ESTIMATION OF RELATIONSHIP BETWEEN COEFFICIENT OF CONSOLIDATION AND LIQUID LIMIT OF MIDDLE AND SOUTH IRAQI SOILS

Asma Y. Al- Tae'e
Lecturer, Civil Eng. Dept.
College of Eng./ University of Baghdad
Email: Asmayounis2004@yahoo.com

Abbas F. Al- Ameri
Assistant Lecturer, Civil Eng. Dept.
College of Eng./ University of Baghdad
Email: Abficivil@yahoo.com

ABSTRACT

In this paper, a relationship between the liquid limit and the coefficient of consolidation of Iraqi soils are studied. The samples of soil used in study are undisturbed silty clay. These samples are taken from different locations and depths of Middle and South of Iraq by cooperation with Consulting Engineering Bureau- University of Baghdad- College of Engineering. The depth reached about 20 meters. The experimental work is made to calculate the liquid limit and the coefficient of consolidation. From these sites, 280 points are obtained. The relationship between the liquid limit and the coefficient of consolidation is drawn as a curve. This curve is studied and compared with the curve that obtained from other studies.

From these curves, it can be noticed that the curves are close to each other when the liquid limit is equal to 60 while they diverge when the liquid limit is less or greater than 60. Therefore, the coefficient of consolidation of Iraqi soils can be obtained when the liquid limit is given.

الخلاصة:

في هذا البحث، تم دراسة العلاقة التي تربط بين حد السيولة ومعامل الانضمام لترب عراقية. فالنماذج التي تم اخذها هي عبارة عن ترب غرينية طينية غير مخلخلة. وقد تم اخذ هذه النماذج من مناطق مختلفة في وسط وجنوب العراق وعلى اعماق مختلفة وهذه الاعماق وصلت الى 20 متر حيث تم اخذ هذه النماذج بالتعاون مع المكتب الاستشاري التابع لجامعة بغداد- كلية الهندسة. لقد اجريت تجارب عملية لحساب مقدار حد السيولة ومعامل الانضمام. من هذه المواقع تم الحصول على 280 نقطة وعليه تم الحصول على علاقة تربط بين حد السيولة ومعامل الانضمام لترب عراقية وتم مقارنتها مع دراسات اخرى.

من هذه العلاقات تم ملاحظة ان المنحنيين يقتربان عند حد السيولة يساي 60 ويتباعدان عندما يكون حد السيولة اقل او اكثر من 60. لذلك يمكن ايجاد معامل الانضمام لتربة عراقية عند اعطاء حد السيولة لتاك التربة.

Keywords: Liquid limit, Coefficient of consolidation, clay, Iraq, relationship.

INTRODUCTION

Attention was first drawn to the problem of the long term consolidation of clays by Terzaghi (1925), with the publication in Vienna of "Erdbaumechanik".Terzaghi proposed a theoretical approach to the consolidation process, and he had already designed the first consolidation apparatus which he had named an "oedometer".(**Head**, **1988**)

In the field, when the stress on a saturated clay layer is increased – for example, by the construction of a foundation- the pore water pressure in the clay will increase. Because the hydraulic conductivity of clays is very small, sometimes will be required for the excess pore water pressure to dissipate and the increase in stress to be transferred to the soil skeleton. (**Das,2007), (Head, 1986).**

Sometimes consolidation is called *primary consolidation* to distinguish it from the other time- dependent component of total settlement, *secondary compression* occur after essentially all of the excess pore water pressure has dissipated, that is, it occurs at constant effective stress. In some soils, especially inorganic clay, primary consolidation is the largest component of total settlement, whereas secondary compression constitutes a major part of the total settlement of peats and other highly organic soils **(Holts and Kovacs, 1981).**

DETERMINATION OF THE COEFFICIENT OF CONSOLIDATION Cv:

(a) Casagrande′s Logarithm of Time Fitting Method:
In this method, the deformation dial readings are plotted versus the logarithm of time, as shown in **Fig.(1)**. The idea is to find R_{50} and thus t_{50}, which is the time for 50% consolidation, by approximating R_{100}, the dial reading corresponding to the time for 100% primary consolidation, t_{100}. Refer to **Fig.(1)**, the intersection of the tangent and the asymptote to the theoretical curve defines U_{ave} =100%. The time for 100% consolidation, of course, occurs at $t=\infty$. Casagrande (1938) suggested that R_{100} could be approximated rather arbitrarily by the intersection of the two corresponding tangents to the laboratory consolidation curve. Later research (for example, Leonards Girault, 1961) has shown this procedure defines to a good approximation the dial reading at which the excess pore water pressure approaches zero, especially when the LIR is large and the preconsolidation stress is exceeded by the applied load increment. Once R_{100} is defined, then it is fairly easy to determine R_{50} and t_{50}, once we find R_0, the initial dial reading. Therefore, the coefficient of consolidation is:
$C_v = 0.197 * H^2 / t_{50}$
Where:
H= the average height of specimen during the increment (for one way drainage)
H= the average height of specimen during the increment/2 (for two way drainage)

(b) Taylor′s Square root of Time Fitting Method:
Taylor (1948) also developed a procedure for evaluating c_v, using the square root of time. It will be used the same data as before in Casarande′s method to illustrate the square root of time t fitting method. These data are ploted in Fig.(2). Usually a straight line can be drawn through the data points in the initial part of the compression curve. The line is projected backward to zero time to define R_0. The common point at R_0 may be slightly lower than the initial dial reading (at zero time) observed in the laboratory due to immediate compression of the 1.15 times as large as corresponding values on the first line. The intersection of this second line and the laboratory curve defines R_{90} and is the point of 90% consolidation. Its time is t_{90}. The coefficient of consolidation is (Holts and Kovacs,1981):

TYPICAL VALUES OF C_V:

Typical values of the coefficient of consolidation c_v for a variety of soils are listed in **Table(1)**. Approximate correlation of c_v with the liquid limit are presented in **Fig.(3)** (Holtz and Kovacs, 1981).

ATTERBERG LIMITS:

The condition of a clay soil can be altered by changing the moisture content; the softening of clay by the addition of water is a well- known example. For every clay soil there is a range of moisture contents within which the clay is of a plastic consistency, and the Atterberg limits provide a means of measuring and describing the plasticity range in numerical terms.

If sufficient water is mixed with clay, it can be made into slurry, which behaves as a viscous liquid. This is known as the ′liquid′ state. If the moisture content is gradually reduced by allowing it to dry out slowly, the clay eventually begins to hold together and to offer some resistance to deformation; this is the ′plastic′ state. With further loss of water the clay shrinks and the stiffness increases until there is little plasticity left, and the clay becomes brittle; this is the ′semi-solid′ state. As drying continues, the clay continues to shrink in proportion to the amount of water lost, until it reaches the minimum volume attainable by this process. Beyond that point further drying results in no further decrease in volume, and this is called the ′solid′ state.

These four states, or phases, are shown in diagrammatically in **Fig.4**. The change from one phase to the next is not observable as a precise boundary, but takes place as a gradual transition. Nevertheless three arbitrary but specific boundaries have been established empirically, as indicated in **Fig. 4**, and are universally recognized. The moisture contents at these boundaries are known as the

Liguid limit (LL)
Plastic limit (PL)
Shrinkage limit (SL)

The moisture content range between the PL and LL is known as the plasticity index (PI) and is a measure of the plasticity of the clay. Cohesionless soils have no plasticity phase, so their PI is zero (Head, 1984)

Liquid Limit- Casgarande One Point Method:

This method provides a quick means of determining the liquid limit of a soil, because only one moisture content measurement is needed (Head, 1984).

The one- point liquid limit test is based on research conducted on a large number of soil sample by the U. S. waterway experiment station, Vicksburg Mississippi. It was determined that the liquid limit could be established from single test using the following equation:

$$LL = w_N\ (N/25)^{0.121}$$

N is the number of drops required to close the standard groove at water content w_N. N should be between 20 and 30 and preferably close to 25, otherwise the test should be repeated. This test is dependent on the accuracy of the one point. It is more difficult to run than the multipoint test, because one must be confident that the groove will close within the range of drops specified. This requires the sample be mixed at water content close to its liquid limit. The one- point test may be conducted on dry or wet samples using the sample preparation procedure described earlier (Al- Khafaji and Andersland, 1992).

EXPERIMENTAL WORK

Many locations in Middle and South of Iraq are studied. These studies are made to determine the liquid limit and the coefficient of consolidation. The liquid limit is determined by using Casgarande one point method. The coefficient of consolidation is determined by using Taylor′s square root of time method and under normal stress equal to 200 kpa. The samples are silty clay soils. These samples are undisturbed and they are taken from different depth by cooperation with Consulting Engineering Bureau-University of Baghdad- College of Engineering.

RESULTS AND DISCUSION

The number of sites for each Governorate is shown in **Table (2), Fig.(5) (**State Company of Geological Survey and Mining) and **Fig.(6)** .

From these samples, 280 points are obtained. According to these points, the relationship between the liquid limit and the coefficient of consolidation for silty clay soils of Iraqi soil can be drawn as shown in **Fig. (6)**.

Table (3) shows the correlation coefficients and statistical information for the data used in this paper.

From **Fig.(6)** and **Table (3)**, the following statements can be concluded:

1. For cohesive soils, the physical properties must be found. The first experimental work is the Atterberg Limit so the coefficient of consolidation of Iraqi soil can be directly

evaluated if the liquid value of the soil is given.

2. The relationship can be expressed by the following equation:

$$C_v = 4258\ X^{\wedge(-1.75)}$$

Comparing the data that obtained from Iraqi soil (**Fig.6**) and the data that obtained from other studies (Navy study) **(Fig. 3)**, it can be noticed that the curves are approach one another when the liquid limit is equal to 60 while they are diverge when the liquid limit is less or greater than 60. The comparison is cleared in **Fig.7**

The frequency histograms for coefficient of consolidation and liquid limit are shown in **Fig. 8**. From the frequency histograms, it appears realistic to assume a normal distribution.

CONCLUSIONS

Based on the results, the following conclusion can be drawn:

1- For Middle and South Iraqi soils the relation between liquid limit and coefficient of consolidation is established. So, the coefficient of consolidation can be obtained when the liquid is given.

2- The two curves are (the curve is obtained from Iraqi soils and the curve is obtained from Navy study) approach one another when the liquid limit is equal to 60 while the two curves are diverge when the liquid limit is less or greater than 60.

3- The relationship can be expressed by the following equation:
$C_v = 4258\ X^{\wedge(-1.75)}$

4- For experimented soils, the liquid limit is changed from 25- 65 %.

5- For experimented soils, the coefficient of consolidation is changed from 2.3- 12.3 m^2/yr.

REFERENCES

- Al- Kafaji, A. W., and Adersland, O., B., "Geotechnical Engineering and Soil Testing", 1992.
- Casagrande, A., "Note on Soil Mechanics- First Semester", Harvard University (Unpublished), 1938.
- Consulting Engineering Bureau- University of Baghdad- College of Engineering.
- Das, B., M., "Principles of Foundation Engineering", Sixth Edition, 2007.
- Head, K. H., "Manual of Soil Laboratory Testing", Volume 1, 1984.
- Head, K. H., "Manual of Soil Laboratory Testing", Volume 2, 1988.
- Head, K. H., "Manual of Soil Laboratory Testing", Volume 3, 1986.
- Holtz, R., D., and Kovacs, W., D., "An Introduction to Geotechnical Engineering", 1981.
- Leonards, G. A., and Girault, P., "A Study of the One- Dimensional Consolidation Test", Proceedings of the Fifth International Conference on Soil Mechanics and Foundation Engineering, Paris, Volume 1, pp- 116- 130, 1961.
- Navy, U. S., "Soil Mechanics, Foundations, and Earth Structures", NAVFAC Design Manual DM- 7, Washington, D.C., 1971.
- Terzaghi, K, "Erdbaumechanik auf bodenphysikalischer Grundlage, Deuticke, Wien", 1925.
- Taylor, D. W., "Fundamental of Soil Mechanics", John Wiley and sons, Inc., New York, 700 pp, 1948.

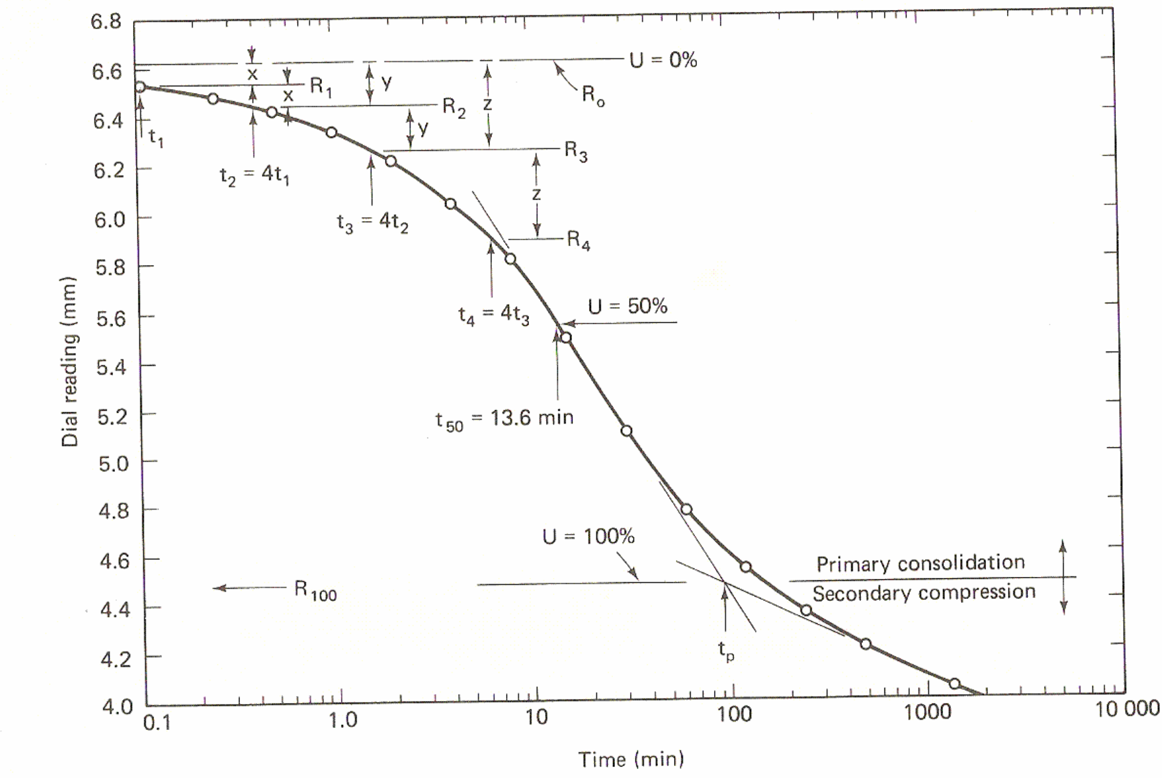


Figure (1) Determination of t_{50} by the Casagrande method (Holts and Kovacs,1981).

$$C_v = 0.848\ H^2/t_{90}$$

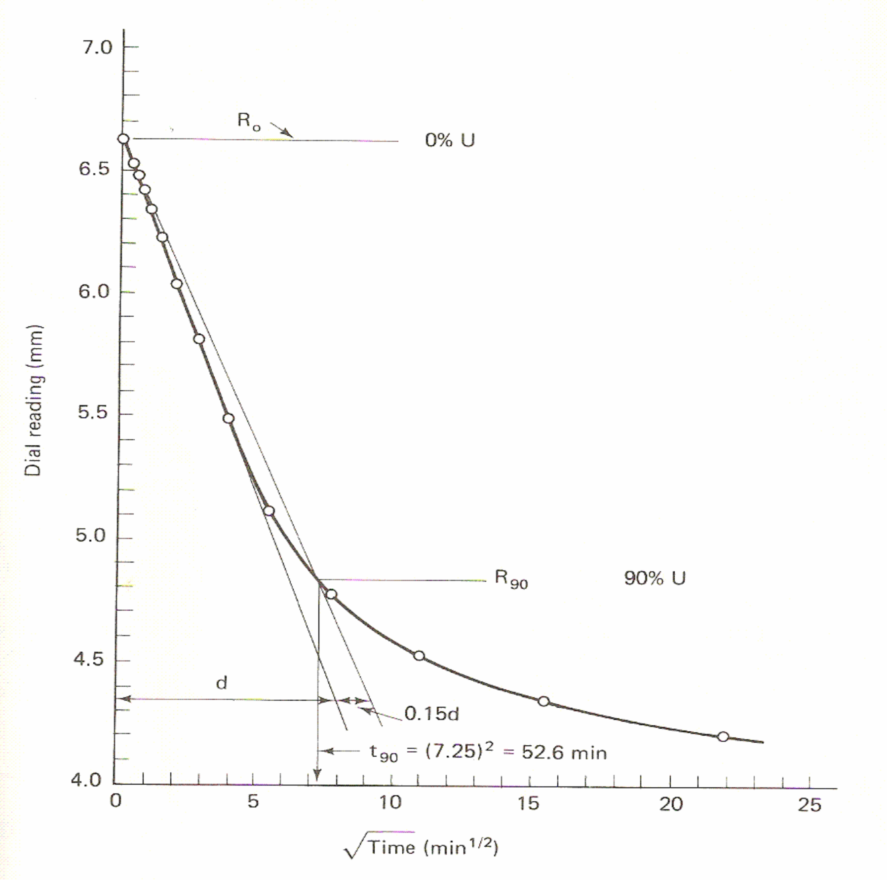


Figure (2) Determination of c_v using Taylor′s square root of time method (Holts and Kovacs,1981)

Table(1) Typical values of the coefficient of consolidation c_v (from Holtz and Kovacs, 1981).

Soil	C_v (m^2/year)
Boston blue clay (CL) (Ladd and Luscher, 1965)	12 + 6
Organic silt (OH) (Lowe, Zaccheo, and Feldman,1964)	0.6 -3
Glacial lake clays (CL) (Wallace and Otto, 1964)	2 – 2.7
Chicago silty clay (CL) (Terzaghi and Peck, 1967)	2.7
Swedish medium sensitive clays (CL-CH) (Holtz and Broms, 1972) 1- Laboratory 2- field	 0.1 – 0.2 0.2 - 1.0
San Francisco Bay Mud (CL)	0.6 – 1.2
Mexico City clay (MH) (Leonards and Girault, 1961)	0.3 – 0.5

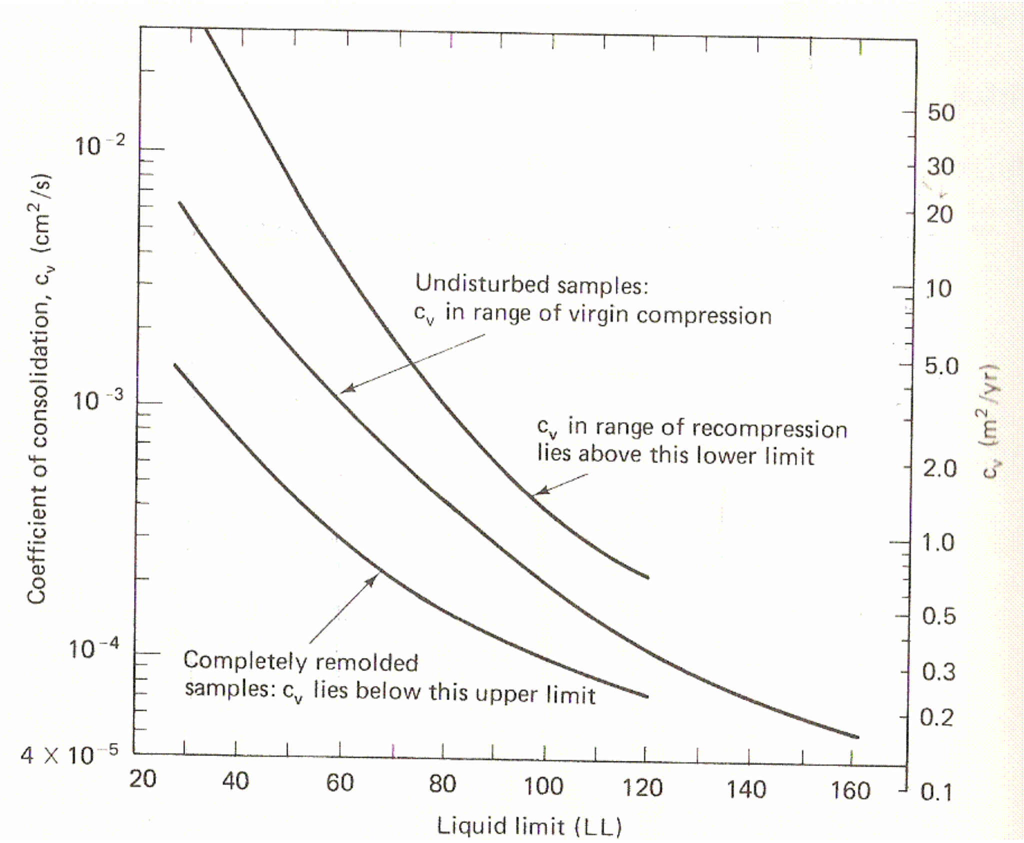


Figure (3) Approximate correlations of the coefficient of consolidation c_v with the liquid limit (after U. S. Navy, 1971).

Phase	Solid State	Semi-Solid State	Plastic State	Liquid Limit	Suspension
Water	Water content decreasing				
Limits	Dry soil	Shrinkage Limit SL	Plastic Limit PL	Liquid Limit LL	
Shrinkage	Volume constant	Volume decreasing			
Condition	Hard to stiff	Workable	sticky	Slurry	Water-held suspension
Shear Strength (kN/m^2)	Shear strength increasing (≈170) (1.7)			Negligible to nil	
Moisture content	SL	PL	LL		

Figure 4 Phases of soil and the Atterberg limits (Head, 1984)

Table 2 Number of sites for each Governorate in Iraq.

Governorate	Number of locations
Baghdad	26
Babil	2
Wassite	6
Karbala	4
Anbar	1
Missan	10
Qadissiya	3
Najaf	1
Thi- Qar	5
Muthanna	0
Basrah	2

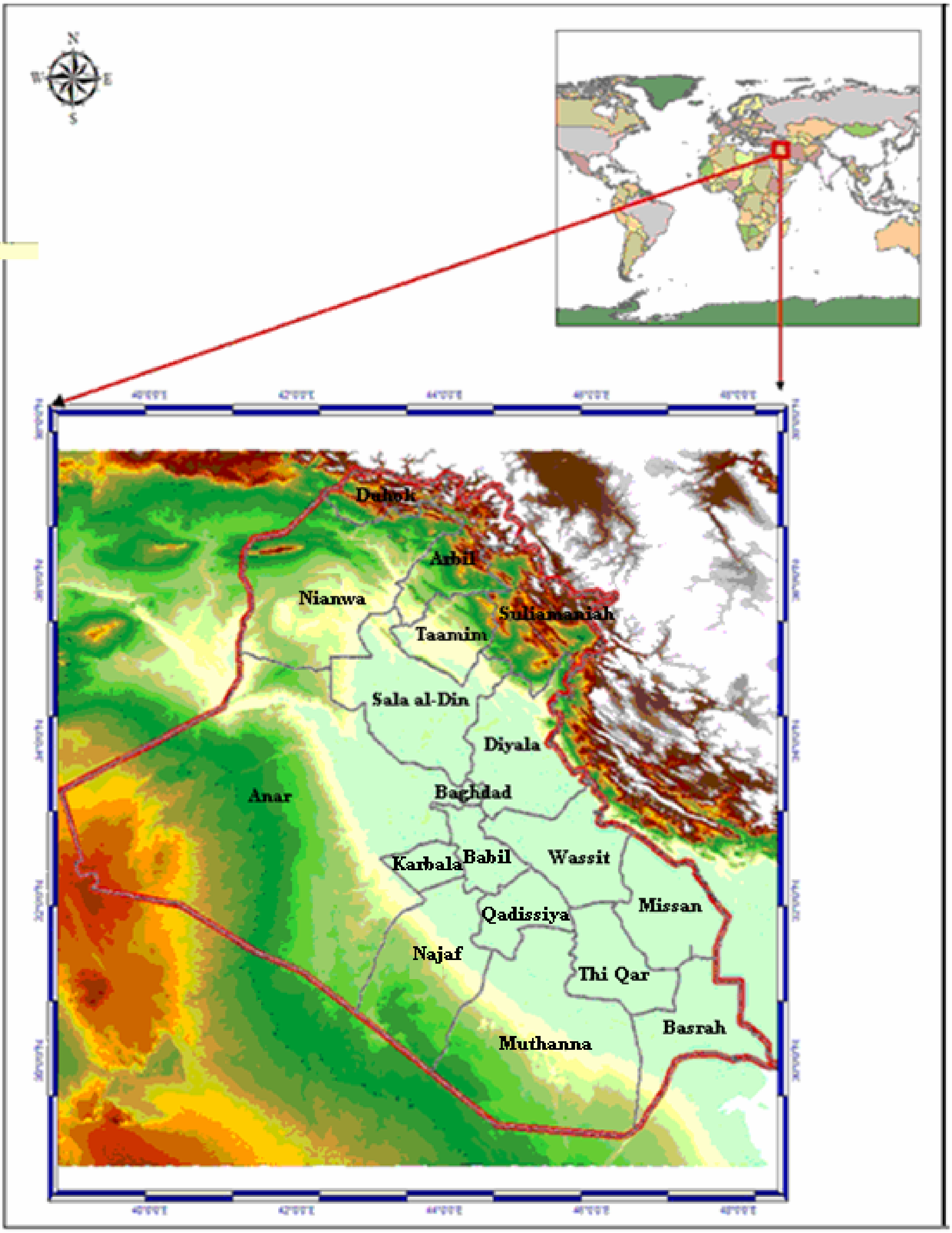


Figure (5) Map of Iraq (State Company of Geological Survey and Mining)

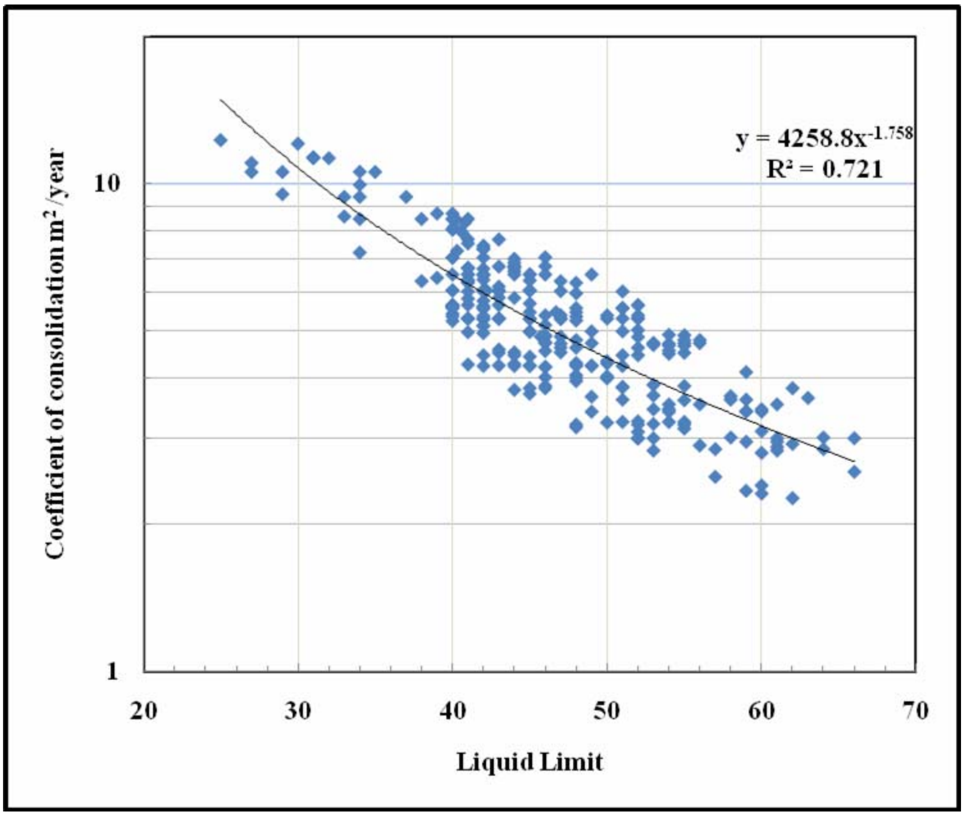


Figure 6 The relationship between the liquid limit and the coefficient of consolidation for Iraqi soils

Table (3) statistical information for the database of liquid limit and coefficient of consolidation

Power fitting used (general expression)	Y=A X$^{\wedge B}$ +C
Resulting equation	C_v= 4258 X$^{\wedge(-1.75)}$
Number of data	280
Maximum liquid limit value (LL)	25
Minimum liquid limit value (LL)	68
Maximum coefficient of consolidation (C_v)	2.3
Minimum coefficient of consolidation (C_v)	12.3
Coefficient of determination, R^2	0.721

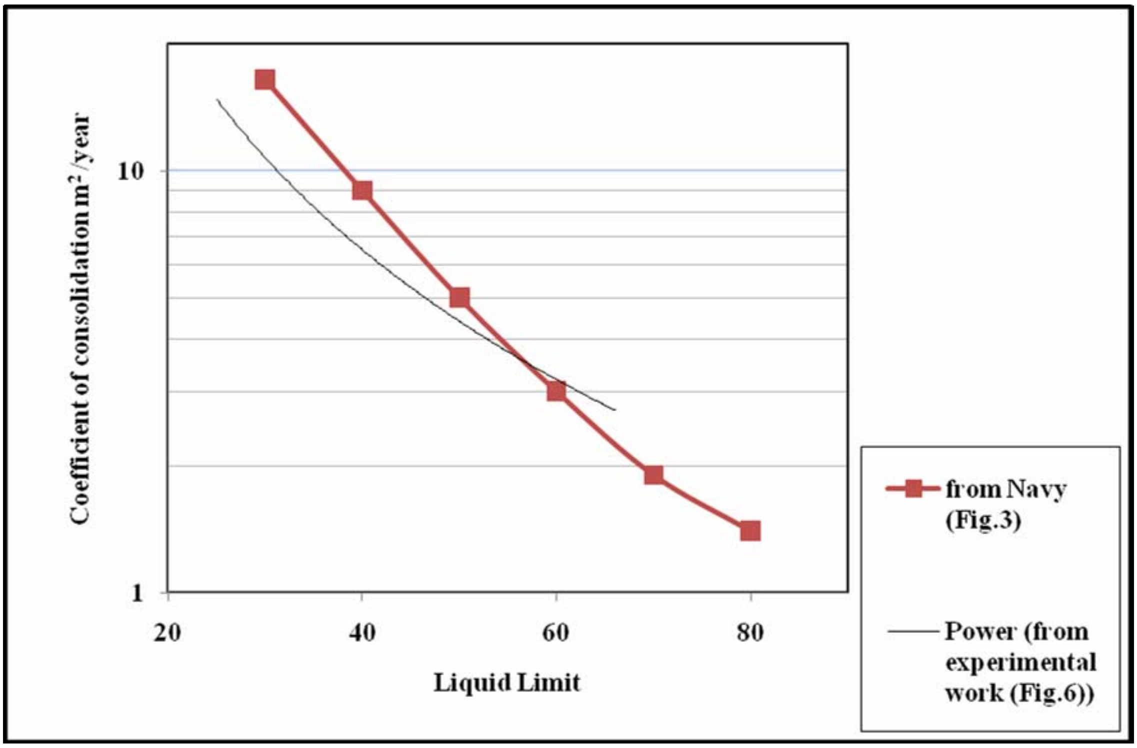
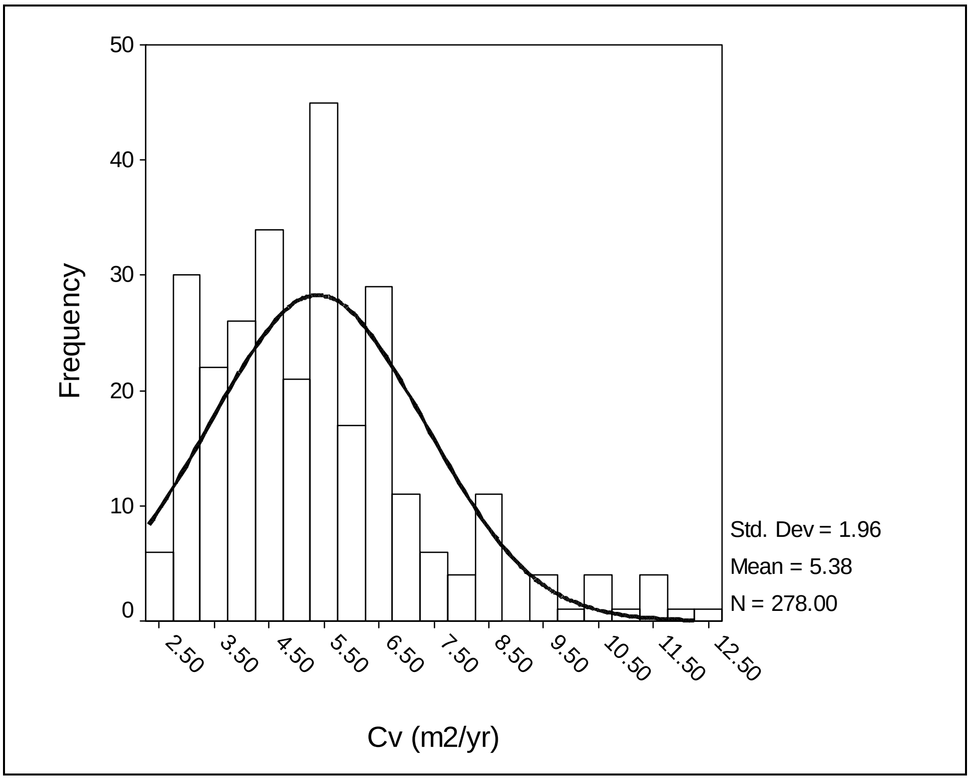
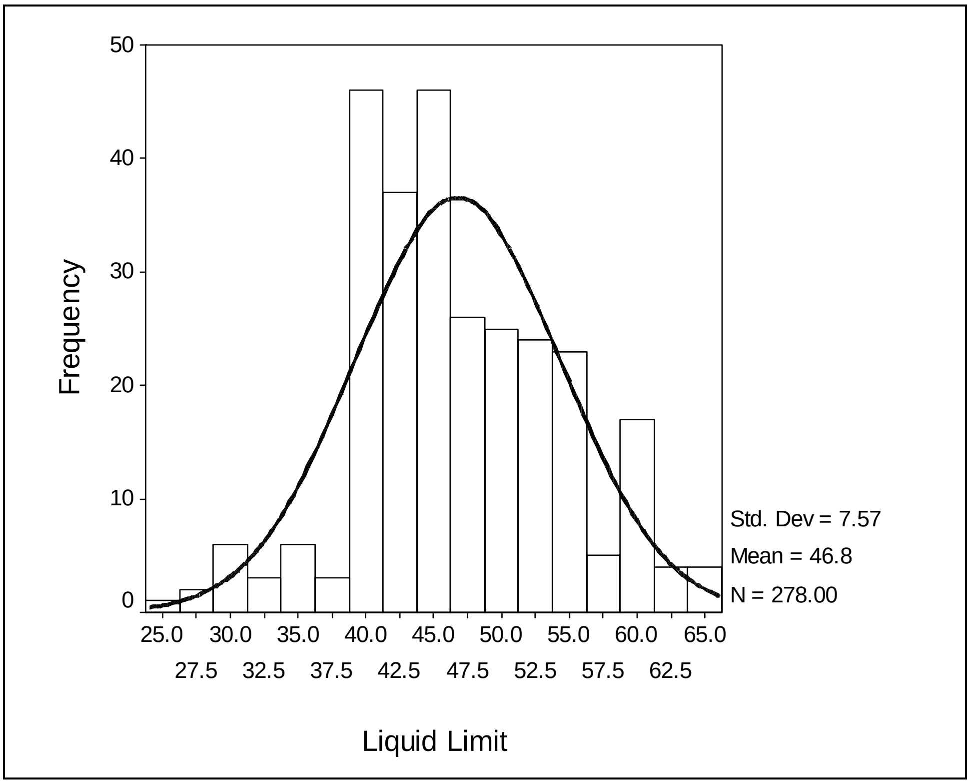


Figure 7 the comparison between experimental work and Navy study



(a)



(b)

Figure 8 (a) Frequency histogram for coefficient of consolidation (b) Frequency histogram for liquid limit.