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Stabilization Of Gypseous Soil By Cutback Asphalt For Roads Construction

Lecture Dr. Ali J. Kadhim
Transportation and Highway Engineering Department
Al-Mustansiriya University

Abstract:

Numerous low- to medium volume roads constructed on gypseous soils, especially in the west and north parts in Iraq such as Al-Anbar & Salah-Al-din, encounter severe pavement cracking and premature loss of serviceability. The roads built on problematic Gypsum soils often become distressed due to volume changes associated with seasonal moisture content fluctuations.

The objective of this paper is to study the effect of cut-back asphalt (MC-30) on the geotechnical properties of gypseous soil as stabilizing agent and investigate the ability of construct the road on this type of soil and obtain some mathematical models using SPSS program.

The soil used in this study has been brought from Tikrit City at Salah-Al-din Governorate in Iraq with (34%) average gypsum content and classified as (SP) according to (USCS).

A series of laboratory tests included physical, chemical, shear strength, collapsibility and stability tests are conducted on both untreated and treated soil samples with cut-back asphalt. Compacted soil samples with specification are prepared and five different percentage of cut-back asphalt are added to the soil samples and named as a binder content as (2, 4, 6, 8, and10) % and then tested.

The results showed that using cut-back asphalt represents good solution and suitable alternative to improve the properties of gypseous soils by elimination the dissolving of gypsum when become in touch with water as well as increase in strength and stability properties of soil by increasing CBR values and reducing the collapse potential. Furthermore, it is noticed that the values of (6-8) % binder content of cut-back asphalt consider the best percentage that can be added to this type of soil to improve its physical, strength and water proofing properties.

The analytical approach was introduced to study the behavior of Stabilization of Gypseous soil stabilized by cutback Asphalt for roads construction. All results were entered into SPSS statistics17.0program. Many mathematical models were obtained on developed model as a result of regression analysis. A general mathematical expression linearly and nonlinear for C.B.R and unconfined compression strength with regression of about 0.9.The models could be valid for all required values which shows that the modelling effort has been well defined and successful.

Keywords: Binder Content; Bitumen; Cut-back asphalt; Engineering properties; Gypsum; Roads; Soil; Stabilization.

تثبيت الترب الجبسية باستخدام مادة Cutback asphalt في انشاء الطرق

م.د. علي جبار كاظم
قسم هندسة الطرق والنقل – كلية الهندسة – الجامعة المستنصرية

الخلاصة :

هناك العديد من الطرق ذات الحجم المروري القليل والمتوسط تنشئ على ترب جبسيه وخصوصا في الأجزاء الغربية والشمالية من العراق مثل الانبار وصلاح الدين، هذا الطرق تواجه مخاطر حدوث التشققات والتي تؤثر على الأداء الوظيفي لها. ان الطرق المنفذة على هذه الترب الجبسية تصبح غير مرغوب بها نتيجة التغيرات الحجمية التي تعاني منها التربة والمرتبطة بالتغيرات الموسمية واختلاف محتوى الرطوبة لها.

إن الهدف الرئيسي لهذا البحث هو لدراسة تأثير الإسفلت السائل المعروف ب (cut-Back Asphalt) (MC-30)على الخصائص الجيوتكنيكية للتربة الجبسية وتأثيره كمادة على تثبيتها وتحسين خصائصها ومن ثم بحث إمكانية إنشاء طريق عليها. مع استعمال برنامج احصائيSPSS للجصول عى موديلات رياضية تحقق العلاقات ألمختبريه.

التربة المستخدمة في هذه الدراسة هي تربة جبسيه بمحتوى جبس (34%) تم جلبها من محافظة صلاح الدين في العراق والتربة هي عبارة عن رمل سيئ التدرج مخلوط مع الجبس.

تم اجراء سلسلة من الفحوصات ألمختبريه والمتضمنة الفحوصات الفيزيائية، الكيميائية، مقاومة القص،الانهيار والثبوتية على التربة الجبسيه قبل وبعد إضافة الإسفلت لها. تم إضافة الإسفلت إلى نماذج التربة بنسب مختلفة هي (2, 4, 6, 8, & 10%) وعرفت النسب ب (Binder Content %).

النتائج بينت ان الإسفلت السائل المعروف ب (Cut-Back Asphalt) يعد حل جيد ومادة جدا مناسبة لتحسين خصائص التربة الجبسية عن طريق زيادة مقاومة القص وتقليل مقدار التغيرات الحجمية التي تحصل بالتربة عندما تكون بتماس مع الماء حيث أن الإسفلت يعمل كعامل يعزل الماء عن التربة ويمنع التماس معها. ان النتائج بينت ان افضل نسبة للاسفلت هي (6-8 %) ممكن إضافتها الى التربة لتحسينها.

بناء على ذلك فأنه بالامكان ان نوصي باستخدام التربة التي تم تحسينها وبالنسبة المشار اليها لتنفيذ طبقة ما تحت الاساس في الاماكن التي تقل فيها المواد الملائمة لتنفيذ تلك الطبقة أو لارتفاع كلفة النقل.

وقدم النهج التحليلي لدراسة السلوك لتحقيق الاستقرار في التربة الجبسية المثبتة بالإسفلت المخفف للطرق المشيدة.تم استعمال برنامج أس بي أس أس الإحصائي . وتم الحصول على العديد من النماذج الرياضية التي تم تطويرها كنتيجة لتحليل الانحدار خطيا وغير الخطية لاقيام التحمل الكاليفورني وقوة الانضغاط غير المحصورة مع الانحدار .تبين انه يمكن أن تكون صالحة لجميع القيم المطلوبة مما يدل على ان العلاقات الرياضية مستوفية.

Introduction:

In the last two decades, there has been a rapidly expanding road construction programs in the Middle East and in many world's hot desert regions where evaporation exceeds precipitation. To minimize the construction cost for road projects in such regions, the use of locally available materials will always be a necessary task of highway and soil engineers.

Due to the wide extent of salt – bearing soils in the Middle East **(Fookes and French 1977, Fookes, 1978, Fookes et al. 1985)**[11,12,13] , they have been used extensively in road construction both as general embankment material and subbase material **(Subhi, 1987)**[20]. **Stipho (1986)**[19] reported that the successful use of saline soils (Sabkha) for the construction of roads is based on the condition that they are kept free of moisture. Investigations of road constructed on such soils containing excessive amounts of total soluble salt revealed serious pavement cracking and differential settlement **(Ahmed, 1985, Subhi, 1987, Razouki et al. 1994, Al-Alawee, 2001)[1,20,18,2] .** Gypsum is one of the soluble salts that could have a detrimental effect on pavements if and when these soils are subjected to soaking **(Fookes and French, 1977, Subhi, 1987)[11,20].**

Numerous low–to medium volume roads constructed on gypseous soil subgrades, especially in the west and north parts in Iraq such as **Al-Anbar & Salah-Al-din**, encounter severe pavement cracking and premature loss of serviceability. The maintenance costs, in some cases, are greater than the initial construction costs. The roads built on problematic gypsum soils often become distressed due to volume changes associated with seasonal moisture content fluctuations.

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, cut-back asphalt and emulations asphalt or bitumen can be added to the base soil of roads.

The cut-back asphalt is most commonly type of asphaltic materials used for soil stabilization especially medium-curing types **(Transport and Road Research Laboratory, 1974)[9].**

Gypseous Soil:

The term Gypseous soil is used to identify soils that contain gypsum. Gypseous soils are usually stiff specially when they dry because of the cementation of soil particles by gypsum, but great losses in strength and sudden increase in compressibility occur when the soil is wet or leaching because the cementing gypsum dissolved between soil particles **(Nashat, 1990)[16]**. Gypseous soils are mostly found in arid and semi-arid regions, they are considered collapsible soils, therefore, they are usually considered to be problematic and they exhibit unpredictable behaviour which could cause significant troubles concerning civil works **(Petrukhin & Boldyrev, 1978)[17]**.

Many problems have been reported on damages occurred to structures and roads supported on gypsum soils such as cracks, tilting, cavities and overturning of structures, these problems may be very dangerous, therefore improvement of the gypsum soils are very important. Several studies have been pointed out the change in engineering properties as a result of water movement in the soils and leaching out of gypsum from it **(Nafie, 1989)[15]**.

In Iraq, gypseous soils are spreads in some countries, **(Barazanji, 1973)[8]** estimated that gypseous soils in Iraq covers approximately (20%) of Iraq area, the amount of gypsum in Iraqi soils differs from one area to another. The amount of gypsum is up to (80%) in the upper north and in the middle parts of the **Ephrates and Tigris** beds, while the gypsum content of **Al-Jazirah** area ranges from (3-10%) in the upper parts and may exceed (50%) in the lower parts. **(Al-Deffaee, 2002)[3]** mentioned the gypseous soils in Iraq are distributed in **Samara,**

Northwest of Baghdad, Anna, Faluja, Najaf, Karbala, Nassirya, Baiji, Tikrit, Mosul, Heet & Ramadi.

Many additives may be used to improve the gypseous soils characteristics, such as cut back asphalt, emulsion asphalt and lime which are used for stabilizing gypseous soils. In Iraq, lime and asphalt are used to stabilize gypseous soil due to favourable weather conditions and stabilization of gypseous soils with asphalt may be recognized as an economical treatment because cut back and emulsion asphalt are produced from the refineries **(Al-Morshedy, 2001, Esho, 2004, Al-Safrany, 2007)**[4,10,6].

Construction Problems of Gypseous Soils:

The main problem of gypseous soils in Iraq is when they are exposed seeping water. It is shown that moving water (unsaturated with gypsum) can cause leaching of gypsiferous soils and formation of serious cavities. The rise in ground water table causes serious softening resulting in loss of shear strength and increased settlement. The wetting or saturation of gypsiferous soil during the lifetime of road and structure may cause a sudden settlement due to collapse **(Al-Deffaee, 2002)**[3].

Civil engineers often face severe problems when constructing roads and pavements in or on gypseous soils and rocks. Failure by excessive leakage and cavities may take place because of defects in the structural arrangement of the underlying strata if they contain gypsum, which dissolves when exposed to seeping water. Therefore, failure may occur in constructed road due to the formation of cavities in underlying gypseous soil.

Stabilization of Gypseous Soils:

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Regardless of the purpose for stabilization, the desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of the project **(Unified Facility Criteria)(UFC), (1994)**[21]**.**The soil can be stabilized by one of the following methods **(Al-Mufty, 1997)**[5] (Mechanical stabilization, Cement stabilization, Lime stabilization or Bituminous stabilization)

The selection of soil stabilizer depends on many factors as the following:

1- The type of soil to be stabilized.
2- The purpose for which the stabilized layer will be used.
3- The type of soil improvement desired.
4- The required strength and ability of the stabilization.

Different methodology has been used to improve these soils, such as:

1. The suitability of lime in treatment of the gypseous soil.
2. Used cement as an improvement material.
3. Bituminous materials are considered as main water proofing agent that could be used for gypseous soil.
4. Used cut back bitumen as a stabilizer.
5. The stabilization of gypseous soil by lime and emulsion asphalt.

Soil stabilization with asphalt is one of the oldest methods used to improve soil characteristics. The main function of asphalt is to provide cohesive strength to the soil mass and act as waterproofing agent.

Stabilization Mechanize by Asphalt:

The main function of asphalt material is to reduce the effect of water on gypsum particles and to increase the strength parameters of the soil. The mechanism of treatment with bituminous material consists of adding cohesive strength and reducing water penetration by the physical presence of bitumen; there is no chemical interaction in this process. Bitumen stabilization includes both water proofing and cementation actions **(Ingles and Matcalf, 1972)[14].**When the asphalt mixed with soil it may either bind the particles together or it may waterproof the soil, thus preserving the bonding action of water films between the particles or both these effects may be occur together **(Transport and Road Research Laboratory, 1974)[9].**

The amount of asphalt required depends on which of these two effects is desired and upon the soil type. Climatic conditions also influence the concentration that can be employed since they affect the amount of moisture content that already present in the soil **(Transport and Road Research Laboratory, 1974)[9].**

Experimental program:

Materials Used:

Disturbed soil samples were collected from Hay Al-Khadsia in Tikrit City at Salah Al-Din Governorate. Four boreholes were taken in order to study its properties which consist of highest gypsum content (see specified boring logs in the **Figures (1 & 2).** A laboratory testing program was conducted to aid classification and to evaluate the physical, mechanical, & chemical properties of the sub-surface soil. The scope of the laboratory testing program is summarized in **Table (1)**.

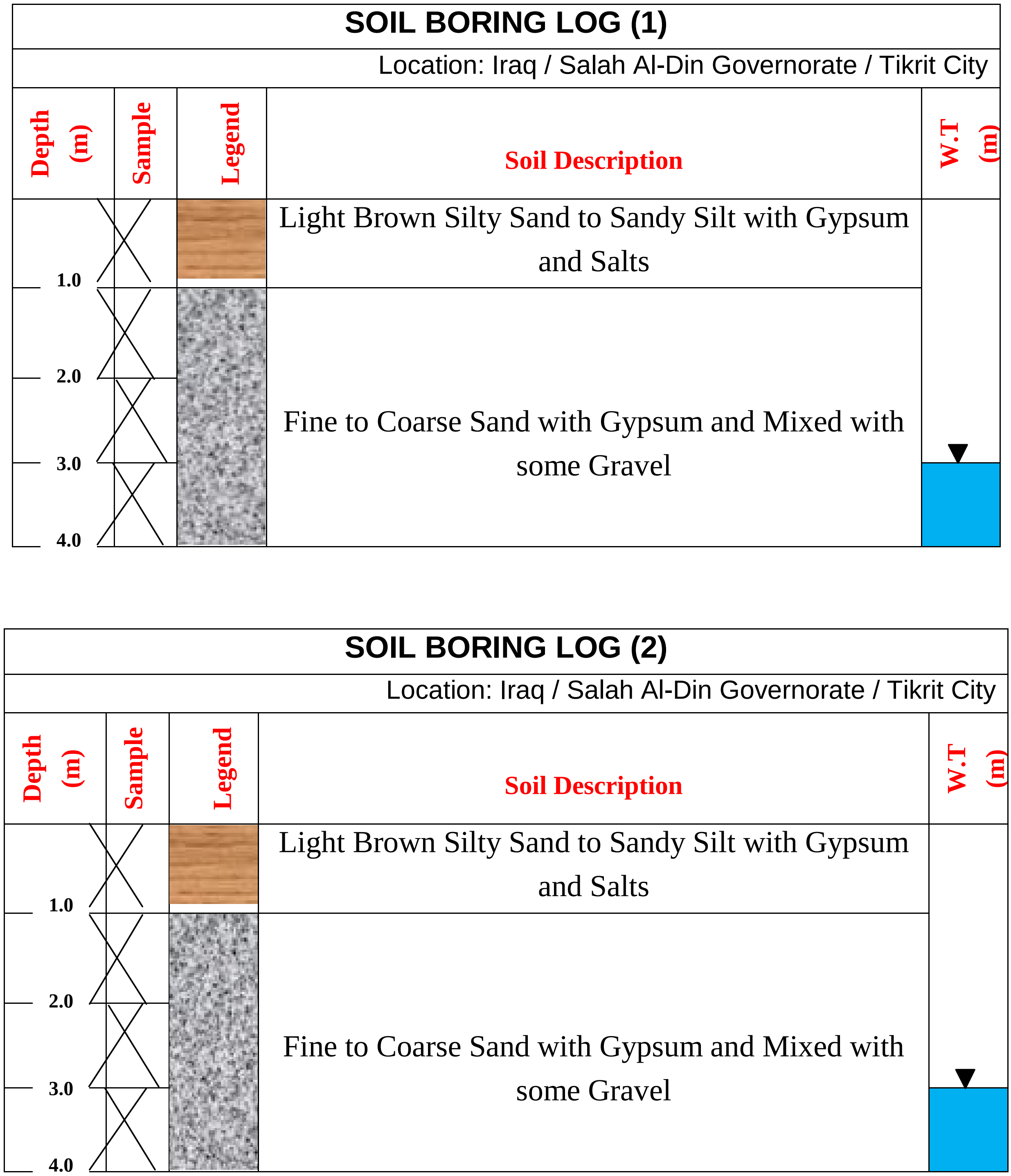


Figure (1) Boring Log for Specified Boreholes (1 & 2)

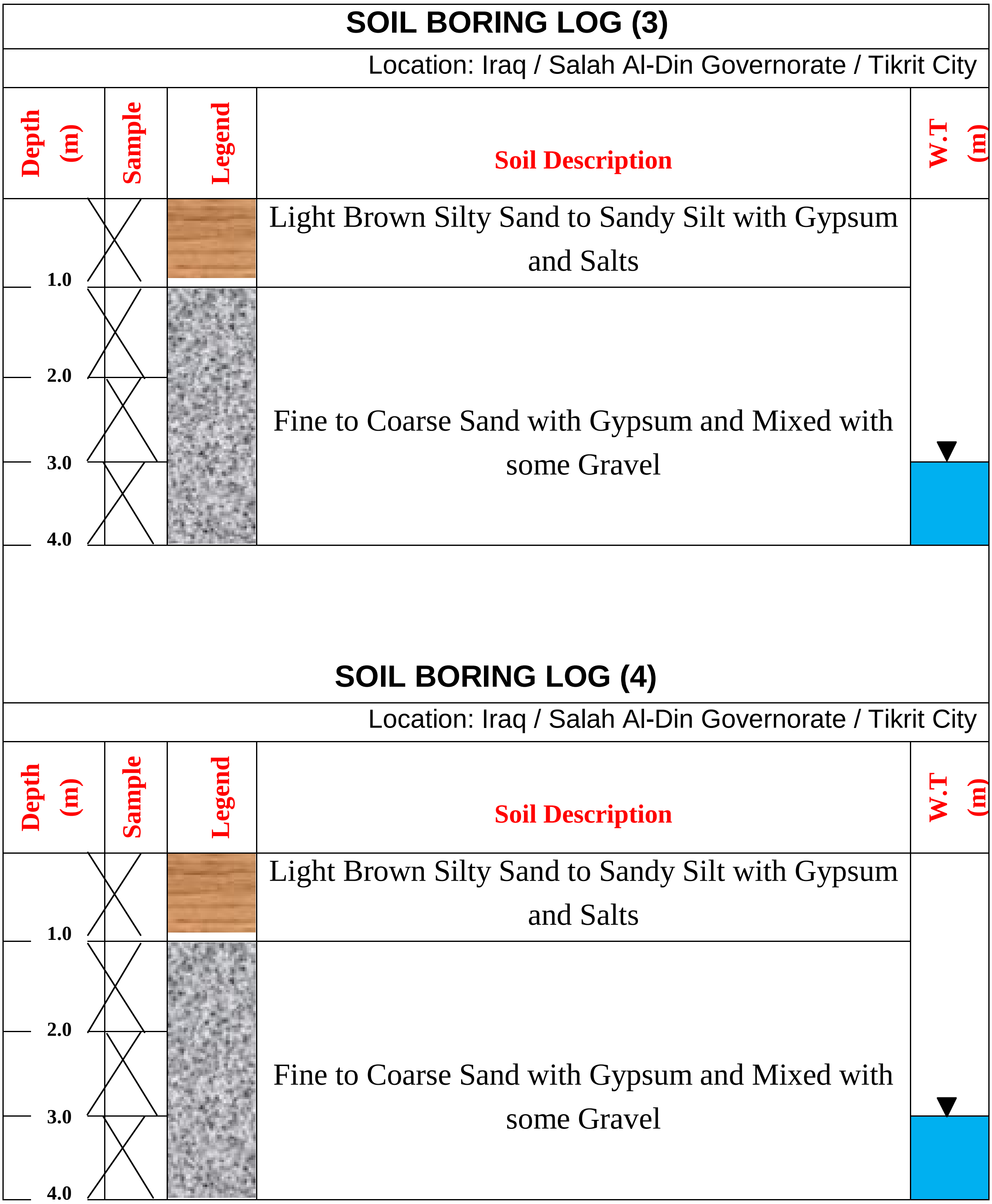


Figure (2) Boring Log for Specified Boreholes (3 & 4)

Asphalt Used:

The type of asphalt used in this study is Medium Curing Cut-Back (MC-30) Liquid Asphalt produced by Al-Dora Refinery in Baghdad Governorate. This type is manufactured at Al-Dora Refinery by mixing of (91.2%) asphalt cement and (8.8%) Kerosene. The properties of asphalt used are given in **Table (2).**

Table (1) Summery of Laboratory Test Results for Soil Used

SOIL PROPERTY	TESTING STANDARD	B.H (1)	B.H(2)	B.H (3)	B.H (4)
Liquid Limit (L.L) %	ASTM D-4318 [7]	27.0	27.0	25.0	31.0
Plastic limit (P.L) %		N.P	N.P	N.P	N.P
Plasticity Index (P.I) %		N.P	N.P	N.P	N.P
%Clay	ASTM D-422	1.0	0.0	0.0	1.0
%Silt		4.0	4.0	4.0	6.0
%Sand		89.0	90.0	91.0	87.0
%Gravel		6.0	6.0	5.0	6.0
Unified Soil Classification System (USCS)		SP	SP	SP	SP
Spesific Gravity (Gs)	ASTM D-854	2.53	2.53	2.54	2.57
Maximum Dry Density (γ_{dry}), kN/m³	ASTM D-1557	15.9	15.8	16.1	15.6
Optimum Moisture Content (% Wc)		14.0	14.2	14.8	13.6
Soked Cohesion (c), kPa	ASTM D-3080	20.0	18.0	23.0	16.0
Soked Angle of Internal Friction (Ø°)		31.0	31.0	33.0	28.0
Unsoked Clifornia Bearing Ratio (CBR %)	ASTM D-1883	49.0	47.0	53.0	43.0
Soked Clifornia Bearing Ratio (CBR %)		9.0	8.0	12.0	6.0
Collapse Potential (C.P%)	ASTM D-4546	9.7	10.0	9.6	10.3
Organic Matters Content (%)	BS 1377: 1990 Part 3	3.0	3.0	3.3	2.9
Gypsum Content(%)		34.0	33.8	31.0	33.0
Total Soluble Salt (TSS) Content (%)		37.0	37.0	35.0	37.0
Sulphate Salt (SO_3) Content (%)		16.0	16.0	15.8	15.9

Table (2) Properties of asphalt used (Al-Dora Refinery Lab.)

PROPERTIES	GRADES
Type	Medium Curing Cut-Back Languid Asphalt (MC-30)
Specific Gravity	0.99
Kinematics Viscosity at 60° C	75-150
Distillate Test, % Volume of Total Distillate to 360° C To 225° C To 260° C To 315° C Residue from Distillate to 360° C, % Volume by Difference	 25 Maximum 40-70 75-93 50 Minimum
Test on Residue from Distillation Penetration at 25° C (100g, 5 sec.) Ductility at 25° C Solubility in CCL_4, % Weight	120-300 100 Minumum 99.5 Minumum

Sample Preparation:

To prepare sample for testing, the dry soil is mixed with the required amount of water (optimum water content) until the mixture has a homogenous and uniform appearance, then the required percentages of binder (Cut-Back Asphalt) expressed as a percentage of total dry weight of soil are added to permit satisfactory compaction. The mixing process may require (5 minutes), so that the soil particles will be coated properly by a thin film of asphalt binders **(Ingles and Matcalf, 1972)**[14].

Testing Program:

Different percentages of Cut-Back asphalt are added to the preparation samples in order to perform the testing programme. The Percentages of Cut-Back asphalt varied from (2%, 4%, 6%, 8%, and 10%) and expressed as binder content (%). **Table (3)** presence the summery of testing programme on soil samples.

Table (3) Summery of Testing Programme on Soil Samples

PHYSICAL PROPERTIES TESTS	**Liquid Limit (L.L) %**
	Plastic limit (P.L) %
	Plasticity Index (P.I) %
	Specific Gravity (Gs)
COMPACTION CHARACTERSTICS TESTS	**Dry Unit Weight**
	Optimum Moisture Content
SHEAR STRENGHT TESTS	**Unconfined Compression**
	Direct Shear
	CBR
COLLAPSE TESTS	**Single Collapse Test**
STABILITY TESE	**Cne Penetration Resistance Test**

Results and Discussions:

1. PHYSICAL PROPERTIES:

- **Specific Gravity Test:**

The results of specific gravity test are shown in **Table (4)** and **Figure (3).** The test results show that the specific gravity of soil decreases as the binder content increase (Cut-Back Asphalt). This may be attributed to the low specific gravity of residual bitumen (Cut-Back Asphalt).

Table (4) Results of Specific Gravity Test

Binder Content %	Specific Gravity (Gs)			
	B.H (1)	B.H (2)	B.H (3)	B.H (4)
0.0	2.530	2.530	2.540	2.570
2.0	2.527	2.527	2.536	2.567
4.0	2.520	2.522	2.531	2.562
6.0	2.518	2.519	2.528	2.557
8.0	2.513	2.513	2.525	2.551
10.0	2.510	2.500	2.521	2.548

- **Atterberg Limits Test:**

The effect of Cut-Back asphalt on Atterberg Limits is shown in Table (5) and Figure (4). The results indicated that the liquid limit of soil decreases as the binder content increases, while the soil is non-plastic for all percentages of Cut-Back asphalt added to the soil.

Table (5) Results of Atterberg Limits Test

Binder Content %	Liquid Limit (L.L %)			
	B.H (1)	B.H (2)	B.H (3)	B.H (4)
0.0	27.0	27.0	25.0	31.0
2.0	26.0	26.0	23.5	30.0
4.0	24.0	23.0	22.0	28.5
6.0	22.5	22.0	19.5	26.0
8.0	21.5	20.0	17.0	24.0
10.0	19.0	18.5	16.0	21.5

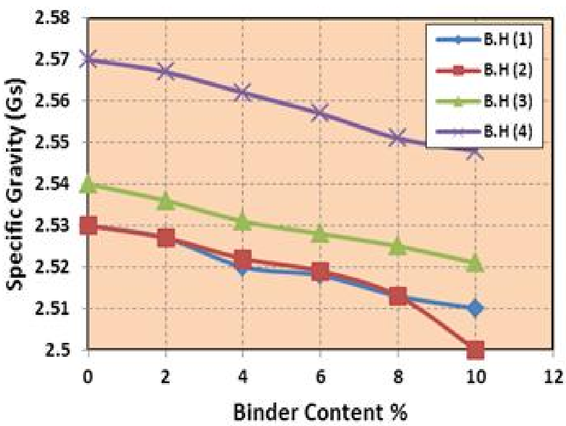


Figure (3) Relationship between Binder Binder Content and Specific Gravity

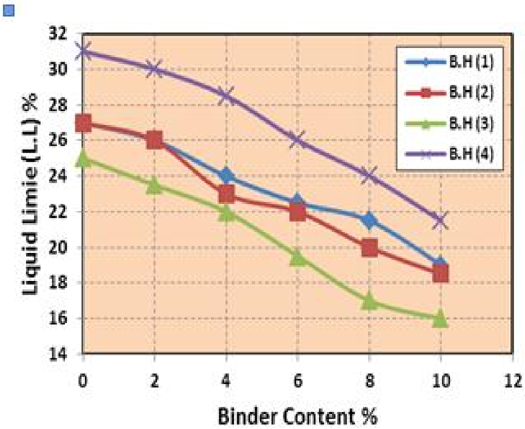


Figure (4) Relationship between Content and Liquid Limit

- **Compaction Test:**

The binder- maximum dry density & binder- optimum moisture content relationships of the soil for different binder contents is shown in **Figures (5 & 6)** and also listed in **Table (6).** As expected, maximum dry density of treated soil decrease as the binder content increase, while, the optimum moisture content increase with the increase of binder contents.

2. Shear Strength Properties:

- **Unconfined Compression Test :**

Soil sample was prepared and compacted at maximum dry density and optimum moisture content and specified percentages of asphalt (binder) were added to determine the effect of cut-back asphalt on the unconfined compressive strength of gypseous soil. The typical results of unconfined compression test of soil are presented in **Table (7)** and **Figure (9).** As shown in **Figure (9),** it can be noticed that the unconfined compressive strength (q_u) increases as the binder content increases to a certain point, then it decreases. The increase in the compressive strength with the addition of Cut-Back Asphalt is accepted to be due to the internal friction and the cohesion between the soil particles by continues films of formed binder surrounding the soil particles. On the other hand, a reduction compressive strength is due to the reduction in friction between soil particles due to the increases in the thickness of the formed binder film coating the particles.

Table (6) Results of Compaction Test

Binder Content %	B.H (1)		B.H (2)		B.H (3)		B.H (4)	
	(g_{dry}) max kN/m³	O.M.C %	(g_{dry})max kN/m³	O.M.C %	(g_{dry})max kN/m³	O.M.C %	(g_{dry})max kN/m³	O.M.C %
0.0	15.9	14.0	15.8	14.2	16.1	14.8	15.6	13.6
2.0	15.5	14.4	15.5	14.5	15.7	15.3	15.2	14.0
4.0	15.1	14.6	15.0	14.7	15.2	15.5	14.7	14.2
6.0	14.5	14.9	14.6	14.9	14.8	15.7	14.3	14.6
8.0	14.2	15.3	14.2	15.4	14.1	16.1	14.0	15.0
10.0	13.6	15.9	13.8	16.0	13.5	16.6	13.2	15.7

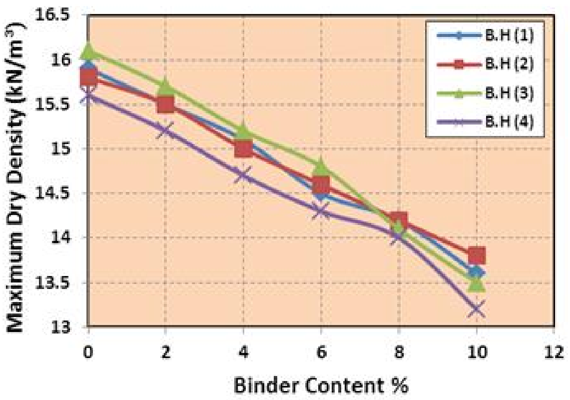


Figure (5) Relationship between Binder Content and Maximum Dry Density

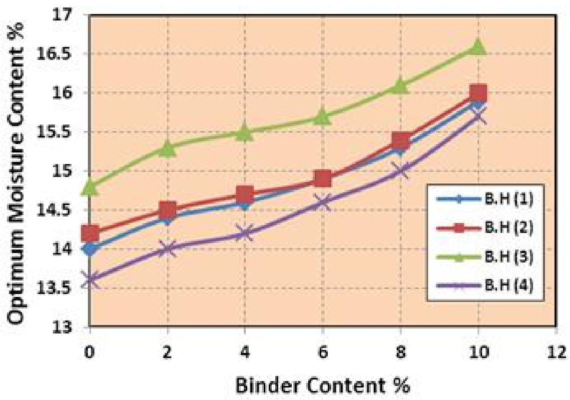


Figure (6) Relationships between Binder Content and Optimum Moisture Content

Table (7) Results of Unconfined Compression Test

Binder Content %	Unconfined Compressive Strength (q_u), kPa			
	B.H (1)	B.H (2)	B.H (3)	B.H (4)
0.0	123.0	121.0	126.0	116.0
2.0	147.0	143.0	148.0	139.0
4.0	171.0	170.0	172.0	161.0
6.0	222.0	220.0	227.0	210.0
8.0	201.0	200.0	205	190.0
10.0	186.0	184.0	190.0	175.0

- **Direct Shear Test:**

This test is carried out to study the effect of added Cut-Back Asphalt on shear strength parameters of soil (c and Ø°). **Figures (7 & 8)** and **Table (8)** shows the results of the direct shear test of soil. From the test results, it can be noticed that the value of cohesion (c) increases when the Cut-Back Asphalt increases and reached a peak value then decreases, while the angle shearing resistance (Ø) was founded to be nearly constant with slightly increase in first stages of test.

Table (8) Results of Direct Shear Test

Binder Content %	B.H (1)		B.H (2)		B.H (3)		B.H (4)	
	c (kPa)	Ø°	c (kPa)	Ø°	c (kPa)	Ø°	c (kPa)	Ø°
0.0	20.0	31.0	18.0	31.0	23.0	31.0	16.0	28.0
2.0	29.0	31.0	27.0	32.0	33.0	31.0	25.0	28.0
4.0	40.0	34.0	37.0	33.0	44.0	33.0	35.0	32.0
6.0	52.0	34.0	50.0	33.0	57.0	33.0	47.0	32.0
8.0	46.0	35.0	43.0	35.0	51.0	35.0	40.0	33.0
10.0	39.0	35.0	36.0	36.0	45.0	36.0	36.0	34.0

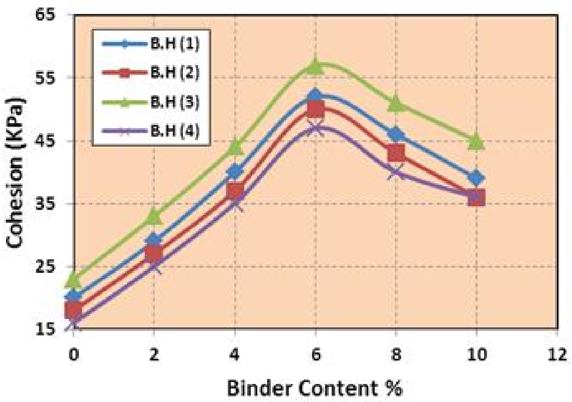


Figure (7) Relationship between Binder Content and Soil Cohesion

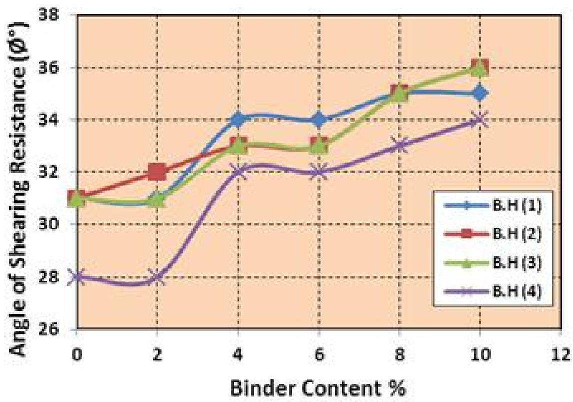


Figure (8) Relationship between Binder Content and Angle of Shearing Resistance

- **California Bearing Ratio (CBR) Test:**

The California bearing ratio (CBR) test is the most common test for evaluating the bearing capacity of subgrade soils. It measures the force needed to cause a plunger to penetrate (2.5 or 5mm) into a soil sample compacted into a 2-litre cylindrical mould with a diameter of (150mm). The measured force is taken as a percentage of a standard force. Initially, the test was performed on the untreated soil sample both unsoaked and soaked case to determine the effect of soaking in bearing capacity as shown in **Table (1)** of laboratory test results. It can be noted that the high reduction in soil strength (CBR) when the gypseous soil subjected to soaking. Then the soil sample is prepared as recommended at maximum dry density and optimum moisture content and the asphalt is added with specified percentages to investigate on the effect of asphalt on the (CBR) value of gypseous soil. The test results are presented in **Table (9)** and **Figure (10).** From the test results, it can be found that the (CBR) value of soil increase with increase of binder content until reach the maximum value at (8%) binder content and then decrease this because the affect of asphalt as a waterproof agent which prevent the soaking of soil with water, while the decreasing in (CBR) after (8%) of binder content because the increase in soil plasticity, this causes the increase in penetration in of test machine. As shown in test result, the maximum value of (CBR) reached during the test is not equal the value of unsoaked (CBR) which initially tested, this can be linked to the cementation action of unsoaked gypseous soil where the gypseous soil have a high bearing capacity in dry state.

Table (9) Results of California Bearing Ratio (CBR) Test

%Binder Content	B.H (1) Unsoaked CBR %	B.H (1) Soaked CBR %	B.H (2) Unsoaked CBR %	B.H (2) Soaked CBR %	B.H (3) Unsoaked CBR %	B.H (3) Soaked CBR %	B.H (4) Unsoaked CBR %	B.H (4) Soaked CBR %
0.0	49.0	9.0	47.0	8.0	53.0	12.0	43.0	6.0
2.0		13.0		13.0		17.0		14.0
4.0		21.0		20.0		25.0		23.0
6.0		32.0		30.0		35.0		34.0
8.0		41.0		38.0		45.0		35.0
10.0		33.0		30.0		38.0		28.0

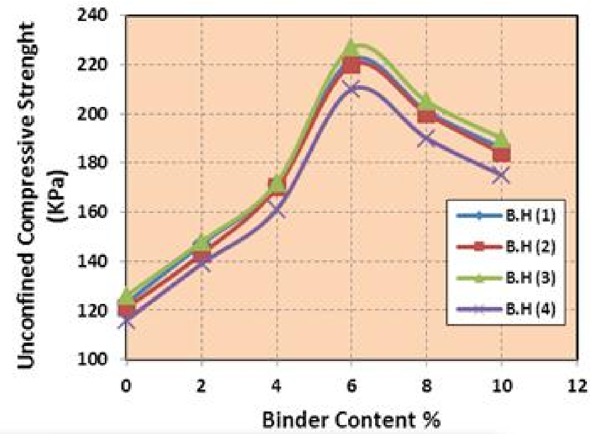


Fig.(9) Relationship between Binder Content and Unconfined Compressive Strength

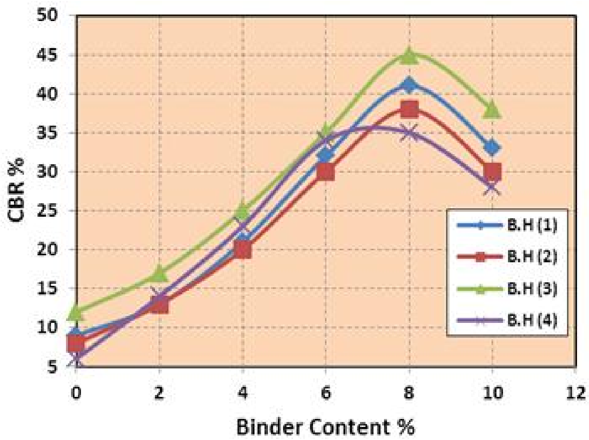


Fig.(10) Relationship between Binder Content and Soaked CBR %

3. Collapsibility Properties:

- **Single Collapse Test:**

This test carried out on the untreated and treated soil samples with different binder content of (2, 4, 6, 8, and 10) % to study the effect of the binder content on the collapse characteristics of the soil-asphalt mixture. The sample is placed in consolidometer at maximum dry density and optimum water content. Then the soil sample is soaked with water and the load is applied. The collapse potential (C.P) is calculated of untreated and treated soil. The results of collapse test are shown in **Table (10)** and **Figure (11)**. It can be found that in the untreated soil sample, the value of collapse potential is high (9.8%) and classified trouble. The results of treated soil, it can be noticed that the value of collapse potential decreases when the binder content increases and the soil changes from trouble state to moderate. This may be linked to the cementing bind produced by soil-asphalt mixture and waterproof action of asphalt which reduces the rate of dissolution of gypsum in water.

Table (10) Results of Single Collapse Test

Binder Content %	Collapse Potential (C.P %)			
	B.H (1)	B.H (2)	B.H (3)	B.H (4)
0.0	9.8	10.0	9.6	10.3
2.0	7.24	7.45	7.0	7.75
4.0	5.9	6.11	5.65	6.4
6.0	4.0	4.17	3.75	4.5
8.0	3.1	3.3	2.8	3.61
10.0	2.5	2.7	2.25	3.0

4. Stability Properties:

- **Stability Test:**

The stability test carried out on the treated soil samples only with different binder content to study the effect of the cut-back asphalt on the stability of soil-asphalt mixture .In this test, a measurement is made of the resistance offered by soil-asphalt mixture to penetration of a right-angled cone. A stabilized soil mixture sample is prepared at the appropriate cut-back asphalt and compacted at maximum dry density and optimum moisture content and then the mould is covered with a glass plate to prevent the evaporation of moisture content and allowed to stand (24 hours) before testing, to enable the cut-back asphalt to develop its full effect. After this period of curing the glass plate is removed and the penetrometer test is performed and cone penetration resistance (C.P.R) of soil is then calculated in (Kg/cm^2). The minimum value of (C.P.R) required is (20 Kg/cm^2). The results of this test are presented in **Table (11)** and **Figure (12)**, the results showed that, the minimum value of cone penetration resistance (C.P.R) which was obtained during the test was found to be (45 Kg/cm^2) at (2%) binder content and increase to reach (125Kg/cm^2) at binder content of (10%). This means the cone penetration resistance of soil-asphalt mixture increases with binder content increases; this can be interpreted due to cementation action of cut-back asphalt.

Table (11) Results of Cone Penetration Resistance Stability Test

Binder Content %	(C.P.R) Kg/m²			
	B.H (1)	B.H (2)	B.H (3)	B.H (4)
2.0	45.0	43.0	47.0	40.0
4.0	58.0	55.0	60.0	52.0
6.0	75.0	72.0	76.0	70.0
8.0	96.0	92.0	98.0	90.0
10.0	125.0	122.0	127.0	120.0

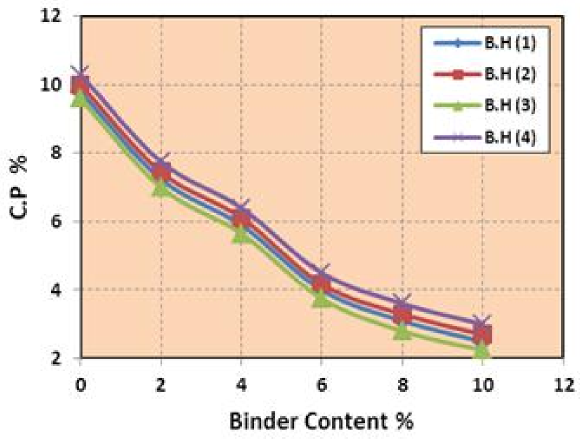


Fig. (11) Relationship between Binder Content and Collapse Potential C.P %

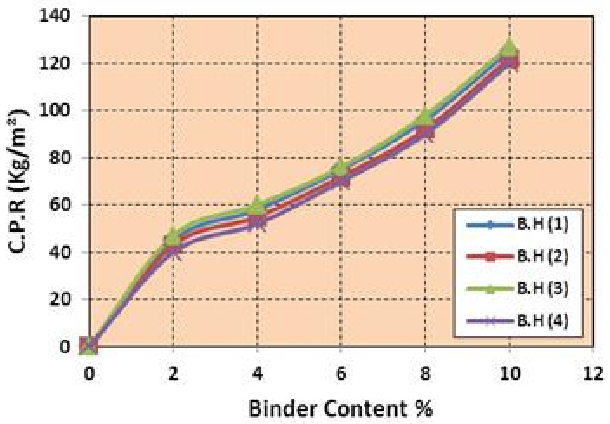


Fig.(12) Relationship between Binder Content and Cone Penetration Resistance (C.P.R)

- **Statistical Analysis & Mathematical Modeling**

The analytical approach was introduced to study the behavior of Stabilization of Gypseous soil stabilized by cutback Asphalt for roads construction .The statistical analysis is used to construct and develops the mathematical modeling for the prediction the all properties required for evaluating using cutback Asphalt in mathematical models are collected from the results of experimental laboratory works .A suitable data representing many variables is presented to be used in the process of the mathematical models development. These data includes; C.B.R; Unconfined compression Strength, Cohesion, angle of friction, collapsibility and soil properties.

SPSS stands for statistical package for the social sciences. It is general statistical software tailored to the need of social science and general public is good for organizing and analyzing engineering problems and is comprehensive system for analyzing data.

- **Structure of SPSS Statistics 17.0 Program**

SPSS statistics has many windows. It can be quite confusing in the beginning but will get use it as worked along. SPSS includes four basic elements which are:

1. The Menu Bar
2. The Tool Bar
3. Data Editor Window
4. Output Viewer Window.

- **Process of Modeling Building**

The following steps, which are recommended by many researchers **(**Keller and Warrack, 2000) are followed by:

1. Identify the dependent and independent variables
2. Listing potential predictors
3. Gathering the required observations for the potential model
4. Using statistical software to analyze the dependent and independent variables
5. Using the engineering judgment and the statistical output to select the best models.

- **Data Sources**

The required data for building the models are collected from experimental work results obtained from various tests which carried out on Gypseous soil stabilized by cutback Asphalt with different amount of asphalt cutback. **Tables (4 to11)** list the data required for models building.

- **Regression Analysis**

Regression analysis is a statistical method that uses the relationship between two or more quantity variables to generate a model that may predict one variable from the other **(**Montgomry & Peck 1992**)**. Regression models describe the relationship between a set of independent (predictor) variables(X's) and dependent (response) variables(Y). This relationship between(X) and (Y) is defined by coefficients, which are estimated from a given data of (X's and Y) using linear or nonlinear regression analysis. .The term multiple linear regression is employed when a model is a function of more than one predictor variable. So in this study the multiple linear regression analysis using SPSS statistics by Stepwise method and nonlinear regression are used to obtain adequate models for behavior of Gypseous soil stabilized with asphalt cutback with different proportions using the variables of experimental data.

- **Developed Models**

An attempt made to develop a general expression for the Gypseous soil stabilized with asphalt cutback with different proportions for roads .Many variable are plotted to be as dependent or independent variables .The chosen variables are then entered in a multiple linear analysis by use of Stepwise method and nonlinear regression analysis using SPSS by getting an approximate relation between all main variables. Many models developed as a result of regression analysis .The general mathematical expressions for CBR, Cohesion and Unconfined Compression can be written. The summary of the regression analysis and developed models which provided from SPSS statistics can be tabulated in **Table (12)**. The Coefficient of determination (R^2) for each variable model is found to be in the range of 0.744 to 0.917, while the first model gets the max. Coefficient of determination value (0.917).

Figures (13, 14 & 15) shows the relation between the predicated values and the observed values of the nonlinear regression analysis process in SPSS statistics (17.0).While **Figure (17)** shows that for the multiple linear regressions.

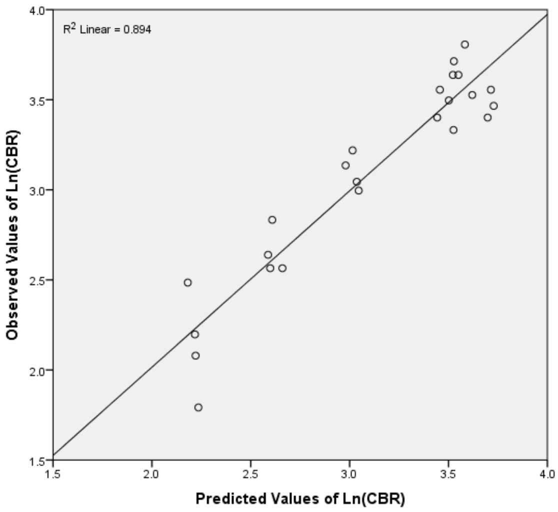
- **Discussion of the results**

Referring to each models: four variables found to be common to the general picture of the models development, these are C.B.R, Angle of friction, Cohesion and unconfined compression strength. It was found that the non linear forms of the variable result in best correlation between independent and dependent variables.

Table (12) Model Summary

No.	Model	Adjusted R^2	S.E.E	Sig.
1	$Ln(C.B.R.) = -0.007 + 2.06\ Ln(Qu) - 2.78\ Ln(\gamma_{dry})$ $C.B.R. = 0.99 * (Qu)^{2.06} * (\gamma_{dry})^{-2.78}$	0.917	0.1639	0.000
2	$Ln(C.B.R.) = -9.802 + 2.063 Ln(Qu) + 0.07\ (\emptyset)$ $C.B.R. = 5.534 * 10^{-5} (Qu)^{2.063} * e^{0.07\ (\emptyset)}$	0.913	0.1674	0.000
3	$Ln(C.B.R.) = -10.302 + 2.608\ Ln\ (Qu)$ $C.B.R. = 3.357 * 10^{-5} * (Qu)^{2.608}$	0.882	0.1950	0.000
4	$Qu = 75.649 + 1.653\ (C) + 1.571\ (C.B.R)$	.744	19.05081	0.000

Where S.E.E=Standard Error of Estimate, Sig.= Significant (P-value<0.05)



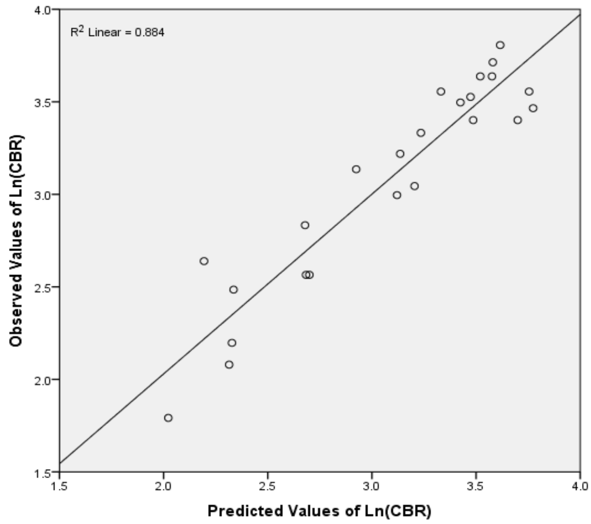
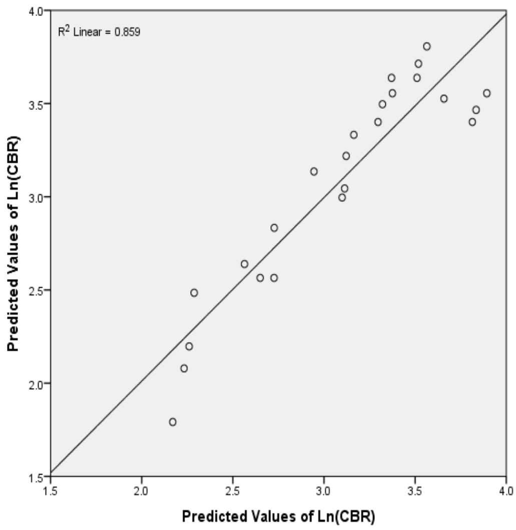


Fig. (13) Predicted Versus Observed Value for Model No.1

Fig.(14) Predicted Versus Observed Value for Model No.2



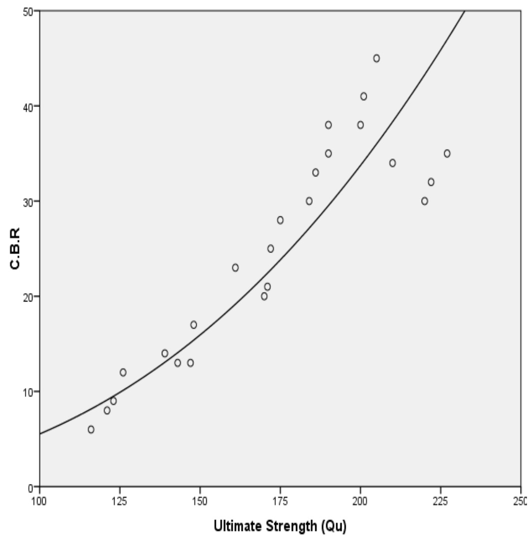


Fig. (15) Predicted Versus Observed Value for Model No.3

Fig. (16) Correlation between CBR and Qu

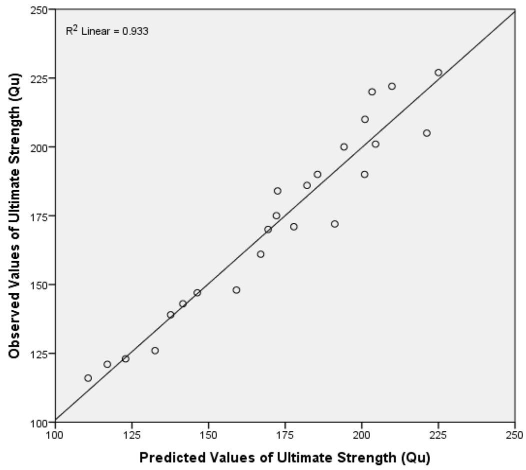


Fig.(17) Predicted Versus Observed Value for Model No.4

- **The Models Validation**

The final step in the model building is the validation of the developed models. It can be seen from tables that the values agree closely, establishing the validity of mathematical models developed. The objective of validation is to assess the ability of present models to accurately predict the amount of C.B.R and unconfined compression with other variables from test results and as well from correlations of models obtained using SPSS. To verify the validity of the models, it can be seen from figures plotted predicted versus observed variables that all mathematical models can be seen that all values agree closely, establishing the validity of mathematical models developed.

Conclusions:

Based on the results presented in this study which conducted on the soil samples taken from Hay Al-Khadsia in Tikrit City at Salah Al-Din Governorate, the following conclusions can be drawn:

1- The liquid and plastic limit, specific gravity, maximum dry density decrease as the binder content increases. While, the optimum moisture content increases as the binder content increases.

2- As the binder content increases, the cohesion of soil increased at the maximum value for (6%) binder content, while the angle of shearing resistance approximately remains constant with slightly increasing.

3- As the binder content increase, the unconfined compressive strength of soil increased at the maximum value for (6%) binder content.

4- The maximum value of soaked California Bearing Ratio (CBR %) was obtained at (8%) binder content. And (CBR %) increased with binder content increase until the (8%) binder content.

5- The value of collapse potential (C.P %) decreases when the binder content increases. The collapse potential changes from trouble to moderate when the cut-back asphalt increases up to (10 %). No optimum content of cut-back asphalt was observed during the test and the increasing in binder content causes decreasing in collapse potential.

6- From results of stability test, it can be found that, the gypseous soil become more stable with cut-back asphalt addition and the cone penetration resistance of treated soil increases with the increases of binder content. Cut-back asphalt makes the soil mixture more stable and durable due to cementation action and waterproof action of cut-back asphalt.

7- From the tests results of physical and strenght, it can be found that, the optimum and best percentage of cut-back asphalt added to the soil for treating was founded to be between (6-8)%.

8- No optimum percentage of cut-back asphalt was observed from the results of collapse test and the collapse potential of soil-asphalt mixture decreases when the cut-back percentage increases.

9- Asphalt consider a good solution to treatment of gypseous soil under the roads in Iraq, this because of availability this materials in Iraq as well as ability of this materials to eliminate the problems concerning gypseous soil.

10- From the all tests results were conducted on the soil-asphalt mixture, it was clearly observed that the cut-back asphalt have a great effect on the both physical, mechanical properties of gypseouse soil. Cut-back increrase the strenght of gepseouse soil and modify its properties and make the soil more stable due to cementation and waterproof actions.

11- Asphalt consider a good solution suitable to treatment the gypseous soil under the roads in Iraq, this because of availability of this materials in Iraq as well as ability of this materials to eliminate the problems concerning gypseous soil.

12- By using SPSS,It was found that the linear and nonlinear forms of the parameters result in best correlation between independent and dependent variables.

13- All mathematical models using in SPSS can be showed that all values predicted and observed agree closely, establishing the validity of mathmatical models developed.

- **Recommendation:**

It is concluded that the values of (6-8) % binder content of cut-back asphalt is considered the best percentage that can be added to this type of soil to improve its physical, strength and waterproofing properties. Accordingly, this composition is recognized to be used as a subbase layer wherever there is a lack of granular materials and/or high cost of materials transportation

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