EFFECT OF COMPACTION ON THE BEHAVIOUR OF KIRKUK GYPSEOUS SOIL

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ABSTRACT

The purpose of the present work is to investigate the effect of compaction on the behaviour of gypseous soil. A testing program carried out to study the geotechnical properties and the behaviour of gypseous soil (gypsum content χ = 37% & 56%) taken from Kirkuk city.

The tests include classification tests, chemical tests, X-ray diffraction analysis, compaction characteristics, compressibility & collapsibility, California Bearing Ratio (CBR) & shear strength tests.The effect of dry unit weight, water content, compactive efforts, relative compaction & soaking on the engineering properties of the soil tested are included in the program. All tests were carried out using Standard and Modified Proctor.

Based on the results, several conclusions have been obtained. The soil compacted at the dry side of optimum tends to collapse upon soaking while the soil compacted at the wet side of optimum tends to swell . The percent of swelling for soil with χ =37% is more than that with χ =56%.

Through the observation of shear strength test results, for the two compactive efforts and the two types of gypseous soil,the cohesion(c) increases with decreasing gypsum contents.The angle of internal friction (φ) decreases with increasing moulding water content and increases with increasing gypsum contents.The soaked CBR values increase with increasing compactive efforts and gypsum content.

الخلاصة

الغرض من هذا البحث هو التحري عن تأثير الرص على تصرف التربة الجبسية. وقد تضمنت الفحوص المختبرية برنامج لدراسة الخصائص الجيوتكنيكية والسلوك الهندسي للتربة تحت الدراسة بمحتوى جبسي% 37 و56% مأخوذة من مدينة كركوك. هذا وقد اشتملت الفحوص تصنيف التربة والفحوص الكيميائية وتحليل انحراف الاشعة السينية وخصائص الرص وفحوص الانضغاطية والانهيارية و نسبة التحمل الكاليفورني CBR وفحوص مقاومة القص .وتضمن البرنامج ايضاً دراسة وحدة الوزن الجاف والمحتوى المائي و جهد الرص والرص النسبي والغمر على الخصائص الهندسية للترب المفحوصة,و قد جرت كل الفحوص باستخدام بروكتور القياسي والمحسن.

وعلى ضوء النتائج فقد تم الحصول على استنتاجات عديدة .لوحظ أن الترب المرصوصة بمحتوى مائي الى الجانب الجاف تكون معرضة للانهيار عند غمرها بالماء بينما الترب المرصوصة بمحتوى مائي الى الجانب الرطب تكون معرضة للانتفاخ .كما و ان النسبة المئوية للانتفاخ للترب بمحتوى جبسي % 37 كانت اكثر من تلك ذات المحتوى الجبسي% 56 .

من خلال ملاحظة نتائج فحوص مقاومة القص ,نستنتج أنه لكل من جهديّ الرص وكلا النوعين من التربة الجبسية , التماسك يزدادمع نقصان نسبة الجبس.أما زاوية الاحتكاك الداخلي فتقل مع ازدياد المحتوى المائي وتزداد مـــع ازديـــاد نـــسبة الجبس. لوحظ ان قيم نسبة التحمل الكاليفورني المغمورة تزداد مع ازدياد جهد الرص ونسبة الجبس.

KEY WORDS
standard compaction, modified compaction, optimum, water content, maximum dry unit weight, gypsum content, cohesion, angle of friction,collapse potential, and CBR.

INTRODUCTION

Soil compaction is the process where by soil particles are constrained to pack more closely together through a reduction in the air voids ,generally by mechanical means, **Ingles and Metcalf(1972)**.

Gypseous soil is that soil which contains enough gypsum($CaSO_4.2H_2O$) to interfere with engineering construction .It is the worst among the problematic soils as it contains soluble salt and its chemical reactions.Gypseous soil in Iraq constitutes (11 to 15)% of the area of Iraq. Many major projects suffered from several problems related to construction on or by gypseous soils such as cracks, tilting, collapse and leaching the soil, **Mahdi(2004).**

Proper construction of gypseous soil embankment essentially requires a careful and slow process of compaction control since it involves a prior selection of proper fill borrow areas which have the potential contractual degree of compaction.The compaction control of gypseous soils also requires the slow heating in temperature ranging between (60-80)°C for 48 hrs ,instead of 24 hrs for non gypseous soils, **Al-Khafaji(1997).**

MATERIALS USED:

To achieve the purpose of this study, natural gypseous soil of two different percentages of gypsum (37%,56%) was taken from Kirkuk city.The chemical properties of these samples are shown in **Table (1).**

Table (1). Chemical Properties of Soils

Chemical composition, %	K1 (χ=37%)	K1 (χ=56%)
Al_2O_3	5.9	4.96
CaO	21.98	25.2
SO_3	13.8	22.6
Gypsum content	37	56
Cl^-	0.088	0.096
pH	7.8	7.8

The components of the minerals for each type of saline soil are given in **Table (2).** It can be noted that gypsum, quartz, calcite, and Palygroskite are the predominated minerals in the soils.

Table (2). Mineralogical composition of soils

Soil Type	Non Clayey Mineral	Clayey Mineral
χ=37%	Gypsum, Calcite, Quartz.	Palygroskite
χ=56%	Gypsum, Calcite, Quartz, Dolomite, Feldspar.	Palygroskite

Classification tests were performed first. Physical tests include specific gravity Gs, grain size distribution and Atterberg limits. Standard and modified compaction tests were carried out to determine the moisture-density relationships.Series of engineering tests were conducted on compacted samples. The tests performed include standard oedometer test, double oedometer test, triaxial and CBR tests.
The physical and compaction characteristics are given in **Table (3)**.

Table (3). Summary of physical and classification tests results.

Soil Property	Soil Designation	
	K1	K2
Gypsum Content,%	37	56
Specific gravity	2.51	2.46
Liquid limit,%	29	29
Plasticity Index,%	8	7
%Sand	82.31	77.18
%Fines	17.66	22.82
Moisture-density relations (D698) Optimum water content (%) Maximum dry unit weight(kN/m3)	13.5 17.73	13.85 17.6
Moisture-density relations (D1557) Optimum water content (%) Maximum dry unit weight(kN/m3)	10.75 18.75	9 18.8
Soil Classification According to ASTM D 2487	SM	SM

PREPARATION OF COMPACTED SAMPLES:

The following procedure was adopted in preparing the compacted soil samples for the oedometer and collapse tests. The soil was compacted using standard and modified Proctor procedure, and then the compacted samples were extruded from compaction mould by pushing the test ring to the required thickness. The faces were leveled after trimming

A manufactured hammer was adopted to carry out the preparing of compacted soil samples for triaxial shear tests. A hammer of 1.9 cm diameter, 500 gm mass and 30 cm drop as shown in **Plate (1). Table (4)** shows the required number of blows that gives the same compactive effort of the standard and modified compactive effort. The drop height, weight of hammer and number of blows were determined on the basis of the standard and modified compactive efforts.

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Plate (1). Manufactured hammer.

Table (4). Corresponding compactive efforts in the manufactured hammer.

Type of compaction	No. of blows / layer in the compaction mould	Compactive effort, CE in compaction mould (kN.m/m^3)	No. of blows / layer in manufactured mould	Compactive effort, CE in manufactured mould (kN.m/m^3)
Standard compaction	25 blows (*3 layers*)	593.7	3 layers (*2 of them compacted @12 blows and the other @ 11 blows*)	597.525
Modified compaction	25 blows (*5 layers*)	2710	5 layers (*4 of them compacted @ 32 blows and the other @ 31 blows*)	2714.48

* Compaction Mould of 4 " diameter.

COMPRESSIBILITY TESTS:

A series of Oedometer tests were carried out using standard back loading Oedometer. The sample size used 50 mm in diameter by 19 mm in height.

The series of Oedometer tests include two tests as follows:

Standard consolidation tests:

These tests were carried out on compacted samples to determine the compressibility characteristics. These tests were performed on samples prepared at different water content and dry unit weights of the standard and modified compaction tests.

Double Oedometer Tests:

This test was conducted according to **Jennings & Knight (1957)**. In this test, two samples were tested. The first one was loaded at its initial water content throughout the test without addition any water (dry test). Precautions were taken to minimize the evaporation of water from specimen by covering the cell with a nylon bag. The other sample was primarily saturated them loaded progressively as in the standard consolidation test. The difference between the two curves quantifies the amount of deformation that would occur at any stress level if the soil to be saturated during it is loading history.

SHEAR TESTS

The purpose of those tests was to investigate the shear strength characteristics of the compacted gypseous soil. Further more the effects of soaking on the strength characteristics were studied.

Triaxial Compression Tests:

To study the effect of water content and dry unit weight on shear strength of the soil tested, Unconsolidated Undrained tests, U-U were conducted on specimens (38 mm in diameter and 76 mm in height) compacted at different water contents and dry unit weights of the standard & modified compaction tests by mean of manufactured hammer .

California Bearing Ratio (CBR) test

Two series of tests were conducted on each soil sample (K1, K2). For the first series, the preparation of specimens and testing procedure were generally in accordance with **AASHTO** T143-81. Three specimens were prepared at optimum water content of the standard compaction test. And compacted in three layers using 2.5 kg hammer dropped from a height of 30.5 cm. Ten, thirty and sixty-five blows per layer were used for compacting the three specimens.

Identified specimens were prepared and testing after soaking in water until the swelling is ended to simulate the effect of saturation on the bearing characteristics.

In the second series, the whole program was repeated on specimens prepared at optimum water content of the modified compaction test and compacted in five layers using 4.5 kg hammer dropped from height of 45 cm.

In these entire tests, surcharge weights of 4.5 kg, in form of annular steel rings, were placed on the top surface of the prepared specimens before testing. The surcharge simulates the effect of the thickness of road construction overlaying the layer being tested.

RESULTS AND DISCUSSION:

Grain size distribution:

Table (5) shows the grain size distribution data. This table revealed that both soils with gypsum content χ=37%, χ=56% consist of coarse, medium and fine sand. The data for both soils reflects a significant difference between the dry and wet sieving by water, with respect to soil with gypsum content equal 37% the dry sieving showed only 13.84% fines while the wet sieving or natural specimen results in 70.02% fines.

The variation in the grain size distribution by both techniques (dry andwet by water) is attributed to the cementing agent (gypsum), which softens or dissolves in water, **Ismael and Mollah (1998).**

However, depending on either dry or wet sieving by kerosene, the soils can be classified according to **ASTM** D 2487 as (SM), i.e., silty sand.

Table (5). Results of Sieve Analysis.

Sample Type		Sieving method	Gravel (>4.75) mm	Coarse (2-4.75) mm	Medium sand (0.427-2) mm	Fine sand (0.075-0.425) mm	Silty clay (<0.075) mm	Specific gravity Gs
χ =37%	Natural	Dry	0.04	11.15	42.61	32.36	13.84	-
	Natural	Wet (water)	0	0.64	8.7	20.63	70.02	2.49
	Natural	Wet (kerosene)	0.03	10.93	38.59	32.79	17.66	2.51
χ =56%	Natural	Dry	0	2.52	42.28	30.52	24.69	-
	Natural	Wet (water)	0	0.25	12.38	20.46	66.91	2.47
	Natural	Wet (kerosene)	0	2.48	42.53	32.17	22.82	2.46

COMPACTION TESTS:

Relationships between dry unit weight and water content for the tested soil are shown in **Fig. (1)** for compactive efforts associated with the modified and standard Proctor.It is noticed that the standard maximum dry unit weight of the soil with gypsum content χ =37% is somewhat higher than the standard maximum dry unit weight of the soil with gypsum content χ=56%, while the opposite is true for modified compaction test as shown in **Fig. (1)**.

This behaviour may be explained by the role of gypsum in the soil as stated by **Al-Mufty (1997).** In other words, the standard compaction curve where specific gravity and cementing of gypsum (both of them decreases as the gypsum content increase which tends to decrease the unit weight) are the predominate factors, while in the modified compaction tests, filling the voids which tends to increase the unit weight with increasing gypsum content is the controlled factor rather than the other two factors (specific gravity and cementing of gypsum).

It can be concluded from the water-unit weight relationships, that the test results are depending on the soluble salt content (gypsum content) water content, soil components, the solubility degree of gypsum in water and compactive effort.

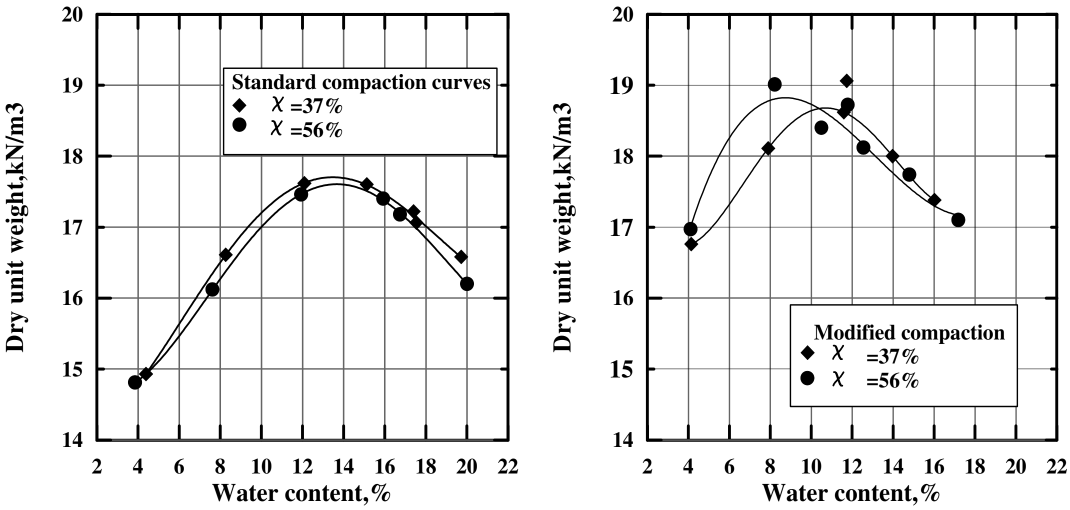


Fig. (1). Compaction curves for χ=37% and χ=56%.

OEDOMETER TESTS:

Compression Tests:

The results are presented as void ratio versus logarithm of vertical pressure and are shown in **Figs (2) and (3)** for all tested specimens.

It can be seen that the shape of e-log pressure curves for compacted samples with gypsum content χ=56% is steeper than the curves of samples with gypsum content χ=37%. This is due to the effect of gypsum content.

Table (6) and **Figs (2)** and **(3)** show the tests results for the two groups. It is noticed from **Table (6)** that compression index increased for soaked specimens. This is due to soften and dissolve of gypsum.

Double Oedometer:

The effect of compaction on the collapse behaviour of the tested soil was investigated by conducting the double oedometer test. To give a clear picture of tests results, collapse potential, CP, % for both gypsum contents and both compactive efforts as a function of moulding water content for all vertical pressures are plotted as shown in **Figs (4) to (5).**

Table (6). Results of compression tests.

Soil type	Compaction	As compacted specimens					Soaked specimens				
		γd kN/m^3	w.c %	e∘	Cc	Cr	γd kN/m^3	w.c %	e∘	Cc	Cr
χ=37%	Standard	17.73	13.5	0.416	0.128	0.024	17.73	13.5	0.416	0.1	0.020
		17.46	11	0.437	0.161	0.021	17.46	11	0.437	0.173	0.023
		17.46	16.1	0.437	0.131	0.026	17.46	16.1	0.437	0.134	0.023
		16.5	8	0.52	0.171	0.0193	16.5	8	0.52	0.146	0.022
	Modified	18.75	0.75	0.339	0.156	0.024	18.75	10.75	0.339	0.071	0.029
		17.46	6.25	0.437	0.134	0.023	17.46	6.25	0.437	0.128	0.028
		17.46	15.75	0.437	0.203	0.01	17.46	15.75	0.437	0.125	0.011
		18.125	8	0.385	0.116	0.019	18.125	8	0.385	0.111	0.027
χ=56%	Standard	17.6	13.85	0.396	0.11	0.017	17.6	13.85	0.396	0.095	0.022
		17.46	11.6	0.4078	0.1	0.019	17.46	11.6	0.408	0.164	0.023
		17.46	16	0.7078	0.133	0.017	17.46	16	0.408	0.166	0.019
		16.25	8	0.513	0.181	0.016	16.25	8	0.513	0.17	0.025
	Modified	18.8	9	0.307	0.097	0.027	18.8	9	0.307	0.091	0.023
		17.46	4.75	0.4078	0.117	0.025	17.46	4.75	0.408	0.11	0.028
		17.46	15.5	0.4078	0.137	0.022	17.46	15.5	0.408	0.199	0.037
		18.75	8	0.311	N.D	N.D	18.75	8	0.311	N.D	N.D

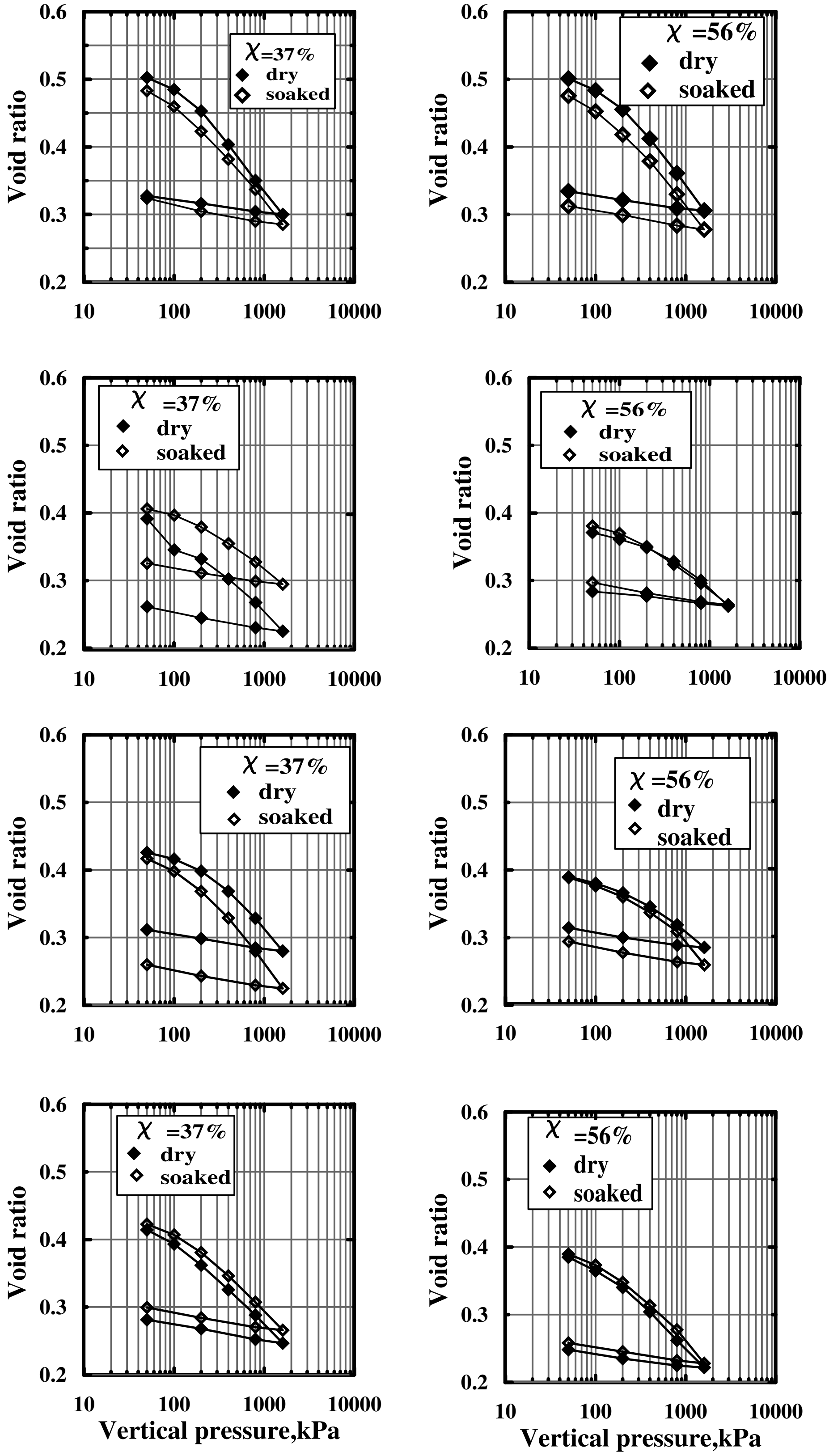


Fig.(2). Compression curves for soil samples of standard compaction at: (a) w.c=8%, (b) dry side, (c) optimum water content, (d) wet side.

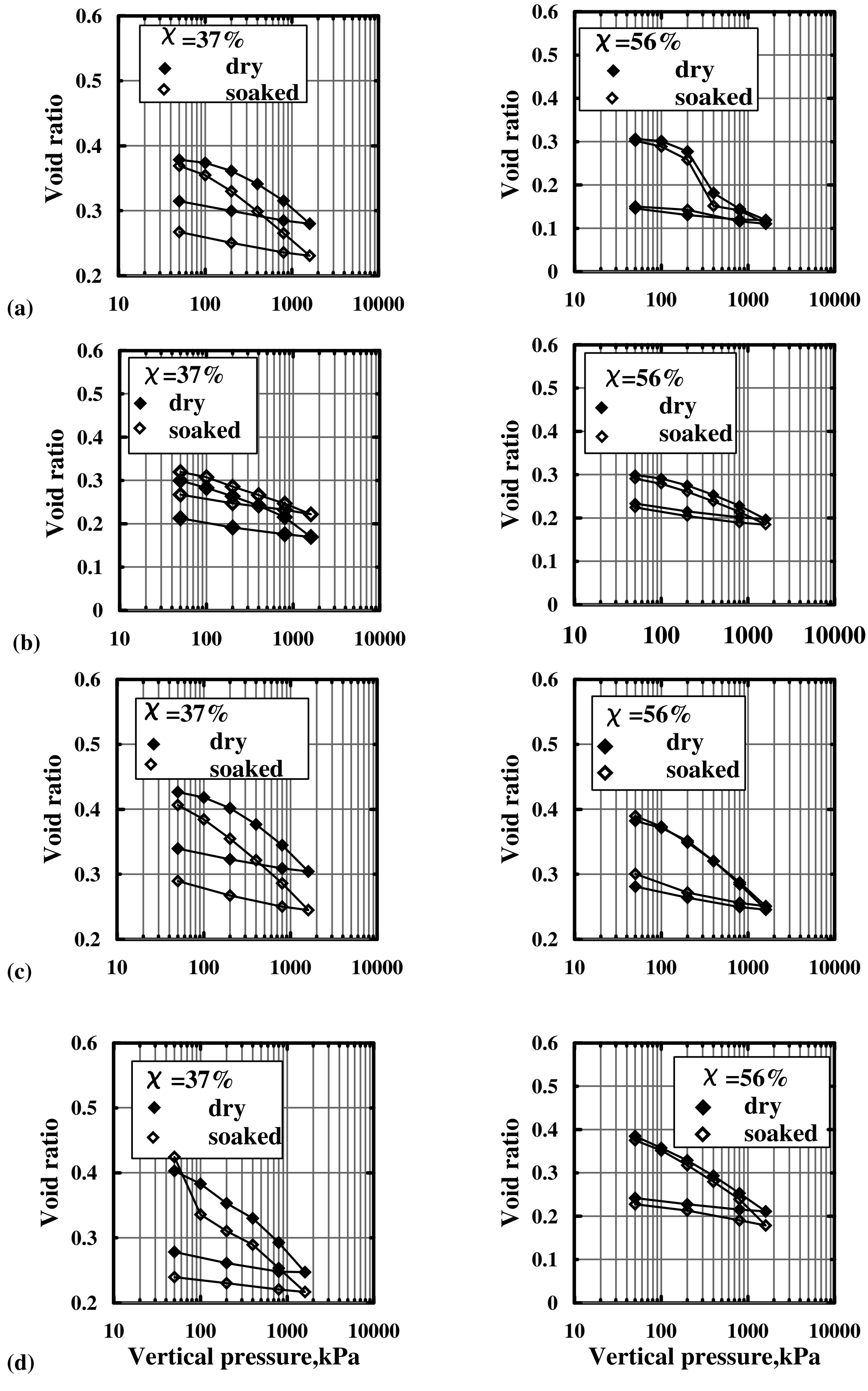
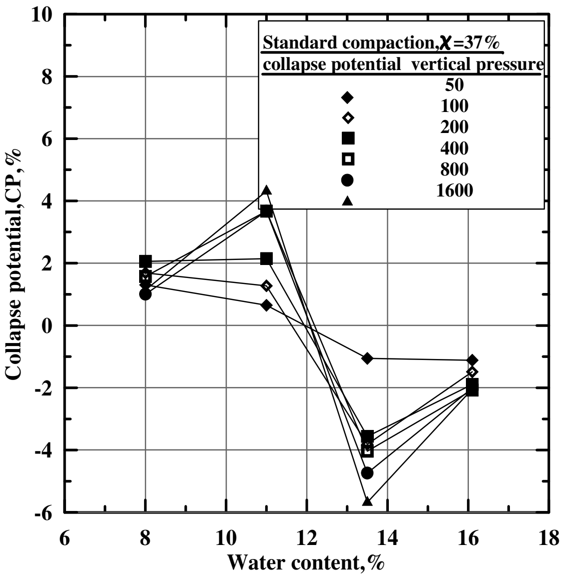


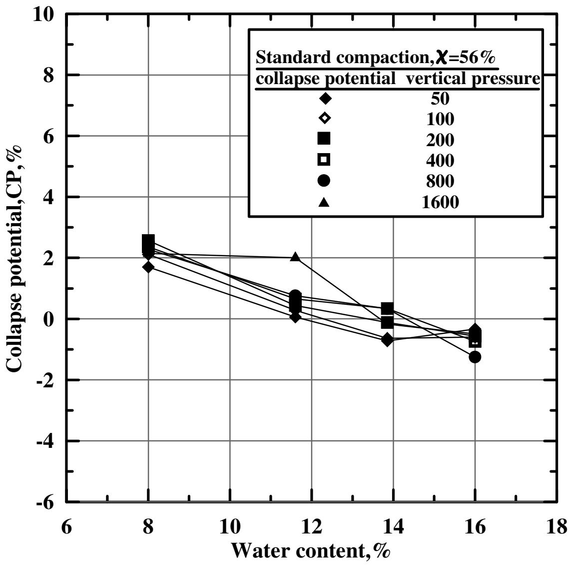
Fig. (3). Compression curves for soil samples of modified compaction at: w.c=8%, (b) dry side, (c) optimum water content, (d) wet side

From these figures, in general, the trend of the tested samples were found to collapse from dry side of optimum for both gypsum contents and both compactive efforts until it reached the optimum water content the trend was changed to swell where the swelling is higher for samples of gypsum content 37%. This behaviour can be explained as follows: as the water enters the soil void leads to soften the cementing bonds that took place in term of collapse potential. Collapse potential increased with a decrease in gypsum content. This may be attributed to the effect of sand-silt mixture, as the amount of silt size particles become angular in shape due to crushing of sand by compaction. As a result of that, the collapse decreased. This behaviour was noticed by **Assallay, Rogers and Smalley (2004).** They found that higher collapse values were obtained when the angular silt fraction was replaced with smooth, spherical glass balls thus confirming that the geometrical properties of the silt particles have a significant effect on the hydro collapse behaviour of loess deposits.

As the water content increased, the role of Palygroskite will begin in term of swelling which increased then decreased. The swelling can occur when anhydrous calcium sulphate imbibes water ,**Abduljawad (1994).**This process of gypsification refers to the addition of water crystallization to the mineraland is associated with a volume increase of up to 62%,**Blatt et al.(1980).** The swelling was noticed to increase as the gypsum content decreased. This phenomenon could be attributed to the effect of gypsum in limiting the amount of swelling at higher water content as reported by **Bridge and Tunny (1973).** They explained this effect to the replacement of ions in the clay mineral by the calcium on the clay exchange sites.

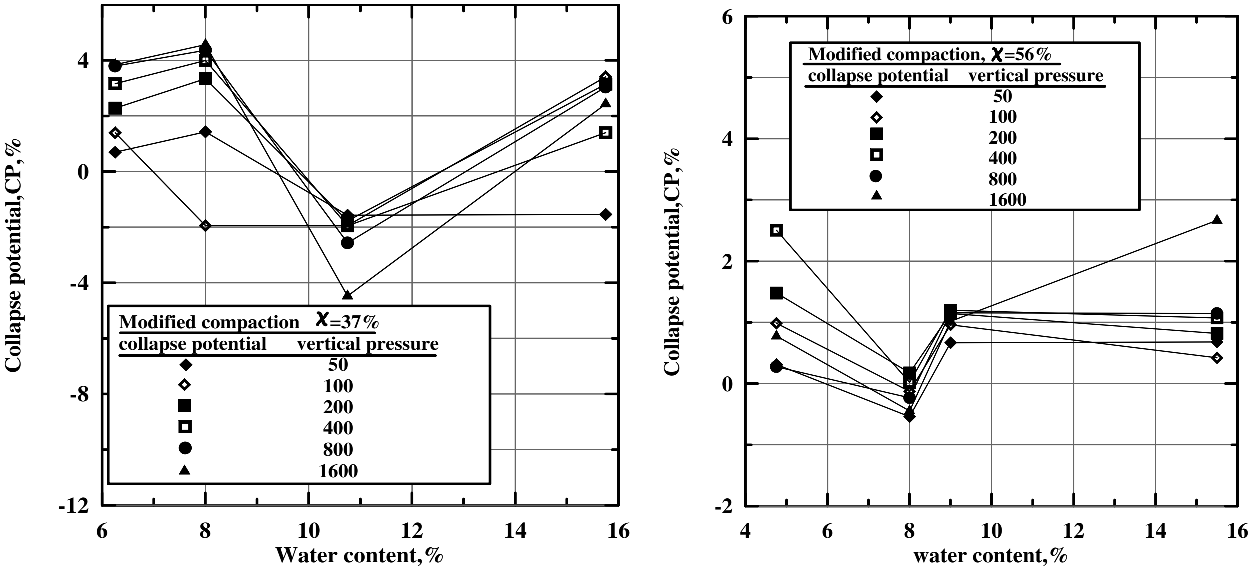


(a)



(b)

Fig. (4). Influence of moulding water content on collapse potential from double oedometer of compacted soil specimens: (a) χ =37% (b) χ =56% of standard compaction.



(a) (b)

Fig. (5). Influence of moulding water content on collapse potential from double oedometer of compacted soil specimens: (a) χ =37%, (b) χ =56% of modified compaction.

SHEAR STRENGTH CHARACTERISTICS:

Triaxial Compression Tests:

Different dry unit weights and moulding water contents of the standard and modified compaction tests were adopted to obtain a complete picture of effect compactive effort on shear behaviour of the tested gypseous soils.

Fig.(6) shows the shear strength parameters cohesion c and angle of internal friction φ as a function of compactive effort for both gypsum contents. From the results, the following can be observed:

a- The cohesion c increased as the compactive effort increased for both gypsum content.
b- The angle of internal friction **φ** also increased with an increase in compactive effort for both gypsum content with a decrease in moulding water content.

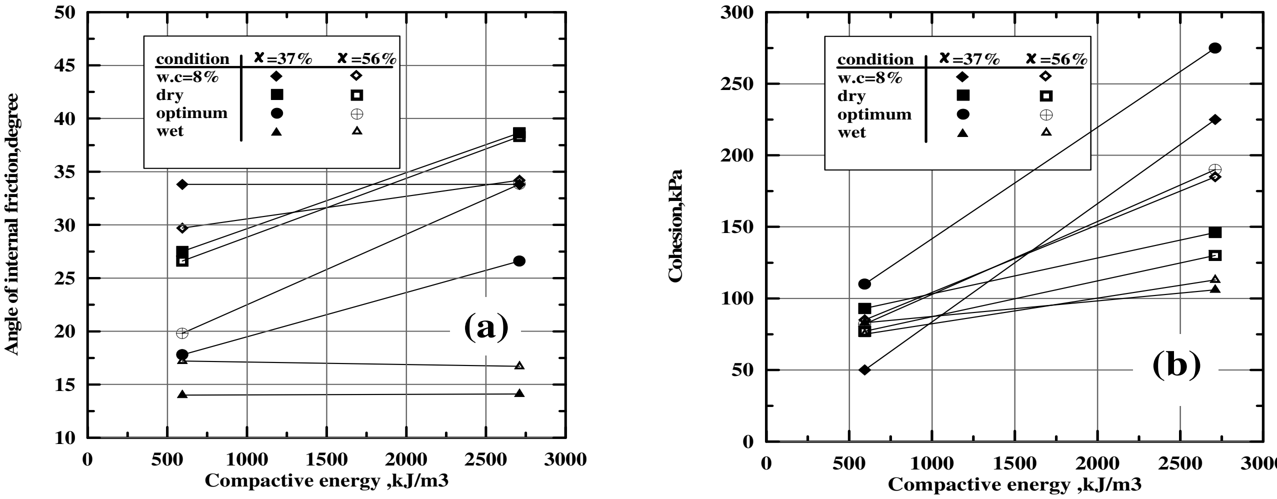


Fig. (6). (a) Angle of internal friction, (b) cohesion versus compactive energy.

To show a clear picture of effect moulding water content on shear strength parameters c and φ, **figs (7)** and **(8)** are plotted.

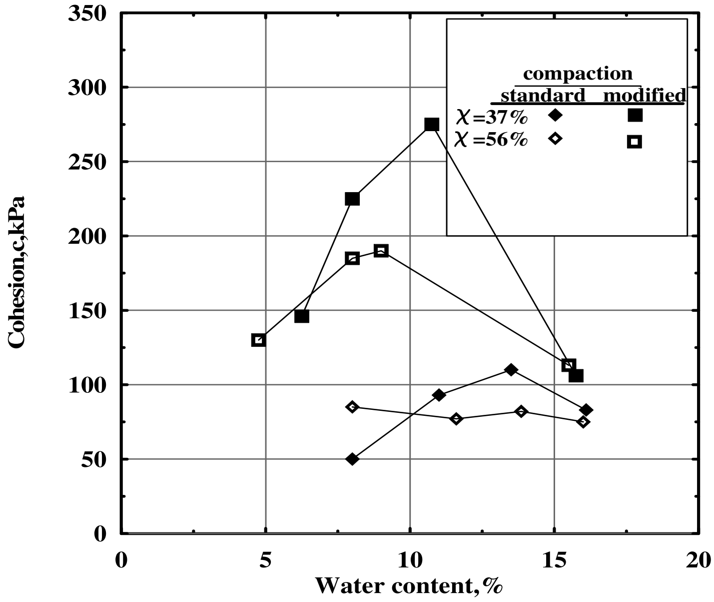


Fig. (7). Relationship between cohesion and moulding water content of soil tested.

Fig. (7) shows that the cohesion c increased with increasing compactive effort and decreased with increasing gypsum content. The increase in cohesion for all compactive efforts and gypsum content with increasing moulding water content till it reaches a maximum value at optimum water content then tends to decrease in similar manner of compaction curve.

As the cohesion which is due to internal forces holding soil particles together in a solid mass so, as the gypsum content increased, the generated crystal formation pressure in the pore spaces increased leading to rupture of primary and newly bond, as a result of which cohesion is reduced.

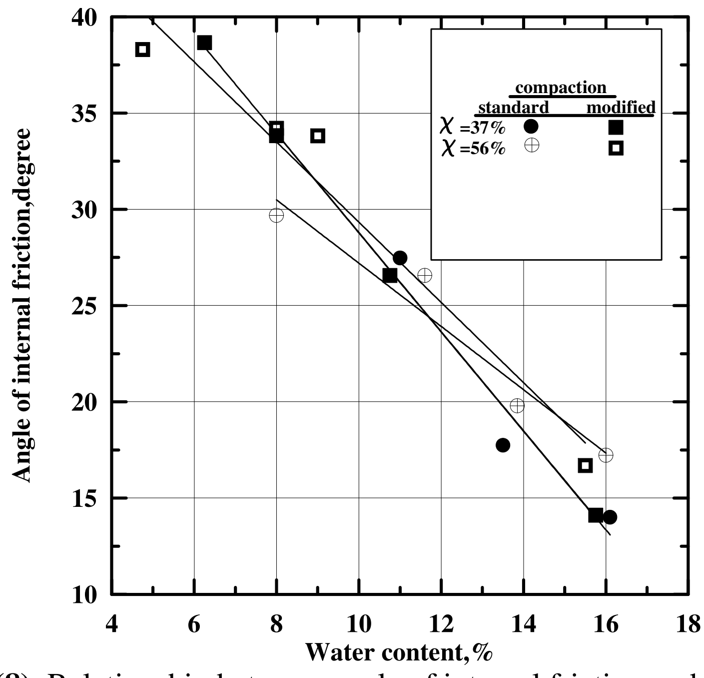


Fig. (8). Relationship between angle of internal friction and moulding water content of soil tested.

Examining **Fig.(8)** revealed that the angle of internal friction decreased with increase moulding water content because water acts as a lubricant reducing friction and minimizing the sliding effect, which leads to reduce the angle of friction. It is also clear that angle of internal

friction increased with increasing gypsum content for both compactive efforts. This may be attributed to the fact that φ increased with increasing coefficient of uniformity *Cu* of the soil, where *Cu*=17 for soil with gypsum content=37% while *Cu*=25 for soil gypsum content=56%. Furthermore, the friction between gypsum particles is greater than mineral components of the soil.

Figs (9.a) and **(9.b)** show the shear strength as a function of moulding water content. From the results, the following can be observed:

a- The shear strength tends to increase with increasing confining pressure for both compactive efforts and both gypsum contents. This increased is somewhat little at wet side of optimum. As seen in compaction curves for both soils (χ=37%and χ=56%), the selected points at wet side of optimum could be considered nearly saturated soils (S=92.35% and S=90.3%for standard and modified compaction tests of χ=37% and S=96.44% and S=93.42% for standard and modified compaction tests of χ=56%). This behaviour can be explained in terms of pore pressure in the saturated soil, the pore water takes up which is a portion of applied load.

b- In standard compactive effort for both gypsum content, shear strength decreases as the moulding water content increased, while in modified compactive effort the shear strength increased as the moulding water content increased until it reached the optimum water content then decreased as the water content increased.

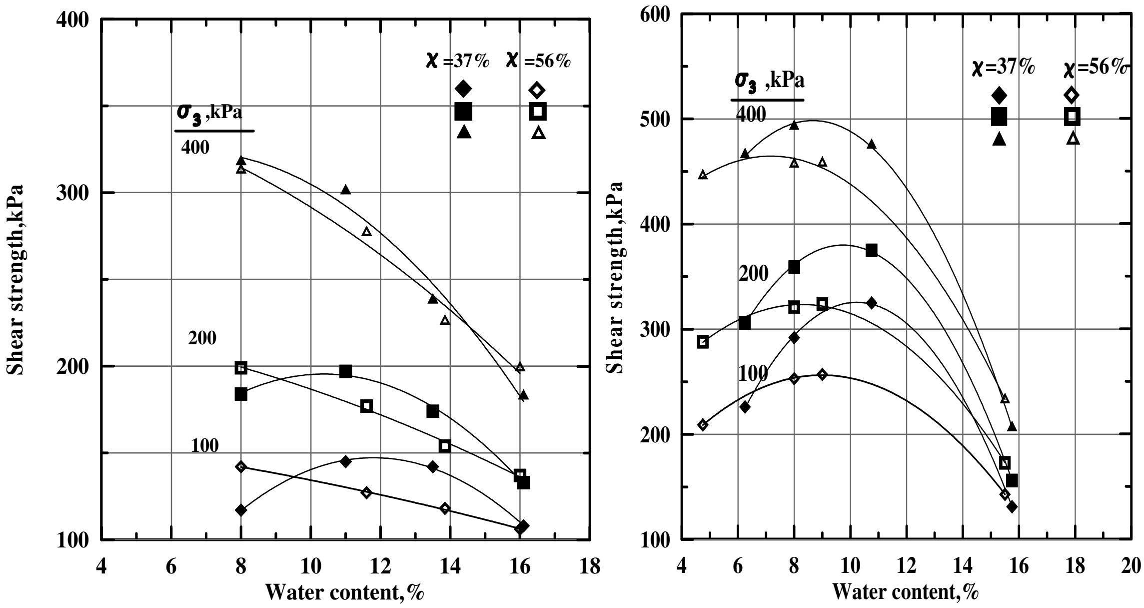


Fig. (9). Influence of moulding water content on shear strength compacted soil samples of χ =37%and χ =56%: (a) standard, (b) modified.

California Bearing Ratio (CBR) Tests:

The tests were performed on samples prepared at optimum water content and compacted to various unit weights. A second series of tests were performed on specimen soaked in water for 4 days to give an indication of strength loss due to saturation and to give information concerning

Soaked CBR values at 2.5 and 5 mm penetration are summarized in **Table (7).**

Table (8). Results of CBR Tests.

Soil type		No. of blows	2.5 kg hammer		4.5 kg hammer	
			CBR @2.5mm penetration	CBR @5.0mm penetration	CBR @2.5mm penetration	CBR @5.0mm penetration
K1	χ =37 %	10	1.133	2.987	4.0	4.13
		30	3.437	2.8557	7.93	8.767
		65	5.589	4.959	10.196	12.024
K2	χ =56 %	10	2.077	1.754	2.832	3
		30	9.479	9.143	7.55	10.52
		65	13.784	14.024	35.876	42.08

It can be seen that CBR values are greater at 2.5 and 5 mm penetration for gypsum content χ =56% than the corresponding values for gypsum content χ =37%. This may be attributed to the gypsum content as this result coincides with the effect of gypsum in reducing the plasticity of the tested soil, since the plasticity index can be considered as a shear index as well **Rodrigues, Castillo and Sowers (1988).** A summary of all CBR soaking test results for both gypsum contents at 2.5 and 5 mm penetration are presented in **Fig. (10).**

The soaked values of CBR are plotted against the number of blows per layer in **Fig (11).** In all cases shown in this figure, CBR values found to increase with increase in number of blows, weight of hammer used and gypsum content. Fifty six blows per layer are generally required to mould CBR specimen to hundred percent of the maximum dry unit weight determined by **ASTM D 678-70 and D 1557-70**, at this number of blows, a soaked CBR values of 5% and 11% are obtained for soil with gypsum content χ =37% whereas, for soil with gypsum content χ =56%, soaked CBR gives high values in the range (12.5 - 34%).

It is worth to mention that at this stage: by relating the soaked CBR values obtained at 100% of the maximum dry unit weight and optimum water content of the standard and modified compactive efforts with the shear parameters cohesion c and angle of internal friction φ that gained from triaxial tests of samples compacted at maximum dry unit weight and optimum water content of the standard and modified compactive efforts for both gypsum content as shown in **Fig. (12).**

From this figure, the cohesion is observed to decrease with increasing soaked CBR values while the angle of internal friction is seemed to increase with increasing soaked CBR values with increasing compactive efforts.

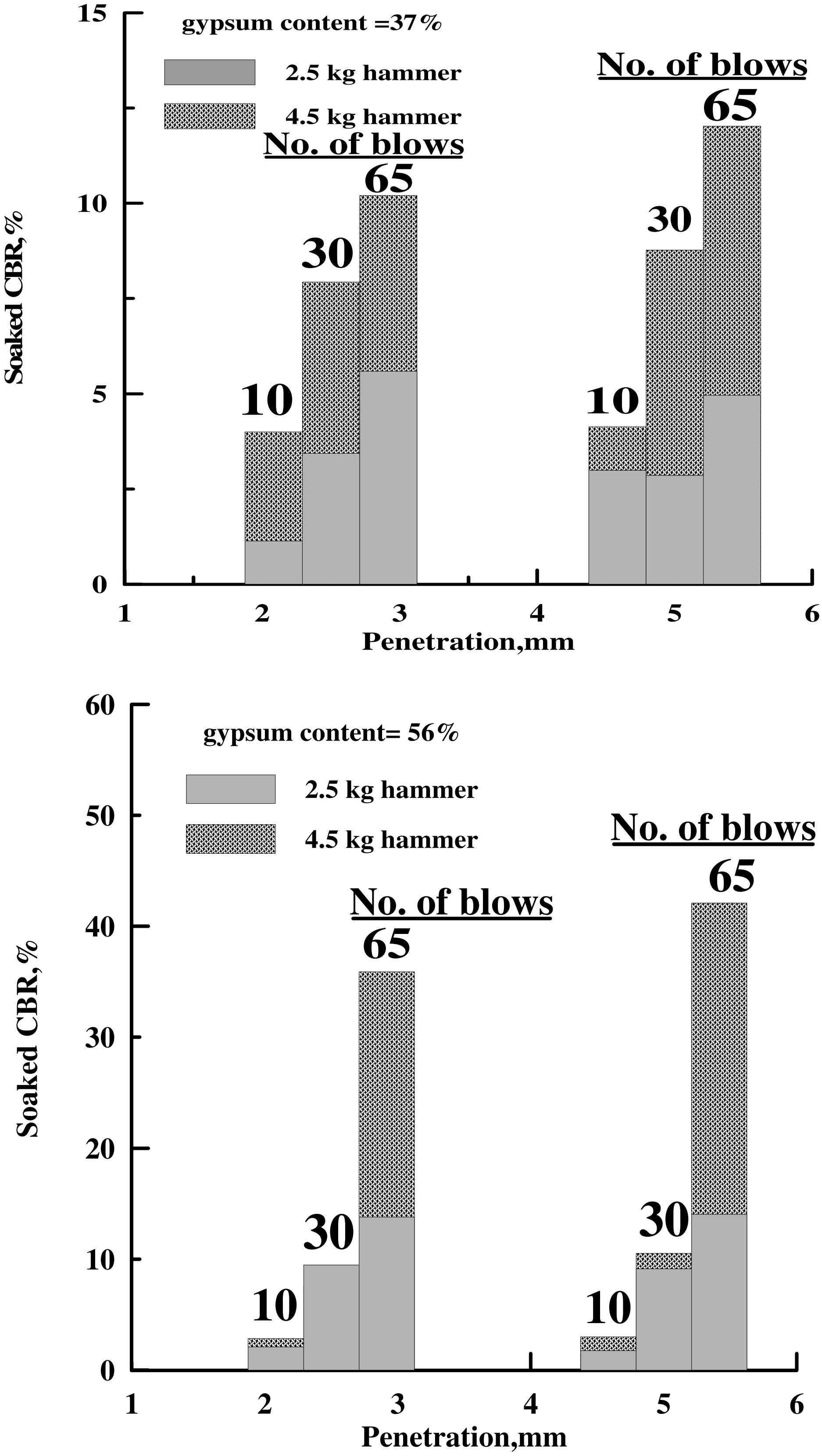


Fig. (10). CBR values at 2.5 and 5 mm penetration for gypsum content: (a) χ =37%, (b) χ =56%.

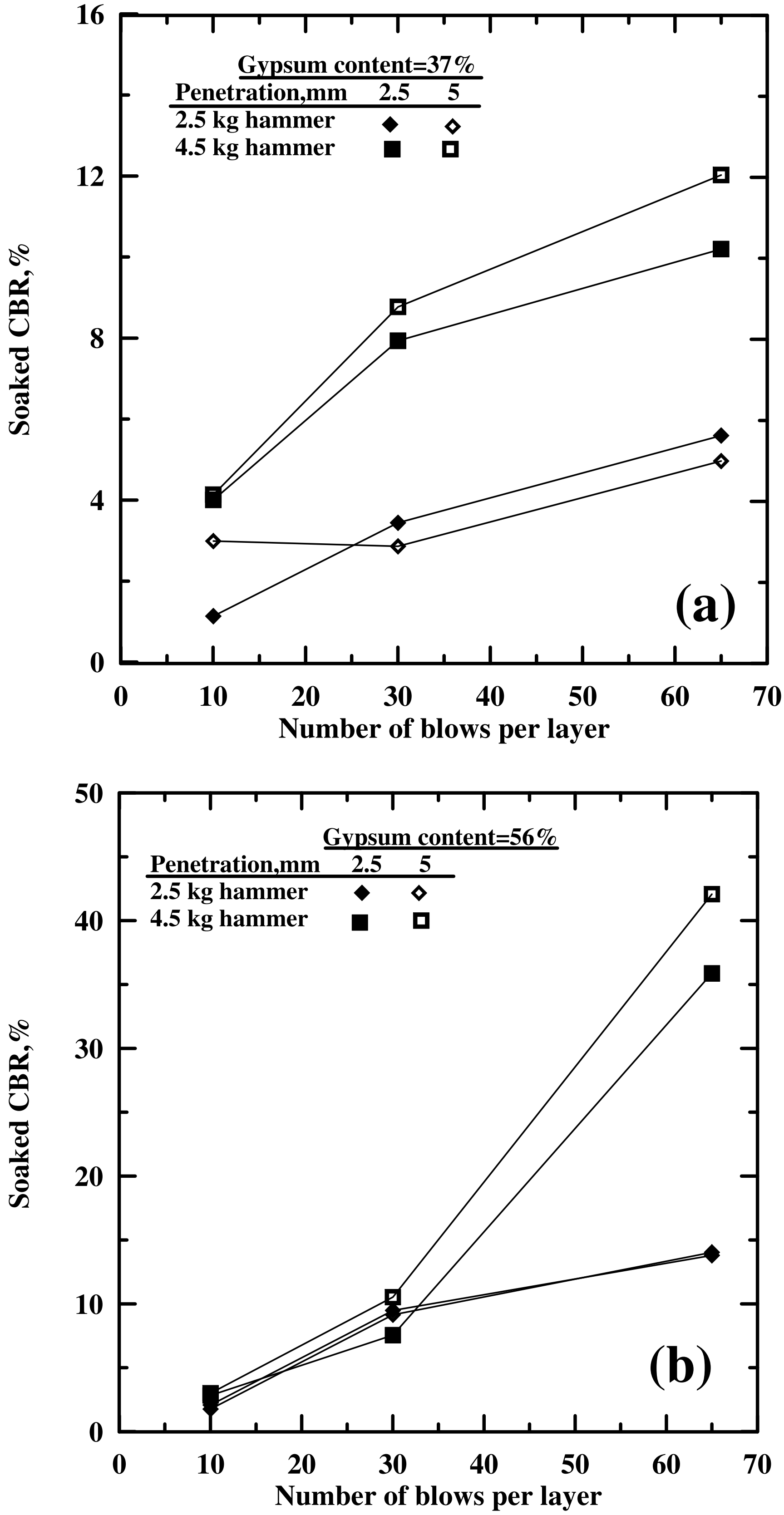


Fig. (11). Number of blows per layer versus CBR: (a) χ =37%, (b) χ =56%.

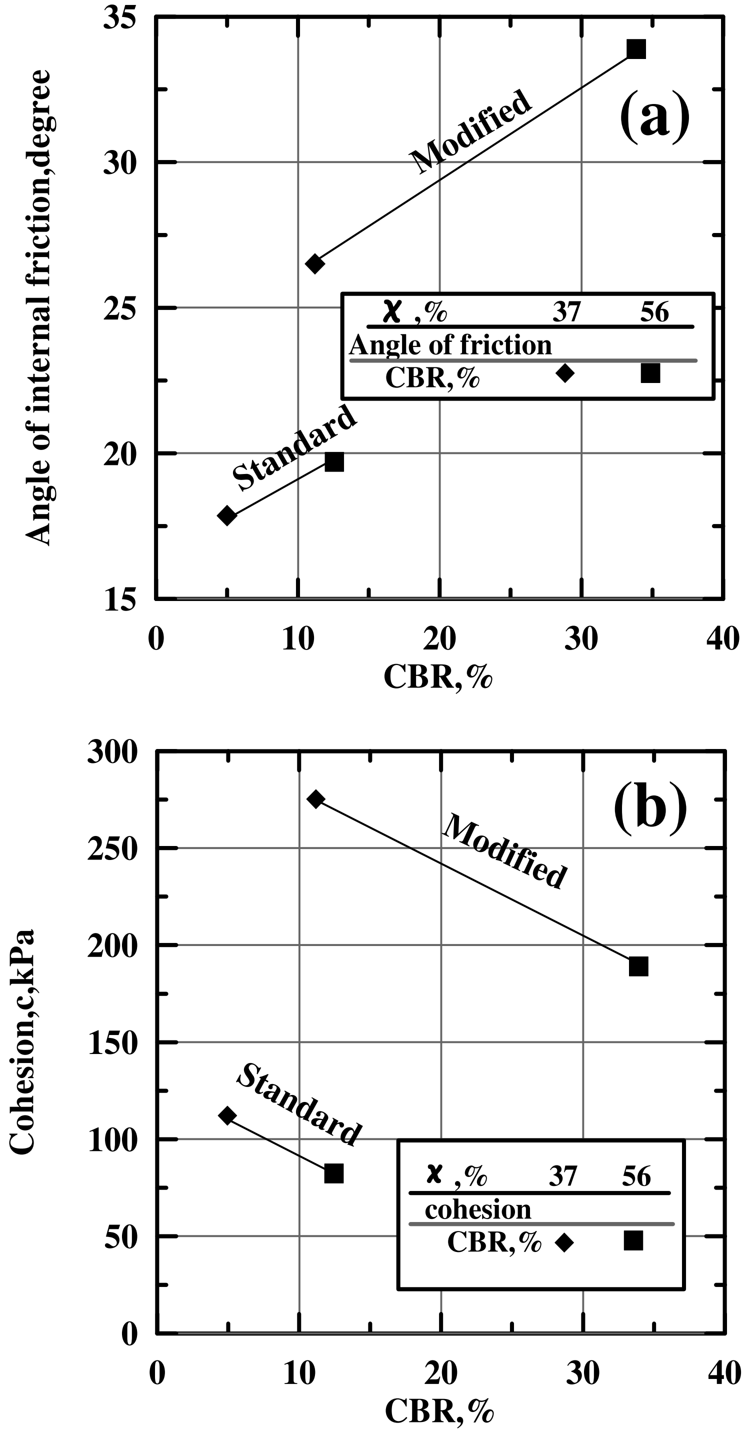


Fig. (12). Variation of shear strength parameters with soaked CBR values: (a) Angle of internal friction, (b) Cohesion.

CONCLUSIONS

A program of laboratory tests was carried out on two types of gypseous soil taken from Kirkuk city. Tests were performed on compacted soil samples using Standard and Modified Proctor. Based on the results, the following conclusions are made:

-With the increase in compactive effort, the maximum dry unit weight increases and the optimum water content decreases for both types of gypseous soil. The percent increase in dry unit weight is 5.75% and 6.82% and the percent decrease in optimum water content is 20.4% and 35.02%for soils with gypsum content χ=37% and χ=56% respectively.
-Compacted soil specimens at dry side of optimum tend to collapse after soaking with water while soil specimens compacted at wet side of optimum tend to swell for both compactive efforts. The percent of swell of soil with χ =37% is more than that with χ =56%.
-Shear strength parameters (***cohesion and friction***) increase with increase in gypsum content. The cohesion (c) increases with the increase in moulding water content till it reaches a maximum value at optimum water content then tends to decrease in a manner similar in shape of compaction curve. This behaviour is independent of compactive effort and gypsum content.

The angle of internal friction (φ) decreases with the increase in moulding water content and with the decrease in gypsum content for both compactive efforts.
- Values of California Bearing Ratio (CBR) at 2.5 mm and 5 mm penetration are higher for soil with gypsum content χ=56% as compared with the corresponding values for gypsum content χ =37%.
- The soaked CBR values increase with the increase in compactive efforts (number of blows, weight of hammer used) and gypsum content.
-The increase in soaked CBR values obtained at maximum dry unit weight and optimum water content were found to be compatible with the increase in angle of friction and decrease in cohesion for both types of compactive efforts.

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ABBREVIATIONS AND NOTATIONS

AASHTO:	American Association of State Highway and Transportation Officials
ASTM:	American Sociaty of Testing Material
CBR:	California Bearing Ratio,%
Cu:	Coefficient of uniformity
CP:	Collapse potential, %
c:	Cohesion(kPa)
Gs:	Specific gravity
K1:	Soil with gypsum content 37%
K2:	Soil with gypsum content 56%
S:	Degree of saturation
SM:	Silty Sand
U-U:	Unconsolidated Undrained
χ:	Gypsum content
f:	Angle of internal friction