damages happened to structures supported on gypseous soils like cracks, overturning of structures. These problems are very dangerous, thus improvement of gypseous soils are urgently necessary. On the other hand, asphalt material can be used as improvement material for the problematic soils where the main function of asphalt is to reduce the effect of water on gypsum particles and to increase the strength parameters of the soil**, Al-Obaydi et.al, 2007.** In Iraq, asphalt is a cheap and available material; it can be easily used to improve the properties of gypseous soil. Many forms of asphalt are available such as asphaltic bitumen, tars, Cutback Asphalt and emulsion asphalt or bitumen can be added to the base soil of roads, Kadhim**, 2014.**

The Cutback Asphalt is most common and economical type of asphaltic materials used for soil stabilization especially medium-curing types where it's produced from the refineries**, Transport and Road Research Laboratory, 1987**. Moreover, **Jasim, 2015** assessed the durability of asphalt stabilized gypseous soil by using emulsion asphalt. It was stated that after exposing the specimens to cycles of (heating – cooling), the undrained shear strength increased up to 10 cycles then decreased with further increased number of cycles. The dissolution of gypsum due to distillation, irrigation and hail water or from other provenance is a risky case in gypseous soil age. This process will command to on undue and sometimes tragic settlement. Shear strength of soil will minimize as a result of this process. The safety and good execution of the foundation of structures particularly in hydraulic structures and earth structure like embankments and dams will be administered by the changes in the properties of these soils.

2. PREVIOUS EXPERIENCES

The behavior of gypseous soils and its improvements attempts were carried out by many research works which can be outlined as follows:

Al-Rawi, 1971 suggested that both cutback and emulsion asphalt could be used to stabilize Iraqi soils.

Epps et.al, 1971 studied the mixture of sandy soil with asphalt and found that 4-5% is the optimum cutback percent for maximum stability.

Al-Kawaaz, 1990 studied the behavior of sandy gypesous soil asphalt mix in Oedometer test; the main conclusion is the increase in binder content.

Al-Shakayree, 2003 showed that, in sandy soil the maximum dry unit weight decreases, and the optimum water content increases with the increase in gypsum content result in increase in rebound strain.

Al-Obaidi, 2003 used two materials in order to improve the collapsibility characteristics of sandy gypseous soil with gypsum content of 70% from Al-Ramady city west of Iraq. The first material was Glass sand as a natural residual material, and the second was powder of destroyed ceramic as a residual of industrial material. Both materials succeeded to improve the collapse deformation of gypseous soil with more than 50%, where the collapse potential reduced from about 10% to 4.5%.

Al-Harbawy and Al-Khashab, 2004 reported the effect of stabilizing gypseous soil using liquid asphalt types such as cutback and emulsion on its behavior of shear strength is considerably observed. Addition of liquid asphalt provides cohesion strength to the soil mass and also acts as a waterproofing agent. Cutback Asphalt increases the resistance of gypseous soil to permeability, such resistance increases as void ratio increases.

Al-Saidi et.al, 2011 demonstrated that the stabilizing of gypseous soil using the optimum fluid content of 16% (5%Cutback Asphalt+11% water) led to improve the unconfined compressive strength, compressibility, and rebound consolidation. The additive acts as waterproofing of gypseous soil. While under absorbed condition, lime-cutback mixture was used in order to satisfy the base course construction requirements.

Aziz, 2011 showed that fuel oil is a good material to modify the basic properties of the gypseous soil such as collapsibility and permeability, which are the main problems of this soil. The fuel oil provides an appropriate amount of the cohesion in the soil which is suitable for carrying the loads from the structure.

3. MATERIALS

3.1 Gypseous Soil

The soil samples were taken from Eaan Tamur city, Karbala governorate, south west of Iraq. From a depth of 3m up to 6m below the natural ground level. The samples are packed in a double nylon bags and transported to the soil mechanics laboratory at University of Technology in Baghdad for testing.

3.2 Asphalt

The type of asphalt used in this research is medium curing cutback (MC-30) liquid asphalt which is used in maintenance of surface layers of asphalt produced by Al- Dora Refinery in Baghdad Governorate. This type is fabricated by one step:

$$91.2\ \%\ [(40\text{-}50)\ \text{asphalt cement}] + 8.8\%\ [\text{kerosene}] \rightarrow (\text{MC-30}) \quad (1)$$

Properties of Cutback Asphalt (MC-30) used are given in **Table 1.**

4. PROPERTIES OF GYPSEOUS SOILS

4.1 Physical Properties

The summary of the physical tests results are shown in **Table 2.**

4.1.1 Grain size distribution

The grain size distribution was determined according to **(ASTM D422- 63, (2007))** using dry sieving. The grain size distribution curve of the soil is clarified in **Fig.1.**

4.1.2 Specific gravity

The specific gravity was determined according to BS 1377: 1975, Test No.6 (B). Kerosene was used instead of distilled water because of the dissolving action of gypsum by water**, Head, 1980.**

4.1.3 Water content

This was determined in accordance to BS 1377:1975, Test (A).The oven dry temperature was kept at 45°C due to dehydration of gypsum.

4.1.4 Compaction test

Standard compaction tests are carried out on soil sample to determine the water content –unit weight relationship according to**, ASTM D698, 2000**.

4.2 Chemical Properties

The gypsum content is determined according to the method presented by**, Al-Mufty and Nashat, 2000**. This method consists of oven drying the soil at 45°C until the weight of the sample becomes constant. The weight of the sample at 45 °C is recorded, then the same sample is dried at 110°C for 24 hrs and the weight is recorded again. The gypsum content is then calculated according to the following equation:

$$X\ (\%) = \frac{[\![w_{45^\circ c} - w_{110^\circ c}]\!]}{w_{45^\circ c}} x4.778x100 \quad (2)$$

Where:
x= gypsum content (%).

$w_{45^\circ c}$ = weigth of the sample at 45 °C.

$w_{110^\circ c}$ = weigth of the sample at 110°C.

4.3 Geotechnical Properties

4.3.1 Collapsibility

Gypseous soils exhibits collapse behavior as results of volume change upon wetting. The term of "collapse"commonly refers to the deformation of the soil mass due to reduction in its volume when exposed to water. **Jennings and Knight, 1957** proposed a single Oedometer collapse test to predict the collapsibility of the soil under the foundation. The collapse potential C.P is defined as:

$$C.P = \frac{\Delta e}{1 + e_\circ} \quad (3)$$

Where:
Δe = the difference in void ratio of the sample at a specific stress.
$e_\circ$ = the natural void ratio.
The severity of collapse according to the collapse potential is shown in **Table 3**.
It was found that, the value of collapse potential for the natural soil is (10%), and according to the specification listed in **Table.3** the case of severity is classified as trouble to severe, and hence the soil needs to be treated.

5. EXPERIMENTAL PROGRAM

The experimental program in this study can be categorized into the following groups:

Group (A): Consisting of five mixtures which were prepared from various percentages of Cutback Asphalt and added to the natural gypseous soil samples in order to perform the testing program. The percentages of Cutback Asphalt are 3%, 6%, 9%, 12%, and 15% and expressed as binder content (%) these values were chosen depending on numerous references that stated and specified. The range of the binder content used by**, Kadhim, 2014** who employed percentages of binder was equal 2%, 4%, 6%, 8%, 10%. The mixed samples were tested by single Oedometer collapse test, the sample was prepared in Oedometer ring with initial condition unit weight equal 12.5 $\frac{kN}{m^3}$ .The loading sequence of single Oedometer collapse test is 25, 50, 100, 200 and 400 kPa, and the loading interval is 1 hour for each vertical stress. However, the loading duration for the collapse stress of 200 kPa is 24 hours for both unsaturated (drying) and saturated (soaking) conditions. The loading sequence of single Oedometer test is according to **Jennings and Knight, 1957 and ASTM D5333, 2003**.

Group (B): The geotechnical model tests of this group were conducted in proposed steel model box with dimensions of 30 cm in length, 30 cm in width and 35 cm in depth. The filter layer of fine gravel material was placed to a depth of 5cm from the bottom of steel box. The soil was prepared at the same properties used in group A. The soil strata extend to the depth of 2B from the surface filter where B is the footing width. The model is soaked with water by means of flexible pipe connected at the container bottom. Two values of collapse potential (6.2% and 2.6%) were chosen to be treated, which are corresponding to asphalt contents of (9% and 12%) respectively. These values of asphalt contents represented the best treatment percentages, which succeeded to obtain significant reduction in collapse potential from single Oedometer collapse test. This treatment can be induced to a depth of 6 cm and 12 cm under model foundation. A square footing of dimension 6 × 6 cm was placed on the surface of the treated soil layer and subjected to vertical static loading where the loads are applied at regular time intervals of (4-15) min according to **ASTM D1194, 1994** for each load increments. One dial gauge was used and the vertical settlement of the footing for each increment of load was recorded.

6. DISCUSSION OF TEST RESULTS

6.1 Collapse Test

The results of single Oedometer collapse test can be shown in **Table 4.** and **Fig.2** The reduction in collapse potential of gypsum soil is clearly observed as a result of adding the Cutback Asphalt material (MC-30) as shown in **Fig.2**. The collapse potential (C.P) is considerably decreased from 10% to 2.6% with the increase in the percentage of (MC-30) to 12%. This behavior is attributed to the action of asphalt material as water proofing for gypsum particles, in other words the (MC-30) film fill the air voids in soil mass as well as covering the gypsum grain and reduce its ability to dissolve by water. The improvement results showed that 12% of Cutback Asphalt additive is the optimum value for collapse reduction. Adding (MC-30) material such as 15% leads to a reverse behavior where the deformation of the soil mass increased dramatically as shown in **Fig.2** The increasing of soil deformation with high percentage of (MC-30) asphalt can be related to two reasons, the first reason is the lubricant action of (MC-30) layer which causes sliding of soil particles each one on other during loading. The second one can be related to the increase of the total volume and liquidity of the soil mass with the increase of (MC-30) content which may cause direct decrease in the value of dry density and increases the collapse potential.

6.2 Effect of Cutback Additive on the Coefficient of Salt Dissolved

Firstly, the material of Cutback Asphalt additive tries to reduce the water accessibility to the gypsum particles. Then, the presence of Cutback Asphalt as a thin layer surrounded the soil particle also leads to decreasing the interaction between the water and gypsum subsequently, the reaction between them would be slow. Thus, the salts dissolution need more time to be significantly settled. It is worthy mentioned, that (C.V) is expressed as the rate of settlement of soil or by other words represents the coefficient of salt dissolved during soaking.

The addition of Cutback Asphalt to the gypseous soil shows a good reduction in settlement value so that the asphalt percentage has a proportional relation with the time required for collapse to occur. **Table 5** presents the variation the coefficient of salt dissolved with different amounts of asphalt ranging from 0 to 15%. It is noticed that, adding (0%, 3%, 6%, 9%, 12%, and 15%) asphalt require to (8, 11, 13, 15, 31, and 33) minutes to achieve 90% of total dissolve of salts. However, the test results indicated the high suitability of Cutback Asphalt to be used as improvement material for collapsibility of gypseous soils. The results also demonstrate an excellent indication on the asphalt efficiency to be used in reducing the gypsum soil collapse. The effect of asphalt content on the coefficient of salt dissolved can be displayed in **Fig.3 to 8.** From the **Fig.3 to 8** it was observed that, the irregular shapes of curves upon loading are attributed to the addition of asphalt to the gypseous soil reduce the amount of dissolved gypseous and coefficient of salt dissolved (C.V).

6.3 Bearing Capacity Test

The bearing capacity of gypseous soil after treatment with 9% and 12% of (MC-30) asphalt was investigated using proposed foundation model with treatment depth of 6 cm and 12 cm. The results of load-settlement relationship shown in **Fig.11** indicate that, the bearing capacity decreases after treatment with (MC-30) material. The total settlement of 25 mm of treated soil can be achieved at vertical stress lower than those value required for natural soil. Moreover, treatment of gypseous soil to a depth deeper than 1B (i.e. 6 cm) causes more reduction in the value of bearing capacity of the soil. This behavior can be attributed to decreasing of the shear strength of the soil with adding of (MC-30) material as a result of decrease in angle of internal friction. Moreover, the load distribution under proposed foundation extends normally to a depth of 2B, therefore in this case study it can be observed that the bearing capacity in the first case of treatment (i.e. to a depth 2B of 12 cm) is lower than the first case of treatment (i.e. to a depth 1B of 6 cm). That is clearly shown in **Fig.13.**

On the other hand at a depth equivalent to foundation width, it was noted that the bearing improvement ratio (B.I.R) increased from 136% to 192% when the asphalt amount in soil decreased from 12% to 9% respectively. This could be explained that the best percent of improvement was gained when the amount of asphalt is 9%. In other words, any increase in asphalt percent could lead to a negative effect on the bearing capacity. This could be attributed to the amount of asphalt existed in the soil at 12% which causes increasing the soil compressibility and reducing the shear strength at this percent more than its effect on soil collapse; hence, reducing the bearing capacity and increasing the settlement value. This is clear in **Fig.11.** When the depth of soil-asphalt mixture equals to double foundation width, the asphalt presence at any percent at this depth reduces significantly the bearing capacity because: a large area of influence zone beneath the foundation would be increased in terms of compressibility and decreased in terms of modulus of elasticity. Thus, the shear properties (C and φ) would considerably reduce and this explains the reduction in (B.I.R) value with respect to asphalt percent. **Fig.13** clarifies the result.

In sequence the settlement values after using the admixture was less than their corresponding values without admixture. The value of settlement reduction ratio (S.R.R) decreased to 0.52 and 0.68 at an admixture ratio of 12% and 9% respectively. Therefore, the best percent in reducing the settlement at depth (asphalt + soil) equal to foundation width was 9%, as clearly is shown in **Fig. 11.**

Regarding the stabilized soil with asphalt at a depth of double value of foundation width, it was found that, the settlement in both cases of asphalt 9% and 12% increases the settlement with respect to that calculated from the untreated soils. Thus, stabilizing at a depth of 2B at any admixture percent would has a negative effect on the settlement values. This is clearly shown in **Fig.13.**

7. CONCLUSIONS

1. The Cutback Asphalt (MC-30) material can be used successfully to improve the collapsibility characteristics of gypseous soil and the optimum (MC-30) asphalt recommended is 12 %.
2. The bearing capacity of the soil decreases after treatment with (MC-30) asphalt. Thus this additive is not suitable for improvement of the bearing capacity of gypseous soils.
3. The total settlement of 25 mm of treated soil with (MC-30) material can be achieved at vertical stress lower than that value required for natural soil.
4. The thickness of treated layer with Cutback Asphalt material below the proposed foundation has a significant effect on the value of bearing capacity of the footing.
5. The rate of collapse (C.V) extremely decreases using all the percentages of Cutback Asphalt.
6. The best percent of bearing improvement ratio (B.I.R) and settlement reduction ratio (S.R.R) are acquired at a depth equal to foundation width, and when the asphalt content is 9%.

REFERENCES

- Al-Harbawy, A.F.Q., Al-Khashab, M.N., 2004, *The Effect of Emulsified Asphalt Addition on Some of the Engineering Properties of Expansive Clayey Soils*, Eng. And Technology, Vol.2, No. 23, PP.51-71.

- Al-Kawaaz, N., 1990, *Characteristics of Soil Asphalt Mixture*, M.Sc. Thesis, College of Engineering, University of Baghdad.
- Al-Mufty, A. A, and Nashat, E. H., 2000, *Gypsum Content Determination in Gypseous Soil and Rock*, Proceedings of the 3^{th} Jordanian International Mining Conference Amman, Vol.2, PP.485-492.

- Al-Obaydi, A. A. H., Mohmmed, Y. T., and Omar, M. E. T., 2007, *The Use of Liquid Asphalt to Improve Gypseous Soils*, internet reference www.iasj.net/iasj.

- Al-Obaidi, Q.A.J., 2003, *Studies in Geotechnical and Collapsible Characteristics of Gypseous soil*, M.Sc. Thesis, Civil Engineering Department, College of Engineering, Al-Mustansiriyah University, Baghdad, Iraq.

- Alphen, J.G.V., and Romero, F.D.E., 1971, *Gypsiferou Soils*, Bulletin-21, Int., Inst. for Land Reclamation and Improvement, Wegeningen, Holland.

- Al-Rawi N., 1971, *Prospects of Using Asphalt to Stabilize Iraqi Soils,* AL-Muhandis, Vol.15, No.3, Baghdad, Iraq.

- Al-Saoudi, N. K. S., Al-Khafaji, A. N., and Al-Mosawi, M. J., 2013, *Challening Problems of Gypseous Soils in Iraq,* Proceeding of the18^{th}International Conference on Soil Mechanics and Geotechnical Engineering.

- Al-Shakayree, T.K.K., 2003, *Improvement of Gypseous Soil below Foundation Using Quick Lime*, M. Sc. Thesis, Department of Building and Construction, University of Technology.

- Al-Saidi, Aamal. A., Ban, H. Al-Khayat, and Saad, I. Sarasam, 2011, *Implementation of Gypseous Soil- Asphalt Stabilization Technique for Base Course Construction*, Journal of Engineering, Vol.5, and PP.1.

- Aziz, H. Y., 2011, *Gypseous Soil Improvement Using Fuel Oil*, International Journal of Civil, Environmental, structural, Construction and Architectural Engineering, Vol.5, No.3.

- ASTM D5333, 2003, *Standard Test Method for Measurement of Collapse Potential of Soil,* Annual Book of ASTM Standards, Vol.04.08,

- ASTM D1194, 1994, *Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footing.*

- ASTM D422 -63, 2007, *Standard Test Method for Particle- Size Analysis of Soils.*

- ASTM D698, 2000, *Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (*$600\frac{KN-M}{m^3}$*).*

- British Standard Institution BS 1377, 1975, *Method of Testing Soils for Civil Engineering Purposes*, London.

- Department of the Environmental, Transport and Road Research Laboratory, 1987, *Soil Mechanics for Road Engineering*, London.

- Kadhim, A.J., 2014, S*tabilization of Gypseous Soil by Cutback Asphalt for Roads Construction*, Journal of Engineering and Development, Vol. 18, No.1, ISSN 1813-7822.

- Epps J.A., Dun lap W.A., Gallaway B.M., and Currin D., 1971, *Soil Stabilization*, HRB-HRR No.351.

- FAO, 1990, *Management of Gypseous Soils*, Soil Resources, Management and Conservation Service, FAO Land and Water Development Division.

- Head, K.H., 1980, *Manual of Soil Laboratory Testing*, Vol. 1, Prentch Press, London.

- Ismail, H.N., 1994, *The Use of Gypseous Soils, Symposium on the Gypseous Soils and Their Effect on Strength*, NCCL, Baghdad.

- Jasim .A. L., 2015, *Assessing the Durability of Asphalt Stabilized Gypseous Soil Embankment*, M. Sc. Thesis, Department of Civil Engineering, University of Baghdad.

- Jennings J.E., and Knight K., 1957, *The Additional Settlement of Foundation Sandy Subsoil on Wetting*, Proceeding 4th Int. Conf. Soil mechanics and foundation engineering, Vol.1, PP.316-319.

- Khalid, I. A., 2013, *Effect of Gypsum on The Hydro Mechanical Characteristics of Partially Saturated Sandy Soil*, Ph.D Thesis, College of Cardiff School of Engineering, Cardiff University, British.

NOMENCLATURE

Cc = coefficient of curvature.
Cu = coefficient of uniformly.
C.P = collapse potential (%).
C.V = coefficient of salt dissolve.
$e_{\circ}$ = is the natural void ratio.
Gs = specific gravity.
X = gypsum content (%).
$w_{45^{\circ}c}$ = weigth of the sample at 45 °C.
$w_{110^{\circ}c}$ = weigth of the sample at 110°C.
$\emptyset$ = angle of internal friction.
Δe = is the difference in void ratio of the sample at a specific stress.

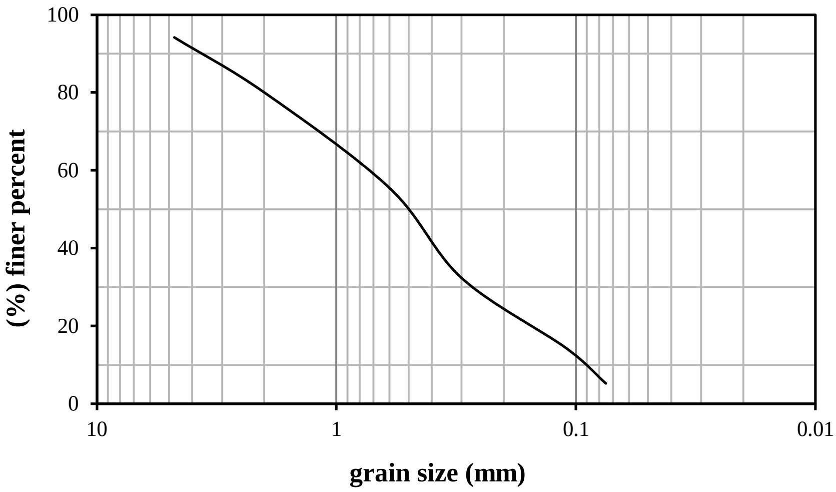

Figure 1. Grain size distribution of soil.

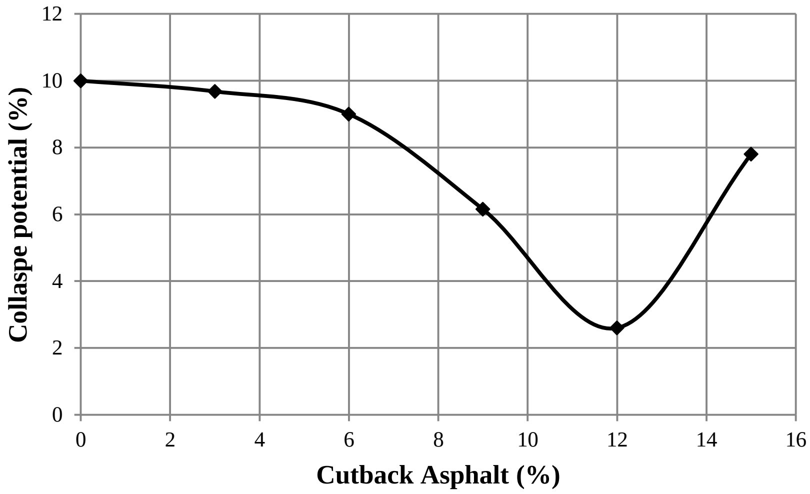

Figure 2. Variation of collapse potential with respected to percentage of Cutback Asphalt**.**

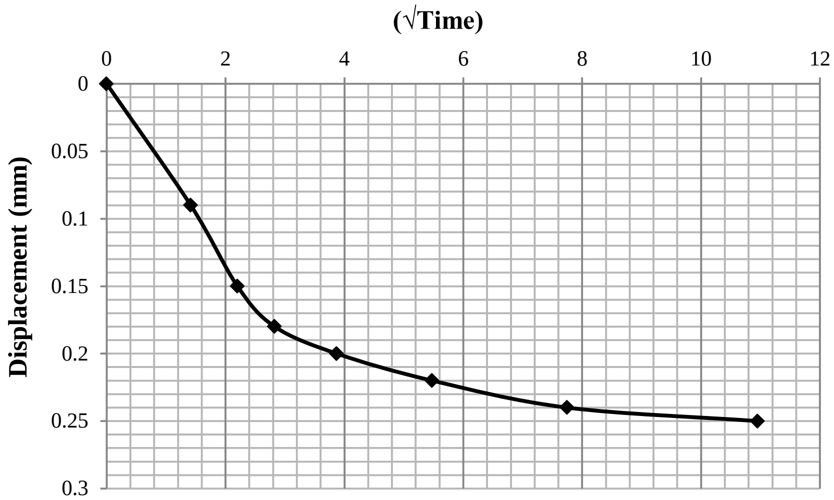

Figure 3. Relationship between displacement vs. time for (the natural case).

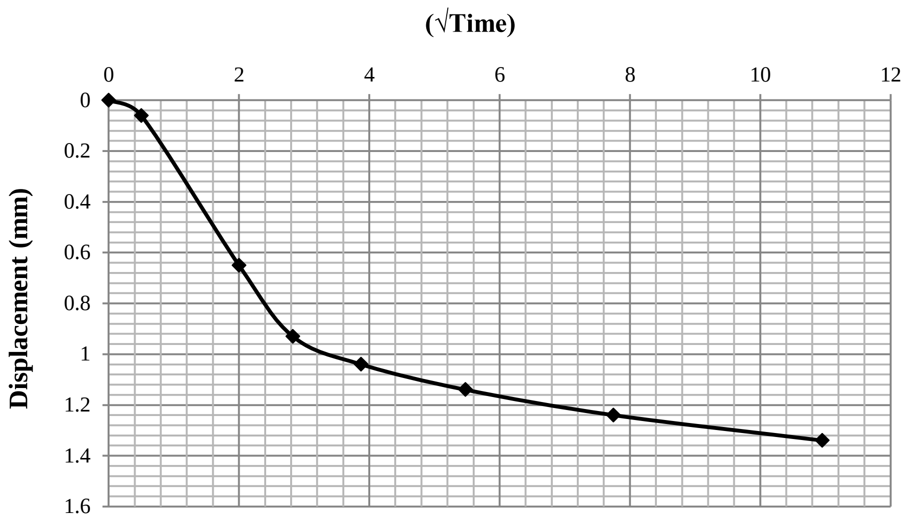

Figure 4. Relationship between displacement vs. time for (3% Cutback Asphalt).

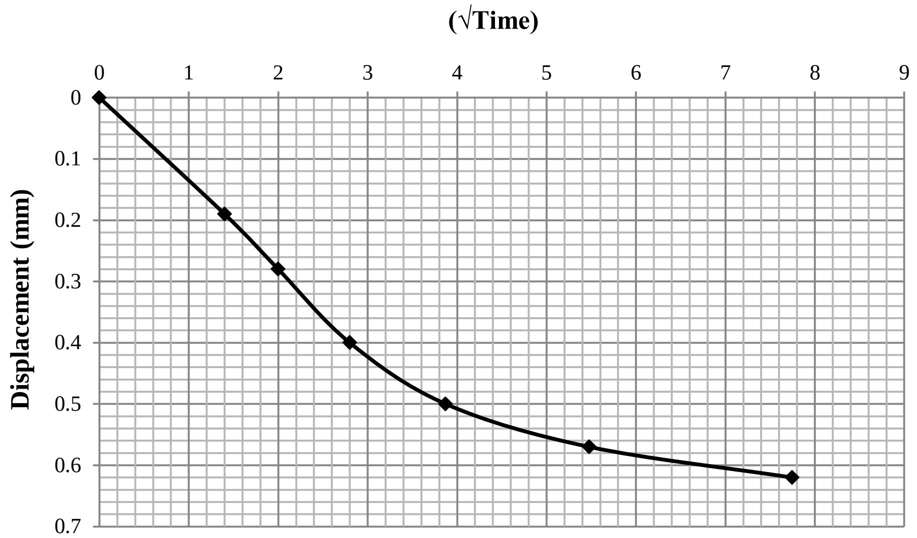

Figure 5. Relationship between displacement vs. time for (6% Cutback Asphalt).

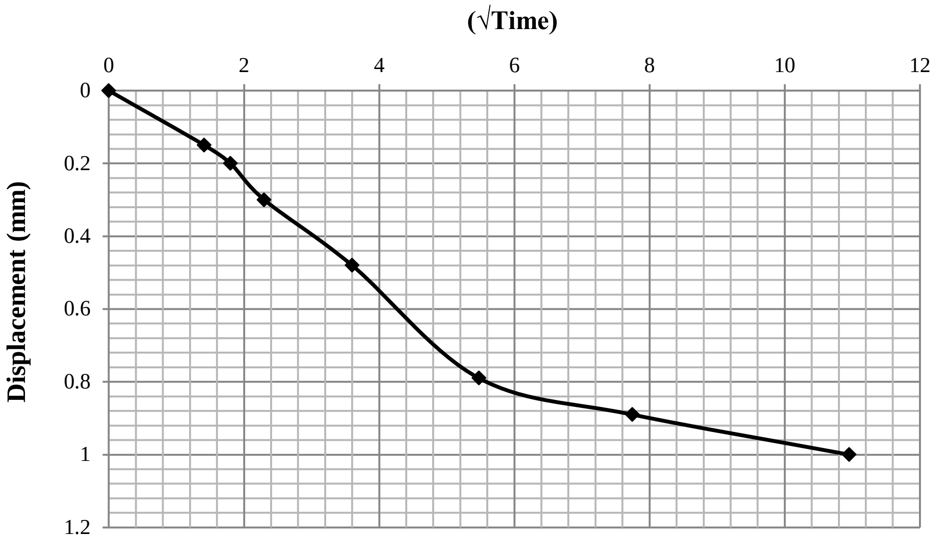

Figure 6. Relationship between displacement vs. time for (9% Cutback Asphalt).

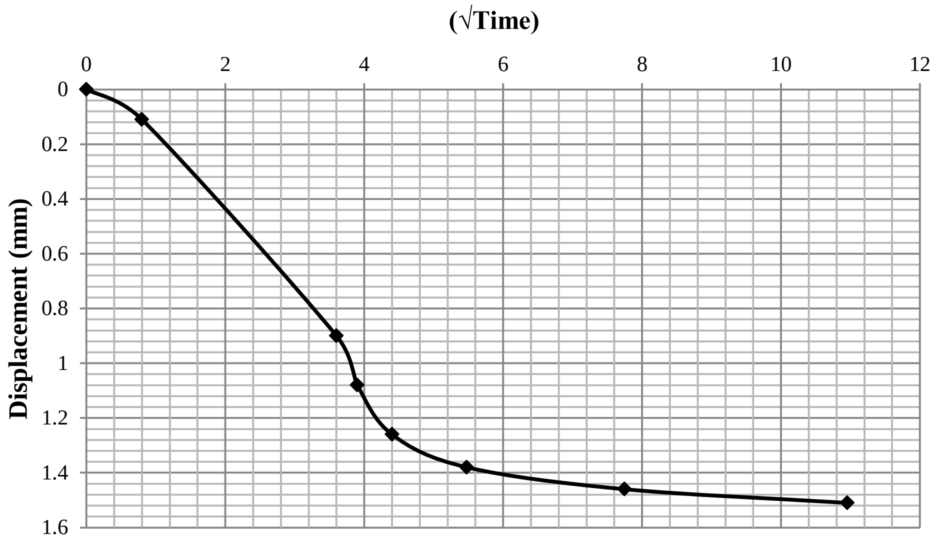

Figure 7. Relationship between displacement vs. time for (12% Cutback Asphalt).

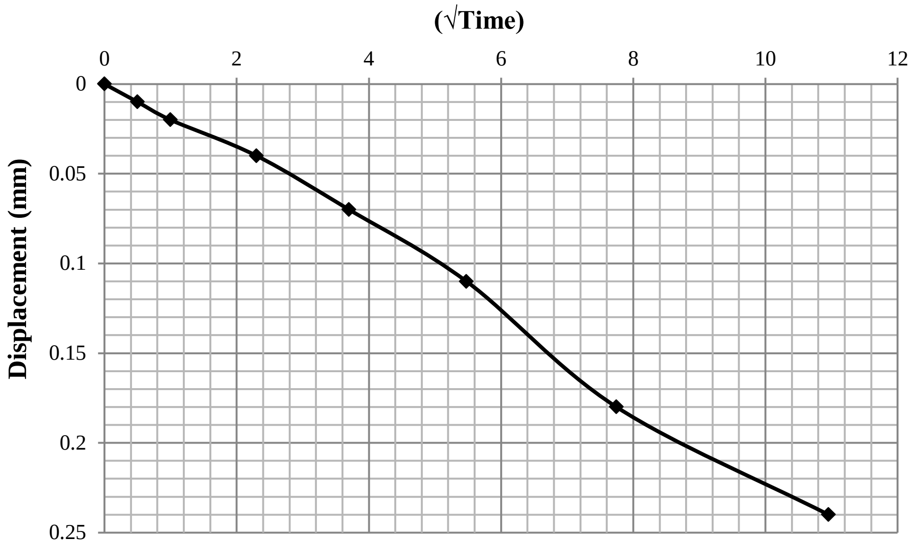

Figure 8. Relationship between displacement vs. time for (15% Cutback Asphalt).

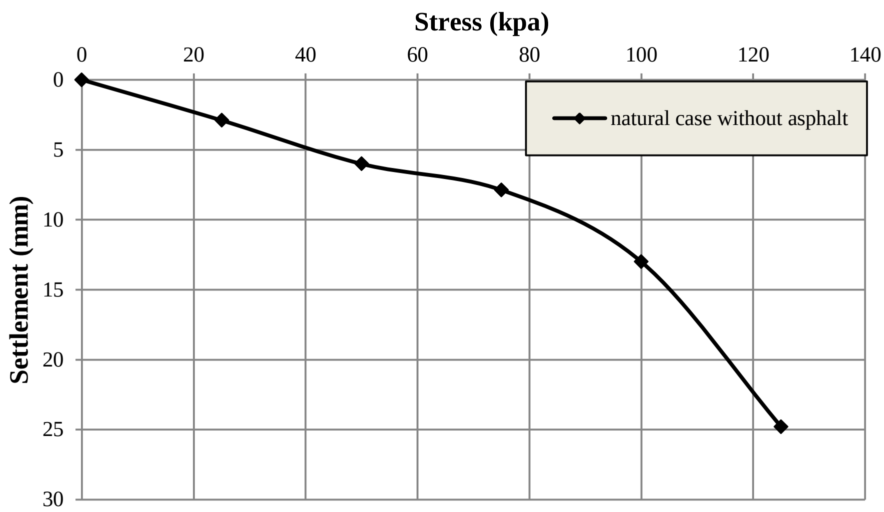

Figure 9. Stress-settlement curve for untreated soil.

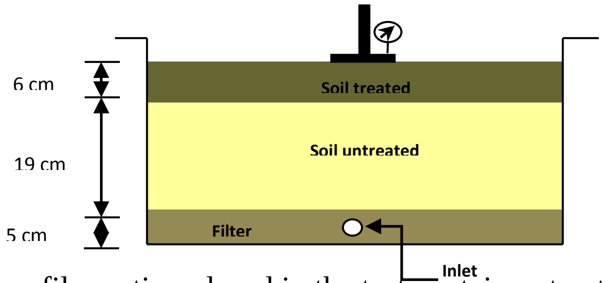

Figure 10. Soil profile section placed in the test container, treated layer equal to footing width(B).

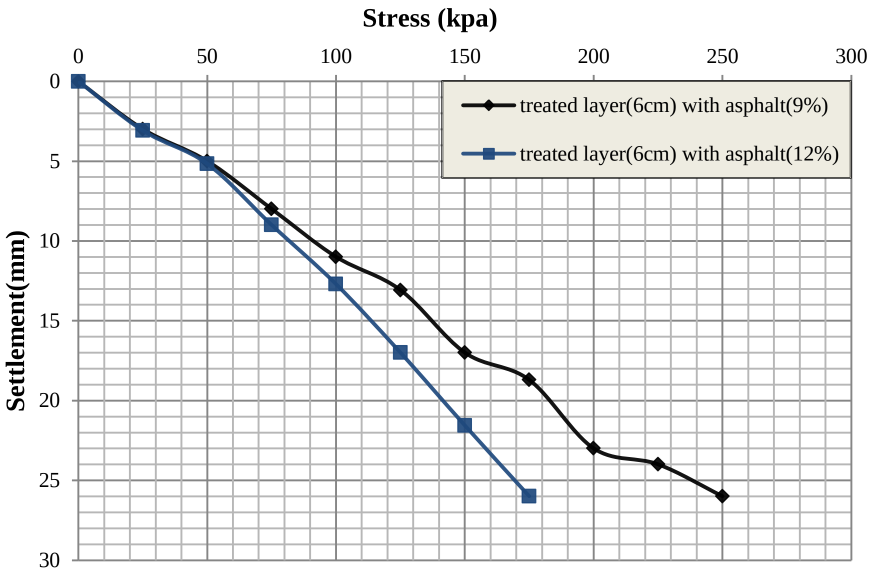

Figure 11. Stress- Settlement curve for soil treated with 9 %and 12% of the asphalt content at a depth equal to footing width.

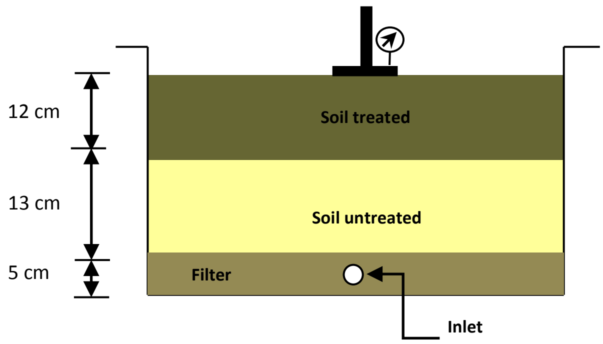

Figure 12. Soil profile section placed in the test container, treated layer equal to footing double width (2B).

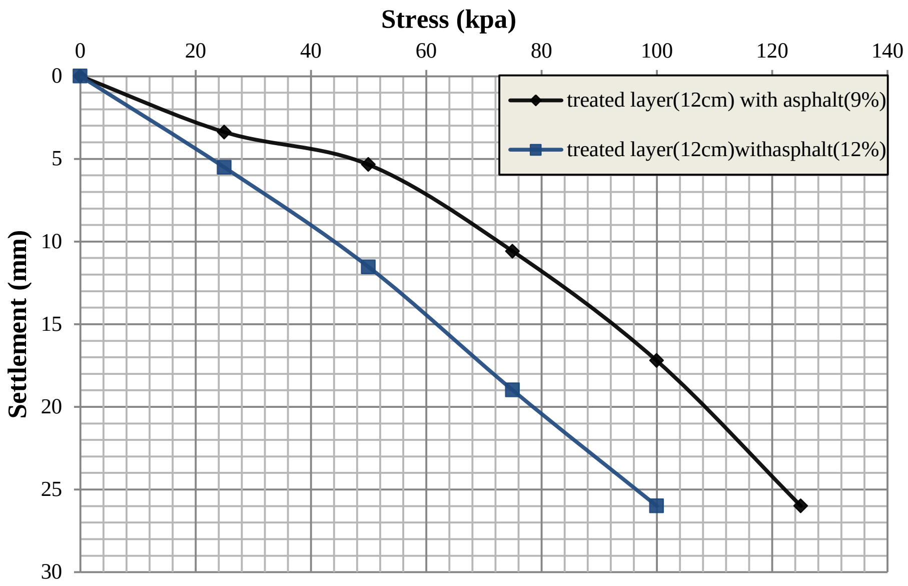

Figure 13. Stress- Settlement curve for soil treated with 9% and 12% of the asphalt content at a depth equal to double footing width.

Table 1. Properties of Cutback Asphalt (as tested by Al-Dora refinery lab).

Properties	Grades
Type	Medium curing cutback languid asphalt (MC-30)
Specific gravity	0.99
Test on residue from distillation penetration at 25°c (100g, 5 sec) Ductility at 25°c Solubility in CCL_4,%weight	120-300 100minimum 99.5 minimum
Kinematics viscosity at 60°c	75-150

Table 2. Summary of the physical properties of the soil**.**

Soil properties	Result value
***Gypsum content (%)	30
Specific gravity (Gs)	2.54
Initial void ratio (e_o)	1.03
Initial water content (%)	12.4
Maximum dry unit weight ($\frac{kN}{m^3}$)	18.1
Optimum water content (%)	13.5
Angle of internal friction ($\emptyset^{\circ}$)	30
Gravel (G) (%)	5.84
Sand (S) (%)	89.36
Silt (M) + Clay (C) (%)	4.8
Soil classification according to (unified soil classification system)	SW
Coefficient of uniformly (Cu)	8.1
Coefficient of curvature (Cc)	1.3

*Gypsum content is determined according to equation (2) section (4.2)

Table 3. Collapse identification (after Jennings and Knight, 1957)**.**

Severity	No problem	Moderate	Trouble	Severe	Very severe
C.P (%)	0-1	1-5	5-10	10-20	20

Table 4. Results of collapse potential.

Cutback Asphalt (%)	Collapse potential (%)
0	10
3	11.2
6	9
9	6.2
12	2.6
15	7.8

Table 5. The coefficient of salt dissolve results with respect to asphalt percentages**.**

Asphalt content (%)	T_{90}	**C.V**
0	8	0.432
3	11	0.3
6	13	0.26
9	15	0.2301
12	31	0.108
15	33	0.102