Number 3 Volume 13 September2006 Journal of Engineering

EVALUATION OF COLLAPSIBILITY OF GYPSEOUS SOILS IN IRAQ

Shewnim N. Seleam
Lecturer - Building and Construction Department - University of Technology

ABSTRACT

Gypseous soils can be found in arid and semi arid region. In civil engineering it can be defined that a soil is a gypseous soil when it has gypsum content enough to change the properties of this soil. Collapsibility of these soils was found to be of major importance.

The collapsibility of the soil can be estimated from the term "Collapse Potential (CP)" which can be obtained from two types of tests performed in the oedometer device; (1) Single Collapse Test (SCT) and (2) Double Oedometer Test (DOT).

In this study, an analysis of the results obtained by 7 researchers in Iraq was performed. The data collected included basic properties for each sample in addition to the results of the two collapsibility tests. A total of 50 samples were analyzed and it was noticed that 33 % of the investigated soils have a CP less than 1% which are considered as "No Trouble" soils and about 60% have a CP ranging between 1 and 5 which are considered as "moderate trouble" soils.

The factors affecting collapsibility were studied and it appeared that the initial water content, void ratio and total unit weight are the major factors while the gypsum content and plasticity index seem to have lesser effect.

Three proposed equations are introduced to estimate CP at 200 kPa as obtained from (SCT) from other parameters. These equations are: (1) CP from (DOT) (2) CP from different soaking pressures and (3) CP from basic soil properties (initial water content, void ratio and gypsum content). These equations have a regression (R-squared) ranging between 0.7 and 0.85.

الخلاصه

تتواجد الترب الجبسية في المناطق القارية وشبة القارية. يمكن تعريف الترب الجسية في مجال الهندسة المدنية على انها التربة التي تحتوي نسبة جبس كافية لتؤثر على الخواص الهندسية لتلك التربة. ان خاصية "الانهيارية" هي الصفة المميزة لهذه الترب.

يمكن تقدير انهيارية التربة من خلال مصطلح "قابلية الانهيار" والذي من الممكن الحصول عليه من خلال اجراء احد فحصين باستخدام جهاز الانضمام الاعتيادي وهما: (1) فحص الانهيار المنفرد (SCT) (2) فحص الانهيار المزدوج (DOT).

في هذه الدراسة تم تحليل نتائج سبعة باحثين من العراق. تكونت البيانات من الخواص الاساسية لكل نموذج من التربة الجبسية اضافة الى نتائج الصفات الانهيارية باستخدام الفحصين. كان مجموع النماذج في هذه الدراسة هو 50 ولوحظ ان 33% من نتائج "قابلية الانهيار" كانت قيمها اقل من 1% والتي يمكن اعتبارها "بدون مشاكل" بينما كانت قيم 60% من النتائج تتروح بين 1 و 5% مما يدل ان الترب الجبسية تعتبر "معتدلة المشاكل".

تم دراسة العوامل المؤثرة على "قابلية الانهيار" وتبين ان نسبة الرطوبة الابتدائية وكثافة التربة هي من اهم العوامل بينما كانت نسبة الجبس ومقياس اللدونة ذات تاثير قليل.

تم اقتراح ثلاثة معادلات وضعية لتقدير مقدار "قابلية الانهيار" كما يمكن الحصول عليها من فحص (SCT) من نتائج المعاملات الاخرى. ان هذه المعادلات هي: (1) قابلية الانهيار من فحص الانهيار المزدوج (2) قابلية الانهيار من ضغوط انغمار مختلفة (3) قابلية الانهيار من الخواص الاساسية للتربة (نسبة الرطوبة الابتدائية ونسبة الفراغ ونسبة الجبس). لقد كان معامل الترابط لهذه المعادلات يتراوح بين 0.7 و 0.85.

INTRODUCTION

Civil engineers often face severe problems when constructing structures in or on gypseous soils and rocks. Failure by excessive settlement may take place mostly due to leakage of water from the defects in the building services, rainfall or/and rising of water table. The reorientation of the particles of underlying strata if they contain gypsum, which dissolves when exposed to seeping water, will lead to a collapsing behavior of the soil.

Several investigators studied the collapsibility behavior of gypseous soils and agreed to consider a term named "Collapse Potential" proposed by **Jennings and Knight, 1957**, as a guide in the design of the foundations on gypseous soils. This term can be measured through testing an oedometer sample after a simple alteration of the procedure of the test.

This paper presents an evaluation of the "Collapse Potential" and an attempt to define the factors affecting this term. These factors can be dependent on:

- Type of sample (gypsified, undisturbed gypsiferous or compacted gypsiferous)
- Ordinary classification tests (such as gypsum content, void ratio, total unit weight, initial water content, dry unit weight and Atterberg limits)
- Applied pressure of the building (soaking pressure or stress level)
- Procedure of test

In addition, proposed equations joining these factors are presented in the study.

GYPSIFEROUS SOILS

The term "gypsiferous soil" as used by **Van Alphen and Romero, 1971,** refers to soils containing more than (2%) gypsum, while **Saaed and Khorshid , 1989,** defined gypsiferous soil, as soil that contains more than (6%) gypsum. ***Smith and Robertson 1962 (see FAO, 1990),*** working in Iraq, found that (3-10)% of gypsum does not interfere significantly with soil characteristics such as structure, consistency and water holding capacity, while in soil containing (10-25) % of gypsum, the gypsum crystals tend to break the continuity of the soil mass. In civil engineering it can be defined that a soil is a "gypseous soil" when it has gypsum content enough to change the properties of this soil. The term "gypseous soil" and "gypsiferous soil" are synonymous terms.

The term "gypsified soil" refers to natural soils which a predefined percent of gypsum is added. This type is usually used by many investigators to study the effect of gypsum on the soil properties and behavior. Sometimes it is considered as a type of soil stabilization especially for road construction fields.

Gypsum is hydrated calcium sulphate, $CaSO_4.2H_2O$. The gypsum mineral has a specific gravity of 2.32 (**Nashat, 1990**). The two requirements necessary to form gypsum in the soil are an external source of gypsum and a sufficiently arid climate (high temperatures, more than 20^oC, and low rainfalls, less than 450 mm annual). Hence gypsified soils seldom behave as natural gypsiferous soil since it needs special environments such as many cycles of wetting and drying or migration of salts through it.

COLLAPSIBLE SOILS

A collapsible soil is defined as "any unsaturated soil that goes through a radical rearrangement of particles and great loss of volume upon wetting with or without additional loading" (**Clemence and Finbar, 1981**).

Jennings and Knight, 1957, suggested a collapse test to predict collapse settlement for foundation design purposes which they called "***Double Oedometer Test (DOT)***". Figure 1(a) shows a typical results of the test.

Knight, 1963, suggested a laboratory test to calculate the collapsibility of soils called ***"Single Collapse Test (SCT)"***. Figure 1(b) shows an idealized view of the test.

The ***Collapse Potential*** (CP) is defined as:

$$\text{CP, \%} = \frac{\Delta H}{H_O} * 100 = \frac{\Delta e}{1 + e_O} * 100 \text{-------------------------(1)}$$

where: ΔH : Change in height of sample from natural water content to saturation upon soaking.
H_o: Initial height. Δe: Change in void ratio upon soaking. e_o: Initial void ratio.

Jennings and Knight, 1975, proposed some values of collapse potential to describe the degree of severity of the problem as shown in Table (1).

Gypseous soils offer a relatively rapid settlement due to the addition of water because the loose particle structure is cemented together with soluble minerals and/or with small quantities of clay. Water infiltration into such soils can break down the inter particles cementation, resulting collapse of the soil structure.

Data Collected

Data collected for this study were taken from various works of seven researchers namely (**Seleam (1988), Nashat (1990), Al-Ani and Seleam (1993), Mohammad (1993), Abood (1994), Sheika (1994)** and **Al-Gabri (2003)**). From each work, the data of the tests performed by the researcher were tabulated in an Excel worksheet in the form of rows *(or cases)* with several columns *(or variables)*. These variables were divided into two parts (see Table 2)

- **Classification Parameters:** which included the author, location, sample no. as recorded by the reference, type of sample (gypsified [g], undisturbed [u] and compacted [c]) in addition to the basic properties such as (gypsum content (GC), initial void ratio (eo), initial total unit weight (γ), initial water content (w), Liquid Limit (LL) and Plastic Limit (PL)). The dry unit weight (γ_{dry}) and Plasticity Index (PI) were calculated for these data from basic relationships.
- **Collapse Potential Results**: which included the results obtained from the Single Collapse Test and Double Oedometer Test. The results were recorded for each soaking pressure and for both tests [CP200 represent the collapse potential at soaking pressure of 200 kPa and so on].

A total of 50 cases (lines) were collected in the worksheet. This type of worksheets is very beneficial in defining the effect of each parameter. The data were carefully selected to give "random" samples from a "population" samples in addition to the high confidence of the test results performed by the investigators.

Although **Knight (1963)** originally defined collapse potential at a soaking pressure of 200 kPa, however several investigators (among which are **Mohammad (1993)** and **Al-Gabri (2003)**) proposed a soaking pressure of 100 kPa as a substitute since it represents the traditional actual applied pressure of buildings in Iraq. Therefore, both results are presented in this study separately.

The data were also utilized in another computer package called "STATISTICA" to analyze the data statistically and to introduce proposed equations (or mathematical models) which can be easily used to predict the collapse potential from the input parameters or other soaking pressures. The modeling were performed by the statistics package through an optimization iteration procedure.

STATISTICAL ANALYSIS OF DATA

Table (3) shows a statistical analysis of the data from Table (2). The analysis includes the basic statistical terms such as (Number of Data, Mean Value (or average), Standard Deviation, Coefficient of Variance (c.o.v.), Minimum Value and the Maximum Value). The data is divided into three categories which are "Undisturbed", "Compacted" and "Gypsified" in addition to the "All Samples" category. The lower part of the table presents the number of samples as categorized by Table (1). From this table the following can be observed:

1. The total number of each category are 12, 31 and 7 for undisturbed, compacted and gypsified samples respectively giving a total number of samples of 50.
2. The tested samples have a gypsum content ranging from 5% to 81 %.
3. Most soils have an initial void ratio ranging between 0.3 and 0.7 with an average value of 0.5. This indicates that most soils have few voids, i.e. compacted samples.
4. Most soils have an initial unit weight ranging between 15 and 18 kN/m^3 which indicates a low density soils. This is in contrast with the previous point and can be attributed to the low specific gravity of the gypseous soils which can affect the density very much.
5. The plasticity of the soil (for samples with clayey soils) have low values indicating that there is a mixed action for gypsum and clay that greatly affects the behavior.
6. It can be observed that the mean value of CP-200 for "all samples" is 1.6% which is considered very low.
7. It can be noticed from the lower part of the table that 32 samples out of 33 samples lies in the category of "No Trouble " or "Moderate Trouble" as defined by **Jennings and Knight (1975**).

FACTORS AFFECTING COLLAPSE POTENTIAL

There are many factors that affect the collapse potential (CP) as defined from Single Collapse Test at 200 kPa or at 100 kPa. These are :

Gypsum Content (GC)

Figure 2 shows the effect of gypsum content on the collapse potential. It can be noticed that most researchers found it has insignificant effect since the collapse potential ranged from 0.71 to 1.45 which can be considered as a narrow range. However, **Nashat (1990)** gave results indicating an increase in the collapse potential for a GC of 20 to 60% for Baiji soil. Beyond this range the CP decreased. **Seleam (1988)** showed a decrease in CP with the increase of GC for samples at depth of 3m.

This behavior can be explained since most researchers samples were compacted samples except for **Seleam (1988)** and **Nashat (1990)** who tested undisturbed samples. Hence, the honeycomb structure of the samples is responsible for the high value of the CP. This is more obvious in the 3m depth samples for **Seleam (1988)** due to the least disturbance of the soil.

INITIAL VOID RATIO

Figure 3 shows the relationship between the collapse potential and the initial void ratio. It can be noticed that there are two trends; the first indicates that there is insignificant change in the collapse potential (ranging between 0.71 and 1.45) as the void ratio increases while the second indicates clearly that the collapse potential increases with the increase of the void ratio. The second is more logical since it is obvious that as the void ratio decreases the soil has fewer voids to collapse.

INITIAL TOTAL UNIT WEIGHT

From basic relationships, the void ratio is inversely proportional to the total unit weight for a constant specific gravity. Hence, the relationship with the total unit weight has the same trend as that for void ratio previously discussed. Figure 4 shows the relationship between the collapse potential and the total unit weight. It can be noticed that there are two trends; the first indicates that there is insignificant change in the collapse potential (ranging between 0.71 and 1.45) as the unit weight increases while the second indicates clearly that the collapse potential decreases with the increase of the total unit weight. The second is more logical since it is obvious that as the unit weight increases the soil has fewer voids to collapse.

INITIAL WATER CONTENT

The addition of water is the cause of collapse. Hence, the increase of initial of water content will definitely decrease the values of the collapse potential. This is clearly observed for all researcher from Fig. 5.

Dry Unit Weight

The dry unit weight was calculated from basic relationship as follows

$$\gamma_{dry} = \frac{\gamma_{total}}{1+w} \qquad \text{………. } \mathbf{(2)}$$

It can be seen from the equation that there seem to be two contradicting behavior. These are:

1. For a constant total unit weight, as water content decreases, the dry unit weight increases and hence the collapse potential will increase. This behavior was observed by **Al-Ani and Seleam (1993)** in Fig. 6 (a).
2. For a constant water content, as the total unit weight increases, the dry unit weight increases and hence the collapse potential decreases. This behavior was observed for all other investigators as can be shown in Fig. 6.

It is obvious that both behaviors are logically explained.

PLASTICITY OF THE SOIL

Sandy gypseous soils may seem to behave as a plastic soil since the gypsum acts as a binding agent between the soil particles. Hence when performing liquid limit test in Casagrande device (**Bowles, 1978**), some misleading results may be obtained. However, plastic limit results can not be obtained for sandy gypseous soils unless the soil have some clay in it. Therefore, plasticity index (PI) [which is the difference between liquid limit (LL) and plastic limit (PL)] can be considered as an indication of the plasticity of gypseous soils.

Figure 7 (a) shows the results of CP at 200 kPa or CP at 100 kPa with the plasticity index (PI) for three investigators. On the same figure the results for liquid limit for the same samples are plotted. It can be observed there is no clear trend for the results. This can be attributed to the mixed action of the plasticity of the soils and the binding of the gypsum. Therefore, the author does not recommend any results obtained from this test.

Figure 7 (b) shows the plasticity chart for the three researchers which shows that the soils may be classified as (CL) soils for **Nashat (1990)** and **Al-Gabri (2003)** while **Abood (1994)** showed that the soil may be classified as (ML) soil bearing in mind that the soil samples was a gypsified one.

SOAKING PRESSURE

Many studies took this important effect on collapse into consideration. All results showed that collapse potential increases as the soaking pressure increases. Figure 8 (a) shows the collapse potential and the soaking pressure results from single collapse test while Fig. 8 (b) shows the results for double oedometer test.

MAGNITUDE OF SOAKING PRESSURE

Since there are two trends to define the soaking pressure which are CP at 200 kPa and CP at 100 kPa , Fig. 9 (a) shows the relation between the values of the two soaking pressure from the results of single collapse test while Fig. 9(b) shows the relation from the double oedometer test. This figure shows that the collapse potential at 200 kPa has greater values than that of 100 kPa since all points lies above the 45^o line (dotted line) which represent the line of equal values.

Type Of Test

Figure 10 shows the relation between the collapse potential obtained from single collapse test with the results obtained from double oedometer test for collapse potential at 200 kPa (Fig. 10 a) and collapse potential at 100 kPa (Fig. 10 b). Most of the results lie below the 45^o line (dotted line) which represent the line of equal values. This indicates that the values of the double oedometer gives higher values than that of the single collapse test.

Other Factors

Other factors such as (mineralogy, lithology and texture of the gypsum, percentage of each type of clay mineral, shape of the bulky grains, grain size distribution, pores size and shape, cementing agents, type of ion in the pore fluid [using other soaking fluids such as kerosene or gas oil], type of testing apparatus [Rowe Cell], soaking time, delayed compression, leaching at soaking pressure, using additives to decrease the collapsibility, etc..) are beyond the scope of this study.

ANALYSIS OF RESULTS AND PROPOSED EQUATIONS

Three equations are proposed in this research which can help engineers to predict the collapse potential (CP) from other test results. The analysis was performed using a statistical computer package called "STATISTICA". These are:

CP FOR SINGLE COLLAPSE TEST USING DOUBLE OEDOMETER TEST

In order to help the engineer to predict the collapse potential obtained usually from Single Collapse Test by performing Double Oedometer Test, the following equation is proposed.

$$CP200_{SCT} = 0.37 * (CP200_{DOT})^{1.828} - 0.0108 * \exp(CP200_{DOT}) + 0.606 \quad \ldots\ldots\textbf{(3)}$$

This equation was obtained from the analysis of 14 points and gave a good statistical regression (R- squared = 0.85) [A perfect relation is when R-squared =1.0]. To use this equation, obtain the collapse potential at 200 from the double oedometer results [say 3.05 from **Seleam (1988)** for sample no. S3-1(see Table 2)] and after substituting in Eq. 3, one can get CP-200_{SCT} equals to 4.30 which is very near to the actual value of 4.31.

Figure 11 shows the relation between the observed values (obtained from single collapse test) and the predicted values as obtained from the proposed equation. The dotted line presents the line of equal values. As can be noticed the points lying on the dotted line mean that there is good agreement.

CP AT 200 kPa FROM CP AT DIFFERENT PRESSURES

Although **Knight (1963)** originally defined the soaking pressure at 200 kPa as the standard soaking load, however many investigators performed single collapse test at 100 kPa or other soaking pressures as a substitute. Therefore, to standardize the collapse potential at 200, the following equation is proposed where the collapse potential at any pressure is substituted and the collapse potential at 200 can be obtained.

$$CP_{200} = 140.25 * (CP_{pressure})^{0.0135} * \left(\frac{200}{pressure}\right)0.0069 - 139.05 \quad \ldots\ldots\ldots\ldots\ldots\textbf{(4)}$$

The equation is analyzed from 18 points and gave a good regression of 0.722. The data included the results from single collapse test (4 cases) and other soaking pressures.

As an example of the use of this equation one can use the result of the CP -100 [say **Nashat (1990)** sample no. B-3 with a value of 1.52] and after substituting in Eq. 4, one can get the value of 2.75 compared with the actual value of 2.7 which can be considered as a good agreement.

Figure 12 shows the relation of the observed (actual) values of CP-200 with the values obtained from Eq. 4. The dotted line shows the line of equal value for the purpose of comparison. As can be observed, the values are in good agreement.

CP AT 200 kPa FROM BASIC PROPERTIES

The most important thing that the engineer is seeking for is to predict the collapse potential at 200 from basic properties that one can be obtained from simple routine tests. However, gypseous soils behave unpredictably due to many reasons such as (mineralogy of the material, percentage of each type of clay mineral, shape of the bulky grains, grain size distribution, natural water content, void ratio, pores size and shape, cementing agents and the type of ion in the pore water). To study such effects, one need to ignore the results obtained from gypsified soils and that with plasticity index. The proposed equation is

$$CP_{200} = \frac{398.68}{\left(1.5 + \frac{GC(\%)}{50.16}\right)^{410}\left(0.245 + \frac{eo}{65.5}\right)^{162.4}\left(1.5 + \frac{w(\%)}{4.52}\right)^{149.4}} + 0.694 \quad \ldots\ldots\ \textbf{(5)}$$

The number of data is 23 and the regression was 0.72 which may be considered as encouraging.

CONCLUSIONS

The following remarks can be withdrawn from the previous discussion

1. Several parameters affect the collapsibility of gypseous soils. This paper concentrate on the most traditional factors such as: (gypsum content, initial void ratio, initial unit weight, initial water content, dry unit weight, plasticity index, type of test (SCT or DOT), soaking pressure). Other parameters which are beyond the scope of the work are: (mineralogy of the gypsum, percentage of each type of clay mineral, shape of the bulky grains, grain size distribution, pores size and shape, cementing agents, the type of ion in the pore water, type of testing apparatus).
2. The collapse potentials at 200 kPa have low values. About 33% of the tested samples have values less than 1% which can be considered to have "No Trouble". Also, about 60% have values ranging between 1 and 5% which is considered to be of "Moderate Trouble" according to **Jennings and Knight (1975)** [see Table 1]. Therefore, it is recommended to perform more rigorous tests such as leached test at soaking pressure after soaking with water for 24 hours and after the delayed compression has seized since continuous deformation and collapse upon leaching due to water movement will be maintained.
3. The most important basic soil properties that affect the collapsibility (in the opinion of the author and from the collected data) are the initial water content, and the total unit weight and/or initial void ratio.
4. Gypsum content and plasticity appeared to have a minor effect on the results of the collapsibility of gypseous soils.
5. Wetting is the main environmental factor that affects the gypseous soil properties. This effect is represented either by soil varying from dry to fully saturated conditions or by seepage when water begins to flow through soil sections.
6. The three equations proposed in the paper offer a rapid method to predict the collapse potential of any gypseous soil using only basic soil tests without the need for more elaborated tests. These equations can be considered as a rough estimate of the collapsibility of the gypseous soils.
7. The proposed equations need more detailed future investigations by collecting more data from tests performed on various types of gypseous soils due to relatively moderate regression of the equations at the available data.

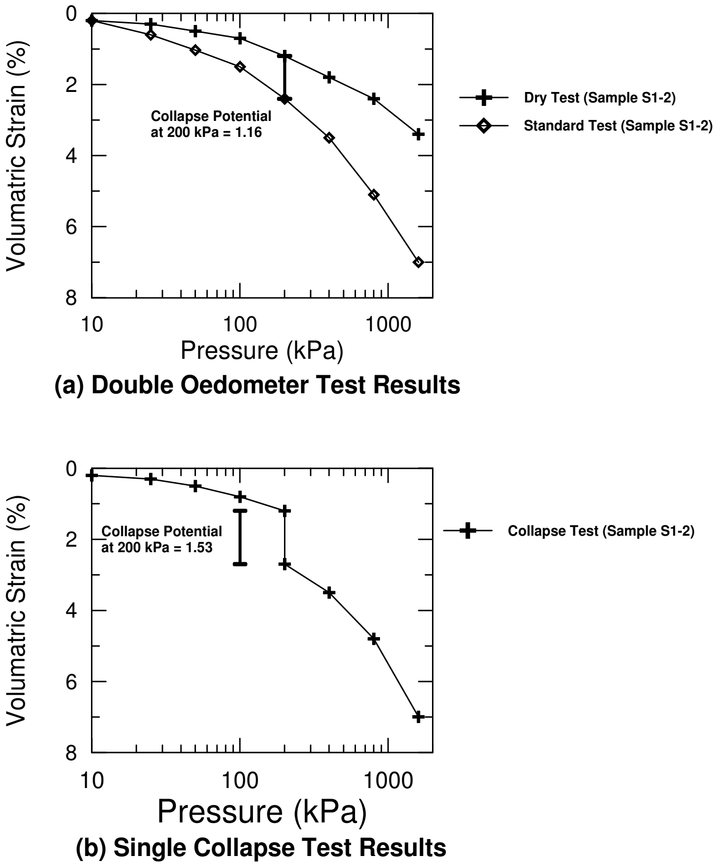
REFERENCES

- ***Abood, M.*** (1994), Treatment of Gypseous Soil with Sodium Silicate, M.Sc. Thesis-University of Technology, Department of Building and Construction.
- ***Al-Ani, M. M. and Seleam, S. N.*** (1993), Effect of Initial Water Content and Soaking Pressure on the Geotechnical Properties of Gypseous Soils, Journal of Al-Muhandis, No.116
- ***Al-Gabri, M. K.*** (2003), Collapsibility of Gypseous Soils Using Three Different Methods, M.Sc. Thesis-University of Technology, Department of Building and Construction
- ***Barden, L., McGown, A. and Collins, K***. (1973), The Collapse Mechanism in Partly Saturated Soil, Journal of Engineering Geology, Vol.7

- ***Bowles, J. E.*** (1978), Engineering Properties of Soils and Their Measurements, McGraw Hill Book Company, 2nd Edition.
- ***Clemence, S.P. and Finbar, O. A.*** (1981), Design Considerations for Collapsible Soils, Journal of Geotechnical Engineering, Vol.107-No.GT3
- ***FAO*** (1990***) ,*** Management of Gypsiferous Soils, Food and Agricultural Organization of the United Nations, Rome.
- ***Ismail, H. N.*** (1994), The Use of Gypseous Soils (In Arabic), Symposium on Gypseous Soils and Its Effect on Structures-NCCL, Baghdad
- ***Jennings, J. E. and Knight, K.*** (1957)***,*** The Addition Settlement of Foundations Sandy Subsoil on Wetting, Proceeding of 4th International Conference on Soil Mechanics and Foundation Engineering Vol.1.
- ***Jennings, J. E. and Knight, K.*** (1975) ***,*** A Guide to Construction on or with Materials Exhibiting Additional Settlement Due to Collapse of Grain Structure, Proceeding of 6th Regional Conference on Soil Mechanics and Foundation Engineering , Durban , South Africa, pp. 99-105.
- ***Knight K.*** (1963)***,*** The Origin and Occurrence of Collapsing Soils, Proceeding of 3rd Regional Conference of Africa on Soil Mechanics and Foundation Engineering Vol.1, pp. 127-130.
- ***Mohammad***, R. K. (1993), Effect of Wetting and Drying on Engineering Characteristics of Gypseous Soils, M.Sc. Thesis-University of Technology, Department of Building and Construction
- ***Nashat, I. H.,*** (1990), Engineering Characteristics of Some Gypseous Soils in Iraq, Ph.D. Thesis-College of Engineering-University of Baghdad, Department of Civil Engineering
- ***Saaed, S. A., and Khorshid, N. N.,*** (1989): Some Essential Characteristics of the Gypseous soils of Al-Dour Area. Proc. of the 5th Scientific Conference, Vol. 4, Part2, Scientific Research Council, Baghdad. (in Arabic).
- ***Seleam,S.N.*** (1988), Geotechnical Characteristics of Gypseous Sandy Soil Including the Effect of Contamination with Some Oil Products, M.Sc. Thesis-University of Technology, Department of Building and Construction
- ***Sheika, A.A.*** (1994) The Collapsibility of Gypseous Soil and the Effect of Leaching on Its Behavior, M.Sc. Thesis-University of Technology, Department of Building and Construction
- ***Van Alphen and Romero*** (1971), Gypseous Soils , Notes on their Characteristics and Management, International Institute for Land Reclamation and Improvement, Wageningen , Netherlands.

Table (1): The Severity of Collapse Potential
(after **Jennings and Knight, 1975**)

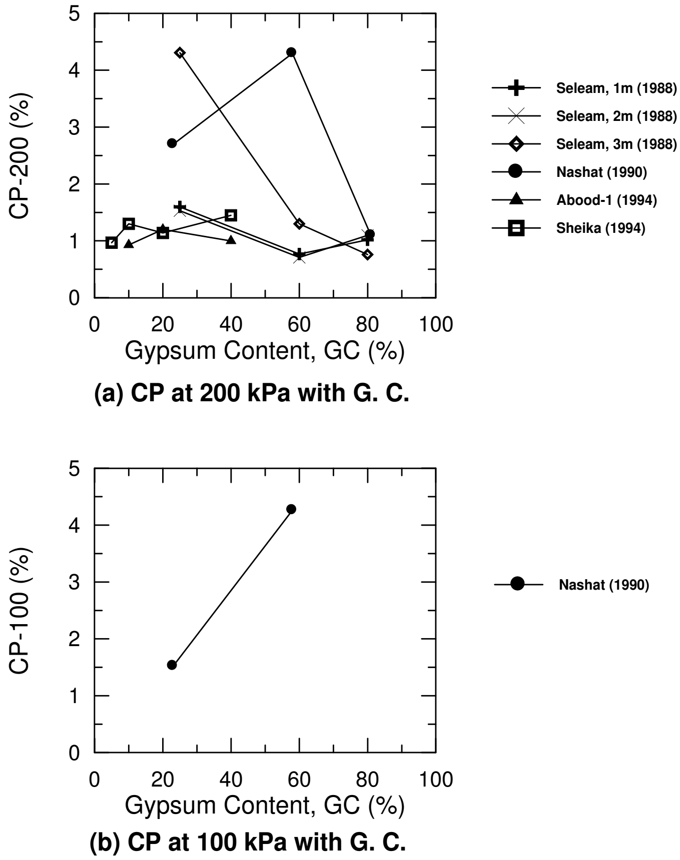
Collapse Potential %	0-1	1-5	5-10	10-20	>20
Severe Trouble	No Problem	Moderately Trouble	Trouble	Severe Trouble	Very Severe Trouble



(a) Double Oedometer Test Results

(b) Single Collapse Test Results

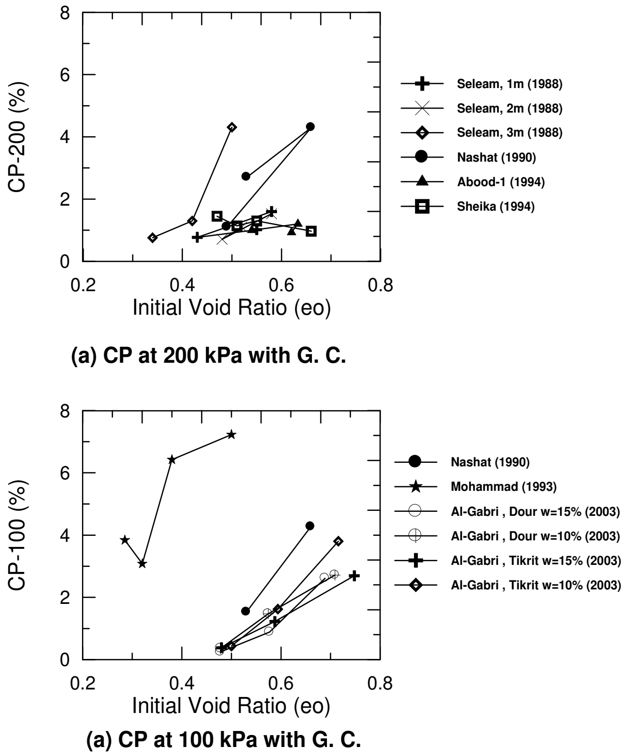
Fig. 1 Typical Results for Double Oedometer Test and Single Collapse Test (After Seleam, 1988)



(a) CP at 200 kPa with G. C.

(b) CP at 100 kPa with G. C.

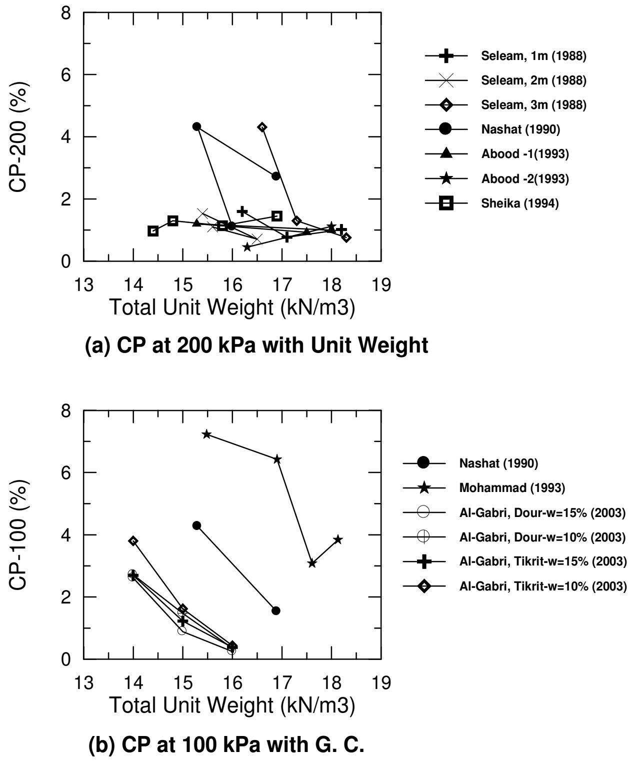
Fig 2 Relation between Collapse Potential and Gypsum Content for Various Researchers



(a) CP at 200 kPa with G. C.

(a) CP at 100 kPa with G. C.

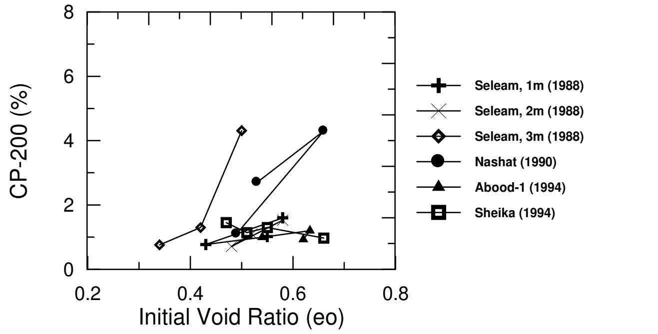
Fig 3 Relation between Collapse Potential and Initial Void Ratio for Various Researchers



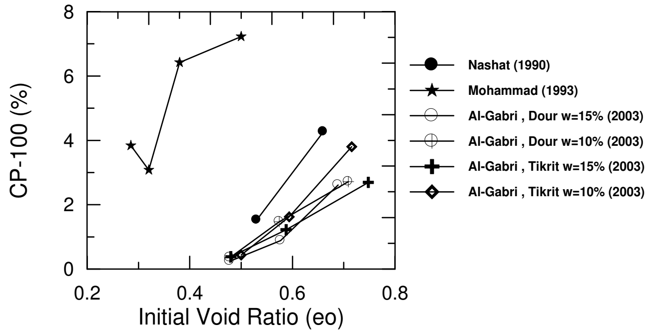
(a) CP at 200 kPa with Unit Weight

(b) CP at 100 kPa with G. C.

Fig 4 Relation between Collapse Potential and Unit Weight for Various Researchers

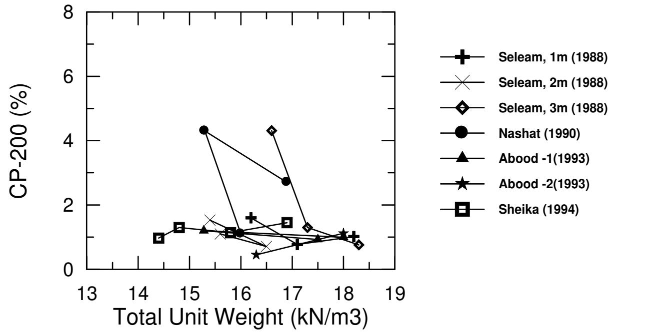


(a) CP at 200 kPa with G. C.

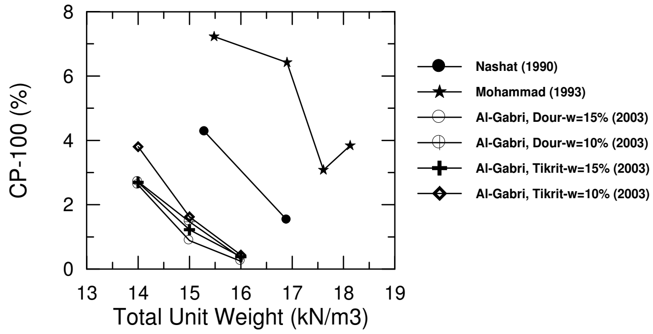


(a) CP at 100 kPa with G. C.

Fig 3 Relation between Collapse Potential and Initial Void Ratio for Various Researchers

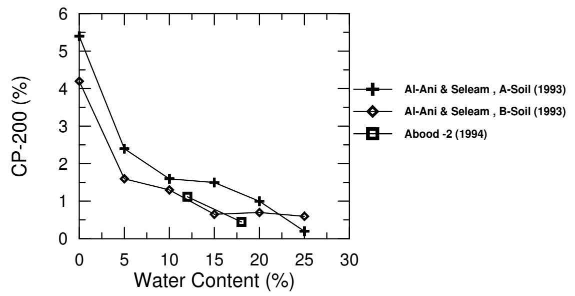


(a) CP at 200 kPa with Unit Weight

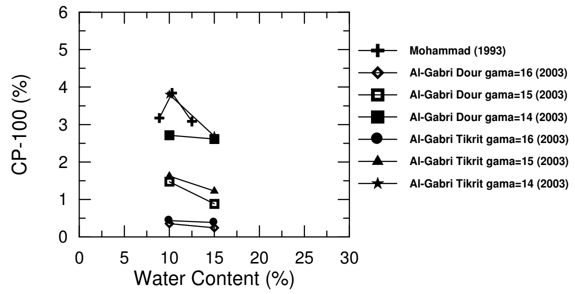


(b) CP at 100 kPa with G. C.

Fig 4 Relation between Collapse Potential and Unit Weight for Various Researchers

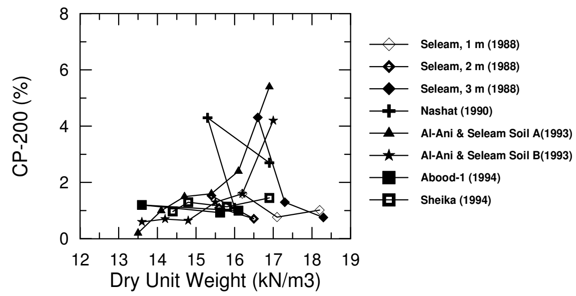


(a) CP at 200 kPa with Water Content

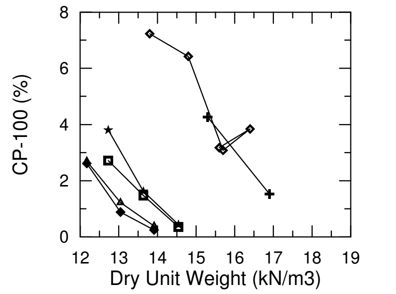


(b) CP at 100 kPa with Water Content

Fig 5 Relation between Collapse Potential and Water Content for Various Researchers

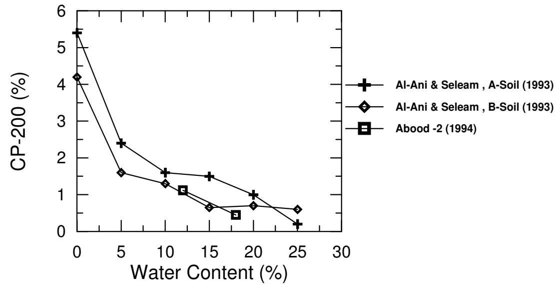


(a) CP at 200 kPa with Dr Unit Weight

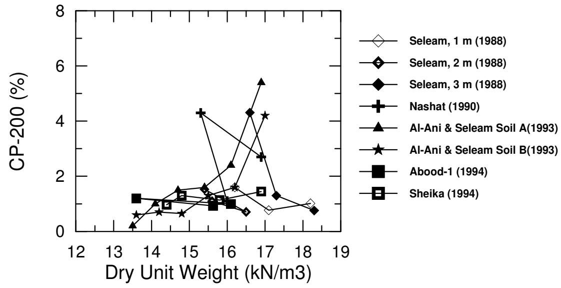


(b) CP at 100 kPa with Dr Unit Weight

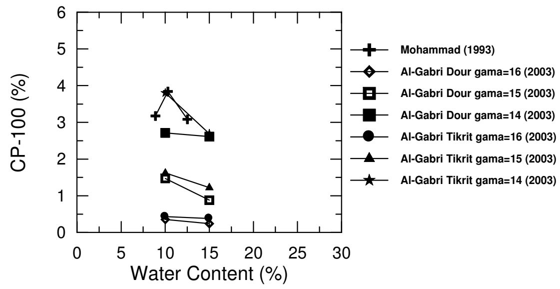
Fig 6 Relation between Collapse Potential and Dry Unit Weight for Various Researchers



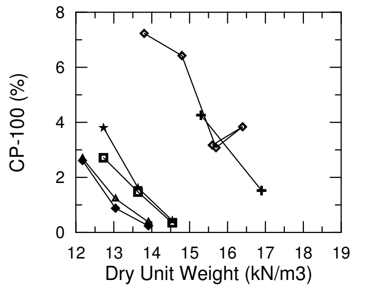
(a) CP at 200 kPa with Water Content



(a) CP at 200 kPa with Dr Unit Weight



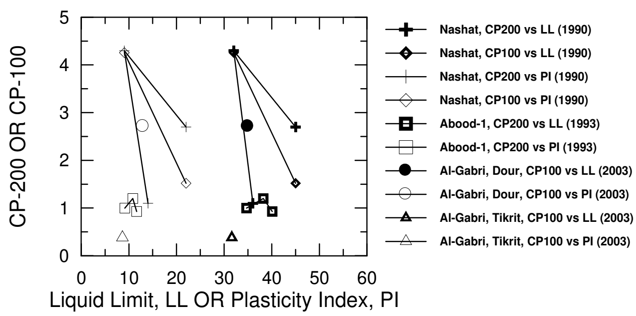
(b) CP at 100 kPa with Water Content



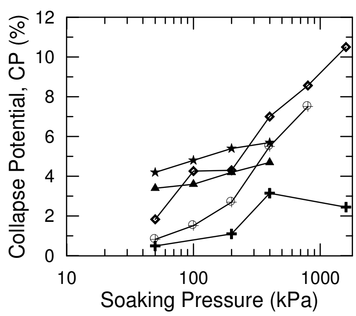
(b) CP at 100 kPa with Dr Unit Weight

Fig 5 Relation between Collapse Potential and Water Content for Various Researchers

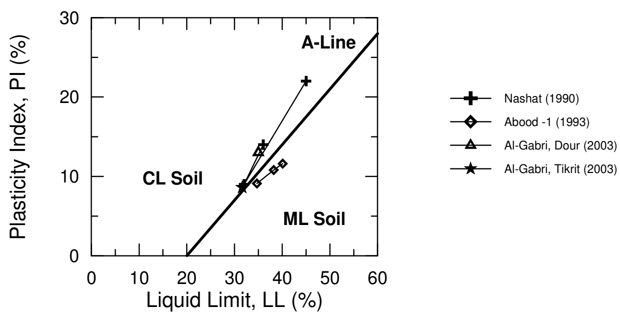
Fig 6 Relation between Collapse Potential and Dry Unit Weight for Various Researchers



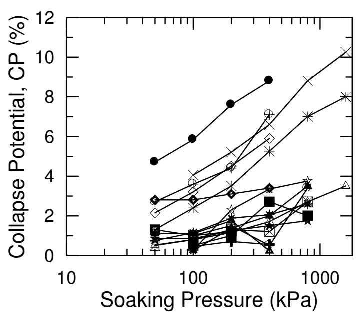
a) CP at 200 kPa OR CP at 100 kPa with Liquid Limt OR Plasticity Index



(a) Single Collapse Test



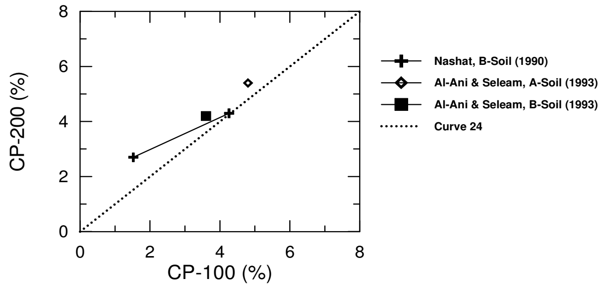
(b) Plasicity Chart



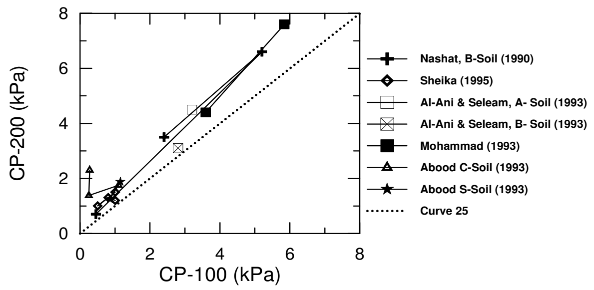
(b) Double Oedometer Test

Fig 7 Relations of Liquid Limit and Plasticity Index for Various Researchers

Fig 8 Relation between Collapse Potential and Soaking Pressure for different Types of Test

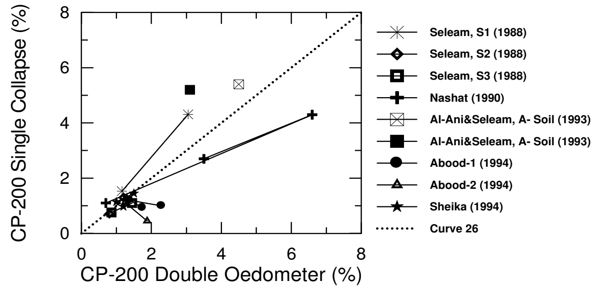


(a) Single Collapse Test

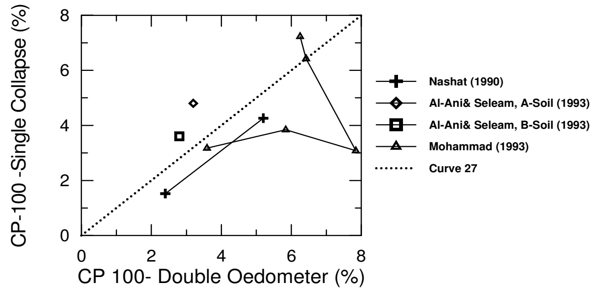


(b) Double Oedometer Test

Fig 9 Relation between Collpse Potential at 200 kPa and 100 kPa for different investigators



(a) Collapse Potential at 200 kPa



(b) Collapse Potential at 100 kPa

Fig 10 Relation between Collapse Potential for Single Collapse Test and Double Oedometer Test for Various Researchers

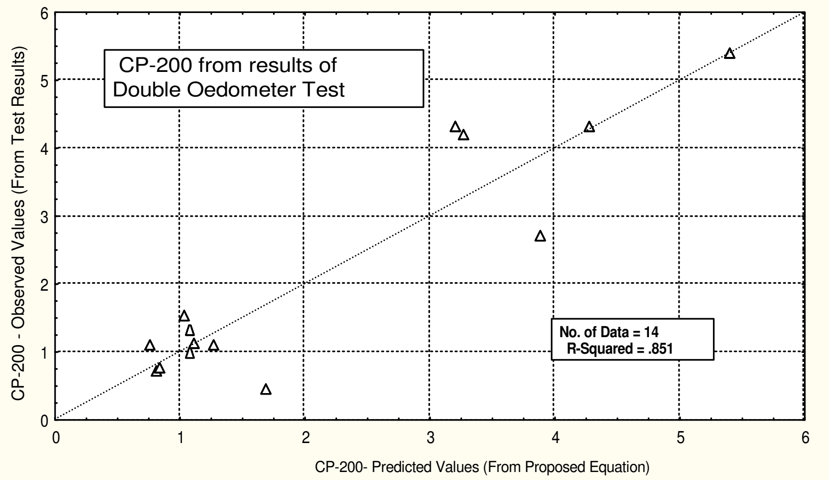


Fig. 11 Statistical Results for Proposed Eq.3

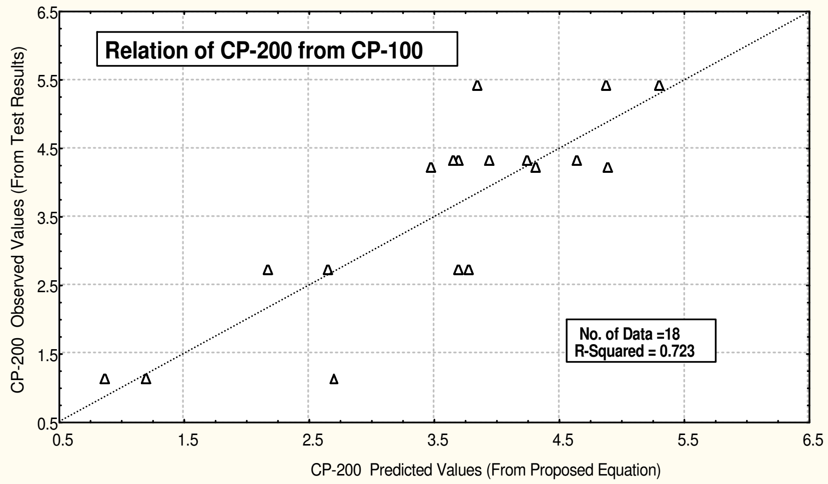


Fig. 12 Statistical Results of Eq. 4

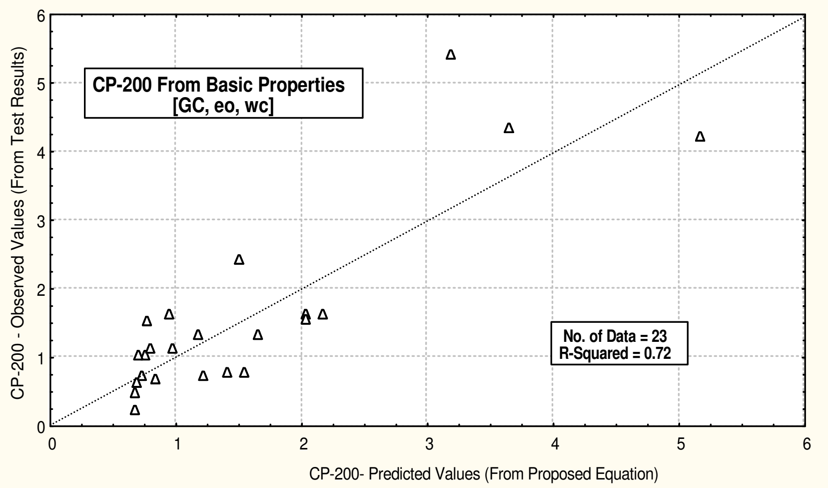


Fig. 13 Statistical Results for the Proposed Eq. 5