Strength and Consolidation Characteristics of Compacted Clayey Soil Having a Special Case of Standard Compaction Curve

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Received on: 9/5/2011 & Accepted on: 8/11/2012

ABSTRACT

This paper deals with the results of an experimental study carried out on compacted clayey soil, to investigate the strength and consolidation characteristics of this soil. This soil having special case of standard compaction curve contain two values of maximum dry unit weight and two values of optimum moisture content between these point minimum dry unit weight was occurred.

The results show that the maximum compressive and tensile strength lies on point near the point of second peak on standard compaction curve. Also the maximum bearing capacity and minimum settlement at the same point on standards compaction curve. Finally the preferred zone to conducted the compaction in field at this point where the dry unit weight at this point was 16.5kN/m^3 while the moisture content was 18%.

Keywords: Clayey soil, Standard compaction curve, Strength, Consolidation.

خصائص المقاومة والانضمام لتربة طينية مرصوصة ذات حالة خاصة لمنحني الرص القياسي

الخلاصة

يتضمن هذا البحث دراسة عملية لإيجاد خصائص كل من المقاومة وخصائص الانضمام لتربة طينية مرصوصة، منحني الرص القياسي لهذه التربة ذو شكل خاص يختلف عما هو مألوف في الترب الطينية، اذ ظهر فيه قيمتين للكثافة الجافة العظمى وقيمتين للمحتوى الرطوبي الأمثل بين هاتين النقطتين توجد نقطة ذات الكثافة الأقل.

أظهرت النتائج إن أعلى قيمة لكل من قوة الانضغاط غير المحصور وقوة الشد كانت في نقطة قريبة من النقطة القمة الثانية لمنحني الرص القياسي كما بينت النتائج ان على قابلية تحمل للتربة واقل هبوط يحصل فيها عند نفس النقطة الواقعة على منحني الرص القياســي.ومن ذلك فان أفضل جزء لرص هذه التربة في الحقل هو في النقطة المذكورة في أعلاه أي عند الكثافة الجافة العظمــى(kN/m^3 ١٦.٦) والمحتوى الرطوبي الامثل ١٨%.

https://doi.org/10.30684/etj.2013.82190
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INTRODUCTION

Most of the current design practices in geotechnical engineer -ing are based on settlement and strength criteria. The recommenda -tion for the allowable bearing capacity to be used for design is based on the *minimum* of either limiting the settlement to a tolerable amount, or the allowable bearing capacity, which considers soil strength, as computed . where shear strength is considered as one of the most important design parameters, also the settlement must not be exceed the allowable settlement. The safe design of structures therefore depends on the what happened to the shear strength of soil in the field during the construction process and what is the total settlement occurred[1].

Construction of earth structure involves the use of compacted soils also, construction of concrete structure generally based on soil, compacted before starting construction. The main geotechnical problems like bearing capacity failure or settlement may be exceed the allowable settlements [2].

Many studies were conducted on shear strength of the soil, including some factors that affected on its value. Such of these factors are suction, water content, normal stress, wetting and drying cycles, repeated loads and loading/unloading [3, 4, 5, 6]. For consolidation characteristics many researchers were studied in this field to calculate the settlement of soil .where the some of these study conducted on Mosul clayey soil to study the effect of deformation of soil under load on the structure building it [7]. The Compressibility behavior of various type of soil was measured using Rowe Cell consolidation test for accuracy and conventional oedometer test for comparison purpose. Compressibi -lity index Cc and Cr was identified as two crucial parameters to estimate settlements of soil [8].

Also in other study in this field was conducted on 10 types of soil covering a sufficiently wide range of liquid limit, plastic limit, and shrinkage limit were selected and conventional consolidation tests were carried out starting with their initial water contents almost equal to their respective liquid limits. The compressibility behave -or is vastly different for pairs of soils having nearly the same liquid limit, but different plasticity characteristics. The relationship between void ratio and consolida -tion pressure is more closely related to the shrinkage index (shrinkage index = liquid limit - shrinkage limit) than to the plasticity index. Wide variations are seen with the liquid limit. For the soils investigated, the compres -sion index is related better with the shrinkage index than with the plasticity index or liquid[9].

In this study, the clayey soil was used to find the standard compaction curve and preparation the strength and consolidation specimens at many selected points on standard compaction curve by trimming process for the standard compaction specimens. Then strength characteristics such as (unconfined compressive strength , tensile strength, shear strength parameters "effective cohesion and effective angle of internal friction") and consolidation characteristics were founded then finally limited the preferred zone to conducted the compaction in field.

MATERIALS

- Soil

The soil used in the present study was brought from the thermal power station near hammam Ali city, south of Mosul city, see Figure (1). The index properties such as (Atterberg limits, grain size analysis and specific gravity) and the chemical properties as(sulfate attack percent, (So_3%), Total soluble salts percent, (T.S.S %), pH value and Organic matter content (OM%)). The results of these tests are shown in Table (1).

- Water

Tap water was used in the tests and distilled water used as required by testing procedure.

TESTING METHOD

This research was contained two main sets of tests first strength tests and second consolidation tests, before conduct -ing the above tests, the standard compaction test for this soil must be done.

- Compaction test

The compaction test was done on the soil specimens prepared as followed, starting, take some quality of oven dry soil and divide it many samples then different varies of water content were added and mixed the soil water and put the mixture for each soil sample in the closed plastic bag then left to 24 hour to ensure the homogenous the mixture (distribution of water in the soil), after that, the compaction test was conducted according to standard procedure method of compaction ASTM (D:498)[10].

- Strength test

a) Unconfined compression test.
b) Flexural test.
c) Direct shear test

a) Unconfined compression test: The unconfined compression test was conducted to obtain the unconfined compressive strength of the soil. The oven dry soil was used to prepare the soil specimens and varies percentage of water were added to the soil samples. After that put the mixture in closed plastic bag to prevent loss of water from the soil sample. These samples were left for 24 hour to distribution of water in the soil. To prepare the specimens of the unconfined compression test, the soil is compacted in the mold with dimensions (D=5cm and H=10cm). The applied energy enough to give the same density of compaction curve at the same water content. Finally the unconfined compression test was conducting according to ASTM (D:2166)

b) Flexural test

The tensile strength of the soil specimens is a vital parameter to judge its suitability as road base material. Flexural strength determination is one of the effective alternative methods to determine the combined compressi -ve and tensile strength. In the present study an attempt has been made to study the flexural strength characteristics of clayey soil. However, a prismatic beam (50*50*300 mm) was used in this investigation. The samples were prepared by compacting the soil at the varies moisture content to get varies dry unit weight like that in the standard compaction curve. The specimens were mounted in the compression machine and a load was applied at rate of (0.127mm/min)(B.S.118) [11]. Finally the flexural strength were evaluated.

c) Direct shear test

The shear strength parameter (ć and ǿ) were found by conducting the direct shear test on remolded soil specimens. The soil specimens were prepared by trimming process. Where, the shear specimens taken from the compaction soil specimens by trimming to get the direct shear specimens, after that the direct shear test was done according ASTM (:3080-72).

- Consolidation test

The consolidation test conducting on remolded soil specimens. These specimens were prepared. The preparation process of specimens were done by trimming for the specimens of standard compaction were the ring of consolidation putting on the specimens and trimming was conduced from all sides until prepare the consolidation specimen this method for perpetrating the specimens is done to ensure that taken the specimens having the same density and the same moisture content on the compaction curve. After that the specimens were tested by consolidation apparatus according to ASTM (D:2435-70).

RESULTS AND DISCUSSION

- Compaction characteristics

The standard compaction curve of remolded clayey soil specimens are shown in figure (2). It is noticed that the soil having two values of maximum dry density with two values of optimum moisture content at points designated by T_1 and T_2 , these values was (15.8kN/m^3) and the optimum moisture content (14.1%). To know how the dry unit weight were changed with water content to certain the unusual shape of compaction curve then the water lead to decrease the unit weight, because the soil plate lets begin to be oriented and aligned and inter particles distance tend to widen as more as water is captured, finally the arrangement of soil structure in form of dispersed [12].

- Strength characteristics

a) Unconfined compressive strength

The results shown in Figure (3) and Table (2), were given that the unconfined compressive strength is slightly increase with initial water content in spite of decrease in dry unit weight after point T1 towards point B. At point T1 the value of unconfined compressive strength was 190kN/m^2 at the right side of point T1 the unconfined compressive strength is increase to reach point B (a minimum dry unit weight) was 400 kN/m^2, these behavior may be due to the increase in initial moisture content lead to increase in cohesion between soil particles, finally increase in the unconfined compressive strength. After point B the unconfined compressive strength also increase to reach point having initial water content (T2-2%) or (water content is 18%) at this point the maximum value of unconfined compressive strength was occurred where was 470 kN/m^2 for continue increase in initial water content lead to decrease in the value of unconfined compressive strength through point T2 having the value of 450kN/m2, when the water content reached to the plastic limit (PL) the value of unconfined compressive strength was 300kN/m^2. After that, at water content (PL +2%) the plastic failure occurred.. The decrease in the values of unconfined compressive strength after point (T1 - 2%) may be due to the initial water content cause the diverge of soil particles and lead to decrease in cohesion and friction between particles.

b) Flexural strength or tensile strength

The results of the tensile strength have been presented for clayey soil specimens. It is illustrated in Figure(4) and Table (2). The results show that the tensile strength at point T1 equal to 20kN/m^2 then, increase with water content on standard compaction curve to reach 40 kN/m^2 at point B that is having lower dry unit weight, this behavior may be due to increase in cohesion with water content.

After point B the tensile strength continue increase to reach 50 kN/m^2 at point (T2-2%) after this point the tensile strength decrease to 48 kN/m^2 at point T2 where maximum dry unit weight, then the tensile strength continue decrease to reach 25 kN/m^2 at point PL, this behavior may be due to water higher water content that act to diverge of clay particle and decrease the friction and cohesion between clay particles.[13]. Finally, it is noticed that the trend of tensile strength is like the trend of compressive strength with compact -tion curve but, the value of tensile strength at any point on standard compaction curve equal to 10% from the value of compressive strength at the same point on compaction curve.

c) Shear strength parameters

The direct shear test was conducted to find the shear strength parameters (effective cohesion ć and effective angle of internal friction ǿ). The results are shown in Figure (5) and Table (2), it is noticed that the angle of internal friction decrease with initial water content , where the angle of friction was 24° at point T1 then decrease with water content to reach 21° at point B and continued decrease to reach 15° at point T2 after this point the angle of friction also decrease to reach approximate zero at a point having initial moisture content (PL+2%) also the angle of friction decrease with decrease in dry density after point T1 to reach point B after this point the angle of friction continue decrease to zero at point (PL+2%) while the density increase after point B to reach the maximum value at point T2 then decrease..

The results in Figure (6) and Table (2) shown that the cohesion at point T1 was 23kN/m^2 then increase with initial water content to reach 30kN/m^2 at point B and continued increase to reach 50kN/m^2 at point (T2-2%) then decrease to 45kN/m^2 at point T2 and decrease to 20kN/m^2 at PL, and less value at point (PL+2%).

- Consolidation characteristics

The results shown in Figure (7) and Table (3), the initial void ratio having maximum value at point B where the lowest dry unit weight, the void ratio was o.73, while the void ratio at points of maximum dry unit weight were 0.613 and 0.639 for points T1 and T2 respectively. Also the maximum compression index was 0.205 at point B where lowest dry unit weight and maximum void ratio, while the compression index at points T1 and T2 were 0.165 and 0.163 respectively. The swell index were 0.017, 0.008 and 0.005 for points T1 , T2 and B respectively.

The results of coefficient of consolidation were given that the maximum value at point T2 (Cv=0.012cm/min) while the other values were (Cv=0.011 and 0.0104 cm/min) for points T1 and B respectively. Finally the results shown that the maximum value of settlement was occurred at point B equal to 3mm this behavior may be due to that the point B having the lowest dry unit weight while the minimum settlement was occurred at point T2 equal to 1.8mm.

- Bearing capacity calculations

To calculate the bearing capacity of the compacted soil, it is assumed that the footing is continuous footing and carryout at the depth 1m below the ground surface and also the with of footing is 1m.

The aim of bearing capacity calculation to limit the prefer zone to conducted the compaction in field. Four points were selected on standard compaction curve to find the bearing capacity of soil. These points were T1 , T2, T2-2% and B.

At point T1: This point having the maximum dry unit weight (16.9kN/m^3) and optimum moisture content (3%). Practically, it is cannot reached the water content of soil to 3% in field. This conclusion leads to neglect this zone of standard compaction curve.

At point T2: This point having the maximum dry unit weight (16.7kN/m^3) and optimum moisture content (20%), and the moisture unit weight (20kN/m^3). The bearing capacity was found using Terzaghi equation [14].

For ǿ=15 the bearing capacity factors were Nc=12.86, Nq=4.45 and Nγ=1.52

ć=50kN/m^2

q_{ult}= C.Nc + q.Nq + 0.5.B. γ. Nγ

q_{ult}= 50 * 12.86 + 1 * 20 * 4.45 + 0.5 * 1 * 20 * 1.52

q_{ult}= 750 kN/m^2 , q_{all}=(q_{ult}/s.f) , for clayey soil use S.f =3

q_{all}=(q_{ult}/3)

q_{all}= (750/3)= 250 kN/m^2

At point T2-2%: This point having the dry unit weight (16.5kN/m^3) and moisture content (18%),and the moisture unit weight (19.47kN/m^3). The bearing capacity was found using Terzaghi equation .

For ǿ=18 the bearing capacity factors were Nc=15.12, Nq=6.04 and Nγ=2.59

ć=45kN/m^2

q_{ult}= C.Nc + q.Nq + 0.5.B. γ. Nγ

q_{ult}= 45 * 15.12 + 1 * 19.47 * 6.04 + 0.5 * 1 * 19.47 * 2.59

q_{ult}= 827 kN/m^2

q_{all}=(q_{ult}/3)

q_{all}= (827/3)= 276 kN/m^2

At point B: This point having the minimum dry unit weight (15.8kN/m^3) and optimum moisture content (14.1%). And the moisture unit weight (18kN/m^3). The bearing capacity was found using Terzaghi equation .

For ǿ=21 the bearing capacity factors were Nc=18.92, Nq=8.26 and Nγ=4.31

ć=30kN/m^2

q_{ult}= C.Nc + q.Nq + 0.5.B. γ. Nγ

q_{all}= (827/3)= 276 kN/m^2

q_{ult}= 30 * 18.92 + 1 * 18 * 8.26 + 0.5 * 1 * 18 * 4.31

q_{ult}= 755 kN/m^2

q_{all}=(q_{ult}/3)

q_{all}= (755/3)= 251 kN/m^2

q_{ult}= 30 * 18.92 + 1 * 18 * 8.26 + 0.5 * 1 * 18 * 4.31

q_{ult}= 755 kN/m^2

q_{all}=(q_{ult}/3)

q_{all}= (755/3)= 251 kN/m^2

From the above results, it is observed that the maximum bearing capacity was 275kN/m^2 at point (T2-2%) on compaction curve. This conclusion leads to that the proffered zone to conducting the compaction in field that at and nearest to point (T2-2%) on standard compaction curve.

CONCLUSIONS

1. The standard compaction curve having two values of maximum dry unit weight (16.9 and 16.7kN/m^3) and two values of optimum moisture content (3% and 20%) for points T1 and T2 respectively.
2. The maximum compressive strength of soil was (470 kN/m^2) and the maximum tensile was (50 kN/m^2) these values were lies at point (T2-2%) on standard compaction curve.
3. The minimum settlement of this soil was 1.8mm at point T2 having compression index 0.163, while the maximum settlement was 3mm at point B having compression index 0.205.
4. The effective cohesion increases with water content to reach (15 kN/m^2) at point (T2-2%) where water content 18% after this point the cohesion decreases to reach little value at PL of the soil. Effective angle of internal friction slightly decreases with water content on compaction curve.
5. The maximum allowable bearing capacity of this soil was 276 kN/m^2 at point (T2-2%) on standard compaction curve.
6. For construction any structure the preferred zone to conducted the compaction presses at point (T2-2%), where this point given maximum strength and maximum bearing capacity and minimum settlement.

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Table (1) Index properties of soil.

Atterberg Limits	L.L (%)	ASTM (D:4318) [10]	62
	P.L (%)		25
	P.I (%)		37
Specific Gravity	Gs	ASTM (D:854)	2.73
Grain size analysis	Sand (%)	ASTM (D:422)	15
	Silt (%)		36
	Clay (%)		49
Unified classification system	U.S.C.S	ASTM (D: 2487)	CH
Chemical properties	SO3(%)	B.S 1377[14]	0.045
	T.S.S (%)	Earth manual [15]	2.85
	O.M (%)	B.S 1377[14]	2.36
	P.H	ASTM (D: 4972)	7.9

Table (2) Shear strength of soil.

Points / Strength characteristics		T1	B	T2-2%	T2	PL	PL+2%
Unconfined compressive strength		190	400	470	450	300	P.F
Flexural strength (kN/m^2)		20	41	50	48	28	......
Shear strength parameters	ć	23	30	45	50	20	....
	ǿ	24	21	18	15	12	......

Table (3) Consolidation properties of soil.

points / properties	T1	T2	B
e	0.613	0.639	0.73
Cc	0.165	0.163	0.205
Cs	0.017	0.008	0.005
Cv(cm/min)	0.011	0.012	0.0104
ΔH(mm)	1.93	1.80	3.00

Figure (1) location of the thermal power station near hammam Ali city, South of Mosul city.

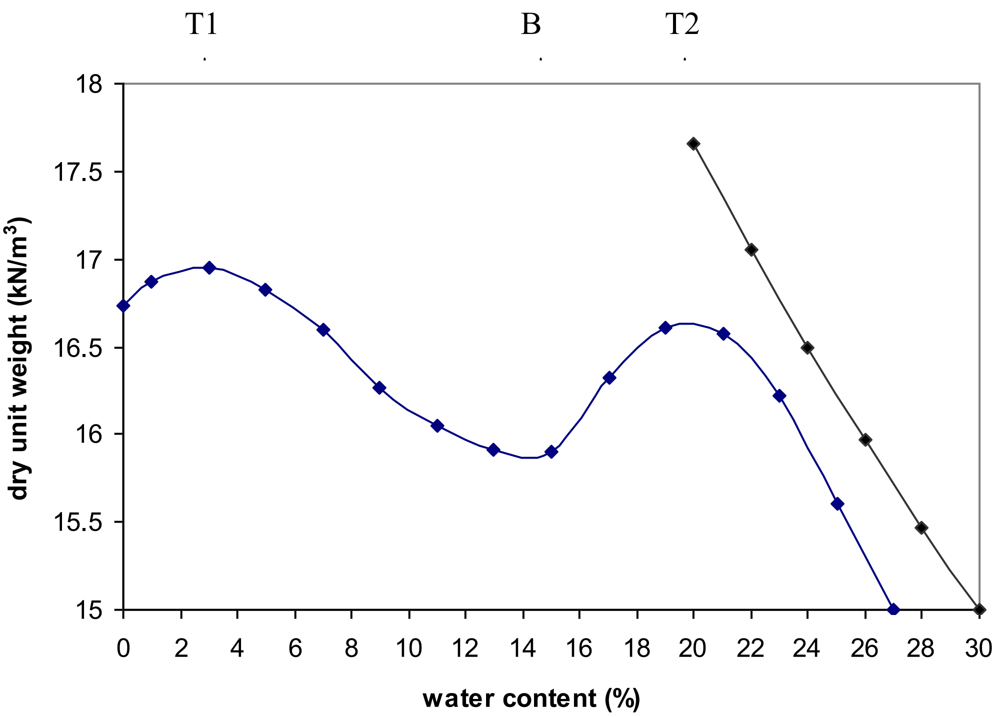

Figure (2) standard compaction curve.

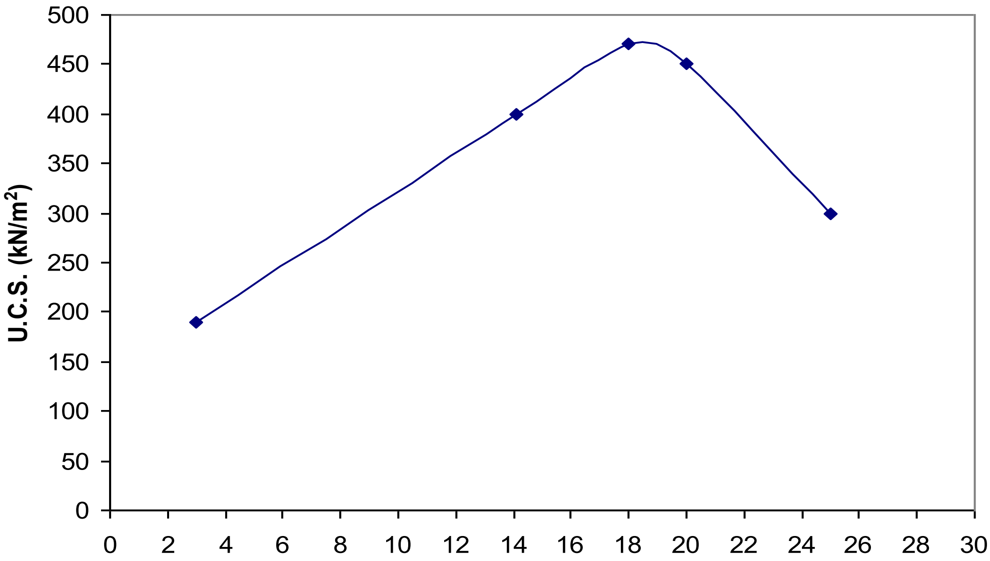

Figure (3) Unconfined compressive strength of soil.

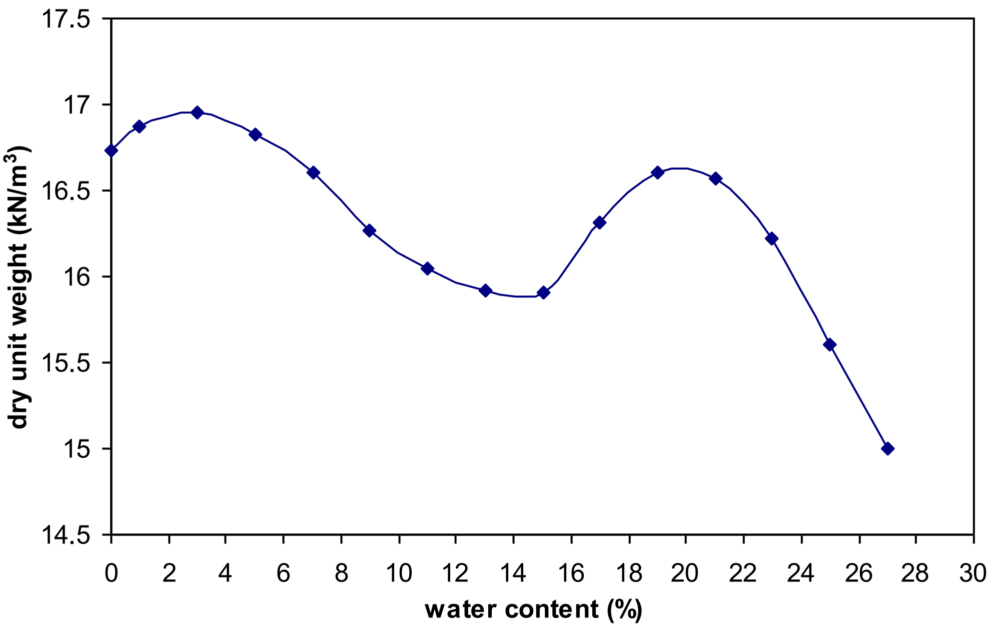

Figure (4) Flexural strength of soil.

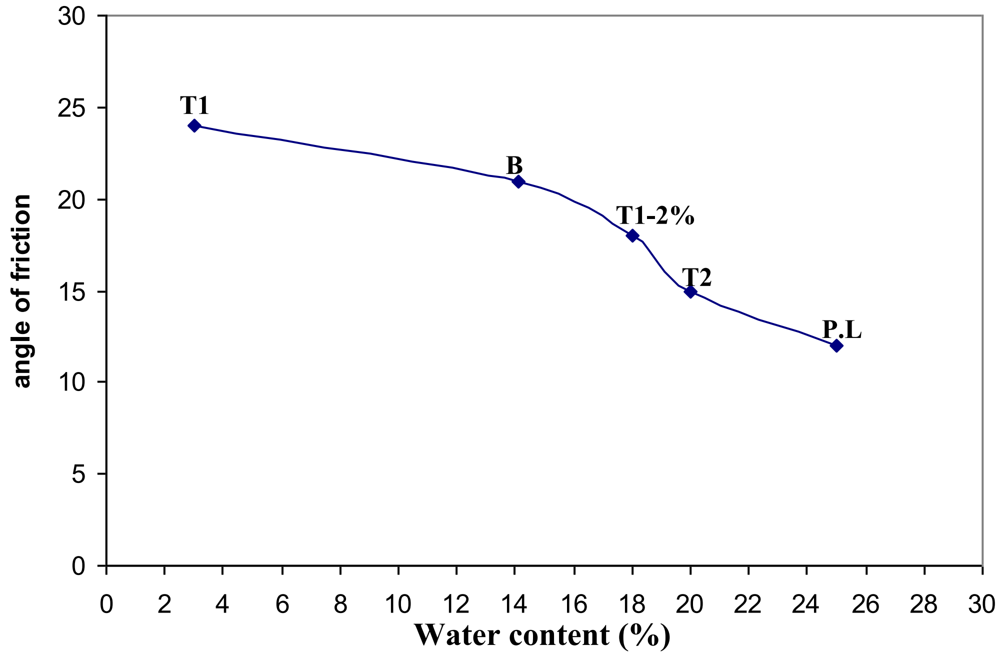

Figure (5) Relation between angle of friction and water content on compaction curve For Direct shear test.

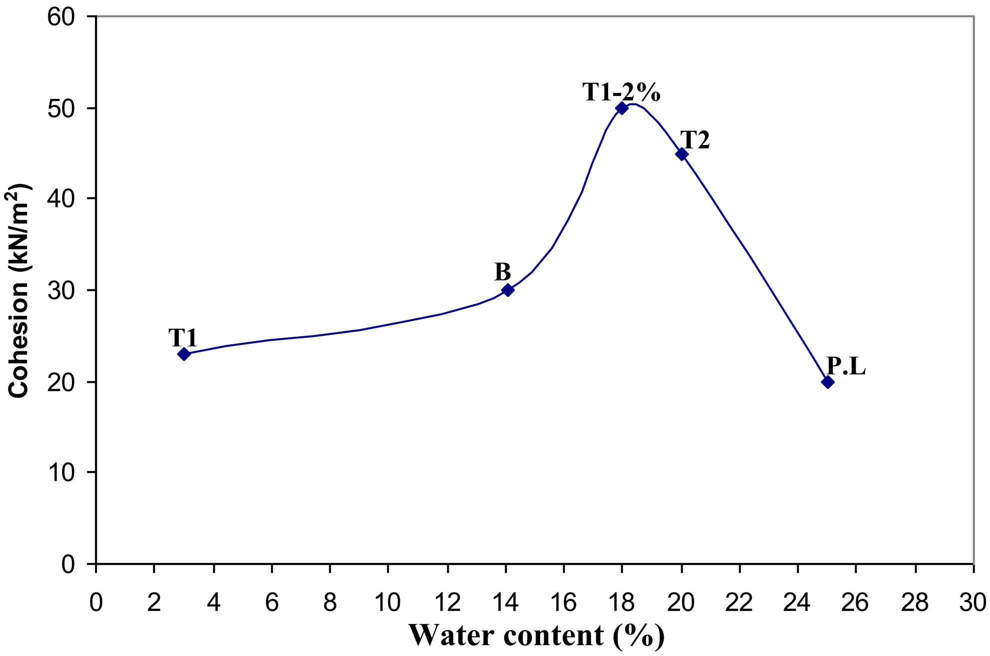

Figure (6) Relation between cohesion and water content on compaction curve for Direct shear test.